May 2017 **SCH No. 2014091020**

TESORO
LOS ANGELES REFINERY

INTEGRATION AND COMPLIANCE PROJECT

FINAL
ENVIRONMENTAL IMPACT REPORT

VOLUME XI: Appendix G3 (Part 3)

Executive Officer
Wayne Nastri

Deputy Executive Officer
Planning, Rule Development, and Area Sources
Philip Fine, Ph.D.

Assistant Deputy Executive Officer
Planning, Rule Development, and Area Sources
Susan Nakamura

Submitted to:
SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Prepared by:
ENVIRONMENTAL AUDIT, INC.

Reviewed by: Jillian Wong, Ph.D. – Planning and Rules Manager
Danny Luong – Senior Enforcement Manager
Tran Vo – Air Quality Analysis and Compliance Supervisor
Sam Wang – Air Quality Specialist
Barbara Baird – Chief Deputy Counsel
Veera Tyagi – Principal Deputy District Counsel
Cal Enviro Metrics, LLC

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APPENDIX G3 - Part 3 of 4

Comments Received that Do Not Require Response

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APPENDIX G3

Opposition Comments Received that Do Not Require Response

Jillian Wong

From:	s arredondo <sylvia1203@msn.com>
Sent:	Friday, February 17, 2017 11:27 AM
To:	Wayne Nastri; Jillian Wong; Danny Luong
Cc:	Jacob Haik (Bus)
Subject:	Letter Re: Tesoro LARIC Project recirculated EIR in Draft from
Attachments:	Letter-to-AQMD-TESORO-2017-2-16.pdf

Hello Mr Nastri and AQMD staff,
Cc: AQMD Governing Board Member Joe Buscaino c/o Jacob Haik

Please see the attached pdf document. My letter urging you to recirculate the Tesoro LARIC project EIR as a NEW draft.

I am a life-long Wilmington resident and after hearing my councilman speak very briefly about this project it is my duty to make my councilman aware that I, a constituent of CD15, am requesting a Draft EIR.

Respectfully,
Sylvia Arredondo

February 17, 2017

Wayne Nastri, Executive Officer, South Coast Air Quality Management District
Jillian Wong, Planning and Rules Manager
Danny Luong, Senior Enforcement Manager
21865 Copley Drive Diamond Bar CA 91765
wnastri@aqmd.gov, jwong1@aqmd.gov, dluong@aqmd.gov
cc. AQMD Governing Boardmember Joe Buscaino, c/o Jacob Haik, Deputy Chief of Staff,
jacob.haik@lacity.org

Re: Tesoro LARIC Project must be recirculated in Draft Form

Dear Mr. Nastri and AQMD Staff,

I am writing to you today because I urge you to recirculate the Tesoro LARIC (Los Angeles Refinery Integration and Compliance) project Environmental Impact Report (EIR) as a new draft, and not to publish it as a final EIR. Growing up in Wilmington exposed me to refinery explosions at a very young age. My family and I have evacuated our home twice due to refinery explosions. It is my duty to write to you today to advocate for a less polluted community. It is your duty to protect the health of residents.

It is my understanding that AQMD intends to finalize the EIR. Public health, community and worker health and safety is at serious risk if this EIR is published as a final document. Instead, you need to correct fatal errors, such as the draft's failure to evaluate Tesoro's admitted crude oil switch, with its public health, environmental, and explosion hazards. The California Environmental Quality Act requires an accurate project description and evaluation of potentially significant impacts in the draft environmental report. These cannot happen in a last-minute explanation in the final EIR.

A large body of evidence submitted to the AQMD by Dr. Phyllis Fox, Communities for a Better Environment (CBE), Earthjustice, East Yard Communities for Environmental Justice (EYCEJ), Coalition For A Safe Environment (CFASE), and many others, showed overwhelmingly that the Draft EIR failed as an informational document. It needs to be re-written in draft form to address these comments.

Delay of Tesoro's business plans is no justification to rush the EIR! You should not consider business profits before the wellbeing of entire communities. Tesoro could have entirely prevented any "delay" if it had disclosed the crude oil switch plan two years ago, when it acknowledged the plans to its investors. It is necessary to provide public disclosure in order to respect the public's right-to-know about increased hazards and pollution, and to comply with the California Environmental Quality Act. **Please let me know what you intend to do.**

Sincerely,

Sylvia Arredondo
sylvia1203@msn.com
1203 Hyatt Ave, Wilmington CA 90744

Jillian Wong

From:	Carmen Nogueron <noguerontcarmen@gmail.com>
Sent:	Wednesday, March 1, 2017 3:12 PM
To:	Wayne Nastri; Jillian Wong; Danny Luong
Cc:	Jacob Haik (Bus); alicia@cbecal.org
Subject:	Tesoro LARIC Project must be recirculated

Dear Mr. Nastri and AQMD Staff,

I write to urge you to recirculate the Tesoro LARIC (Los Angeles Refinery Integration and Compliance) project Environmental Impact Report (EIR) as a new draft, and not to publish it as a final EIR. We have been told the AQMD intends to finalize the EIR. Instead, you need to correct fatal errors, such as the draft's failure to evaluate Tesoro's admitted crude oil switch, with its public health, environmental, and explosion hazards. The California Environmental Quality Act requires an accurate project description and evaluation of potentially significant impacts in the draft environmental report. These cannot happen in a last-minute explanation in the final EIR. A large body of evidence submitted to the AQMD by Dr. Phyllis Fox, Communities for a Better Environment, Earthjustice, Eastyard, CFASE, and many others, showed overwhelmingly that the Draft EIR failed as an informational document. It needs to be re-written in draft form to address these comments. Delay of Tesoro's business plans is no justification to rush the EIR! Tesoro could have entirely prevented any "delay" if it had disclosed the crude oil switch plan two years ago, when it acknowledged the plans to its investors. It is necessary to provide public disclosure in order to respect the public's right-to-know about increased hazards and pollution, and to comply with the California Environmental Quality Act. Please let me know what you intend to do.

Sincerely,

Carmen Nogueron

Carmen Nogueron
Kalamazoo College 2018
Wilmington,CA resident

CARSON COALITION
P.O. Box 11061
Carson, CA 90746

March 16, 2017

Chairman Burke and Governing Board of the South Coast Air Quality Management District
Wayne Nastri, Executive Officer, SCAQMD
21865 Copley Avenue
Diamond Bar, CA 91765

Via email: mwpatrick@aqmd.gov, bbenoit@cityofwildomar.org, rtbscaqmd@gmail.com, dyork@cityofwildomar.org, mashley@rivco.org, Kcline@rivco.org, jenny.chavez@lacity.org, sarah.bonner@lacity.org, Jacob.haik@lacity.org, macacciotti@yahoo.com, ealty@bos.lacounty.gov, joe@ccair.org, lmccallon@cityofhighland.org, JudyM@ci.Rolling-Hills-Estates.ca.us, Shawn.Nelson@ocgov.com, clarkeparker@aqmd.gov, drobinson@lakeforestca.gov, SupervisorRutherford@sbcounty.gov, wnastri@aqmd.org

Re: Draft EIR for the Tesoro Integration and Compliance Project

Honorable Chairman Burke and Members of the Governing Board, Mr. Nastri:

The Carson Coalition is group of citizens actively involved in issues that affect the residents of the City of Carson, and on the Coalition's behalf we write this letter to express serious concerns about Tesoro's proposed refinery integration project, which will combine its Wilmington and Carson facilities to create the largest refinery on the West Coast right in our back yards.

We understand that despite SCAQMD's promise to include the City of Carson, a responsible agency, in the environmental review process, your agency did not avail itself of the City's input or resources, and largely did not address the City's important concerns regarding air quality and localized impacts, which are very real to those of us who live so close to the refinery and will be impacted the most by the project. As you are likely aware, there are five elementary schools and a middle school within a mile of the refinery – our children therefore will be also impacted by the refinery's operations, even assuming no accidents occur. However, as a reminder, as recently as August of 2016, a tank exploded at the refinery, spewing hazardous sulfur dioxide and hydrogen sulfide fumes into the community, endangering the residents and causing massive gridlock in the surrounding area due to the ensuing shelter-in-place order.

We are particularly worried about the lack of data and analysis relating to current and localized impacts that the refinery will have on our community. AQMD does not have an air-quality monitoring station at the refinery – the closest one is in Long Beach, two miles away. Thus, air quality emissions at the Tesoro refinery are estimated based on engineering studies, and not on real measurements. In light of the recent AQMD-backed study that concluded that Los Angeles area refineries routinely emit 12 times more chemicals than they report, more accurate and localized measurements of refinery emissions should be the lowest bar of analysis for the EIR. Yet, the data relied on is out-of-date and not localized, and the EIR ignores hundreds of complaints about odors emanating from the refinery in the past decade. This is flatly inadequate.

As the City of Carson's City Manager wrote in a June 2016 letter to AQMD, "[t]he draft environmental impact report utterly fails to address the potentially higher cumulative pollution impacts on low-income communities." And on Wednesday of last week, the City Attorney's office sent another objection to the EIR, reiterating that "[s]uch a large project in a severely disadvantaged community deserves and requires a thoroughly detailed study and analysis. This EIR fails the task." It is often low-income communities that bear the brunt of such projects, hence the state legislature's concern with environmental justice. At a minimum, one or more public hearings must be held before certification of the EIR -- to wit, in Torrance SCAQMD appropriately held public hearings to address the environmental impacts of refineries. Why not do the same for the City of Carson? Our citizens, and our children, are just as worthy of concern and protection as the residents of Torrance. We recognize that living in a densely populated urban setting imposes certain burdens, but no single community should bear those burdens disproportionately.

This issue is compounded by the fact that the EIR does not address the environmental impacts that the additional 1400+ daily truck trips will have on the community. Tesoro contributes very little to the City to address environmental impacts in general, and the added truck trips will further increase the burden on the City's taxpayers to repair roads damaged by the additional truck trips – funds the City must expend to fix roads are funds that cannot be used to address environmental issues and emergencies.

Finally, the draft EIR is obscure. State guidelines emphasize that EIRs should readily be understandable by the layperson. The EIR is inaccessible to people who do not have an engineering background. As laypersons we have little ability to thoroughly understand the document, and now we discover that we will not be given the opportunity to ask questions and seek clarifications, or to provide input or objections, as no public hearing will be held. It is hard to believe that the environmental document for a project of this magnitude will not be subject to at least one public hearing. Furthermore, a public hearing is necessary precisely because the project is in a disadvantaged community – we count on your agency to ensure that that the environmental impacts of this project are fully analyzed and mitigated. Additionally, a significant number of the citizens affected are senior citizens, and in order to fully participate, the public hearing should take place in the City of Carson, and be well advertised.

We therefore demand the following:

1. That SCAQMD provide an accurate baseline for the EIR that takes into account current and localized emissions and health impacts.
2. That SCAQMD hold a public hearing in the City of Carson prior to certifying the Tesoro Integration Project EIR.

We thank you for your time and attention. Attached to this letter you will find signature pages for additional signatories to this letter, who are members of the community surrounding the Carson Tesoro refinery. Please feel free to contact Ms. Diane Thomas on (310) 632-0756 if you have any questions regarding this letter.

Very truly yours,

Rob Lesley

Robert Lesley, President, Carson Coalition

Dianne Thomas

Dianne Thomas

cc: Mayor and City Council, City of Carson
Ken Farfsing, City Manager
Sunny K. Soltani, City Attorney
John Raymond, Director of Community Development
Saied Naaseh, Planning Manager
Barbara Baird, Chief Deputy Counsel, SCAQMD
Jillian Wong, Planning and Rules Manager
Alicia Romero, Communities for Better Environment

SCAQMD/Tesoro Refinery Integration
March 16, 2017
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NAME	ADDRESS	SIGNATURE
1. Juanita Looney	20008 So. Hillford Ave	Juanita Looney
2. Mrl Rooney	20008 So. Hillford Ave	Marcel Looney
3. DIANNE THOMAS	20219 NESTOR AVE CARSON, CA 90746	Dianne Thomas
4. JOAN GIVENS	20024 S. HILLFORD CARSON, CA 90746	Joan Givens
5. FRANK MILES	20014 NESTOR AVE CARSON CA 90746	Frank Miles
6. JEAN YOUNG	1472 E GLADWICK ST CARSON CA. 90746	Jean Young
7. Kelvin BROWN	1307 E FERNROCK, CRSN	Kelvin B
8. LARhonda BROWN	" " "	LaRhonda Brown
9. Joyce STRother	1303 E. FERNROCK St Carson 90746	Joyce A Strother
10. Dino T. Richardson	1317 E. FERNROCK St. CARSON CA	Dino T. Richardson
11. DELORICE RICHARDSON	20118 So. Midtown Ave CARSON, CA. 90746	Delorice Richardson
12. ELI RICHARDSON	20118 So Midtown Ave CARSON CA 90746	Eli Richardson
13. HOWE JACQUELINE	CARSON, CA 90746 1427 E. ABBOTTSON ST.	Jacqueline Howe
14. Teylor J. Caesar	20025 Nestor Ave Carson CA 90746	
15. RICHARD MCCAULEY	20109 NESTOR AVE CARSON, CA. 90746	R. McCauley

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16. Robert Lesley	19213 Midtowning Ave	
17. Milton Cruem	19602 galway ave	Milton Cruem
18. Sandra Queen	19608 Galway Ave	Sandra Q
19. Jennie Reddick	19622 Galway Ave	
20. NORRIS DAVIS	19732 ALONDA DR	
21. VENETTA BRYANT	19806 ALONDA DR.	Venetta L. Bryant
22. Olivia Hunter	19807 Alonda Dr	
23. Mary Blassingame	19802 Alonda Drive	M.A. Blassingame
24. Arlena Brazier	19733 Alonda Drive	Arlena B
25. Chris Brazier	19733 Alonda Dr	
26. Ellis BRAZIER	19733 ALONDA DR	Ellis Brazier
27. Eugenia S Breland	19717 Alonda DR.	Eugenia S. BRELAnd
28. Juliana Daniel	19723 Alonda Dr.	
29. WINFIELD HINKSON	19723 Alonda Dr	
30. Art Cotton	19711 Alonda Drive	

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NAME	ADDRESS	SIGNATURE
31. Cheryl Wilson	20108 Nester Ave Carson, Ca. 90746	Cheryl Wilson
32. Doris J. Wilson	20108 Nestor Ave. Carson, Ca. 90746	Doris J. Wilson
33. Vera Rhone	20112 Nestor ave Carson Cal 90746	Vera Rhone
34. Albert Owens	20212 Nestor Ave. Carson, CA 90746	Albert Owens
35. Lillian Hopson	1628 Edom St Carson, CA 90746	Lillian Hopson
36. William Hopson	1628 Edom st CARSON 90746	William Hopson
37. Roderic Daniels	1628 Edom St Carson CA 90746	
38. Cheryl Weathers	21820 Bonita St. Carson CA (Carnegie Middle School)	CWeth
39. Leonard thoms	Carnegie middle school 21820 Bonita St Carson CA 90746	Leonard Thomas
40. Juliet Okonkwo	Carnegie Middle School 21820 Bonita st Carson CA 90745	JULIET OKONKWO
41. Torie Takaki	carnegie Middle school 21820 Bonita Street. Carson, CA 90745	
42. EVA Gonzales	Bonita 21929 Bonita Carson	
43. LINDA THompson	BONITA ELEM. 21929 BONITA, CARSON	Linda Thompson
44. Jennifer Stanley	Bonita Street School 21929 BONITA CARSON	Jennifer Stanley
45. Terika Hemeth	Bonita Street. Elem 21929 Bonita Carson CA	

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NAME	ADDRESS	SIGNATURE
46. Ezel Waters	19613 GaLway Av	Ezel B Waters
47. Laura Waters	19613 GALway Av	Laura J. Wate
48. Gwen Washington	19621 Galway Ave.	Gwendolyn Washington
49. Brenda Crum	19602 Galway Ave	Brenda Crum
50. Sallie Johnson	641 E Holborn Dr.	Sallie Johnson
51. DAVID Jones	640 E HolBorn DR	David Jones
52. Charlie Davis	634 E. Holborn Dr.	Charlie Davis
53. Linda Davis	634 E HolBORN Dr.	Linda Davis
54. Harold Douglas	617 E. Holborn DR	Harold Douglas
55. LOYMON BATISTE	19701 Reinhart Ave.	Loymon Batiste
56. BERNICE JONES	607 E. HOLBORN	Bernice Jones
57. CaNisha Jones	607 e. Holborn Dr.	
58. Ethel Jennings	19722 Reinhart AVE CARSON 90746	Ethel Jennings
59. Willie [illegible]	19803 Reinhart Ave 90746	WILLIE [illegible]
60. marion Butler	19818 REINHART AVE 90746	MARION BUTLER

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March 16, 2017
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NAME	ADDRESS	SIGNATURE
61. Angela Porter	864 E Turmont St Carson Ca 90746	
62. Mike Morris	21820 BONITA STREET CARNEGIE MIDDLE SCHOOL	
63. Melissa A. Buck	21820 Bonita St. CMS	
64. Ingrid Jordan	21820 Bonita St. Carnegie Middle School	
65. Carolina Dousdebes	21820 Bonita St Carnegie Middle School	Dousdebes
66. LAVONNE S. MOORE	20203 Campris Dr	
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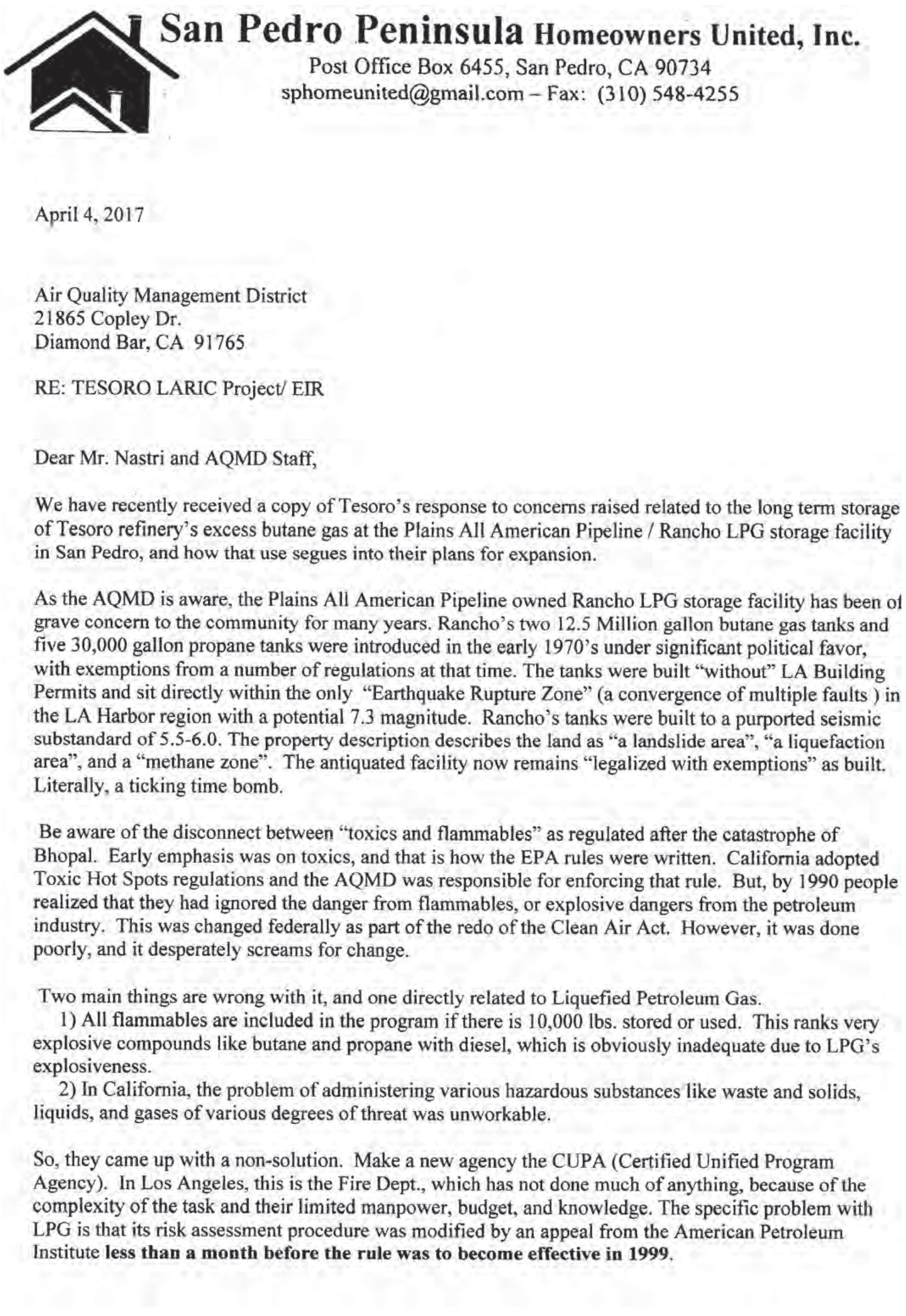
NAME	ADDRESS	SIGNATURE
76. William H. Taylor	19713 Reinhart	William H. Taylor
77. Amanda Shipman	19531 Belshaw Av	Amanda Shipman
78. Nathaniel Shipman	19531 Belshaw Ave	Nathaniel Shipman
79. CHRIS BRADLEY	1403 E. KRAMER DR	
80. MELVIN JOHNSON	19101 PRICETOWN AVE	Melvin Johnson
81. Barbara Shears	19105 Pricetown Ave	Barbara Shears
82. Gilbert Shears	19105 Pricetown Ave	Gilbert Shears
83. CASSANDRA Reed	19115 Pricetown Ave	Cassandra Reed
84. Linda M. Wyatt	19213 Midtown Ave	
85. Addison D. Carter	19207 Midtown Ave	Addison D Carter
86. BERNIE D. MORRIS	19204 Midtown Ave	Bernie D. Morris
87. AUTHER J. MORRIS	19204 MIDTOWN AVE.	Auther J Morris
88. Sharon Cobb Johnson	19212 Midtown Ave	
89. Antoine Johnson	19212 Midtown Ave	
90.		



San Pedro Peninsula Homeowners United, Inc.
Post Office Box 6455, San Pedro, CA 90734
sphomeunited@gmail.com – Fax: (310) 548-4255

April 4, 2017

Air Quality Management District
21865 Copley Dr.
Diamond Bar, CA 91765

RE: TESORO LARIC Project/ EIR

Dear Mr. Nastri and AQMD Staff,

We have recently received a copy of Tesoro's response to concerns raised related to the long term storage of Tesoro refinery's excess butane gas at the Plains All American Pipeline / Rancho LPG storage facility in San Pedro, and how that use segues into their plans for expansion.

As the AQMD is aware, the Plains All American Pipeline owned Rancho LPG storage facility has been o grave concern to the community for many years. Rancho's two 12.5 Million gallon butane gas tanks and five 30,000 gallon propane tanks were introduced in the early 1970's under significant political favor, with exemptions from a number of regulations at that time. The tanks were built "without" LA Building Permits and sit directly within the only "Earthquake Rupture Zone" (a convergence of multiple faults) in the LA Harbor region with a potential 7.3 magnitude. Rancho's tanks were built to a purported seismic substandard of 5.5-6.0. The property description describes the land as "a landslide area", "a liquefaction area", and a "methane zone". The antiquated facility now remains "legalized with exemptions" as built. Literally, a ticking time bomb.

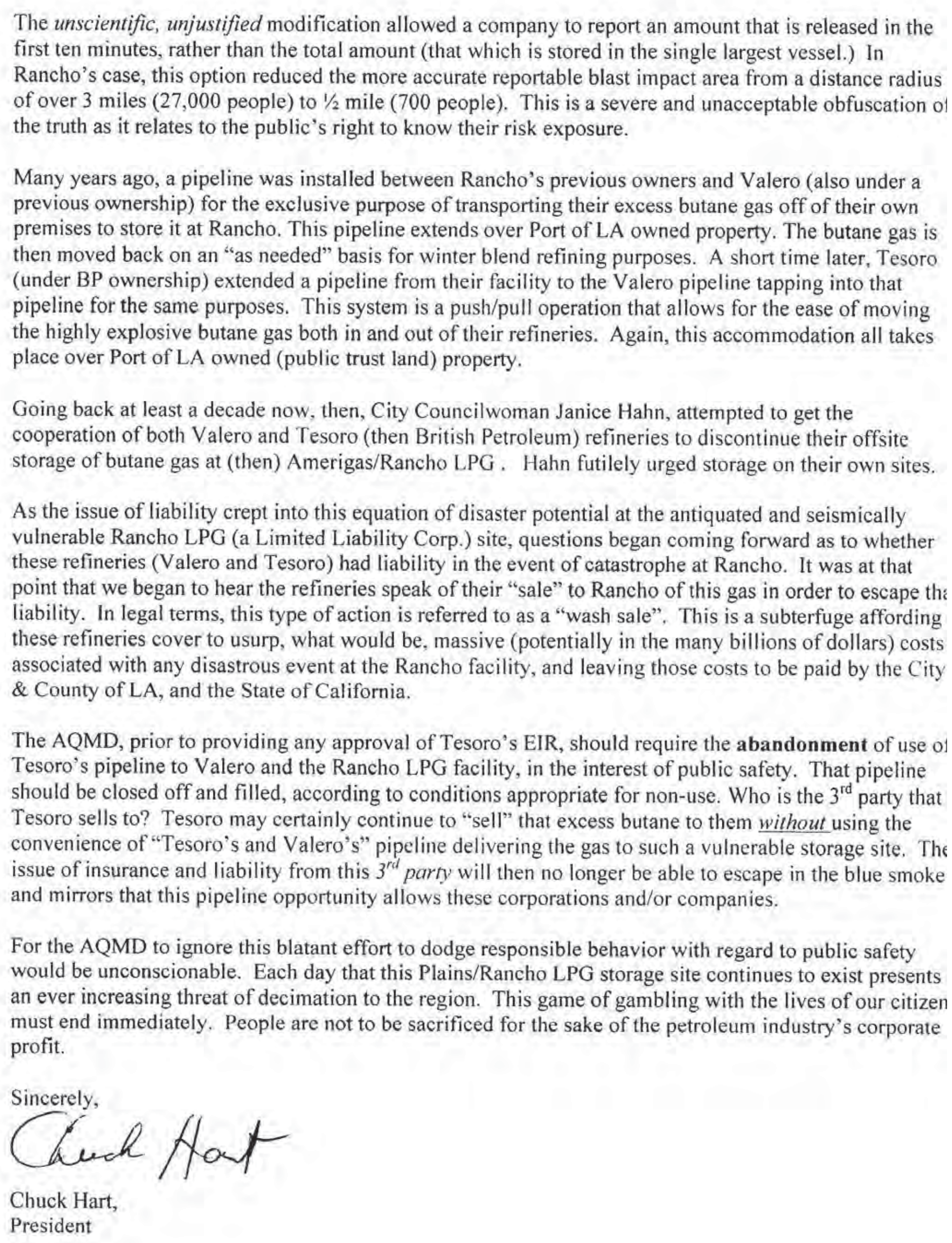
Be aware of the disconnect between "toxics and flammables" as regulated after the catastrophe of Bhopal. Early emphasis was on toxics, and that is how the EPA rules were written. California adopted Toxic Hot Spots regulations and the AQMD was responsible for enforcing that rule. But, by 1990 people realized that they had ignored the danger from flammables, or explosive dangers from the petroleum industry. This was changed federally as part of the redo of the Clean Air Act. However, it was done poorly, and it desperately screams for change.

Two main things are wrong with it, and one directly related to Liquefied Petroleum Gas.

1) All flammables are included in the program if there is 10,000 lbs. stored or used. This ranks very explosive compounds like butane and propane with diesel, which is obviously inadequate due to LPG's explosiveness.

2) In California, the problem of administering various hazardous substances like waste and solids, liquids, and gases of various degrees of threat was unworkable.

So, they came up with a non-solution. Make a new agency the CUPA (Certified Unified Program Agency). In Los Angeles, this is the Fire Dept., which has not done much of anything, because of the complexity of the task and their limited manpower, budget, and knowledge. The specific problem with LPG is that its risk assessment procedure was modified by an appeal from the American Petroleum Institute **less than a month before the rule was to become effective in 1999.**



The *unscientific, unjustified* modification allowed a company to report an amount that is released in the first ten minutes, rather than the total amount (that which is stored in the single largest vessel.) In Rancho's case, this option reduced the more accurate reportable blast impact area from a distance radius of over 3 miles (27,000 people) to ½ mile (700 people). This is a severe and unacceptable obfuscation o the truth as it relates to the public's right to know their risk exposure.

Many years ago, a pipeline was installed between Rancho's previous owners and Valero (also under a previous ownership) for the exclusive purpose of transporting their excess butane gas off of their own premises to store it at Rancho. This pipeline extends over Port of LA owned property. The butane gas is then moved back on an "as needed" basis for winter blend refining purposes. A short time later, Tesoro (under BP ownership) extended a pipeline from their facility to the Valero pipeline tapping into that pipeline for the same purposes. This system is a push/pull operation that allows for the ease of moving the highly explosive butane gas both in and out of their refineries. Again, this accommodation all takes place over Port of LA owned (public trust land) property.

Going back at least a decade now, then, City Councilwoman Janice Hahn, attempted to get the cooperation of both Valero and Tesoro (then British Petroleum) refineries to discontinue their offsite storage of butane gas at (then) Amerigas/Rancho LPG . Hahn futilely urged storage on their own sites.

As the issue of liability crept into this equation of disaster potential at the antiquated and seismically vulnerable Rancho LPG (a Limited Liability Corp.) site, questions began coming forward as to whether these refineries (Valero and Tesoro) had liability in the event of catastrophe at Rancho. It was at that point that we began to hear the refineries speak of their "sale" to Rancho of this gas in order to escape th liability. In legal terms, this type of action is referred to as a "wash sale". This is a subterfuge affording these refineries cover to usurp, what would be, massive (potentially in the many billions of dollars) costs associated with any disastrous event at the Rancho facility, and leaving those costs to be paid by the City & County of LA, and the State of California.

The AQMD, prior to providing any approval of Tesoro's EIR, should require the **abandonment** of use o Tesoro's pipeline to Valero and the Rancho LPG facility, in the interest of public safety. That pipeline should be closed off and filled, according to conditions appropriate for non-use. Who is the 3rd party that Tesoro sells to? Tesoro may certainly continue to "sell" that excess butane to them <u>*without*</u> using the convenience of "Tesoro's and Valero's" pipeline delivering the gas to such a vulnerable storage site. Th issue of insurance and liability from this *3rd party* will then no longer be able to escape in the blue smoke and mirrors that this pipeline opportunity allows these corporations and/or companies.

For the AQMD to ignore this blatant effort to dodge responsible behavior with regard to public safety would be unconscionable. Each day that this Plains/Rancho LPG storage site continues to exist presents an ever increasing threat of decimation to the region. This game of gambling with the lives of our citizen must end immediately. People are not to be sacrificed for the sake of the petroleum industry's corporate profit.

Sincerely,

Chuck Hart

Chuck Hart,
President

Jillian Wong

From:	Julia May <julia@cbecal.org>
Sent:	Tuesday, April 18, 2017 11:39 AM
To:	Jillian Wong; Danny Luong; Veera Tyagi
Cc:	Wayne Nastri; Gladys Limon
Subject:	Please submit Study on refinery underestimation into Tesoro LARIC EIR & Ti5 record
Attachments:	FluxSense_SCAQMD2015_Project1_FinalReport (April 2017) (1).pdf; SoCalPublRadio LA-area-refineries-emit-up-to-12-times-more-toxics.pdf; 2016 AGU Fall Meeting Oil industry emissions underestimated.pdf
Categories:	Comment Letters, Facilities - Petroleum - Tesoro, CEQA - Permit

Dear Ms. Wong, Mr. Luong, and Ms. Tyagi,

Please submit this email, the attached study, and the other attachments reporting on the study at the American Geophysical Union, into the Tesoro LARIC EIR & Title V permit comments public record, as an additional CBE Comment on the Tesoro LARIC EIR and Title V Permit. We just received this report on Friday, It was released last week, April 11th, 2017, although reporting on the study was unveiled last December. We applaud the District for carrying out this study, and urge you to account for this information in the Tesoro LARIC project through a re-calculation of the project air emissions and impacts.

The joint Swedish and SCAQMD study clearly demonstrates that standard methods used by the District for estimating or modeling refinery emissions grossly underestimates them. This is another reason why the Tesoro LARIC EIR & Title V permit must be sent back to draft form and recirculated, as we have requested, in order to accurately reflect the existing conditions and the project impacts. Underestimation of emissions associated with the project because of deficiencies in standard methods (for example EPA's Tanks model) requires a re-assessment of project baseline and increases. The study shows both that the refinery baseline is worse than previously estimated by the District, further increasing the burden faced by the Wilmington, Carson, and W. Long Beach communities, and demonstrates that the increases will be much worse than estimated in the EIR & Title V permit (especially VOCs including benzene), since the project changes were calculated using the same methods that are used by the District to calculate the existing refinery emissions.

Attached are:
Emission Measurements of VOCs, NO2 and SO2 from the Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Optical Remote Sensing Methods, Final Report, FluxSense Inc, 11 April 2017, **Authors:** Johan Mellqvist1,2, Jerker Samuelsson1,2, Oscar Isoz1, Samuel Brohede1, Pontus Andersson1, Marianne Ericsson2, John Johansson1

In addition to the full report on the study, also attached is a pdf of the Southern California Public Radio webpage regarding this study, as it was first unveiled last December at the American Geophysical Union (AGU).
(Also available at: http://www.scpr.org/news/2016/12/29/67663/la-area-refineries-emit-up-to-12-times-more-toxic/)

Also attached is the Abstract and additional materials provided at the AGU conference in December 2016.
(Also available at: https://agu.confex.com/agu/fm16/meetingapp.cgi/Paper/180782)

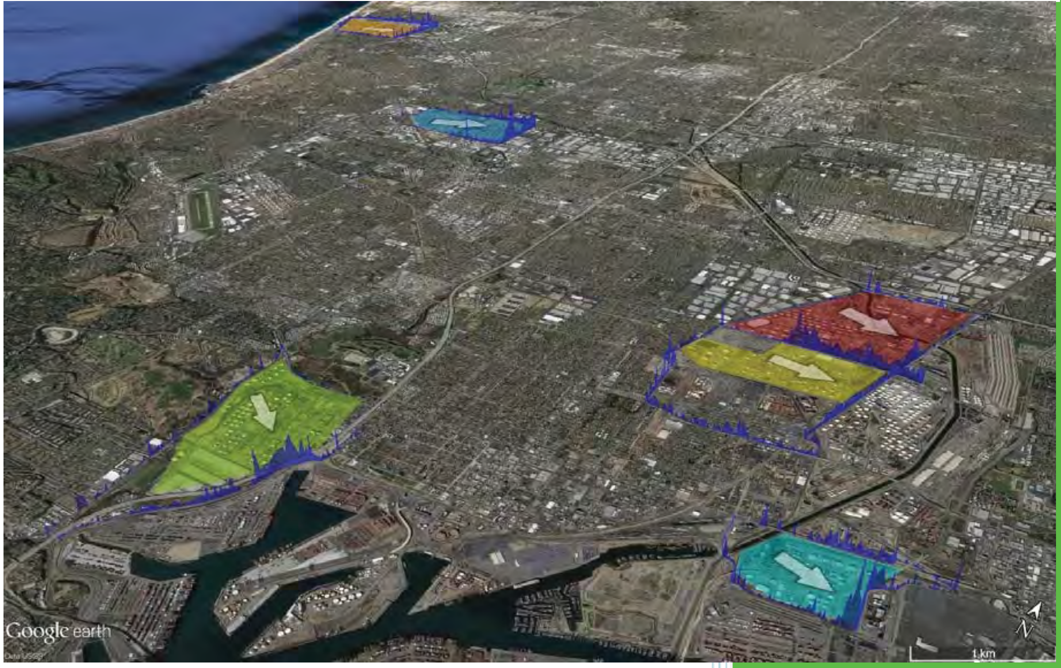
Thanks very much.

Julia May
Senior Scientist
Communities for a Better Environment (CBE)

cc. Wayne Nastri, Executive Officer, AQMD

2015

Emission Measurements of VOCs, NO_2 and SO_2 from the Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Optical Remote Sensing Methods



FluxSense

FINAL REPORT

FluxSense Inc

11 April 2017

Date: 11 April 2017

Title: Emission Measurements of VOCs, NO_2 and SO_2 from the Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Optical Remote Sensing Methods

Authors: Johan Mellqvist[1,2], Jerker Samuelsson[1,2], Oscar Isoz[1], Samuel Brohede[1], Pontus Andersson[1], Marianne Ericsson[2], John Johansson[1]

[1]FluxSense AB, Hörsalsvägen 11, SE-41296 Göteborg, Sweden
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FluxSense Inc is subsidiary of FluxSense AB (www.fluxsense.se; San Diego, CA). FluxSense started as a spin-off company from research conducted at Chalmers University of Technology in Sweden and has been active for more than 10 years. FluxSense has carried out more than 100 industrial site surveillances in Austria, Belgium, Denmark, France, Middle East, Netherlands, Norway, Sweden and the US.

[Cover: Visualization of alkane plume transects (blue curves) from Solar Occultation Flux (SOF) measurements conducted at the six refineries for this study during similar wind conditions. The apparent height of the blue line is proportional to the integrated vertical column concentration expressed in mg/m^2. White arrows indicate wind directions during these measurements. Image mapped on Google Earth © 2016.]

Executive summary

BACKGROUND

Accurate characterization of facility-wide emissions from industrial sources on a real or near-real time basis is critical for developing effective control strategies to improve regional air quality, promoting compliance, and reducing exposure for nearby communities. To improve the understanding of such emissions in the South Coast Air Basin (SCAB), the South Coast Air Quality Management District (SCAQMD) has sponsored a series of measurement projects to study industrial emissions using Optical Remote Sensing (ORS) methods. The projects include experimental studies of emissions from refineries, oil depots, treatment facilities, oil wells, gas stations, fuel islands and barges. In addition, SCAQMD has sponsored technology demonstration and validation studies to assess potential uncertainties of different optical techniques through side-by-side measurements of real sources and controlled source gas releases.

Numerous research studies using ORS conducted in the US and worldwide (including a 2013 pilot project sponsored by SCAQMD) suggest that measured emissions of VOCs from industrial facilities are larger compared to emission inventory estimates developed based on accepted reporting conventions. Given the large number of refineries and other industrial activities in the SCAB, it is therefore very important to evaluate novel measurement methods for detecting and quantifying industrial emissions directly.

This report presents the results of a two and a half month long measurement campaign aimed at characterizing and quantifying emissions of VOCs, NOx, and SO_2 from six major refineries in the SCAB. The measurements spanned from August 28 to November 11 2015, with up to 15 individual measurement days at each site. Additionally, a detailed eight day long measurement study inside the tank farm of one of the refineries was conducted to quantify emissions from the tank farm, locate potential leak sources, and validate the SOF technique by comparative measurements to other ORS methods.

Mobile surveys using two ORS techniques, namely SOF (Solar Occultation Flux) and Mobile SkyDOAS (Differential Optical Absorption Spectroscopy), were conducted around the refineries' perimeters to estimate facility-wide emission fluxes of VOCs, SO_2 and NO_2. These ORS techniques were complemented by extractive optical methods, including MeFTIR (Mobile extractive Fourier Transform Infra-Red spectroscopy) and MWDOAS (Mobile White cell DOAS) to map ground concentrations of alkanes, methane and aromatic VOCs and to calculate inferred fluxes for methane and aromatics. The required wind information was collected using a stationary wind-LIDAR (LIght Detection and Ranging; which provides vertical wind profiles) and conventional wind mast measurements.

SOF is a proven technique employed by FluxSense in over 100 fugitive emission studies around the world. In Europe the SOF technique is considered Best Available Technology (BAT) for measurements of fugitive emission of VOCs from refineries (Barthe *et al.* 2015), and in Sweden it is used together with tracer correlation and optical gas imaging to annually screen all larger refineries and petrochemical industries. In Swedish facilities, ORS emission measurements are conducted annually for at least ten days, during different seasons, in order to obtain a good representation of the annual mean. These measurements represent the total emission flux coming from the entire refinery, divided into sub parts such as process areas, crude oil storage, product storage tanks, water treatment facilities, flares, and loading operations. In the study presented here, such sub-area measurements were demonstrated for the tank farm of Refinery A.

The estimated uncertainty for the SOF emission measurements is typically 30 % for total site emissions, and usually slightly higher for individual sub-parts. The estimated measurement uncertainties have been verified in several (blind and non-blind) controlled source gas release experiments (including the one performed during this study and discussed elsewhere) and in side-by-side measurements with other techniques. The uncertainties in the total refinery emissions of BTEX and CH_4 obtained from inferred fluxes are larger than for the direct flux measurements of alkanes. Ideally, the gases should be well mixed in the plume for this method to work the best, but in reality there will be a stronger weighting towards low elevated sources (tanks) compared to higher elevated ones (process units) depending on the measurement geometry. Based on canister samples collected in several European refineries in the past, we know that typically the BTEX fraction is higher in the process units (10-15 % of total VOCs) compared to tank farms (5-10 % of total VOCs). The inferred BTEX flux will consequently be a low estimate of actual BTEX emissions because plumes from tanks are usually located closer to the surface, while plumes from process areas can extend further up into the atmosphere. In this study the overall BTEX to alkane ratio was 0.11.

RESULTS

Table ES.1 shows the measured hourly emission rates (kg/h) of various gaseous species from the refineries investigated during this study. The emissions presented in table ES 1 represent median values of all valid transects obtained during the two and a half month study period. The BTEX and CH_4 emission values have been extrapolated from concentration ratios of these species to alkanes measured at ground level and scaled with direct alkane emission measurements by SOF. It should be noted that, rather consistently for all the refineries, the BTEX emissions are typically one tenth of the total VOC emissions, while CH_4 emissions are on average two thirds of the alkane emissions.

Table ES.1. Median values of all measured site emissions during the 2015 SCAQMD survey. The fluxes of alkanes, SO_2 and NO_2 are obtained from direct measurements, while BTEX and CH_4 are inferred from gas ratio measurements. Note that benzene is part of BTEX.

Measured Refinery SCAQMD Survey 2015	**N Days**	**Alkane Flux** [kg/h]	**SO_2 Flux** [kg/h]	**NO_2 Flux** [kg/h]	**BTEX Flux** [kg/h]	*Benzene Flux [kg/h]*	**CH_4 Flux** [kg/h]
Refinery A	15	269	62	66	24	*3.4*	167
Refinery B	5	70	53	31	11	*1.1*	53
Refinery C	4	244	37	57	37	*8.2*	142
Refinery D	7	164	17	34	16	*1.6*	79
Refinery E	7	244	53	63	31	*2.7*	207
Refinery F	4	139	37	18	10	*0.8*	57
Sum		**1130**	**259**	**269**	**129**	*18*	**705**

In Table ES.2 the measured emission data for the various sites has been normalized by the corresponding crude oil capacity for each facility and compared to the reported emission inventories. The table shows that the measured VOC emission factors for the studied refineries range from 0.017 % to 0.045 % (mass emission per mass capacity of crude). SOF measurements carried out in other well-run refineries typically show average VOC emission factors of 0.03 % to 0.1 %. Thus, according to this data, the refineries in the SCAB are generally performing well, with relatively low emission compared to their capacity. However, as highlighted in Table ES.2, significant differences exist between measured and reported inventory emissions for VOCs and, for all refineries combined, the overall discrepancy between measured and reported inventory values was a factor of 6.2. For benzene the corresponding overall discrepancy ratio was about 34, although the magnitude of BTEX emissions was relatively small. Refinery C stands out with a measured benzene emission being more than twice as high as the next refinery in order. The measured SO_2 and NO_2 emissions are much closer to, and in some instances lower than, those reported in the inventories. In Table ES 2, the reported annual emissions have been divided by 12 to obtain a monthly inventory value to compare to the measured monthly median emissions from this survey. Hence, the discrepancies and emissions factors are representative for September 2015 (the time-period when the majority of the ORS measurements were performed).

Table ES.2. VOC emission factors normalized by the corresponding crude oil capacity for the various sites, and ratios between measured values and reported inventories for the 2015 SCAQMD survey.

Measured Refinery Representative of September 2015	**Crude capacity 2015***		**Measured Monthly Emission for Sept. 2015**	**Emission Factor****	**Discrepancy factor (Measured/Reported^{2})**			
	bbl/day	**Tons^{1}/mo**	**Alkanes+BTEX Tons^{1}/mo**	**Alkanes+BTEX %**	**Alkanes+ BTEX**	**SO_2**	**NO_2**	**Benzene**
Refinery A	257300	1086215	214	0.020 %	6.4	1.2	1.0	43
Refinery B***	139000	586801	59	0.045 %	8.3	1.5	0.8	33
Refinery C***			205		11.8	2.7	1.1	202
Refinery D	104500	441156	132	0.030 %	10.5	1.7	1.1	39
Refinery E	269000	1135608	201	0.018 %	5.4	1.7	0.8	38
Refinery F	149500	631128	109	0.017 %	2.7	1.1	0.3	3.2
Overall****	**919300**	**3880908**	**919**	**0.024 %**	**6.2**	**1.5**	**0.83**	**34**

* Crude capacity data is obtained from the 2016 California Energy Commission report.

** Mass emission per mass capacity of crude oil.

*** Crude capacity for Refinery B and Refinery C are reported together since Refinery B processes the crude oil and the Refinery C upgrades intermediate products to finished products.

**** The overall discrepancy values are calculated from the total sum of reported and measured emissions, respectively. The overall emission factor is based on the sum of measured emissions for all refineries relative to the total capacity. Reported annual values have been divided by 12 to obtain a monthly inventory value to compare to the measured monthly average emissions from this survey. The comparisons are representative for September 2015 (the time-period when most of the measurements were performed).

[1] metric tons.

[2] Note that total nitrogen oxides (NO_x) are reported while only the NO_2 fraction was measured by SkyDOAS.

ORS measurements were also conducted for eight days inside the tank farm of one of the refineries listed above. The objective of this part of the study was to demonstrate the capability of real time ORS techniques to identify and quantify emissions and potential gas leak sources inside a refinery. Several storage and crude oil tanks were identified as VOC emitters, including a large underground reservoir containing vacuum gas oil (VGO).

While conducting measurements inside one of the refineries, our mobile optical methods identified an area characterized by elevated alkane concentrations of about 70,000 ppb, in contrast to the ten to a few hundred ppb normally measured downwind of similar sources. An infrared gas imaging camera (FLIR) was used to visualize and confirm alkane gas emissions through a shallow pool of water on the ground. Once the leak was discovered, the refinery staff took swift action to investigate and repair the source of the leak. The investigation discovered a pinhole-size leak in a pipeline buried 30 cm below the ground. After the leak was repaired additional ORS measurements were conducted to verify that the problem was resolved. This event illustrates how mobile ORS measurements combined with conventional gas imaging can quickly identify an unknown leak and allow it to be fixed before any serious complications may occur.

Within this project we also conducted a separate study to compare the SOF readings to those of other ORS techniques such as DIAL (Differential Absorption Lidar) and long-path FTIR through side-by-side measurements on various tanks inside one of the refineries. The agreement between emissions from different tanks and reservoirs inside the refinery measured by SOF and DIAL was excellent (within 10-20 %). As part of the SOF, DIAL and long-path FTIR technology comparison and validation, a blind gas release experiment was also carried out using a controlled source emitting 2-25 kg/h of odorless propane at the flat open parking lot of the Angels stadium in Anaheim, CA. In this study, the SOF measurements consistently underestimated the true emissions by 35%, but showed excellent correlation for the different release rate configurations (R^2 ~98%). The detailed results of this technology inter-comparison study are compiled and presented in a separate report.

DISCUSSION

A common concern when comparing measured emissions with those reported in the inventories is that the reported data are calculated for a full year while measurements are typically conducted over a limited time period. This may impact uncertainties when translating measured emission rates to annualized values, as external environmental parameters such as wind, temperature and solar insolation, affect tank emissions. An additional concern is whether a sufficient number of measurements (and measurement days) have been sampled to eliminate the influence of any intermittent emissions due to tank cleaning, maintenance, flaring, etc. To address these concerns, we carefully analyzed the frequency distributions (histograms) of the measured emissions and wind data, and studied how they may be impacted by seasonal variations in meteorological conditions. In addition, the effect of ambient temperature and wind speed on tank emissions was investigated. For this study we concluded that variations in emissions resulting from environmental changes are relatively small and within the uncertainties of the SOF and SkyDOAS measurements.

The observed differences between measured emissions and reported inventories (based on the US EPA AP-42 standard) are considerably higher than what can be explained by measurement uncertainties alone, or incomplete diurnal and seasonal sampling. Refineries and tank farms are complex environments with a large number of components and numerous potential leak sources (e.g. tank seals, valves, gauges, flares, vapor recovery units, etc.). Many of these components can show degrading performance over time, and to appropriately account for the impact of non-ideal performance in emission inventory reporting is, we believe, an impossible task. Nevertheless, EPA's AP-42 system provides valuable insights for a specific facility on the production and abatement techniques applied and on what emission level the site could reach given ideal performance of all installations. Comparing measured emissions to ideal performance levels could therefore provide a basis for benchmarking of different refineries or sites.

OUTLOOK

Studies conducted in the SCAB, the Bay Area, Texas, and other places worldwide, show that field measurements provide a reliable way to determine actual emissions of VOCs and other pollutants from refineries and various industrial sites. Accurate estimates of VOC and other pollutant emissions from industrial sources are crucial for improving air quality models, to guide air pollution mitigation strategies, promote successful compliance strategies, and reduce exposure for nearby communities.

In our experience, the observed difference in fugitive VOC emissions between measured and inventory estimates is a general issue for the petroleum industry worldwide. We believe that a possible path forward could be to conduct monitoring in parallel with continued AP 42 based reporting, and to use the measurements to guide and verify the efficiency of the emission reduction efforts at the industrial sites.

Future longer-term ORS studies spanning over different seasons can be conducted in order to alleviate concerns stemming from comparison of emissions measured over limited-time to annual emissions reported through the inventories. Additionally, future studies could combine ORS measurements and site-specific emission modeling performed for inventory calculations. A better dialog between scientists conducting the measurements and the facility operators could also be crucial to improve our understanding of how site activities may affect measured emissions.

Traditional Leak Detection and Repair (LDAR) is an important practice to control and limit unplanned VOC emissions from refineries and to identify potential leak sources. The ORS techniques used in this study have demonstrated their ability to quickly quantify and map refinery emissions and to identify potential air pollution sources within a facility. Using real time measurements, refinery personnel and air quality regulators can enhance LDAR programs by prioritizing LDAR activities. Addressing the most concerning issues first is important to reduce occupational risks for refinery workers, avoid public hazard exposures, and limit the economic losses due to unplanned evaporation of refinery products.

A continued path towards improved air quality involves a good understanding of current emission levels and sources. Repeated and systematic emission measurements will be an important tool for benchmarking industry’s environmental performance as well as for sustaining and verifying efficient emission improvement plans, ultimately resulting in cleaner air and a better environment.

Acronyms, Units and Definitions

Acronyms used in this report

ASOS	Surface Weather Observation Stations
BPD	Barrels per day
BTEX	Sum of Benzene, Toluene, Ethyl Benzene and Xylene
DOAS	Differential Optical Absorption Spectroscopy
FTIR	Fourier Transform InfraRed
LDAR	Leak Detection And Repair
LIDAR	Light Detection and Ranging
MWDOAS	Mobile White cell DOAS
MeFTIR	Mobile extractive FTIR
SOF	Solar Occultation Flux
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
VOC	Volatile organic compound, used interchangeably for non-methane VOC

Units

Air temperature	degrees C
Atmospheric Pressure	mbar
Relative Humidity	%
Wind direction	degrees North
Wind speed	m/s
Column	mg/m^2
Concentration	mg/m^3
Flux	kg/h

Unit Conversions

1 lbs = 0.4536 kg
1 kg/h = 52.9 lbs/day
1 bbl = 159 l
1 bbl/day = 5.783 kg/h (crude oil)
1 (short) ton = 907.2 kg
1 kton/year = 104 kg/h
1 klbs/year = 0.052 kg/h

Definitions

Alkane or alkanes are considered to be all non-methane alkane species.

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1 Introduction and Background

Industrial volatile organic compound (VOC) emissions contribute to significant formation of ground level ozone which is formed through atmospheric chemical reactions of volatile organic compounds (VOCs) and nitrogen oxides NO_x in the presence of sunlight, often called photo chemical smog. Elevated ozone concentrations are known to reduce crop yields and constitute a public health concern.

Larger metropolitan areas in the US, including the South Coast Air Basin, have trouble meeting ozone standards since anthropogenic sources tend to be concentrated in urban areas, including both mobile and stationary sources. VOC emissions from the latter category, i.e. refineries, petrochemical industries and solvent use, are typically dominated by evaporative losses from storage tanks and process equipment, so called fugitive emissions. Industrial NO_x and SO_2 emissions, on the other hand, occur primarily from external combustion sources. These channeled emissions are quite well understood since they come from relatively few places in an industrial site and since they can be monitored using conventional technology. Evaporative losses of VOCs can potentially occur in every unit in which petroleum products are stored, processed or transported. Units that are malfunctioning, in need of maintenance, or irregularly operated can have drastically elevated emissions without giving any indication. These types of irregular emissions can remain unnoticed if measurements of diffuse emissions are not made.

The industries typically estimate their emissions with emission factors calculated using methods and formulas described in AP-42, Compilation of Air Pollutant Emission Factors (US-EPA 2013). New Technologies for quantitatively measuring these types of VOC emissions exist but have so far only been applied at limited facilities. Estimates of VOC emissions from refineries and petrochemical are therefore rarely verified by quantitative measurements. Since reported total VOC emissions from a facility are typically a very small fraction (typically in the order of 0.01-0.10 %) of its crude oil capacity, emissions would remain insignificant in any type of mass balance even if they were many times larger than reported.

Measurements during the 2000 TexAQS (Texas Air Quality Study) and the 2006 TexAQS II indicated that current emission inventories significantly underestimate industrial VOC emissions in Houston (Kleinman *et al.* 2002; Ryerson 2003; Wert *et al.* 2003; Jobson 2004; Mellqvist *et al.* 2010; Karl 2003; De Gouw, J. A. de *et al.* 2009; Washenfelder *et al.* 2010; Parrish *et al.* 2009). Similar conclusions have also been drawn from international studies elsewhere such as Sweden (Kihlman 2005; Kihlman *et al.* 2005), The Netherlands (Mellqvist *et al.* 2009), France (INERIS 2010) and Belgium (Samuelsson *et al.* 2011). Several studies have concluded that industrial VOC emissions contribute significantly to ozone formation (Kleinman *et al.* 2002; Ryerson 2003; Jobson 2004; Gilman *et al.* 2009; Kim *et al.* 2011; Wert *et al.* 2003; Kim *et al.* 2011).

In order to improve the understanding of VOC, NO_2 and SO_2 emissions in the South Coast Air Basin (SCAB) and to assess whether they impact the ground level ozone in a significant way, the South Coast Air Quality Management District (SCAQMD) has promoted and sponsored several measurement projects to study these emissions using optical remote sensing methods. The projects include experimental studies of emissions from refineries, oil depots, treatment facilities, oil wells, gas stations, fuel islands, barges and shipping. In addition, a technology demonstration and validation study was carried out to assess the uncertainties of different optical techniques using side-by-side measurements of real sources and controlled source gas releases. This work is an extension of a pilot study that was carried out by FluxSense in Los Angeles area in September/October 2013 (Mellqvist *et al.* 2013a, 2013b).

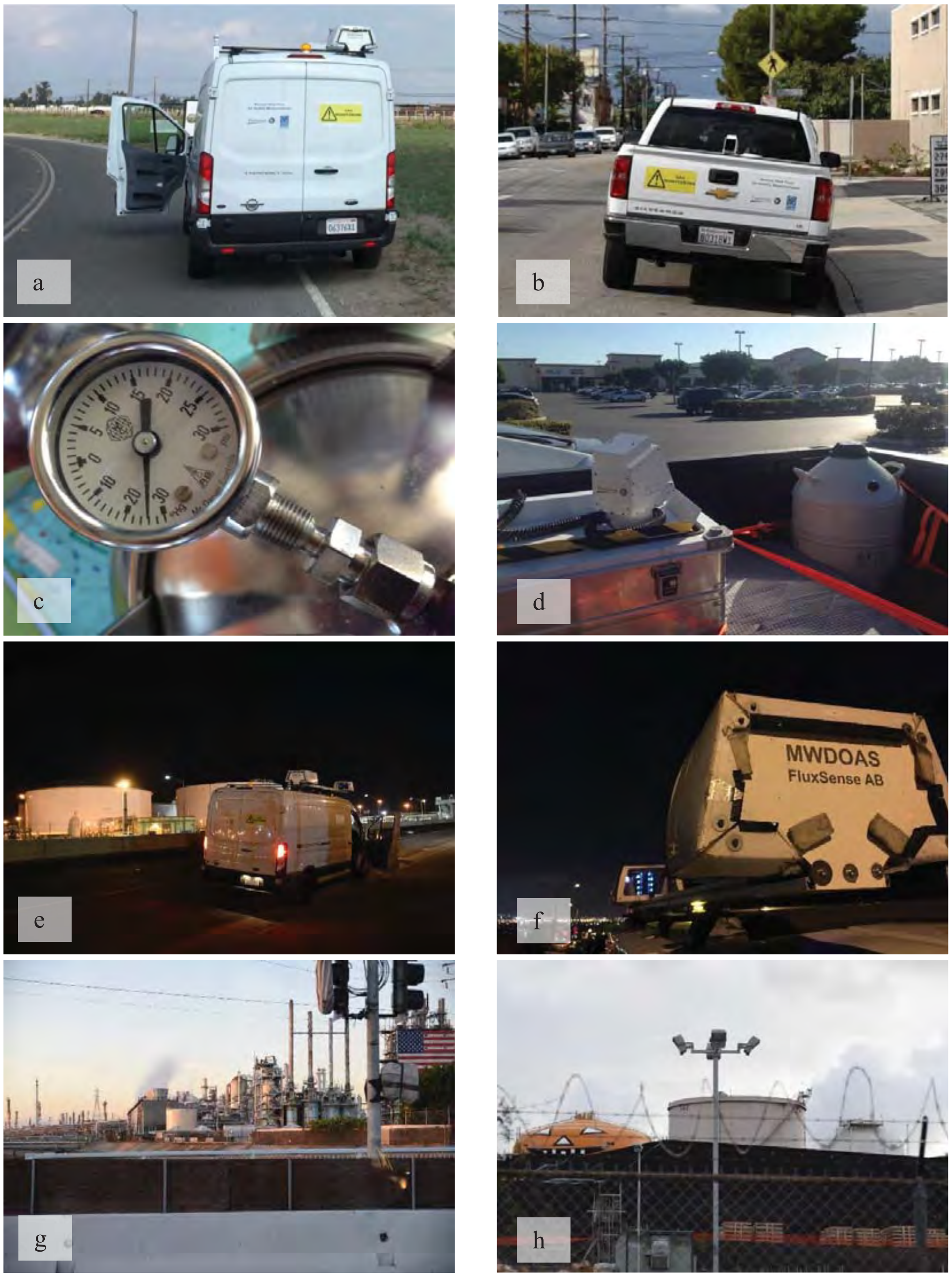

Figure 1. Example images from the 2015 SCAQMD measurement survey. a) FluxSense Mobile lab, b) secondary SOF vehicle, c) Canister sampling, d) Secondary SOF system, e) Night-time MeFTIR measurements, f) MWDOAS measurement, g) Refinery view, h) Tank park view.

This report covers the results from the first of three SCAQMD projects. This project studied emissions of VOCs, CH_4, SO_2 and NO_x from the six main refineries in the SCAB over several months and to compare these to current inventories. This report is one of several other reports describing measurements of smaller emission sources, ship emissions and validation activities. The refineries are denoted Refinery A, Refinery B, Refinery C, Refinery D, Refinery E, and Refinery F respectively. These refineries have a total reported crude oil capacity of more than 900,000 bbl/day (California Energy Commission 2016) and are major contributors of VOC-emissions and, consequently, smog formation in the region.

Two mobile remote gas sensing techniques, SOF (Solar Occultation Flux) and Mobile Sky-DOAS (Differential Optical Absorption Spectroscopy) were operated around the perimeter of the six selected refineries for estimation of facility-wide mass emission fluxes of VOCs, SO_2 and NO_2. The remote gas sensing techniques were complemented by mobile extractive optical methods, i.e. MeFTIR (Mobile extractive FTIR) and MWDOAS (Mobile White cell DOAS) to map ground concentrations of alkanes, methane and aromatic VOCs to calculate inferred fluxes. A mobile wind LIDAR station supplied by SCAQMD allowed for the continuous measurements of vertical wind profiles. Wind data was also obtained from local meteorological stations to complement the LIDAR results. See Figure 1 for example of measurement situations.

SOF is a proven technique employed by FluxSense in over 100 fugitive emission studies around the world. In Europe the SOF technique is Best Available Technology (European Commission 2015) for measurements of fugitive emission of VOCs from refineries and in Sweden it is used together with tracer correlation and optical gas imaging to screen all larger refineries and petrochemical industries annually. The Swedish facilities are visited during at least 10 days per year, spread out over the different seasons, to give a good representation of annual mean conditions. The measurements represent the total emission coming from the entire refinery, divided into sub parts such as process areas, crude oil storage, product storage tanks, water treatment facilities, flares and loading operations. The estimated uncertainty for the emissions is typically 30 % for the total site emissions, and somewhat higher for the individual parts. This has been concluded from several controlled source gas release experiments (blind and non-blind) and side-by-side measurements with other measurement techniques.

The measurements were carried out in the period August 28 to November 11 2015, with up to 15 individual measurements days at the individual sites, and up to 40 individual measurements. Representative statistics of measured emissions (e.g. average, standard deviation, median, etc.) were determined for this time period. Measurements were generally conducted outside the facilities fence-lines along public roads measuring both upwind and downwind the refineries to account for inflow of pollutants from the background. During a week and a half (September 28 to 7 October), measurements were also conducted inside the Refinery A at the main eastern tank farm. The aim was to quantify and to locate leaking tanks and components and to validate the technique by comparative measurements.

In this report, the results from these refinery measurements are compared to the reported annual emission inventories. Discrepancies between reported annual inventories and measured emissions are discussed and further investigated.

In parallel to this project an additional study was carried out in which the SOF method was compared to other optical techniques, DIAL (Differential Absorption LIDAR) and long-path FTIR using side-by-side measurements on various tanks inside a refinery, a treatment plant and an oil well cistern; here the agreement with the other methods was excellent, i.e. 10-20 %. As part of the same study, a blind gas release experiment was carried out, using a controlled source releasing 2-25 kg/h of propane at the parking lot of the Angels of Anaheim baseball stadium, Anaheim, CA. Here the SOF measurements consistently underestimating the true emission by 35% but with a good correlation (R^2 ~98%). This study is compiled in a separate paper.

2 Instrumentation and Methods

The FluxSense mobile laboratory was equipped with four instruments for gas monitoring during the survey; SOF, SkyDOAS, MeFTIR and MWDOAS. Individual measurement methods are described briefly in the subsections below. SOF and SkyDOAS both measure gas columns through the atmosphere by means of light absorption. SOF utilizes infrared light from the direct sun whereas SkyDOAS measure scattered ultraviolet light from the sky. MeFTIR and MWDOAS both measure ground level concentrations of alkanes and BTEX respectively. Accurate wind data is necessary in order to compute emission fluxes. Wind information for the survey was derived from several different sources as described in detail in Section 2.5. A wind LIDAR was used to measure vertical profiles of wind speed and wind direction from 50-1000 m height. The LIDAR data was supported with complimentary data from several wind masts at fixed met network- and mobile stations.

Figure 2 gives a general overview of the measurement setup and the data flow and pictures of the FluxSense mobile lab is found in Figure 3.

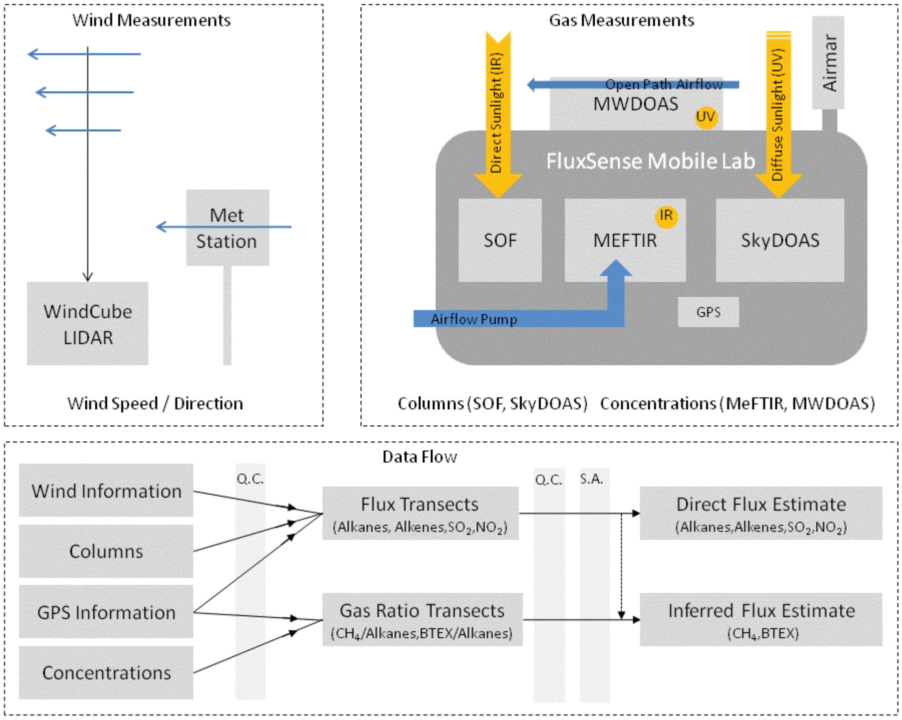

Figure 2. Overview of the FluxSense mobile lab main instruments; SOF, MeFTIR, MWDOAS and SkyDOAS (upper right panel) and wind measurements (upper left panel) and simplified data flow diagram (lower panel). SOF and SkyDOAS are column integrating passive techniques using the Sun as the light source while MeFTIR and SkyDOAS sample local air concentrations using active internal light sources. The data flow describes what information that goes into the flux emission estimates. Direct flux emissions are given from measured columns (SOF and SkyDOAS) of alkanes, SO_2 and NO_2, while inferred fluxes are calculated via gas concentration ratios (MeFTIR and MWDOAS) of BTEX and CH_4. See section 3.2 for principal equations. All emission flux estimates are based on statistical analysis of measured data. Q.C. = Quality Control, S.A.= Statistical Analysis (see Appendix for details).

In order to derive final emission flux estimates, the GPS-tagged gas column measurements by SOF and SkyDOAS are combined with wind data and integrated across plume transects at the various source locations. Gas mass ratio measurements by MeFTIR and MWDOAS are then used to infer emission estimates also for methane and BTEX (which can't be measured directly by SOF and SkyDOAS).

During some of the measurement days at the end of the survey (29 October to 9 November), a second SOF instrument was also used. This additional SOF platform was placed on the bed of a pick-up truck (see Figure 1b) and operated independently of the FluxSense mobile lab, but with a similar optical setup. The second instrument made it possible cover more objects within the survey time frame.

Figure 3. Internal and external view of the FluxSense mobile lab.

A table summarizing the main features and characteristics of all measurement techniques used for this study is found in Table 1.

Table 1. Summary of FluxSense gas measurement techniques. *For typical wind conditions at an optimal distance from the source.

Method	**SOF**	**SkyDOAS**	**MeFTIR**	**MWDOAS**
Compounds	**Alkanes**: (C_nH_{2n+2}) **Alkenes:**C_2H_4, C_3H_6	**SO_2** **NO_2**, **HCHO**	**CH_4** **Alkanes:** (C_nH_{2n+2}) **Alkenes:** C_2H_4, C_3H_6	**BTEX**
Detection limit Column	0.1-5 mg/m^2	0.1-5 mg/m^2	1-10 ppbv	0.5-3 ppbv
Detection limit Flux*	0.2-1 kg/h	1 kg/h	0.2-2 kg/h	1-2 kg/h
Wind Speed Tolerance	1.5-12 m/s	1.5-12 m/s		
Sampling Time Resolution	1-5 s	1-5 s	5-15 s	8-10 s
Measured Quantity [unit]	Integrated vertical column mass [mg/m^2]	Integrated vertical column mass [mg/m^2]	Mass concentration at Vehicle height [mg/m^3]	Concentration at Vehicle height [mg/m^3]
Inferred Quantity [unit]	Mass Flux [kg/h]	Mass Flux [kg/h]	Alkane ratio of ground plume combined with SOF gives mass flux [kg/h] and plume height information [m]	Combined with MeFTIR and SOF gives Mass Flux [kg/h]
Complementary data	Vehicle GPS-coordinates, Plume wind speed and direction	Vehicle GPS-coordinates, Plume wind speed and direction	Vehicle GPS-coordinates, Plume wind direction	Vehicle GPS-coordinates, Plume wind direction

2.1 The SOF method

The SOF method (Mellqvist 1999; Mellqvist *et al.* 2008b; Mellqvist *et al.* 2008a; Mellqvist *et al.* 2009; Mellqvist *et al.* 2010; EPA 2011) is based on the recording of broadband infrared spectra of the sun with a Fourier transform infrared spectrometer (FTIR) that is connected to a solar tracker. The latter is a telescope that tracks the sun and reflects the light into the spectrometer independent of the orientation of the vehicle. From these solar spectra, it is possible to use multivariate optimization to retrieve the path-integrated concentrations (referred to as column concentrations) of various species between the sun and the spectrometer (in the unit mg/m^2). The system used in this project consists of a custom built solar tracker, transfer optics and a Bruker IRCube FTIR spectrometer with a spectral resolution of 0.5 cm^{-1}, equipped with a dual InSb (Indium Antimonide) / MCT (Mercury Cadmium Telluride) detector. A reference spectrum is taken outside the plume so that atmospheric background concentrations can be removed. This means that all measured SOF columns are analyzed relative to the background column concentrations.

The system is installed in a measurement vehicle which allows consecutive column concentration measurements to be performed while driving. The flux of a species in a plume from an industry is measured by collecting spectra while driving the vehicle so that the light path from the sun to the instrument gradually cuts through the whole plume, preferably as orthogonally as possible to the wind direction, see Figure 4.

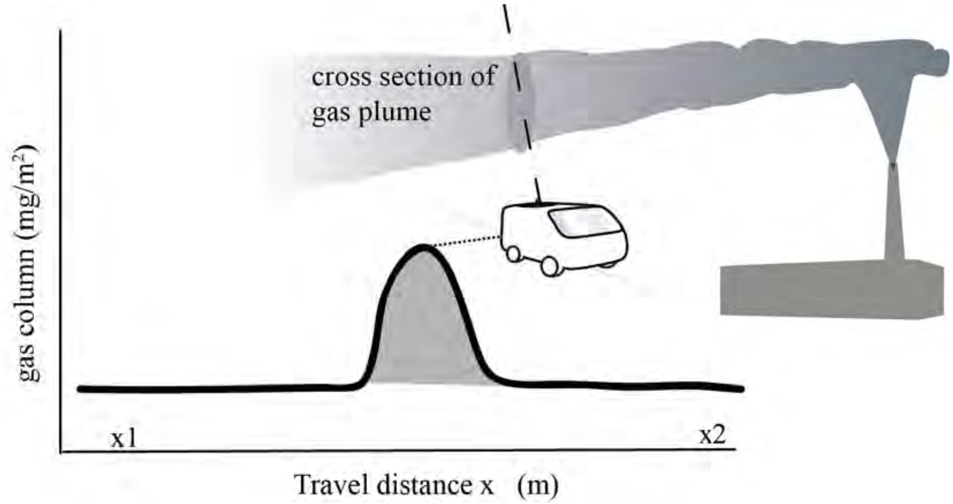

Figure 4. Schematic of the SOF measurement where the vehicle is driven across the prevailing wind so that the solar beam cuts through the emission plume while the sun is locked into the FTIR spectrometer by the solar tracking device on the roof. The VOC mass (or other compound of interest) is integrated through the plume cross section. See section 3.2 for complete equations.

For each spectrum a column concentration of the species is retrieved using custom software (QESOF, i.e. Quantitative evaluation of SOF) (Kihlman *et al.* 2005). These column concentrations, together with positions recorded with a GPS (Global Positioning System) receiver and the solar angle calculated from the time of the measurements, are used to calculate the area integrated column of the species in the intersection area between the plume and the light path. The flux of the species is then obtained by multiplying this area integrated concentration with the orthogonal wind speed vector component.

The IR spectra recorded by the SOF instrument are analyzed in QESOF by fitting a set of spectra from the HITRAN infrared database (Rothman *et al.* 2003) and the PNNL database (Sharpe *et al.* 2004) in a least-squares fitting procedure. Calibration data from the HITRAN database is used to simulate absorption spectra for atmospheric background compounds present in the atmosphere with high enough abundance to have detectable absorption peaks in the wavelength region used by SOF. Spectra, including water vapor, carbon dioxide and methane, are calibrated at the actual pressure and temperature and degraded to the instrumental resolution of the measurements. The same approach is applied for several retrieval codes for high resolution solar spectroscopy developed within Network for the Detection of Atmospheric Composition Change (NDACC) (Rinsland *et al.* 1991; Griffith 1996), and QESOF has been tested against these with good agreement, better than 3%. For the retrievals, high resolution spectra of ethylene, propene, propane, n-butane and n-octane were obtained from the PNNL (Pacific Northwest National Laboratory) database and these are degraded to the spectral resolution of the instrument by convolution with the instrument line shape. The uncertainty in the absorption strength of the calibration spectra is about 3.5% for all five species.

In this project, the SOF method was used to measure VOCs in two different modes. Most VOCs with C-H-bonds absorb strongly in the 3.3-3.7 μm (2700-3005 cm^{-1}) spectral region. This region is mainly used for alkane measurements using a spectral resolution of 8 cm^{-1}. Alkenes (including ethylene and propylene) are instead measured in the spectral region between 910 and 1000 cm^{-1} using a spectral resolution of 0.5 cm^{-1}. In the alkane mode – the IR light absorption is essentially sensitive to the total alkane mass (number of alkane C-H bonds) present in the plume. The absorption structures (cross sections) for the various alkane compounds are rather similar, with the absorption strength scaling to the mass of the alkane species. Hence, the actual mix of alkanes in the plume does not affect the retrieved total alkane mass flux much, although only cross sections from a subset of all alkanes (propane, n-butane and octane) are fitted in the spectral analysis. Typically, the rare event of significant absorption from other species in the plume shows up as elevated residuals and is further investigated in the re-analysis. For the alkene mode the specificity of the measurements is good, since the absorption of different species is rather unique in this so called “fingerprint region” and absorption features are often sharp and well separable from each other at 0.5 cm^{-1} resolution.

2.2 Mobile SkyDOAS

The principle for Mobile SkyDOAS (Mobile Differential Optical Absorption Spectroscopy) measurements is very similar to that of SOF. Instead of measuring direct sun light in the infrared region, scattered light in the UV and visible region is measured in zenith angle with a telescope connected with an optical fiber to a Czerny-Turner spectrometer with a CCD camera. Column concentrations are retrieved from spectra in a similar way as with the SOF, although absorption is generally weaker. The system that was used for this project consists of a quartz telescope (20 mrad field of view, diameter 7.5 cm) connected with an optical fiber (liquid guide, diameter 3 mm) to a 303 mm focal length Czerny-Turner spectrometer with a 1024 by 255 pixels, thermoelectrically cooled CCD camera, see Figure 5.

Figure 5. The mobile Sky-DOAS system: Telescope, optical fibre, spectrometer and control computer.

The system was installed in the same measurement vehicle as the SOF system. Plumes were transected in the same way as with the SOF system and the retrieved column concentrations used to calculate fluxes exactly the same way, except that the SkyDOAS measurement direction is always zenith.

In this project, mobile SkyDOAS was used to measure SO_2, NO_2 and HCHO. NO_2 is retrieved in the wavelength region between 324 and 350 nm and SO_2 in the region 310-325 nm. HCHO is measured in the region 322-350 nm. It was however never found above detection limit in any repeatable measurement during the campaign and is therefore not included in the result section. Apart from SO_2, NO_2 and HCHO the spectral analysis also includes other atmospheric compounds such as O_3 and O_4. The rare event of significant absorption from other species in the plume than those included in the spectral fit shows up as elevated residuals and is further investigated in the re-analysis. The absorption line parameters of the retrieved compounds are well established in published databases, stating an uncertainty of 4% (Vandaele *et al.* 1998) for the UV cross section of NO_2 and less than 2% for the SO_2 cross sections (Bogumil *et al.* 2003).

The DOAS technique was introduced in the 1970's (Platt *et al.* 1979) and has since then become an increasingly important tool in atmospheric research and monitoring both with artificial light sources and in passive mode utilizing the scattered solar light. In recent time the multi axis DOAS technique (scanning passive DOAS) has been applied in tropospheric research for instance measuring formaldehyde (Heckel *et al.* 2005; Pikelnaya *et al.* 2007).

Passive DOAS spectroscopy from mobile platforms has also been quite extensively applied in volcanic gas monitoring (Galle *et al.* 2003) for SO_2 flux measurements and for mapping of formaldehyde flux measurements in megacities (Johansson *et al.* 2009), . Mobile SkyDOAS has been used in several studies for measurements of industries i.e. SO_2, NO_2 and HCHO for several campaigns in Texas including NO_2 measurements at Longview in 2012 (Johansson *et al.* 2014a; Johansson & Mellqvist 2013). (Rivera 2009) did SO_2 measurements on a power plant in Spain for validation purposes. They also made measurements at an industrial conglomerate in Tula in Mexico (Rivera *et al.* 2009a) and measurements of SO_2, NO_2 and HCHO during the TexAQS 2006 campaign (Rivera *et al.* 2009b; Rivera *et al.* 2010). There are also groups in both China and Spain working with mobile mini DOAS.

2.3 Mobile extractive FTIR

Mobile Extractive FTIR (MeFTIR) (Galle *et al.* 2001; Börjesson *et al.* 2009) in combination with tracers has been used to quantify VOC emissions from refinery and petrochemical sources in Europe and in the U.S. Alkanes and alkenes are typically measured, but also methane and other climate gases can be retrieved. MeFTIR is an optical technique capable of monitoring gas concentrations at ppb-sensitivity in mobile field operations. It is used both independently for concentration mapping and flux measurements, but often combined together with simultaneous SOF flux measurements to provide more detailed VOC speciation of plumes and for plume height assessments (Johansson *et al.* 2014b). The plume height can be estimated by dividing measured columns (mg/m^2) with ground concentrations (mg/m^3), assuming that the plume is evenly distributed up to the plume height (and zero above).

The MeFTIR system contains a mid-infrared spectrometer with medium resolution (0.5 cm^{-1}). It utilizes an internal glow bar as an infrared radiation source, and by customized optics this light is transmitted through an optical multi-pass measurement cell with selectable path-length of 9.6-107.2 meters. The system is mounted on a vibration dampening platform to allow for real time plume mapping from a mobile platform, such as a vehicle or boat, see Figure 6.

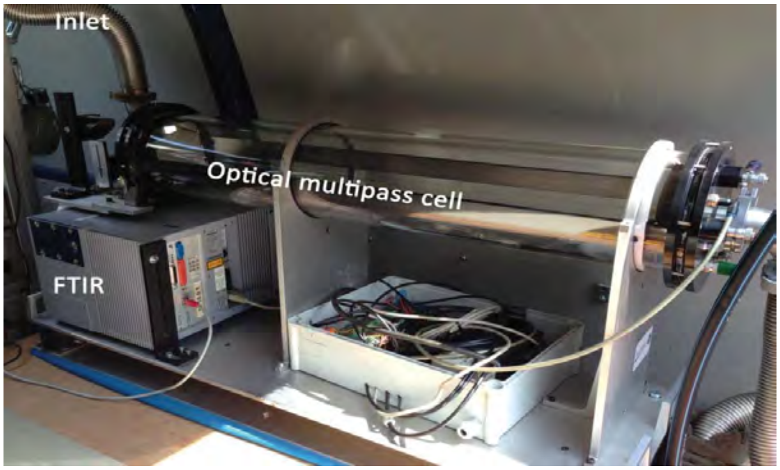

Figure 6. The MeFTIR instrumentation consisting of a Bruker FTIR spectrometer connected to an optical multi-pass cell.

The transmitted light is detected simultaneously with an InSb-detector (Indium Antimonide) in the 2.5–5.5 µm (1800–4000 cm^{-1}) region and a MCT (Mercury Cadmium Telluride) detector in the 8.3–14.3 µm (700–1200 cm^{-1}) region. Temperature and pressure in the cell are averaged over the duration of each measurement. Atmospheric air is continuously pumped at high flow rate through the optical cell from the outside, taking in plume air from the roof of the vehicle (2.5 m height) through a Teflon tube. A high flow pump is used to ensure that the gas volume in the cell is fully replaced within a few seconds. Spectra are typically recorded with an integration time of 10 seconds. A GPS-receiver is used to register the position of the vehicle every second.

The concentration in the spectra is analyzed in real time by fitting a set of calibrated spectra from the Hitran infrared database (Rothman *et al.* 2003) and the PNNL database (Sharpe *et al.* 2004) in a least-squares fitting procedure. Compounds being analyzed include ethylene, propylene, total alkane mass (based on fitting cross sections of ethane, propane, n-butane, i-pentane, n-octane), water, methane, CO, CO_2 and N_2O. The analysis routines are very similar to the ones for SOF, but less complex because strong absorption by atmospheric trace gases (water, methane, CO_2) has less consequence at the shorter path length in the MeFTIR measurement cell.

The MeFTIR tracer approach has been tested in a so called gas release "blind test" together with other techniques in U.S. (Babilotte 2011). In that test, methane was released from an area-distributed source in four different configurations and flow rates ranging from 1.1-3.3 g/s. At a downwind distance of 400 meters MeFTIR retrieved the fluxes within 6% in 3 cases and 19% in the fourth. This is consistent with other validation experiments, showing a flux estimate accuracy of better than 20%. Concentration measurement by FTIR is a widely used procedure, and the main uncertainties are associated with the absorption cross sections (typically < 3.5%) and spectral retrieval, with an aggregate uncertainty better than 10% in the analysis. Concentrations are monitored in real time in order to detect emission plumes and to judge whether any interfering sources are being sampled. Unwanted signals from local traffic exhaust or from the measurement vehicle itself could be filtered out by looking at the carbon monoxide (typical exhaust compound) concentrations. A stationary source is, on the contrary to any local traffic plumes, characterized by recurrent downwind plumes. Transient and non-repeatable observations are therefore excluded from the results. Furthermore, measurements of ambient concentrations of methane and carbon dioxide (with known atmospheric concentrations) are used for consistency check.

2.4 Mobile White Cell DOAS (MWDOAS)

The ground level mass concentration of benzene, toluene, ethylbenzene, *meta*- and *para*- xylene (BTEX) was measured using a mobile real-time system: Mobile White cell DOAS (MWDOAS). The Mobile White cell DOAS system consists of an open, 2.5 m long optical White cell that is mounted on the roof of the measurement vehicle (see Figure 7). By multiple reflections in the White cell mirror system an overall path length of 210 m is obtained, resulting in low detection limits (ppb). The light from the internal lamp is transmitted through the White cell and then analyzed in a DOAS spectrometer, using the UV wavelength region 255 - 285 nm.

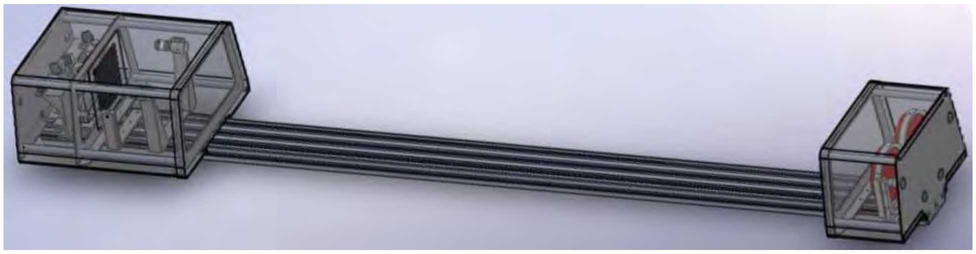

Figure 7. The open path MWDOAS cell having an overall optical path-length of 210 m.

A measurement begins by acquiring a reference spectrum outside the plume, usually upwind of the facility. Spectra are then sampled and averaged continuously while driving through emission plumes. The averaging time is set to around 8 seconds in order to achieve acceptable SNR (see below). This is the lower limit of the temporal sampling between independent measurements, but the spatial sampling is also dependent by the vehicle's velocity. A typical driving speed for MWDOAS measurements is 10-20 km/h for sufficient plume sampling.

The spectra are geo-tagged and evaluated online using the standard DOAS technique, giving information of plume locations and constituents. Cross-sections included in the evaluation are tabulated in Table 2.

Table 2. The UV-cross-sections used in the evaluation of the MWDOAS spectra.

Chemical compound	**Origin of reference spectrum**
O_3	(Burrows *et al.* 1999)
SO_2	(Bogumil *et al.* 2003)
O_2	(Bogumil *et al.* 2003)
Toluene	(Fally *et al.* 2009)
Benzene	(Etzkorn *et al.* 1999)
1,3,5-Trimethylbenzene	(Etzkorn *et al.* 1999)
1,2,4-Trimethylbenzene	(Etzkorn *et al.* 1999)
Styrene	(Etzkorn *et al.* 1999)
Phenol	(Etzkorn *et al.* 1999)
p-xylene	(Etzkorn *et al.* 1999)
m-xylene	(Etzkorn *et al.* 1999)
Ethylbenzene	(Etzkorn *et al.* 1999)

The MWDOAS data is later post evaluated and merged with the corresponding MeFTIR data to produce a plume specific BTEX/alkane mass ratio. The mass ratio of BTEX/alkanes is then used to calculate the aromatic flux from individual sub areas where alkane fluxes have been measured by SOF, assuming they have the same source. Specific area plumes are ideally probed at several times, and an overall average of all plume transect BTEX/alkane ratios is then made. The method requires in situ access to the plume of the studied source, and as instrumentation typically are mounted on a truck, highly elevated sources with a strong plume lift like hot flares, chimneys and high process towers will not be possible to survey at close distance.

The MWDOAS technique has been validated in various surveys by comparison with canister samples acquired at several different locations and which were subsequently analyzed by gas chromatography (GC-FID). The validation shows that the result from MWDOAS lies well within 10% of the result of the certified canister results for BTEX. Due to an absorption cross-section too weak to be used with reliability in the MWDOAS analysis, the ortho isomer of the xylene has been omitted in this comparison. When total xylene is presented in the present survey, the sum of *m*- and *p*-xylenes from the MWDOAS measurement is multiplied by 1.32. This number comes from a ratio comparison of xylene isomers in 49 canister samples analyzed by GC/FID and taken from eight refineries and tank parks from two countries. The standard deviation in this comparison was 0.07 and adds a 4.5% uncertainty to the total xylene concentration. Hence, the xylene concentration from MWDOAS is defined as the sum of the measured *m*- and *p*-isomers and the inferred *o*-isomer.

The MWDOAS system has been used in previous campaigns in USA during 2013 with good results. During the 2013 DISCOVER-AQ campaign in Houston, Texas, the system was run in parallel to a mobile Proton Transfer Mass spectrometer (PTrMS) lab as a validation check. The results of benzene, toluene and styrene was compared and showed good agreement, with the PTrMS showing slightly elevated benzene concentrations compared to the MWDOAS. The sensitivity of MWDOAS is better than 1 ppb for benzene, better than 3 ppb for toluene, ethylbenzene and *m*-xylene and as good as 0.5 ppb for *p*-xylene.

Since the distribution of the BTEX constituents varies with source we will also present the benzene to alkane ratio to facilitate the calculation of benzene flux and identify specific benzene sources.

Unwanted BTEX signals from local traffic exhausts are generally only significant in congestions (at traffic lights etc.) or in confined spaces, e.g. tunnels. Apart from this, large emitters are also occasionally seen elsewhere. They are generally recognized, partly by their typical gasoline composition signature and partly by their transient nature. A stationary BTEX source is, on the other hand, characterized by recurrent downwind plumes. Transient and non-repeatable BTEX observations are therefore excluded from the result. Note that all concentrations are above the reference/background.

2.5 Wind Measurements and Auxiliary Data

Wind LIDAR

An infrared 3D wind LIDAR provided by the SCAQMD (shown in Figure 8) was used to measure vertical wind profiles of wind speed and wind direction. The unit used for this study (i.e. model WindCube 100S) produced by Leosphere (France) provides wind profiles in the vertical range 50 to around 1000 m above surface level, or even further if atmospheric conditions allow it. Within this range data can be retrieved in 25 m vertical resolution. Stated wind speed accuracy is 0.5 m/s. Applicable radial wind speed range is -30 to 30 m/s. The system records 1s data, but 10 minute averages were used for flux calculations in this study. The principle of detection is based on the Doppler shift of the infrared pulse that the instrument sends out and retrieves. Numerous validation surveys attesting the accuracy of the WindCube LIDARs are publically available through: www.leosphere.com.

Figure 8. The WindCube 100S (Leosphere) LIDAR used for wind profile measurements in this project.

Wind Mast

Meteorological parameters were measured at selected sites using a portable 10 m mast, see Figure 9. This mast was equipped with a calibrated RM Young 05108 “prop and vane” anemometer and a Campbell Scientific CR200 data logger.

The weather mast was installed at an open location near the refinery of interest and with un-obstructed fetch for wind directions that was used for SOF measurements. The sensor was adjusted to point towards magnetic north but compensated to true north in the post-processing. Wind speed information from the 10 m mast or other wind stations in the area is used to fill in the gap of the lowest 40 m of the atmosphere where no LIDAR data exists. Since the plume heights from petrochemical facilities generally are several hundred meters during sunny conditions (some hundred meters downwind where SOF measurements are done), the wind speed information below 40 m does not influence the flux calculations substantially (typically a few percent).

Figure 9. The FluxSense mobile wind mast used in the 2015 SCAQMD survey with an RM Young anemometer mounted on top. The mast could be erected from 3 to 10 m.

Airmar (mobile weather station)

An Airmar WeatherStation (200 WX) sensor was installed on the roof of the measurement vehicle to complement the other wind measurements and give local ground winds at the vehicle. The wind information from the Airmar is not used for flux calculation but acts as a real-time aid to keep track of the plume directions when making the gas emission measurements.

The Airmar provides wind speed and direction relative to true north (compensating for vehicle position), air temperature, pressure and relative humidity. It also provides GPS positions which may be used as back-up to the other GPS-receiver.

GPS

The FluxSense vehicle is equipped with two standard USB GPS-L1 receivers (GlobalSat BU-353S4) hooked up to the SOF and DOAS-computers. They are placed horizontally by the windscreen and on the roof for optimal reception. The receivers give the position at a rate of 1 Hz.

3 Measurement Methodology

Typically the main instruments in the FluxSense mobile lab are operated during favorable meteorological conditions for each individual instrument. SOF and SkyDOAS are mainly used during solar/daytime measurements and MWDOAS and MeFTIR for gas ratio measurements during day or cloudy/nighttime conditions. Plume height calculations are dependent on simultaneous SOF and MeFTIR measurements of alkanes, so MeFTIR was typically running during solar/daytime conditions when feasible. MWDOAS and SkyDOAS were sharing the same spectrometer in this survey. Hence, time sharing between these two different techniques was necessary. In addition to the gas mass ratio measurements by MWDOAS and MeFTIR, some canisters were also sampled in selected plumes for further VOC speciation and complimentary data.

By keeping track of wind directions and avoiding strong upwind sources, the same plumes were essentially sampled during solar/daytime and cloudy/nighttime measurements so that representative gas ratios were collected. Only MeFTIR and MWDOAS measurements with repeated plume signature and high correlation between target and alkane concentrations were accepted. Canister sampling was only performed during cloudy/nighttime measurements when ground plumes are generally present and monitored in real-time.

3.1 Survey Setup

The main objective of this study was to quantify the total gas emissions of non-methane VOCs (alkanes and BTEX), NO_2, SO_2 and methane from six major refineries in the Los Angeles Basin denoted Refinery A, Refinery B, Refinery C, Refinery D, Refinery E and Refinery F respectively (see Figure 10). This was done by conducting fence-line measurements along accessible roads outside the facilities using mobile optical measurements (SOF and mobile DOAS) to obtain total gas emission fluxes from the refineries. Furthermore, ground concentration measurements were carried out with mobile MWDOAS and MeFTIR instruments to infer emission of methane, BTEX and specifically benzene.

Gas measurements were combined with wind data, primarily from SCAQMD's wind LIDAR system, but also from meteorological stations and from a mobile 10 m wind mast, to calculate fluxes and identify sources. Throughout the study the wind LIDAR was moved between four different locations (L1-L4, see Figure 10) depending on the facilities measured. The geographical positions of the refineries are noted as colored areas in Figure 10 along with various meteorological sites and wind LIDAR positions. In general, each measurement day was dedicated to one specific refinery except for Refinery B and Refinery C which were both surveyed within the same time frame.

Emissions from each refinery were calculated by driving around the targeted facility to capture the entire downwind plume and then subtracting potential contributions from emissions deriving from upwind sources. This approach is referred to as “box-measuring” in this report. When complete upwind plume measurement was not possible (e.g. lack of accessible roads), relevant upwind measurement transects were made in close proximity in space and time. The aim was to make multiple measurements during several days over the entire duration of the study (from 28 August to 10 November 2015) in order to map detected plumes at different times, during variable wind conditions, and from different distances from the sites to better understand emission variability, plume dispersion, and the potential for local community exposure.

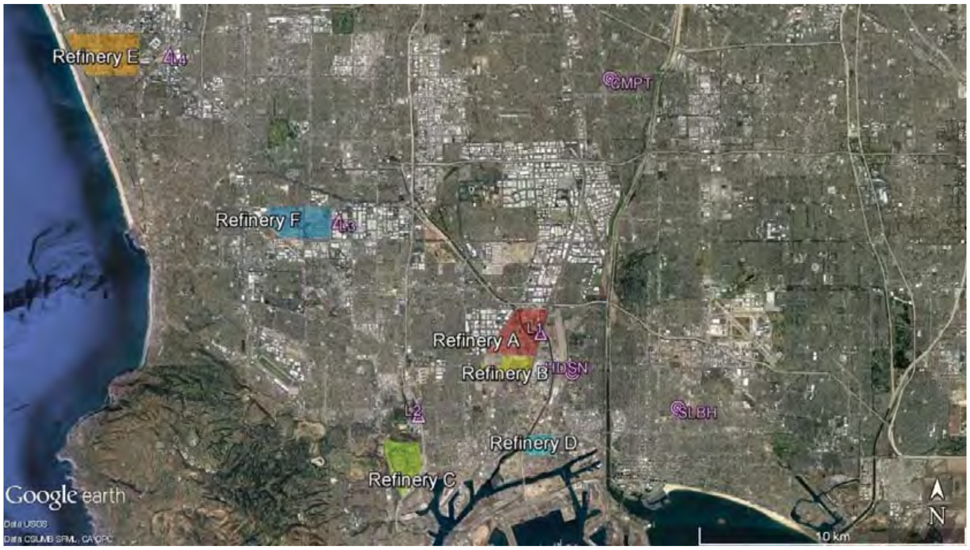

Figure 10. Map showing the locations of the six refineries that were targeted for this study. Also shown are meteorological sites and LIDAR positions. Map from Google Earth © 2016.

Altogether, measurements were carried out during 40 days, however the number of successful and quality assured measurements varied substantially from day to day and from facility to facility depending on weather conditions, local measurement conditions (e.g. road accessibility), and time sharing between different refineries and instruments.

Refinery A is the largest refinery in the Southern California Air Basin (along with Refinery E) and it has been collaborating with SCAQMD to support this campaign and making it possible to carry out 7 days of onsite measurements. In addition, 15 measurement days of total emissions were carried out on refinery fenceline. A statistical estimate of flux emissions (kg/h) was computed for each measurement day at each refinery. Total mean and median values for the entire survey period were calculated in parallel. This data was compared to the reported annual emission inventories. Extreme events (beyond 1.5 times the inter-quartile range) and possible point sources within a refinery were also noted in the report.

3.2 Principal Equations

This report includes two different techniques to measure emission mass fluxes as specified below. The primary method in this project is the direct flux measurements of alkanes from SOF. BTEX and methane fluxes are calculated using inferred fluxes from MWDOAS/MeFTIR gas mass ratios.

DIRECT FLUX MEASUREMENTS:

Direct flux is measured by SOF or SkyDOAS. The emission mass flux (*Q*) of species (*j*) for a single transect (*T*) across the plume (*P*) along path (*l*), can be expressed by the following integral (Si-units in gray brackets):

$$Q_T^j[\mathrm{kg/s}] = \bar{v}_T[\mathrm{m/s}] \cdot \int_P C_l^j[\mathrm{kg/m^2}] \cdot \cos(\theta_l) \cdot \sin(\alpha_l)\, dl\, [\mathrm{m}]$$

Where,

$\bar{v}_T$ = the average wind speed at plume height for the transect,
C_l^j = the measured slant column densities for the species j as measured by SOF or SkyDOAS,
θ_l = the angles of the light path from zenith ($\cos(\theta_l)$ gives vertical columns),
α_l = the angles between the wind directions and driving directions
dl = the driving distance across the plume

Note that SOF and SkyDOAS have different light paths, where the SkyDOAS telescope is always looking in the zenith direction while the SOF solar tracker is pointing toward the Sun. Hence, the measured SOF slant column densities will vary with latitude, season and time of day.

To isolate emissions from a specific source, the incoming/upwind background flux must be either insignificant or subtracted. If the source is encircled or "box-measured", the integral along *l* is a closed loop and the flux calculations are done with sign. This is taken care of by the FluxSense software.

INFERRED FLUX MEASUREMENTS:

Inferred flux is computed using a combination of SOF and MeFTIR/MWDOAS measurements. The inferred mass flux ($\hat{Q}^i$) for species (*i*) are calculated from MeFTIR and/or MWDOAS ground level gas ratios integrated over the plume (*P*) along path (*l*) are given by (Si-units in gray brackets):

$$\hat{Q}^i[\mathrm{kg/s}] = \bar{Q}^j[\mathrm{kg/s}] \cdot \frac{1}{k}\sum_k \frac{\int_P N_l^i[\mathrm{kg/m^3}]\, dl[\mathrm{m}]}{\int_P N_l^j[\mathrm{kg/m^3}]\, dl[\mathrm{m}]}$$

Where,
$\bar{Q}^j$ = the average flux of species *j* from multiple transects as measured by SOF,
N_l^i = the number density concentrations of species *i* as measured by MWDOAS or MeFTIR,
N_l^j = the number density concentrations of species *j* as measured by MeFTIR,
k = the number of gas ratio measurements

Note that the inferred flux calculation operates on average values since simultaneous SOF/SkyDOAS, MWDOAS and MeFTIR measurements are generally not performed and because individual gas ratios are more uncertain than the average. Although not necessarily simultaneously measured, SOF and MeFTIR/MWDOAS measurements must represent the same source plume. Note also that gas ratios do not intrinsically depend on complete plume transects (like for direct flux methods) as long as the emission plume is well mixed at the sampling distance.

The uncertainties in the total refinery emissions of BTEX and CH_4 obtained from inferred fluxes are larger than for the direct flux measurements of alkanes. Ideally the gases should be well mixed in the plume for this method to work the best, but in reality there will be a stronger weighting towards low elevated sources (tanks) compared to higher elevated ones (process units) depending on the measurement geometry. In the past we have done canister sampling in several European refineries, and typically the BTEX fraction is higher in the process units (10-15 %) compared to tank farms (5-10 %). The inferred emission flux of BTEX will consequently be a low estimate of the BTEX emission. For smaller, more isolated sources we estimate that the uncertainty of the inferred fluxes is only slightly higher than the direct flux measurement.

PLUME HEIGHT ESTIMATES:

This is a method to calculate approximate plume heights from simultaneous SOF slant columns and MeFTIR ground level concentrations, measured across an emission plume. The plume height,h_T , for a transect, *T*, across a plume, *P*, along the path, *l*, is given by the following equation (Si-units in gray brackets):

$$h_T^j[\mathrm{m}] = \frac{\int_P \; C_l^j[\mathrm{kg/m^2}] \cdot \cos(\theta_l) \; dl[\mathrm{m}]}{\int_P \; N_l^j[\mathrm{kg/m^3}] \; dl[\mathrm{m}]}$$

Where,

C_l^j = the slant column density of species j as measured by SOF,
θ_l = the angle of the light path from zenith ($\cos(\theta_l)$ gives vertical columns),
N_l^j = the number density concentrations of species j from MeFTIR,

This method distributes the plume homogeneously from the ground to the plume height (and zero above). In reality, however, emission plumes have a vertical gradient controlled by wind shear, turbulence, atmospheric lapse rate, release altitude e t c. Hence, the plume height as calculated using the equation above, is only a first order approximation. In this report, plume heights have consistently been calculated using alkane measurements (i.e. j=*alkane*). Median values of multiple plume height estimates are used to decrease uncertainties.

3.3 Uncertainties and Error Budget

Table 3 summarizes the accuracy, precision, and data completeness for measurements from each instrument employed during this field campaign.

Table 3. Accuracy, precision, and data completeness for measurements from each of FluxSense's measurement methods.* For the optical measurements conducted in this project data completeness is difficult to estimate since the measurements are dependent on external parameters such as weather conditions.

Measurement Parameter	Analysis Method	Accuracy	Precision	Completeness*
SOF column concentrations alkanes, alkenes	QESOF spectral retrieval	±10%	±5%	70-90%
SkyDOAS column concentrations NO_2, SO_2	DOAS spectral retrieval	±10%	±5%	70-90%
MeFTIR concentrations CH_4, VOC,	QESOF spectral retrieval	±10%	±5%	95%
MWDOAS concentrations BTEX, Benzene	MWDOAS spectral retrieval	±10%	±5%	90%
Wind Speed (5m)	R.M. Young Wind monitor	±0.3 m/s or 1%	±0.3 m/s	95%
Wind Direction (5m)	R.M. Young Wind monitor	±5°	±3°	95%
Wind Speed (10m)	Gill WindSonic	±2%	-	95%
Wind Direction (10m)	Gill WindSonic	±3°	-	95%
LIDAR Wind Direction (50-1000m)	Leosphere Windcube 100S	-	-	>90% except in heavy fog
LIDAR Wind Speed (50-1000m)	Leosphere Windcube 100S	±0.5 m/s	-	
GPS position	USB GPS receiver	±2m	±2m	100%
SOF mass flux Alkanes, alkenes	SOF flux calculations	±30%	±10%	80% (in suitable weather conditions)
SkyDOAS mass flux NO_2, SO_2	SkyDOAS flux calculations	±30%	±10%	80% (in suitable weather conditions)

Accuracy of measurement parameters is determined by comparing a measured value to a known standard, assessed in terms of % bias, using the following equation:

$$\left[1-\left(\frac{Measurement}{Standard}\right)\right]\times 100$$

Precision is a measure of the repeatability of the results. The precision for the SOF and mobile SkyDOAS system is difficult to measure when inside the gas plumes. However, it is assumed that the precision of the instrument corresponds to the 1-sigma noise when measuring in clean air background. The precision of each instrument used in this project is listed in Table 3.

Data completeness is calculated on the basis of the number of valid samples collected out of the total possible number of measurements. Data completeness is calculated as follows:

$$\%\ Completeness = \left(\frac{Number\ of\ valid\ measurements}{Total\ possible\ measurements}\right)\times 100$$

3.4 Wind Statistics and Plume Heights

The largest source of error in SOF and SkyDOAS emission flux calculations is typically determined by the quality of the collected wind measurements. The flux is directly proportional to the wind speed (at average plume height) and to the cosine of the wind direction relative to the driving direction. The total wind uncertainty results from a combination of wind measurements errors (see Table 3) and errors due to the assumption that the measured wind velocity measured is representative of the average plume velocity. Wind profile data, as supplied by a LIDAR, has the major advantage of allowing an average wind for an arbitrary height interval to be calculated. Given some approximate information about the mixing height of the plume, a suitable averaging interval can be chosen, and the LIDAR data can also be used to estimate the sensitivity of the wind error to the error in the mixing height. Estimates of the plume mixing height estimates can in turn be retrieved by simultaneous concentration and column measurements with SOF and MeFTIR as described in section 3.2. The method assumes homogeneous plume concentrations from ground level to the plume height. Plume height results for the different refineries in this study are found in Table 4 and Figure 11.

Table 4. Summary of plume height (median values) estimations for all refineries surveyed during this study. Wind information used for flux calculations is also reported (all non-LIDAR winds scaled to LIDAR 0-400m with the given scaling factors). *Measurements at Refinery D were conducted during a flaring event with high elevated plumes.

Refinery	**Number of Measurements**	**Median Plume Height** [m]	**Primary Wind** (0-400m)	**Secondary Wind** (Scaling factor)
Refinery A	19	475	LIDAR L1	Refinery A Mast (1.34)
Refinery B	3	514	LIDAR L1	Refinery A Mast (1.34)
Refinery C	5	464	LIDAR L2	AQMD-SLBH (1.0)
Refinery D*	2	835	LIDAR L1	ASOS-KLGB (1.17)
Refinery E	11	239	LIDAR L4	ASOS-KLAX (0.83)
Refinery F	6	292	LIDAR L3	LIDAR L1 (1.0)
All Refineries	**46**	**413**		

These results indicate a plume height of 250-500 m with an overall median for all refineries of around 400m. The high values at Refinery D were estimated during a flaring event on November 1, 2015, with non-typical elevated emissions and should be treated cautiously. Based on these estimates, the average wind for the interval 50-400 m, as measured by the wind LIDAR, has been used for flux calculations in this survey. Wind information from Refinery A's 10 m mast during the calibration period (October 2-6, 2015) was used to account for the lowest 50 m of the air column. In this compensation, the 10 m wind data was used from 0 to 20 m and a linear interpolation was applied between the 10 m wind and the LIDAR wind between 20 and 50 m. Although this compensation had a very small effect (~2%) on the total wind speed as provided by the LIDAR between 50 and 400m, it was applied to all flux calculations for consistency.

Note that plumes of different gases may behave differently. Plumes originating from combustion sources (e.g. SO_2 and NO_2), are generally stack releases. As such, they are released at a high altitude and more buoyant (hotter) than fugitive and cold VOC emissions. Hence, SO_2 and NO_2 are expected to be found at a slightly higher altitude than alkanes when measuring refinery emissions at a fence-line distance like in this survey. Plume height estimations are, however, not possible for SO_2 and NO_2 (no simultaneous concentrations measurements). But since the wind gradient with height was weak during the survey and with the emissions confined within in the boundary layer (see discussion below), the effect on the calculated fluxes are small and well within the measurement uncertainty.

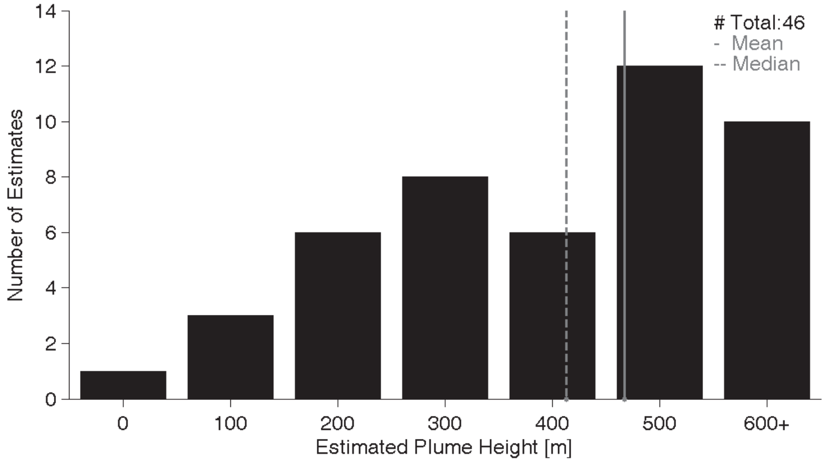

Figure 11. Plume height estimations for all refineries during the 2015 SCAQMD survey. The last bin, denoted '600+', contains all data points above 600 m. The median and average values are indicated as dashed and solid gray lines, respectively.

Wind LIDAR data has always been used as the primary wind information for flux calculations in this survey. The different LIDAR locations/sites are specified in Figure 10. For cases where no LIDAR information was available (e.g. LIDAR malfunction or data collected at non-representative sites) an appropriate secondary wind source was used based on its proximity to the measured refinery. Secondary wind data was scaled to match the 50-400 m LIDAR wind at a location closest to the measurement site using the slope of a linear least-squares-fit, see *Scaling Factors* in Table 4 and plots in Appendix B.

In order to assess the sensitivity of the flux calculations to deviations from the assumed plume mixing height, wind LIDAR data (10 min average) for different altitude ranges (i.e. 50-100 m, 50-200 m, 50-300 m, 50-400 m, and 50-500 m) were compared to the reference LIDAR wind (50-400 m) during the two calibration periods (October 2-6, 2015 at LIDAR site L1 and October 9-16, 2015, at site L3; see Figure 10). For both calibration periods, the wind speed comparisons show that the systematic difference for the alternative height intervals is less 4% compared to the reference interval (50-400 m) and that the vast majority of data points are within 30% of the reference wind (50-400 m) (see example in Figure 12 and the complete data set in Appendix B). For the wind direction, the same comparisons showed a systematic difference of less than 5° to the reference wind and a total spread of the random differences of less than 30° for almost all data points.

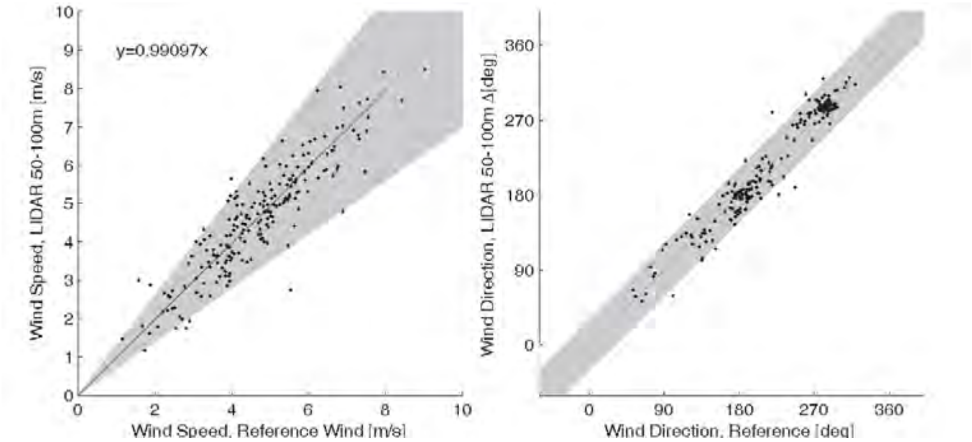

Figure 12. Wind LIDAR data (10 min average from 10AM to 5PM) for 50-100 m versus the reference LIDAR wind (50-400 m) during the calibration period (October 2-6, 2015) at LIDAR site L1. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as a solid line. See Appendix B for the complete data set.

The variability of the wind with height and time is further illustrated in Figure 13. The two upper panels show the average wind (solid lines) at each height level relative to the 50-400 m reference average as well as the average standard deviation (±1σ; dashed lines). These profiles show that the wind does not systematically deviate more than 15% or 5° at any height level and that the standard deviation of the random deviations are generally less than 20% in wind speed and 20° in wind direction, except for the highest levels in the interval. The two lower panels in Figure 13 show the results of comparison between the reference wind and the same reference wind a few minutes earlier. These plots also show the average wind deviation as a function of the time difference (solid lines), as well as the average standard deviation (±1σ; dashed lines). As expected, the random deviations increase with the time difference, while the systematic deviations are close to zero. The reason why the average deviation is not actually zero is that the prevailing wind conditions during the study featured a distinct pattern of winds increasing throughout the day while also shifting direction in a recurring pattern.

Two examples of the evolution of the wind profile over the course of a day are shown in Figure 14. Both of them show clear signs of the prevailing wind pattern throughout the study, with weak winds in the morning that increase in magnitude from approximately 10:00 AM to 12:00 PM and forward while also shifting direction. Since a wind speed of at least 1-2 m/s is typically needed in order to accurately calculate flux, useful data could normally not be collected before 10:00 am. As also seen in these examples, the wind is relatively homogenous within a layer up to 300-500 m, but at higher altitudes the wind direction often varies dramatically. This altitude range coincides very well with the typical plume mixing height estimates in Table 4 indicating that this layer of homogenous wind is the convective boundary layer. The exact height of this layer varies throughout the day and this explains why the wind was on average weaker and more variable in the uppermost levels of the 50-400 m height interval, as seen in Figure 13. The convective boundary layer simply does not always extend above this height level.

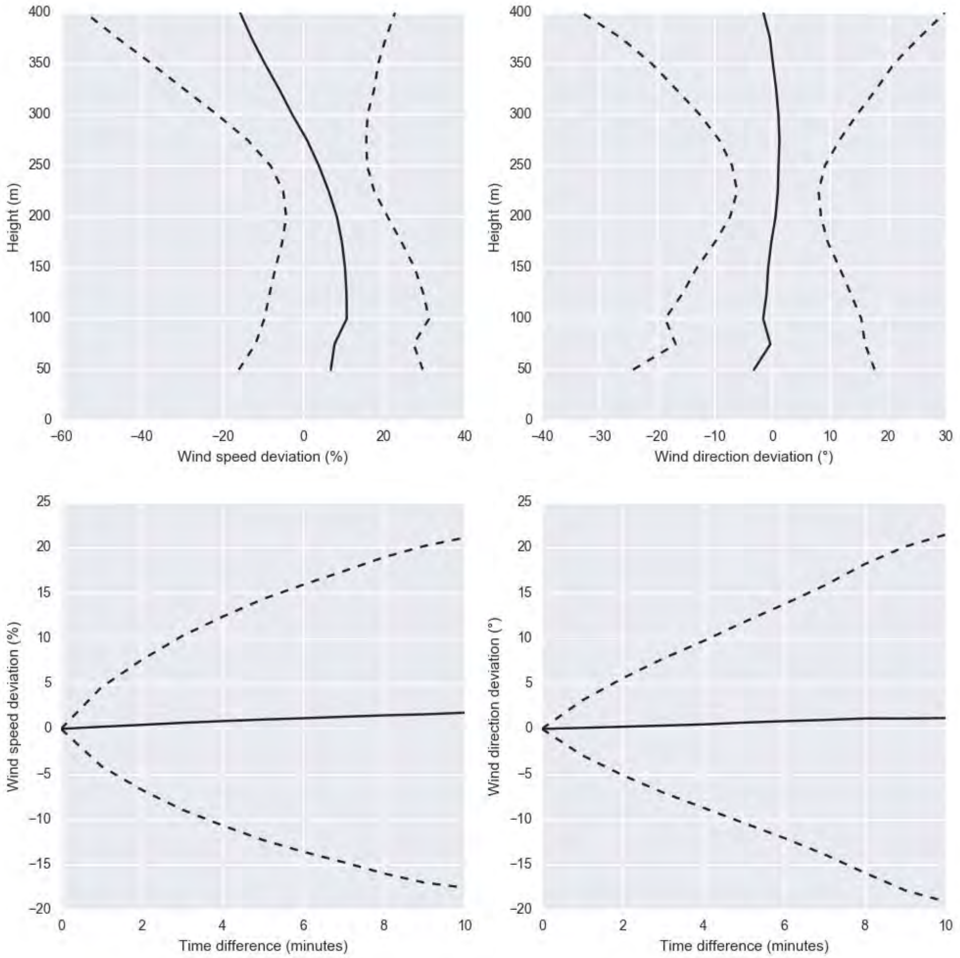

Figure 13. 10-min wind LIDAR data for the entire 2015 SCAQMD survey. Average (solid lines) and standard deviation (±1σ; dashed lines). Top row panels show altitude information and the lower row panels show time dependence (see Appendix B for additional plots).

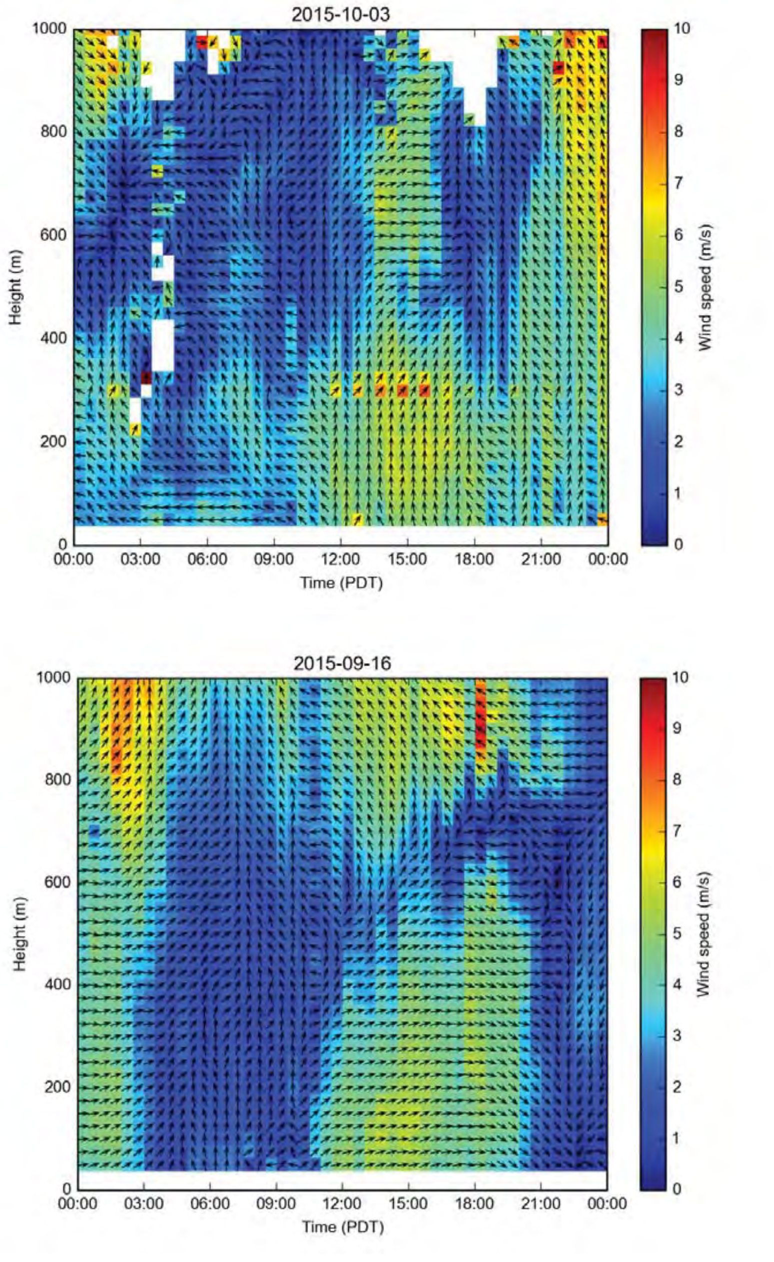

Figure 14. Wind LIDAR raw data at the L1 and L4 site. 30 min averages from 50 to 1000 m measured on October 3, 2015 at the L1 site (upper panel) and on September 16, 2015 at the L4 site (lower panel). The color scale gives the magnitude of the wind speed and the black arrows show the wind direction. Both plots show typical low wind speeds during night-time conditions and stable winds with little altitude variation (wind shear) from 50 to 400m from noon to sunset. See Appendix B for additional data.

4 Results - Total Refinery Measurements

Emission flux measurement results (median values) for the six refineries surveyed during this study are summarized in Table 5. Figure 15 through Figure 17 present graphical representations of measured emissions of alkanes, SO_2, and NO_2. Collectively, refineries in the South Coast Air Basin were found to emit 1130 kg/h of alkanes, 259 kg/h SO_2, 269 kg/h NO_2, 129 kg/h BTEX (of which 18 kg/h is Benzene) and 705 kg/h methane. Section 4.1 through 4.6 below provides detailed description of measured emissions from each studied refinery in the South Coast Air Basin.

Table 5. Summary of emission flux measurements during the 2015 SCAQMD survey. SOF and SkyDOAS results are reported here as median values of all quality assured transects to reduce sensitivity to outliers. *MWDOAS and MeFTIR are inferred values through measured ground level gas mass concentration ratios (See section 2.3 and 2.4). †Excluding eastern tank park that is not owned by Refinery B.

	SOF			*SkyDOAS*				*MWDOAS*		*MeFTIR*
Refinery	**N Days**	**N Meas**	**Alkane Flux** [kg/h]	**N Days**	**N Meas**	**SO_2 Flux** [kg/h]	**NO_2 Flux** [kg/h]	**BTEX Flux*** [kg/h]	**Benzene Flux*** [kg/h]	**CH_4 Flux*** [kg/h]
Refinery A	15	40	269	10	39/34	62	66	24	3.4	167
Refinery B†	5	15	70	10	35	53	31	11	1.1	53
Refinery C	4	15	244	3	9	37	57	37	8.2	142
Refinery D	7	33	164	4	20	17	34	16	1.6	79
Refinery E	7	35	244	7	29/19	53	63	31	2.7	207
Refinery F	4	16	139	2	3	37	18	10	0.8	57
Sum			**1130**			**259**	**269**	**129**	**18**	**705**

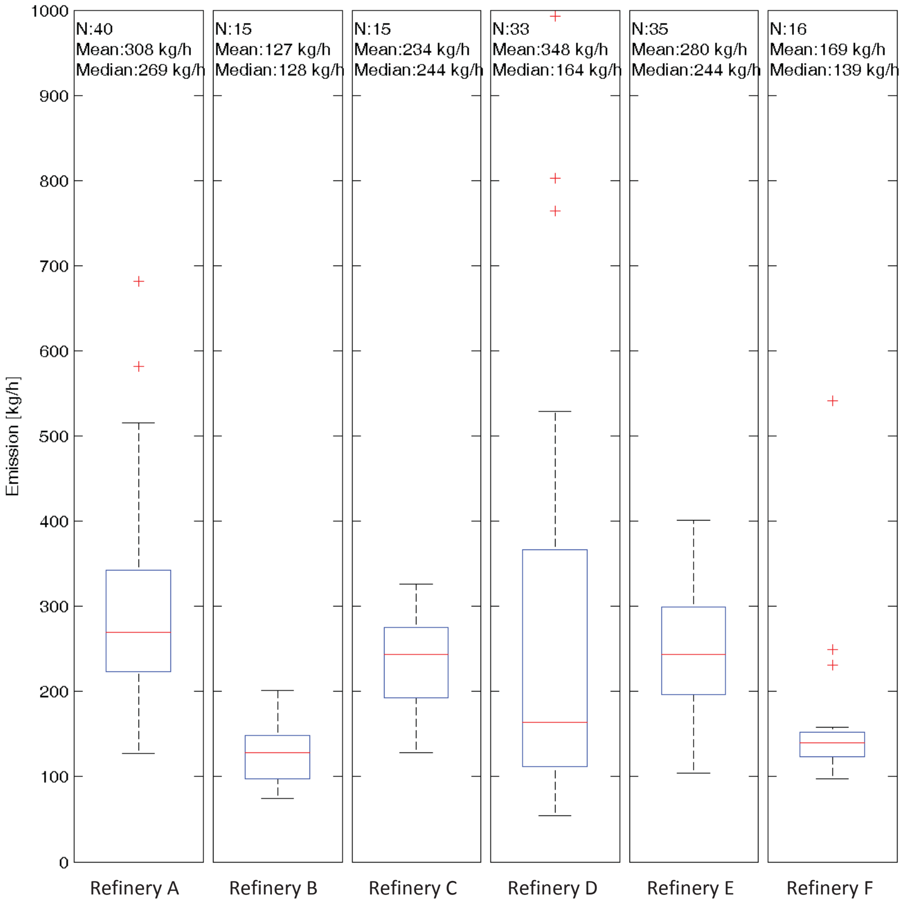

Figure 15. Box-plots of measured alkane emissions (kg/h) from the six refineries surveyed during the 2015 SCAQMD study. Median (50-percentile) values are presented as red bars and upper and lower quartiles as blue boxes with dashed whiskers extending to 1.5 times the inter-quartile range. Outliers beyond the whisker lengths are indicated by red crosses.

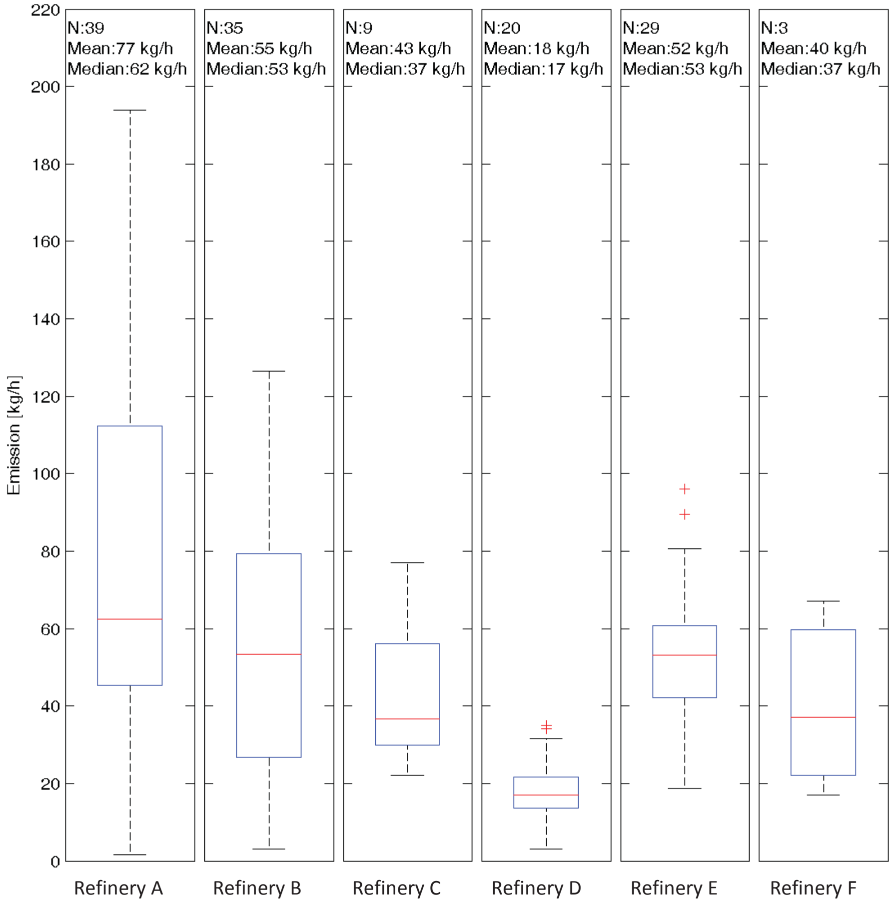

Figure 16. Box-plots of measured SO_2 emissions (kg/h) from the six refineries surveyed during the 2015 SCAQMD study. Median (50-percentile) values are presented as red bars and upper and lower quartiles as blue boxes with dashed whiskers extending to 1.5 times the inter-quartile range. Outliers beyond the whisker lengths are indicated by red crosses.

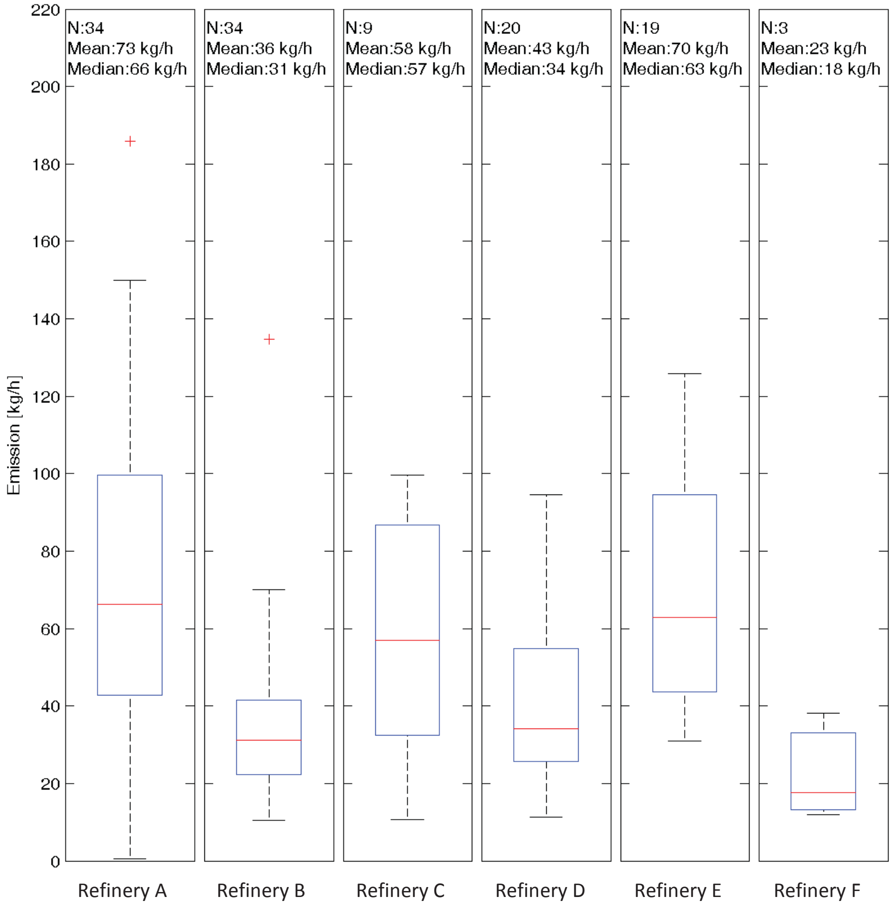

Figure 17. Box-plots of measured NO_2 emissions (kg/h) from the six refineries surveyed during the 2015 SCAQMD study. Median (50-percentile) values are presented as red bars and upper and lower quartiles as blue boxes with dashed whiskers extending to 1.5 times the inter-quartile range. Outliers beyond the whisker lengths are indicated by red crosses.

4.1 Refinery A

At Refinery A (crude oil capacity 257 kBPD (California Energy Commission 2016)) 15 measurement days of total emissions have been carried out and additionally one week of measurements inside the facility (see Section 5) through a collaboration between the refinery and SCAQMD.

The measurements were conducted over a period of eleven weeks, stretching from August 28 to November 10. Note that, typically, the number of successful measurements for each day varies considerably depending on acceptable solar- and wind conditions, interfering background levels and instrument availability. To accurately compensate for incoming background plumes, it was necessary to drive around the targeted facility for multiple times (see example in Figure 18), which is time-consuming.

Wind information for flux calculations were provided by a wind LIDAR (50-400 m average) right across the refinery's fence-line. This wind data was complemented with information collected by a 10 m wind station (scaled to match 50-400 m LIDAR) operated inside Refinery A. Typical wind velocities and direction at these locations were 4-5 m/s and 300°N, respectively (see Figure 19).

4.1.1 Alkanes (non-methane)

Alkane emissions from Refinery A were measured with the SOF during 15 different days from August 29 to November 10, 2015 (see Table 6). Daily means varied from 215 kg/h (September 5) to over 800 kg/h (October 29). The grand total average and standard deviation of all 40 quality assured transects amount to 308±113 kg/h. The median value was 269 kg/h. Histograms of all transects (Figure 20) show a sharp peak at around 250 kg/h and a "tail" of measurements above 500 kg/h. Most transects show a typical column peak directly downwind of the southern tank park (especially downwind of the large reservoir and tank-16) and of the process area (Figure 18).

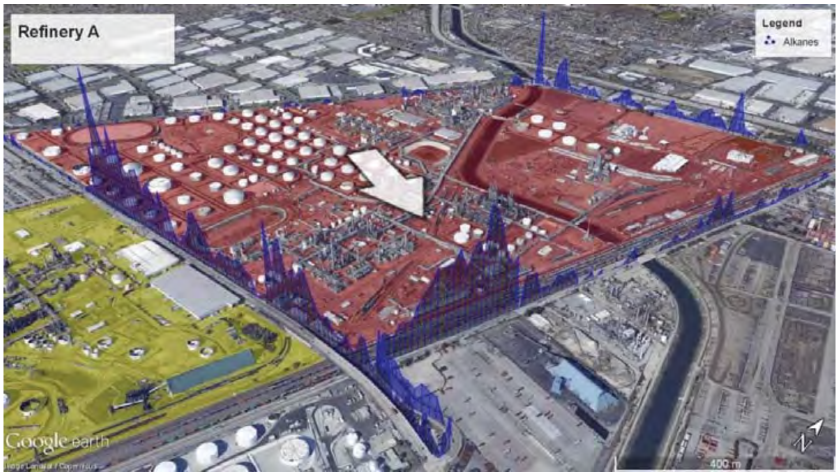

Figure 18. Example of SOF measurements around Refinery A (red area) conducted on September 5, 2015, from 15:20 to 15:37. The height of the blue line is proportional to the amount of alkanes in the gas column (i.e. 10 m is equivalent to 1 mg/m^2; max measured value was 64 mg/m^2). The wind direction is indicated by the white arrow. Average wind speed during this measurement was 6 m/s. Emissions on the upwind side of the facility were subtracted from the downwind side in order to obtain emissions from within the measured area. This particular transect measured 267 kg/h of Alkanes from Refinery A.

Table 6. Summary of SOF alkane measurements for Refinery A. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150829	144942 -173531	3	413.1±88.6	5.4-7.4	289-295
150902	142535 -154524	3	319.2±74.7	4.7-5.4	305-310
150903*	130746 -131654	1	271.8	3.8	136
150904	134638 -154706	3	226.8±45.2	3.9-5.0	193-199
150905	112732 -165808	7	214.9±84.2	3.1-6.0	181-295
150906	135041 -160653	3	304.7±76.8	2.7-5.5	262-299
150907	142422 -164733	3	223.8±85.7	3.9-7.0	284-285
150908	111515 -123733	2	322.0±223.7	2.6-2.6	272-323
151003	135421 -151958	2	281.8±70.9	4.9-5.2	174-191
151010*	100622 -102546	1	220.8	2.2	65
151018*	143919 -145556	1	281.5	3.7	188
151020	142108 -154446	4	333.5±165.7	4.2-6.0	276-298
151029	110714 -115044	2	866.0±260.3	7.3-7.3	313-316
151107	103907 -114442	3	265.5±38.6	2.7-4.1	17-38
151110	142726 -145648	2	260.6±29.7	9.8-10.1	253-263
Average±SD	-	**(total 40)**	**308±113 (37%)**	-	-
Median	-	**(total 40)**	**269**	-	-

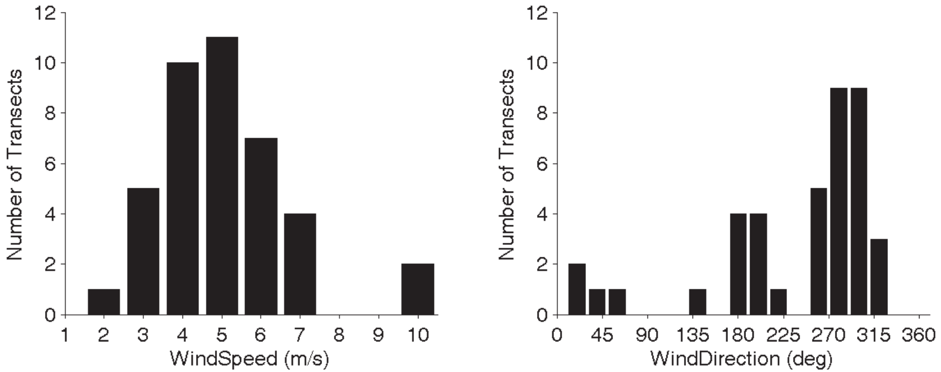

Figure 19. Histograms of wind speed (left) and wind direction (right) for all SOF measurements at Refinery A during the 2015 SCAQMD survey.

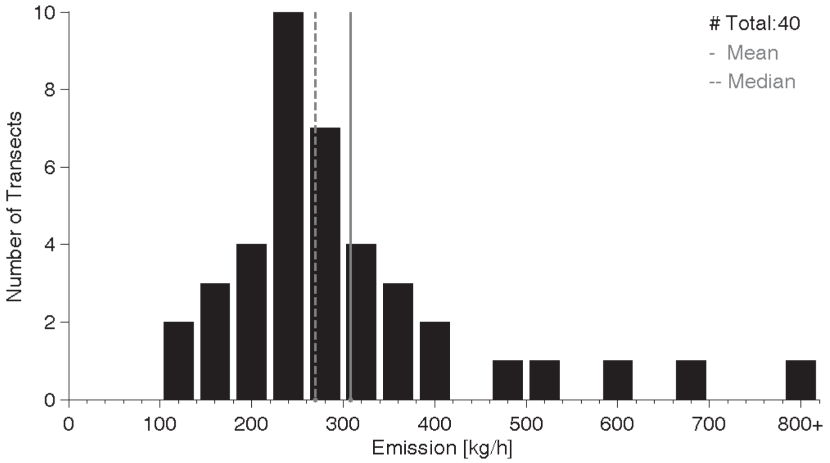

Figure 20. Histogram of all SOF measurements at Refinery A during the 2015 SCAQMD study. The last bin, denoted '800+', contains all data points above 800 kg/h. The median and average values are indicated as dashed and solid gray lines, respectively.

4.1.2 SO_2 and NO_2

SO_2 and NO_2 emissions from Refinery A facility were measured for 10 measurement days during the campaign, from August 29 to November 30 2015 (some of the transects can be seen in Figure 21). Summaries and histograms of SkyDOAS emission measurements are presented in Table 7, Table 8, Figure 22 and Figure 23. Emissions averaged 73 and 77 kg/h for NO_2 and SO_2, respectively. Median values for these two gaseous pollutants were 66 (NO_2) and 62 kg/h (SO_2). The precise origins of the plumes cannot be decided from these measurements, although the Cogen-plant seems to be a matching source for some of the NO_2 plumes.

Figure 21. Transects of plumes originating from Refinery A. NO_2 (pink line) and SO_2 (brown line) were impacted by westerly winds. Conversely, BTEX (blue line) and alkane (yellow line) plumes were measured in the presence of northerly winds. The column thickness for both NO_2 and SO_2 is reported on the same scale (max NO_2 = 3 mg/m^2 flux NO_2 = 114 kg/h, max SO_2 = 11 mg/m^2 flux SO_2 = 46 kg/h). Alkanes and BTEX columns are scaled separately for better visibility (max BTEX = 0.25 mg/m^3, max alkanes = 1.95 mg/m^3). The examples presented here are single transects made on September 2 and on September 19, 2015.

Table 7. Summary of Refinery A NO_2 measurements.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150829	144857 -172703	3	57.0±69.3	5.4-7.6	285-296
150902	140707 -151247	3	59.3±49.8	4.4-6.5	300-314
150903	125302 -134150	2	119.7±42.8	4.1-4.5	115-131
150904	134011 -154225	4	76.2±26.5	4.3-4.9	185-200
150905	113143 -161302	5	67.9±22.9	3.5-6.0	180-295
150906	111801 -165522	5	54.3±18.8	1.8-4.3	266-302
150907*	151830 -152142	1	49.6	5.0	286
150908	113158 -123350	2	26.8±2.1	2.5-2.7	258-323
151029	105412 -150635	7	105.3±49.9	7.0-11.0	275-324
151030	112454 -161144	2	65.7±92.3	2.7-5.0	142-199
Average±SD	**-**	**(total 34)**	**72.8±45.1 (61.9%)**	**-**	**-**
Median	**-**	**(total 34)**	**66.3**	**-**	**-**

Table 8. Summary of Refinery A SO_2 measurements.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150829	144857 -173037	3	114.5±69.1	5.4-7.6	285-296
150902	140726 -154429	4	59.4±40.2	4.4-6.5	298-314
150903	125302 -134150	3	44.2±37.0	2.4-4.5	116-133
150904	134011 -154225	4	66.5±34.2	4.3-4.8	185-200
150905	104604 -161046	7	41.4±28.3	2.1-6.0	103-295
150906	111801 -165332	5	73.2±35.1	1.8-4.4	266-301
150907	134339 -152051	2	54.0±44.8	3.8-5.0	264-286
150908	113244 -123504	2	60.6±11.5	2.6-2.7	259-318
151029	105412 -150635	6	125.5±36.3	6.9-11.0	275-325
151030	112531 -161409	3	129.9±67.3	2.7-5.0	142-202
Average±SD	-	**(total 39)**	**77.1±42.0**	-	-
Median	-	**(total 39)**	**62.4**	-	-

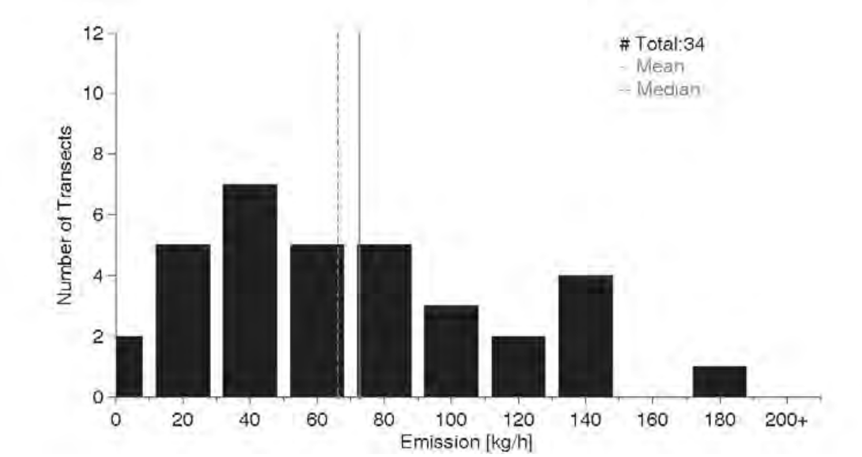

Figure 22. Histogram of all SkyDOAS NO_2 measurements at the Refinery A during the 2015 SCAQMD survey. The last bin, denoted '200+', contains all data points above 200 kg/h. The median and average values are indicated as dashed and solid gray lines, respectively.

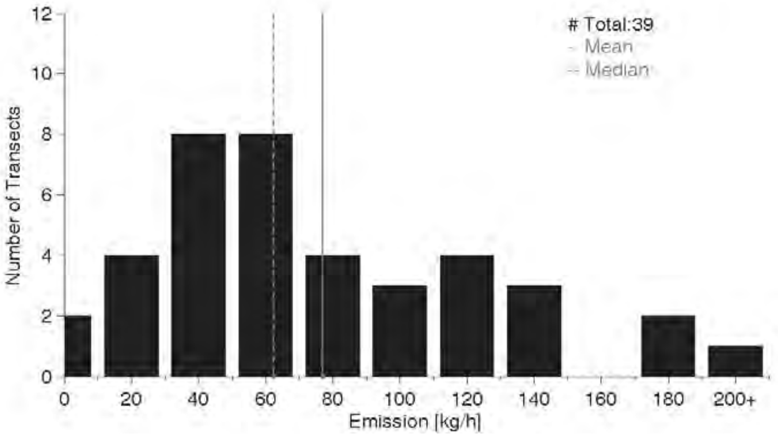

Figure 23. Histogram of all SkyDOAS SO_2 measurements at Refinery A during the 2015 SCAQMD survey. The last bin, denoted '200+', contains all data points above 200 kg/h. The median and average values are indicated as dashed and solid gray lines, respectively.

4.1.3 BTEX

The fraction of BTEX compounds present in the measured alkane plumes emitted from Refinery A was measured either in the late evening or early morning when plumes are closer to the ground. This fraction is calculated by combining BTEX measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured along two roads depending on wind direction. Results for these measurements are shown in Table 9. The average mass fraction of BTEX to alkanes was 0.087 or 8.7%. The average flux of BTEX can be calculated by multiplying this value by the total alkane flux as measured by the SOF-technique. The average mass fraction of benzene to alkanes was 1.3% and the benzene flux can be calculated in the same way as above.

Table 9. Summary of MWDOAS BTEX measurements at Refinery A. *BTEX/alkane mass fraction.

Day [yymmdd]	Time span [hhmmss-hhmmss]	BTEX Fraction* [%]	Benzene Fraction* [%]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150919	221347-221949	7.8	0.98	2.3	323
150919	231317-231938	5.4	0.92	1.5	329
150921	051934-052525	12.8	1.7	1.8	73
150922	062223-063032	13.4	1.7	2.4	110
150922	073305-074108	6.8	0.65	1.9	81
150922	051356-051759	3.6	0.21	2.1	83
150922	183651-184148	11.2	2.7	2.1	181
Average±SD	-	**8.7±3.8**	**1.3±0.8**	-	-

4.1.4 Methane

The average fraction of methane to total non-methane alkanes in the plume originating from Refinery A was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). Methane measurements were conducted during different times of the day and a summary of these results is shown in Table 10. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux as measured by SOF provides an estimate of the methane flux from the refinery. The average methane-to-alkanes mass fraction for Refinery A was 0.62.

Table 10. Summary of MeFTIR methane measurements at the Refinery A. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction* [%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	221206 -231956	2	44	1.6-2.2	332-347
150922	062220 -063024	1	41	1.9	88
151018	144244 -145057	1	64	3.4	177
151020	122426 -154604	6	71	2.4-5.7	135-312
151029	105144 -150803	6	67	4.0-11.3	285-328
151030	113932 -155450	3	57	1.3-4.0	186-289
Average±SD	**-**	**(total 19)**	**62±25**	**-**	**-**

4.2 Refinery B

Refinery B (crude oil capacity (together with Refinery C) 139 kBPD (California Energy Commission 2016)) is located just south of Refinery A, see Figure 24. This site was frequently surveyed in combination with the Refinery A facility. However, due to the proximity to other sources, such as Tank Farm G and Refinery A, there is an increased possibility of interference depending on wind direction and therefore there were fewer valid emissions measurements. Note that the surveyed area also included a crude tank park on the west side that is not owned by Refinery B. Emission contributions from this crude tank park have been accounted for in the data post-processing (see below).

Wind information from the wind LIDAR (L1, 0-400 m average) was mainly used for the flux calculations. This was complemented by Refinery A's 10 m wind station data (scaled to match 0-400 m LIDAR) when needed. Typical wind directions and velocities during the measurements were 4 m/s and 180 or 270°N, see Figure 25.

4.2.1 Alkanes (non-methane)

Alkane emissions from Refinery B were measured with SOF during five non-consecutive days from September 4 to November 10, 2015, see Table 11 and discussion above. Daily means varied from 83 kg/h (September 6) to 173 kg/h (September 7). The grand total average and median for all 15 quality assured transects were 127±23 kg/h and 128 kg/h, respectively. Histogram of all transects shows a "compact" distribution at around 130 kg/h with no outliers, see Figure 26.

Measurement transects typically showed the presence of two peaks, one downwind the western side and another downwind the eastern side, see Figure 24. Based on transects where a complete separation between the two sides/peaks was possible (during S to SW winds), 45% of the emissions were attributed to the western side and 55% to the eastern side. The 55 correction factor has been applied in the survey mean/median calculations (e.g. Table 5), but not for daily means (e.g. Table 11) or individual measurements (e.g. Figure 26). The correction was done in order to exclude the emissions that should not be attributed to Refinery B when inter-comparing the different refineries in this report.

Figure 24. Example of SOF measurements conducted at Refinery B (yellow area) on September 4, 2015, 16:10-16:13. The alkane column is shown as a blue line with apparent height proportional to the gas column (10 m equivalent to 1 mg/m^2, max 32 mg/m^2). Wind direction during the measurements is indicated by the white arrow. The average wind speed during these particular measurements was 3.2 m/s. Emissions on the upwind side are insignificant and not shown in this figure. Emissions resulting from this particular transect were estimated at 107 kg/h.

Table 11. Summary of SOF alkane measurements for Refinery B (including the crude tank park west of the refinery).

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150904	134712 -165939	6	116.3±23.6	3.2-5.5	178-253
150905	153737 -171908	3	121.9±7.4	5.8-6.1	268-279
150906	124744 -163755	2	83.2±13.0	3.4-3.7	165-279
150907	140251 -150726	2	172.8±39.8	3.9-4.3	284-285
151110	143118 -145107	2	161.5±17.6	9.4-10.2	255-255
Average±SD	-	**(total 15)**	**127±23 (18%)**	-	-
Median	-	**(total 15)**	**128**	-	-

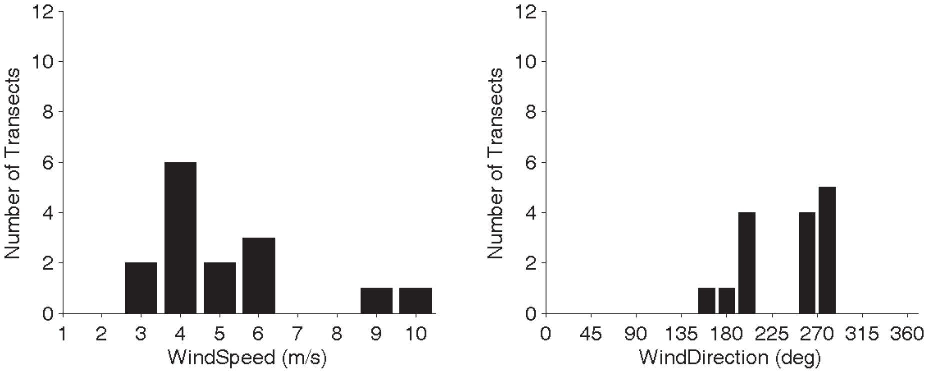

Figure 25. Wind histograms at Refinery B summarizing all wind speed (left) and wind direction (right) measurements conducted during the 2015 SCAQMD study.

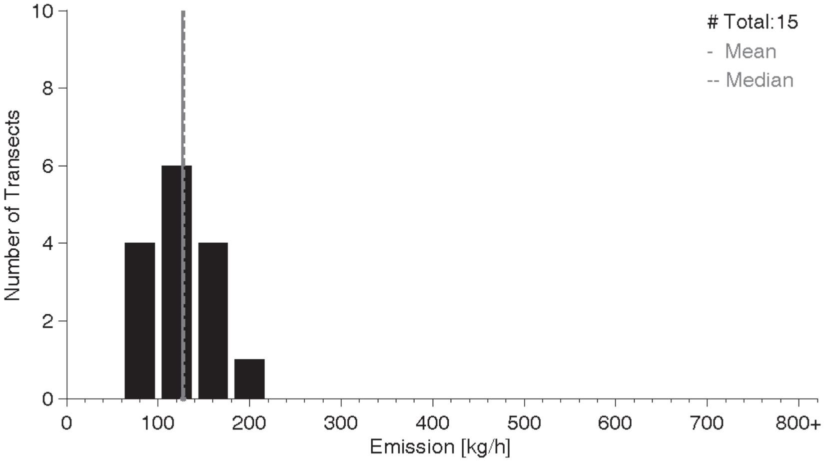

Figure 26. Histogram of all SOF measurements conducted at Refinery B (including crude tank park west of the refinery) during the 2015 SCAQMD study. The median and average values are shown as dashed and solid gray lines, respectively.

4.2.2 SO_2 and NO_2

SO_2 and NO_2 emissions were measured for 10 measurement days during the campaign, from August to October, 2015. Figure 27 shows examples of measurement transects conducted on September 2 and September 19, 2015. Summaries and histograms of SkyDOAS emission measurements are presented in Table 12, Table 13, Figure 28 and Figure 29. In this case NO_2 emissions averaged 36 kg/h and SO_2 55 kg/h. Median values for these two gaseous pollutants were 31 (NO_2) and 53 kg/h (SO_2).

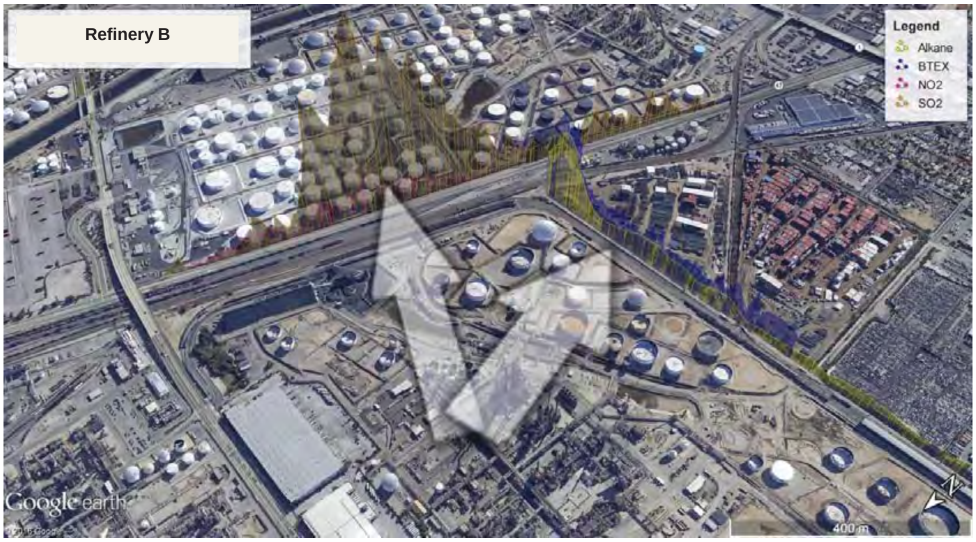

Figure 27. Transects of plumes originating from Refinery B. NO_2 (pink line) and SO_2 (brown line) were impacted by westerly winds (4.3 m/s). Conversely, BTEX (blue line) and alkane (yellow line) plumes were measured in the presence of northerly winds. The column thickness for both NO_2 and SO_2 is reported on the same scale (max NO_2 = 5.6 mg/m^2, flux NO_2 = 11.7 kg/h, max SO_2=25 mg/m^2, flux SO_2 = 68.2 kg/h). Alkanes and BTEX columns are scaled separately for better visibility (max BTEX = 0.03 mg/m^3, max alkanes = 0.36 mg/m^3). The examples shown here were collected on September 8 and on September 19, 2015.

Table 12. Summary of NO_2 measurements at Refinery B.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150829	152225 -152509	1	31.8	7.0	295
150902	132957 -141007	2	21.8±0.7	5.0-6.3	303-315
150903	130123 -133346	2	30.7±15.3	3.9-4.9	106-148
150904	134837 -152937	4	41.2±8.3	3.7-4.9	193-203
150905	103515 -171321	11	27.7±9.2	1.0-6.2	112-286
150906	130316 -163207	4	52.6±12.9	2.6-4.5	162-286
150907	132433 -161506	4	28.5±8.9	3.5-6.1	242-285
150908	110353 -124134	3	57.7±67.2	2.0-8.8	313-327
151029	121217 -121936	1	67.9	7.3	312
151030	114718 -153206	2	19.3±12.6	2.0-4.5	112-193
Average±SD	-	**(total 34)**	**35.6±22.4 (62.8%)**	-	-
Median	-	**(total 34)**	**31.2**	-	-

Table 13. Summary of SO_2 measurements at Refinery B.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150829	152225 -152509	1	126.5	7.0	295
150902	133006 -141007	2	17.9±0.8	5.1-6.3	303-316
150903	130123 -133323	3	34.0±8.6	3.9-4.9	105-150
150904	134828 -152937	4	37.5±20.1	3.7-4.9	193-203
150905	103537 -171321	11	56.1±28.7	1.0-6.2	111-287
150906	130316 -163207	4	78.3±13.5	2.6-4.5	162-286
150907	132433 -161506	4	79.9±18.3	3.5-6.1	242-285
150908	110353 -124134	3	68.9±26.9	2.0-8.8	314-327
151029	121150 -133517	2	14.7±16.5	7.1-7.3	311-313
151030	114718 -115224	1	9.0	2.2	114
Average±SD	-	**(total 35)**	**54.5±21.5 (39.3%)**	-	-
Median	-	**(total 35)**	**53.4**	-	-

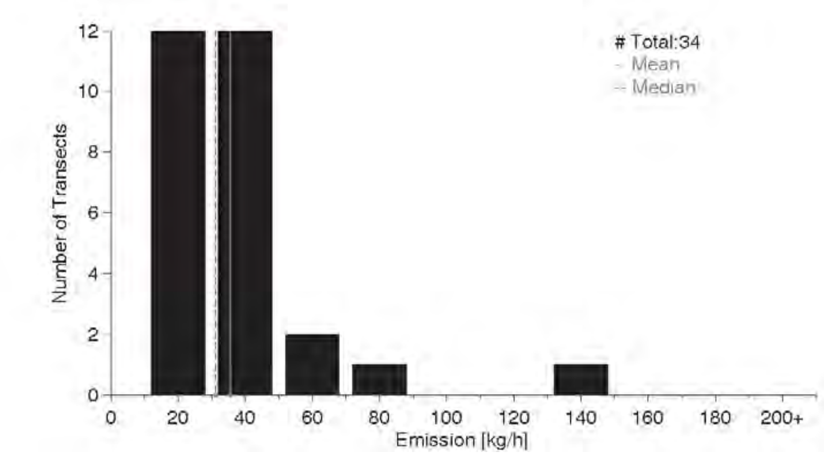

Figure 28. Histogram of all SkyDOAS NO_2 measurements at the Refinery B during the 2015 SCAQMD study. The median and average values are indicated as dashed and solid gray lines, respectively.

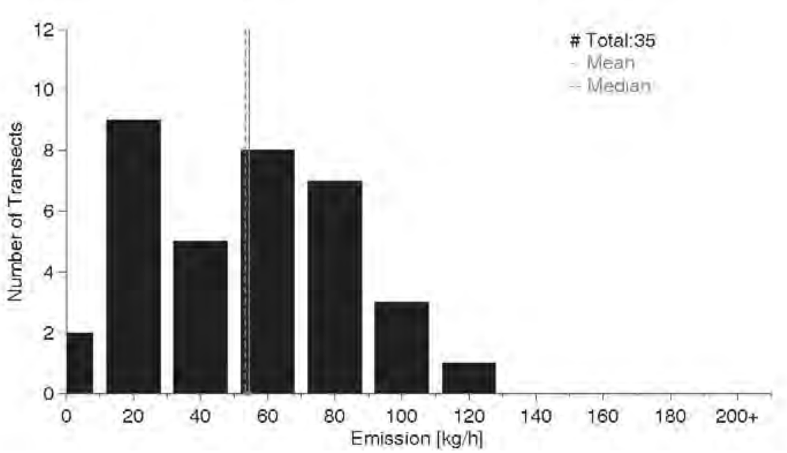

Figure 29. Histogram of all SkyDOAS SO_2 measurements taken at Refinery B during the 2015 SCAQMD study. The median and average values are indicated as dashed and solid gray lines, respectively.

4.2.3 BTEX

The fraction of BTEX compounds present in the measured alkane plumes emitted from Refinery B was measured either in the late evening or early morning when the plume was closer to the ground. This fraction is calculated by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured along two roads depending on wind direction. A summary of these measurements is shown in Table 14 and an example of a plume transect illustrated in Figure 27.

The average mass fraction of BTEX to alkanes was 0.084 or 8.4%. The average flux of BTEX can be calculated by multiplying this value by the total alkane flux as measured by the SOF-technique. The average mass fraction of benzene to alkanes was 0.9% and the benzene flux can be calculated in the same way as above.

Table 14. Summary of MWDOAS BTEX measurements at Refinery B. *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	222903-223809	11.3	0.18	2.5	345
150919	232406-232758	5.5	0.75	2	325
150919	220447-220915	7.3	0.71	2	302
150921	053955-054412	6.5	1.9	0.9	64
150922	070636-071237	11.4	0.9	1.5	64
Average±SD		**8.4±2.8**	**0.9±0.6**		

4.2.4 Methane

The average fraction of methane to total non-methane alkanes in the plume originating from Refinery B was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). Methane measurements were conducted during different times of the day and a summary of these results is shown in Table 15. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux as measured by SOF provides an estimate of the methane flux from the refinery. The average methane-to-alkanes mass fraction for Refinery B was 0.75.

Table 15. Summary of MeFTIR methane measurements at Refinery B. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction* [%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	222929 -232735	2	73	2.0-2.6	325-346
151018	145106 -145455	1	91	3.1	171
151020	134959 -162614	3	110	1.6-5.4	163-295
151029	121145 -122309	1	23	4.9	317
151030	112324 -155949	3	53	2.1-4.1	121-188
Average±SD	**-**	**(total 10)**	**75±36**	**-**	**-**

4.3 Refinery C

Refinery C, (crude oil capacity together with Refinery B 139 kBPD, (California Energy Commission 2016)) is located north of the Los Angeles port, see Figure 10. Significant upwind background plumes from the port and oil wells on the west side must be compensated for in the flux calculations. This is done by encircling ('box-measuring') the facility when possible (see example in Figure 18).

Wind information for the flux calculations on September 18, 2015 came from the wind LIDAR (0-400 m average) at position L2, located at the golf course parking lot north of the refinery, see Figure 30. For the other days, wind information from the SCAQMD met station at South Long Beach (SLBH) was used (scaled to match 0-400m LIDAR). See section 3.4 for additional wind analysis. Typical wind speeds and wind directions during the measurements are 3 m/s and 130-320°N, see Figure 31. Winds are generally weak at this site due to the hills on the west side.

4.3.1 Alkanes (non-methane)

Alkane emissions from Refinery C was measured with SOF during four days in the period September 7 to November 4, see Table 16. The daily means varied from 128 kg/h (4 November, single measurement) to over 297 kg/h (29 October). The average emission determined from the 15 quality assured transects was 234±36 kg/h and the median emission was 244 kg/h. Histograms of all transects (Figure 32) show a peak at around 230 kg/h and no extreme outliers. Most transects show a typical column peak directly downwind the north-west tank park and the process area, see Figure 30.

Table 16. Summary of SOF alkane measurements for Refinery C. *Single measurement

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150907	104256 -121838	4	296.5±22.4	2.1-2.9	134-163
150918	133231 -165721	5	200.5±47.1	2.6-3.7	301-323
151022	144739 -161143	5	238.4±31.1	2.9-3.9	170-204
151104*	121336 -122731	1	128.2	2.9	239
Average±SD	-	**(total 15)**	**234±36 (15%)**	-	-
Median	-	**(total 15)**	**244**	-	-

Figure 30. Example of a SOF 'box' measurement of the Refinery C (green area) 7 September 2015, 11:57-12:18. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 76 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed was 2.9 m/s for this particular measurement. Emissions on the upwind side (from LA harbor) are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 285 kg/h from Refinery C.

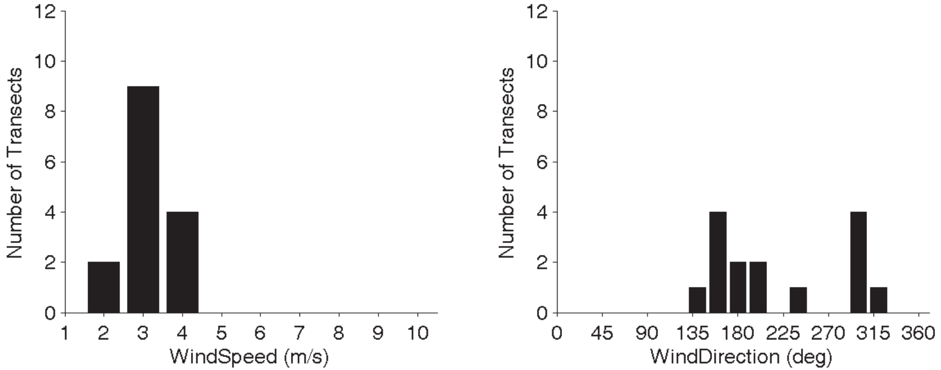

Figure 31. Wind histograms at Refinery C of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

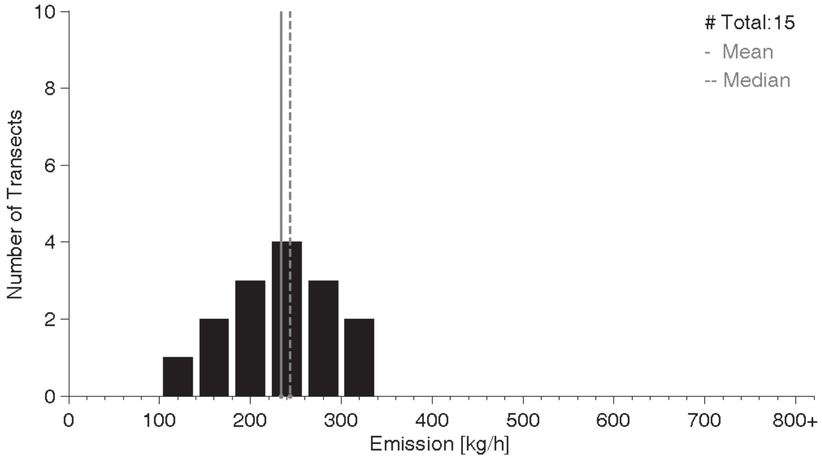

Figure 32. Histogram of all SOF measurements at Refinery C during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.3.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured for three measurement days during the campaign, twice in September and once in November. Summaries and histograms of SkyDOAS emission measurements are presented in Table 17, Table 18, Figure 34 and Figure 35. An example of a measurement is shown in Figure 33. Emissions averaged 58 and 43 kg/h and medians were 57 and 37 kg/h for NO_2 and SO_2 respectively.

Table 17. Summary of NO_2 measurements at Refinery C.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150907	95140 -121752	4	44.7±38.6	1.5-4.0	167-320
150918	134001 -153244	4	78.0±14.4	2.1-3.9	309-329
151104	121533 -122359	1	34.1	4.1	265
Average±SD	**-**	**(total 9)**	**58±29 (50%)**	**-**	**-**
Median	**-**	**(total 9)**	**57**	**-**	**-**

Table 18. Summary of SO_2 measurements at Refinery C.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150907	95122 -121752	4	48.7±21.9	1.4-4.2	166-310
150918	134212 -153244	4	39.5±16.4	1.9-3.9	309-331
151104	121405 -122616	1	30.7	4.1	271
Average±SD	**-**	**(total 9)**	**43±19 (45.4%)**	**-**	**-**
Median	**-**	**(total 9)**	**37**	**-**	**-**

Figure 33. Transects of plumes originating from Refinery C. the NO_2 (pink) and SO_2 (brown) plume from Refinery C in north-westerly wind (3.7 m/s). Max NO_2 = 9.5 mg/m^2, flux NO_2 = 81 kg/h, max SO_2=5.6 mg/m^2, flux SO_2 = 37.5 kg/h Data from September 18 2:59 PM.

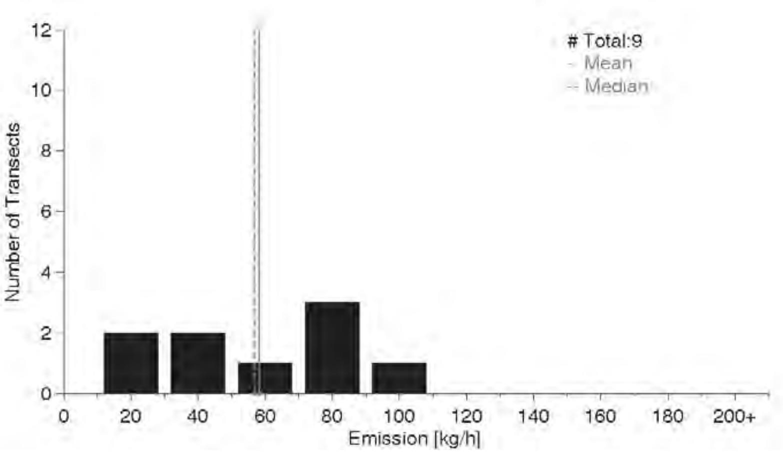

Figure 34. Histogram of all SkyDOAS NO_2 measurements at Refinery C during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

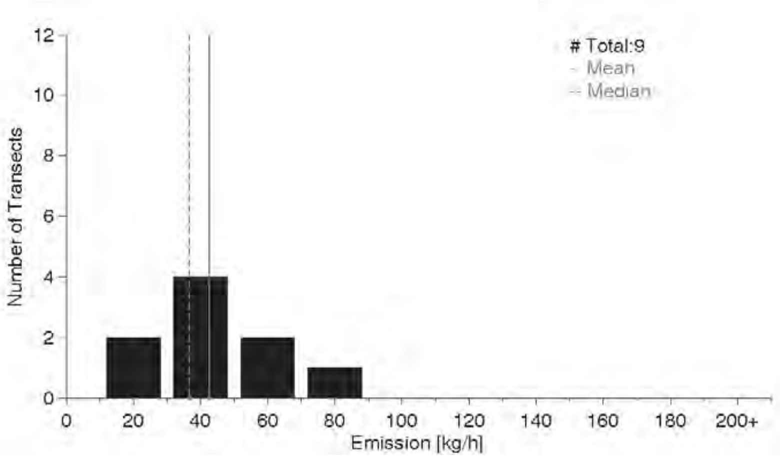

Figure 35. Histogram of all SkyDOAS SO_2 measurements at Refinery C during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.3.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery C were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from the SCAQMD-SLBH wind station were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured on different public roads surrounding the facility, depending on wind direction. The measurements are shown in Table 19.

The average mass fraction of BTEX to alkanes was 15.1%. The average flux of BTEX can be calculated by multiplying this figure with the total alkane flux as measured by the SOF-technique. The average fraction of benzene to alkanes was 3.4% and the benzene flux can be calculated in the same way as above. The plumes sampled during the measurement at Refinery C were weak and the low levels of both alkanes and BTEX causes a higher degree of uncertainty than usual in the mass ratio determination.

Table 19. Summary of MWDOAS BTEX measurements at Refinery C . *BTEX/alkane fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150918	220402-221009	12.6	1.4	2.5	323
151102	155155-155401	8.3	3.2	3.4	235
151102	150946-152855	13.8	2.4	3.5	254
151102	154248-154634	16.1	3.1	3.2	246
151104	160717-162206	24.8	6.7	3.3	275
Average±SD	-	**15.1±6.1**	**3.4±2.0**		

4.3.4 Methane

The average fraction of methane to total non-methane alkanes in the plume originating from Refinery C was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes measured simultaneously. Wind information from either LIDAR in position L2 or SCAQMD-SLBH was used, only wind direction, not wind speed matters for these measurements. Measurements were made both during the day and in late evenings and are shown in Table 20. Applying the measured fence-line ground level methane-to-alkane mass fraction to the by SOF measured alkane flux, gives an estimate of the methane flux from the refinery. The average methane-to alkane-mass fraction for Refinery C was 0.58.

Table 20. Summary of MeFTIR methane measurements at Refinery C. *Methane/alkane mass fraction.

Day [yymmdd]	**Timespan** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** **[%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150918	213422 -225735	2	61	2.9-3.0	321-327
151022	150050 -161331	5	49	3.1-5.2	182-193
151102	150921 -164835	3	68	2.8-3.8	243-279
151104	144900 -161529	2	62	4.0-12.0	230-262
Average±SD	**-**	**(total 12)**	**58±31**	**-**	**-**

4.4 Refinery D

Refinery D, (crude oil capacity: 105 kBPD (California Energy Commission 2016)) is located north of the Long Beach port, about 4 kilometers south of Refinery A, see Figure 10. To accurately compensate for incoming background plumes, it is necessary to make ‘box’ measurements (see example in Figure 36) which was easily done using public roads. Some measurements were however excluded since the incoming fluxes were comparable in size to the outgoing fluxes (adding too much uncertainty to the calculated flux). This was especially true for northerly and westerly winds carrying VOC-rich air from Refinery A and Refinery B.

Wind information for the flux calculations comes from the wind LIDAR (0-400 m average) at position L1 - (see Figure 10) or the Long Beach Airport ASOS station (scaled to match 0-400m LIDAR) or SCAQMD South Long Beach (SLBH) (scaled to match 0-400 m LIDAR). See section 3.4 for additional wind analysis. Typical wind directions and velocities during the measurements are 2-5 m/s and around 180°N or 270 degrees, see Figure 37.

4.4.1 Alkanes (non-methane)

Alkane emissions from Refinery D were measured with SOF during 7 days in the period September 3 to November 9, see Table 21. The daily means varied substantially from 90 kg/h (6 September) to an extreme of almost 1000 kg/h (1 November). A flaring event occurred 1 November which explains the large deviation for this day. The grand total average and standard deviation of all the 33 quality assured transects amounts to 348±253 kg/h and the median 164 kg/h. Histogram of all transects, Figure 38, show a gathered distribution at around 120 kg/h and some extreme outliers above 500 kg/h (which exclusively emanate from 1 November). Most transects show a typical column peak directly downwind the process area, see Figure 36. On November 1, significant VOC columns were detected directly downwind the flares in the west corner.

Table 21. Summary of SOF alkane measurements for Refinery D. *Single measurement. †Significantly deviating results due to flaring event.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150903*	140059 -140320	1	191.6	4.3	204
150906	171235 -180214	2	90.3±20.2	3.9-4.2	289-300
150907*	170803 -172210	1	125.6	6.6	269
150908	132545 -173630	9	192.0±66.9	4.0-7.8	274-296
150919	113306 -143232	10	116.7±47.1	2.2-2.6	160-198
151101†	104629 -150057	8	974.7±497.0	2.1-5.3	183-206
151109	135330 -144219	2	141.7±31.2	6.8-7.9	245-256
Average±SD	**-**	**(total 33)**	**348±253 (73%)**	-	-
Median	**-**	**(total 33)**	**164**	-	-

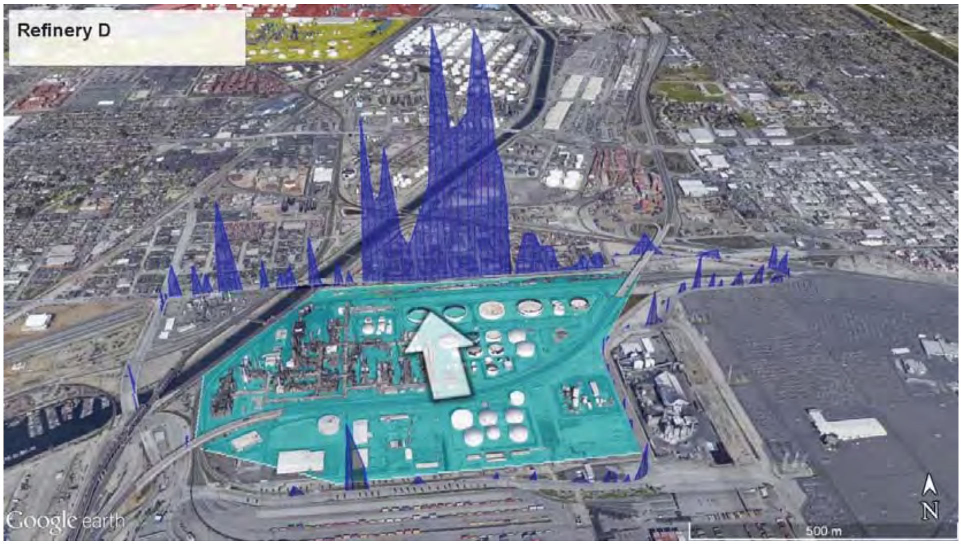

Figure 36. Example of a SOF 'box' measurement of Refinery D (cyan area) 19 September 2015, 13:08-13:20. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 80 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed during was 2.5 m/s. Emissions on the upwind side are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 185 kg/h from Refinery D.

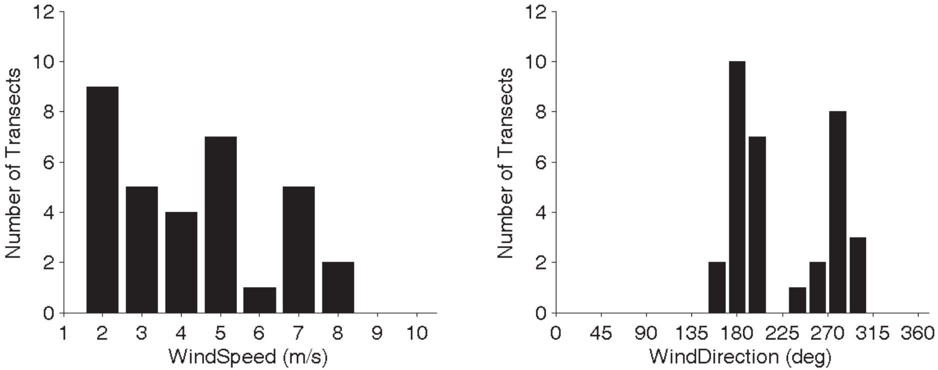

Figure 37. Wind histograms at Refinery D of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

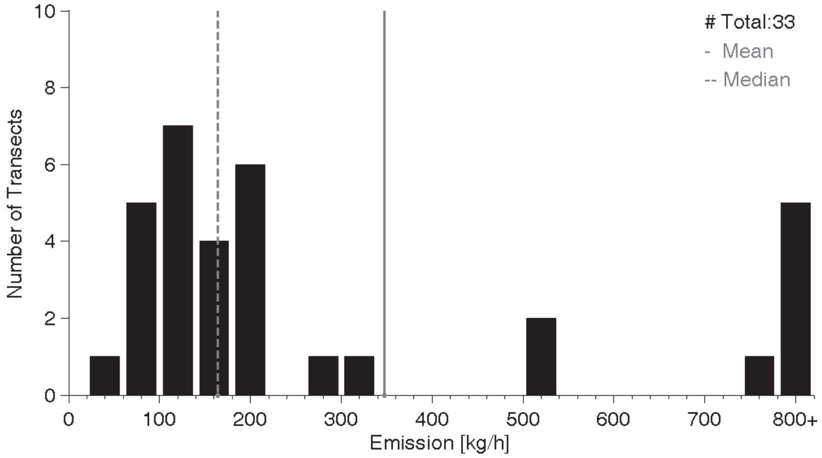

Figure 38. Histogram of all SOF measurements at Refinery D during the SCAQMD survey 2015. The last bin, denoted '+', contains all data points above 800 kg/h. The median and average values are indicated as dashed and solid gray lines.

4.4.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured for four measurement days in September during the campaign, example of a measurement is shown in Figure 39. Summaries and histograms of SkyDOAS emission measurements are presented in Table 22, Table 23, Figure 40 and Figure 41. Emissions averaged 43 and 18 kg/h and medians were 34 and 17 kg/h for NO_2 and SO_2 respectively.

Table 22. Summary of NO_2 measurements at Refinery D. *Single measurement.

Day [yymmdd]	**Timespan** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150902 *	160645 -160817	1	52.0	4.0	229
150906 *	100048 -100200	1	11.4	2.2	322
150908	132935 -152837	6	42.4±25.9	4.0-6.6	290-324
150919	114002 -142810	12	44.4±23.2	3.7-5.6	156-201
Average±SD	**-**	**(total 20)**	**43±24 (55%)**	**-**	**-**
Median	**-**	**(total 20)**	**34**	**-**	**-**

Table 23. Summary of SO_2 measurements at Refinery D . *Single measurement.

Day [yymmdd]	Timespan [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150902*	160645 -160817	1	19.4	4.0	229
150906*	100048 -100205	1	13.6	2.2	322
150908	132935 -152823	6	26.8±8.3	4.0-6.6	289-322
150919	114057 -142758	12	14.0±5.6	3.5-5.7	166-204
Average±SD	**-**	**(total 20)**	**18±6.5 (36%)**	**-**	**-**
Median	**-**	**(total 20)**	**17**	**-**	**-**

Figure 39. Transects of plumes originating from Refinery D: NO_2 (pink), SO_2 (brown) in south wind and BTEX (blue) and alkane (yellow) in north-westerly winds. NO_2 and SO_2 show column thickness and are both on the same scale (max SO_2 = 10.1 mg/m^2, flux SO_2 = 18.3 kg/h, max NO_2 = 9.8 mg/m^2, flux NO_2 = 39.3 kg/h), alkanes and BTEX show concentrations and are scaled independently for visibility (max BTEX =0.02 mg/m^3, max alkanes = 0.29 mg/m^3). Data from September 19, 12:42 PM and 8:32 PM.

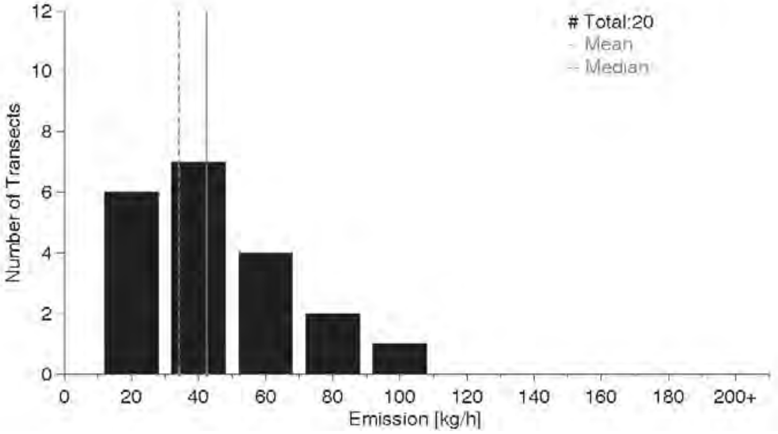

Figure 40. Histogram of all SkyDOAS NO_2 measurements at Refinery D during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

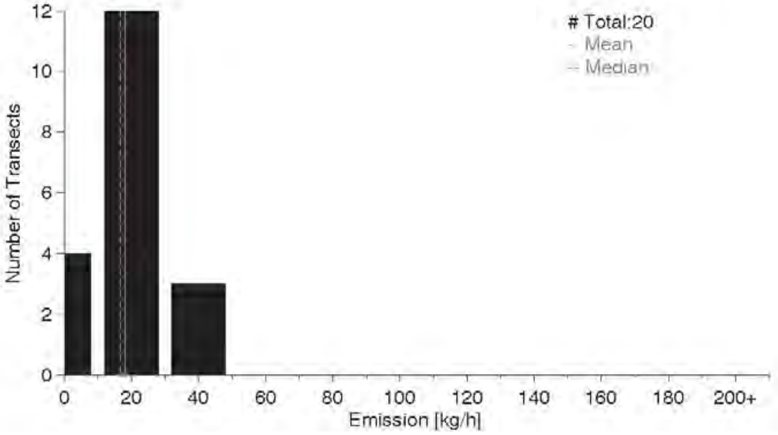

Figure 41. Histogram of all SkyDOAS SO_2 measurements at Refinery D during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.4.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery D were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. A measurement example is shown in Figure 39. To determine the source of the plume, wind directions from the LIDAR positioned at L1 or the SCAQMD-HDSN wind station were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured on different public roads surrounding the facility, depending on wind direction. The measurements are shown in Table 24.

The average fraction of BTEX to alkanes was 0.099 or 9.9%. The average flux of BTEX can be calculated by multiplying this figure with the total alkane flux as measured by the SOF-technique.

The average fraction of benzene to alkanes was 1.0% and the benzene flux can be calculated in the same way as above.

Table 24. Summary of MWDOAS BTEX measurements at Refinery D. *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	200817-201303	6.3	0.81	3.4	309
150919	205012-205749	16.2	0.93	1.8	330
150919	203234-204133	5.1	1.3	3	331
150919	214233-215112	4.1	0.33	1.2	320
151104	170956-171120	20.7	2.5	2.2	266
151104	171422-171457	11.9	0.7	2.6	273
151104	171504-171546	4.7	0.46	3.8	295
Average±SD		**9.9±6.5**	**1.0±0.7**		

4.4.4 Methane

The average fraction of methane to total non-methane alkanes in the plume from Refinery D was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume were compared to the average concentration of correlating alkanes measured simultaneously. Wind information from ASOS_KLGB was used, though only wind direction, not accurate wind speed matters for these measurements. Measurements were made during daytime and are shown in Table 25. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux measured by SOF, gives an estimate of the methane flux from the refinery. The average methane-to-alkane fraction for Refinery D was 0.48.

Table 25. Summary of MeFTIR methane measurements at Refinery D. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** **[%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	115502 -234019	10	46	0.5-4.5	41-345
151101	102640 -121744	3	55	0.8-3.9	141-190
Average±SD	**-**	**(total 13)**	**48±20**	**-**	**-**

4.5 Refinery E

Refinery E (crude oil capacity: 269 kBPD, (California Energy Commission 2016)) is located at the Pacific coast, around 20 kilometers northwest of Refinery A (Figure 10). This refinery is totally isolated from the other refineries in this study. There are however, other significant background plumes from the oil wells and power plants along the coast line that must be compensated for in the flux calculations. This is done by encircling (‘boxing’) the facility when possible (see example in Figure 42). No prevailing night-time VOC-rich air masses during AM were present in this coastal location (as compared to the other refineries in this survey).

Wind information for the flux calculations comes from the wind LIDAR (0-400 m average) at position L4 located around 1 km east of the refinery (see Figure 42) for the period 9-16 September. For the other days, wind information from the Los Angeles International Airport (KLAX) ASOS met station, 3 km north of the refinery, was used (scaled to match 0-400 m LIDAR). See section 3.4 for additional wind analysis. Typical wind directions and velocities during the measurements are 4-7 m/s and 270°N, see Figure 43. Winds were generally steady at this site due the sea breeze.

4.5.1 Alkanes (non-methane)

Alkane emissions from Refinery E were measured with SOF during seven days in the period September 9 to November 6, see Table 26. The daily means varied from 185 kg/h (13 September) to over 700 kg/h (11 September). The increased emissions 11 September points toward the tank park in the northwest corner. The grand total average and standard deviation of all the 35 quality assured transects amounts to 280±223 kg/h and the median 244 kg/h. Histograms of all transects (Figure 44) show a peak at around 240 kg/h and one extreme outlier (from 11 September). Most transects show a broad column peak downwind the core of the facility, see Figure 42.

Figure 42. Example of a SOF 'box' measurement of Refinery E (orange area) 6 November 2015, 10:47-11:22. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 55 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed during this particular measurement was 1.8 m/s. Emissions on the upwind side are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 229 kg/h from Refinery E.

Table 26. Summary of SOF alkane measurements at Refinery E. *Single measurement. †Extremely deviating results due to (likely) tank park event.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150909	120735 -152659	5	242.2±83.3	4.6-6.7	266-279
150911†	110544 -133021	3	701.9±718.8	2.3-5.3	240-252
150913	112120 -144848	4	185.0±62.3	1.9-6.4	239-261
150916	145339 -160447	2	206.1±96.9	4.9-5.3	253-254
150920	105011 -143901	7	302.7±75.6	4.2-6.0	265-270
150927	120435 -152615	9	218.9±44.8	3.4-4.9	257-270
151106	104724 -140220	5	249.1±41.5	1.8-4.2	235-255
Average±SD	-	**(total 35)**	**280±223 (80%)**	-	-
Median	-	**(total 35)**	**244**	-	-

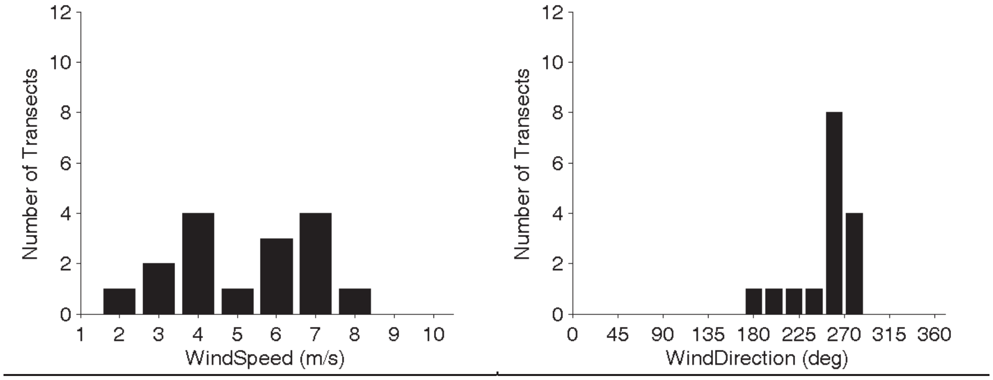

Figure 43. Wind histograms at Refinery E of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

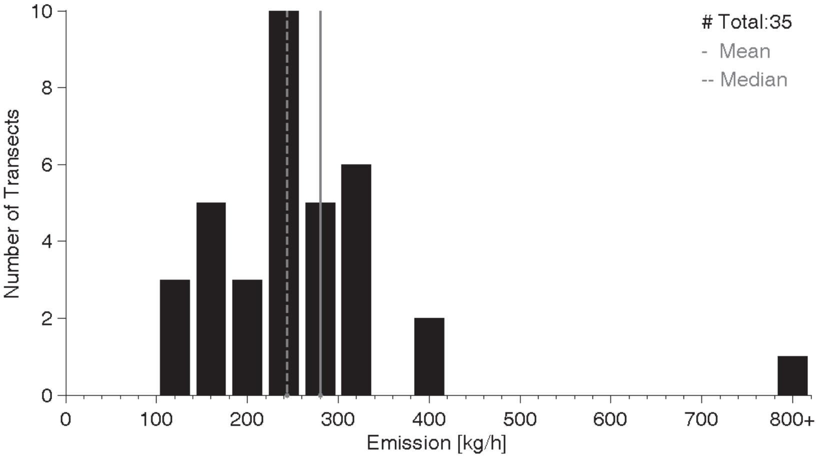

Figure 44. Histogram of all SOF measurements at Refinery E during the SCAQMD survey 2015. The last bin, denoted '+', contains all data points above 800 kg/h. The median and average values are indicated as dashed and solid gray lines.

4.5.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured during 7 measurement days in September and November during the campaign, examples of such measurements can be seen in Figure 45. As these plumes are from combustion sources and presumably stack releases, the plumes are expected to be at a higher altitude than the VOC plume when measuring near the facility, as in nearly all the measurements. Summaries of SkyDOAS emission measurements are presented in Figure 46, Figure 47, Table 27 and Table 28. Emissions were determined using LIDAR-wind, measured at position L4 or scaled KLAX ASOS met station. Typically, baselines were corrected for background (vehicle and other sources for NO_2) thus setting inflow to zero. Emissions averaged 70 and 52 kg/h and medians were 63 and 53 kg/h for NO_2 and SO_2 respectively.

Table 27. Summary of NO_2 measurements at Refinery E. *Single measurement.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150909	114049 -145759	5	99.1±19.9	4.6-5.0	260-268
150911	111924 -132450	2	67.2±47.0	3.6-5.0	259-270
150913	112658 -144342	4	60.4±13.9	4.0-5.9	245-258
150916	145850 -163249	3	45.5±16.2	3.7-4.5	249-265
150920	110103 -114007	2	101.3±29.2	4.4-4.8	263-268
150927	140555 -144335	2	44.3±6.3	4.2-4.9	254-264
151106 *	123305 -124620	1	35.9	2.9	251
Average±SD	-	**(total 19)**	**70±23 (33%)**	-	-
Median	-	**(total 19)**	**63**	-	-

Table 28. Summary of SO_2 measurements at Refinery E. *Single measurement.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150909	114700 -152537	6	40.5±20.4	4.0-5.2	258-272
150910 *	154026 -155223	1	42.1	4.4	266
150911	103551 -132450	4	49.3±25.7	3.5-5.0	252-270
150913	091458 -144342	7	47.4±11.7	2.3-5.9	242-258
150916	145850 -163249	3	55.6±9.8	3.8-4.7	249-268
150920	105910 -113707	2	76.4±27.7	4.5-4.9	261-271
150927	140555 -151747	4	61.7±9.4	4.2-4.9	254-264
151106	114611 -124623	2	70.7±26.6	2.5-2.8	250-252
Average±SD	-	**(total 29)**	**52±19 (35%)**	-	-
Median	-	**(total 29)**	**53**	-	-

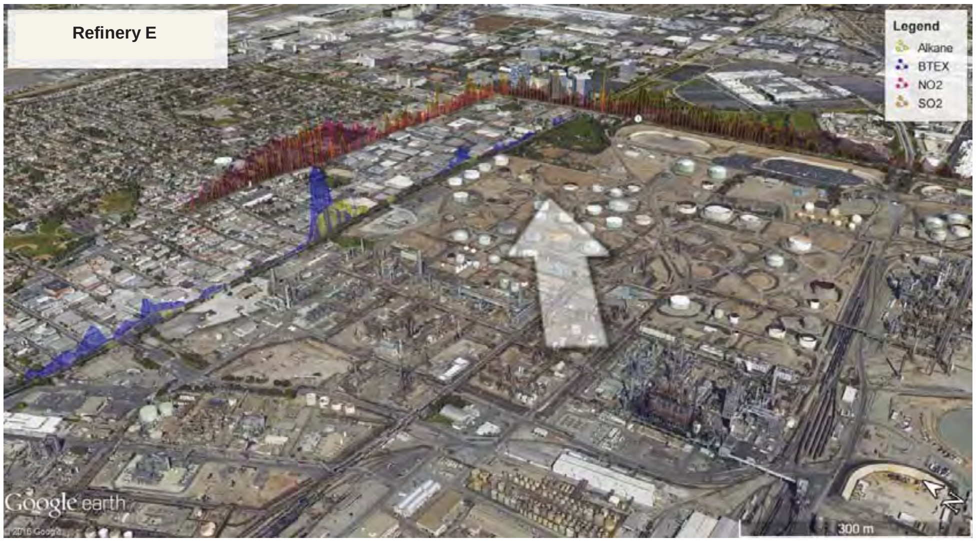

Figure 45. Transects of plumes originating from Refinery E: NO_2 (pink), SO_2 (brown), BTEX (blue) and alkane (yellow). NO_2 and SO_2 show column thickness and are both on the same scale (max NO_2 = 5.9 mg/m^2, flux NO_2 = 42.5 kg/h, max SO_2 = 6.4 mg/m^2, flux SO_2 = 48.9 kg/h), alkanes and BTEX show concentrations and are scaled independently for visibility (max BTEX = 0.04 mg/m^3, max alkanes = 0.13 mg/m^3). Example transects from September 16, 4:23 PM and 9:07 PM.

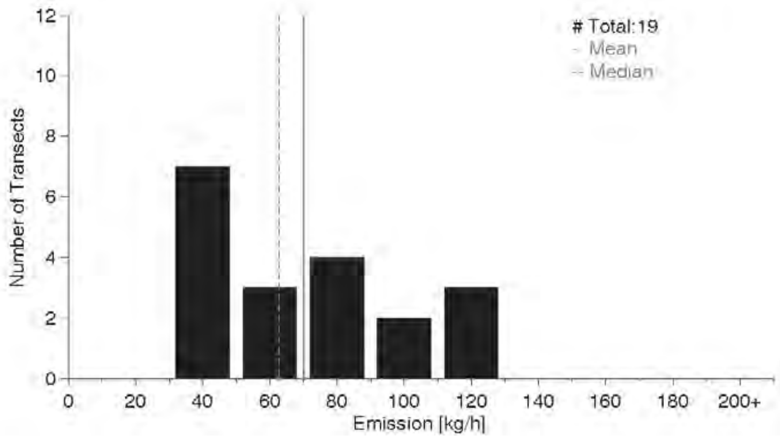

Figure 46. Histogram of all SkyDOAS NO_2 measurements at Refinery E during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

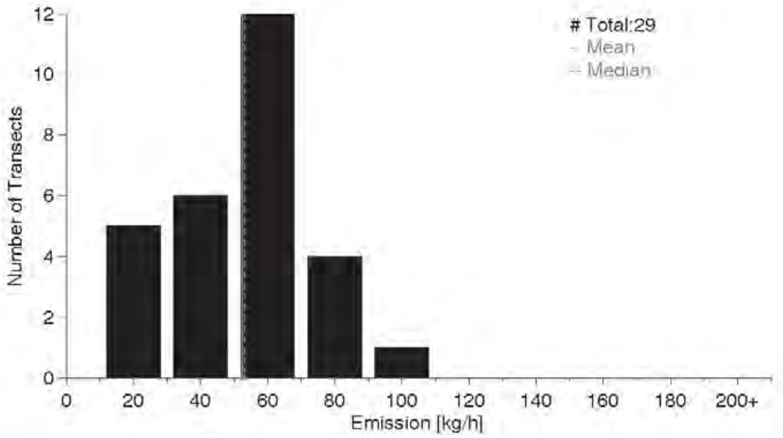

Figure 47. Histogram of all SkyDOAS SO_2 measurements at Refinery E during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.5.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery E were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. Figure 45 shows an example of a measurement. To determine the source of the plume, wind directions from the LIDAR positioned at L4 or the ASOS-KLAX wind station were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured north of the facility. The measurements are shown in Table 29.

The average mass fraction of BTEX to alkanes was 0.13 or 13.0%. The average flux of BTEX can be calculated by multiplying this figure with the total alkane flux as measured by the SOF-technique. The average mass fraction of benzene to alkanes was 1.1% and the benzene flux can be calculated in the same way as above.

Table 29. Summary of MWDOAS BTEX measurements at Refinery E. *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150916	112732 -165808	12	0.53	0.8	353
150916	130746 -131654	13.5	0.71	1.3	330
150916	134638 -154706	2.1	1	1	331
150916	142535 -154524	20	2	2	320
150916	144942 -173531	17.2	1.4	2.1	317
Average±SD	-	**13±6.8**	**1.1±0.6**	-	-

4.5.4 Methane

The average fraction of methane to total non-methane alkanes in the plume from Refinery E was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes measured simultaneously.

Wind information from ASOS_KLAX was used, only wind direction, not wind speed matters for these measurements. Measurements were made during daytime and late evening and are shown in Table 30. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux measured by SOF, gives an estimate of the methane flux from the refinery. The average methane-to-alkane fraction for Refinery E was unusually high on the night of September 19 and might have been affected by some temporary release source. Therefore the measurements from September 19 will not be used in the result. When measured on September 27 the fraction was no longer extreme and the average from that day, 0.85 will represent the resulting fraction for Refinery E.

Table 30. Summary of MeFTIR Methane measurements at Refinery E. *Methane/alkane mass fraction. †Extremely deviating results likely due to other non-identified temporal source.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150916†	170318 -224508	5	180	4.0-5.1	230-268
150927	112103 -151358	5	85	4.0-4.0	230-230
Average±SD	**-**	**(total 10)**	**85±7**	**-**	**-**

4.6 Refinery F

Refinery F (crude oil capacity 150 kBPD, (California Energy Commission 2016)) is located around 10 kilometers northwest of Refinery A, see Figure 10. Emission plumes from other refineries in this study or other large emitters do not interfere directly with plumes from Refinery F with the prevailing wind directions. But there are some minor oil wells and storage tanks west of the refinery which must be compensated for in the flux calculations by 'boxing' the facility during westerly winds (see example in Figure 48).

Wind information for the flux calculations comes from the wind LIDAR (0-400 m average) at position L3 located 300 m east of the refinery (see Figure 48) 17 September. For the other days, wind information from the L1 LIDAR site was used. See section 3.4 for additional wind analysis. Typical wind directions and velocities during the measurements are around 4 m/s and around 180 or 270°N, see Figure 49.

4.6.1 Alkanes (non-methane)

Alkane emissions from Refinery F were measured with SOF during four days: 9, 13 and 17 September and 7 November, see Table 31. The daily means varied from 117 kg/h (13 September) to 219 kg/h (17 September). The grand total average and standard deviation of all the 16 quality assured transects amounts to 169±105 kg/h and the median 140 kg/h. Histograms of all transects (Figure 50) show a peak at around 120 kg/h and one extreme outlier (from 17 September). Transects show a column peak downwind the southeast tank park and the process area, see Figure 48.

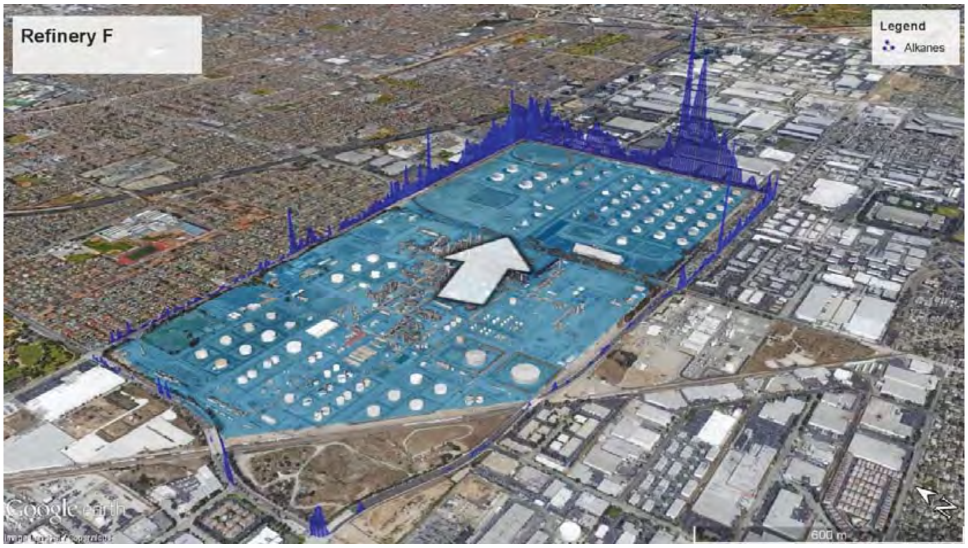

Figure 48. Example of a SOF 'box' measurement of the Refinery F (light blue area) 17 September 2015, 12:39-13:04. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 83 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed during was 3.1 m/s. Emissions on the upwind side are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 230 kg/h from Refinery F.

Table 31. Summary of SOF alkane measurements for Refinery F. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150909*	164857 -165755	1	157.7	3.6	226
150913	153509 -170800	4	117.1±18.0	6.2-7.1	270-277
150917	120844 -161940	7	219.4±152.4	3.1-7.6	251-261
151107	133217 -145646	4	135.3±6.5	2.5-4.5	189-277
Average±SD	-	**(total 16)**	**169±105 (62%)**	-	-
Median	-	**(total 16)**	**140**	-	-

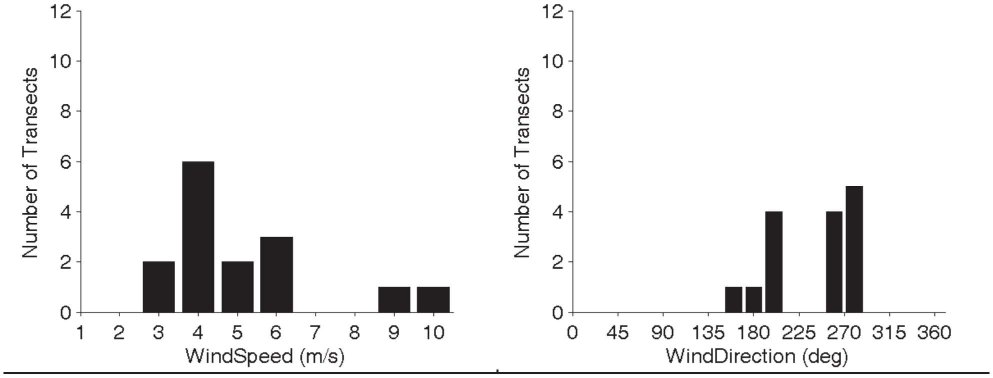

Figure 49. Wind histograms at Refinery F of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

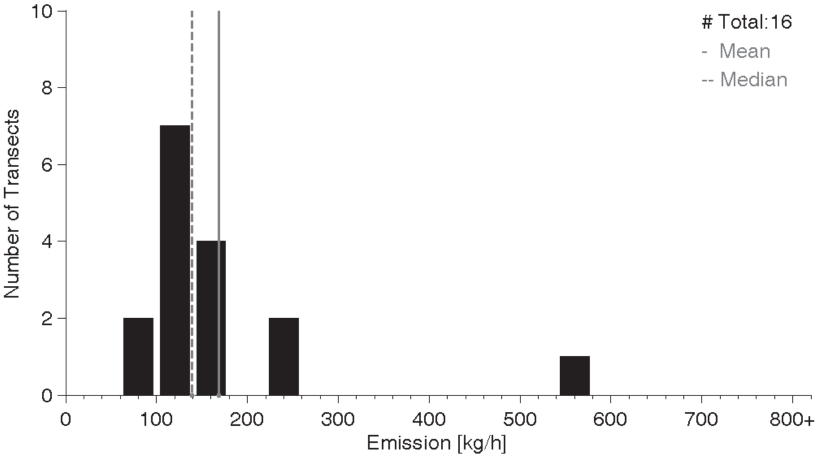

Figure 50. Histogram of all SOF measurements at Refinery F during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.6.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured for 2 measurement days in September. Summaries of SkyDOAS emission measurements are presented in Table 32 and Table 33. An example of a measurement is shown in Figure 51. For Refinery F the number of measurements is very low and the result may therefore be less reliable as a representation of typical emissions. Emissions averaged 23 and 40 kg/h and medians were 18 and 37 kg/h for NO_2 and SO_2 respectively.

Table 32. Summary of NO_2 measurements at Refinery F. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150913	153603 -160753	2	14.8±4.1	6.1-6.1	258-273
150917	132227 -132826	1	38.2	5.0	252
Average±SD	-	**(total 3)**	**23±4.1 (18%)**	-	-
Median	-	**(total 3)**	**18**	-	-

Table 33. Summary of SO_2 measurements at Refinery F. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150913*	153535 -154138	1	67.2	6.2	260
150917	121200 -132803	2	27.0±14.2	3.3-4.9	248-252
Average±SD	-	**(total 3)**	**40±14 (35%)**	-	-
Median	-	**(total 3)**	**37**	-	-

Figure 51. Transects of plumes originating from Refinery F: NO_2 (pink), SO_2 (brown), BTEX (blue) and alkane (yellow). NO_2 and SO_2 show column thickness and are both on the same scale (max NO_2 = 5.0 mg/m^2, flux NO_2 = 38.2 kg/h, max SO_2 = 4.4 mg/m^2, flux SO_2 = 17 kg/h), alkanes and BTEX show concentrations and are scaled independently for visibility (max BTEX = 0.01 mg/m^3, max alkanes = 0.55 mg/m^3). Example transects from September 17, 1:22 PM and 11:36 PM.

4.6.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery F were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX ground level measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from the LIDAR positioned at L3 or the KLAX-ASOS wind station were used (wind speed is irrelevant for these measurements). BTEX mass ratios were measured along one road picking up the plume from the tank park, and along another cutting through the facility and enabling a measurement of the process plume in westerly wind. The measurements are shown in Table 34 and Table 35.

The average mass fraction of BTEX to alkanes was 0.137 or 13.7% and 0.017 or 1.7% for the process and the tank park respectively. The average flux of BTEX can be calculated by multiplying this figure with the alkane flux as measured from these two sources by the SOF-technique. The average mass fraction of benzene to alkanes was 0.9% for the process plume and 0.3% for the tank park plume. Benzene flux can be calculated in the same way as above. Both the total BTEX flux and the benzene flux for Refinery F can be found in Table 5.

Table 34. Summary of MWDOAS BTEX measurements at Refinery F. Tank park plume *BTEX/alkane mass fraction.

Day [yymmdd]	Time span [hhmmss-hhmmss]	BTEX Fraction* [%]	Benzene Fraction* [%]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150917	214724-215203	1.9	0.44	1.8	270
150917	232708-232841	1.4	0.19	2.8	251
Average±SD	-	**1.7±0.4**	**0.3±0.2**	-	-

Table 35. Summary of MWDOAS BTEX measurements at Refinery F. Process plume *BTEX/alkane mass fraction.

Day [yymmdd]	Time span [hhmmss-hhmmss]	BTEX Fraction* [%]	Benzene Fraction* [%]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150917	221740-221813	12.8	0.87	1.7	244
150917	233614-233641	13.3	1	2.6	252
150917	231920-232007	15.1	0.71	4	45
Average±SD		**13.7±1.2**	**0.9±0.3**		

4.6.4 Methane

The average fraction of methane to total non-methane alkanes in the plume from Refinery F were measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of alkanes measured simultaneously. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux measured by SOF, gives an estimate of the methane flux from the refinery. Wind information from LIDAR in position L3 was used, only wind direction, not wind speed matters for these measurements. Only three measurements were made on one evening September 17 as shown in Table 36. The average methane-to-alkane fraction for the Refinery F was 0.41.

Table 36. Summary of MeFTIR methane measurements at Refinery F. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction* [%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150917	211536 -233000	3	41	1.9-3.3	251-274
Average±SD	**-**	**(total 3)**	**41±6**	**-**	**-**

5 Results – On-site Measurements in a Refinery Tank Farm

On site measurements in the tank farm of a major refinery in the South Coast Air Basin were carried out for 8 days between 28 September and 7 October 2015 using the mobile optical methods described in the previous sections (i.e. SOF, MWDOAS and MeFTIR). The objective of this activity was to demonstrate the capability of these real time optical techniques to identify and quantify gas leakages inside a refinery and to compare the results with other optical methods used during the same time frame. These include a DIAL (Differential Absorption LIDAR; a laser-based method) operated by NPL (National Physics Laboratory, UK) at different locations within the tank farm, and a stationary long path FTIR system that was operated by Atmosfir in the west part of the tank farm. Here the FTIR coupled to a telescope was automatically pointed towards multiple reflectors put at strategic positions in different parts of the tank farm and at different heights to estimate ground source emissions using the EPA's OTM-10 method (see separate report by Atmosfir). These various methods were used independently but on several occasions side by side measurements were carried out for validation purposes (see report by Pikelnaya et. al. (2016)).

In this study we carried out mobile optical measurements throughout the tank farm on available roads in order to localize potential hot-spot emission areas and quantify emissions from selected tanks and tank groups. The emphasis was to investigate emissions from tank groups and tanks rather than the whole tank farm emissions, although this was also done.

Figure 52. Overview of the tank farm part of the refinery where on site measurements with SOF + MeFTIR + MWDOAS were conducted for about one week in September/October 2015. Tanks, tank groups and specific areas have been given numbers and names respectively for reference to measurement results. North is upwards. Groups of quantified tanks are denoted by coloured rectangles, and individual tanks that have been quantified are indicated by blue shapes/circles. The surveyed part (large light green area) is restricted in the west and south by the site fence-line, and in the east and north by roads going east of tank 1-11-21-Pump slab and then between the "Tanks NorthEast" and tank groups "52-58+66-71" and to the northeast corner of group "86-95".

This limited study included alkane column measurements and ground concentration measurements of alkanes, methane and aromatic VOCs. A wind meter was positioned on an elevated plateau on a big open field inside the tank farm, thus sampling wind at a height comparable to a typical tank roof height.

The real-time capability and sensitivity of the instruments (2 s sampling time resolution for SOF and MWDOAS, 10 s for MeFTIR) was essential to this work as shown in Figure 53. By observing the geo-tagged emissions in real time, any occurring hot-spots can immediately be investigated further to for example conclude if the sources are intermittent or continuous. By driving on the upwind and downwind side of the tanks and unit areas, any incoming emission fluxes or interfering sources can be identified and accounted for.

Figure 53. A picture from the measurement van showing real time data while passing through a source. The column and concentration data is shown together with the measurements position on a map for fast hotspot identification and interpretation.

Validation between SOF (FluxSense) and DIAL (NPL) was done on tank 16 (crude), tank 13 (crude) and on reservoir 502 (vacuum gas oil).

5.1 Tank Park

Table 37 summarizes the plume transects including the whole tank farm in one run. The median emission of all these complete tank farm emission measurements was 145 kg/h based on 9 measurements distributed over four days. This corresponds to approximately half the total measured refinery emission (see section 4.1.1). The overall tank farm single observations ranged from 104-194 kg/h for the daily averages (4 different days).

Figure 54 shows an example of SOF measurements around the tank farm at the selected refinery. In this transect the highest column (165 mg/m^2) of VOC was measured at the elliptically shaped tank (here referred as tank reservoir no 502) in the lower left corner. This is explained by the pass being close to the source before the release was dispersed by convection and turbulence. It’s evident that reservoir 502 is a substantial source of alkanes. However, when following the measurement transect along the perimeter of the tank farm several extended plume sections are observed, and these add up to emission being several times that of reservoir 502 alone. The contribution from different parts of the tank farm is discussed in the next section.

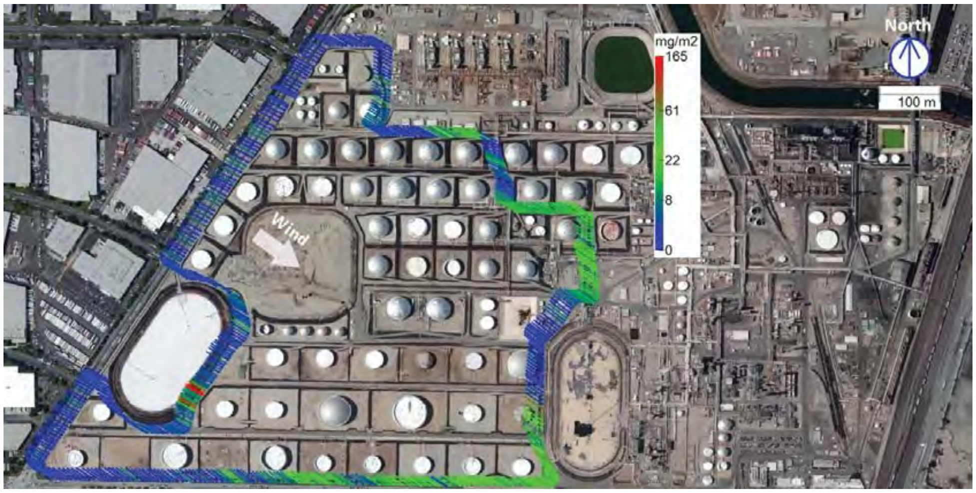

Figure 54. SOF measurement of alkanes around the major body of the tank farm on September 29, 2015 between 2:51 PM and 3:15 PM. Each measured spectrum is represented by a single line, with color indicating the evaluated integrated vertical alkane column. The line orientation indicates the direction from which the wind is blowing. North is upwards and in this case the wind blew from northwest.

Table 37. Summary of SOF alkane measurements for the refinery tank park considered in this study.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150928	143009 -153658	2	187.6±89.2	5.2-5.5	291-299
150929	145455 -150723	2	193.9±33.2	4.7-6.3	302-302
151002	143351 -154352	4	136.5±33.7	4.4-5.5	277-294
151006	140304 -150009	2	104.4±24.7	3.7-5.4	280-285
Average±SD	**-**	**(total 9)**	**153±53 (35%)**	**-**	**-**
Median	**-**	**(total 9)**	**145**	**-**	**-**

5.2 Individual Tanks and Tank groups

Based on 233 measurement transects of different tanks and tank groups, specific tank emissions have been summarized in Table 38. Adding up all the measured tank farm objects give on average 191 kg/h of alkanes. This is in line with the estimate from the SOF measurements for the complete tank farm in one run (153 kg/h, Table 37). Note that these numbers represent two different approaches with varying coverage in time and space. The statistic basis is quite variable among the tank farm objects, ranging from Reservoir 502 having 80 measurements distributed over 8 days to a few objects having only a single observation.

Table 38. Summary of onsite measurements (SOF) of tanks and tank groups. [a)] For the BTEX emission the average BTEX to alkane mass fraction (6.0 %) has been used for the tanks where the BTEX fraction was not quantified. [b)] For the benzene emission the average benzene to alkane mass fraction (0.59 %) has been used for the tanks where the benzene fraction was not quantified. *Items in italics and aligned to the right are either subgroups part of other items or not part of the overall Tank farm average.*

Tank_ID	**Average alkane (kg/h)**	**SD (kg/h)**	**No. meas.**	**No. days**	**BTEX to alkane mass fraction (%)**	**BTEX emission a) (kg/h)**	**Benzene to alkane mass fraction (%)**	**Benzene emission b) (kg/h)**
Tank_1	1	0.4	5	3	2	0.02	0.37	0.00
Tank_2	2.8	4.9	3	2	n.m.	0.17	n.m.	0.02
Tank_3	1.3	0.3	4	3	n.m.	0.08	n.m.	0.01
Tank_4	0.6	0.1	4	3	n.m.	0.04	n.m.	0.00
Tank_5	1.7	0.2	4	3	n.m.	0.10	n.m.	0.01
Tank_6	4.2	1.7	8	4	3.3	0.14	0.39	0.02
Tank_8	2.6	1.8	9	3	n.m.	0.16	n.m.	0.02
Tank_11	10.9	5.4	9	4	7.6	0.83	0.65	0.07
Tank_12	2.4	1.7	9	4	5.3	0.13	0.73	0.02
Tank_13	21.6	10.4	32	5	8.9	1.92	0.55	0.12
Tank_14	5.4	4.1	9	4	1.5	0.08	0.48	0.03
Tank_16_all days	*259*	*134*	*55*	*6*	*1.4*	*3.63*	*0.34*	*0.88*
Tank_16_excl. 151005	42	34	13	5	1.4	0.59	0.34	0.14
Tank_17	2.8	1	10	5	0.6	0.02	0.54	0.02
Tank_18	0.7	0.6	2	2	n.m.	0.04	n.m.	0.00
Tanks_19-20	15.8		1	1	n.m.	0.95	n.m.	0.09
Tank_21	6.3	1.4	5	2	12.3	0.77	n.m.	0.04
Tank_22	1.2	0.5	6	2	11.4	0.14	0.25	0.00
Tank_25	2.1		1	1	n.m.	0.13	n.m.	0.01
Tanks_27-30	5.3	0.2	5	4	5.6	0.30	1.5	0.08
Tanks_31-35_42-45	12.6		1	1	n.m.	0.76	n.m.	0.07
Tank_40	*4.5*	*0.1*	*2*	*1*	*n.m.*	*0.27*	*0.48*	*0.02*
Tanks_56-60	*7.6*	*0.6*	*2*	*2*	*n.m.*	*0.46*	*n.m.*	*0.04*
Tank_57	*3.0*		*1*	*1*	*5.6*	*0.17*	*0.24*	*0.01*
Tank_71	*3.7*		*1*	*1*	*5.6*	*0.21*	*0.37*	*0.01*
Tanks_52-58_66-71	13.7		1	1	9.3	1.27	0.88	0.12
Tanks_86-95	8.0	0.7	6	4	4.4	0.35	n.m.	0.05
Reservoir_502	26.1	11.4	80	8	10.7	2.79	1.1	0.29
Total all measured tanks:	**191**		**233**			**12**		**1.2**

As seen in Table 38, Tank 16 had one day (5 October, 2015) where atypical emissions were observed. Including this day would raise the overall average for Tank 16 to 259 kg/h if compared to 42 kg/h if this day is excluded. In the presented grand total average for the tank farm, this atypical event was left out for Tank 16 (42 measurements were conducted on tank 16 this day in a validation experiment with other optical techniques, whereas 13 measurements were done for the other days being included in the average). BTEX to alkane mass fractions were also measured for many of the tanks, and ranged from 1.4 to 12.3 % which is quite normal values for a tank farm containing both crude and refined petroleum product tanks. Last four columns in Table 38 specify measured BTEX fractions, inferred BTEX emissions and corresponding columns for benzene, using the SOF alkane emission and the BTEX and benzene fractions respectively. For tanks where BTEX or benzene were not measured, the average BTEX mass fraction (6.0 %) or benzene average fraction (0.59 %) has been used. Overall a BTEX emission of 12 kg/h is estimated from the tank farm, of which 1.2 kg is estimated to be benzene.

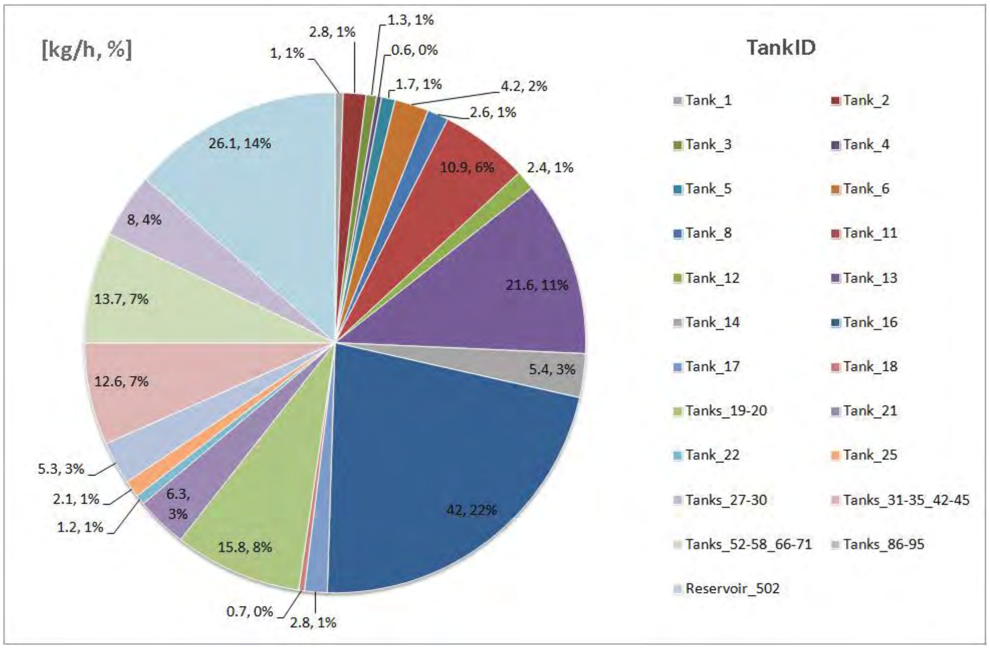

Figure 55. Summary of all measurements on the specified tanks and tank groups and their relative contribution to the total emission of 192 kg/h. The measurements on tank 16 from 5 October were omitted here due an atypical release event.

Figure 55 shows the absolute and relative contribution from all measured tanks and tank groups to the tank farm overall sum of alkanes (191 kg/h). Three tanks stand out with single contributions above 10% each, with Tank_16 being the strongest source (22%, Crude) followed by Reservoir_502 (14%, Vacuum Gas Oil (VGO)) and Tank_13 (11%, Crude). These tanks were also studied in more detail, to obtain better statistics. A validation study between the SOF and DIAL techniques were also done on these tanks with very good agreement of the results (see Pikelnaya et. al. (2016)).

The 502 source is a large covered reservoir which contain vacuum gas oil (VGO). It has two ventilations shafts, one in the north and one in the south. Specific data from tank 502 are found in Table 39 and Figure 56. Histograms of the 80 individual plume transects of this source, from 8 different days, resemble something close to a normal distribution with an average emission of 26 kg/h, very close to the median of 25 kg/h. The observed spread in day to day averages ranged from 20 to 36 kg/h. The emissions from Reservoir 502 were split up on contributions from the north and the south vent respectively, showing that the vast majority of the reservoir emissions originated from the south vent with 90% of the reservoir's overall emission.

With a BTEX mass fraction of 11%, this was the strongest source of aromatics found in the tank farm, with an estimated emission of 2.8 kg/h BTEX (23% of the overall). Also when considering benzene, Reservoir 502 was the strongest source with 0.3 kg/h. Tank 13 and Tank 16 were found to have a BTEX emission of 1.9 kg/h and 0.6 kg/h respectively. Corresponding benzene emissions were 0.12 kg/h and 0.14 kg/h. The BTEX and benzene results for Tank 13, 16 and Reservoir 502 were based on 8, 57 and 28 observations within each category respectively.

Table 39. Summary of SOF alkane measurements reservoir no 502. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150928	140807 -155200	4	27.7±7.4	4.2-6.0	287-294
150929	140318 -151343	2	20.2±7.7	3.4-3.8	272-291
150930	133031 -150355	6	26.1±13.4	2.1-3.6	192-303
151001	100906 -152231	9	28.8±11.5	1.5-4.7	276-295
151002	141403 -143033	7	36.3±15.6	3.8-4.9	262-294
151005*	155251 -155806	1	32.3	3.8	173
151006	121009 -160214	16	20.7±8.6	2.6-6.2	256-324
151007	134310 -153441	35	25.9±11.7	3.0-5.5	264-317
Average±SD	-	**(total 80)**	**26.1±11.4 (44%)**	-	-
Median	-	**(total 80)**	**24.7**	-	-

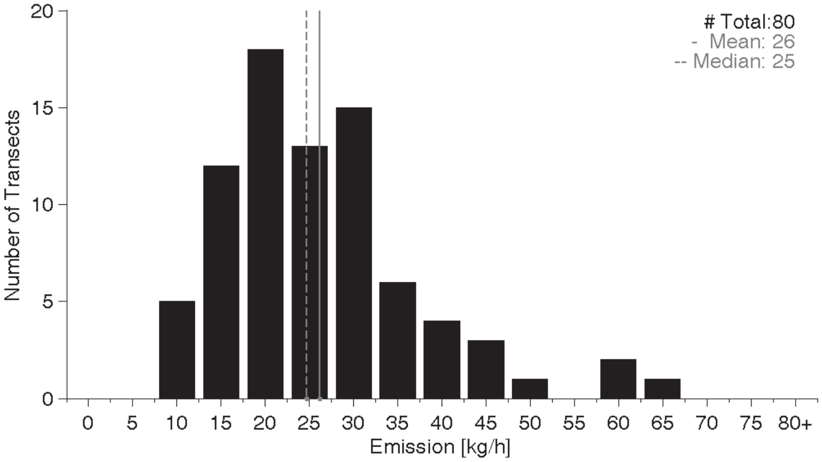

Figure 56. Histogram of all SOF measurements at reservoir 502 during the SCAQMD survey 2015. The median (24.7 kg/h) and average (26.5 kg/h) values are indicated as dashed and solid gray lines.

Figure 57 shows SOF measurements of VOCs in the crude oil part of the tank farm. Here the height of the column corresponds to the measured vertical column of alkanes (non-methane) and the arrow shows the wind direction (south-east in this case). The large columns downwind of the second tank from the left in the middle row (here referred to as tank 16) suggest the presence of a distinct leak at this tank. During the campaign, this tank showed large emissions during several days, see Table 40, and large variability range suggesting a dependence on operations. The refinery personnel and SCAQMD were notified of this finding and service personnel carried out an inspection showing that one of the valves was leaking. When the tank was filled with new product and the floating roof accordingly moved upwards, the displacement of VOC contaminated air between the internal floating roof and the external dome generated the large emissions through the malfunctioning vent gauge. The measurements illustrated in this figure were compared against DIAL measurements with very good agreement (see separate report by Pikelnaya et. al. (2016)).

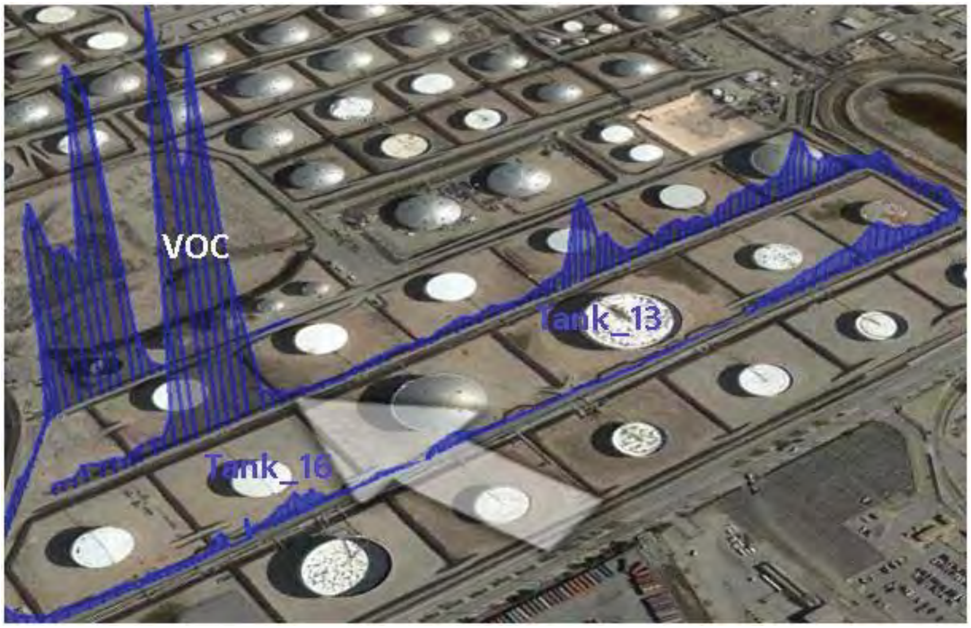

Figure 57. Measurements of VOCs with SOF in the crude oil part of the tank farm. Here the height of the blue columns corresponds to the amount of alkanes present in the column measured by SOF and the white arrow corresponds to the wind direction (south-east in this case).

Figure 57 also shows Tank_13 (two tanks right of tank 16 in the middle row) being a source of emissions – compare the clean upwind columns to the clear VOC plume downwind of tank 13 and 16 respectively. Table 40 and Table 41 include daily average emission data and the total average and median values from SOF measurements at tank 16 and tank 13 respectively.

Table 40. Summary of SOF alkane measurements for tank 16. *Single measurement.† Non-typical event with malfunctioning valve at tank roof on the 5 October 2015.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150928*	141036 -141127	1	28.0	4.9	294
150930*	135622 -135646	1	0.33	2.8	188
151001	133101 -141133	5	73.6±29.9	3.3-4.9	147-194
151002	123616 -133233	5	29.5±12.9	3.1-5.1	147-194
151005†	113438 -155044	42	326.6±151.4	3.1-6.2	144-204
151006*	151220 -151258	1	2.1	4.8	283
Average±SD	All days	(total 55)	259±134 (52%)	-	-
Median	All days	(total 55)	222	-	-
Average±SD	**Excluding 151005**	**(total 13)**	**42.0±33.6 (80%)**	**-**	**-**
Median	**Excluding 151005**	**(total 13)**	**41.5**	**-**	**-**

Table 41. Summary of SOF alkane measurements for tank 13. * Single measurement

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150928*	141153 -141257	1	1.1	4.9	292
150930*	135449 -135542	1	12.9	12.9	194
151001	132928 -141655	5	22.9±10.5	3.4-4.9	154-190
151002	112139 -133118	11	16.1±8.5	2.1-5.1	139-194
151005	123245 -160628	14	27.5±12.0	4.0-7.7	166-205
Average±SD	-	**(total 32)**	**21.6±10.4 (48%)**	-	-
Median	-	**(total 32)**	**18.1**	-	-

Figure 58 and Figure 59 show the frequency distribution of the SOF alkane measurements at tank 13 and tank 16 respectively, for the week of on site measurements. As seen in the distributions, tank 16 emissions show a large spread, almost as two source distributions overlay with a secondary maximum and tail of observations above 250 kg/h corresponding to the atypical event with a malfunctioning valve at the tank roof during filling on October 5 as discussed previously. Tank 13 in Figure 58 showed a more typical tank emission distribution.

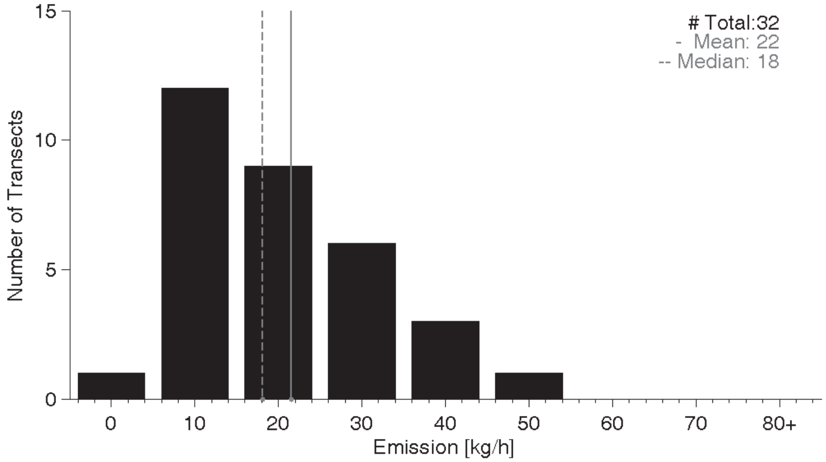

Figure 58. Histogram of all SOF measurements at Tank 13 during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

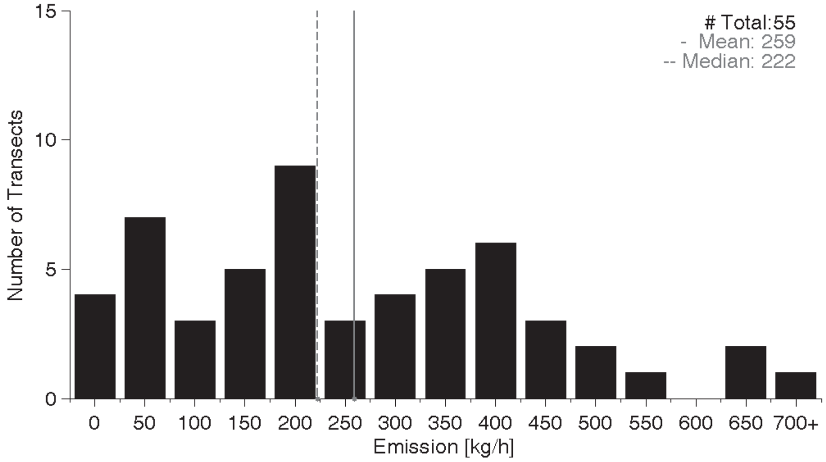

Figure 59. Histogram of all SOF measurements at Tank 16 during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

The ground concentration of aromatic BTEX and alkanes across the refinery tank farm are shown in Figure 60 and Figure 61 respectively. The ratio of aromatics to alkanes was measured using MWDOAS and MeFTIR while driving through the tank park. Measurements were specifically concentrated on tanks 13, 16 and 502.

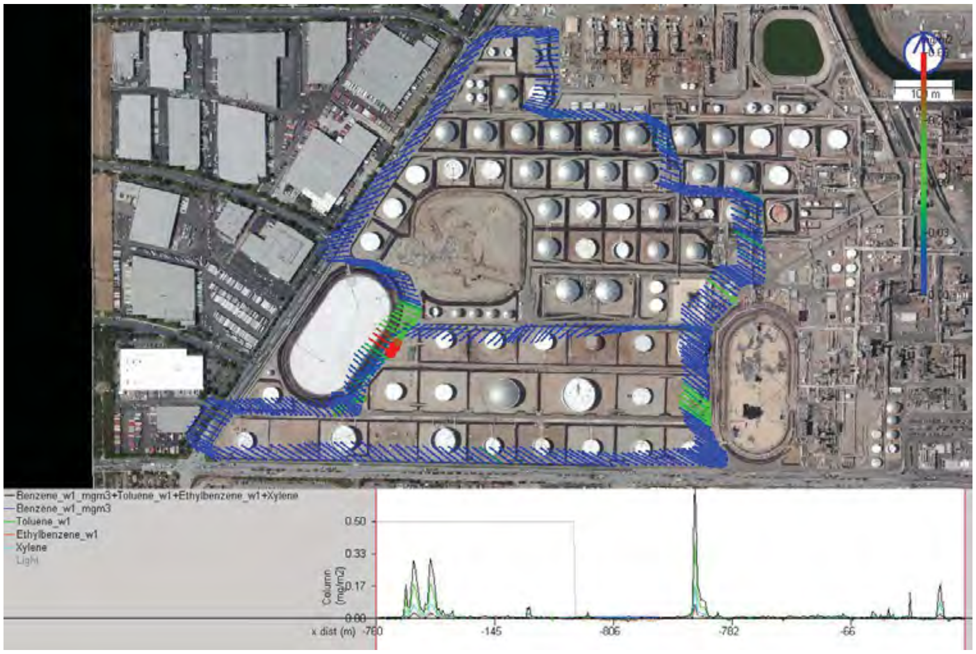

Figure 60. Aromatic VOC concentrations in mg/m^3 across the tank farm measured using MWDOAS. Bars are pointing towards the wind, hence in the direction of the source. North is upwards in the figure.

Figure 61. Alkane concentrations in mg/m^3 measured using MeFTIR across the tank farm. Bars are pointing towards the wind, hence in the direction of the source. North is upwards in the figure.

5.3 Further Leak search and Leak Detection

On site measurements with the real time geo-tagged result capabilities of the SOF + MeFTIR + MWDOAS techniques, as described in the previous section, are in a way a continuous leak search task. By driving the mobile lab on accessible roads on the upwind and downwind side of the different sources it's possible to rather quickly (within hours) build a concentration map of a whole tank farm with located hot spots of elevated concentrations/emissions. Repeating this several times makes it possible to judge whether an observed emission pattern seems recurring or just being an intermittent release (for the time frame of the measurements). Repeated measurements at a site also build confidence in what emission levels that are normally observed, and when an aberration is observed and should be alarmed to the operations department.

During the 8 days of on site measurements between 28 September and 7 October, two major atypical emission events were identified, and reported to the operations and SCAQMD representatives. Tank_16, has already been discussed previously where a malfunctioning vent at the external roof of the crude tank inferred atypical high concentration levels and emission rates downwind of the tank 5 October. This was observed both by the MeFTIR and SOF measurements, and an inspection by operations verified the vent being stuck open.

Another atypical leak was found in the southern part of the so called *Tanks_Northeast* area, see Figure 52. Passing on the road south of the area, elevated alkane concentrations was observed with about 70,000 ppb in contrast to ten to hundred ppb normally observed downwind the various tanks. The leak was discovered late in the day, short before working permits ended as well as the sun setting to low for continued work. SOF and MeFTIR measurements pointed out an area next to the ground in the vicinity of several pipe lines. A gas camera was brought in to visualize that gas was indeed emerging from the soil beneath the pipes. Tubing was also attached to the MeFTIR instrumentation for “walk around” leak search with the tubing sampling air from locations around the pipe lines and at the ground. Figure 62 shows a SOF measurement from the particular site. Six SOF measurements between 4 PM and 5 PM on 30 September estimated the leak to be on average 31 kg/h.

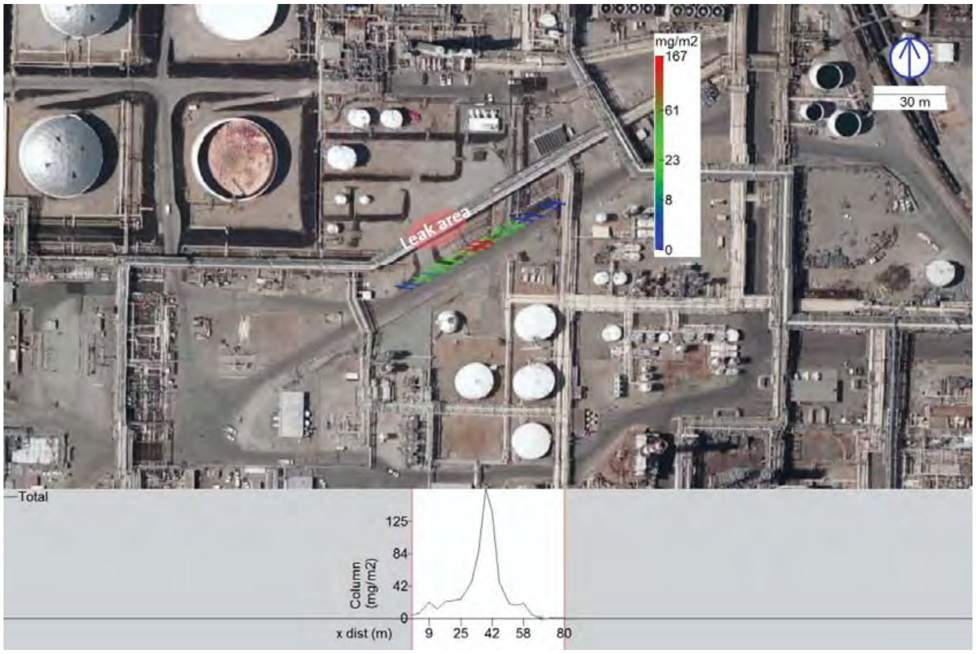

Figure 62. SOF measurement observing an atypical leak from the soil ground near a set of pipe lines. The leak area is indicated by a light-red area. The colored lines show observed alkane column (mg/m^2) with the lines pointing towards the wind and potential source. The graph beneath the picture shows integrated alkane column along the transect through the plume with traversed distance in meters.

Personnel from operations and SCAQMD were notified about the findings at once, and the source of emissions was further investigated by the refinery staff who immediately took appropriate actions. A leak, the size of a pinhole, was found in an alkane pipeline buried 30 cm below the ground. After the leak was repaired additional SOF and MeFTIR measurements were conducted to verify that the issue was resolved.

This case illustrates how mobile optical measurements and gas imaging information can be used to identify unknown leaks, and that immediate call upon and guidance of repair efforts can safely mitigate and suppress the risk of any further, potentially serious, complications. In general during the onsite measurements, working together with the experienced operations staff provided valuable input for interpreting the observed emissions and potential deviations from normal operations.

6 Discussion and Conclusion

Emission measurements of VOCs (alkanes, methane, and BTEX), SO_2 and NO_2 from six major refineries in the SCAB have been carried out by FluxSense Inc. using several state-of-the-art ORS techniques during a two and a half month campaign. The six refineries have a combined capacity of more than 900,000 barrels of crude oil per day and constitute an important stationary source of VOC emissions in Southern California.

For each refinery we compared the measured emission rates to the corresponding emission inventory values obtained by means of the US EPA AP-42 model (US-EPA 2013). The reported annual emissions have been divided by 12 to obtain average monthly emission rates, which were then compared to measured monthly median emissions obtained in this study. Thus, the comparisons are representative for September 2015 (the time-period when most of the measurements were performed).

An analysis of measured monthly emissions from each refinery normalized by the corresponding crude oil capacity is presented in Table 42. The overall alkane emission factor for all refineries in the SCAB (% of total emitted mass of alkanes to total capacity mass of crude oil) is 0.024%, ranging between 0.017 % and 0.045 % for the different facilities. This average emission factor is within 0.03 % and 0.1 %, a range observed from previous measurements conduced at well-run refineries in Europe (Kihlman *et al.* 2005; Mellqvist *et al.* 2009; INERIS 2010; Samuelsson *et al.* 2011). Thus, according to this data, the refineries in the SCAB are characterized by relatively low emissions compared to their capacity.

Table 42. Capacity normalized VOC (Alkanes+BTEX) emission factors * for the 2015 SCAQMD survey.

Measured Refineries 2015 Survey	**Crude Oil Capacity***		**Measured Monthly Emission**	**Emission Factor**
			Alkanes + BTEX	Alkanes + BTEX
	[bbl/day]	Tons^1/mo	Tons^1/mo	[%]
Refinery A	257300	1086215	214	0.020%
Refinery B	139000**	586801**	59	0.045%
Refinery C			205	
Refinery D	104500	441156	132	0.030%
Refinery E	269000	1135608	201	0.018%
Refinery F	149500	631128	109	0.017%
Sum of all	**919300**	**3880908**	**919**	**0.024%**

*Crude capacity data is obtained from the 2016 California Energy Commission report. The overall emission factor is based on the sum of measured emissions for all refineries relative to the total capacity.

**Crude capacity for Refinery B and Refinery C are reported together since Refinery B processes the crude oil and Refinery C upgrades intermediate products to finished products.

[1] Metric Tons

A comparison between the measured monthly emissions and the average monthly emissions from the inventories (i.e., annual inventory emission divided by 12) is presented in Table 43. For all major refineries in the SCAB, the ratio between measured and reported emissions for September 2015 (denoted as D in table 43) is 6.2 for VOCs, 1.5 for SO_2, and 0.83 for NO_x. For benzene this ratio is ~34, although the total measured benzene emissions were relatively small. Note that the inventories report NO_x (NO_2+NO), while only NO_2 is measured by the SkyDOAS. However, previous studies have shown that NO_2 typically constitutes 75 % or more of the NO_x found in the air around refineries (Rivera *et al.* 2010).

Table 43. Reported (*Rep*) average monthly emissions [metric tons per month] from the available inventory for the six SCAB refineries and measured emissions (*Meas*) for the 2015 SCAQMD survey. *D* denotes the ratio between measured and reported emissions (Meas/Rep). The overall discrepancy values (last row) are calculated from the total sum of reported and measured emissions, respectively. The comparisons are representative for September 2015.

Refineries	*Total VOC*			*SOx*			*NOx* [1]			*Benzene*		
2015 Survey	**Rep.**	**Meas.**	**D**	**Rep.**	**Meas.**	**D**	**Rep.**	**Meas.**	**D**	**Rep.**	**Meas.**	**D**
	Tot VOC	*Alk+ BTEX*		*SOx*	*SO_2*		*NOx*	*NO_2*				
	tons /mo	tons /mo	[]	tons /mo	tons /mo	[]	tons /mo	tons /mo	[]	tons /mo	tons /mo	[]
Refinery A	33	214	6.4	38	46	1.2	50	48	1.0	0.06	2.5	43
Refinery B	7	59	8.3	26	39	1.5	30	23	0.8	0.03	0.8	33
Refinery C	17	205	12	10	27	2.7	37	42	1.1	0.03	6.0	202
Refinery D	12	132	11	7	12	1.7	23	25	1.1	0.03	1.2	39
Refinery E	37	201	5.4	23	39	1.7	57	46	0.8	0.05	2.0	38
Refinery F	40	109	2.7	25	27	1.1	39	13	0.3	0.19	0.6	3.2
All refineries	**148**	**919**	**6.2**	**129**	**190**	**1.5**	**237**	**197**	**0.8**	**0.38**	**13**	**34**

[1] Nitrogen oxides (NO_x) are reported in inventories while only the NO_2 fraction was measured by SkyDOAS.

The comparison of measured emissions with annual inventory values presents a number of challenges. Firstly, it is important to know whether the studied refineries operated under typical conditions during the measurement campaign. Since operational data from the facilities is not available for this project, we estimated the average monthly emission rate at each site by dividing the reported annual emission inventory value for each facility by 12.

Secondly, it has to be established that a sufficient number of measurements have been conducted during the measurement period to eliminate the risk of disproportional influence from intermittent emissions due to tank cleaning, maintenance, flaring, etc. To address this point the frequency distributions of the measured emission (as shown in Figure 15) have been analyzed and taken into account in our calculations. As a result median measured emissions were used for comparison with inventories instead of average measured emissions, therefore reducing the sensitivity to outliers.

Thirdly, the effects of differences in meteorological conditions between September 2015 and the entire year need to be considered to establish how representative the emissions measured during the study were to the entire year. In our experience, tank emissions contribute approximately 2/3 of the total refinery emissions (Kihlman 2005). At the same time, emissions from tanks are also more affected by environmental parameters such as wind, temperature and solar insolation, than emissions from process units. Therefore, a sensitivity study for two types of crude oil tanks, external floating roof tank (EFRT) and internal floating roof tank (IFRT), utilizing the formulas in the AP-42 model was conducted. A very similar approach has been previously applied to evaluate seasonal variations of refinery emissions (Johansson *et al.* 2014b). During the measurement campaign, the average maximum daytime temperature was 5.4 °C higher than the 2015 average annual temperature of 19.6 °C (data from weatherunderground.com for Torrance Airport), while the 2015 monthly and annual average wind speeds were both 2.2 m/s (data from weatherunderground.com for Long Beach Airport). In addition, the monthly average solar radiation was 22 W/m^2 higher than the annual average of 226 W/m^2 (data from Torrance airport from the National Solar Radiation Database). According to AP-42 model, these differences in meteorology combined resulted in 11 % and 29 % higher modeled emissions for September 2015 than for the annual average for the IFRT and EFRT, respectively. These values are within the uncertainty of the SOF method.

Additionally, no dependency of measured emissions on temperature and wind speed was observed. Figure 63 illustrates that there was no obvious correlation between measured alkane emissions and wind speed or temperature at Refinery A. Therefore, the observed discrepancies between measured emissions and reported inventories (based on the AP-42 standard (US-EPA 2013)) are considerably higher than what can be explained by measurement uncertainties or short-term sampling alone.

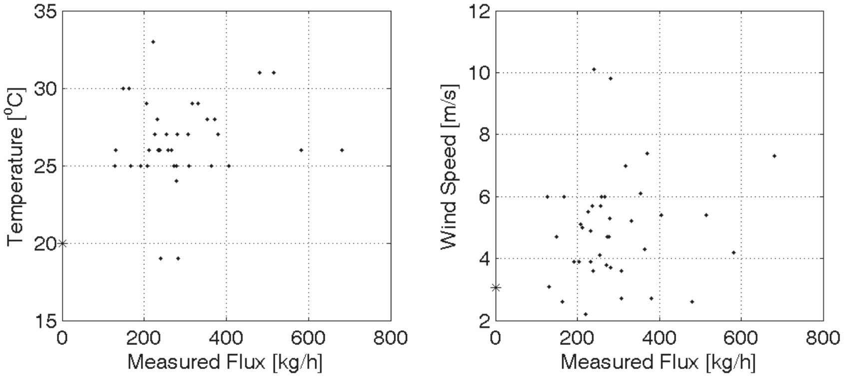

Figure 63. SOF emission data from Refinery A plotted against the corresponding local temperature and wind speed values (left and right plots, respectively). *Annual average values from the meteorological station at Torrance Airport (KTOA) 2015 [www.weatherunderground.com].

Refineries and tank farms are complex environments with a large number of installations and numerous potential emission sources (e.g. tank seals, valves, gauges, flares, vapor recovery units, etc.). Many of these components can show degrading performance over time, and to accurately account for the impact of non-ideal performance in emissions inventory reporting is, we believe, an impossible task. Nevertheless, EPA's AP-42 system provides valuable insights for a specific facility on the production and abatement techniques applied, and on what emission level the site could reach given ideal performance of all installations. Comparing measured emissions to ideal performance levels established by AP-42 could provide a basis for benchmarking of different refineries or sites.

OUTLOOK

Studies conducted in the SCAB, the Bay Area, Texas, and other places worldwide, show that field measurements provide a reliable way to determine actual emissions of VOCs and other pollutants from refineries and various industrial sites. Accurate estimates of VOC and other pollutant emissions from industrial sources are crucial for improving air quality models, to guide air pollution mitigation strategies, promote successful compliance strategies, and reduce exposure for nearby communities.

In our experience, the observed difference in fugitive VOC emissions between measured and inventory estimates is a general issue for the petroleum industry worldwide. We believe that a possible path forward could be to conduct monitoring in parallel with continued AP 42 based reporting, and to use the measurements to guide and verify the efficiency of the emission reduction efforts at the industrial sites.

Longer-term ORS studies spanning over different seasons could be conducted in order to alleviate concerns stemming from comparison of emissions measured over limited-time to annual emissions reported through the inventories. Additionally, future studies could combine ORS measurements and site-specific emission modeling performed for inventory calculations. A better dialog between scientists conducting the measurements and the facility operators could also be crucial to improve our understanding of how site activities may affect measured emissions.

Traditional Leak Detection and Repair (LDAR) is an important practice to control and limit unplanned VOC emissions from refineries and to identify potential leak sources. The ORS techniques used in this study have demonstrated their ability to quickly quantify and map refinery emissions and to identify potential air pollution sources within a facility. Using real time measurements, refinery personnel and air quality regulators can enhance LDAR programs by prioritizing LDAR activities. Addressing the most concerning issues first is important to reduce occupational risks for refinery workers, avoid public hazard exposures, and limit the economic losses due to unplanned evaporation of refinery products.

A continued path towards improved air quality involves a good understanding of current emission levels and sources. Repeated and systematic emission measurements will be an important tool for benchmarking industry’s environmental performance as well as for sustaining and verifying efficient emission improvement plans, ultimately resulting in cleaner air and a better environment.

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9 Appendix A: Quality Assessments

Quality checks and measures are performed at several levels in order as indicated in Figure 2 and given below. On arrival, FluxSense personnel will power up the equipment, check operating parameters, and test the instruments. The purpose is to run operational checks to catch problems prior to field deployment and repair all malfunctioning equipment.

Quality Checks and Routines

PRIOR TO MEASUREMENTS:

Vehicle:
1. Checking vehicle status according to safety and performance
2. Mount warning lights and signs
3. Make sure that battery pack is fully charged
4. Make sure any loose items are stowed away securely

Instruments:
1. Turn on instruments and make sure that detectors are properly cooled
2. Optimize signals by optical alignment (SOF, SkyDOAS, MWDOAS, MEFTIR)
3. Cleaning mirrors and optics if necessary (SOF, SkyDOAS, MWDOAS)
4. Rotational alignment (SOF). Tolerance: ±2 mg/m^2 in any direction
5. Checking spectral resolution and response (SOF, SkyDOAS, MWDOAS, MEFTIR)
6. Take calibration spectra (SkyDOAS, MWDOAS)

GPS:
1. Checking that GPS information is available and reasonable
2. Check time synchronization of all instruments and computers

Wind:
1. Checking that the time difference of logger and computer and synchronize if necessary. Tolerance 1s.
2. Select an open flat surface at a representative location for the measurements
3. Erecting the wind mast vertically and secure it firmly
4. Directing sensor correctly (toward magnetic north) using a compass. Tolerance: ±5 deg
5. Put the LIDAR truck on level ground.
6. Check that wind information is available and reasonable.

DURING MEASUREMENTS:

1. Drive slowly and steadily to reduce vibration noise. Around 20-30 km/h for SOF/SkyDOAS and around 10-20 km/h for MWDOAS/MEFTIR (dependent on distance to source and the spatial resolution required)
2. Avoid shadows as far as possible during solar measurements (SOF, SkyDOAS).
3. Try boxing the facilities when possible or make relevant upwind/background measurements continuously.
4. Keep track of wind directions and measured columns/concentrations so that the entire plume from a facility is captured.
5. Always try to start new measurements outside the plume.

6. Aim for 3-5 transects with acceptable quality (See section on data analysis below) per facility and day and at least 1 upwind measurement (if not boxing).
7. Take notes and photos on interesting findings and events
8. Check the wind meter on a regular basis to make sure that it is operational

AFTER MEASUREMENTS:

1. Turn off instruments and download gas measurement data to external hard drive
2. Download data from wind mast logger and save to external hard drive
3. Download data from wind LIDAR and save to external hard drive
4. Dismount wind mast if not in safe location
5. Turn off wind LIDAR and store securely over night
6. Store Airmar data and measurement notes on external hard drive
7. Update survey documents and Google Earth maps accordingly
8. Charge vehicle, LIDAR and data logger batteries over night
9. Make sure that instruments are well protected inside the vehicle from rain/moisture

DATA ANALYSIS:

1. Discard transects with noise levels above the detection limits (see Table 1)
2. Discard transects with significant baseline variations
3. Discard transects with significant data gaps in the plume
4. Discard transects with extended vehicle stops
5. If incoming plumes are of significant magnitude compared to the outgoing plume (SOF and SkyDOAS) treat transects with extra care and require further statistics
6. Discard transects with average wind speeds below 1.5 m/s (SOF and SkyDOAS)
7. Discard transects with highly varying wind directions

Data Analysis, Interpretation, and Management

DATA REPORTING REQUIREMENTS:

A Draft and Final Report will be delivered to SCAQMD electronically (i.e., via file transfer protocol (FTP) or e-mail) in MS-WORD format no later than the established deliverable due date. After post-processing, validation and analysis, the data will be delivered to SCAQMD at the time of the final report.

DATA VALIDATION PROCEDURES:

Project personnel will maintain records that include sufficient information to reconstruct each final reported measurement from the variables originally gathered in the measurement process. This includes, but is not limited to, information (raw data, electronic files, and/or hard copy printouts) related to sampler calibration, sample collection, measurement instrument calibration, quality control checks of sampling or measurement equipment, "as collected" or “raw” measurement values, an audit trail for any modifications made to the "as collected" or “raw” measurement values, and traceability documentation for reference standards.

Difficulties encountered during sampling or analysis, such as interference between adjacent plumes, large upwind fluxes or highly variable wind fields will be documented in narratives that clearly indicate the affected measurements. All electronic versions of data sets should reflect the limitations associated with individual measurement values.

The data collected in the project will be made available in electronic format at the time of the final report. For all data we will produce ASCII tables with the geo-positioning and time. In addition kml files will be produced for the most useful data for Google Earth viewing.

To ensure high quality data an internal audit procedure of the data is carried out. In the project, gas columns obtained from SOF and mobile DOAS measurements are used to calculate gas fluxes through a procedure which includes manual checking of each measurement transect and manual choices of baselines etc (see previous section). In the audit procedure the completed transects will be reviewed by an independent experienced SOF-operator that was not involved in the actual data evaluation. At least one of the persons involved in the data processing must have been in the FluxSense mobile lab while the actual measurements were made

STATISTICAL PROCEDURES:

The final data will be presented as daily means and standard deviations for each facility together with histograms showing all individual measurements. The variability of the result will be a combination of measurement uncertainties, wind variability and actual variability in the emissions from the facility.

Extreme outliers are generally not excluded, unless non-typical conditions/operations at the facility are reported. In this case, the outliers will be reported separately so that these conditions/operations can be followed up.

More samples will provide a closer estimate of the actual emissions. In reality, the number of measurement will be a trade-off between acceptable statistics and available time and conditions for making the measurement and time sharing between other measurements. The aim is 3-5 transects with acceptable quality per facility and day during at least four days. If boxing is not performed, at least 1 representative upwind measurement per facility should be made.

DATA SUMMARY AND ANALYSIS:

The data will be post processed with the spectral retrieval programs QESOF (SOF) and QDOAS (mobile DOAS). This will give time series of column concentrations, positions and solar angles stored in ASCII-files. These files are loaded into custom software, SOF-Report, used to calculate fluxes.

Wind LIDAR data will be processed using the output from Leosphere WindCube system. Data files are saved as ASCII-files.

The weather mast will be connected to a real time data logger and will be periodically downloaded to a computer. The data logger samples the input voltage of each instrument at a set time interval, digitizes it, and stores the data sequentially into a record.

ASCII tables with time stamped geo positioned data will be produced. In addition kml files will be produced for viewing the data in Google Earth. The data will also be retained for a minimum of 5 years at FluxSense.

DATA STORAGE REQUIREMENTS:

The spectra from the spectroscopic measurements (SOF, SkyDOAS, MEFTIR, MWDOAS) are directly saved to the hard drive of the computer used to operate these instruments. At the end of each measurement day, all new such data will be copied to an external hard drive by the operator. Approximately 1 GB of data will be produced per measurements day.

10 Appendix B: Wind Plots

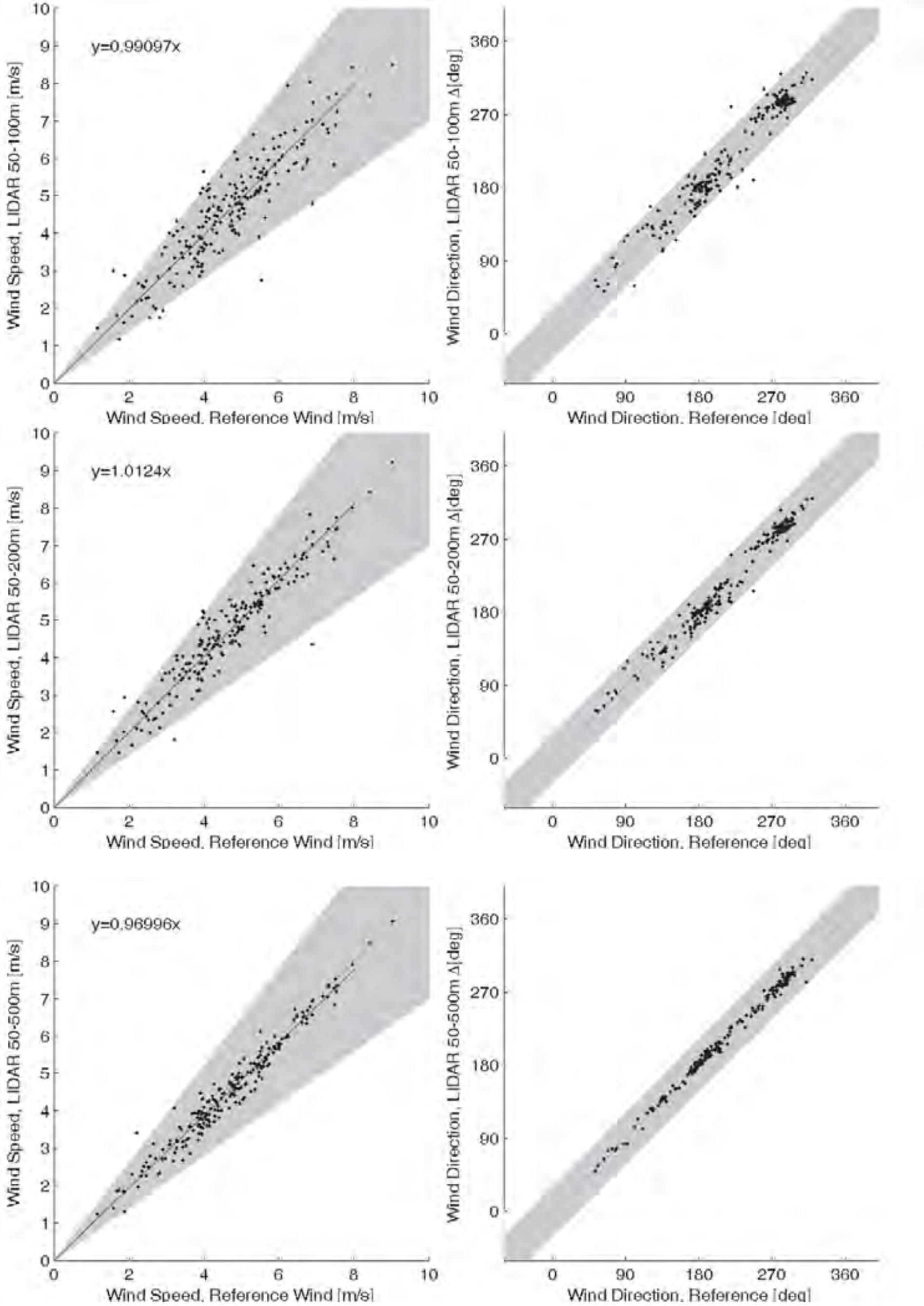


Figure 64. Wind LIDAR data for different altitude ranges versus the reference LIDAR wind (50-400m) during the calibration period 2-6 October 2016 at LIDAR site L1 (10 min average from 10AM to 5PM) . The shaded areas indicate ±30% relative deviation from reference wind speed (left panels) and ±30° deviation from reference wind direction (right panels). Fitted least squares are shown as solid lines.

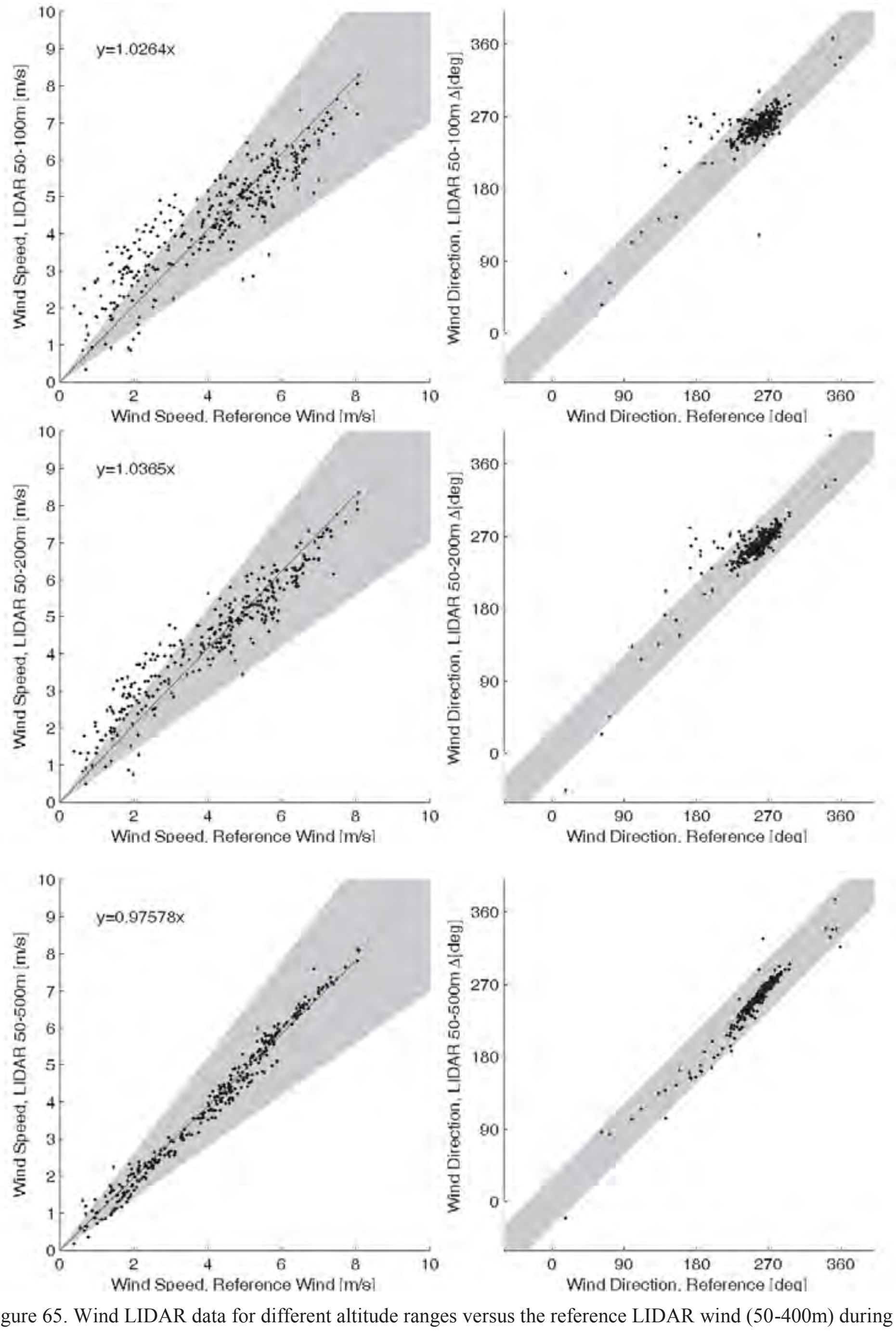


Figure 65. Wind LIDAR data for different altitude ranges versus the reference LIDAR wind (50-400m) during the calibration period 9-16 October 2016 at LIDAR site L4 (10 min average from 10AM to 5PM). The shaded areas indicate ±30% relative deviation from reference wind speed (left panels) and ±30° deviation from reference wind direction (right panels). Fitted least squares are shown as solid lines.

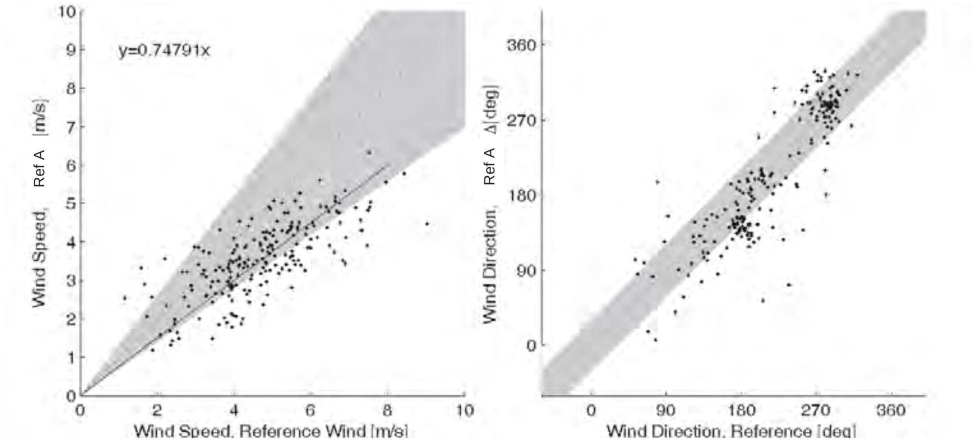


Figure 66. Refinery A´s 10m wind mast data versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM) during the calibration period 2-6 October 2016 at LIDAR site L1. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

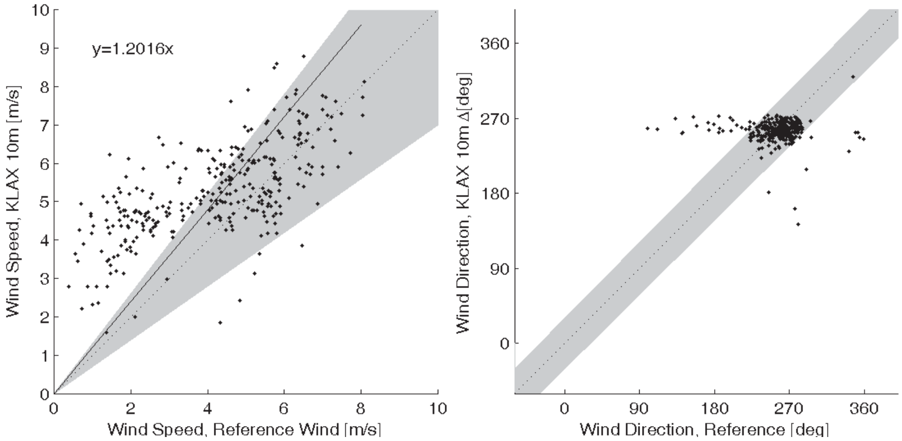


Figure 67. ASOS Met station at Los Angeles International Airport-KLAX versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM)during the calibration period 9-16 October 2016 at LIDAR site L3. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

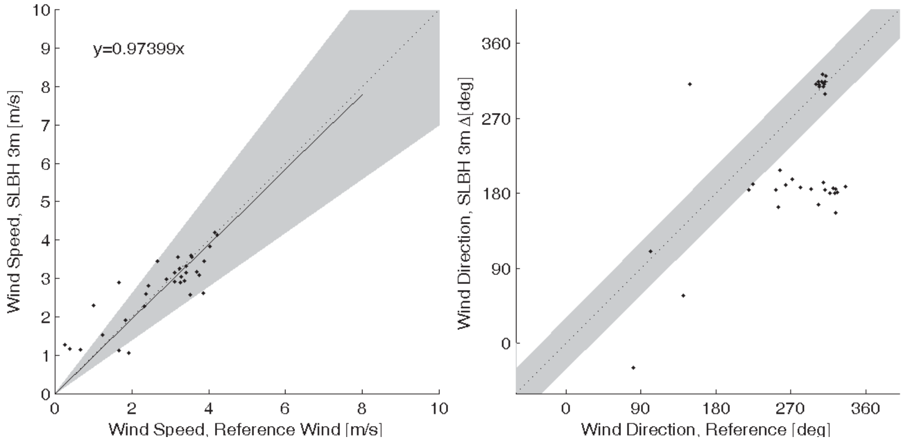


Figure 68. SCAQMD Met station at South Long Beach (SLBH) versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM)during the calibration 18 October 2016 at LIDAR site L2. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

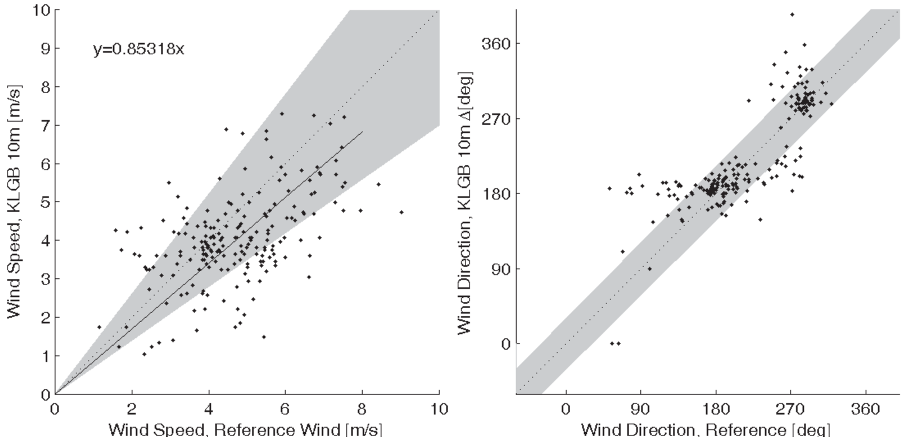


Figure 69. ASOS Met station at Long Beach Airport (KLGB) versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM)during the calibration period 2-6 October 2016 at LIDAR site L1. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

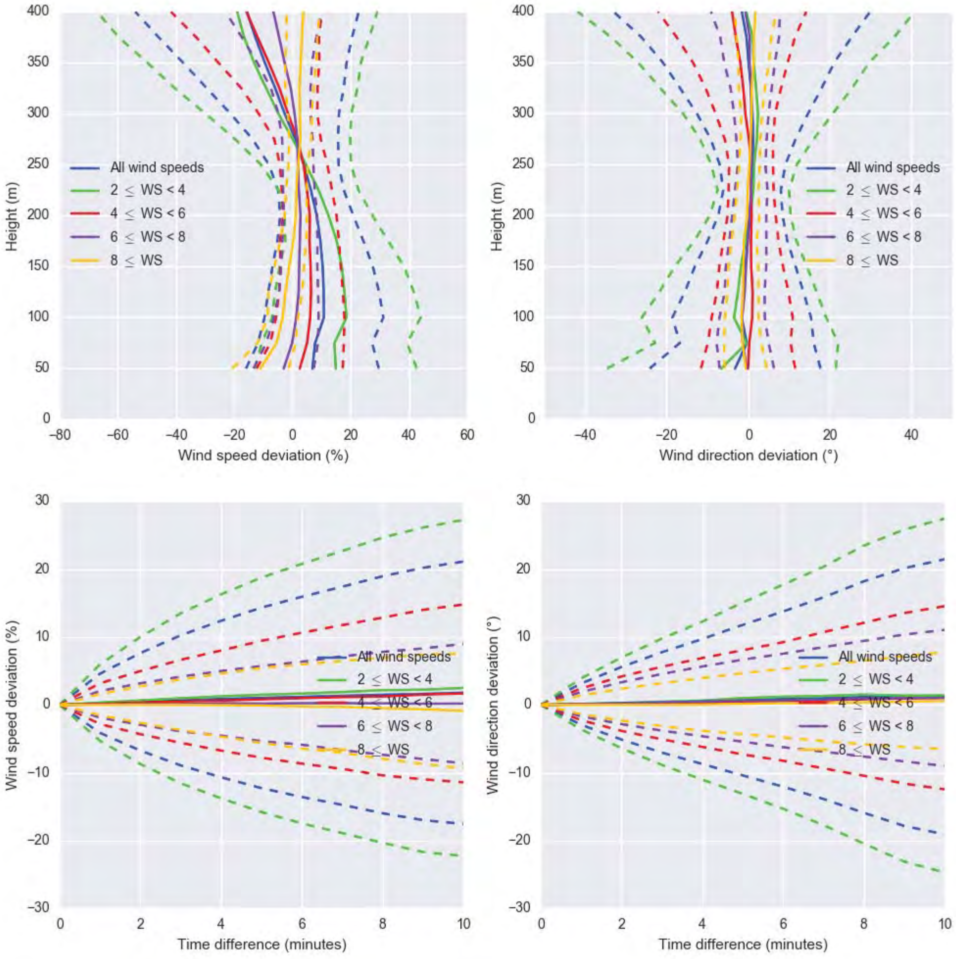


Figure 70. Wind LIDAR 10-min data for the entire SCAQMD survey 2015. Average (solid lines) and 1σ deviations (dashed lines). Top row panels show altitude information and the lower row shows time dependence. Different colors represent different wind speed ranges.

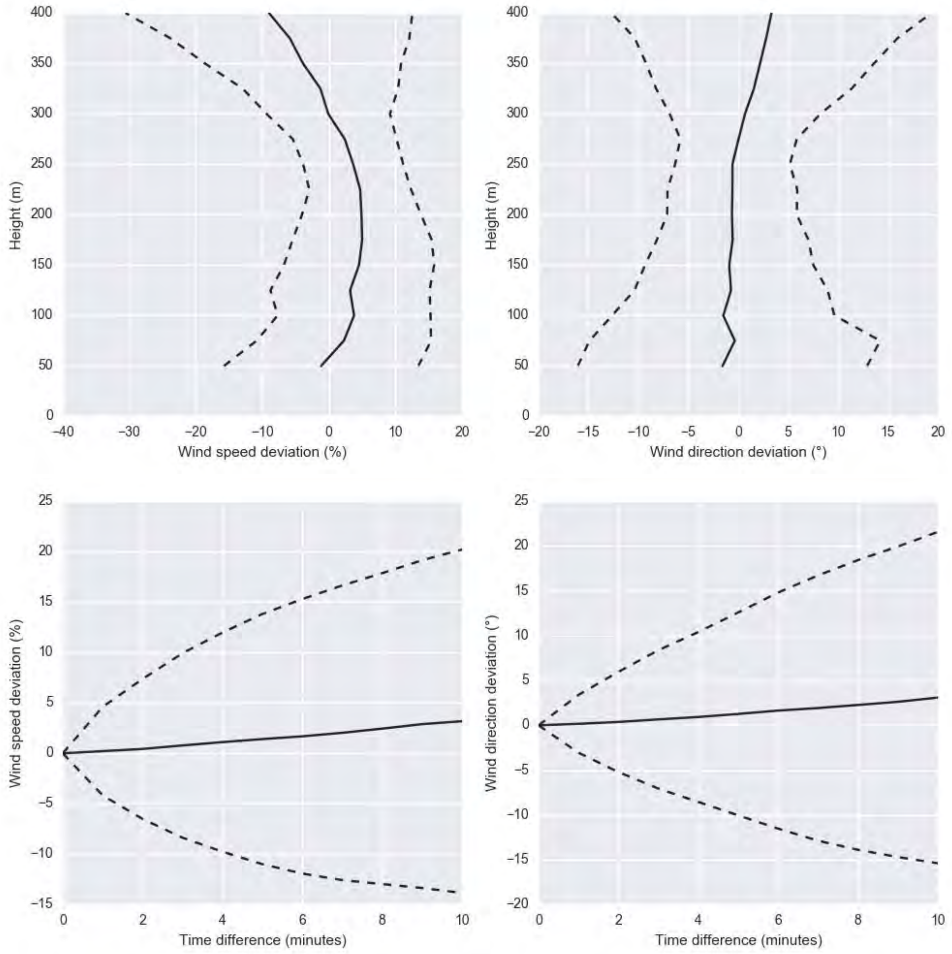


Figure 71. Wind LIDAR 10-min data at L1. Wind data averages (solid lines) and 1σ deviations (dashed lines) for the calibration period (9-16 Oct) during the SCAQMD survey 2015. Top row panels show altitude information and the lower row shows time dependence.

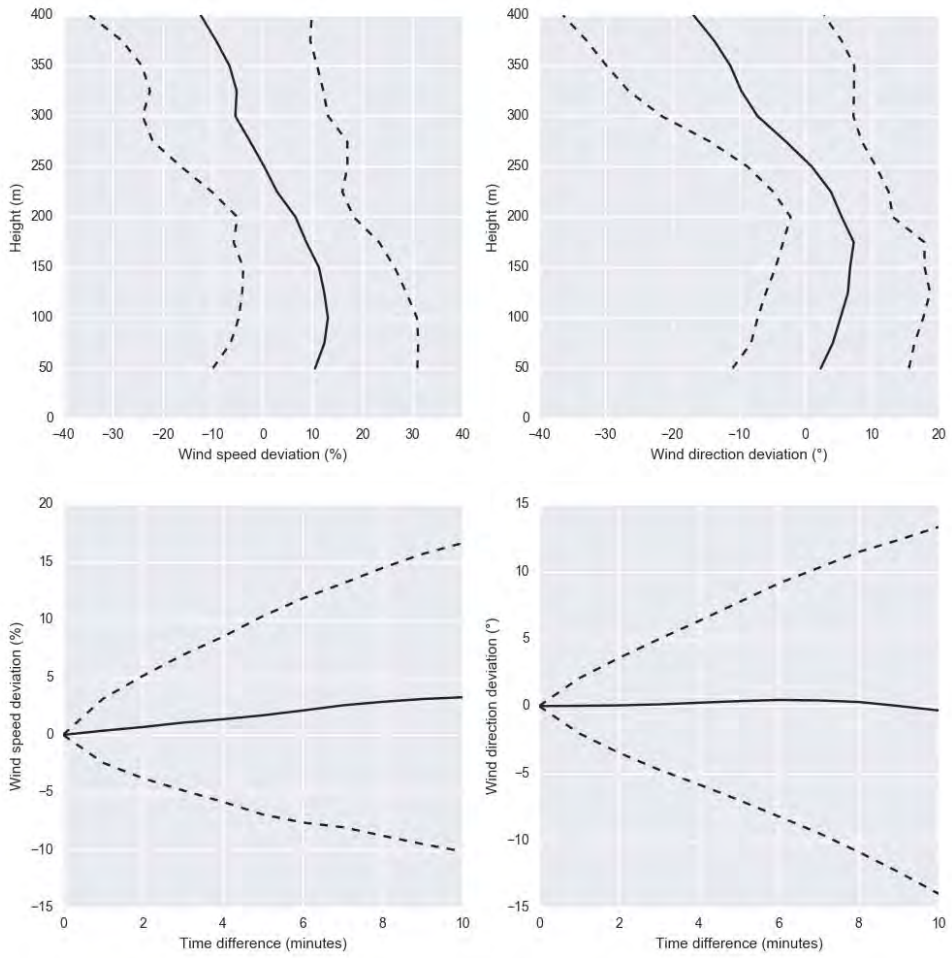
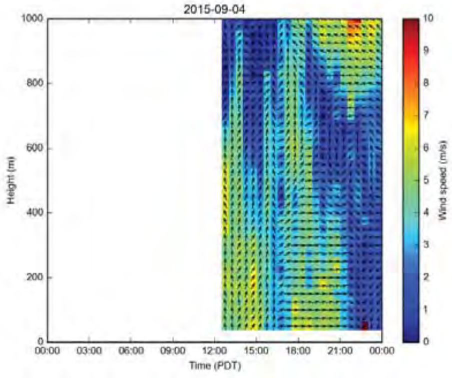


Figure 72. Wind LIDAR 10-min data at L4. Wind data averages (solid lines) and 1σ deviations (dashed lines) for the calibration period (2-6 Oct) during the SCAQMD survey 2015. Top row panels show altitude information and the lower row shows time dependence.

Figure 73. Wind LIDAR data (30 minute averages) from 50 to 1000 m for all measurement daysin this project. Arrows indicate wind direction and color wind speed (0-10 m/s). White gaps when no data available due to limited back scatter signal or other reason. **All panels below**.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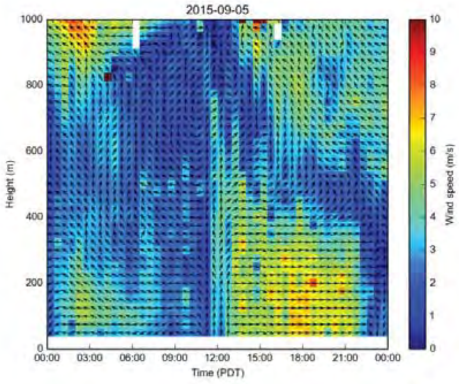
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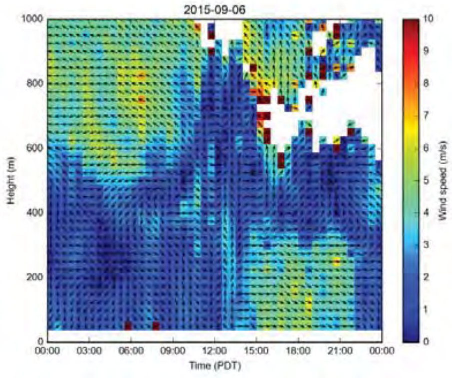
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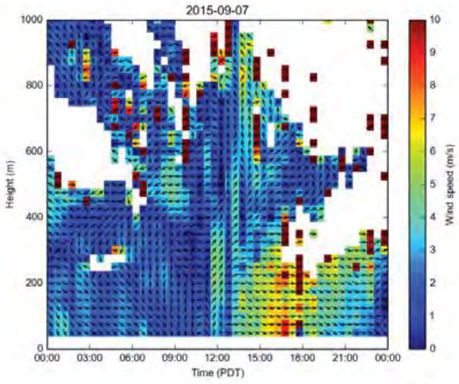
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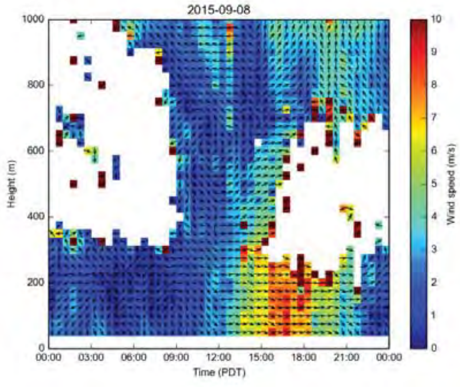
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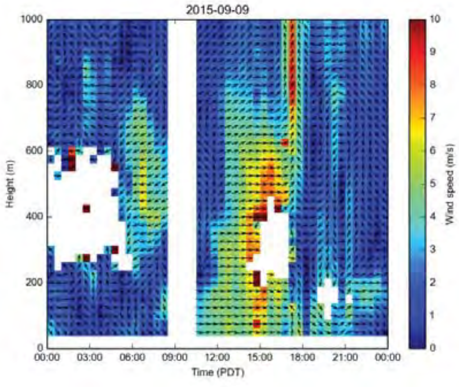
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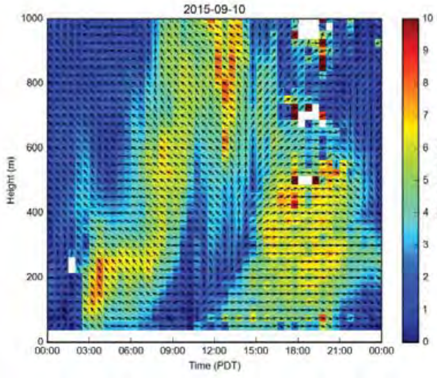
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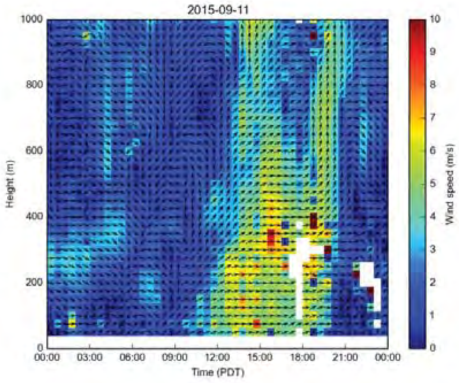
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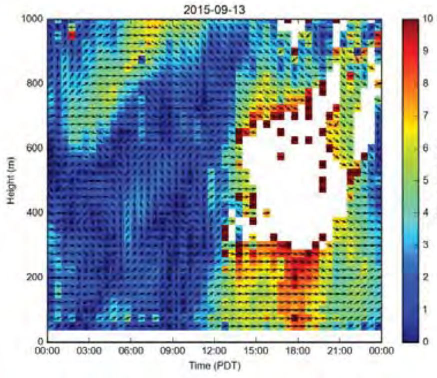
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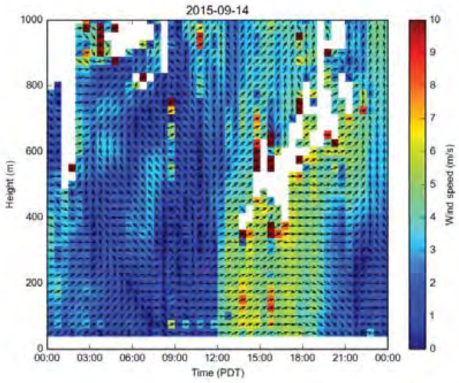
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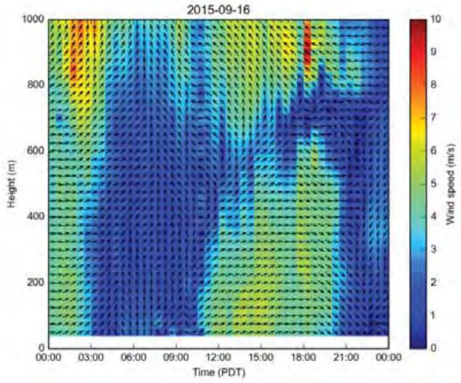
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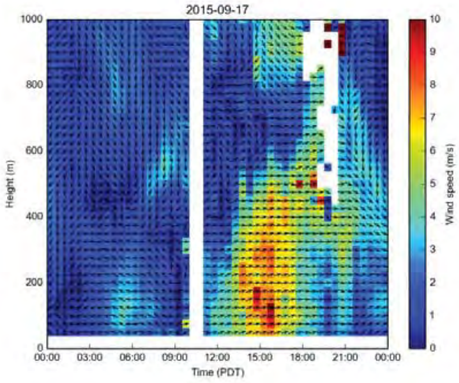
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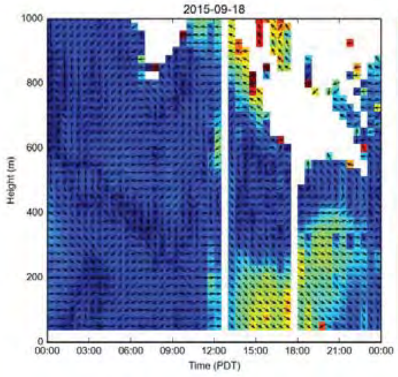
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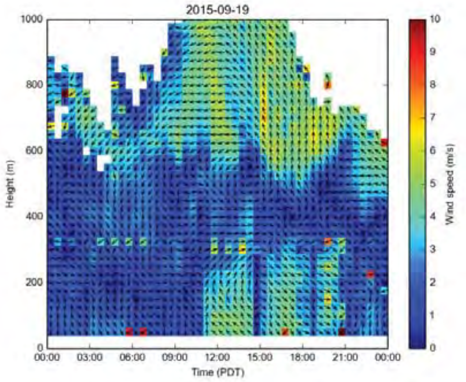
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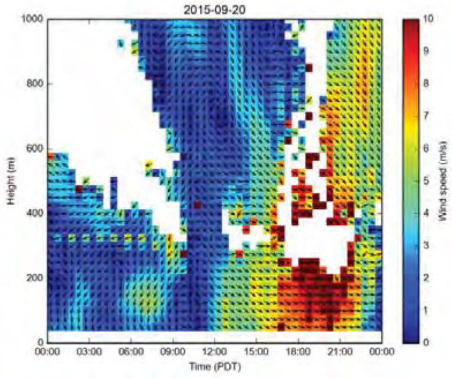
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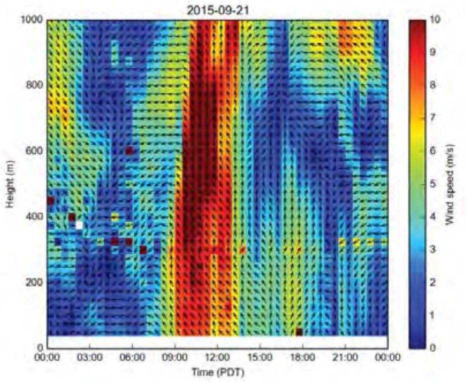
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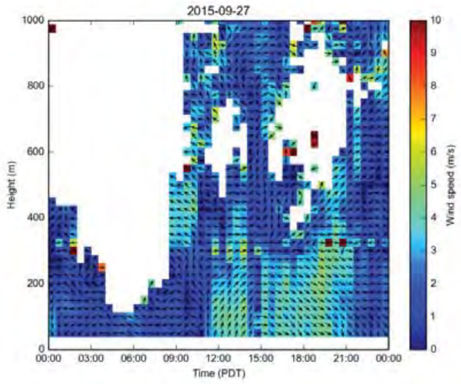
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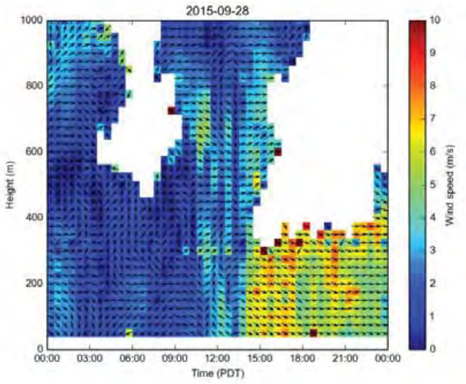
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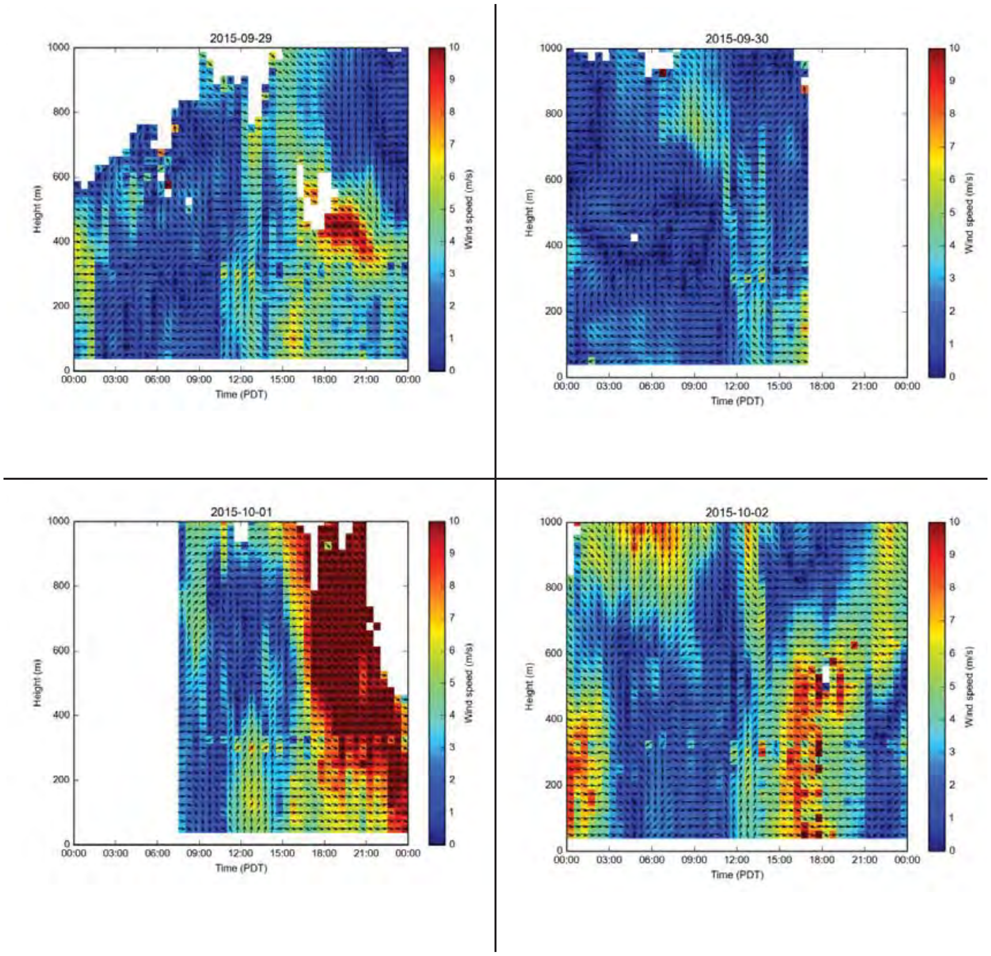
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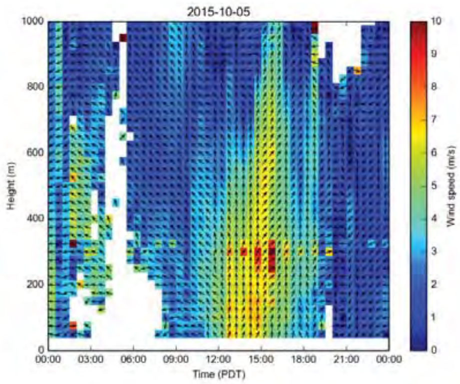
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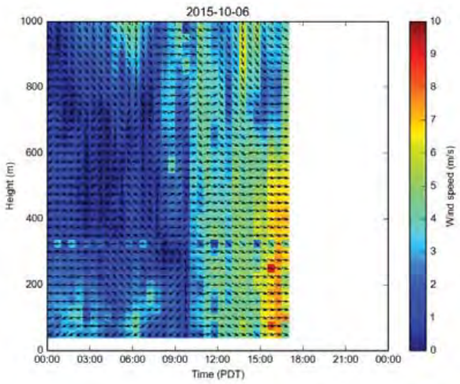
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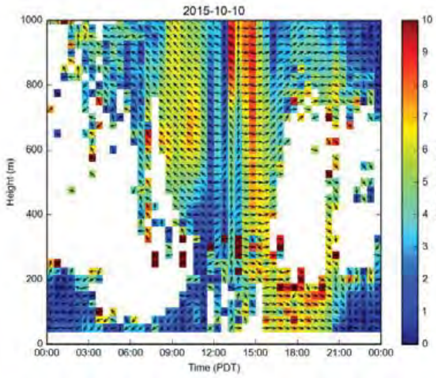
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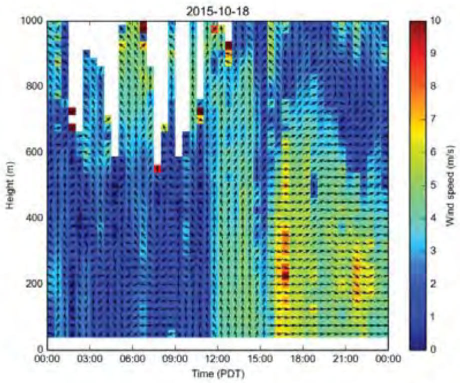
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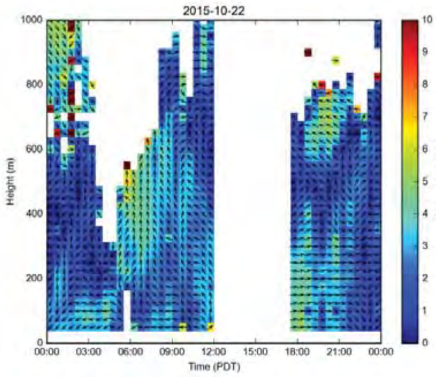
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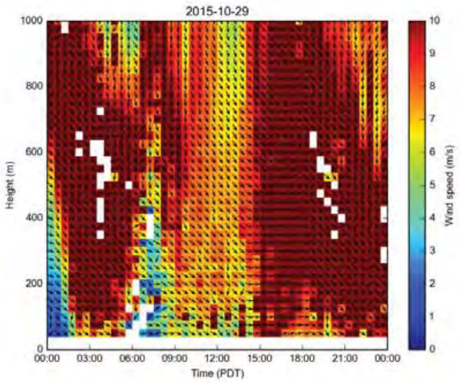
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AGU FALL MEETING
San Francisco | 12–16 December 2016

A13N-02: Quantification of Gas Emissions from Refinieries, Gas Stations, Oil Wells and Agriculture using Optical Solar Occultation Flux and Tracer Correlation Methods

Monday, 12 December 2016
13:56 - 14:09
Moscone West - 3006

Industrial volatile organic compound (VOC) emissions may contribute significantly to ozone formation. In order to investigate how much small sources contribute to the VOC concentrations in the Los Angeles metropolitan area a comprehensive emission study has been carried out on behalf of the South Coast Air Quality Management District (SCAQMD). VOC emissions from major sources such as refineries, oil wells, petrol stations oil depots and oil platforms were measured during September and October 2015 using several unique optical methods, including the Solar Occultation Flux method (SOF) and tracer correlation technique based on extractive FTIR and DOAS combined with an open path multi reflection cell. In addition, measurements of ammonia emissions from farming in Chino were demonstrated. The measurements in this study were quality assured by carrying out a controlled source gas release study and side by side measurements with several other techniques. The results from the field campaign show that the emissions from the above mentioned sources are largely underestimated in inventories with potential impact on the air quality in the Los Angeles metropolitan area. The results show that oil and gas production is a very significant VOC emission source. In this presentation the techniques will be discussed together with the main results from the campaign including the quality assurance work.

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http://www.scpr.org/news/2016/12/29/67663/la-area-refineries-emit-up-to-12-times-more-toxic/

89.3 KPCC

LA-area refineries emit up to 12 times more toxic chemicals than reported

Emily Guerin

December 29 2016

An explosion at an ExxonMobil refinery in Torrance caused four minor injuries on Wednesday, February 18, 2015. Researchers say things like flares, leaks and venting contribute to higher-than reported emissions at area refineries. DANIELLA SEGURA/KPCC

AUDIO FROM THIS STORY

Refineries in greater Los Angeles are emitting up to 12 times more toxic chemicals than previously reported, according to a new study by Swedish researchers and the South Coast Air Quality Management District.

The results, which were unveiled at the American Geophysical Union conference in San Francisco earlier this month, have substantiated the concerns environmental justice advocates and residents of industrial cities like Torrance, Carson and Wilmington.

Those advocates have complained of headaches, cancer and other health problems that they attribute, in part, to the area's numerous refineries.

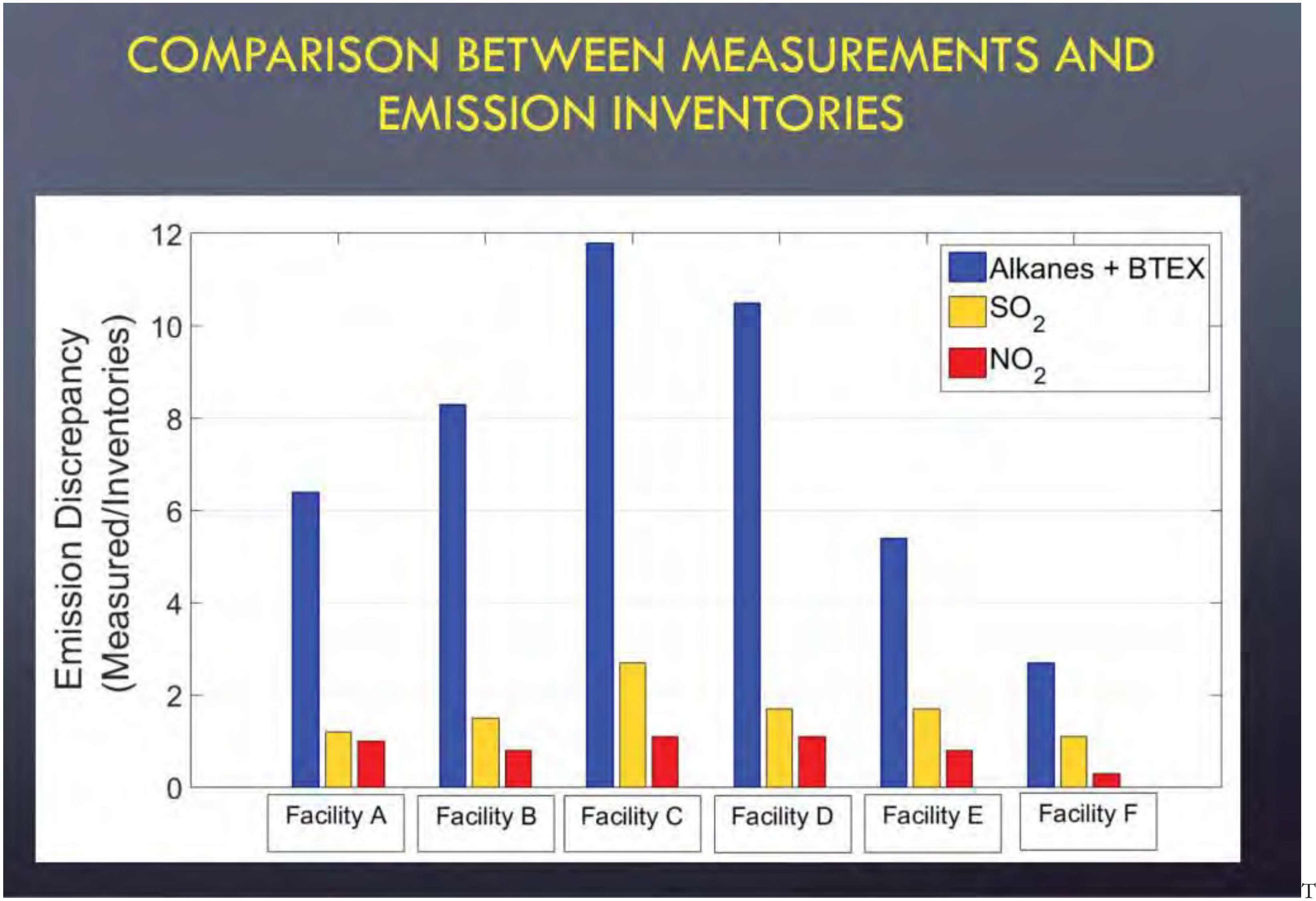
"Now we are validated for what we've been experiencing and saying to AQMD all along, that we were not satisfied about the type of analysis they were doing," said Alicia Rivera, a community organizer in Wilmington for Communities for a Better Environment. "Finally, AQMD did the proper study that the community deserves."

There is a growing body of evidence that refineries are underestimating emissions of volatile organic chemicals (or VOCs), things like benzene, xylene and toluene. Indeed, the Environmental Protection Agency wrote a memo to staff about this topic back in 2007. Exposure to these chemicals can cause headaches, fatigue, dizziness and cancer.

Since then, real-time monitoring technology has come a long way, allowing researchers to quantify just how much emissions may be underestimated, and what chemicals, exactly, are being emitted.

Last fall, AQMD partnered with researchers from Sweden to put mobile monitors on vans and drive around the fence line of six refineries in the South Coast (the agency won't release the names of the refineries until January, when it makes the results public).

They found that VOC emissions were three to 12 times greater than what refineries were officially reporting.



COMPARISON BETWEEN MEASUREMENTS AND EMISSION INVENTORIES

The researchers' sensors found VOC emissions (which includes alkanes and "btex," or benzene, toluene, ethylbenzene and xylene) were much greater than what the refineries were reporting to regulators.SCAQMD

“That’s very typical. People have done the same sort of [study] in other areas and invariably, it’s a similar result,” said Jay Olaguer, the director of air quality science at the Houston Advanced Research Center, who was familiar with the AQMD study but not involved with it.

That’s because currently, most refineries do not measure their emissions. Instead, they use an engineering handbook to calculate what emissions from flares, tanks, pipelines, smokestacks and valves might be, and then report their best estimate to state and federal regulators.

“It’s only somewhat better than a wild-ass guess, but it’s basically a wild-ass guess,” said Olaguer, who has authored a book on air emissions from the oil and gas industry. The calculations do not capture things like unexpected days of flaring, releases of hydrocarbons or leaks, he said.

Matt Miyasato, the deputy executive officer for science and technology advancement at AQMD, whose team undertook the study, said his agency’s findings made him skeptical of the emission calculation method, which is used by both the Environmental Protection Agency and AQMD to figure out how much progress is being made towards meeting Clean Air Act standards for pollutants like ozone.

“It makes us want to investigate these calculations better,” he said. “How were these calculations developed? Can we inform the EPA on what would be a more accurate way to resolve those?”

The reason why the calculation method is used at all at refineries is because until recently, real-time monitoring technology didn’t exist.

“This is an area which is undergoing rapid development,” Olaguer said. “There’s a whole new generation of analytical techniques that allow us to do much more than what we were able to do some time ago.”

Indeed, in November the AQMD board set aside over $720,000 to continue real-time air monitoring around refineries in Carson and Wilmington next year.
“We’re concerned about it. That’s why we’re continuing the investigation,” said Miyasato.

He said the next step is to figure out when to use which type of remote monitoring, and how accurate each technology is. For example, should the new remote sensors be used to help refineries detect leaks? To give real-time emissions data to community members? To monitor emissions for official reporting purposes?

Whatever AQMD decides, it will likely take a long time to change how refineries are required to report their emissions.

"EPA is heavily invested in the conventional technology," said Olaguer. "Like an elephant, you can't just turn it around on a dime."

But Alicia Rivera, the community organizer, wants the AQMD to crack down now.

“How can you allow polluters to say how much pollution they are emitting? That’s a joke,” she said. “I would hope (AQMD) would take the necessary steps to regulate what has been underreported and penalize the refineries for underreporting. And put in stricter regulations about how refineries report emissions.”

In addition to being unhealthy to breathe, VOC emissions are also a key component of smog, also known as ozone, which forms when tailpipe and other industrial emissions are baked by sunlight. That’s why Evan Gillespie, of the Sierra Club's My Generation campaign, was frustrated by the study’s results.

“We have such a long way to go meet basic smog standards, so it's especially maddening to learn that emissions are significantly higher than originally reported,” he wrote in an email.

“It's great to see the South Coast Air District supporting this important study, but the question becomes, with this new information will they finally use their authority to hold the oil industry accountable for their pollution?”

April 27, 2017

Wayne Nastri, Executive Officer,
South Coast Air Quality Management District (AQMD)

Re: New evidence from AQMD / Swedish Study shows Tesoro LARIC emissions drastically underestimated, EIR & Title V must go back to Re-Draft

Dear Mr. Nastri,

We write to follow-up on our request on the Draft EIR for the Tesoro Refinery expansion project. Recent findings by your own agency provide significant new evidence that warrant recirculation of the DEIR.

The April 11th publication of the full report on the joint Swedish /AQMD study made details available showing South Coast oil refinery emissions are drastically underestimated. In particular, the study shows that Tesoro grossly underreported emissions– with **43 times the benzene emissions** (cancer-causing), and **6.4 times the VOC emissions** compared to the District inventory.[1] Storage tank emissions were found to be especially significant, which is extremely disconcerting given Tesoro's plans to almost double crude oil storage capacity.

These findings reveal not only that existing burdens for Wilmington/Carson/W. Long Beach communities are underestimated, but also that projected **increases** of emissions due to the Tesoro merger and expansion are severely underestimated in the draft EIR and Title V permit analyses.

We applaud the District for jointly carrying out this ground-breaking study, and we urge you to now use these new findings and uphold responsibilities to correct the inaccuracies and deficiencies in the environmental documents. The communities' request that the massive Tesoro LARIC is not finalized before emissions are re-assessed and project deficiencies are fixed is very reasonable. **We ask that you re-assess the Tesoro baseline and LARIC increases, and recirculate the EIR as a Draft, incorporating the new study's data.** This will be an extremely important step that will show the AQMD's commitment to present accurate information to the community and decision-makers, and will demonstrate the agency's commitment to equity and its Environmental Justice principles. Please let us know your response.

All the undersigned organizations and individuals urge these actions.

(Regarding any questions, please contact Bahram Fazeli, CBE, Research and Policy Director, 323-826-9771, x 100, bfazeli@cbecal.org.)

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[1] *Emission Measurements of VOCs, NO2 and SO2 from the Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Optical Remote Sensing Methods,* Final Report, FluxSense Inc, 11 April 2017, Johan Mellqvist et al; Table 43, p. 94, Refinery A (Tesoro Carson). The study also states: "In our experience, tank emissions contribute approximately 2/3 of the total refinery emissions (Kihlman 2005)." p. 94.

Sincerely,

Alicia Rivera, Wilmington Community Organizer, Julia May, Senior Scientist, Bahram Fazeli, Research and Policy Director, and Gladys Limon, Staff Attorney, **Communities for a Better Environment** (CBE)

Adrian Martinez, Staff Attorney and Yana Garcia, Associate Attorney, **Earthjustice**

Taylor Thomas, Research and Policy Analyst, **East Yard for Environmental Justice**

Jesse N Marquez, Executive Director, **Coalition For A Safe Environment**

Jack Eidt, Cofounder, **SoCal 350 Climate Action and Tar Sands Action SoCal**

Sherry Anne Lear, Co-Organizer, and Joe Galliani, Founding Organizer,
South Bay Los Angeles 350 Climate Action Group

Alice Stevens, **Long Beach 350**

David Pettit, Senior Attorney, **Natural Resources Defense Council**

Christian L. Guzman, Sustainability Chair, **Central San Pedro Neighborhood Council**

Evan Gillespie, Director, My Generation Program, **Sierra Club**

Anabell Romero Chavez, Board Member, **Wilmington Improvement Network**

Gisele Fong, Ph.D., Executive Director, **EndOil / Communities for Clean Ports,** Chair, **Building Healthy Communities: Long Beach, Environmental Health Work Group**

Stella Ursua, President, **Green Education, Inc.**

Dean Toji, Ph.D., Chair, **Asian Pacific Planning and Policy Council (A3PCON), Environmental Justice Committee**

Maya Golden-Krasner, Senior Attorney, Climate Law Institute, **Center for Biological Diversity** (CBD)

Steve Colman, Executive Director, **Century Villages at Cabrillo**

David Braun, Director, **Rootskeeper**

cc.
Veera Tyagi, Principal Deputy District Counsel, Jillian Wong, Planning & Rules Manager, and Danny Luong, Sr. Enforcement Manager, AQMD

Mayor Garcetti, City of Los Angeles, Mayor Robles, City of Carson, Mayor Garcia, City of Long Beach

Matt Petersen, Chief Sustainability Officer, City of Los Angeles, Uduak Ntuk, Petroleum Administrator, City of Los Angeles

Jillian Wong

From:	Alisha C. Pember <apember@adamsbroadwell.com>
Sent:	Friday, May 5, 2017 2:17 PM
To:	Jillian Wong
Cc:	Rachael E. Koss
Subject:	Tesoro Los Angeles Refinery Integration and Compliance Project
Attachments:	3094-063acp - Tesoro LARIC Additional Comments re DEIR 5-4-17.pdf

Good afternoon,

Please see the attached Comments and Attachment A.

Due to the size of the supporting exhibits, they will be sent via overnight mail for Monday delivery with a hard copy of the Comments.

If you have any questions, please contact Rachael Koss.

Thank you.

Alisha Pember

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May 5, 2017

VIA EMAIL AND OVERNIGHT MAIL

Ms. Jillian Wong, Program Supervisor, CEQA
c/o Office of Planning, Rule Development and Area Sources
South Coast Air Quality Management District
21865 Copley Drive
Diamond Bar, CA 91765
jwong1@aqmd.gov

Re: Tesoro Los Angeles Refinery Integration and Compliance Project

Dear Ms. Wong:

We are writing on behalf of Safe Fuel and Energy Resources California ("SAFER California"), Peter Estrada, Leonardo Parra and Nicolas Garcia regarding the Draft Environmental Impact Report ("DEIR") prepared by the South Coast Air Quality Management District ("SCAQMD"), pursuant to the California Environmental Quality Act ("CEQA"), for the Tesoro Los Angeles Refinery Integration and Compliance Project ("Project"). We submitted comments on the DEIR on June 10, 2016. In April of 2017, a report entitled "FluxSense Inc., Emission Measurements of VOCs, NO2 and SO2 from Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Remote Sensing Methods" ("FluxSense Report") was published. The FluxSense Report compares real-time measurements of volatile organic compounds ("VOC"), Nitrogen Oxides, Sulfur Oxides, Benzene, Toluene, EthylBenzene and Zylenes ("BTEX") at six refineries and one tank farm in the SCAQMD, including the Tesoro Carson refinery. We reviewed the FluxSense Report with the assistance of refinery and air quality expert Phyllis Fox, Ph.D., QEP, PE, DEE. We found that the FluxSense Report supports our previous comments and provides additional evidence that the DEIR substantially underestimates the Project's VOC emissions and health risks. Specifically, the FluxSense Report shows that the DEIR's analyses of the Project's VOX and BTEX emissions rely on generic emission factors that are known to underestimate emissions. Dr. Fox's attached letter (**Attachment A**) shows that when site-specific

3094-063acp

measurements are used to estimate the Project's VOC emissions, the Project results in significant air quality and public health impacts. Therefore, the DEIR must be revised and recirculated for public review and comment.

I. The Project's 6,000 Barrels Per Day Increase in Crude Throughput Would Result in a Significant Air Quality Impact from VOC Emissions

The Project proposes to increase crude throughput by 6,000 barrels per day. According to the DEIR, the project would increase VOC emissions by 49.09 lb/day, which is just under the SCAQMD's 55 lb/day significance threshold. The FluxSense Report provides evidence that the DEIR significantly underestimates the Project's VOC emissions.

According to the FluxSense Report, the Tesoro Carson refinery underestimated its VOC emissions reported to the SCAQMD in its emissions inventories by a factor of 6.4.[1] Dr. Fox explains that Tesoro's emissions inventories for VOCs are based on calculations similar to those used in the DEIR.[2] Dr. Fox also explains that the FluxSense Report results (0.020% of the crude throughput at the Tesoro Carson refinery was emitted as VOCs) can be used to estimate the Project's increase in VOCs from the 6,000 barrel/day throughput increase. Using the FluxSense Report results, Dr. Fox determined that ***the Project's throughput increase would result in an increase in VOC emissions of at least 312 lb/day.***[3] This increase alone exceeds the SCAQMD's significance threshold by a factor of almost six. This is a significant air quality impact that was not identified or mitigated in the DEIR. Notably, as explained in our previous comments on the DEIR, the throughput increase is just one of several Project components that would increase VOC emissions.

II. The Project's Increase in Tank VOC Emissions Would Result in a Significant Air Quality Impact

The DEIR estimates that storage tanks are the Project's major source of VOC emissions, totaling 322.62 lb/day. 141.64 lb/day are attributed to two new tanks at

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[1] FluxSense Report, Table 43.

[2] **Attachment A**, p. 4.

[3] *Id.*

the Wilmington refinery and 112.51 lb/day are from six new tanks at the Carson refinery. Conversion of two existing fixed roof tanks to internal floating roof tanks and increased utilization of 11 existing tanks provide an additional 68.4 lb/day.

Dr. Fox previously commented that if VOC emissions from these new and existing tanks were as little as two percent more than estimated in the DEIR, the Project's operational VOC emissions would exceed the SCAQMD's daily VOC significance threshold. Dr. Fox also identified several errors and omissions in the DEIR's tank emissions calculations that, when corrected, would increase tank VOC emissions above the VOC significance threshold of 55 lb/day. Citing actual measurements at refinery tanks using optical remote sensing methods similar to those used in the FluxSense Report, Dr. Fox explained that the method (TANKS 4.09d) used in the DEIR to estimate the Project's tank emissions underestimated emissions by factors of two to fifteen.

The FluxSense Report used mobile optical measurements at the Carson tank farm for eight days to estimate tank VOC and BTEX emissions. The Report confirms that the tanks are the major source of VOC emissions at the Carson refinery (71 percent). The Report also shows that measured VOC emissions from the Carson refinery are 6.5 times higher than reported to the SCAQMD in emissions inventories using the same calculation method used in the DEIR. Assuming the DEIR underestimated tank emissions by a factor of 6.5, Dr. Fox explains that the net change in Project VOC emissions would increase from 49.09 lb/day to 1,422 lb/day, exceeding the significance threshold of 55 lb/day by a factor of 25.[4] The FluxSense Report provides additional evidence to support Dr. Fox's previous comments that the DEIR substantially underestimates the Project's tank VOC emissions. The DEIR must be revised accordingly.

III. The Project's Increase in VOC Emissions Would Result in Significant Public Health Impacts

VOCs are converted into ozone in the atmosphere. The South Coast Air Basin is in extreme nonattainment with the federal 1-hour and 8-hour ozone standards and in nonattainment with the state 1-hour and 8-hour ozone standards. Dr. Fox explains that the Project area has the worst ozone pollution in the United States and the Los Angeles/Long Beach area has been at the top of the worst ozone

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[4] *Id.*, p. 8.

pollution list for 17 of the 18 years that the American Lung Association has ranked pollution in its State of the Air Report.[5] Further, there are more than 18 million people in the Project area that belong to seven groups known to be vulnerable to the effects of breathing ozone, including those under the age of 18, those over the age of 65, those with pediatric asthma, those with adult asthma, those with COPD, those with cardiovascular disease and those living in poverty.[6]

A revised Health Risk Assessment ("Revised HRA") was prepared for the Project, which identifies 23 sensitive receptors (schools, hospitals, child care facilities and churches) located in close proximity to the Project. Yet, the Revised HRA fails to identify significant health impacts from elevated ozone levels, as summarized by the American Lung Association in its 2017 State of the Air report, including premature death, developmental harm, reproductive harm, asthma attack, wheezing and coughing, shortness of breath, cardiovascular harm, susceptibility to infections, lung tissue redness and swelling, increased admission to hospitals for asthma, increased asthma in adolescents, and lower birth weight and decreased lung function in newborns.[7] Dr. Fox also references a new study that shows that cancer patients face increased risks from ozone exposure.[8] The Revised HRA and DEIR must be revised to include these significant health impacts.

The Revised HRA reports an increase in cancer risk at the maximally exposed individual residential receptor ("MEIR") of 3.7 in one million, which is less than the cancer significance threshold of 10 in one million. The Revised HRA also reports that emissions from the Project's tanks and associated fugitive components are the major source of cancer risk at the MEIR, contributing 78 percent of the total cancer risk. According to the Revised HRA, benzene is responsible for 33.2 percent of the cancer risk at the MEIR.

The FluxSense Report concludes that benzene was underestimated in emissions reported to the SCAQMD for the Carson refinery by a factor of 43. Based on the FluxSense Report, Dr. Fox explains that the cancer risk at the MEIR would increase from 3.7 in one million to 55 in one million.[9] Further, according to Dr. Fox, "the cancer risk at all of the 'most exposed sensitive receptors,' which are all schools,

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[5] *Id.*, p. 5.
[6] *Id.*
[7] *Id.*, p. 6.
[8] *Id.*
[9] *Id.*, p. 9.

would exceed the cancer significance threshold by a significant amount, when adjusted as for the MEIR."[10] Thus, the Project would result in significant cancer risks, and the Revised HRA and DEIR must be revised.

IV. Conclusion

The FluxSense Report supports our previous comments on the DEIR and provides additional evidence that the Project would result in significant, undisclosed and unmitigated air quality and public health impacts from VOC emissions. The SCAQMD must revise the DEIR accordingly and recirculate it for public review and comment.

Sincerely,

Rachael Koss

REK:acp

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[10] *Id.*

ATTACHMENT A

Phyllis Fox, Ph.D., PE
745 White Pine Ave.
Rockledge, FL 32955
321-626-6885

May 4, 2017

Rachael Koss
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard, Suite 1000
South San Francisco, CA 94080-7037

Dear Ms. Koss:

Per your request, I have reviewed the FluxSense Report[1] that compares real-time measurements of Volatile Organic Compounds (VOCs)[2], Nitrogen Oxides (NOx), Sulfur Oxides (SOx), and Benzene, Toluene, EthylBenzene, and Xylenes (BTEX) at six refineries and one tank farm in the South Coast Air Quality Management District (SCAQMD). These six refineries include the Tesoro Carson refinery, the largest refinery included in the study and the second largest in the SCAQMD, as well as a separate study at the Tesoro Carson tank farm.

As I explain below, the FluxSense Report indicates that the Draft Environmental Impact Report (DEIR) for the Tesoro Los Angeles Refinery Integration and Compliance Project (Project)[3] significantly underestimated VOC emissions and health risks due to the Project. The DEIR estimated VOC and BTEX emissions using canned, generic emission factors that are not specific to the subject refineries. These emission factors have long been known to underestimate refinery emissions, based on real-time

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[1] FluxSense Inc., Emission Measurements of VOCs, NO2 and SO2 from Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Remote Sensing Methods, Final Report, April 11, 2017 (FluxSense Report), Exhibit 1.

[2] The VOCs measured in the FluxSense Report are total alkanes minus methane (FluxSense Report, pdf 8, 31: "The main objective of this study was to quantify the total gas emissions of non-methane VOCs (alkanes and BTEX), NO_2, SO_2 and methane from six major refineries in the Los Angeles Basin…"). Thus, these measurements are consistent with the SCAQMD definition of VOCs as ozone precursors. SCAQMD Rule 102 defines VOCs as: "VOLATILE ORGANIC COMPOUND (VOC) is any volatile compound of carbon, excluding methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, ammonium carbonate, and exempt compounds." Methane is typically treated separately from other VOC emissions because it has much lower ozone formation potential.

[3] Environmental Audit, Inc., Tesoro Los Angeles Refinery Integration and Compliance Project, Draft Environmental Impact Report, Submitted to: South Coast Air Quality Management District, SCH No. 2014091020, March 2016 (DEIR); Available at: http://www.aqmd.gov/home/library/documents-support-material/lead-agency-permit-projects.

monitoring at other refineries.[4] When Project VOC and BTEX emissions are revised to use site-specific measurements, the Project results in highly significant air quality and health risks. The responses to comments on the DEIR and drafts sections of the Final Environmental Impact (FEIR), obtained through Public Record Act Requests (PRAs) thus far also do not acknowledge this new information. Thus, the DEIR should be revised to accommodate this new information and recirculated for public comment.

The SCAQMD sponsored a series of measurement projects to study industrial emissions using Optical Remote Sensing (ORS) methods. The results of these studies at six refineries in the SCAQMD were recently reported.[5] One of the refineries included in this study is the Tesoro Carson facility, designated as Refinery A in the study. Refinery A can be identified as Tesoro Carson from the reported crude capacity (257,300 bbl/day)[6] and by comparing the aerial photographs in the FluxSense Report with those in the DEIR.[7] The Tesoro Carson refinery was monitored for 15 days during the period August 28 to November 10, 2015,[8] the longest of any of the six refineries. The tank farm at this refinery was also monitored.[9] This study did not include the Tesoro Wilmington refinery, its much smaller (257,300 bbl/day vs. 104,500 bbl/day) neighbor proposed to be more fully integrated under the Tesoro Los Angeles Refinery Integration and Compliance Project (Project).[10]

The FluxSense Report indicates the Carson refinery collaborated with the SCAQMD in conducting the study.[11] The FluxSense study demonstrates that the increase in volatile organic compound (VOC) emissions from the Project will result in a

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[4] See, for example, John K.E. Johansson and others, Emission Measurements of Alkenes, Alkanes, SO_2, and NO_2 from Stationary Sources in Southeast Texas over a 5 Year Period Using SOF and Mobile DOAS, Journal of Geophysical Research: Atmospheres, February 27, 2014 (Johansson et al. 2014: Exhibit 2);

[5] FluxSense Report, Exhibit 1. See also AGU Fall Meeting, December 2016 Abstracts at: https://agu.confex.com/agu/fm16/meetingapp.cgi/Person/41410 and https://agu.confex.com/agu/fm16/meetingapp.cgi/Paper/180782.

[6] Compare crude capacity in FluxSense Report, pdf 5, Table ES-2 and pdf 45 with reported crude capacities in California Energy Commission, California's Oil Refineries; Available at: http://www.energy.ca.gov/almanac/petroleum_data/refineries.html.

[7] Compare FluxSense Report, Figures 10 and 18 with DEIR, Figures 2-2 (pdf 81), 2-15 (pdf 115), 2-17 (pdf 123), 3.2-1 (pdf 142), 3.5-2 (pdf 188), 3.7-1 (pdf 207), 4.3-1 (pdf 266), 4.3-3 (pdf 268), 5.1-1 (pdf 342), etc.

[8] FluxSense Report, pdf 45.

[9] FluxSense Report, pdf 16 ("[d]uring a week and a half (September 28 to 7 October), measurements were also conducted inside the Refinery A at the main eastern tank farm.")

[10] DEIR, p. 1-5, pdf 24 ("The proposed project is designed to better integrate the Wilmington Operations and Carson Operations.").

[11] FluxSense Report, pdf 32 ("it has been collaborating with SCAQMD to support this campaign and making it possible to carry out 7 days of onsite measurements.")

significant VOC air quality impact that was not identified and mitigated in the FEIR. It also demonstrates that the increase in benzene emissions will result in a significant increase in cancer risk at the maximum exposed individual residential receptor (MEIR).

I. The Increase in VOC Emissions from a 6,000 BBL/Day Increase In Crude Throughput Is Significant

The DEIR estimated the Project would increase VOC emissions by 49.09 lb/day, which is less than the SCAQMD VOC significance threshold of 55 lb/day.[12] This estimate is based on a unit-by-unit analysis in which emissions are estimated using various emission calculation procedures.[13] The FluxSense report demonstrated that these calculation procedures significantly underestimate refinery emissions, including at Carson.[14]

The FluxSense Report demonstrated that the Tesoro Carson refinery underestimated its VOC emissions reported to the SCAQMD in its emission inventories by a factor of 6.4. Similarly, the six refineries studied in the SCAQMD underestimated their VOC emissions by an average factor of 6.2, compared to those reported to the SCAQMD in emission inventories.[15] A ratio of 6.2 means that the emission inventories underestimated VOC emissions by a factor of 6.2 compared to measured VOC emissions. This is consistent with results reported elsewhere for other refineries that also estimate their emissions using AP-42 and other similar methods. Johansson et al (2014), for example reported for refineries in Texas that, "Despite some significant variations from year to year and from area to area, there is a clear pattern of measured VOC emissions (alkanes, ethane, and propene) exceeding reported emissions with almost an order of magnitude on average, while no similar pattern exists for SO_2 and NO_2."[16]

The emission inventories for VOCs are based on calculations similar to those used in the DEIR as VOCs are not monitored, unlike NOx and SOx, for which good agreement between inventories and measurements was found.[17] The average ratio between measured and reported emissions for NOx was 0.8 and for SOx, 1.5, compared to an average ratio of 6.2 for VOCs,[18] consistent with other studies. Most major refining processes that emit NOx and SOx are continuously monitored using continuous

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[12] DEIR, Table 4.2-4, pdf 234.

[13] DEIR, Appendix B.

[14] FluxSense Report, Table 43, pdf 95.

[15] FluxSense Report, Table 43, pdf 95.

[16] Johansson et al. 2014, p. 1983 (Exhibit 2).

[17] FluxSense Report, Table 43, pdf 95; Johansson et al 2014, p. 1983 (Exhibit 2).

[18] FluxSense Report, Table 43, pdf 95.

emission monitoring systems (CEMSs), while VOC emissions are calculated using emission factors from AP-42, or estimated from infrequent stack tests, explaining the discrepancy between VOCs, which are grossly underestimated, and NOx and SOx, which are much more accurately estimated in emission inventories. This supports the importance of assuring that permit conditions for VOCs include monitoring to assure they are practically enforceable.

The FluxSense results can be used to estimate the increase in VOC emissions due to the Project's estimated increase in throughput of the Refinery, approximately 6,000 bbl/day[19]. The FluxSense Report demonstrated that from 0.017% to 0.045% or an average of 0.024% of the crude oil throughput at the six studied refineries is emitted as VOCs. At Carson, 0.020% of the crude throughput was emitted as VOCs, compared to an average of 0.024% for the six refineries that were studied. Assuming a 6,000 bbl/day increase in crude throughput (and my prior comments on the DEIR demonstrate that the actual increase could be much higher), the increase in VOC emissions based on FluxSense measurements at Carson would be 367 lb/day.[20] Assuming the lowest measured percent VOC emitted (Refinery F), the increase in VOC emissions due to the Project would be 312 lb/day.

In sum, the increase in VOC emissions, just due to the asserted 6,000 bbl/day increase in crude throughput, would exceed the CEQA significance threshold of 55 lb/day by a factor of nearly six. This is a significant air quality impact that was not identified in the DEIR and which must be mitigated. As discussed elsewhere in these comments, VOC emissions increase due to increases in crude throughput is only one of several components of the Project that would increase the emissions of VOCs.

Volatile organic compounds (VOCs) are converted into ozone, otherwise known as smog, in the atmosphere. The South Coast Air Basin is in extreme nonattainment with the federal 1-hour and 8-hour ozone standards and in nonattainment with the state 1-hour and 8-hour ozone standards.[21] The federal and state ozone standards were exceeded on 92 and 129 days or 25% to 35% of the time in 2014.[22] In fact, the area where the Project will be located has the worst ozone pollution in the entire United States.

The Los Angeles – Long Beach area, where the Project is located, has remained at the top of the worst ozone pollution list for 17 out of the 18-years that the American

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[19] DEIR, p. 2-27.

[20] Increase in VOC emissions from a 6,000 bbl/day increase in crude throughput: [(1,086,215 MT/mo of crude throughput at Carson)(6,000 bbl/day increase in crude throughput due to Project)/257,300 bbl/day of crude throughput at Carson][(0.020%/100)(2,204.62 lb/MT)(mo/30.4 day) = 367 lb/day.

[21] DEIR, Table 3.2-2.

[22] DEIR, p. 3-4.

Lung Association (ALA) has been ranking pollution in its annual State of the Air Report.[23] Seven groups of people are especially vulnerable to the effects of breathing ozone.[24] In the Project area in 2016, these include over 18 million people that were at risk from ozone pollution, including:

- 4,383,662 under 18;
- 2,376,130 that are 65 and over;
- 313,246 with pediatric asthma;
- 1,099,027 with adult asthma;
- 571,985 with COPD[25];
- 8,096 with cardiovascular disease; and
- 1,409,515 living in poverty.[26]

The revised Health Risk Assessment[27] identified 23 sensitive receptors - schools, hospitals, child care facilities and churches – located in close proximity to the Project. The American Lung Association, in its 2017 State of the Air report, summarized recent research on children that would be present in these facilities due to ozone exposure. The impacts include:

- premature death;
- developmental harm;
- reproductive harm;
- asthma attack;
- wheezing and coughing;
- shortness of breath;
- cardiovascular harm;
- susceptibility to infections;
- lung tissue redness and swelling;[28]

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[23] Laura Parker, See the Best and Worst Places for Breathable Air in the U.S., National Geographic, April 19, 2017; Available at: http://news.nationalgeographic.com/2017/04/ozone-pollution-city-rankings-particles-Clean-Air-Act/.

[24] American Lung Association, State of the Air 2017, 2017 (ALA 2017); Available at: http://www.lung.org/local-content/california/our-initiatives/state-of-the-air/2017/state-of-the-air-2017.html (Exhibit 3).

[25] Chronic Obstructive Pulmonary Disease, also known as COPD, includes emphysema and chronic bronchitis.

[26] ALA 2017, p. 17 (Exhibit 3).

[27] Ashworth Leininger Group, Health Risk Assessment for the Tesoro Los Angeles Refinery Integration and Compliance Project, Carson and Wilmington, California, February 2017, Appendix B-4 (Revised HRA).

[28] ALA 2017, p. 32 (Exhibit 3).

- increased admission to hospitals for asthma, with younger children and those from low-income families more likely than others to need hospital admission;
- some children with certain genes are more likely to develop asthma as adolescents; and
- lower birth weight and decreased lung function in newborns.[29]

The revised HRA failed to identify any of these well known, significant health impacts from elevated ozone levels that would result from the Project.

Further, a major new study found evidence that people with lung cancer faced greater risk from ozone and other outdoor air pollutants. The 2016 study tracked the air pollution levels from 1988 to 2011 experienced by more than 350,000 cancer patients in California. The researchers found that the ozone and other air pollutants shortened their survival.[30] In addition, some evidence suggests that other groups, including women, people who suffer from obesity and people with low incomes, may also face higher risk from ozone.[31] Numerous studies document the serious public health impacts of ozone.[32] Thus, it is critical that the huge increase in ozone precursors that will result from this Project be fully mitigated.

II. The Increase in Project VOC Emissions from Correcting the Underestimate in Tank VOC Emissions Is Significant

The DEIR estimated that storage tanks are the major source of VOC emissions, amounting to 322.62 lb/day. Of this amount, 141.64 lb/day is from two new tanks at Wilmington and 112.51 lb/day are from six new tanks at Carson.[33] In addition, conversion of two existing fixed roof tanks to internal floating roof tanks and increased utilization of 11 existing tanks combined contribute an additional 68.4 lb/day.[34]

I previously commented that if VOC emissions from these new and existing tanks were as little as 2% greater than estimated in the DEIR, operational VOC emissions from the Project (considering other increases and decreases as reported in DEIR Table 4.2-4) would exceed the SCAQMD daily VOC significance threshold. This would be a significant impact not disclosed in the DEIR.

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[29] ALA 2017, p. 34 (Exhibit 3).

[30] S. P. Eckel and others, Air Pollution Affects Lung Cancer Survival, Thorax, v. 71, 2016, pp. 891-898 (Eckel et al. 2016, Exhibit 4).

[31] ALA 2017, p. 33 (Exhibit 3).

[32] See, for example, Exhibits 5 – 19.

[33] DEIR, Appx. B-3, p. B-3-45.

[34] DEIR, Table 4.2-4 and Appx.B-3, p. B-3-45.

I identified a large number of errors and omissions in the tank calculations that could increase tank VOC emissions from the Project enough to exceed the VOC significance threshold of 55 lb/day.[35] I supported my conclusion that the method used to estimate tank VOC emissions in the DEIR (TANKS 4.09d) underestimated tank emissions by factors of two to fifteen by citing actual measurements at refinery tanks using optical remote sensing methods similar to those used in the FluxSense Report.[36]

The FluxSense Report used mobile optical measurements at the Carson tank farm for eight days between September 28 and October 7, 2015 to estimate tank VOC and BTEX[37] emissions. This study confirmed that the tanks are the major source of VOC emissions at the Carson refinery, comprising 71% of the total measured VOC emissions.[38] This is consistent with results reported elsewhere for refinery tank emissions.[39]

The FluxSense Report also demonstrated that measured VOC emissions from the Carson Refinery (214 ton/mo) are 6.5 times higher than reported to the SCAQMD in emission inventories (33 ton/mo) using the same calculation procedures used in the DEIR.[40] As the majority of these emissions is from the tanks, by extension, the TANKS model or the Applicant's use of this model (e.g., selection of input parameters, such as temperature, vapor pressure, vapor molecular weight) underestimates VOC emissions.

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[35] Phyllis Fox, Comments on the Draft Environmental Impact Report (DEIR) for the Tesoro Los Angeles Refinery Integration and Compliance Project, Los Angeles, California, June 10, 2016 (Fox DEIR Comments), Comment VI, pp. 81 - 90.

[36] Fox DEIR Comments, pp. 83-84 and Table 6.

[37] Benzene, toluene, ethylbenzene, and xylene (BTEX).

[38] The VOC emissions from the Carson tank farm, reported as alkane flux (less methane) is 191 kg/hr (FluxSense Report, Table 38). The total VOC emissions from the Carson Refinery including its tank farm, reported as alkane flux (less methane), is 269 kg/hr (FluxSense Report, Table ES-1). Thus, the percent of Carson VOC emissions that originates from the tanks is (191/269)100 = 71%.

[39] Johansson 2014, p. 1989 (Exhibit 2); Kihlman, Application of Solar FTIR Spectroscopy for Quantifying Gas Emissions, Thesis for the Degree of Licentiate of Engineering, Chalmers University of Technology, Göteborg, Sweden, Paper A, Monitoring of VOC Emissions from Refineries in Sweden Using the Solar Occultation Flux Method, pdf 81, 90, Table 4 ("Of the emitted gas 26% originates from the process, 31% from the crude-oil tanks, 32% from product tanks, 8% from the water treatment facility and 2% from transport related activities); Available at: http://webcache.googleusercontent.com/search?q=cache:motv4qkkKjAJ:www.fluxsense.se/wp-content/uploads/ftp-uploads/pdf/SOF%2520Licenciate%2520thesis%2520Kihlman%25202005.pdf+&cd=1&hl=en&ct=clnk&gl=us; M. Kihlman, J. Mellqvist, and J. Sameulsson, Monitoring of VOC Emissions from Refineries and Storage Depots Using the Solar Occultation Flux Method, 2005 (Kihlman et al. 2005), Table 40 (Exhibit 20).

[40] FluxSense Report, Table 43, Meas. Alk + BTEX = 214 tons/mo; Rep. Tot VOC = 33 tons/mo. Thus, reported VOC emissions, which are 71% from tanks, are underestimated by a factor of 214/33 = 6.5.

Assuming the DEIR underestimated tank emission as reported in the FluxSense Report, i.e., by factor of 6.5, the net change in Project VOC emissions would increase from 49.09 lb/day[41] to 1,422 lb/day[42], exceeding the CEQA significance threshold of 55 lb/day by a factor of 25. Thus, the underestimate in tank VOC emissions alone is sufficient to result in a significant VOC impact. In sum, the FluxSense report confirms my DEIR comment on the significant underestimate in tank VOC emissions.

III. Cancer Health Risks Are Significant

The DEIR conducted a health risk assessment (HRA) focused solely on hazardous air pollutants (HAPs) and concluded that health impacts were not significant.[43] In response to comments on the DEIR, the HRA was revised. The Revised HRA also concluded that health risks are not significant. However, the Revised HRA failed to consider the results of the FluxSense report or to acknowledge the very significant health impacts that result from the highly significant increase in VOCs, which are ozone precursors known to cause many very significant health impacts, discussed in Comment I. In particular, the revised HRA failed to acknowledge the synergistic impact of very high ozone levels with very high emissions of hazardous air pollutants.

The Revised HRA reported an increase in cancer risk at the maximally exposed individual residential receptor of 3.7 in one million,[44] which is less than the cancer significance threshold of 10 in one million. The Revised HRA also reported that emissions from the tanks and associated fugitive components are the major source of cancer risk at the MEIR, contributing 78% of the total cancer risk.[45] Benzene was reported to be responsible for 33.2% of the cancer risk at the MEIR.[46]

The FluxSense Report concluded that benzene was underestimated in emissions reported to the SCAQMD by a factor of 3.2 to 202 at the six refineries where benzene was measured. The Carson Refinery underestimated its benzene emissions by a factor

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[41] DEIR, Table 4.2-4.

[42] Revised increase in VOC emissions due to Project, assuming tank emissions are 6.4 times larger than estimated, based on DEIR Table 4.2-4 = total project VOC emissions + increase at Wilmington and Carson tanks - Regulation XIII compliance - Regulation XIII prior compliance: 401.15 lb/day + [(141.64)(6.4) - 141.64] (Wilmington tanks) + [(112.51)(6.4) - 112.51] (Carson tanks) - 317.33 - 34.73 = **1,422 lb/day.**

[43] DEIR, pdf 44, 55-56 and Appendix B.

[44] Revised HRA, p. B-4-34, pdf 36: 38.8+29.4+4.1+3.9+0.6+0.6+0.3+0.3+0.2+0.2+0.1+0.0=78.5%.

[45] Revised HRA, Table 13, pdf 48.

[46] Revised HRA, Table 12, pdf 46.

of 43.[47] Assuming a factor of 43 underestimate in benzene, the cancer risk at the MEIR would increase from 3.7 in one million to 55 in one million.[48] In fact, the cancer risk at all of the "most exposed sensitive receptors", which are all schools, would exceed the cancer significance threshold by a significant amount, when adjusted as for the MEIR.[49] Thus, emissions from the Project would result in a highly significant cancer risk impact at numerous nearby sensitive receptors, requiring mitigation.

The major source of cancer risk is benzene emissions from tanks and associated fugitive components. As I explained in my comments on the DEIR, emissions from tanks and fugitive components can be mitigated by requiring floating roof tanks to be controlled with geodesic domes and by requiring the use of leakless fugitive components.[50] These feasible controls were not required in the DEIR.

In sum, the Project would result in significant air quality and public health impacts when the results of actual measurements at the Carson Refinery and other nearby refineries are considered. In my opinion, it is a serious violation of CEQA to fail to use the most accurate available information to evaluate air quality and public health impacts and to fail to acknowledge and mitigate the significant air quality and cancer impacts that would results from the Project in the communities surrounding the Refinery, including many schools. The DEIR should be revised to incorporate the new FluxSense measurements and recirculated for public review.

Sincerely,

Phyllis Fox, Ph.D., P.E.

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[47] FluxSense Report, Table 43, pdf 95.

[48] The cancer risk at the MEIR, assuming benzene is underestimated by factor of 43: $(3.7\times10^{-6})(0.332)(43) + 3.7\times10^{-6}(1-0.332) = 55\times10^{-6}$.

[49] Revised HRA, Table 11, pdf 45-46. Selecting the lowest reported cancer risk at local schools, 1.12×10^{-6} at Wyo Tech National Institute of Tech, the revised cancer risk is: $(1.12\times10^{-6})(0.332)(43) + 1.12\times10^{-6}(1-0.332) = 17\times10^{-6}$.

[50] Fox DEIR Comments, pp. 82, 89.

2015

Emission Measurements of VOCs, NO_2 and SO_2 from the Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Optical Remote Sensing Methods

FluxSense

FINAL REPORT

FluxSense Inc

11 April 2017

Date: 11 April 2017

Title: Emission Measurements of VOCs, NO_2 and SO_2 from the Refineries in the South Coast Air Basin Using Solar Occultation Flux and Other Optical Remote Sensing Methods

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FluxSense Inc is subsidiary of FluxSense AB (www.fluxsense.se; San Diego, CA). FluxSense started as a spin-off company from research conducted at Chalmers University of Technology in Sweden and has been active for more than 10 years. FluxSense has carried out more than 100 industrial site surveillances in Austria, Belgium, Denmark, France, Middle East, Netherlands, Norway, Sweden and the US.

[Cover: Visualization of alkane plume transects (blue curves) from Solar Occultation Flux (SOF) measurements conducted at the six refineries for this study during similar wind conditions. The apparent height of the blue line is proportional to the integrated vertical column concentration expressed in mg/m^2. White arrows indicate wind directions during these measurements. Image mapped on Google Earth © 2016.]

Executive summary

BACKGROUND

Accurate characterization of facility-wide emissions from industrial sources on a real or near-real time basis is critical for developing effective control strategies to improve regional air quality, promoting compliance, and reducing exposure for nearby communities. To improve the understanding of such emissions in the South Coast Air Basin (SCAB), the South Coast Air Quality Management District (SCAQMD) has sponsored a series of measurement projects to study industrial emissions using Optical Remote Sensing (ORS) methods. The projects include experimental studies of emissions from refineries, oil depots, treatment facilities, oil wells, gas stations, fuel islands and barges. In addition, SCAQMD has sponsored technology demonstration and validation studies to assess potential uncertainties of different optical techniques through side-by-side measurements of real sources and controlled source gas releases.

Numerous research studies using ORS conducted in the US and worldwide (including a 2013 pilot project sponsored by SCAQMD) suggest that measured emissions of VOCs from industrial facilities are larger compared to emission inventory estimates developed based on accepted reporting conventions. Given the large number of refineries and other industrial activities in the SCAB, it is therefore very important to evaluate novel measurement methods for detecting and quantifying industrial emissions directly.

This report presents the results of a two and a half month long measurement campaign aimed at characterizing and quantifying emissions of VOCs, NOx, and SO_2 from six major refineries in the SCAB. The measurements spanned from August 28 to November 11 2015, with up to 15 individual measurement days at each site. Additionally, a detailed eight day long measurement study inside the tank farm of one of the refineries was conducted to quantify emissions from the tank farm, locate potential leak sources, and validate the SOF technique by comparative measurements to other ORS methods.

Mobile surveys using two ORS techniques, namely SOF (Solar Occultation Flux) and Mobile SkyDOAS (Differential Optical Absorption Spectroscopy), were conducted around the refineries' perimeters to estimate facility-wide emission fluxes of VOCs, SO_2 and NO_2. These ORS techniques were complemented by extractive optical methods, including MeFTIR (Mobile extractive Fourier Transform Infra-Red spectroscopy) and MWDOAS (Mobile White cell DOAS) to map ground concentrations of alkanes, methane and aromatic VOCs and to calculate inferred fluxes for methane and aromatics. The required wind information was collected using a stationary wind-LIDAR (LIght Detection and Ranging; which provides vertical wind profiles) and conventional wind mast measurements.

SOF is a proven technique employed by FluxSense in over 100 fugitive emission studies around the world. In Europe the SOF technique is considered Best Available Technology (BAT) for measurements of fugitive emission of VOCs from refineries (Barthe *et al.* 2015), and in Sweden it is used together with tracer correlation and optical gas imaging to annually screen all larger refineries and petrochemical industries. In Swedish facilities, ORS emission measurements are conducted annually for at least ten days, during different seasons, in order to obtain a good representation of the annual mean. These measurements represent the total emission flux coming from the entire refinery, divided into sub parts such as process areas, crude oil storage, product storage tanks, water treatment facilities, flares, and loading operations. In the study presented here, such sub-area measurements were demonstrated for the tank farm of Refinery A.

The estimated uncertainty for the SOF emission measurements is typically 30 % for total site emissions, and usually slightly higher for individual sub-parts. The estimated measurement uncertainties have been verified in several (blind and non-blind) controlled source gas release experiments (including the one performed during this study and discussed elsewhere) and in side-by-side measurements with other techniques. The uncertainties in the total refinery emissions of BTEX and CH_4 obtained from inferred fluxes are larger than for the direct flux measurements of alkanes. Ideally, the gases should be well mixed in the plume for this method to work the best, but in reality there will be a stronger weighting towards low elevated sources (tanks) compared to higher elevated ones (process units) depending on the measurement geometry. Based on canister samples collected in several European refineries in the past, we know that typically the BTEX fraction is higher in the process units (10-15 % of total VOCs) compared to tank farms (5-10 % of total VOCs). The inferred BTEX flux will consequently be a low estimate of actual BTEX emissions because plumes from tanks are usually located closer to the surface, while plumes from process areas can extend further up into the atmosphere. In this study the overall BTEX to alkane ratio was 0.11.

RESULTS

Table ES.1 shows the measured hourly emission rates (kg/h) of various gaseous species from the refineries investigated during this study. The emissions presented in table ES 1 represent median values of all valid transects obtained during the two and a half month study period. The BTEX and CH_4 emission values have been extrapolated from concentration ratios of these species to alkanes measured at ground level and scaled with direct alkane emission measurements by SOF. It should be noted that, rather consistently for all the refineries, the BTEX emissions are typically one tenth of the total VOC emissions, while CH_4 emissions are on average two thirds of the alkane emissions.

Table ES.1. Median values of all measured site emissions during the 2015 SCAQMD survey. The fluxes of alkanes, SO_2 and NO_2 are obtained from direct measurements, while BTEX and CH_4 are inferred from gas ratio measurements. Note that benzene is part of BTEX.

Measured Refinery SCAQMD Survey 2015	**N Days**	**Alkane Flux** [kg/h]	**SO_2 Flux** [kg/h]	**NO_2 Flux** [kg/h]	**BTEX Flux** [kg/h]	*Benzene Flux [kg/h]*	**CH_4 Flux** [kg/h]
Refinery A	15	269	62	66	24	*3.4*	167
Refinery B	5	70	53	31	11	*1.1*	53
Refinery C	4	244	37	57	37	*8.2*	142
Refinery D	7	164	17	34	16	*1.6*	79
Refinery E	7	244	53	63	31	*2.7*	207
Refinery F	4	139	37	18	10	*0.8*	57
Sum		**1130**	**259**	**269**	**129**	*18*	**705**

In Table ES.2 the measured emission data for the various sites has been normalized by the corresponding crude oil capacity for each facility and compared to the reported emission inventories. The table shows that the measured VOC emission factors for the studied refineries range from 0.017 % to 0.045 % (mass emission per mass capacity of crude). SOF measurements carried out in other well-run refineries typically show average VOC emission factors of 0.03 % to 0.1 %. Thus, according to this data, the refineries in the SCAB are generally performing well, with relatively low emission compared to their capacity. However, as highlighted in Table ES.2, significant differences exist between measured and reported inventory emissions for VOCs and, for all refineries combined, the overall discrepancy between measured and reported inventory values was a factor of 6.2. For benzene the corresponding overall discrepancy ratio was about 34, although the magnitude of BTEX emissions was relatively small. Refinery C stands out with a measured benzene emission being more than twice as high as the next refinery in order. The measured SO_2 and NO_2 emissions are much closer to, and in some instances lower than, those reported in the inventories. In Table ES 2, the reported annual emissions have been divided by 12 to obtain a monthly inventory value to compare to the measured monthly median emissions from this survey. Hence, the discrepancies and emissions factors are representative for September 2015 (the time-period when the majority of the ORS measurements were performed).

Table ES.2. VOC emission factors normalized by the corresponding crude oil capacity for the various sites, and ratios between measured values and reported inventories for the 2015 SCAQMD survey.

Measured Refinery Representative of September 2015	**Crude capacity 2015***		**Measured Monthly Emission for Sept. 2015**	**Emission Factor****	**Discrepancy factor (Measured/Reported[2])**			
	bbl/day	**Tons[1]/mo**	**Alkanes+BTEX Tons[1]/mo**	**Alkanes+BTEX %**	**Alkanes+ BTEX**	**SO_2**	**NO_2**	**Benzene**
Refinery A	257300	1086215	214	0.020 %	6.4	1.2	1.0	43
Refinery B***	139000	586801	59	0.045 %	8.3	1.5	0.8	33
Refinery C***			205		11.8	2.7	1.1	202
Refinery D	104500	441156	132	0.030 %	10.5	1.7	1.1	39
Refinery E	269000	1135608	201	0.018 %	5.4	1.7	0.8	38
Refinery F	149500	631128	109	0.017 %	2.7	1.1	0.3	3.2
Overall******	**919300**	**3880908**	**919**	**0.024 %**	**6.2**	**1.5**	**0.83**	**34**

* Crude capacity data is obtained from the 2016 California Energy Commission report.

** Mass emission per mass capacity of crude oil.

*** Crude capacity for Refinery B and Refinery C are reported together since Refinery B processes the crude oil and the Refinery C upgrades intermediate products to finished products.

**** The overall discrepancy values are calculated from the total sum of reported and measured emissions, respectively. The overall emission factor is based on the sum of measured emissions for all refineries relative to the total capacity. Reported annual values have been divided by 12 to obtain a monthly inventory value to compare to the measured monthly average emissions from this survey. The comparisons are representative for September 2015 (the time-period when most of the measurements were performed).

[1] metric tons.

[2] Note that total nitrogen oxides (NO_x) are reported while only the NO_2 fraction was measured by SkyDOAS.

ORS measurements were also conducted for eight days inside the tank farm of one of the refineries listed above. The objective of this part of the study was to demonstrate the capability of real time ORS techniques to identify and quantify emissions and potential gas leak sources inside a refinery. Several storage and crude oil tanks were identified as VOC emitters, including a large underground reservoir containing vacuum gas oil (VGO).

While conducting measurements inside one of the refineries, our mobile optical methods identified an area characterized by elevated alkane concentrations of about 70,000 ppb, in contrast to the ten to a few hundred ppb normally measured downwind of similar sources. An infrared gas imaging camera (FLIR) was used to visualize and confirm alkane gas emissions through a shallow pool of water on the ground. Once the leak was discovered, the refinery staff took swift action to investigate and repair the source of the leak. The investigation discovered a pinhole-size leak in a pipeline buried 30 cm below the ground. After the leak was repaired additional ORS measurements were conducted to verify that the problem was resolved. This event illustrates how mobile ORS measurements combined with conventional gas imaging can quickly identify an unknown leak and allow it to be fixed before any serious complications may occur.

Within this project we also conducted a separate study to compare the SOF readings to those of other ORS techniques such as DIAL (Differential Absorption Lidar) and long-path FTIR through side-by-side measurements on various tanks inside one of the refineries. The agreement between emissions from different tanks and reservoirs inside the refinery measured by SOF and DIAL was excellent (within 10-20 %). As part of the SOF, DIAL and long-path FTIR technology comparison and validation, a blind gas release experiment was also carried out using a controlled source emitting 2-25 kg/h of odorless propane at the flat open parking lot of the Angels stadium in Anaheim, CA. In this study, the SOF measurements consistently underestimated the true emissions by 35%, but showed excellent correlation for the different release rate configurations (R^2 ~98%). The detailed results of this technology inter-comparison study are compiled and presented in a separate report.

DISCUSSION

A common concern when comparing measured emissions with those reported in the inventories is that the reported data are calculated for a full year while measurements are typically conducted over a limited time period. This may impact uncertainties when translating measured emission rates to annualized values, as external environmental parameters such as wind, temperature and solar insolation, affect tank emissions. An additional concern is whether a sufficient number of measurements (and measurement days) have been sampled to eliminate the influence of any intermittent emissions due to tank cleaning, maintenance, flaring, etc. To address these concerns, we carefully analyzed the frequency distributions (histograms) of the measured emissions and wind data, and studied how they may be impacted by seasonal variations in meteorological conditions. In addition, the effect of ambient temperature and wind speed on tank emissions was investigated. For this study we concluded that variations in emissions resulting from environmental changes are relatively small and within the uncertainties of the SOF and SkyDOAS measurements.

The observed differences between measured emissions and reported inventories (based on the US EPA AP-42 standard) are considerably higher than what can be explained by measurement uncertainties alone, or incomplete diurnal and seasonal sampling. Refineries and tank farms are complex environments with a large number of components and numerous potential leak sources (e.g. tank seals, valves, gauges, flares, vapor recovery units, etc.). Many of these components can show degrading performance over time, and to appropriately account for the impact of non-ideal performance in emission inventory reporting is, we believe, an impossible task. Nevertheless, EPA's AP-42 system provides valuable insights for a specific facility on the production and abatement techniques applied and on what emission level the site could reach given ideal performance of all installations. Comparing measured emissions to ideal performance levels could therefore provide a basis for benchmarking of different refineries or sites.

OUTLOOK

Studies conducted in the SCAB, the Bay Area, Texas, and other places worldwide, show that field measurements provide a reliable way to determine actual emissions of VOCs and other pollutants from refineries and various industrial sites. Accurate estimates of VOC and other pollutant emissions from industrial sources are crucial for improving air quality models, to guide air pollution mitigation strategies, promote successful compliance strategies, and reduce exposure for nearby communities.

In our experience, the observed difference in fugitive VOC emissions between measured and inventory estimates is a general issue for the petroleum industry worldwide. We believe that a possible path forward could be to conduct monitoring in parallel with continued AP 42 based reporting, and to use the measurements to guide and verify the efficiency of the emission reduction efforts at the industrial sites.

Future longer-term ORS studies spanning over different seasons can be conducted in order to alleviate concerns stemming from comparison of emissions measured over limited-time to annual emissions reported through the inventories. Additionally, future studies could combine ORS measurements and site-specific emission modeling performed for inventory calculations. A better dialog between scientists conducting the measurements and the facility operators could also be crucial to improve our understanding of how site activities may affect measured emissions.

Traditional Leak Detection and Repair (LDAR) is an important practice to control and limit unplanned VOC emissions from refineries and to identify potential leak sources. The ORS techniques used in this study have demonstrated their ability to quickly quantify and map refinery emissions and to identify potential air pollution sources within a facility. Using real time measurements, refinery personnel and air quality regulators can enhance LDAR programs by prioritizing LDAR activities. Addressing the most concerning issues first is important to reduce occupational risks for refinery workers, avoid public hazard exposures, and limit the economic losses due to unplanned evaporation of refinery products.

A continued path towards improved air quality involves a good understanding of current emission levels and sources. Repeated and systematic emission measurements will be an important tool for benchmarking industry’s environmental performance as well as for sustaining and verifying efficient emission improvement plans, ultimately resulting in cleaner air and a better environment.

Acronyms, Units and Definitions

Acronyms used in this report

ASOS	Surface Weather Observation Stations
BPD	Barrels per day
BTEX	Sum of Benzene, Toluene, Ethyl Benzene and Xylene
DOAS	Differential Optical Absorption Spectroscopy
FTIR	Fourier Transform InfraRed
LDAR	Leak Detection And Repair
LIDAR	Light Detection and Ranging
MWDOAS	Mobile White cell DOAS
MeFTIR	Mobile extractive FTIR
SOF	Solar Occultation Flux
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
VOC	Volatile organic compound, used interchangeably for non-methane VOC

Units

Air temperature	degrees C
Atmospheric Pressure	mbar
Relative Humidity	%
Wind direction	degrees North
Wind speed	m/s
Column	mg/m^2
Concentration	mg/m^3
Flux	kg/h

Unit Conversions

1 lbs = 0.4536 kg
1 kg/h = 52.9 lbs/day
1 bbl = 159 l
1 bbl/day = 5.783 kg/h (crude oil)
1 (short) ton = 907.2 kg
1 kton/year = 104 kg/h
1 klbs/year = 0.052 kg/h

Definitions

Alkane or alkanes are considered to be all non-methane alkane species.

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1 Introduction and Background

Industrial volatile organic compound (VOC) emissions contribute to significant formation of ground level ozone which is formed through atmospheric chemical reactions of volatile organic compounds (VOCs) and nitrogen oxides NO_x in the presence of sunlight, often called photo chemical smog. Elevated ozone concentrations are known to reduce crop yields and constitute a public health concern.

Larger metropolitan areas in the US, including the South Coast Air Basin, have trouble meeting ozone standards since anthropogenic sources tend to be concentrated in urban areas, including both mobile and stationary sources. VOC emissions from the latter category, i.e. refineries, petrochemical industries and solvent use, are typically dominated by evaporative losses from storage tanks and process equipment, so called fugitive emissions. Industrial NO_x and SO_2 emissions, on the other hand, occur primarily from external combustion sources. These channeled emissions are quite well understood since they come from relatively few places in an industrial site and since they can be monitored using conventional technology. Evaporative losses of VOCs can potentially occur in every unit in which petroleum products are stored, processed or transported. Units that are malfunctioning, in need of maintenance, or irregularly operated can have drastically elevated emissions without giving any indication. These types of irregular emissions can remain unnoticed if measurements of diffuse emissions are not made.

The industries typically estimate their emissions with emission factors calculated using methods and formulas described in AP-42, Compilation of Air Pollutant Emission Factors (US-EPA 2013). New Technologies for quantitatively measuring these types of VOC emissions exist but have so far only been applied at limited facilities. Estimates of VOC emissions from refineries and petrochemical are therefore rarely verified by quantitative measurements. Since reported total VOC emissions from a facility are typically a very small fraction (typically in the order of 0.01-0.10 %) of its crude oil capacity, emissions would remain insignificant in any type of mass balance even if they were many times larger than reported.

Measurements during the 2000 TexAQS (Texas Air Quality Study) and the 2006 TexAQS II indicated that current emission inventories significantly underestimate industrial VOC emissions in Houston (Kleinman *et al.* 2002; Ryerson 2003; Wert *et al.* 2003; Jobson 2004; Mellqvist *et al.* 2010; Karl 2003; De Gouw, J. A. de *et al.* 2009; Washenfelder *et al.* 2010; Parrish *et al.* 2009). Similar conclusions have also been drawn from international studies elsewhere such as Sweden (Kihlman 2005; Kihlman *et al.* 2005), The Netherlands (Mellqvist *et al.* 2009), France (INERIS 2010) and Belgium (Samuelsson *et al.* 2011). Several studies have concluded that industrial VOC emissions contribute significantly to ozone formation (Kleinman *et al.* 2002; Ryerson 2003; Jobson 2004; Gilman *et al.* 2009; Kim *et al.* 2011; Wert *et al.* 2003; Kim *et al.* 2011).

In order to improve the understanding of VOC, NO_2 and SO_2 emissions in the South Coast Air Basin (SCAB) and to assess whether they impact the ground level ozone in a significant way, the South Coast Air Quality Management District (SCAQMD) has promoted and sponsored several measurement projects to study these emissions using optical remote sensing methods. The projects include experimental studies of emissions from refineries, oil depots, treatment facilities, oil wells, gas stations, fuel islands, barges and shipping. In addition, a technology demonstration and validation study was carried out to assess the uncertainties of different optical techniques using side-by-side measurements of real sources and controlled source gas releases. This work is an extension of a pilot study that was carried out by FluxSense in Los Angeles area in September/October 2013 (Mellqvist *et al.* 2013a, 2013b).

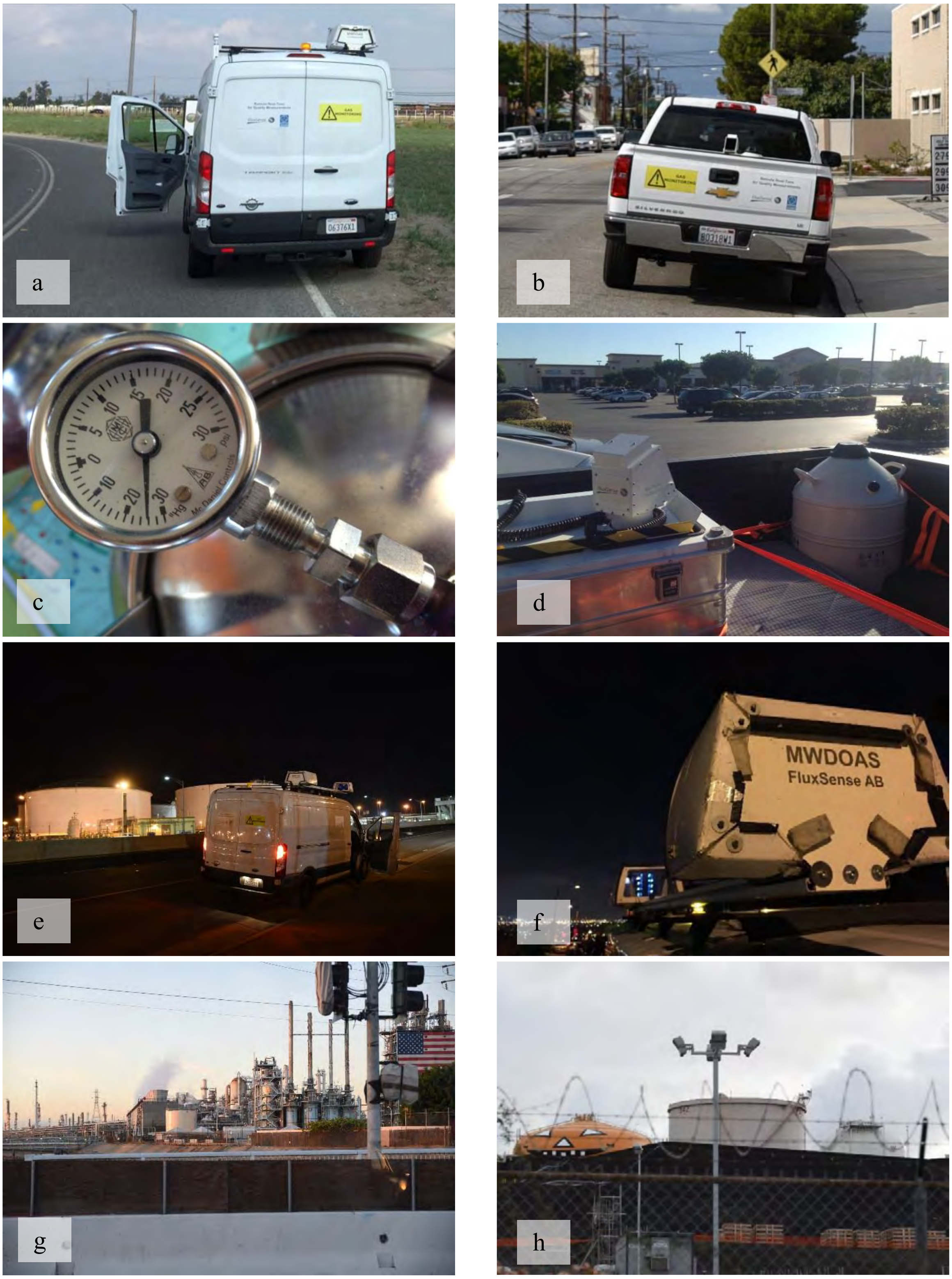

Figure 1. Example images from the 2015 SCAQMD measurement survey. a) FluxSense Mobile lab, b) secondary SOF vehicle, c) Canister sampling, d) Secondary SOF system, e) Night-time MeFTIR measurements, f) MWDOAS measurement, g) Refinery view, h) Tank park view.

This report covers the results from the first of three SCAQMD projects. This project studied emissions of VOCs, CH_4, SO_2 and NO_x from the six main refineries in the SCAB over several months and to compare these to current inventories. This report is one of several other reports describing measurements of smaller emission sources, ship emissions and validation activities. The refineries are denoted Refinery A, Refinery B, Refinery C, Refinery D, Refinery E, and Refinery F respectively. These refineries have a total reported crude oil capacity of more than 900,000 bbl/day (California Energy Commission 2016) and are major contributors of VOC-emissions and, consequently, smog formation in the region.

Two mobile remote gas sensing techniques, SOF (Solar Occultation Flux) and Mobile Sky-DOAS (Differential Optical Absorption Spectroscopy) were operated around the perimeter of the six selected refineries for estimation of facility-wide mass emission fluxes of VOCs, SO_2 and NO_2. The remote gas sensing techniques were complemented by mobile extractive optical methods, i.e. MeFTIR (Mobile extractive FTIR) and MWDOAS (Mobile White cell DOAS) to map ground concentrations of alkanes, methane and aromatic VOCs to calculate inferred fluxes. A mobile wind LIDAR station supplied by SCAQMD allowed for the continuous measurements of vertical wind profiles. Wind data was also obtained from local meteorological stations to complement the LIDAR results. See Figure 1 for example of measurement situations.

SOF is a proven technique employed by FluxSense in over 100 fugitive emission studies around the world. In Europe the SOF technique is Best Available Technology (European Commission 2015) for measurements of fugitive emission of VOCs from refineries and in Sweden it is used together with tracer correlation and optical gas imaging to screen all larger refineries and petrochemical industries annually. The Swedish facilities are visited during at least 10 days per year, spread out over the different seasons, to give a good representation of annual mean conditions. The measurements represent the total emission coming from the entire refinery, divided into sub parts such as process areas, crude oil storage, product storage tanks, water treatment facilities, flares and loading operations. The estimated uncertainty for the emissions is typically 30 % for the total site emissions, and somewhat higher for the individual parts. This has been concluded from several controlled source gas release experiments (blind and non-blind) and side-by-side measurements with other measurement techniques.

The measurements were carried out in the period August 28 to November 11 2015, with up to 15 individual measurements days at the individual sites, and up to 40 individual measurements. Representative statistics of measured emissions (e.g. average, standard deviation, median, etc.) were determined for this time period. Measurements were generally conducted outside the facilities fence-lines along public roads measuring both upwind and downwind the refineries to account for inflow of pollutants from the background. During a week and a half (September 28 to 7 October), measurements were also conducted inside the Refinery A at the main eastern tank farm. The aim was to quantify and to locate leaking tanks and components and to validate the technique by comparative measurements.

In this report, the results from these refinery measurements are compared to the reported annual emission inventories. Discrepancies between reported annual inventories and measured emissions are discussed and further investigated.

In parallel to this project an additional study was carried out in which the SOF method was compared to other optical techniques, DIAL (Differential Absorption LIDAR) and long-path FTIR using side-by-side measurements on various tanks inside a refinery, a treatment plant and an oil well cistern; here the agreement with the other methods was excellent, i.e. 10-20 %. As part of the same study, a blind gas release experiment was carried out, using a controlled source releasing 2-25 kg/h of propane at the parking lot of the Angels of Anaheim baseball stadium, Anaheim, CA. Here the SOF measurements consistently underestimating the true emission by 35% but with a good correlation (R^2 ~98%). This study is compiled in a separate paper.

2 Instrumentation and Methods

The FluxSense mobile laboratory was equipped with four instruments for gas monitoring during the survey; SOF, SkyDOAS, MeFTIR and MWDOAS. Individual measurement methods are described briefly in the subsections below. SOF and SkyDOAS both measure gas columns through the atmosphere by means of light absorption. SOF utilizes infrared light from the direct sun whereas SkyDOAS measure scattered ultraviolet light from the sky. MeFTIR and MWDOAS both measure ground level concentrations of alkanes and BTEX respectively. Accurate wind data is necessary in order to compute emission fluxes. Wind information for the survey was derived from several different sources as described in detail in Section 2.5. A wind LIDAR was used to measure vertical profiles of wind speed and wind direction from 50-1000 m height. The LIDAR data was supported with complimentary data from several wind masts at fixed met network- and mobile stations.

Figure 2 gives a general overview of the measurement setup and the data flow and pictures of the FluxSense mobile lab is found in Figure 3.

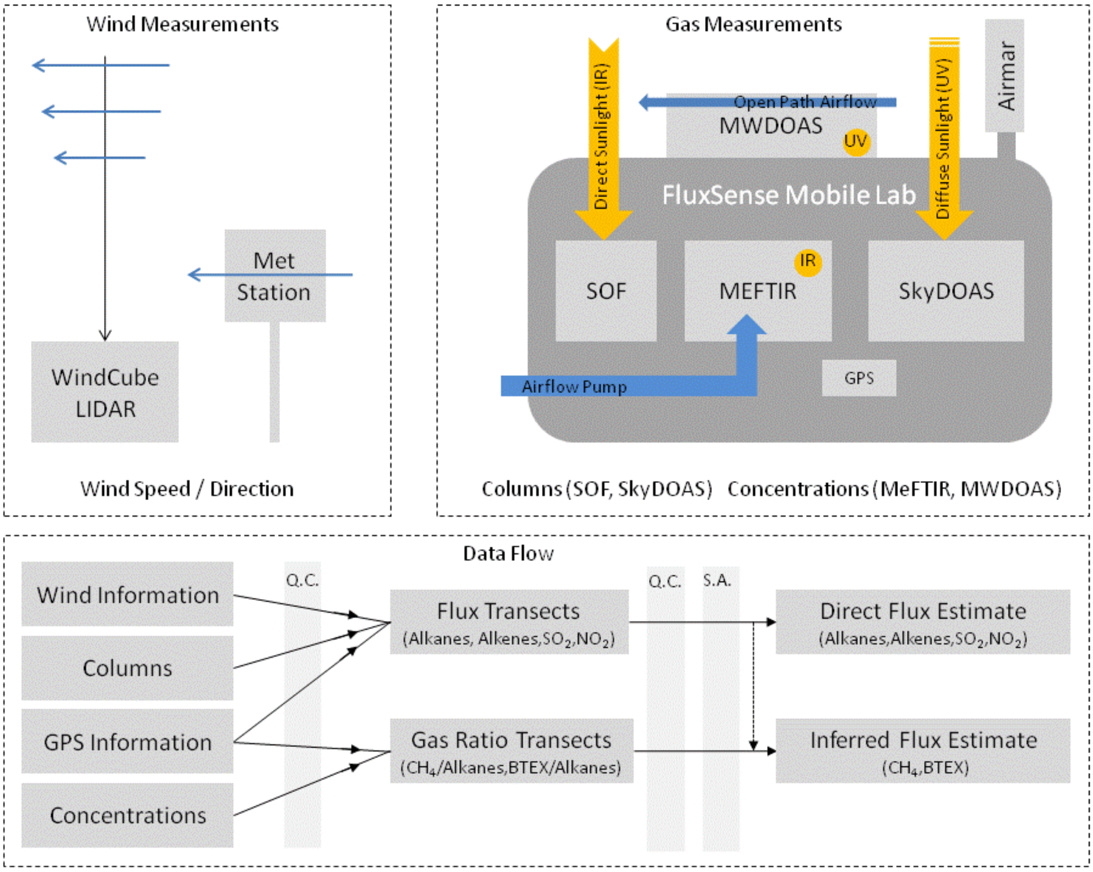

Figure 2. Overview of the FluxSense mobile lab main instruments; SOF, MeFTIR, MWDOAS and SkyDOAS (upper right panel) and wind measurements (upper left panel) and simplified data flow diagram (lower panel). SOF and SkyDOAS are column integrating passive techniques using the Sun as the light source while MeFTIR and SkyDOAS sample local air concentrations using active internal light sources. The data flow describes what information that goes into the flux emission estimates. Direct flux emissions are given from measured columns (SOF and SkyDOAS) of alkanes, SO_2 and NO_2, while inferred fluxes are calculated via gas concentration ratios (MeFTIR and MWDOAS) of BTEX and CH_4. See section 3.2 for principal equations. All emission flux estimates are based on statistical analysis of measured data. Q.C. = Quality Control, S.A.= Statistical Analysis (see Appendix for details).

In order to derive final emission flux estimates, the GPS-tagged gas column measurements by SOF and SkyDOAS are combined with wind data and integrated across plume transects at the various source locations. Gas mass ratio measurements by MeFTIR and MWDOAS are then used to infer emission estimates also for methane and BTEX (which can't be measured directly by SOF and SkyDOAS).

During some of the measurement days at the end of the survey (29 October to 9 November), a second SOF instrument was also used. This additional SOF platform was placed on the bed of a pick-up truck (see Figure 1b) and operated independently of the FluxSense mobile lab, but with a similar optical setup. The second instrument made it possible cover more objects within the survey time frame.

Figure 3. Internal and external view of the FluxSense mobile lab.

A table summarizing the main features and characteristics of all measurement techniques used for this study is found in Table 1.

Table 1. Summary of FluxSense gas measurement techniques. *For typical wind conditions at an optimal distance from the source.

Method	**SOF**	**SkyDOAS**	**MeFTIR**	**MWDOAS**
Compounds	**Alkanes**: (C_nH_{2n+2}) **Alkenes:**C_2H_4, C_3H_6	**SO_2** **NO_2**, **HCHO**	**CH_4** **Alkanes:** (C_nH_{2n+2}) **Alkenes:** C_2H_4, C_3H_6	**BTEX**
Detection limit Column	0.1-5 mg/m^2	0.1-5 mg/m^2	1-10 ppbv	0.5-3 ppbv
Detection limit Flux*	0.2-1 kg/h	1 kg/h	0.2-2 kg/h	1-2 kg/h
Wind Speed Tolerance	1.5-12 m/s	1.5-12 m/s		
Sampling Time Resolution	1-5 s	1-5 s	5-15 s	8-10 s
Measured Quantity [unit]	Integrated vertical column mass [mg/m^2]	Integrated vertical column mass [mg/m^2]	Mass concentration at Vehicle height [mg/m^3]	Concentration at Vehicle height [mg/m^3]
Inferred Quantity [unit]	Mass Flux [kg/h]	Mass Flux [kg/h]	Alkane ratio of ground plume combined with SOF gives mass flux [kg/h] and plume height information [m]	Combined with MeFTIR and SOF gives Mass Flux [kg/h]
Complementary data	Vehicle GPS-coordinates, Plume wind speed and direction	Vehicle GPS-coordinates, Plume wind speed and direction	Vehicle GPS-coordinates, Plume wind direction	Vehicle GPS-coordinates, Plume wind direction

2.1 The SOF method

The SOF method (Mellqvist 1999; Mellqvist *et al.* 2008b; Mellqvist *et al.* 2008a; Mellqvist *et al.* 2009; Mellqvist *et al.* 2010; EPA 2011) is based on the recording of broadband infrared spectra of the sun with a Fourier transform infrared spectrometer (FTIR) that is connected to a solar tracker. The latter is a telescope that tracks the sun and reflects the light into the spectrometer independent of the orientation of the vehicle. From these solar spectra, it is possible to use multivariate optimization to retrieve the path-integrated concentrations (referred to as column concentrations) of various species between the sun and the spectrometer (in the unit mg/m^2). The system used in this project consists of a custom built solar tracker, transfer optics and a Bruker IRCube FTIR spectrometer with a spectral resolution of 0.5 cm^{-1}, equipped with a dual InSb (Indium Antimonide) / MCT (Mercury Cadmium Telluride) detector. A reference spectrum is taken outside the plume so that atmospheric background concentrations can be removed. This means that all measured SOF columns are analyzed relative to the background column concentrations.

The system is installed in a measurement vehicle which allows consecutive column concentration measurements to be performed while driving. The flux of a species in a plume from an industry is measured by collecting spectra while driving the vehicle so that the light path from the sun to the instrument gradually cuts through the whole plume, preferably as orthogonally as possible to the wind direction, see Figure 4.

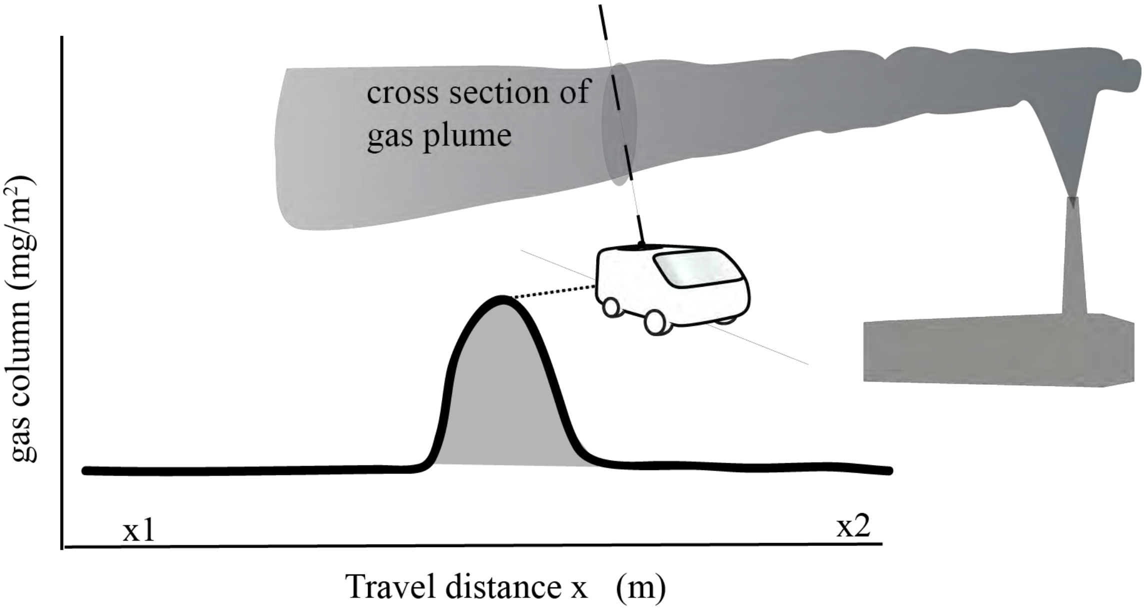

Figure 4. Schematic of the SOF measurement where the vehicle is driven across the prevailing wind so that the solar beam cuts through the emission plume while the sun is locked into the FTIR spectrometer by the solar tracking device on the roof. The VOC mass (or other compound of interest) is integrated through the plume cross section. See section 3.2 for complete equations.

For each spectrum a column concentration of the species is retrieved using custom software (QESOF, i.e. Quantitative evaluation of SOF) (Kihlman *et al.* 2005). These column concentrations, together with positions recorded with a GPS (Global Positioning System) receiver and the solar angle calculated from the time of the measurements, are used to calculate the area integrated column of the species in the intersection area between the plume and the light path. The flux of the species is then obtained by multiplying this area integrated concentration with the orthogonal wind speed vector component.

The IR spectra recorded by the SOF instrument are analyzed in QESOF by fitting a set of spectra from the HITRAN infrared database (Rothman *et al.* 2003) and the PNNL database (Sharpe *et al.* 2004) in a least-squares fitting procedure. Calibration data from the HITRAN database is used to simulate absorption spectra for atmospheric background compounds present in the atmosphere with high enough abundance to have detectable absorption peaks in the wavelength region used by SOF. Spectra, including water vapor, carbon dioxide and methane, are calibrated at the actual pressure and temperature and degraded to the instrumental resolution of the measurements. The same approach is applied for several retrieval codes for high resolution solar spectroscopy developed within Network for the Detection of Atmospheric Composition Change (NDACC) (Rinsland *et al.* 1991; Griffith 1996), and QESOF has been tested against these with good agreement, better than 3%. For the retrievals, high resolution spectra of ethylene, propene, propane, n-butane and n-octane were obtained from the PNNL (Pacific Northwest National Laboratory) database and these are degraded to the spectral resolution of the instrument by convolution with the instrument line shape. The uncertainty in the absorption strength of the calibration spectra is about 3.5% for all five species.

In this project, the SOF method was used to measure VOCs in two different modes. Most VOCs with C-H-bonds absorb strongly in the 3.3-3.7 µm (2700-3005 cm^{-1}) spectral region. This region is mainly used for alkane measurements using a spectral resolution of 8 cm^{-1}. Alkenes (including ethylene and propylene) are instead measured in the spectral region between 910 and 1000 cm^{-1} using a spectral resolution of 0.5 cm^{-1}. In the alkane mode – the IR light absorption is essentially sensitive to the total alkane mass (number of alkane C-H bonds) present in the plume. The absorption structures (cross sections) for the various alkane compounds are rather similar, with the absorption strength scaling to the mass of the alkane species. Hence, the actual mix of alkanes in the plume does not affect the retrieved total alkane mass flux much, although only cross sections from a subset of all alkanes (propane, n-butane and octane) are fitted in the spectral analysis. Typically, the rare event of significant absorption from other species in the plume shows up as elevated residuals and is further investigated in the re-analysis. For the alkene mode the specificity of the measurements is good, since the absorption of different species is rather unique in this so called "fingerprint region" and absorption features are often sharp and well separable from each other at 0.5 cm^{-1} resolution.

2.2 Mobile SkyDOAS

The principle for Mobile SkyDOAS (Mobile Differential Optical Absorption Spectroscopy) measurements is very similar to that of SOF. Instead of measuring direct sun light in the infrared region, scattered light in the UV and visible region is measured in zenith angle with a telescope connected with an optical fiber to a Czerny-Turner spectrometer with a CCD camera. Column concentrations are retrieved from spectra in a similar way as with the SOF, although absorption is generally weaker. The system that was used for this project consists of a quartz telescope (20 mrad field of view, diameter 7.5 cm) connected with an optical fiber (liquid guide, diameter 3 mm) to a 303 mm focal length Czerny-Turner spectrometer with a 1024 by 255 pixels, thermoelectrically cooled CCD camera, see Figure 5.

Figure 5. The mobile Sky-DOAS system: Telescope, optical fibre, spectrometer and control computer.

The system was installed in the same measurement vehicle as the SOF system. Plumes were transected in the same way as with the SOF system and the retrieved column concentrations used to calculate fluxes exactly the same way, except that the SkyDOAS measurement direction is always zenith.

In this project, mobile SkyDOAS was used to measure SO_2, NO_2 and HCHO. NO_2 is retrieved in the wavelength region between 324 and 350 nm and SO_2 in the region 310-325 nm. HCHO is measured in the region 322-350 nm. It was however never found above detection limit in any repeatable measurement during the campaign and is therefore not included in the result section. Apart from SO_2, NO_2 and HCHO the spectral analysis also includes other atmospheric compounds such as O_3 and O_4. The rare event of significant absorption from other species in the plume than those included in the spectral fit shows up as elevated residuals and is further investigated in the re-analysis. The absorption line parameters of the retrieved compounds are well established in published databases, stating an uncertainty of 4% (Vandaele *et al.* 1998) for the UV cross section of NO_2 and less than 2% for the SO_2 cross sections (Bogumil *et al.* 2003).

The DOAS technique was introduced in the 1970's (Platt *et al.* 1979) and has since then become an increasingly important tool in atmospheric research and monitoring both with artificial light sources and in passive mode utilizing the scattered solar light. In recent time the multi axis DOAS technique (scanning passive DOAS) has been applied in tropospheric research for instance measuring formaldehyde (Heckel *et al.* 2005; Pikelnaya *et al.* 2007).

Passive DOAS spectroscopy from mobile platforms has also been quite extensively applied in volcanic gas monitoring (Galle *et al.* 2003) for SO_2 flux measurements and for mapping of formaldehyde flux measurements in megacities (Johansson *et al.* 2009), . Mobile SkyDOAS has been used in several studies for measurements of industries i.e. SO_2, NO_2 and HCHO for several campaigns in Texas including NO_2 measurements at Longview in 2012 (Johansson *et al.* 2014a; Johansson & Mellqvist 2013). (Rivera 2009) did SO_2 measurements on a power plant in Spain for validation purposes. They also made measurements at an industrial conglomerate in Tula in Mexico (Rivera *et al.* 2009a) and measurements of SO_2, NO_2 and HCHO during the TexAQS 2006 campaign (Rivera *et al.* 2009b; Rivera *et al.* 2010). There are also groups in both China and Spain working with mobile mini DOAS.

2.3 Mobile extractive FTIR

Mobile Extractive FTIR (MeFTIR) (Galle *et al.* 2001; Börjesson *et al.* 2009) in combination with tracers has been used to quantify VOC emissions from refinery and petrochemical sources in Europe and in the U.S. Alkanes and alkenes are typically measured, but also methane and other climate gases can be retrieved. MeFTIR is an optical technique capable of monitoring gas concentrations at ppb-sensitivity in mobile field operations. It is used both independently for concentration mapping and flux measurements, but often combined together with simultaneous SOF flux measurements to provide more detailed VOC speciation of plumes and for plume height assessments (Johansson *et al.* 2014b). The plume height can be estimated by dividing measured columns (mg/m^2) with ground concentrations (mg/m^3), assuming that the plume is evenly distributed up to the plume height (and zero above).

The MeFTIR system contains a mid-infrared spectrometer with medium resolution (0.5 cm^{-1}). It utilizes an internal glow bar as an infrared radiation source, and by customized optics this light is transmitted through an optical multi-pass measurement cell with selectable path-length of 9.6-107.2 meters. The system is mounted on a vibration dampening platform to allow for real time plume mapping from a mobile platform, such as a vehicle or boat, see Figure 6.

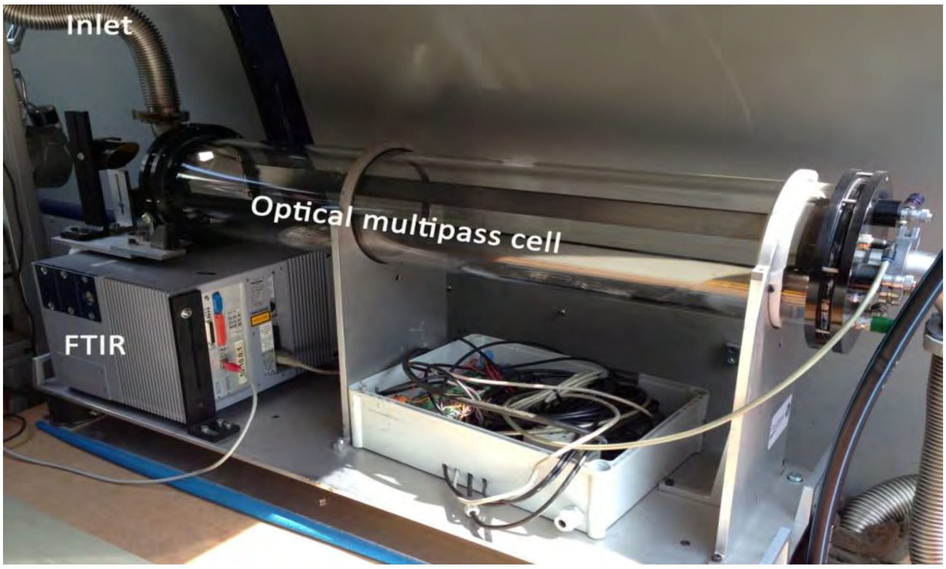

Figure 6. The MeFTIR instrumentation consisting of a Bruker FTIR spectrometer connected to an optical multi-pass cell.

The transmitted light is detected simultaneously with an InSb-detector (Indium Antimonide) in the 2.5–5.5 µm (1800–4000 cm^{-1}) region and a MCT (Mercury Cadmium Telluride) detector in the 8.3–14.3 µm (700–1200 cm^{-1}) region. Temperature and pressure in the cell are averaged over the duration of each measurement. Atmospheric air is continuously pumped at high flow rate through the optical cell from the outside, taking in plume air from the roof of the vehicle (2.5 m height) through a Teflon tube. A high flow pump is used to ensure that the gas volume in the cell is fully replaced within a few seconds. Spectra are typically recorded with an integration time of 10 seconds. A GPS-receiver is used to register the position of the vehicle every second.

The concentration in the spectra is analyzed in real time by fitting a set of calibrated spectra from the Hitran infrared database (Rothman *et al.* 2003) and the PNNL database (Sharpe *et al.* 2004) in a least-squares fitting procedure. Compounds being analyzed include ethylene, propylene, total alkane mass (based on fitting cross sections of ethane, propane, n-butane, i-pentane, n-octane), water, methane, CO, CO_2 and N_2O. The analysis routines are very similar to the ones for SOF, but less complex because strong absorption by atmospheric trace gases (water, methane, CO_2) has less consequence at the shorter path length in the MeFTIR measurement cell.

The MeFTIR tracer approach has been tested in a so called gas release “blind test” together with other techniques in U.S. (Babilotte 2011). In that test, methane was released from an area-distributed source in four different configurations and flow rates ranging from 1.1-3.3 g/s. At a downwind distance of 400 meters MeFTIR retrieved the fluxes within 6% in 3 cases and 19% in the fourth. This is consistent with other validation experiments, showing a flux estimate accuracy of better than 20%. Concentration measurement by FTIR is a widely used procedure, and the main uncertainties are associated with the absorption cross sections (typically < 3.5%) and spectral retrieval, with an aggregate uncertainty better than 10% in the analysis. Concentrations are monitored in real time in order to detect emission plumes and to judge whether any interfering sources are being sampled. Unwanted signals from local traffic exhaust or from the measurement vehicle itself could be filtered out by looking at the carbon monoxide (typical exhaust compound) concentrations. A stationary source is, on the contrary to any local traffic plumes, characterized by recurrent downwind plumes. Transient and non-repeatable observations are therefore excluded from the results. Furthermore, measurements of ambient concentrations of methane and carbon dioxide (with known atmospheric concentrations) are used for consistency check.

2.4 Mobile White Cell DOAS (MWDOAS)

The ground level mass concentration of benzene, toluene, ethylbenzene, *meta*- and *para*- xylene (BTEX) was measured using a mobile real-time system: Mobile White cell DOAS (MWDOAS). The Mobile White cell DOAS system consists of an open, 2.5 m long optical White cell that is mounted on the roof of the measurement vehicle (see Figure 7). By multiple reflections in the White cell mirror system an overall path length of 210 m is obtained, resulting in low detection limits (ppb). The light from the internal lamp is transmitted through the White cell and then analyzed in a DOAS spectrometer, using the UV wavelength region 255 - 285 nm.

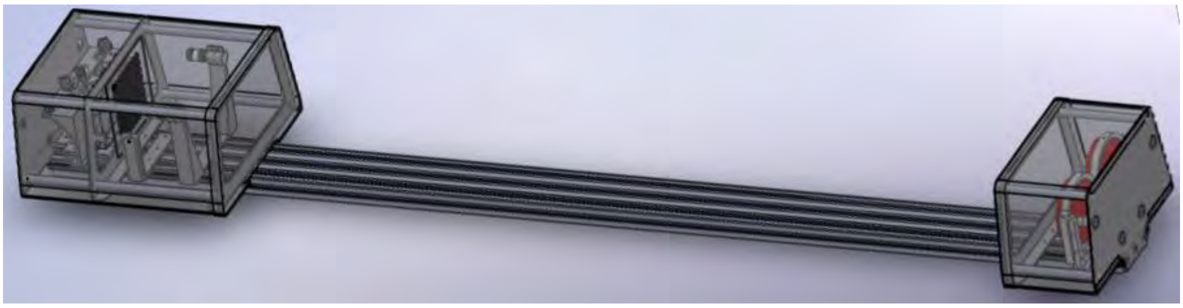

Figure 7. The open path MWDOAS cell having an overall optical path-length of 210 m.

A measurement begins by acquiring a reference spectrum outside the plume, usually upwind of the facility. Spectra are then sampled and averaged continuously while driving through emission plumes. The averaging time is set to around 8 seconds in order to achieve acceptable SNR (see below). This is the lower limit of the temporal sampling between independent measurements, but the spatial sampling is also dependent by the vehicle’s velocity. A typical driving speed for MWDOAS measurements is 10-20 km/h for sufficient plume sampling.

The spectra are geo-tagged and evaluated online using the standard DOAS technique, giving information of plume locations and constituents. Cross-sections included in the evaluation are tabulated in Table 2.

Table 2. The UV-cross-sections used in the evaluation of the MWDOAS spectra.

Chemical compound	**Origin of reference spectrum**
O_3	(Burrows *et al.* 1999)
SO_2	(Bogumil *et al.* 2003)
O_2	(Bogumil *et al.* 2003)
Toluene	(Fally *et al.* 2009)
Benzene	(Etzkorn *et al.* 1999)
1,3,5-Trimethylbenzene	(Etzkorn *et al.* 1999)
1,2,4-Trimethylbenzene	(Etzkorn *et al.* 1999)
Styrene	(Etzkorn *et al.* 1999)
Phenol	(Etzkorn *et al.* 1999)
p-xylene	(Etzkorn *et al.* 1999)
m-xylene	(Etzkorn *et al.* 1999)
Ethylbenzene	(Etzkorn *et al.* 1999)

The MWDOAS data is later post evaluated and merged with the corresponding MeFTIR data to produce a plume specific BTEX/alkane mass ratio. The mass ratio of BTEX/alkanes is then used to calculate the aromatic flux from individual sub areas where alkane fluxes have been measured by SOF, assuming they have the same source. Specific area plumes are ideally probed at several times, and an overall average of all plume transect BTEX/alkane ratios is then made. The method requires in situ access to the plume of the studied source, and as instrumentation typically are mounted on a truck, highly elevated sources with a strong plume lift like hot flares, chimneys and high process towers will not be possible to survey at close distance.

The MWDOAS technique has been validated in various surveys by comparison with canister samples acquired at several different locations and which were subsequently analyzed by gas chromatography (GC-FID). The validation shows that the result from MWDOAS lies well within 10% of the result of the certified canister results for BTEX. Due to an absorption cross-section too weak to be used with reliability in the MWDOAS analysis, the ortho isomer of the xylene has been omitted in this comparison. When total xylene is presented in the present survey, the sum of *m*- and *p*-xylenes from the MWDOAS measurement is multiplied by 1.32. This number comes from a ratio comparison of xylene isomers in 49 canister samples analyzed by GC/FID and taken from eight refineries and tank parks from two countries. The standard deviation in this comparison was 0.07 and adds a 4.5% uncertainty to the total xylene concentration. Hence, the xylene concentration from MWDOAS is defined as the sum of the measured *m*- and *p*-isomers and the inferred *o*-isomer.

The MWDOAS system has been used in previous campaigns in USA during 2013 with good results. During the 2013 DISCOVER-AQ campaign in Houston, Texas, the system was run in parallel to a mobile Proton Transfer Mass spectrometer (PTrMS) lab as a validation check. The results of benzene, toluene and styrene was compared and showed good agreement, with the PTrMS showing slightly elevated benzene concentrations compared to the MWDOAS. The sensitivity of MWDOAS is better than 1 ppb for benzene, better than 3 ppb for toluene, ethylbenzene and *m*-xylene and as good as 0.5 ppb for *p*-xylene.

Since the distribution of the BTEX constituents varies with source we will also present the benzene to alkane ratio to facilitate the calculation of benzene flux and identify specific benzene sources.

Unwanted BTEX signals from local traffic exhausts are generally only significant in congestions (at traffic lights etc.) or in confined spaces, e.g. tunnels. Apart from this, large emitters are also occasionally seen elsewhere. They are generally recognized, partly by their typical gasoline composition signature and partly by their transient nature. A stationary BTEX source is, on the other hand, characterized by recurrent downwind plumes. Transient and non-repeatable BTEX observations are therefore excluded from the result. Note that all concentrations are above the reference/background.

2.5 Wind Measurements and Auxiliary Data

Wind LIDAR

An infrared 3D wind LIDAR provided by the SCAQMD (shown in Figure 8) was used to measure vertical wind profiles of wind speed and wind direction. The unit used for this study (i.e. model WindCube 100S) produced by Leosphere (France) provides wind profiles in the vertical range 50 to around 1000 m above surface level, or even further if atmospheric conditions allow it. Within this range data can be retrieved in 25 m vertical resolution. Stated wind speed accuracy is 0.5 m/s. Applicable radial wind speed range is -30 to 30 m/s. The system records 1s data, but 10 minute averages were used for flux calculations in this study. The principle of detection is based on the Doppler shift of the infrared pulse that the instrument sends out and retrieves. Numerous validation surveys attesting the accuracy of the WindCube LIDARs are publically available through: www.leosphere.com.

Figure 8. The WindCube 100S (Leosphere) LIDAR used for wind profile measurements in this project.

Wind Mast

Meteorological parameters were measured at selected sites using a portable 10 m mast, see Figure 9. This mast was equipped with a calibrated RM Young 05108 “prop and vane” anemometer and a Campbell Scientific CR200 data logger.

The weather mast was installed at an open location near the refinery of interest and with un-obstructed fetch for wind directions that was used for SOF measurements. The sensor was adjusted to point towards magnetic north but compensated to true north in the post-processing. Wind speed information from the 10 m mast or other wind stations in the area is used to fill in the gap of the lowest 40 m of the atmosphere where no LIDAR data exists. Since the plume heights from petrochemical facilities generally are several hundred meters during sunny conditions (some hundred meters downwind where SOF measurements are done), the wind speed information below 40 m does not influence the flux calculations substantially (typically a few percent).

Figure 9. The FluxSense mobile wind mast used in the 2015 SCAQMD survey with an RM Young anemometer mounted on top. The mast could be erected from 3 to 10 m.

Airmar (mobile weather station)

An Airmar WeatherStation (200 WX) sensor was installed on the roof of the measurement vehicle to complement the other wind measurements and give local ground winds at the vehicle. The wind information from the Airmar is not used for flux calculation but acts as a real-time aid to keep track of the plume directions when making the gas emission measurements.

The Airmar provides wind speed and direction relative to true north (compensating for vehicle position), air temperature, pressure and relative humidity. It also provides GPS positions which may be used as back-up to the other GPS-receiver.

GPS

The FluxSense vehicle is equipped with two standard USB GPS-L1 receivers (GlobalSat BU-353S4) hooked up to the SOF and DOAS-computers. They are placed horizontally by the windscreen and on the roof for optimal reception. The receivers give the position at a rate of 1 Hz.

3 Measurement Methodology

Typically the main instruments in the FluxSense mobile lab are operated during favorable meteorological conditions for each individual instrument. SOF and SkyDOAS are mainly used during solar/daytime measurements and MWDOAS and MeFTIR for gas ratio measurements during day or cloudy/nighttime conditions. Plume height calculations are dependent on simultaneous SOF and MeFTIR measurements of alkanes, so MeFTIR was typically running during solar/daytime conditions when feasible. MWDOAS and SkyDOAS were sharing the same spectrometer in this survey. Hence, time sharing between these two different techniques was necessary. In addition to the gas mass ratio measurements by MWDOAS and MeFTIR, some canisters were also sampled in selected plumes for further VOC speciation and complimentary data.

By keeping track of wind directions and avoiding strong upwind sources, the same plumes were essentially sampled during solar/daytime and cloudy/nighttime measurements so that representative gas ratios were collected. Only MeFTIR and MWDOAS measurements with repeated plume signature and high correlation between target and alkane concentrations were accepted. Canister sampling was only performed during cloudy/nighttime measurements when ground plumes are generally present and monitored in real-time.

3.1 Survey Setup

The main objective of this study was to quantify the total gas emissions of non-methane VOCs (alkanes and BTEX), NO_2, SO_2 and methane from six major refineries in the Los Angeles Basin denoted Refinery A, Refinery B, Refinery C, Refinery D, Refinery E and Refinery F respectively (see Figure 10). This was done by conducting fence-line measurements along accessible roads outside the facilities using mobile optical measurements (SOF and mobile DOAS) to obtain total gas emission fluxes from the refineries. Furthermore, ground concentration measurements were carried out with mobile MWDOAS and MeFTIR instruments to infer emission of methane, BTEX and specifically benzene.

Gas measurements were combined with wind data, primarily from SCAQMD's wind LIDAR system, but also from meteorological stations and from a mobile 10 m wind mast, to calculate fluxes and identify sources. Throughout the study the wind LIDAR was moved between four different locations (L1-L4, see Figure 10) depending on the facilities measured. The geographical positions of the refineries are noted as colored areas in Figure 10 along with various meteorological sites and wind LIDAR positions. In general, each measurement day was dedicated to one specific refinery except for Refinery B and Refinery C which were both surveyed within the same time frame.

Emissions from each refinery were calculated by driving around the targeted facility to capture the entire downwind plume and then subtracting potential contributions from emissions deriving from upwind sources. This approach is referred to as “box-measuring” in this report. When complete upwind plume measurement was not possible (e.g. lack of accessible roads), relevant upwind measurement transects were made in close proximity in space and time. The aim was to make multiple measurements during several days over the entire duration of the study (from 28 August to 10 November 2015) in order to map detected plumes at different times, during variable wind conditions, and from different distances from the sites to better understand emission variability, plume dispersion, and the potential for local community exposure.

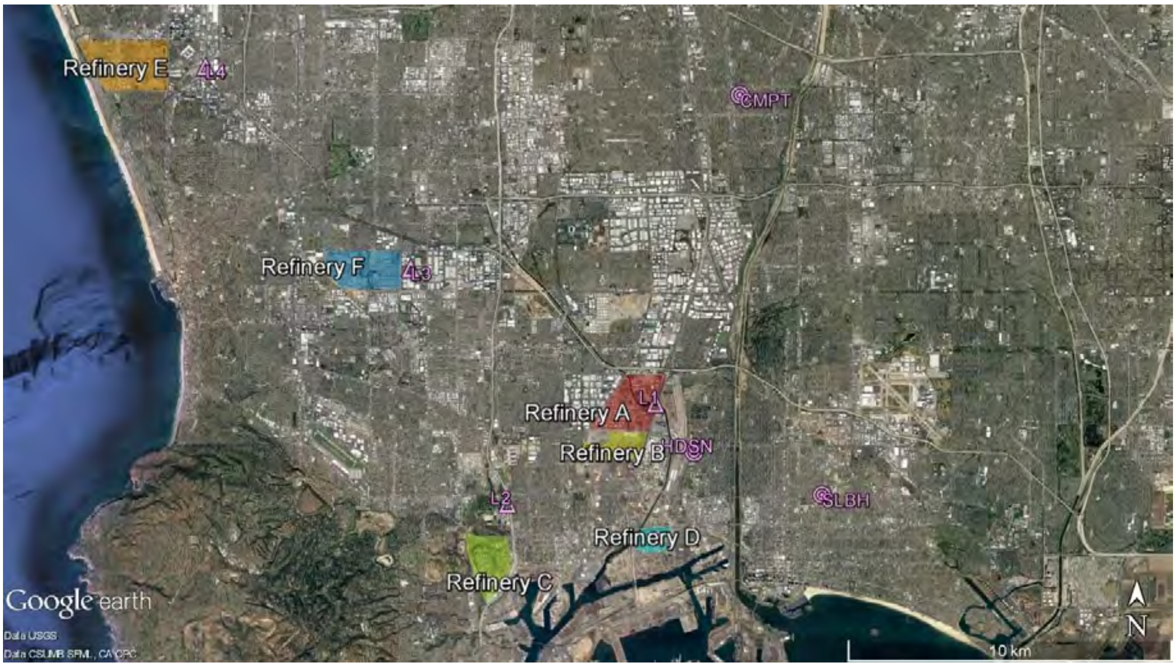

Figure 10. Map showing the locations of the six refineries that were targeted for this study. Also shown are meteorological sites and LIDAR positions. Map from Google Earth © 2016.

Altogether, measurements were carried out during 40 days, however the number of successful and quality assured measurements varied substantially from day to day and from facility to facility depending on weather conditions, local measurement conditions (e.g. road accessibility), and time sharing between different refineries and instruments.

Refinery A is the largest refinery in the Southern California Air Basin (along with Refinery E) and it has been collaborating with SCAQMD to support this campaign and making it possible to carry out 7 days of onsite measurements. In addition, 15 measurement days of total emissions were carried out on refinery fenceline. A statistical estimate of flux emissions (kg/h) was computed for each measurement day at each refinery. Total mean and median values for the entire survey period were calculated in parallel. This data was compared to the reported annual emission inventories. Extreme events (beyond 1.5 times the inter-quartile range) and possible point sources within a refinery were also noted in the report.

3.2 Principal Equations

This report includes two different techniques to measure emission mass fluxes as specified below. The primary method in this project is the direct flux measurements of alkanes from SOF. BTEX and methane fluxes are calculated using inferred fluxes from MWDOAS/MeFTIR gas mass ratios.

DIRECT FLUX MEASUREMENTS:

Direct flux is measured by SOF or SkyDOAS. The emission mass flux (Q) of species (j) for a single transect (T) across the plume (P) along path (l), can be expressed by the following integral (Si-units in gray brackets):

$$Q_T^j[\mathrm{kg/s}] = \bar{v}_T[\mathrm{m/s}] \cdot \int_P C_l^j[\mathrm{kg/m^2}] \cdot \cos(\theta_l) \cdot \sin(\alpha_l)\, dl\ [\mathrm{m}]$$

Where,

$\bar{v}_T$ = the average wind speed at plume height for the transect,
C_l^j = the measured slant column densities for the species j as measured by SOF or SkyDOAS,
θ_l = the angles of the light path from zenith ($\cos(\theta_l)$ gives vertical columns),
α_l = the angles between the wind directions and driving directions
dl = the driving distance across the plume

Note that SOF and SkyDOAS have different light paths, where the SkyDOAS telescope is always looking in the zenith direction while the SOF solar tracker is pointing toward the Sun. Hence, the measured SOF slant column densities will vary with latitude, season and time of day.

To isolate emissions from a specific source, the incoming/upwind background flux must be either insignificant or subtracted. If the source is encircled or "box-measured", the integral along l is a closed loop and the flux calculations are done with sign. This is taken care of by the FluxSense software.

INFERRED FLUX MEASUREMENTS:

Inferred flux is computed using a combination of SOF and MeFTIR/MWDOAS measurements. The inferred mass flux ($\hat{Q}^i$) for species (i) are calculated from MeFTIR and/or MWDOAS ground level gas ratios integrated over the plume (P) along path (l) are given by (Si-units in gray brackets):

$$\hat{Q}^i[\mathrm{kg/s}] = \bar{Q}^j[\mathrm{kg/s}] \cdot \frac{1}{k}\sum_k \frac{\int_P N_l^i[\mathrm{kg/m^3}]\, dl[\mathrm{m}]}{\int_P N_l^j[\mathrm{kg/m^3}]\, dl[\mathrm{m}]}$$

Where,
$\bar{Q}^j$ = the average flux of species j from multiple transects as measured by SOF,
N_l^i = the number density concentrations of species i as measured by MWDOAS or MeFTIR,
N_l^j = the number density concentrations of species j as measured by MeFTIR,
k = the number of gas ratio measurements

Note that the inferred flux calculation operates on average values since simultaneous SOF/SkyDOAS, MWDOAS and MeFTIR measurements are generally not performed and because individual gas ratios are more uncertain than the average. Although not necessarily simultaneously measured, SOF and MeFTIR/MWDOAS measurements must represent the same source plume. Note also that gas ratios do not intrinsically depend on complete plume transects (like for direct flux methods) as long as the emission plume is well mixed at the sampling distance.

The uncertainties in the total refinery emissions of BTEX and CH_4 obtained from inferred fluxes are larger than for the direct flux measurements of alkanes. Ideally the gases should be well mixed in the plume for this method to work the best, but in reality there will be a stronger weighting towards low elevated sources (tanks) compared to higher elevated ones (process units) depending on the measurement geometry. In the past we have done canister sampling in several European refineries, and typically the BTEX fraction is higher in the process units (10-15 %) compared to tank farms (5-10 %). The inferred emission flux of BTEX will consequently be a low estimate of the BTEX emission. For smaller, more isolated sources we estimate that the uncertainty of the inferred fluxes is only slightly higher than the direct flux measurement.

PLUME HEIGHT ESTIMATES:

This is a method to calculate approximate plume heights from simultaneous SOF slant columns and MeFTIR ground level concentrations, measured across an emission plume. The plume height, h_T, for a transect, *T*, across a plume, *P*, along the path, *l*, is given by the following equation (Si-units in gray brackets):

$$h_T^j[\mathrm{m}] = \frac{\int_P C_l^j[\mathrm{kg/m^2}] \cdot \cos(\theta_l)\ dl[\mathrm{m}]}{\int_P N_l^j[\mathrm{kg/m^3}]\ dl[\mathrm{m}]}$$

Where,

C_l^j = the slant column density of species j as measured by SOF,
θ_l = the angle of the light path from zenith ($\cos(\theta_l)$ gives vertical columns),
N_l^j = the number density concentrations of species *j* from MeFTIR,

This method distributes the plume homogeneously from the ground to the plume height (and zero above). In reality, however, emission plumes have a vertical gradient controlled by wind shear, turbulence, atmospheric lapse rate, release altitude e t c. Hence, the plume height as calculated using the equation above, is only a first order approximation. In this report, plume heights have consistently been calculated using alkane measurements (i.e. j=*alkane*). Median values of multiple plume height estimates are used to decrease uncertainties.

3.3 Uncertainties and Error Budget

Table 3 summarizes the accuracy, precision, and data completeness for measurements from each instrument employed during this field campaign.

Table 3. Accuracy, precision, and data completeness for measurements from each of FluxSense's measurement methods.* For the optical measurements conducted in this project data completeness is difficult to estimate since the measurements are dependent on external parameters such as weather conditions.

Measurement Parameter	Analysis Method	Accuracy	Precision	Completeness*
SOF column concentrations alkanes, alkenes	QESOF spectral retrieval	±10%	±5%	70-90%
SkyDOAS column concentrations NO_2, SO_2	DOAS spectral retrieval	±10%	±5%	70-90%
MeFTIR concentrations CH_4, VOC,	QESOF spectral retrieval	±10%	±5%	95%
MWDOAS concentrations BTEX, Benzene	MWDOAS spectral retrieval	±10%	±5%	90%
Wind Speed (5m)	R.M. Young Wind monitor	±0.3 m/s or 1%	±0.3 m/s	95%
Wind Direction (5m)	R.M. Young Wind monitor	±5°	±3°	95%
Wind Speed (10m)	Gill WindSonic	±2%	-	95%
Wind Direction (10m)	Gill WindSonic	±3°	-	95%
LIDAR Wind Direction (50-1000m)	Leosphere Windcube 100S	-	-	>90% except in heavy fog
LIDAR Wind Speed (50-1000m)	Leosphere Windcube 100S	±0.5 m/s	-	
GPS position	USB GPS receiver	±2m	±2m	100%
SOF mass flux Alkanes, alkenes	SOF flux calculations	±30%	±10%	80% (in suitable weather conditions)
SkyDOAS mass flux NO_2, SO_2	SkyDOAS flux calculations	±30%	±10%	80% (in suitable weather conditions)

Accuracy of measurement parameters is determined by comparing a measured value to a known standard, assessed in terms of % bias, using the following equation:

$$\left[1 - \left(\frac{Measurement}{Standard}\right)\right] \times 100$$

Precision is a measure of the repeatability of the results. The precision for the SOF and mobile SkyDOAS system is difficult to measure when inside the gas plumes. However, it is assumed that the precision of the instrument corresponds to the 1-sigma noise when measuring in clean air background. The precision of each instrument used in this project is listed in Table 3.

Data completeness is calculated on the basis of the number of valid samples collected out of the total possible number of measurements. Data completeness is calculated as follows:

$$\%\ Completeness = \left(\frac{Number\ of\ valid\ measurements}{Total\ possible\ measurements}\right) \times 100$$

3.4 Wind Statistics and Plume Heights

The largest source of error in SOF and SkyDOAS emission flux calculations is typically determined by the quality of the collected wind measurements. The flux is directly proportional to the wind speed (at average plume height) and to the cosine of the wind direction relative to the driving direction. The total wind uncertainty results from a combination of wind measurements errors (see Table 3) and errors due to the assumption that the measured wind velocity measured is representative of the average plume velocity. Wind profile data, as supplied by a LIDAR, has the major advantage of allowing an average wind for an arbitrary height interval to be calculated. Given some approximate information about the mixing height of the plume, a suitable averaging interval can be chosen, and the LIDAR data can also be used to estimate the sensitivity of the wind error to the error in the mixing height. Estimates of the plume mixing height estimates can in turn be retrieved by simultaneous concentration and column measurements with SOF and MeFTIR as described in section 3.2. The method assumes homogeneous plume concentrations from ground level to the plume height. Plume height results for the different refineries in this study are found in Table 4 and Figure 11.

Table 4. Summary of plume height (median values) estimations for all refineries surveyed during this study. Wind information used for flux calculations is also reported (all non-LIDAR winds scaled to LIDAR 0-400m with the given scaling factors). *Measurements at Refinery D were conducted during a flaring event with high elevated plumes.

Refinery	**Number of Measurements**	**Median Plume Height** [m]	**Primary Wind** (0-400m)	**Secondary Wind** (Scaling factor)
Refinery A	19	475	LIDAR L1	Refinery A Mast (1.34)
Refinery B	3	514	LIDAR L1	Refinery A Mast (1.34)
Refinery C	5	464	LIDAR L2	AQMD-SLBH (1.0)
Refinery D*	2	835	LIDAR L1	ASOS-KLGB (1.17)
Refinery E	11	239	LIDAR L4	ASOS-KLAX (0.83)
Refinery F	6	292	LIDAR L3	LIDAR L1 (1.0)
All Refineries	**46**	**413**		

These results indicate a plume height of 250-500 m with an overall median for all refineries of around 400m. The high values at Refinery D were estimated during a flaring event on November 1, 2015, with non-typical elevated emissions and should be treated cautiously. Based on these estimates, the average wind for the interval 50-400 m, as measured by the wind LIDAR, has been used for flux calculations in this survey. Wind information from Refinery A's 10 m mast during the calibration period (October 2-6, 2015) was used to account for the lowest 50 m of the air column. In this compensation, the 10 m wind data was used from 0 to 20 m and a linear interpolation was applied between the 10 m wind and the LIDAR wind between 20 and 50 m. Although this compensation had a very small effect (~2%) on the total wind speed as provided by the LIDAR between 50 and 400m, it was applied to all flux calculations for consistency.

Note that plumes of different gases may behave differently. Plumes originating from combustion sources (e.g. SO_2 and NO_2), are generally stack releases. As such, they are released at a high altitude and more buoyant (hotter) than fugitive and cold VOC emissions. Hence, SO_2 and NO_2 are expected to be found at a slightly higher altitude than alkanes when measuring refinery emissions at a fence-line distance like in this survey. Plume height estimations are, however, not possible for SO_2 and NO_2 (no simultaneous concentrations measurements). But since the wind gradient with height was weak during the survey and with the emissions confined within in the boundary layer (see discussion below), the effect on the calculated fluxes are small and well within the measurement uncertainty.

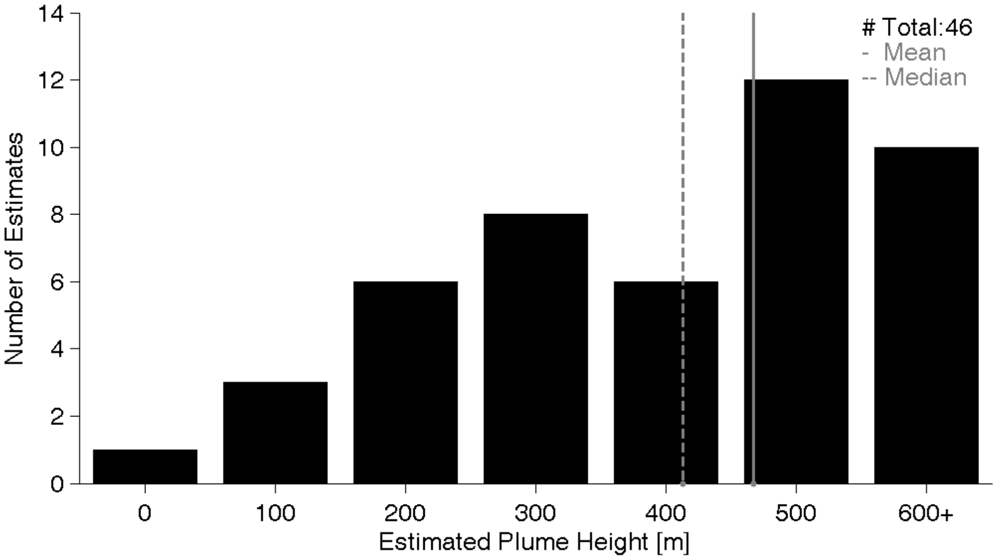

Figure 11. Plume height estimations for all refineries during the 2015 SCAQMD survey. The last bin, denoted '600+', contains all data points above 600 m. The median and average values are indicated as dashed and solid gray lines, respectively.

Wind LIDAR data has always been used as the primary wind information for flux calculations in this survey. The different LIDAR locations/sites are specified in Figure 10. For cases where no LIDAR information was available (e.g. LIDAR malfunction or data collected at non-representative sites) an appropriate secondary wind source was used based on its proximity to the measured refinery. Secondary wind data was scaled to match the 50-400 m LIDAR wind at a location closest to the measurement site using the slope of a linear least-squares-fit, see *Scaling Factors* in Table 4 and plots in Appendix B.

In order to assess the sensitivity of the flux calculations to deviations from the assumed plume mixing height, wind LIDAR data (10 min average) for different altitude ranges (i.e. 50-100 m, 50-200 m, 50-300 m, 50-400 m, and 50-500 m) were compared to the reference LIDAR wind (50-400 m) during the two calibration periods (October 2-6, 2015 at LIDAR site L1 and October 9-16, 2015, at site L3; see Figure 10). For both calibration periods, the wind speed comparisons show that the systematic difference for the alternative height intervals is less 4% compared to the reference interval (50-400 m) and that the vast majority of data points are within 30% of the reference wind (50-400 m) (see example in Figure 12 and the complete data set in Appendix B). For the wind direction, the same comparisons showed a systematic difference of less than 5° to the reference wind and a total spread of the random differences of less than 30° for almost all data points.

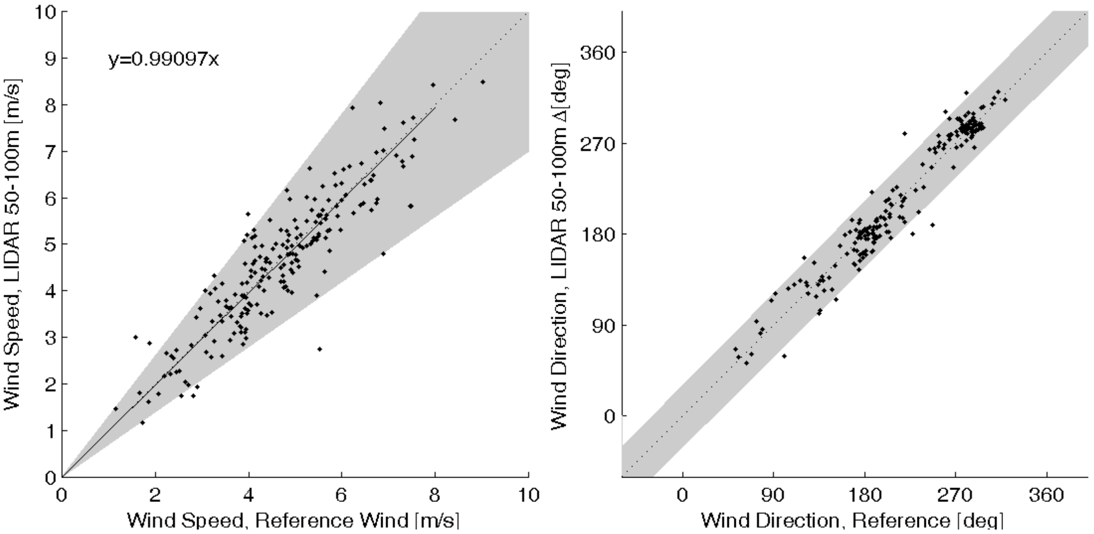

Figure 12. Wind LIDAR data (10 min average from 10AM to 5PM) for 50-100 m versus the reference LIDAR wind (50-400 m) during the calibration period (October 2-6, 2015) at LIDAR site L1. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as a solid line. See Appendix B for the complete data set.

The variability of the wind with height and time is further illustrated in Figure 13. The two upper panels show the average wind (solid lines) at each height level relative to the 50-400 m reference average as well as the average standard deviation (±1σ; dashed lines). These profiles show that the wind does not systematically deviate more than 15% or 5° at any height level and that the standard deviation of the random deviations are generally less than 20% in wind speed and 20° in wind direction, except for the highest levels in the interval. The two lower panels in Figure 13 show the results of comparison between the reference wind and the same reference wind a few minutes earlier. These plots also show the average wind deviation as a function of the time difference (solid lines), as well as the average standard deviation (±1σ; dashed lines). As expected, the random deviations increase with the time difference, while the systematic deviations are close to zero. The reason why the average deviation is not actually zero is that the prevailing wind conditions during the study featured a distinct pattern of winds increasing throughout the day while also shifting direction in a recurring pattern.

Two examples of the evolution of the wind profile over the course of a day are shown in Figure 14. Both of them show clear signs of the prevailing wind pattern throughout the study, with weak winds in the morning that increase in magnitude from approximately 10:00 AM to 12:00 PM and forward while also shifting direction. Since a wind speed of at least 1-2 m/s is typically needed in order to accurately calculate flux, useful data could normally not be collected before 10:00 am. As also seen in these examples, the wind is relatively homogenous within a layer up to 300-500 m, but at higher altitudes the wind direction often varies dramatically. This altitude range coincides very well with the typical plume mixing height estimates in Table 4 indicating that this layer of homogenous wind is the convective boundary layer. The exact height of this layer varies throughout the day and this explains why the wind was on average weaker and more variable in the uppermost levels of the 50-400 m height interval, as seen in Figure 13. The convective boundary layer simply does not always extend above this height level.

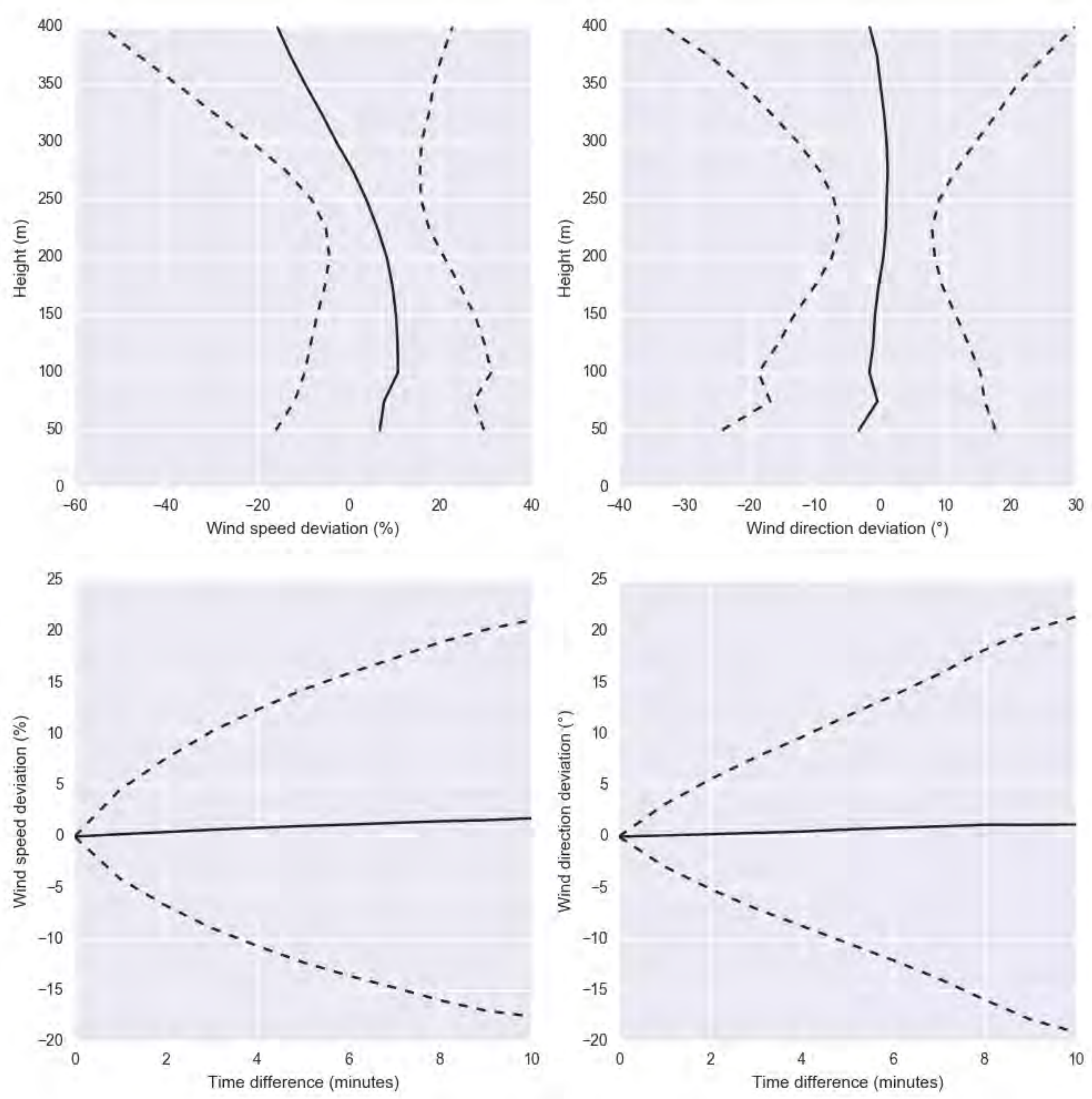

Figure 13. 10-min wind LIDAR data for the entire 2015 SCAQMD survey. Average (solid lines) and standard deviation (±1σ; dashed lines). Top row panels show altitude information and the lower row panels show time dependence (see Appendix B for additional plots).

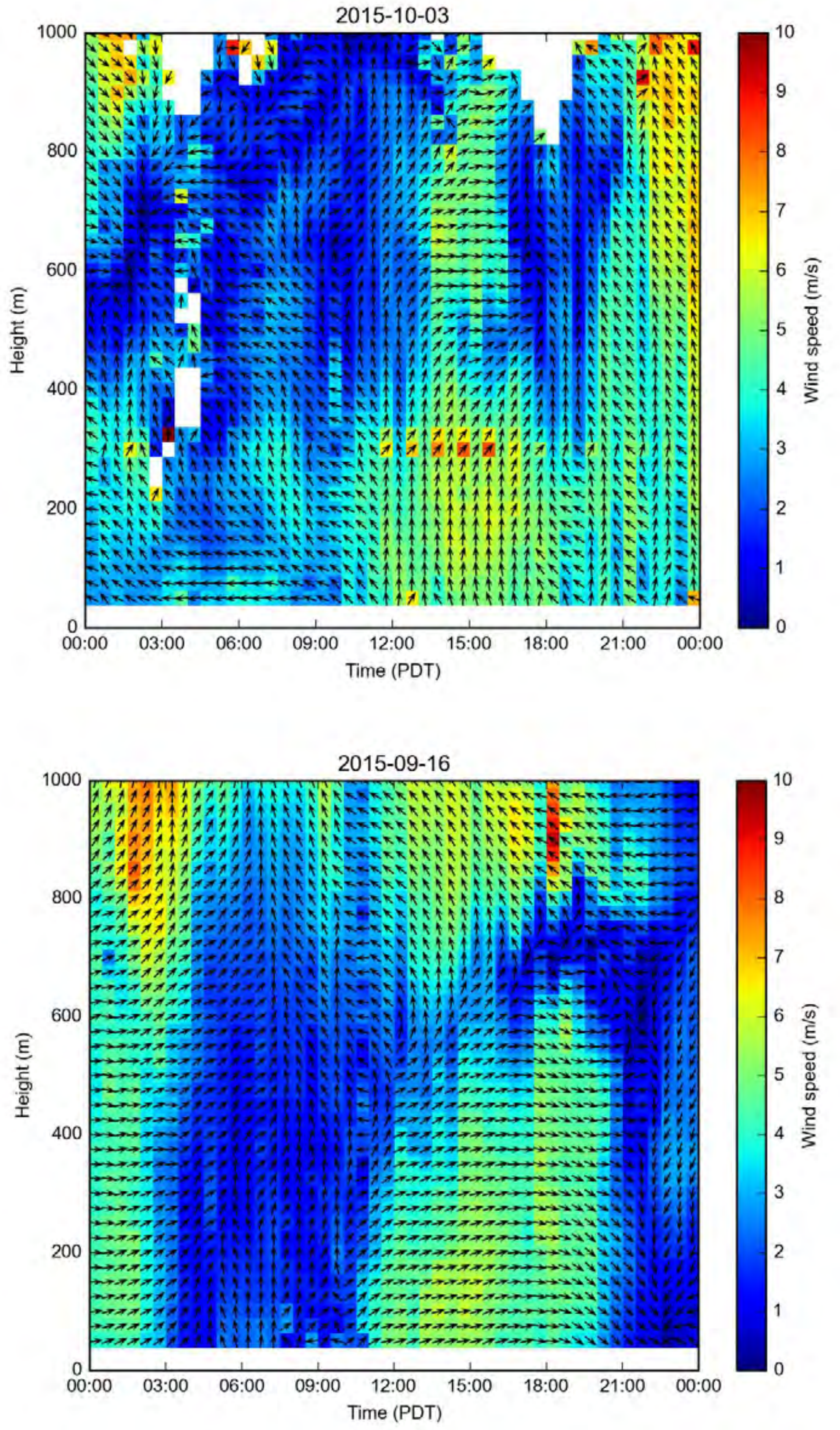

Figure 14. Wind LIDAR raw data at the L1 and L4 site. 30 min averages from 50 to 1000 m measured on October 3, 2015 at the L1 site (upper panel) and on September 16, 2015 at the L4 site (lower panel). The color scale gives the magnitude of the wind speed and the black arrows show the wind direction. Both plots show typical low wind speeds during night-time conditions and stable winds with little altitude variation (wind shear) from 50 to 400m from noon to sunset. See Appendix B for additional data.

4 Results - Total Refinery Measurements

Emission flux measurement results (median values) for the six refineries surveyed during this study are summarized in Table 5. Figure 15 through Figure 17 present graphical representations of measured emissions of alkanes, SO_2, and NO_2. Collectively, refineries in the South Coast Air Basin were found to emit 1130 kg/h of alkanes, 259 kg/h SO_2, 269 kg/h NO_2, 129 kg/h BTEX (of which 18 kg/h is Benzene) and 705 kg/h methane. Section 4.1 through 4.6 below provides detailed description of measured emissions from each studied refinery in the South Coast Air Basin.

Table 5. Summary of emission flux measurements during the 2015 SCAQMD survey. SOF and SkyDOAS results are reported here as median values of all quality assured transects to reduce sensitivity to outliers. *MWDOAS and MeFTIR are inferred values through measured ground level gas mass concentration ratios (See section 2.3 and 2.4). †Excluding eastern tank park that is not owned by Refinery B.

	SOF			*SkyDOAS*				*MWDOAS*		*MeFTIR*
Refinery	**N Days**	**N Meas**	**Alkane Flux** [kg/h]	**N Days**	**N Meas**	**SO_2 Flux** [kg/h]	**NO_2 Flux** [kg/h]	**BTEX Flux*** [kg/h]	**Benzene Flux*** [kg/h]	**CH_4 Flux*** [kg/h]
Refinery A	15	40	269	10	39/34	62	66	24	3.4	167
Refinery B†	5	15	70	10	35	53	31	11	1.1	53
Refinery C	4	15	244	3	9	37	57	37	8.2	142
Refinery D	7	33	164	4	20	17	34	16	1.6	79
Refinery E	7	35	244	7	29/19	53	63	31	2.7	207
Refinery F	4	16	139	2	3	37	18	10	0.8	57
Sum			**1130**			**259**	**269**	**129**	**18**	**705**

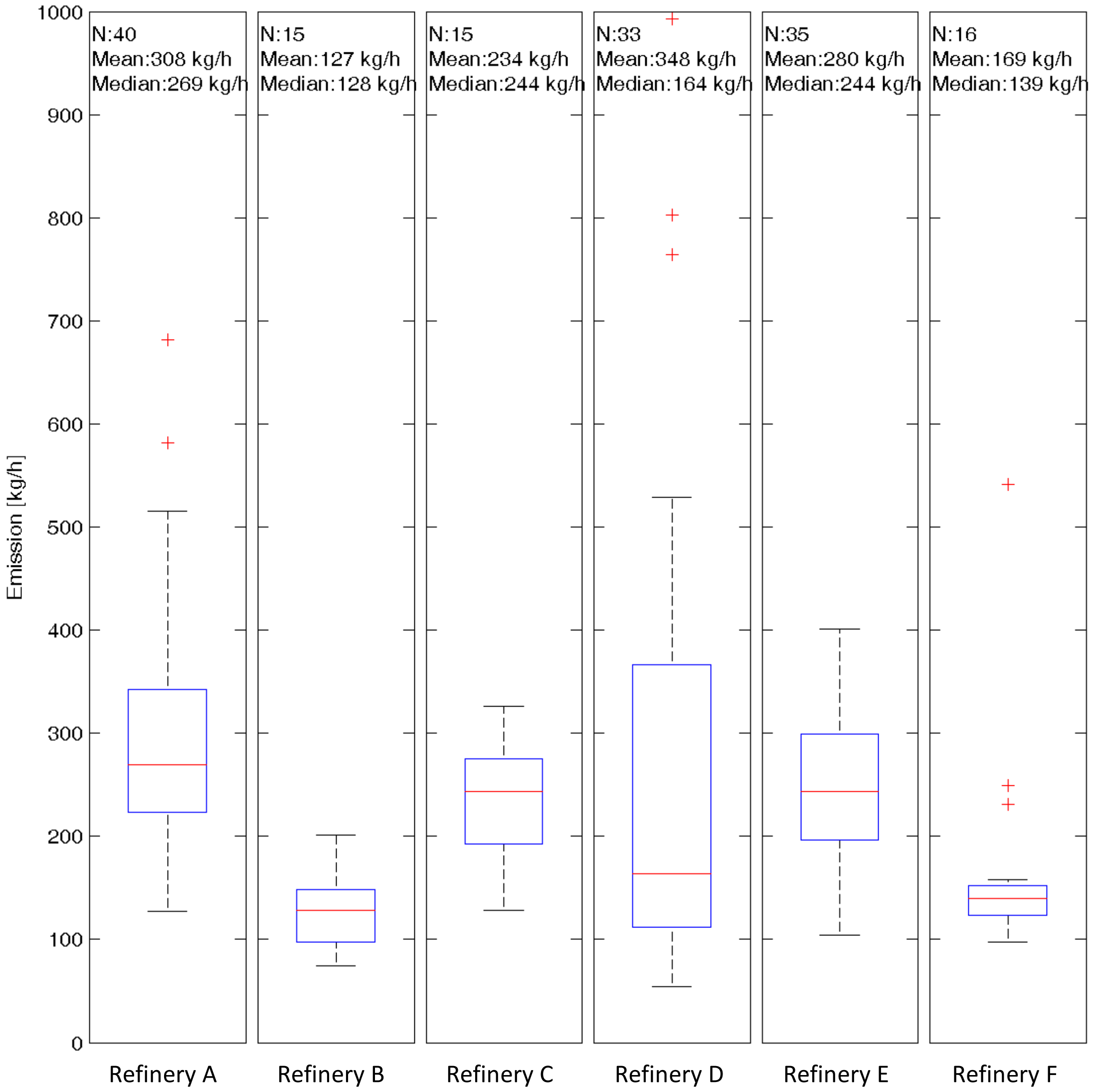

Figure 15. Box-plots of measured alkane emissions (kg/h) from the six refineries surveyed during the 2015 SCAQMD study. Median (50-percentile) values are presented as red bars and upper and lower quartiles as blue boxes with dashed whiskers extending to 1.5 times the inter-quartile range. Outliers beyond the whisker lengths are indicated by red crosses.

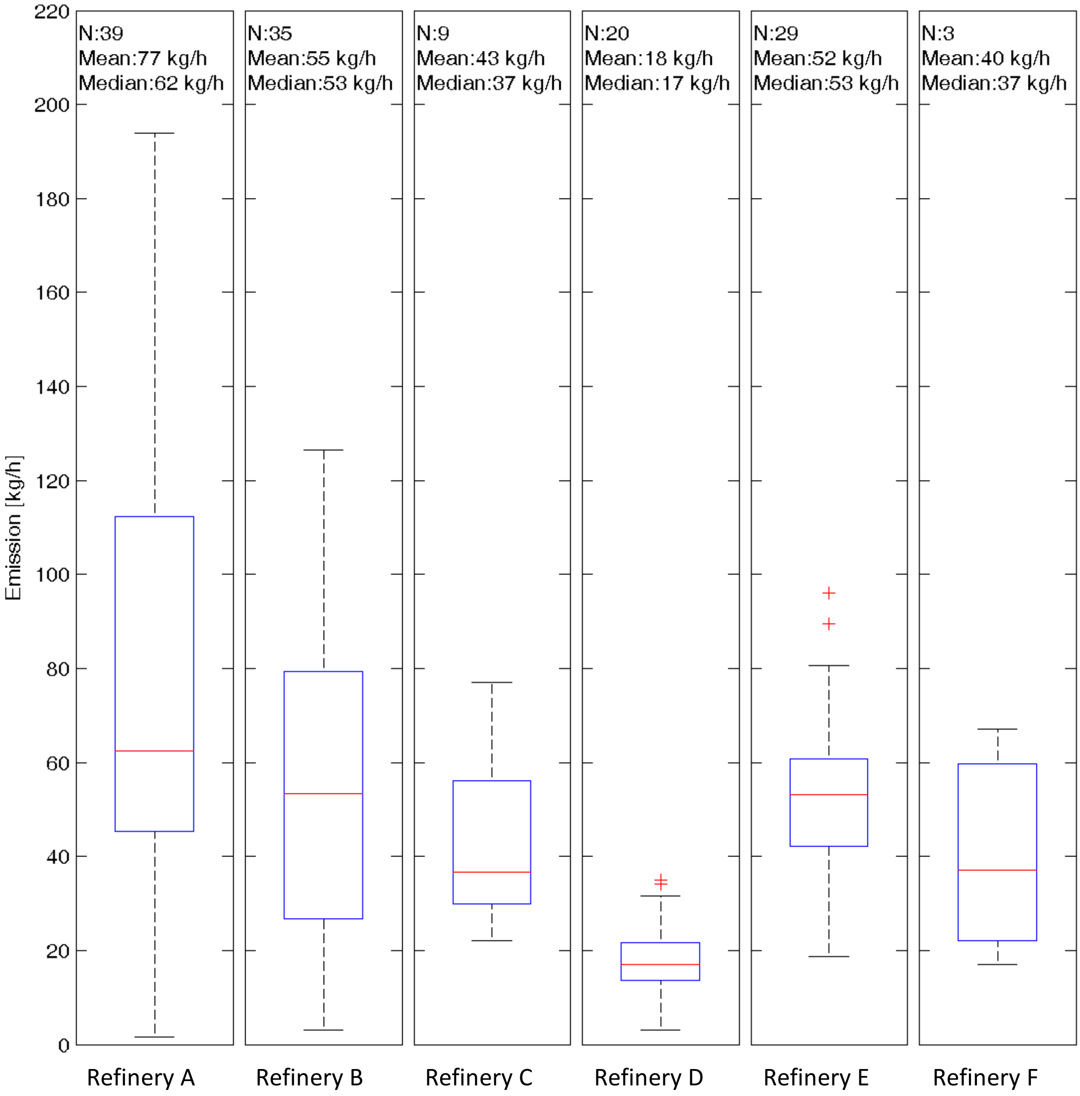

Figure 16. Box-plots of measured SO_2 emissions (kg/h) from the six refineries surveyed during the 2015 SCAQMD study. Median (50-percentile) values are presented as red bars and upper and lower quartiles as blue boxes with dashed whiskers extending to 1.5 times the inter-quartile range. Outliers beyond the whisker lengths are indicated by red crosses.

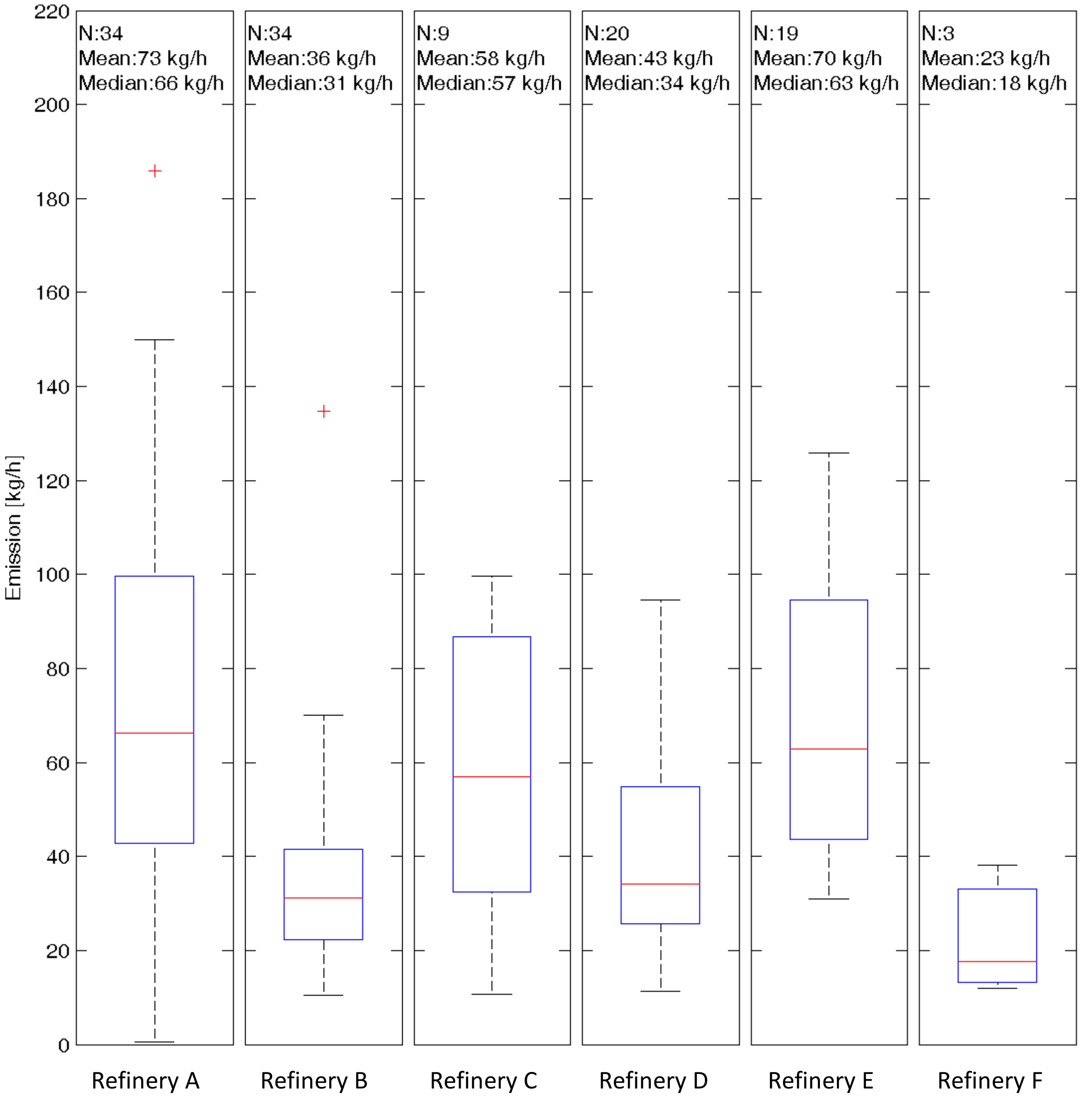

Figure 17. Box-plots of measured NO_2 emissions (kg/h) from the six refineries surveyed during the 2015 SCAQMD study. Median (50-percentile) values are presented as red bars and upper and lower quartiles as blue boxes with dashed whiskers extending to 1.5 times the inter-quartile range. Outliers beyond the whisker lengths are indicated by red crosses.

4.1 Refinery A

At Refinery A (crude oil capacity 257 kBPD (California Energy Commission 2016)) 15 measurement days of total emissions have been carried out and additionally one week of measurements inside the facility (see Section 5) through a collaboration between the refinery and SCAQMD.

The measurements were conducted over a period of eleven weeks, stretching from August 28 to November 10. Note that, typically, the number of successful measurements for each day varies considerably depending on acceptable solar- and wind conditions, interfering background levels and instrument availability. To accurately compensate for incoming background plumes, it was necessary to drive around the targeted facility for multiple times (see example in Figure 18), which is time-consuming.

Wind information for flux calculations were provided by a wind LIDAR (50-400 m average) right across the refinery's fence-line. This wind data was complemented with information collected by a 10 m wind station (scaled to match 50-400 m LIDAR) operated inside Refinery A. Typical wind velocities and direction at these locations were 4-5 m/s and 300°N, respectively (see Figure 19).

4.1.1 Alkanes (non-methane)

Alkane emissions from Refinery A were measured with the SOF during 15 different days from August 29 to November 10, 2015 (see Table 6). Daily means varied from 215 kg/h (September 5) to over 800 kg/h (October 29). The grand total average and standard deviation of all 40 quality assured transects amount to 308±113 kg/h. The median value was 269 kg/h. Histograms of all transects (Figure 20) show a sharp peak at around 250 kg/h and a "tail" of measurements above 500 kg/h. Most transects show a typical column peak directly downwind of the southern tank park (especially downwind of the large reservoir and tank-16) and of the process area (Figure 18).

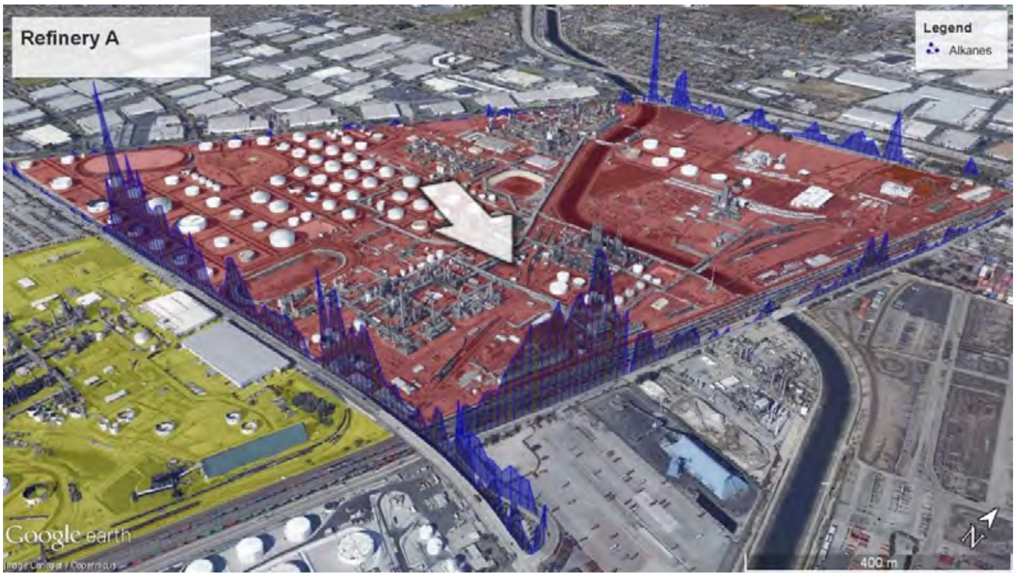

Figure 18. Example of SOF measurements around Refinery A (red area) conducted on September 5, 2015, from 15:20 to 15:37. The height of the blue line is proportional to the amount of alkanes in the gas column (i.e. 10 m is equivalent to 1 mg/m^2; max measured value was 64 mg/m^2). The wind direction is indicated by the white arrow. Average wind speed during this measurement was 6 m/s. Emissions on the upwind side of the facility were subtracted from the downwind side in order to obtain emissions from within the measured area. This particular transect measured 267 kg/h of Alkanes from Refinery A.

Table 6. Summary of SOF alkane measurements for Refinery A. *Single measurement.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150829	144942 -173531	3	413.1±88.6	5.4-7.4	289-295
150902	142535 -154524	3	319.2±74.7	4.7-5.4	305-310
150903*	130746 -131654	1	271.8	3.8	136
150904	134638 -154706	3	226.8±45.2	3.9-5.0	193-199
150905	112732 -165808	7	214.9±84.2	3.1-6.0	181-295
150906	135041 -160653	3	304.7±76.8	2.7-5.5	262-299
150907	142422 -164733	3	223.8±85.7	3.9-7.0	284-285
150908	111515 -123733	2	322.0±223.7	2.6-2.6	272-323
151003	135421 -151958	2	281.8±70.9	4.9-5.2	174-191
151010*	100622 -102546	1	220.8	2.2	65
151018*	143919 -145556	1	281.5	3.7	188
151020	142108 -154446	4	333.5±165.7	4.2-6.0	276-298
151029	110714 -115044	2	866.0±260.3	7.3-7.3	313-316
151107	103907 -114442	3	265.5±38.6	2.7-4.1	17-38
151110	142726 -145648	2	260.6±29.7	9.8-10.1	253-263
Average±SD	**-**	**(total 40)**	**308±113 (37%)**	**-**	**-**
Median	**-**	**(total 40)**	**269**	**-**	**-**

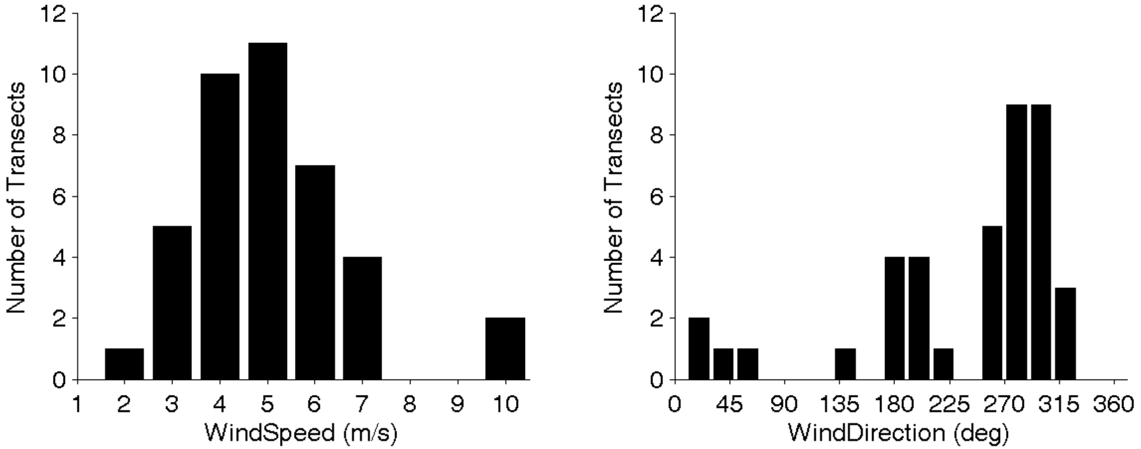

Figure 19. Histograms of wind speed (left) and wind direction (right) for all SOF measurements at Refinery A during the 2015 SCAQMD survey.

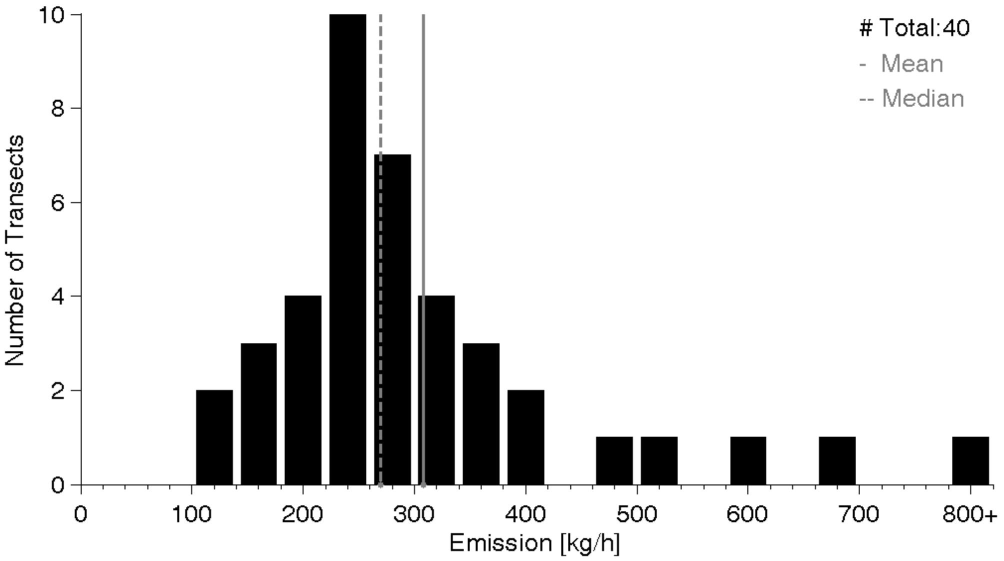

Figure 20. Histogram of all SOF measurements at Refinery A during the 2015 SCAQMD study. The last bin, denoted ‘800+’, contains all data points above 800 kg/h. The median and average values are indicated as dashed and solid gray lines, respectively.

4.1.2 SO_2 and NO_2

SO_2 and NO_2 emissions from Refinery A facility were measured for 10 measurement days during the campaign, from August 29 to November 30 2015 (some of the transects can be seen in Figure 21). Summaries and histograms of SkyDOAS emission measurements are presented in Table 7, Table 8, Figure 22 and Figure 23. Emissions averaged 73 and 77 kg/h for NO_2 and SO_2, respectively. Median values for these two gaseous pollutants were 66 (NO_2) and 62 kg/h (SO_2). The precise origins of the plumes cannot be decided from these measurements, although the Cogen-plant seems to be a matching source for some of the NO_2 plumes.

Figure 21. Transects of plumes originating from Refinery A. NO_2 (pink line) and SO_2 (brown line) were impacted by westerly winds. Conversely, BTEX (blue line) and alkane (yellow line) plumes were measured in the presence of northerly winds. The column thickness for both NO_2 and SO_2 is reported on the same scale (max NO_2 = 3 mg/m^2 flux NO_2 = 114 kg/h, max SO_2 = 11 mg/m^2 flux SO_2 = 46 kg/h). Alkanes and BTEX columns are scaled separately for better visibility (max BTEX = 0.25 mg/m^3, max alkanes = 1.95 mg/m^3). The examples presented here are single transects made on September 2 and on September 19, 2015.

Table 7. Summary of Refinery A NO_2 measurements.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150829	144857 -172703	3	57.0±69.3	5.4-7.6	285-296
150902	140707 -151247	3	59.3±49.8	4.4-6.5	300-314
150903	125302 -134150	2	119.7±42.8	4.1-4.5	115-131
150904	134011 -154225	4	76.2±26.5	4.3-4.9	185-200
150905	113143 -161302	5	67.9±22.9	3.5-6.0	180-295
150906	111801 -165522	5	54.3±18.8	1.8-4.3	266-302
150907*	151830 -152142	1	49.6	5.0	286
150908	113158 -123350	2	26.8±2.1	2.5-2.7	258-323
151029	105412 -150635	7	105.3±49.9	7.0-11.0	275-324
151030	112454 -161144	2	65.7±92.3	2.7-5.0	142-199
Average±SD	**-**	**(total 34)**	**72.8±45.1 (61.9%)**	**-**	**-**
Median	**-**	**(total 34)**	**66.3**	**-**	**-**

Table 8. Summary of Refinery A SO_2 measurements.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150829	144857 -173037	3	114.5±69.1	5.4-7.6	285-296
150902	140726 -154429	4	59.4±40.2	4.4-6.5	298-314
150903	125302 -134150	3	44.2±37.0	2.4-4.5	116-133
150904	134011 -154225	4	66.5±34.2	4.3-4.8	185-200
150905	104604 -161046	7	41.4±28.3	2.1-6.0	103-295
150906	111801 -165332	5	73.2±35.1	1.8-4.4	266-301
150907	134339 -152051	2	54.0±44.8	3.8-5.0	264-286
150908	113244 -123504	2	60.6±11.5	2.6-2.7	259-318
151029	105412 -150635	6	125.5±36.3	6.9-11.0	275-325
151030	112531 -161409	3	129.9±67.3	2.7-5.0	142-202
Average±SD	**-**	**(total 39)**	**77.1±42.0**	**-**	**-**
Median	**-**	**(total 39)**	**62.4**	**-**	**-**

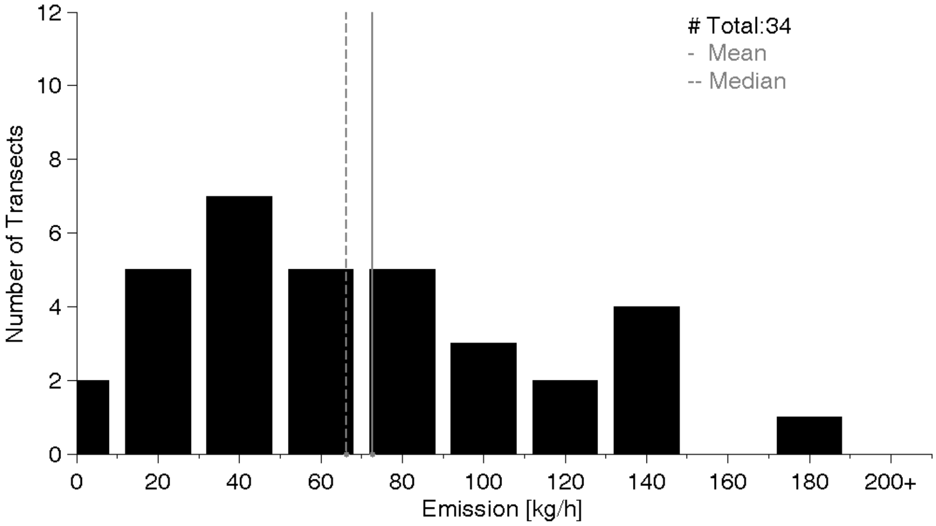

Figure 22. Histogram of all SkyDOAS NO_2 measurements at the Refinery A during the 2015 SCAQMD survey. The last bin, denoted ‘200+’, contains all data points above 200 kg/h. The median and average values are indicated as dashed and solid gray lines, respectively.

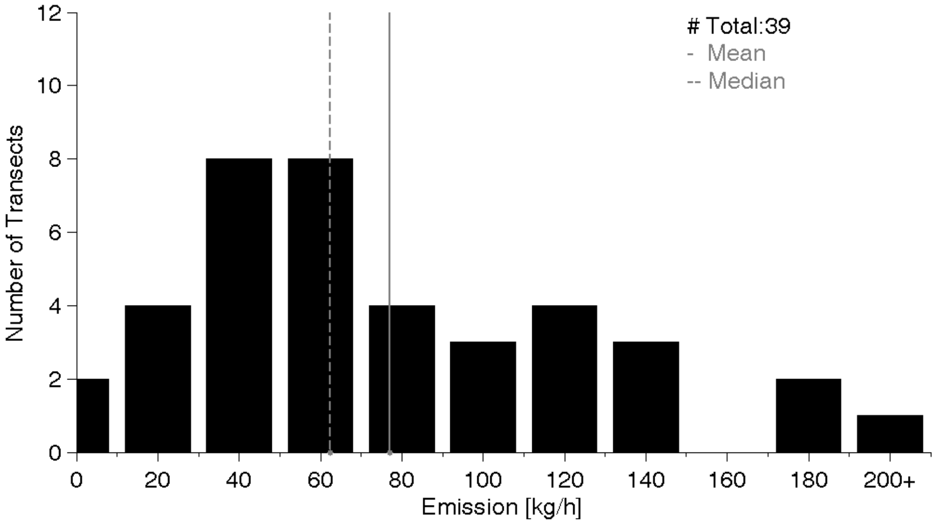

Figure 23. Histogram of all SkyDOAS SO_2 measurements at Refinery A during the 2015 SCAQMD survey. The last bin, denoted '200+', contains all data points above 200 kg/h. The median and average values are indicated as dashed and solid gray lines, respectively.

4.1.3 BTEX

The fraction of BTEX compounds present in the measured alkane plumes emitted from Refinery A was measured either in the late evening or early morning when plumes are closer to the ground. This fraction is calculated by combining BTEX measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured along two roads depending on wind direction. Results for these measurements are shown in Table 9. The average mass fraction of BTEX to alkanes was 0.087 or 8.7%. The average flux of BTEX can be calculated by multiplying this value by the total alkane flux as measured by the SOF-technique. The average mass fraction of benzene to alkanes was 1.3% and the benzene flux can be calculated in the same way as above.

Table 9. Summary of MWDOAS BTEX measurements at Refinery A. *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	221347-221949	7.8	0.98	2.3	323
150919	231317-231938	5.4	0.92	1.5	329
150921	051934-052525	12.8	1.7	1.8	73
150922	062223-063032	13.4	1.7	2.4	110
150922	073305-074108	6.8	0.65	1.9	81
150922	051356-051759	3.6	0.21	2.1	83
150922	183651-184148	11.2	2.7	2.1	181
Average±SD	**-**	**8.7±3.8**	**1.3±0.8**	**-**	**-**

4.1.4 Methane

The average fraction of methane to total non-methane alkanes in the plume originating from Refinery A was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). Methane measurements were conducted during different times of the day and a summary of these results is shown in Table 10. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux as measured by SOF provides an estimate of the methane flux from the refinery. The average methane-to-alkanes mass fraction for Refinery A was 0.62.

Table 10. Summary of MeFTIR methane measurements at the Refinery A. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** **[%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	221206 -231956	2	44	1.6-2.2	332-347
150922	062220 -063024	1	41	1.9	88
151018	144244 -145057	1	64	3.4	177
151020	122426 -154604	6	71	2.4-5.7	135-312
151029	105144 -150803	6	67	4.0-11.3	285-328
151030	113932 -155450	3	57	1.3-4.0	186-289
Average±SD	**-**	**(total 19)**	**62±25**	**-**	**-**

4.2 Refinery B

Refinery B (crude oil capacity (together with Refinery C) 139 kBPD (California Energy Commission 2016)) is located just south of Refinery A, see Figure 24. This site was frequently surveyed in combination with the Refinery A facility. However, due to the proximity to other sources, such as Tank Farm G and Refinery A, there is an increased possibility of interference depending on wind direction and therefore there were fewer valid emissions measurements. Note that the surveyed area also included a crude tank park on the west side that is not owned by Refinery B. Emission contributions from this crude tank park have been accounted for in the data post-processing (see below).

Wind information from the wind LIDAR (L1, 0-400 m average) was mainly used for the flux calculations. This was complemented by Refinery A's 10 m wind station data (scaled to match 0-400 m LIDAR) when needed. Typical wind directions and velocities during the measurements were 4 m/s and 180 or 270°N, see Figure 25.

4.2.1 Alkanes (non-methane)

Alkane emissions from Refinery B were measured with SOF during five non-consecutive days from September 4 to November 10, 2015, see Table 11 and discussion above. Daily means varied from 83 kg/h (September 6) to 173 kg/h (September 7). The grand total average and median for all 15 quality assured transects were 127±23 kg/h and 128 kg/h, respectively. Histogram of all transects shows a "compact" distribution at around 130 kg/h with no outliers, see Figure 26.

Measurement transects typically showed the presence of two peaks, one downwind the western side and another downwind the eastern side, see Figure 24. Based on transects where a complete separation between the two sides/peaks was possible (during S to SW winds), 45% of the emissions were attributed to the western side and 55% to the eastern side. The 55 correction factor has been applied in the survey mean/median calculations (e.g. Table 5), but not for daily means (e.g. Table 11) or individual measurements (e.g. Figure 26). The correction was done in order to exclude the emissions that should not be attributed to Refinery B when inter-comparing the different refineries in this report.

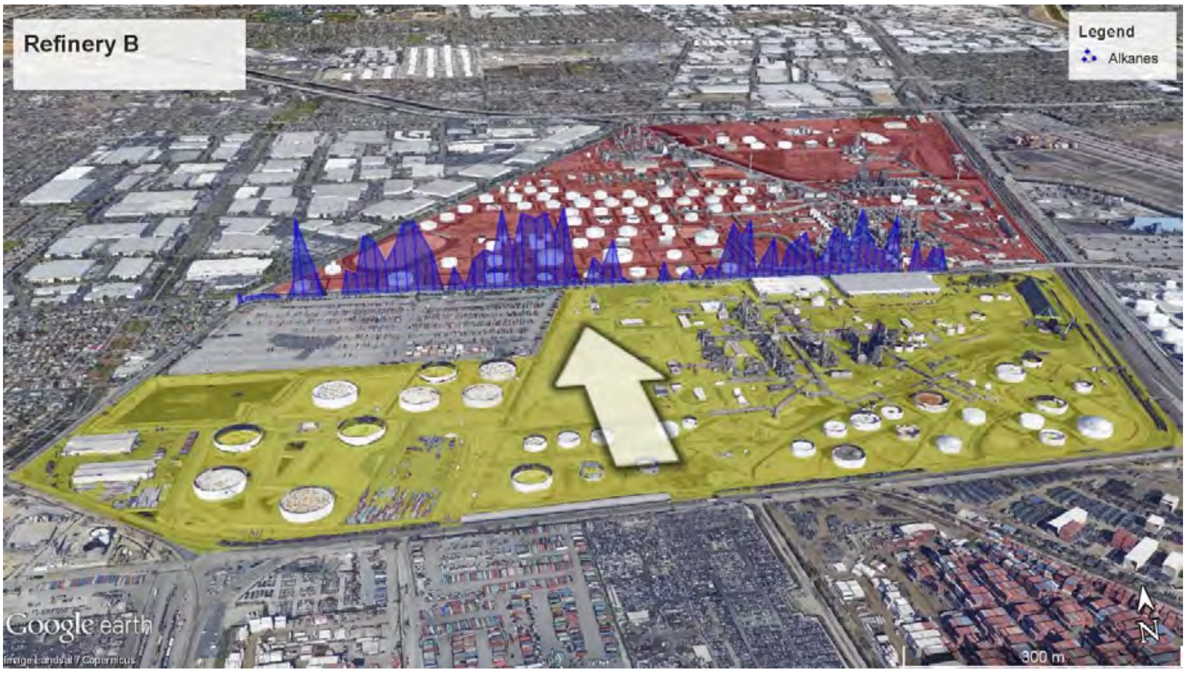

Figure 24. Example of SOF measurements conducted at Refinery B (yellow area) on September 4, 2015, 16:10-16:13. The alkane column is shown as a blue line with apparent height proportional to the gas column (10 m equivalent to 1 mg/m^2, max 32 mg/m^2). Wind direction during the measurements is indicated by the white arrow. The average wind speed during these particular measurements was 3.2 m/s. Emissions on the upwind side are insignificant and not shown in this figure. Emissions resulting from this particular transect were estimated at 107 kg/h.

Table 11. Summary of SOF alkane measurements for Refinery B (including the crude tank park west of the refinery).

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150904	134712 -165939	6	116.3±23.6	3.2-5.5	178-253
150905	153737 -171908	3	121.9±7.4	5.8-6.1	268-279
150906	124744 -163755	2	83.2±13.0	3.4-3.7	165-279
150907	140251 -150726	2	172.8±39.8	3.9-4.3	284-285
151110	143118 -145107	2	161.5±17.6	9.4-10.2	255-255
Average±SD	**-**	**(total 15)**	**127±23 (18%)**	**-**	**-**
Median	**-**	**(total 15)**	**128**	**-**	**-**

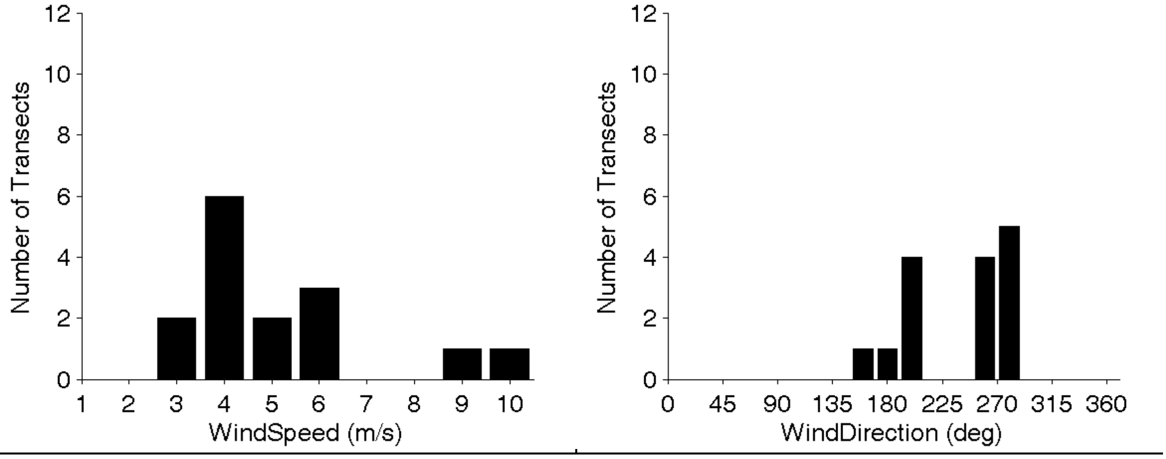

Figure 25. Wind histograms at Refinery B summarizing all wind speed (left) and wind direction (right) measurements conducted during the 2015 SCAQMD study.

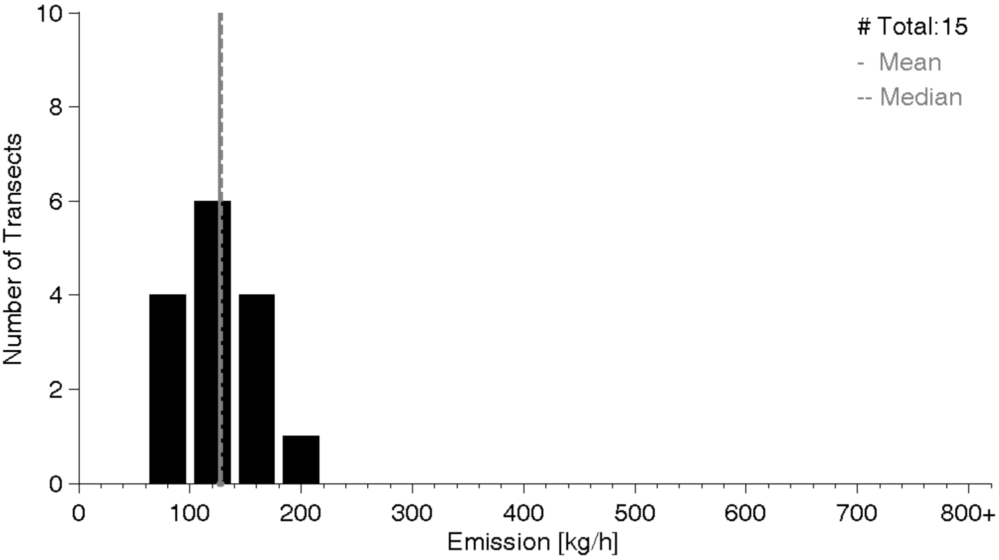

Figure 26. Histogram of all SOF measurements conducted at Refinery B (including crude tank park west of the refinery) during the 2015 SCAQMD study. The median and average values are shown as dashed and solid gray lines, respectively.

4.2.2 SO_2 and NO_2

SO_2 and NO_2 emissions were measured for 10 measurement days during the campaign, from August to October, 2015. Figure 27 shows examples of measurement transects conducted on September 2 and September 19, 2015. Summaries and histograms of SkyDOAS emission measurements are presented in Table 12, Table 13, Figure 28 and Figure 29. In this case NO_2 emissions averaged 36 kg/h and SO_2 55 kg/h. Median values for these two gaseous pollutants were 31 (NO_2) and 53 kg/h (SO_2).

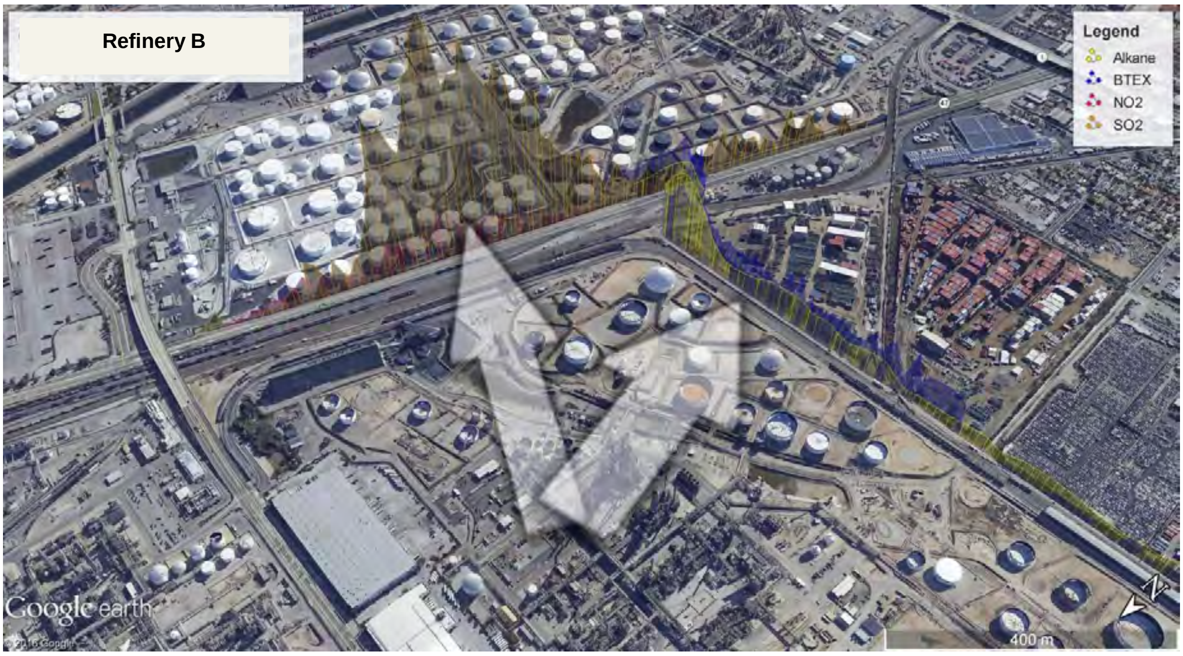

Figure 27. Transects of plumes originating from Refinery B. NO_2 (pink line) and SO_2 (brown line) were impacted by westerly winds (4.3 m/s). Conversely, BTEX (blue line) and alkane (yellow line) plumes were measured in the presence of northerly winds. The column thickness for both NO_2 and SO_2 is reported on the same scale (max NO_2 = 5.6 mg/m^2, flux NO_2 = 11.7 kg/h, max SO_2=25 mg/m^2, flux SO_2 = 68.2 kg/h). Alkanes and BTEX columns are scaled separately for better visibility (max BTEX = 0.03 mg/m^3, max alkanes = 0.36 mg/m^3). The examples shown here were collected on September 8 and on September 19, 2015.

Table 12. Summary of NO_2 measurements at Refinery B.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150829	152225 -152509	1	31.8	7.0	295
150902	132957 -141007	2	21.8±0.7	5.0-6.3	303-315
150903	130123 -133346	2	30.7±15.3	3.9-4.9	106-148
150904	134837 -152937	4	41.2±8.3	3.7-4.9	193-203
150905	103515 -171321	11	27.7±9.2	1.0-6.2	112-286
150906	130316 -163207	4	52.6±12.9	2.6-4.5	162-286
150907	132433 -161506	4	28.5±8.9	3.5-6.1	242-285
150908	110353 -124134	3	57.7±67.2	2.0-8.8	313-327
151029	121217 -121936	1	67.9	7.3	312
151030	114718 -153206	2	19.3±12.6	2.0-4.5	112-193
Average±SD	**-**	**(total 34)**	**35.6±22.4 (62.8%)**	**-**	**-**
Median	**-**	**(total 34)**	**31.2**	**-**	**-**

Table 13. Summary of SO_2 measurements at Refinery B.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150829	152225 -152509	1	126.5	7.0	295
150902	133006 -141007	2	17.9±0.8	5.1-6.3	303-316
150903	130123 -133323	3	34.0±8.6	3.9-4.9	105-150
150904	134828 -152937	4	37.5±20.1	3.7-4.9	193-203
150905	103537 -171321	11	56.1±28.7	1.0-6.2	111-287
150906	130316 -163207	4	78.3±13.5	2.6-4.5	162-286
150907	132433 -161506	4	79.9±18.3	3.5-6.1	242-285
150908	110353 -124134	3	68.9±26.9	2.0-8.8	314-327
151029	121150 -133517	2	14.7±16.5	7.1-7.3	311-313
151030	114718 -115224	1	9.0	2.2	114
Average±SD	**-**	**(total 35)**	**54.5±21.5 (39.3%)**	**-**	**-**
Median	**-**	**(total 35)**	**53.4**	**-**	**-**

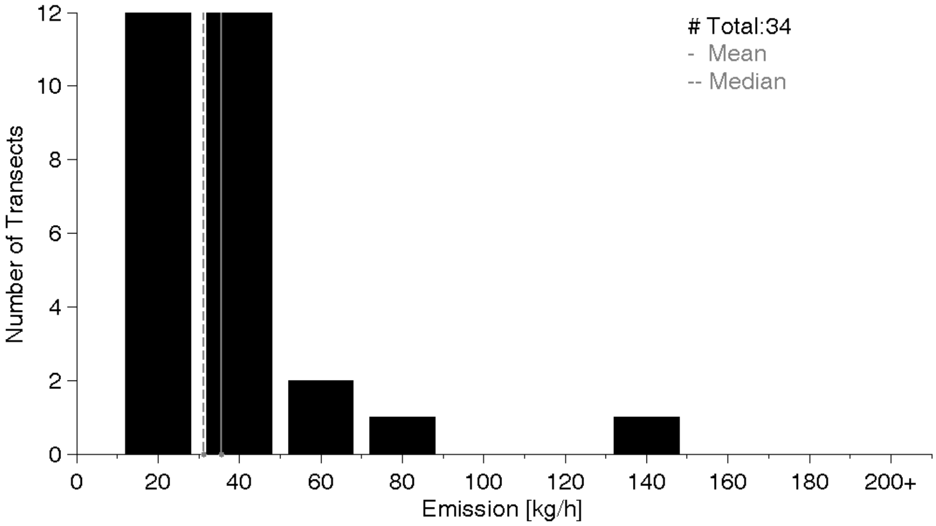

Figure 28. Histogram of all SkyDOAS NO_2 measurements at the Refinery B during the 2015 SCAQMD study. The median and average values are indicated as dashed and solid gray lines, respectively.

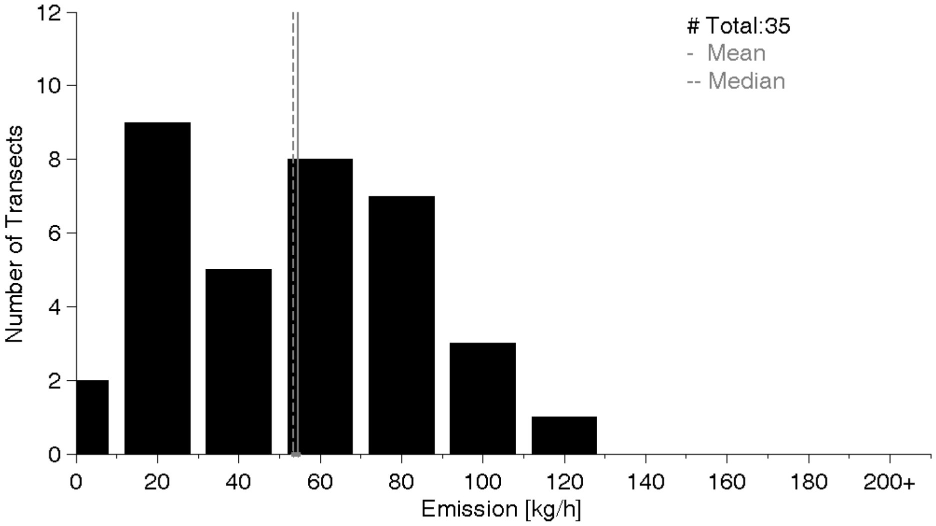

Figure 29. Histogram of all SkyDOAS SO_2 measurements taken at Refinery B during the 2015 SCAQMD study. The median and average values are indicated as dashed and solid gray lines, respectively.

4.2.3 BTEX

The fraction of BTEX compounds present in the measured alkane plumes emitted from Refinery B was measured either in the late evening or early morning when the plume was closer to the ground. This fraction is calculated by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured along two roads depending on wind direction. A summary of these measurements is shown in Table 14 and an example of a plume transect illustrated in Figure 27.

The average mass fraction of BTEX to alkanes was 0.084 or 8.4%. The average flux of BTEX can be calculated by multiplying this value by the total alkane flux as measured by the SOF-technique. The average mass fraction of benzene to alkanes was 0.9% and the benzene flux can be calculated in the same way as above.

Table 14. Summary of MWDOAS BTEX measurements at Refinery B. *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	222903-223809	11.3	0.18	2.5	345
150919	232406-232758	5.5	0.75	2	325
150919	220447-220915	7.3	0.71	2	302
150921	053955-054412	6.5	1.9	0.9	64
150922	070636-071237	11.4	0.9	1.5	64
Average±SD		**8.4±2.8**	**0.9±0.6**		

4.2.4 Methane

The average fraction of methane to total non-methane alkanes in the plume originating from Refinery B was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes. To determine the source of the plume, wind directions from Refinery A's 10 m mast were used (wind speed is irrelevant for these measurements). Methane measurements were conducted during different times of the day and a summary of these results is shown in Table 15. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux as measured by SOF provides an estimate of the methane flux from the refinery. The average methane-to-alkanes mass fraction for Refinery B was 0.75.

Table 15. Summary of MeFTIR methane measurements at Refinery B. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** **[%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150919	222929 -232735	2	73	2.0-2.6	325-346
151018	145106 -145455	1	91	3.1	171
151020	134959 -162614	3	110	1.6-5.4	163-295
151029	121145 -122309	1	23	4.9	317
151030	112324 -155949	3	53	2.1-4.1	121-188
Average±SD	**-**	**(total 10)**	**75±36**	**-**	**-**

4.3 Refinery C

Refinery C, (crude oil capacity together with Refinery B 139 kBPD, (California Energy Commission 2016)) is located north of the Los Angeles port, see Figure 10. Significant upwind background plumes from the port and oil wells on the west side must be compensated for in the flux calculations. This is done by encircling ('box-measuring') the facility when possible (see example in Figure 18).

Wind information for the flux calculations on September 18, 2015 came from the wind LIDAR (0-400 m average) at position L2, located at the golf course parking lot north of the refinery, see Figure 30. For the other days, wind information from the SCAQMD met station at South Long Beach (SLBH) was used (scaled to match 0-400m LIDAR). See section 3.4 for additional wind analysis. Typical wind speeds and wind directions during the measurements are 3 m/s and 130-320°N, see Figure 31. Winds are generally weak at this site due to the hills on the west side.

4.3.1 Alkanes (non-methane)

Alkane emissions from Refinery C was measured with SOF during four days in the period September 7 to November 4, see Table 16. The daily means varied from 128 kg/h (4 November, single measurement) to over 297 kg/h (29 October). The average emission determined from the 15 quality assured transects was 234±36 kg/h and the median emission was 244 kg/h. Histograms of all transects (Figure 32) show a peak at around 230 kg/h and no extreme outliers. Most transects show a typical column peak directly downwind the north-west tank park and the process area, see Figure 30.

Table 16. Summary of SOF alkane measurements for Refinery C. *Single measurement

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150907	104256 -121838	4	296.5±22.4	2.1-2.9	134-163
150918	133231 -165721	5	200.5±47.1	2.6-3.7	301-323
151022	144739 -161143	5	238.4±31.1	2.9-3.9	170-204
151104*	121336 -122731	1	128.2	2.9	239
Average±SD	**-**	**(total 15)**	**234±36 (15%)**	**-**	**-**
Median	**-**	**(total 15)**	**244**	**-**	**-**

Figure 30. Example of a SOF ‘box’ measurement of the Refinery C (green area) 7 September 2015, 11:57-12:18. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 76 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed was 2.9 m/s for this particular measurement. Emissions on the upwind side (from LA harbor) are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 285 kg/h from Refinery C.

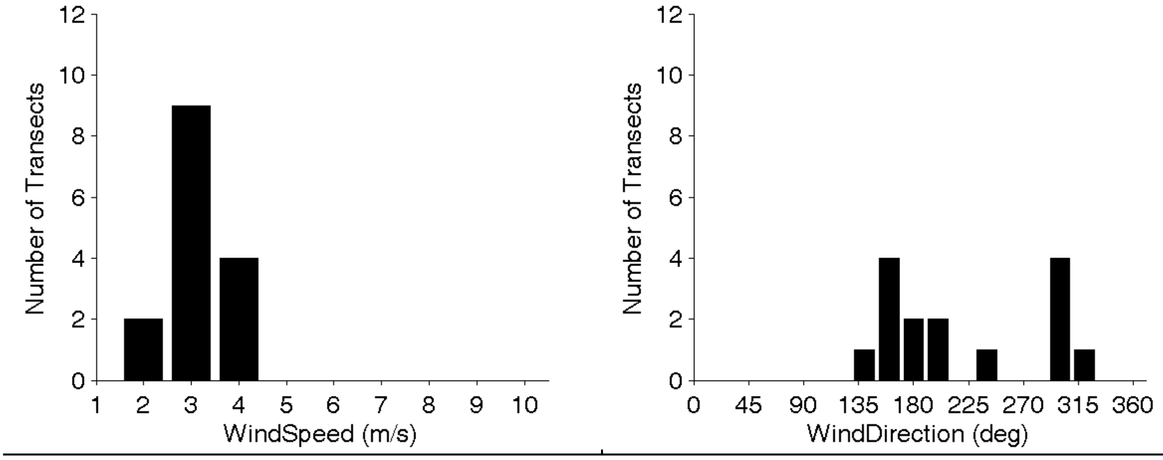

Figure 31. Wind histograms at Refinery C of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

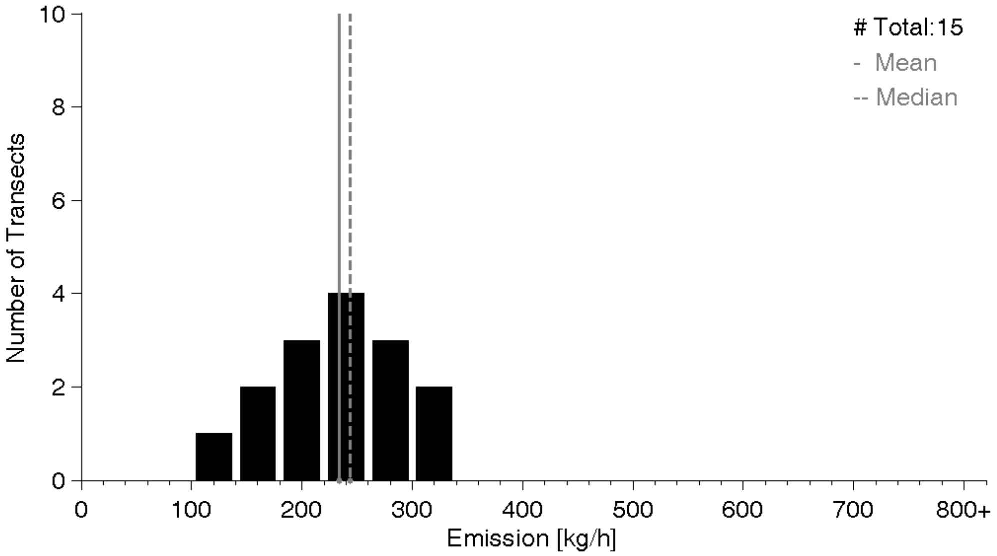

Figure 32. Histogram of all SOF measurements at Refinery C during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.3.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured for three measurement days during the campaign, twice in September and once in November. Summaries and histograms of SkyDOAS emission measurements are presented in Table 17, Table 18, Figure 34 and Figure 35. An example of a measurement is shown in Figure 33. Emissions averaged 58 and 43 kg/h and medians were 57 and 37 kg/h for NO_2 and SO_2 respectively.

Table 17. Summary of NO_2 measurements at Refinery C.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150907	95140 -121752	4	44.7±38.6	1.5-4.0	167-320
150918	134001 -153244	4	78.0±14.4	2.1-3.9	309-329
151104	121533 -122359	1	34.1	4.1	265
Average±SD	**-**	**(total 9)**	**58±29 (50%)**	**-**	**-**
Median	**-**	**(total 9)**	**57**	**-**	**-**

Table 18. Summary of SO_2 measurements at Refinery C.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150907	95122 -121752	4	48.7±21.9	1.4-4.2	166-310
150918	134212 -153244	4	39.5±16.4	1.9-3.9	309-331
151104	121405 -122616	1	30.7	4.1	271
Average±SD	**-**	**(total 9)**	**43±19 (45.4%)**	**-**	**-**
Median	**-**	**(total 9)**	**37**	**-**	**-**

Figure 33. Transects of plumes originating from Refinery C. the NO_2 (pink) and SO_2 (brown) plume from Refinery C in north-westerly wind (3.7 m/s). Max $NO_2 = 9.5$ mg/m^2, flux $NO_2 = 81$ kg/h, max $SO_2=5.6$ mg/m^2, flux $SO_2 = 37.5$ kg/h Data from September 18 2:59 PM.

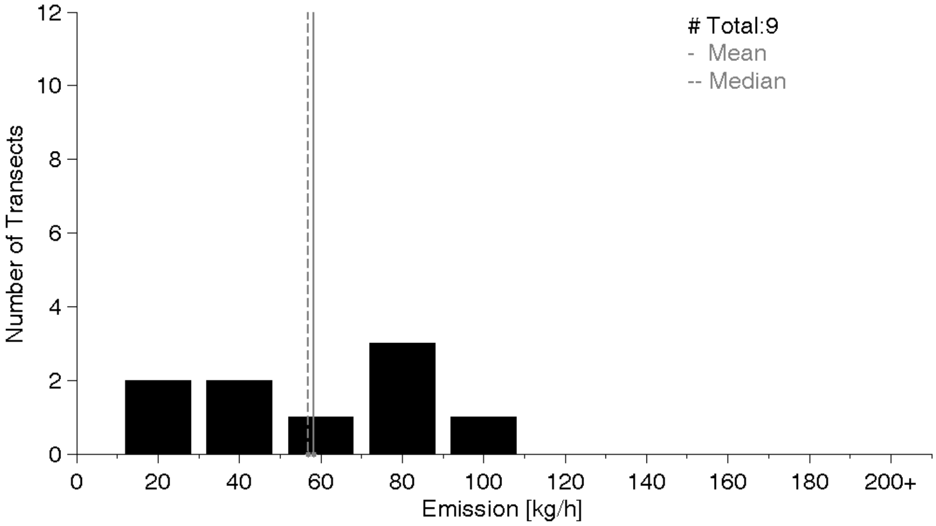

Figure 34. Histogram of all SkyDOAS NO_2 measurements at Refinery C during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

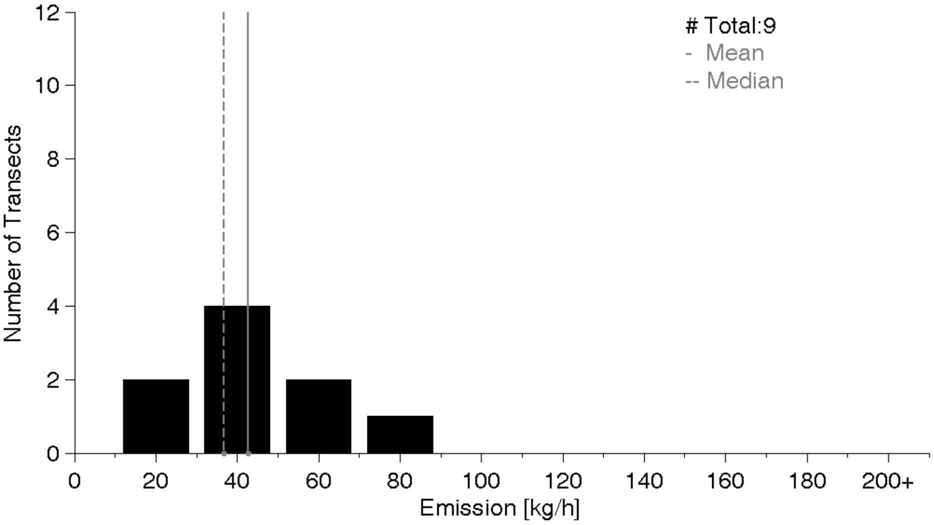

Figure 35. Histogram of all SkyDOAS SO_2 measurements at Refinery C during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.3.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery C were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from the SCAQMD-SLBH wind station were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured on different public roads surrounding the facility, depending on wind direction. The measurements are shown in Table 19.

The average mass fraction of BTEX to alkanes was 15.1%. The average flux of BTEX can be calculated by multiplying this figure with the total alkane flux as measured by the SOF-technique. The average fraction of benzene to alkanes was 3.4% and the benzene flux can be calculated in the same way as above. The plumes sampled during the measurement at Refinery C were weak and the low levels of both alkanes and BTEX causes a higher degree of uncertainty than usual in the mass ratio determination.

Table 19. Summary of MWDOAS BTEX measurements at Refinery C . *BTEX/alkane fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150918	220402-221009	12.6	1.4	2.5	323
151102	155155-155401	8.3	3.2	3.4	235
151102	150946-152855	13.8	2.4	3.5	254
151102	154248-154634	16.1	3.1	3.2	246
151104	160717-162206	24.8	6.7	3.3	275
Average±SD	-	**15.1±6.1**	**3.4±2.0**		

4.3.4 Methane

The average fraction of methane to total non-methane alkanes in the plume originating from Refinery C was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes measured simultaneously. Wind information from either LIDAR in position L2 or SCAQMD-SLBH was used, only wind direction, not wind speed matters for these measurements. Measurements were made both during the day and in late evenings and are shown in Table 20. Applying the measured fence-line ground level methane-to-alkane mass fraction to the by SOF measured alkane flux, gives an estimate of the methane flux from the refinery. The average methane-to alkane-mass fraction for Refinery C was 0.58.

Table 20. Summary of MeFTIR methane measurements at Refinery C. *Methane/alkane mass fraction.

Day [yymmdd]	**Timespan** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** **[%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150918	213422 -225735	2	61	2.9-3.0	321-327
151022	150050 -161331	5	49	3.1-5.2	182-193
151102	150921 -164835	3	68	2.8-3.8	243-279
151104	144900 -161529	2	62	4.0-12.0	230-262
Average±SD	**-**	**(total 12)**	**58±31**	**-**	**-**

4.4 Refinery D

Refinery D, (crude oil capacity: 105 kBPD (California Energy Commission 2016)) is located north of the Long Beach port, about 4 kilometers south of Refinery A, see Figure 10. To accurately compensate for incoming background plumes, it is necessary to make ‘box’ measurements (see example in Figure 36) which was easily done using public roads. Some measurements were however excluded since the incoming fluxes were comparable in size to the outgoing fluxes (adding too much uncertainty to the calculated flux). This was especially true for northerly and westerly winds carrying VOC-rich air from Refinery A and Refinery B.

Wind information for the flux calculations comes from the wind LIDAR (0-400 m average) at position L1 - (see Figure 10) or the Long Beach Airport ASOS station (scaled to match 0-400m LIDAR) or SCAQMD South Long Beach (SLBH) (scaled to match 0-400 m LIDAR). See section 3.4 for additional wind analysis. Typical wind directions and velocities during the measurements are 2-5 m/s and around 180°N or 270 degrees, see Figure 37.

4.4.1 Alkanes (non-methane)

Alkane emissions from Refinery D were measured with SOF during 7 days in the period September 3 to November 9, see Table 21. The daily means varied substantially from 90 kg/h (6 September) to an extreme of almost 1000 kg/h (1 November). A flaring event occurred 1 November which explains the large deviation for this day. The grand total average and standard deviation of all the 33 quality assured transects amounts to 348±253 kg/h and the median 164 kg/h. Histogram of all transects, Figure 38, show a gathered distribution at around 120 kg/h and some extreme outliers above 500 kg/h (which exclusively emanate from 1 November). Most transects show a typical column peak directly downwind the process area, see Figure 36. On November 1, significant VOC columns were detected directly downwind the flares in the west corner.

Table 21. Summary of SOF alkane measurements for Refinery D. *Single measurement. †Significantly deviating results due to flaring event.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150903*	140059 -140320	1	191.6	4.3	204
150906	171235 -180214	2	90.3±20.2	3.9-4.2	289-300
150907*	170803 -172210	1	125.6	6.6	269
150908	132545 -173630	9	192.0±66.9	4.0-7.8	274-296
150919	113306 -143232	10	116.7±47.1	2.2-2.6	160-198
151101†	104629 -150057	8	974.7±497.0	2.1-5.3	183-206
151109	135330 -144219	2	141.7±31.2	6.8-7.9	245-256
Average±SD	**-**	**(total 33)**	**348±253 (73%)**	**-**	**-**
Median	**-**	**(total 33)**	**164**	**-**	**-**

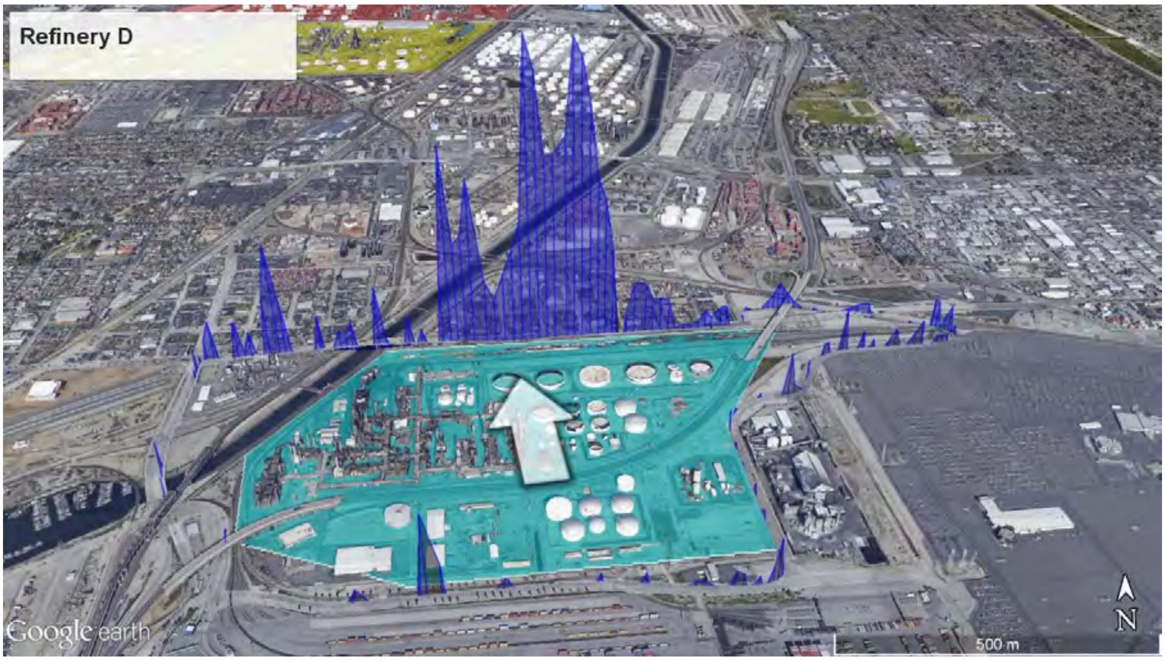

Figure 36. Example of a SOF 'box' measurement of Refinery D (cyan area) 19 September 2015, 13:08-13:20. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 80 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed during was 2.5 m/s. Emissions on the upwind side are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 185 kg/h from Refinery D.

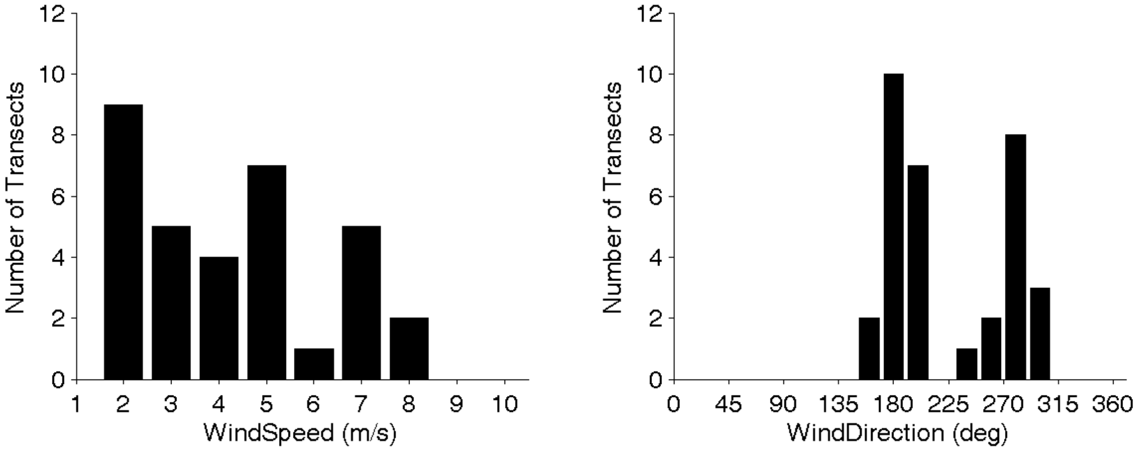

Figure 37. Wind histograms at Refinery D of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

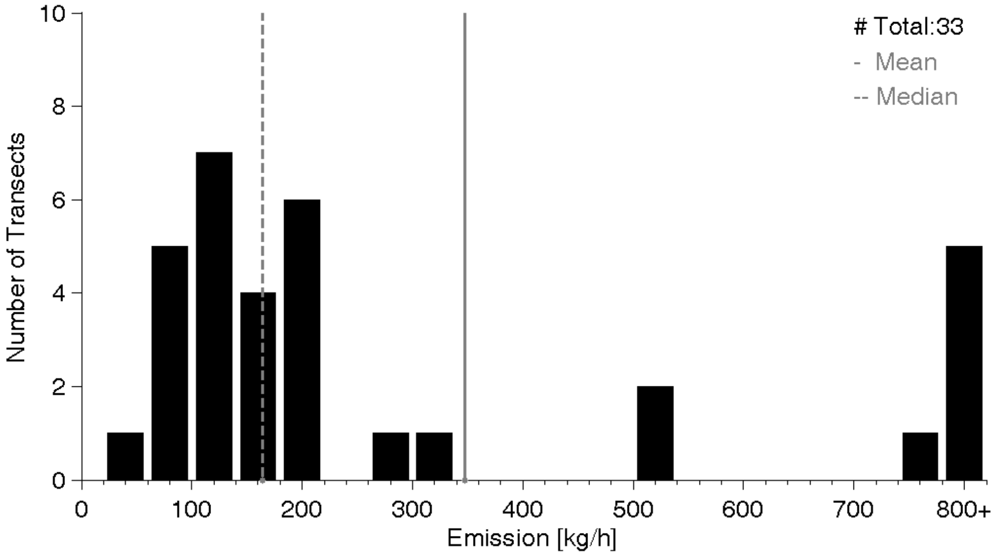

Figure 38. Histogram of all SOF measurements at Refinery D during the SCAQMD survey 2015. The last bin, denoted '+', contains all data points above 800 kg/h. The median and average values are indicated as dashed and solid gray lines.

4.4.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured for four measurement days in September during the campaign, example of a measurement is shown in Figure 39. Summaries and histograms of SkyDOAS emission measurements are presented in Table 22, Table 23, Figure 40 and Figure 41. Emissions averaged 43 and 18 kg/h and medians were 34 and 17 kg/h for NO_2 and SO_2 respectively.

Table 22. Summary of NO_2 measurements at Refinery D. *Single measurement.

Day [yymmdd]	**Timespan** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150902 *	160645 -160817	1	52.0	4.0	229
150906 *	100048 -100200	1	11.4	2.2	322
150908	132935 -152837	6	42.4±25.9	4.0-6.6	290-324
150919	114002 -142810	12	44.4±23.2	3.7-5.6	156-201
Average±SD	**-**	**(total 20)**	**43±24 (55%)**	**-**	**-**
Median	**-**	**(total 20)**	**34**	**-**	**-**

Table 23. Summary of SO_2 measurements at Refinery D . *Single measurement.

Day [yymmdd]	**Timespan** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150902*	160645 -160817	1	19.4	4.0	229
150906*	100048 -100205	1	13.6	2.2	322
150908	132935 -152823	6	26.8±8.3	4.0-6.6	289-322
150919	114057 -142758	12	14.0±5.6	3.5-5.7	166-204
Average±SD	**-**	**(total 20)**	**18±6.5 (36%)**	**-**	**-**
Median	**-**	**(total 20)**	**17**	**-**	**-**

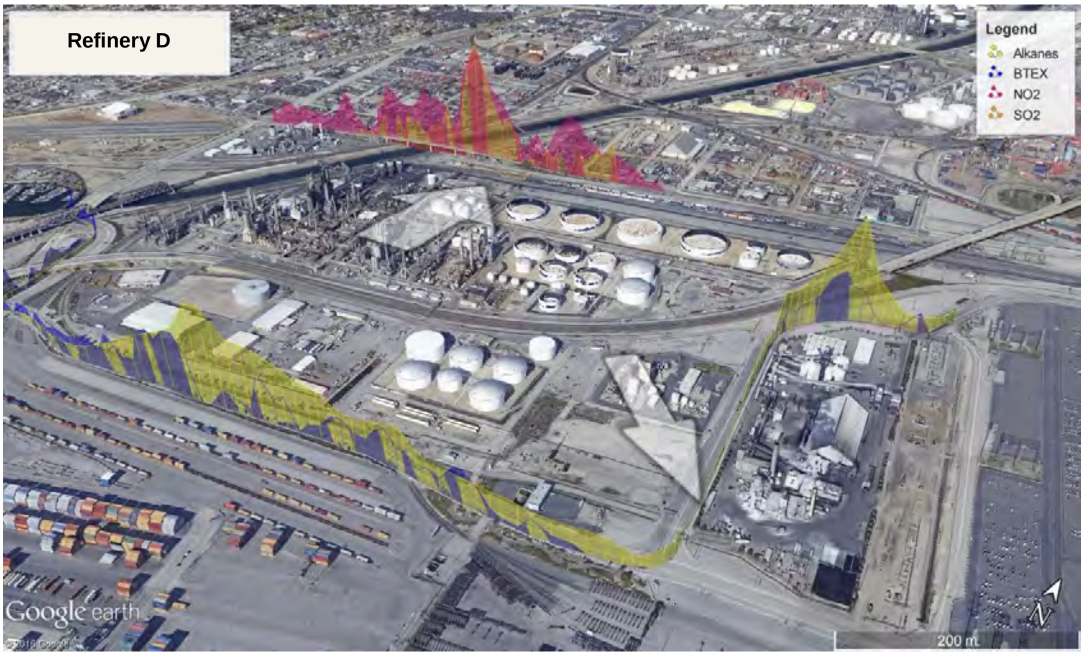

Figure 39. Transects of plumes originating from Refinery D: NO_2 (pink), SO_2 (brown) in south wind and BTEX (blue) and alkane (yellow) in north-westerly winds. NO_2 and SO_2 show column thickness and are both on the same scale (max SO_2 = 10.1 mg/m^2, flux SO_2 = 18.3 kg/h, max NO_2 = 9.8 mg/m^2, flux NO_2 = 39.3 kg/h), alkanes and BTEX show concentrations and are scaled independently for visibility (max BTEX =0.02 mg/m^3, max alkanes = 0.29 mg/m^3). Data from September 19, 12:42 PM and 8:32 PM.

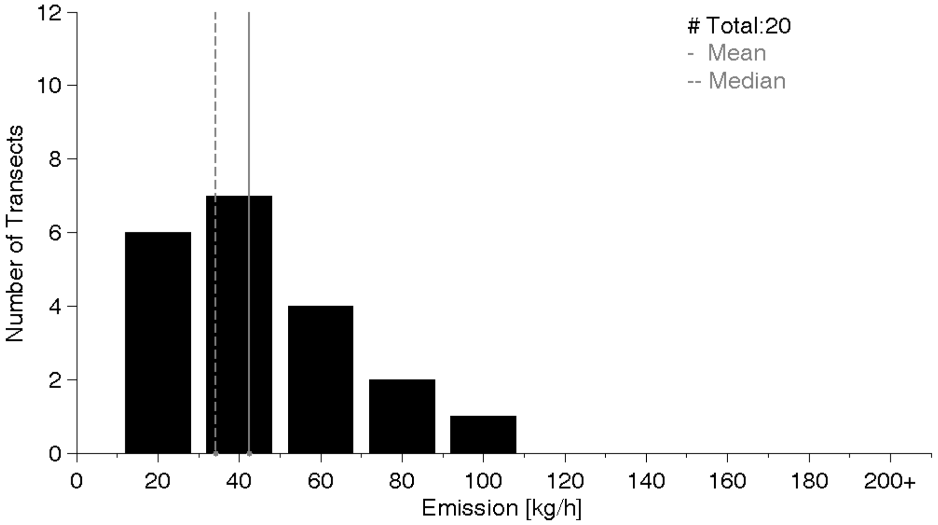

Figure 40. Histogram of all SkyDOAS NO_2 measurements at Refinery D during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

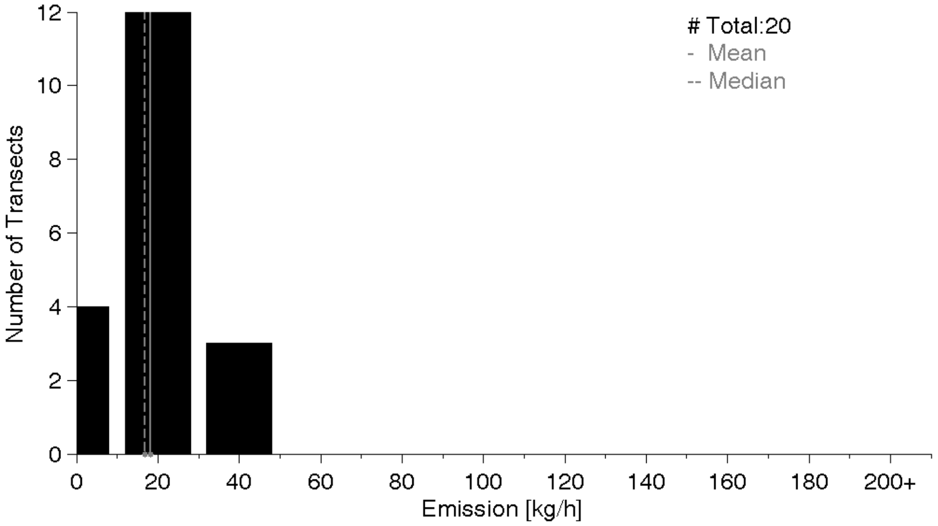

Figure 41. Histogram of all SkyDOAS SO_2 measurements at Refinery D during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.4.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery D were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. A measurement example is shown in Figure 39. To determine the source of the plume, wind directions from the LIDAR positioned at L1 or the SCAQMD-HDSN wind station were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured on different public roads surrounding the facility, depending on wind direction. The measurements are shown in Table 24.

The average fraction of BTEX to alkanes was 0.099 or 9.9%. The average flux of BTEX can be calculated by multiplying this figure with the total alkane flux as measured by the SOF-technique.

The average fraction of benzene to alkanes was 1.0% and the benzene flux can be calculated in the same way as above.

Table 24. Summary of MWDOAS BTEX measurements at Refinery D. *BTEX/alkane mass fraction.

Day [yymmdd]	Time span [hhmmss-hhmmss]	BTEX Fraction* [%]	Benzene Fraction* [%]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150919	200817-201303	6.3	0.81	3.4	309
150919	205012-205749	16.2	0.93	1.8	330
150919	203234-204133	5.1	1.3	3	331
150919	214233-215112	4.1	0.33	1.2	320
151104	170956-171120	20.7	2.5	2.2	266
151104	171422-171457	11.9	0.7	2.6	273
151104	171504-171546	4.7	0.46	3.8	295
Average±SD		**9.9±6.5**	**1.0±0.7**		

4.4.4 Methane

The average fraction of methane to total non-methane alkanes in the plume from Refinery D was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume were compared to the average concentration of correlating alkanes measured simultaneously. Wind information from ASOS_KLGB was used, though only wind direction, not accurate wind speed matters for these measurements. Measurements were made during daytime and are shown in Table 25. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux measured by SOF, gives an estimate of the methane flux from the refinery. The average methane-to-alkane fraction for Refinery D was 0.48.

Table 25. Summary of MeFTIR methane measurements at Refinery D. *Methane/alkane mass fraction.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Methane fraction* [%]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150919	115502 -234019	10	46	0.5-4.5	41-345
151101	102640 -121744	3	55	0.8-3.9	141-190
Average±SD	**-**	**(total 13)**	**48±20**	**-**	**-**

4.5 Refinery E

Refinery E (crude oil capacity: 269 kBPD, (California Energy Commission 2016)) is located at the Pacific coast, around 20 kilometers northwest of Refinery A (Figure 10). This refinery is totally isolated from the other refineries in this study. There are however, other significant background plumes from the oil wells and power plants along the coast line that must be compensated for in the flux calculations. This is done by encircling (‘boxing’) the facility when possible (see example in Figure 42). No prevailing night-time VOC-rich air masses during AM were present in this coastal location (as compared to the other refineries in this survey).

Wind information for the flux calculations comes from the wind LIDAR (0-400 m average) at position L4 located around 1 km east of the refinery (see Figure 42) for the period 9-16 September. For the other days, wind information from the Los Angeles International Airport (KLAX) ASOS met station, 3 km north of the refinery, was used (scaled to match 0-400 m LIDAR). See section 3.4 for additional wind analysis. Typical wind directions and velocities during the measurements are 4-7 m/s and 270°N, see Figure 43. Winds were generally steady at this site due the sea breeze.

4.5.1 Alkanes (non-methane)

Alkane emissions from Refinery E were measured with SOF during seven days in the period September 9 to November 6, see Table 26. The daily means varied from 185 kg/h (13 September) to over 700 kg/h (11 September). The increased emissions 11 September points toward the tank park in the northwest corner. The grand total average and standard deviation of all the 35 quality assured transects amounts to 280±223 kg/h and the median 244 kg/h. Histograms of all transects (Figure 44) show a peak at around 240 kg/h and one extreme outlier (from 11 September). Most transects show a broad column peak downwind the core of the facility, see Figure 42.

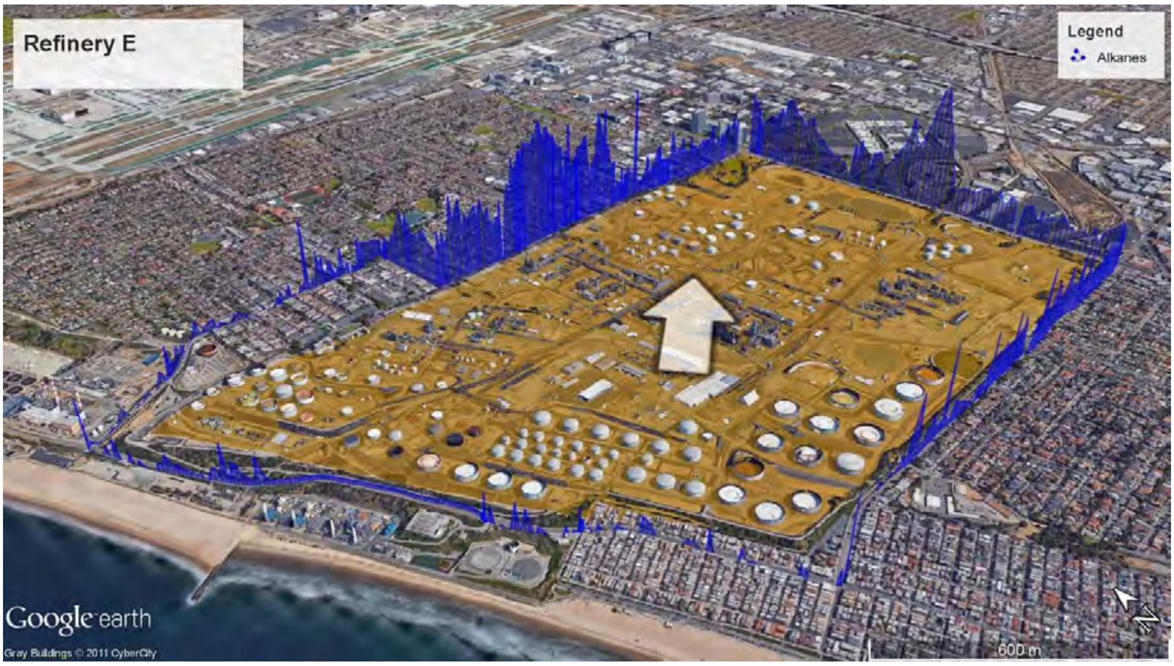

Figure 42. Example of a SOF 'box' measurement of Refinery E (orange area) 6 November 2015, 10:47-11:22. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 55 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed during this particular measurement was 1.8 m/s. Emissions on the upwind side are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 229 kg/h from Refinery E.

Table 26. Summary of SOF alkane measurements at Refinery E. *Single measurement. †Extremely deviating results due to (likely) tank park event.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150909	120735 -152659	5	242.2±83.3	4.6-6.7	266-279
150911†	110544 -133021	3	701.9±718.8	2.3-5.3	240-252
150913	112120 -144848	4	185.0±62.3	1.9-6.4	239-261
150916	145339 -160447	2	206.1±96.9	4.9-5.3	253-254
150920	105011 -143901	7	302.7±75.6	4.2-6.0	265-270
150927	120435 -152615	9	218.9±44.8	3.4-4.9	257-270
151106	104724 -140220	5	249.1±41.5	1.8-4.2	235-255
Average±SD	-	**(total 35)**	**280±223 (80%)**	-	-
Median	-	**(total 35)**	**244**	-	-

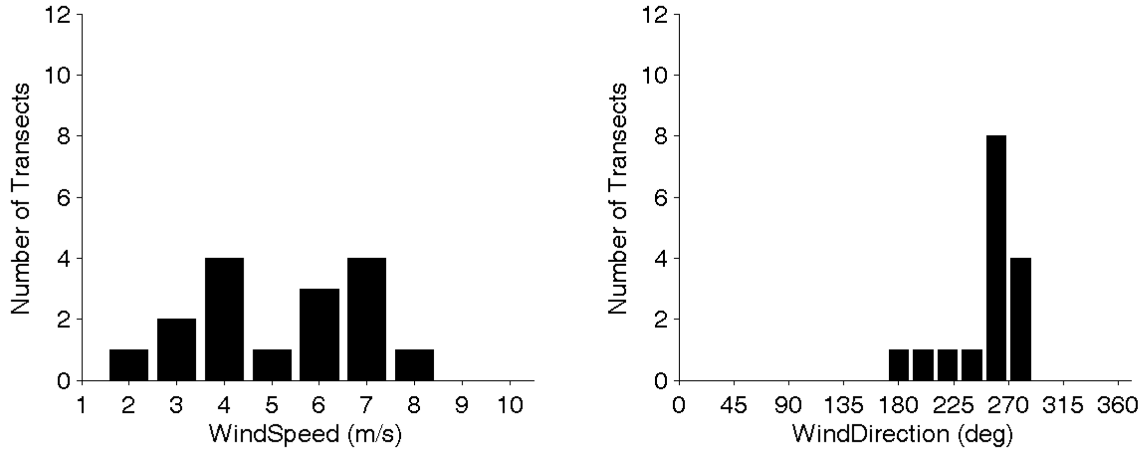

Figure 43. Wind histograms at Refinery E of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

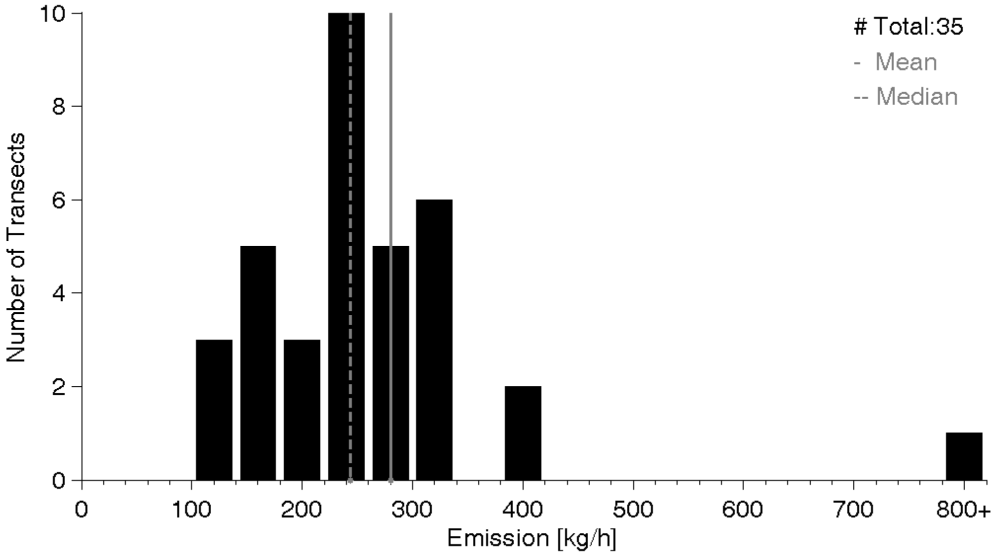

Figure 44. Histogram of all SOF measurements at Refinery E during the SCAQMD survey 2015. The last bin, denoted '+', contains all data points above 800 kg/h. The median and average values are indicated as dashed and solid gray lines.

4.5.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured during 7 measurement days in September and November during the campaign, examples of such measurements can be seen in Figure 45. As these plumes are from combustion sources and presumably stack releases, the plumes are expected to be at a higher altitude than the VOC plume when measuring near the facility, as in nearly all the measurements. Summaries of SkyDOAS emission measurements are presented in Figure 46, Figure 47, Table 27 and Table 28. Emissions were determined using LIDAR-wind, measured at position L4 or scaled KLAX ASOS met station. Typically, baselines were corrected for background (vehicle and other sources for NO_2) thus setting inflow to zero. Emissions averaged 70 and 52 kg/h and medians were 63 and 53 kg/h for NO_2 and SO_2 respectively.

Table 27. Summary of NO_2 measurements at Refinery E. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150909	114049 -145759	5	99.1±19.9	4.6-5.0	260-268
150911	111924 -132450	2	67.2±47.0	3.6-5.0	259-270
150913	112658 -144342	4	60.4±13.9	4.0-5.9	245-258
150916	145850 -163249	3	45.5±16.2	3.7-4.5	249-265
150920	110103 -114007	2	101.3±29.2	4.4-4.8	263-268
150927	140555 -144335	2	44.3±6.3	4.2-4.9	254-264
151106 *	123305 -124620	1	35.9	2.9	251
Average±SD	**-**	**(total 19)**	**70±23 (33%)**	**-**	**-**
Median	**-**	**(total 19)**	**63**	**-**	**-**

Table 28. Summary of SO_2 measurements at Refinery E. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150909	114700 -152537	6	40.5±20.4	4.0-5.2	258-272
150910 *	154026 -155223	1	42.1	4.4	266
150911	103551 -132450	4	49.3±25.7	3.5-5.0	252-270
150913	091458 -144342	7	47.4±11.7	2.3-5.9	242-258
150916	145850 -163249	3	55.6±9.8	3.8-4.7	249-268
150920	105910 -113707	2	76.4±27.7	4.5-4.9	261-271
150927	140555 -151747	4	61.7±9.4	4.2-4.9	254-264
151106	114611 -124623	2	70.7±26.6	2.5-2.8	250-252
Average±SD	**-**	**(total 29)**	**52±19 (35%)**	**-**	**-**
Median	**-**	**(total 29)**	**53**	**-**	**-**

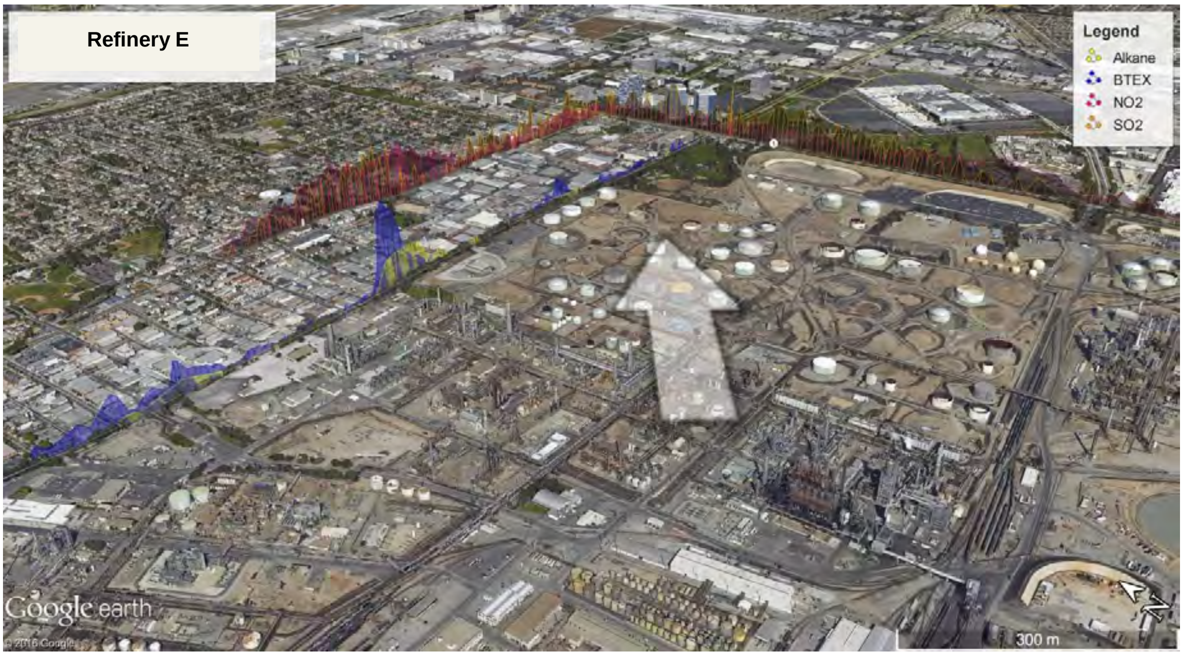

Figure 45. Transects of plumes originating from Refinery E: NO_2 (pink), SO_2 (brown), BTEX (blue) and alkane (yellow). NO_2 and SO_2 show column thickness and are both on the same scale (max NO_2 = 5.9 mg/m^2, flux NO_2 = 42.5 kg/h, max SO_2 = 6.4 mg/m^2, flux SO_2 = 48.9 kg/h), alkanes and BTEX show concentrations and are scaled independently for visibility (max BTEX = 0.04 mg/m^3, max alkanes = 0.13 mg/m^3). Example transects from September 16, 4:23 PM and 9:07 PM.

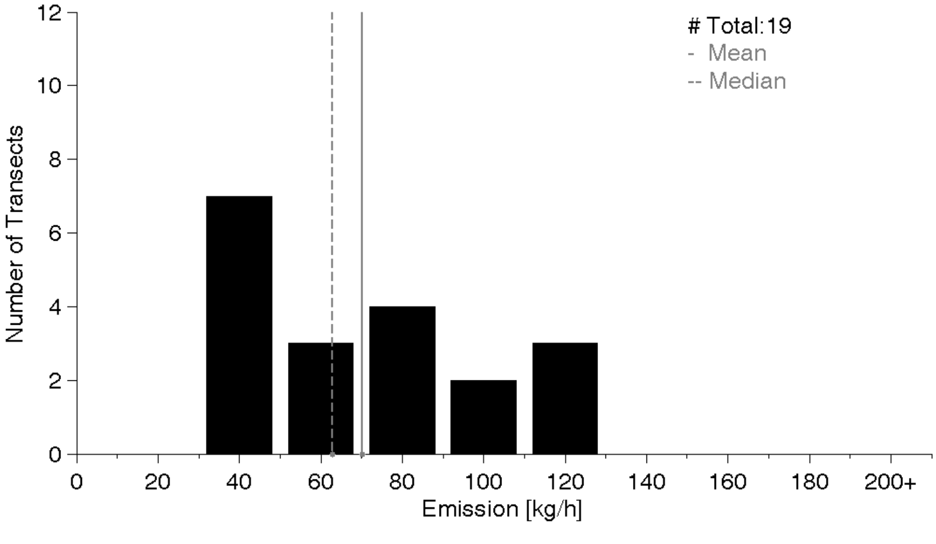

Figure 46. Histogram of all SkyDOAS NO_2 measurements at Refinery E during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

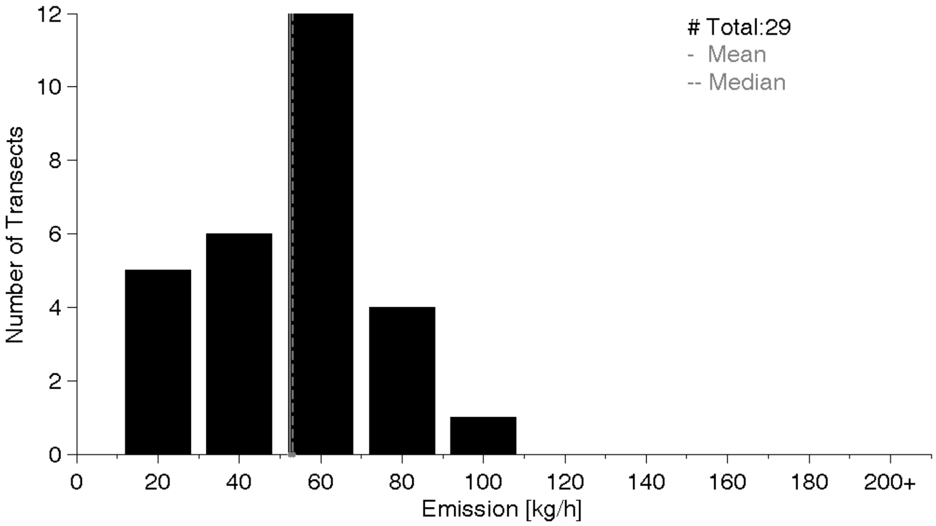

Figure 47. Histogram of all SkyDOAS SO_2 measurements at Refinery E during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.5.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery E were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX level measurements from MWDOAS and alkane measurements from MeFTIR. Figure 45 shows an example of a measurement. To determine the source of the plume, wind directions from the LIDAR positioned at L4 or the ASOS-KLAX wind station were used (wind speed is irrelevant for these measurements). The total BTEX ratio was measured north of the facility. The measurements are shown in Table 29.

The average mass fraction of BTEX to alkanes was 0.13 or 13.0%. The average flux of BTEX can be calculated by multiplying this figure with the total alkane flux as measured by the SOF-technique. The average mass fraction of benzene to alkanes was 1.1% and the benzene flux can be calculated in the same way as above.

Table 29. Summary of MWDOAS BTEX measurements at Refinery E. *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150916	112732 -165808	12	0.53	0.8	353
150916	130746 -131654	13.5	0.71	1.3	330
150916	134638 -154706	2.1	1	1	331
150916	142535 -154524	20	2	2	320
150916	144942 -173531	17.2	1.4	2.1	317
Average±SD	**-**	**13±6.8**	**1.1±0.6**	**-**	**-**

4.5.4 Methane

The average fraction of methane to total non-methane alkanes in the plume from Refinery E was measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of correlating alkanes measured simultaneously.

Wind information from ASOS_KLAX was used, only wind direction, not wind speed matters for these measurements. Measurements were made during daytime and late evening and are shown in Table 30. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux measured by SOF, gives an estimate of the methane flux from the refinery. The average methane-to-alkane fraction for Refinery E was unusually high on the night of September 19 and might have been affected by some temporary release source. Therefore the measurements from September 19 will not be used in the result. When measured on September 27 the fraction was no longer extreme and the average from that day, 0.85 will represent the resulting fraction for Refinery E.

Table 30. Summary of MeFTIR Methane measurements at Refinery E. *Methane/alkane mass fraction. †Extremely deviating results likely due to other non-identified temporal source.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150916†	170318 -224508	5	180	4.0-5.1	230-268
150927	112103 -151358	5	85	4.0-4.0	230-230
Average±SD	**-**	**(total 10)**	**85±7**	**-**	**-**

4.6 Refinery F

Refinery F (crude oil capacity 150 kBPD, (California Energy Commission 2016)) is located around 10 kilometers northwest of Refinery A, see Figure 10. Emission plumes from other refineries in this study or other large emitters do not interfere directly with plumes from Refinery F with the prevailing wind directions. But there are some minor oil wells and storage tanks west of the refinery which must be compensated for in the flux calculations by ‘boxing’ the facility during westerly winds (see example in Figure 48).

Wind information for the flux calculations comes from the wind LIDAR (0-400 m average) at position L3 located 300 m east of the refinery (see Figure 48) 17 September. For the other days, wind information from the L1 LIDAR site was used. See section 3.4 for additional wind analysis. Typical wind directions and velocities during the measurements are around 4 m/s and around 180 or 270°N, see Figure 49.

4.6.1 Alkanes (non-methane)

Alkane emissions from Refinery F were measured with SOF during four days: 9, 13 and 17 September and 7 November, see Table 31. The daily means varied from 117 kg/h (13 September) to 219 kg/h (17 September). The grand total average and standard deviation of all the 16 quality assured transects amounts to 169±105 kg/h and the median 140 kg/h. Histograms of all transects (Figure 50) show a peak at around 120 kg/h and one extreme outlier (from 17 September). Transects show a column peak downwind the southeast tank park and the process area, see Figure 48.

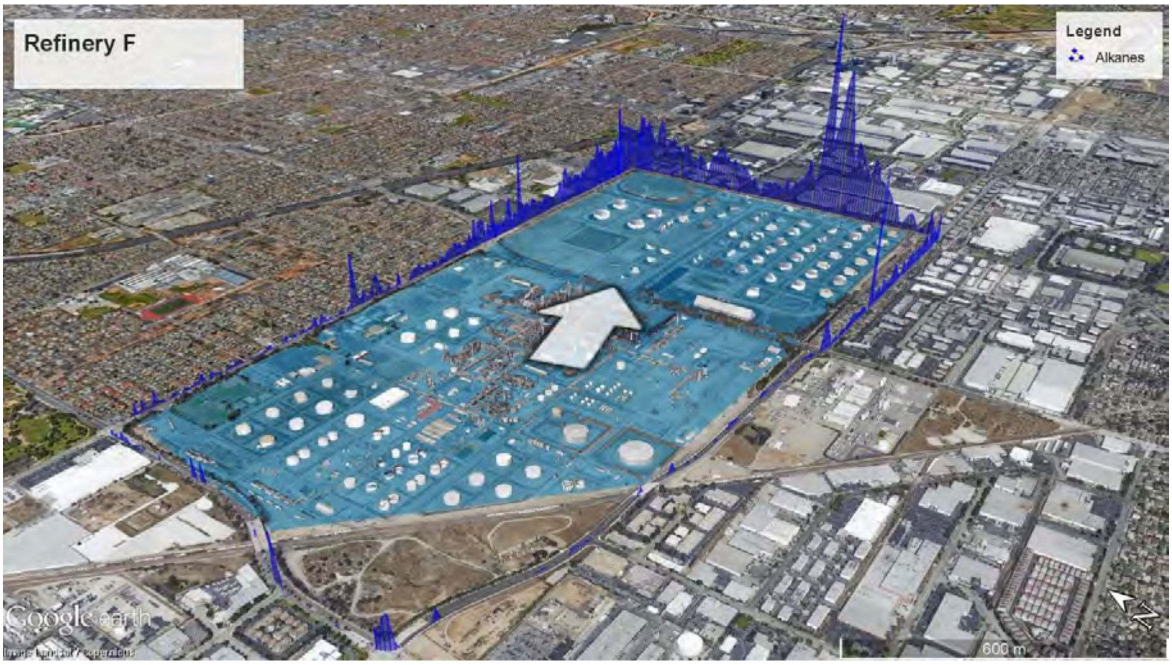

Figure 48. Example of a SOF ‘box’ measurement of the Refinery F (light blue area) 17 September 2015, 12:39-13:04. Alkane column is shown as a blue curve with apparent height proportional to gas column (10 m equivalent to 1 mg/m^2, max 83 mg/m^2). Wind direction during the measurement is indicated by the white arrow. Average wind speed during was 3.1 m/s. Emissions on the upwind side are subtracted from the downwind side in order to get emissions from within the box. This particular transect measured 230 kg/h from Refinery F.

Table 31. Summary of SOF alkane measurements for Refinery F. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150909*	164857 -165755	1	157.7	3.6	226
150913	153509 -170800	4	117.1±18.0	6.2-7.1	270-277
150917	120844 -161940	7	219.4±152.4	3.1-7.6	251-261
151107	133217 -145646	4	135.3±6.5	2.5-4.5	189-277
Average±SD	**-**	**(total 16)**	**169±105 (62%)**	**-**	**-**
Median	**-**	**(total 16)**	**140**	**-**	**-**

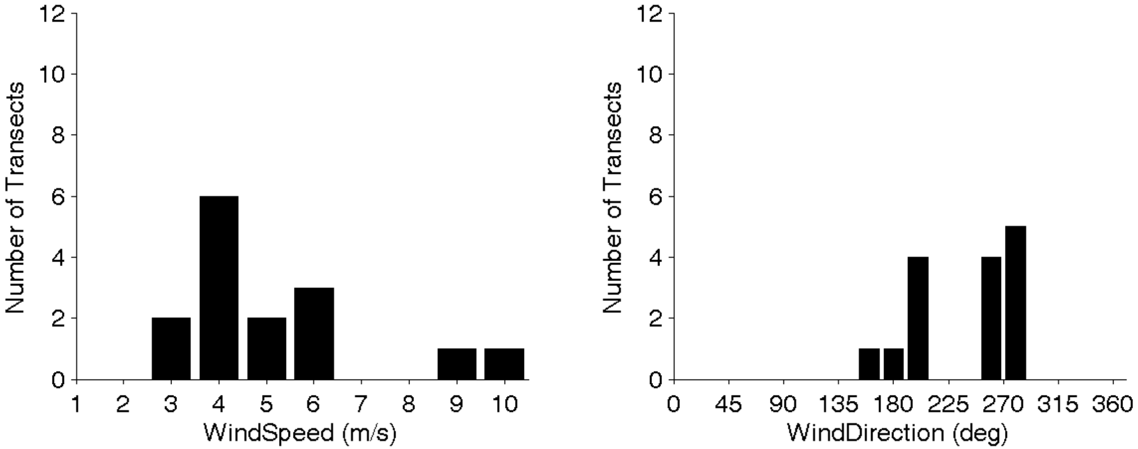

Figure 49. Wind histograms at Refinery F of wind speed (left) and wind direction (right) for the SOF measurements during the SCAQMD survey 2015.

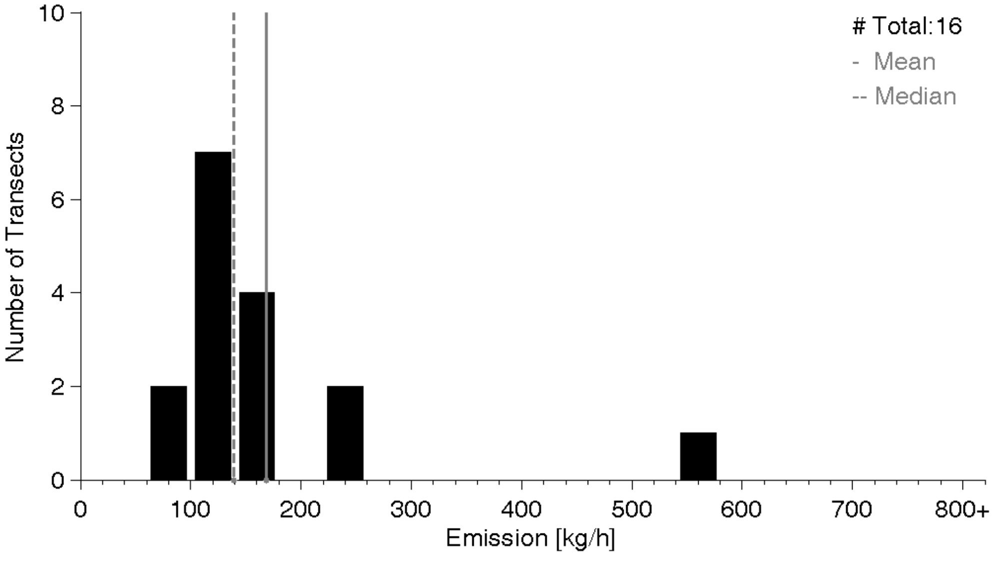

Figure 50. Histogram of all SOF measurements at Refinery F during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

4.6.2 SO_2 and NO_2

SO_2 and NO_2 emissions from the facilities were measured for 2 measurement days in September. Summaries of SkyDOAS emission measurements are presented in Table 32 and Table 33. An example of a measurement is shown in Figure 51. For Refinery F the number of measurements is very low and the result may therefore be less reliable as a representation of typical emissions. Emissions averaged 23 and 40 kg/h and medians were 18 and 37 kg/h for NO_2 and SO_2 respectively.

Table 32. Summary of NO_2 measurements at Refinery F. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150913	153603 -160753	2	14.8±4.1	6.1-6.1	258-273
150917	132227 -132826	1	38.2	5.0	252
Average±SD	**-**	**(total 3)**	**23±4.1 (18%)**	**-**	**-**
Median	**-**	**(total 3)**	**18**	**-**	**-**

Table 33. Summary of SO_2 measurements at Refinery F. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150913*	153535 -154138	1	67.2	6.2	260
150917	121200 -132803	2	27.0±14.2	3.3-4.9	248-252
Average±SD	**-**	**(total 3)**	**40±14 (35%)**	**-**	**-**
Median	**-**	**(total 3)**	**37**	**-**	**-**

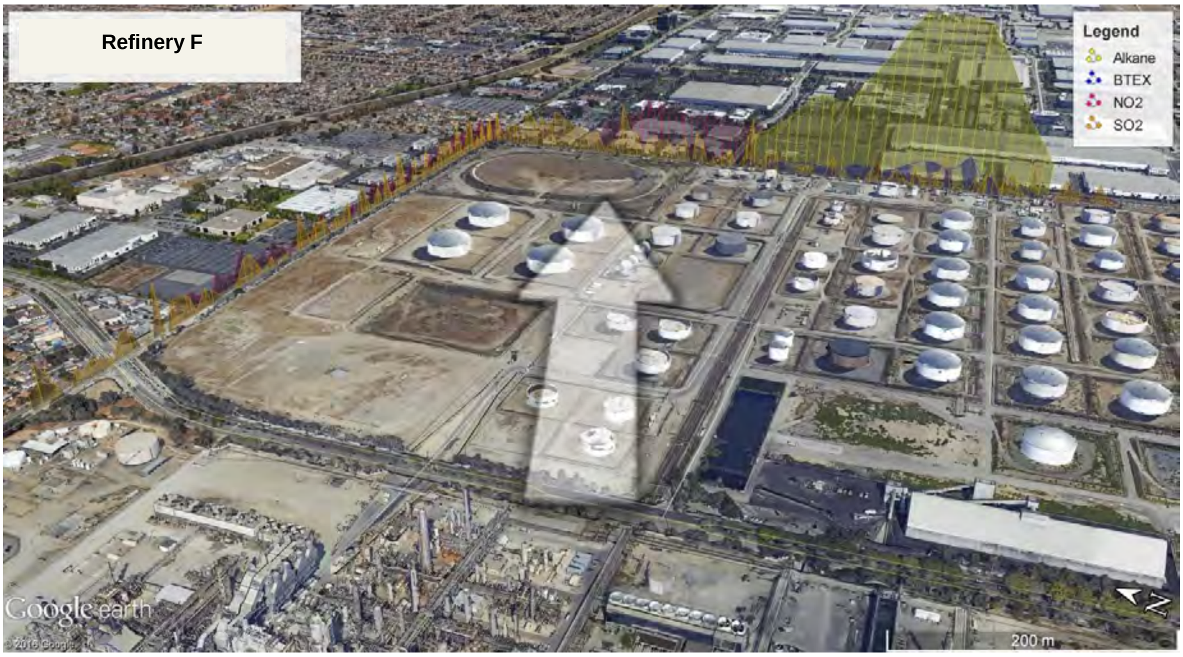

Figure 51. Transects of plumes originating from Refinery F: NO_2 (pink), SO_2 (brown), BTEX (blue) and alkane (yellow). NO_2 and SO_2 show column thickness and are both on the same scale (max NO_2 = 5.0 mg/m^2, flux NO_2 = 38.2 kg/h, max SO_2 = 4.4 mg/m^2, flux SO_2 = 17 kg/h), alkanes and BTEX show concentrations and are scaled independently for visibility (max BTEX = 0.01 mg/m^3, max alkanes = 0.55 mg/m^3). Example transects from September 17, 1:22 PM and 11:36 PM.

4.6.3 BTEX

The BTEX mass fraction to alkane in the plumes emitted from Refinery F were measured either in the late evening or early morning when the plumes were closer to ground. The mass fraction is acquired by combining BTEX ground level measurements from MWDOAS and alkane measurements from MeFTIR. To determine the source of the plume, wind directions from the LIDAR positioned at L3 or the KLAX-ASOS wind station were used (wind speed is irrelevant for these measurements). BTEX mass ratios were measured along one road picking up the plume from the tank park, and along another cutting through the facility and enabling a measurement of the process plume in westerly wind. The measurements are shown in Table 34 and Table 35.

The average mass fraction of BTEX to alkanes was 0.137 or 13.7% and 0.017 or 1.7% for the process and the tank park respectively. The average flux of BTEX can be calculated by multiplying this figure with the alkane flux as measured from these two sources by the SOF-technique. The average mass fraction of benzene to alkanes was 0.9% for the process plume and 0.3% for the tank park plume. Benzene flux can be calculated in the same way as above. Both the total BTEX flux and the benzene flux for Refinery F can be found in Table 5.

Table 34. Summary of MWDOAS BTEX measurements at Refinery F. Tank park plume *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150917	214724-215203	1.9	0.44	1.8	270
150917	232708-232841	1.4	0.19	2.8	251
Average±SD	**-**	**1.7±0.4**	**0.3±0.2**	**-**	**-**

Table 35. Summary of MWDOAS BTEX measurements at Refinery F. Process plume *BTEX/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**BTEX Fraction*** [%]	**Benzene Fraction*** [%]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150917	221740-221813	12.8	0.87	1.7	244
150917	233614-233641	13.3	1	2.6	252
150917	231920-232007	15.1	0.71	4	45
Average±SD		**13.7±1.2**	**0.9±0.3**		

4.6.4 Methane

The average fraction of methane to total non-methane alkanes in the plume from Refinery F were measured at ground level using MeFTIR. The plume was sampled along roads surrounding the facility and the average concentration across the plume was compared to the average concentration of alkanes measured simultaneously. Applying the measured fence-line ground level methane-to-alkane mass fraction to the median alkane flux measured by SOF, gives an estimate of the methane flux from the refinery. Wind information from LIDAR in position L3 was used, only wind direction, not wind speed matters for these measurements. Only three measurements were made on one evening September 17 as shown in Table 36. The average methane-to-alkane fraction for the Refinery F was 0.41.

Table 36. Summary of MeFTIR methane measurements at Refinery F. *Methane/alkane mass fraction.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Methane fraction*** **[%]**	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150917	211536 -233000	3	41	1.9-3.3	251-274
Average±SD	**-**	**(total 3)**	**41±6**	**-**	**-**

5 Results – On-site Measurements in a Refinery Tank Farm

On site measurements in the tank farm of a major refinery in the South Coast Air Basin were carried out for 8 days between 28 September and 7 October 2015 using the mobile optical methods described in the previous sections (i.e. SOF, MWDOAS and MeFTIR). The objective of this activity was to demonstrate the capability of these real time optical techniques to identify and quantify gas leakages inside a refinery and to compare the results with other optical methods used during the same time frame. These include a DIAL (Differential Absorption LIDAR; a laser-based method) operated by NPL (National Physics Laboratory, UK) at different locations within the tank farm, and a stationary long path FTIR system that was operated by Atmosfir in the west part of the tank farm. Here the FTIR coupled to a telescope was automatically pointed towards multiple reflectors put at strategic positions in different parts of the tank farm and at different heights to estimate ground source emissions using the EPA's OTM-10 method (see separate report by Atmosfir). These various methods were used independently but on several occasions side by side measurements were carried out for validation purposes (see report by Pikelnaya et. al. (2016)).

In this study we carried out mobile optical measurements throughout the tank farm on available roads in order to localize potential hot-spot emission areas and quantify emissions from selected tanks and tank groups. The emphasis was to investigate emissions from tank groups and tanks rather than the whole tank farm emissions, although this was also done.

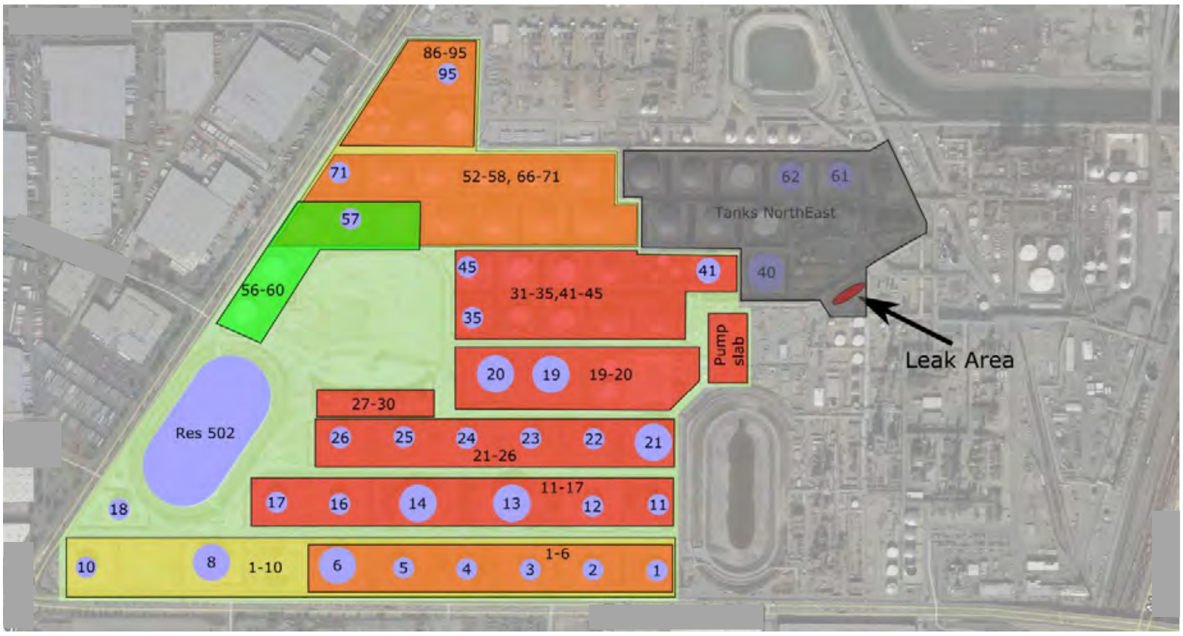

Figure 52. Overview of the tank farm part of the refinery where on site measurements with SOF + MeFTIR + MWDOAS were conducted for about one week in September/October 2015. Tanks, tank groups and specific areas have been given numbers and names respectively for reference to measurement results. North is upwards. Groups of quantified tanks are denoted by coloured rectangles, and individual tanks that have been quantified are indicated by blue shapes/circles. The surveyed part (large light green area) is restricted in the west and south by the site fence-line, and in the east and north by roads going east of tank 1-11-21-Pump slab and then between the "Tanks NorthEast" and tank groups "52-58+66-71" and to the northeast corner of group "86-95".

This limited study included alkane column measurements and ground concentration measurements of alkanes, methane and aromatic VOCs. A wind meter was positioned on an elevated plateau on a big open field inside the tank farm, thus sampling wind at a height comparable to a typical tank roof height.

The real-time capability and sensitivity of the instruments (2 s sampling time resolution for SOF and MWDOAS, 10 s for MeFTIR) was essential to this work as shown in Figure 53. By observing the geo-tagged emissions in real time, any occurring hot-spots can immediately be investigated further to for example conclude if the sources are intermittent or continuous. By driving on the upwind and downwind side of the tanks and unit areas, any incoming emission fluxes or interfering sources can be identified and accounted for.

Figure 53. A picture from the measurement van showing real time data while passing through a source. The column and concentration data is shown together with the measurements position on a map for fast hotspot identification and interpretation.

Validation between SOF (FluxSense) and DIAL (NPL) was done on tank 16 (crude), tank 13 (crude) and on reservoir 502 (vacuum gas oil).

5.1 Tank Park

Table 37 summarizes the plume transects including the whole tank farm in one run. The median emission of all these complete tank farm emission measurements was 145 kg/h based on 9 measurements distributed over four days. This corresponds to approximately half the total measured refinery emission (see section 4.1.1). The overall tank farm single observations ranged from 104-194 kg/h for the daily averages (4 different days).

Figure 54 shows an example of SOF measurements around the tank farm at the selected refinery. In this transect the highest column (165 mg/m^2) of VOC was measured at the elliptically shaped tank (here referred as tank reservoir no 502) in the lower left corner. This is explained by the pass being close to the source before the release was dispersed by convection and turbulence. It’s evident that reservoir 502 is a substantial source of alkanes. However, when following the measurement transect along the perimeter of the tank farm several extended plume sections are observed, and these add up to emission being several times that of reservoir 502 alone. The contribution from different parts of the tank farm is discussed in the next section.

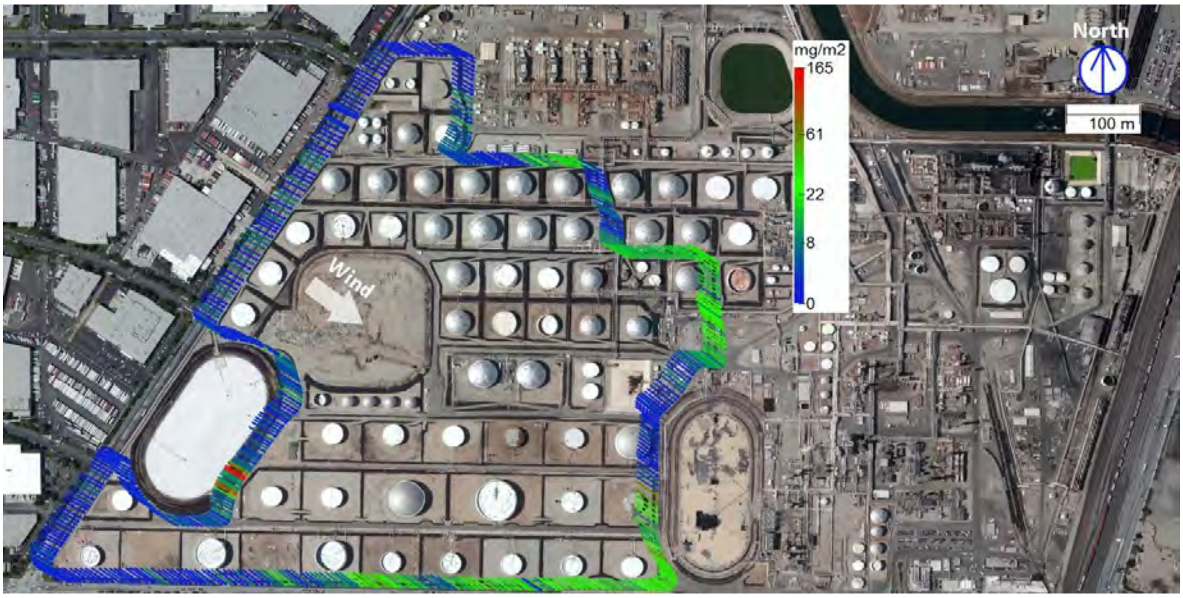

Figure 54. SOF measurement of alkanes around the major body of the tank farm on September 29, 2015 between 2:51 PM and 3:15 PM. Each measured spectrum is represented by a single line, with color indicating the evaluated integrated vertical alkane column. The line orientation indicates the direction from which the wind is blowing. North is upwards and in this case the wind blew from northwest.

Table 37. Summary of SOF alkane measurements for the refinery tank park considered in this study.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150928	143009 -153658	2	187.6±89.2	5.2-5.5	291-299
150929	145455 -150723	2	193.9±33.2	4.7-6.3	302-302
151002	143351 -154352	4	136.5±33.7	4.4-5.5	277-294
151006	140304 -150009	2	104.4±24.7	3.7-5.4	280-285
Average±SD	-	**(total 9)**	**153±53 (35%)**	-	-
Median	-	**(total 9)**	**145**	-	-

5.2 Individual Tanks and Tank groups

Based on 233 measurement transects of different tanks and tank groups, specific tank emissions have been summarized in Table 38. Adding up all the measured tank farm objects give on average 191 kg/h of alkanes. This is in line with the estimate from the SOF measurements for the complete tank farm in one run (153 kg/h, Table 37). Note that these numbers represent two different approaches with varying coverage in time and space. The statistic basis is quite variable among the tank farm objects, ranging from Reservoir 502 having 80 measurements distributed over 8 days to a few objects having only a single observation.

Table 38. Summary of onsite measurements (SOF) of tanks and tank groups. a) For the BTEX emission the average BTEX to alkane mass fraction (6.0 %) has been used for the tanks where the BTEX fraction was not quantified. b) For the benzene emission the average benzene to alkane mass fraction (0.59 %) has been used for the tanks where the benzene fraction was not quantified. *Items in italics and aligned to the right are either subgroups part of other items or not part of the overall Tank farm average.*

Tank_ID	**Average alkane (kg/h)**	**SD (kg/h)**	**No. meas.**	**No. days**	**BTEX to alkane mass fraction (%)**	**BTEX emission a) (kg/h)**	**Benzene to alkane mass fraction (%)**	**Benzene emission b) (kg/h)**
Tank_1	1	0.4	5	3	2	0.02	0.37	0.00
Tank_2	2.8	4.9	3	2	n.m.	0.17	n.m.	0.02
Tank_3	1.3	0.3	4	3	n.m.	0.08	n.m.	0.01
Tank_4	0.6	0.1	4	3	n.m.	0.04	n.m.	0.00
Tank_5	1.7	0.2	4	3	n.m.	0.10	n.m.	0.01
Tank_6	4.2	1.7	8	4	3.3	0.14	0.39	0.02
Tank_8	2.6	1.8	9	3	n.m.	0.16	n.m.	0.02
Tank_11	10.9	5.4	9	4	7.6	0.83	0.65	0.07
Tank_12	2.4	1.7	9	4	5.3	0.13	0.73	0.02
Tank_13	21.6	10.4	32	5	8.9	1.92	0.55	0.12
Tank_14	5.4	4.1	9	4	1.5	0.08	0.48	0.03
Tank_16_all days	*259*	*134*	*55*	*6*	*1.4*	*3.63*	*0.34*	*0.88*
Tank_16_excl. 151005	42	34	13	5	1.4	0.59	0.34	0.14
Tank_17	2.8	1	10	5	0.6	0.02	0.54	0.02
Tank_18	0.7	0.6	2	2	n.m.	0.04	n.m.	0.00
Tanks_19-20	15.8		1	1	n.m.	0.95	n.m.	0.09
Tank_21	6.3	1.4	5	2	12.3	0.77	n.m.	0.04
Tank_22	1.2	0.5	6	2	11.4	0.14	0.25	0.00
Tank_25	2.1		1	1	n.m.	0.13	n.m.	0.01
Tanks_27-30	5.3	0.2	5	4	5.6	0.30	1.5	0.08
Tanks_31-35_42-45	12.6		1	1	n.m.	0.76	n.m.	0.07
Tank_40	*4.5*	*0.1*	*2*	*1*	*n.m.*	*0.27*	*0.48*	*0.02*
Tanks_56-60	*7.6*	*0.6*	*2*	*2*	*n.m.*	*0.46*	*n.m.*	*0.04*
Tank_57	*3.0*		*1*	*1*	*5.6*	*0.17*	*0.24*	*0.01*
Tank_71	*3.7*		*1*	*1*	*5.6*	*0.21*	*0.37*	*0.01*
Tanks_52-58_66-71	13.7		1	1	9.3	1.27	0.88	0.12
Tanks_86-95	8.0	0.7	6	4	4.4	0.35	n.m.	0.05
Reservoir_502	26.1	11.4	80	8	10.7	2.79	1.1	0.29
Total all measured tanks:	**191**		**233**			**12**		**1.2**

As seen in Table 38, Tank 16 had one day (5 October, 2015) where atypical emissions were observed. Including this day would raise the overall average for Tank 16 to 259 kg/h if compared to 42 kg/h if this day is excluded. In the presented grand total average for the tank farm, this atypical event was left out for Tank 16 (42 measurements were conducted on tank 16 this day in a validation experiment with other optical techniques, whereas 13 measurements were done for the other days being included in the average). BTEX to alkane mass fractions were also measured for many of the tanks, and ranged from 1.4 to 12.3 % which is quite normal values for a tank farm containing both crude and refined petroleum product tanks. Last four columns in Table 38 specify measured BTEX fractions, inferred BTEX emissions and corresponding columns for benzene, using the SOF alkane emission and the BTEX and benzene fractions respectively. For tanks where BTEX or benzene were not measured, the average BTEX mass fraction (6.0 %) or benzene average fraction (0.59 %) has been used. Overall a BTEX emission of 12 kg/h is estimated from the tank farm, of which 1.2 kg is estimated to be benzene.

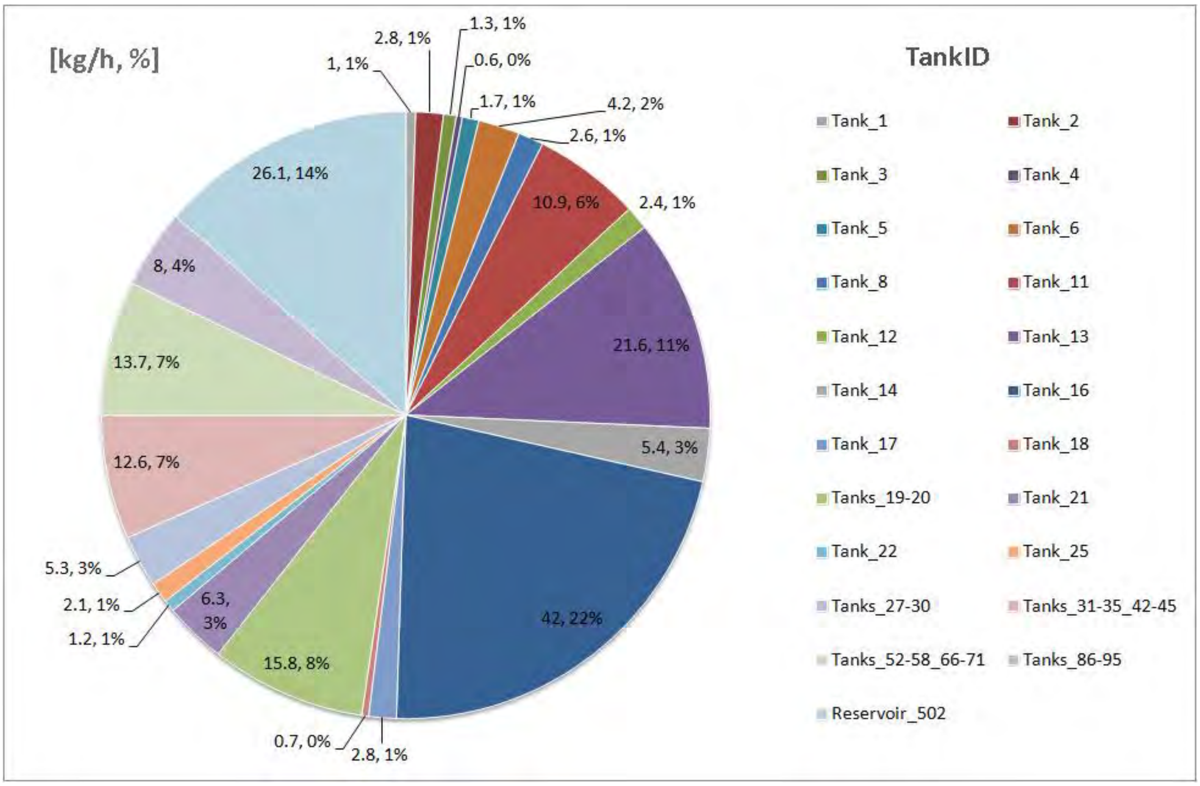

Figure 55. Summary of all measurements on the specified tanks and tank groups and their relative contribution to the total emission of 192 kg/h. The measurements on tank 16 from 5 October were omitted here due an atypical release event.

Figure 55 shows the absolute and relative contribution from all measured tanks and tank groups to the tank farm overall sum of alkanes (191 kg/h). Three tanks stand out with single contributions above 10% each, with Tank_16 being the strongest source (22%, Crude) followed by Reservoir_502 (14%, Vacuum Gas Oil (VGO)) and Tank_13 (11%, Crude). These tanks were also studied in more detail, to obtain better statistics. A validation study between the SOF and DIAL techniques were also done on these tanks with very good agreement of the results (see Pikelnaya et. al. (2016)).

The 502 source is a large covered reservoir which contain vacuum gas oil (VGO). It has two ventilations shafts, one in the north and one in the south. Specific data from tank 502 are found in Table 39 and Figure 56. Histograms of the 80 individual plume transects of this source, from 8 different days, resemble something close to a normal distribution with an average emission of 26 kg/h, very close to the median of 25 kg/h. The observed spread in day to day averages ranged from 20 to 36 kg/h. The emissions from Reservoir 502 were split up on contributions from the north and the south vent respectively, showing that the vast majority of the reservoir emissions originated from the south vent with 90% of the reservoir's overall emission.

With a BTEX mass fraction of 11%, this was the strongest source of aromatics found in the tank farm, with an estimated emission of 2.8 kg/h BTEX (23% of the overall). Also when considering benzene, Reservoir 502 was the strongest source with 0.3 kg/h. Tank 13 and Tank 16 were found to have a BTEX emission of 1.9 kg/h and 0.6 kg/h respectively. Corresponding benzene emissions were 0.12 kg/h and 0.14 kg/h. The BTEX and benzene results for Tank 13, 16 and Reservoir 502 were based on 8, 57 and 28 observations within each category respectively.

Table 39. Summary of SOF alkane measurements reservoir no 502. *Single measurement.

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150928	140807 -155200	4	27.7±7.4	4.2-6.0	287-294
150929	140318 -151343	2	20.2±7.7	3.4-3.8	272-291
150930	133031 -150355	6	26.1±13.4	2.1-3.6	192-303
151001	100906 -152231	9	28.8±11.5	1.5-4.7	276-295
151002	141403 -143033	7	36.3±15.6	3.8-4.9	262-294
151005*	155251 -155806	1	32.3	3.8	173
151006	121009 -160214	16	20.7±8.6	2.6-6.2	256-324
151007	134310 -153441	35	25.9±11.7	3.0-5.5	264-317
Average±SD	**-**	**(total 80)**	**26.1±11.4 (44%)**	**-**	**-**
Median	**-**	**(total 80)**	**24.7**	**-**	**-**

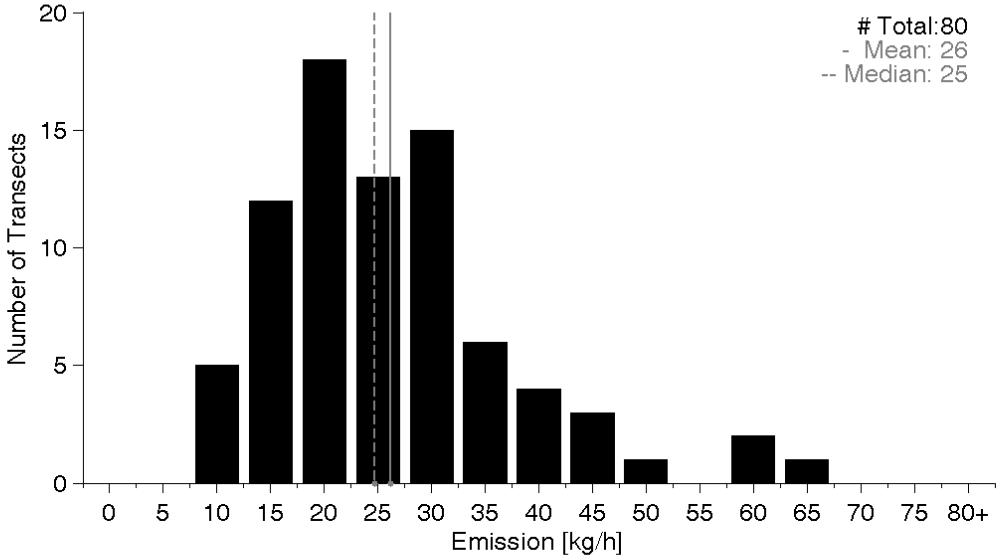

Figure 56. Histogram of all SOF measurements at reservoir 502 during the SCAQMD survey 2015. The median (24.7 kg/h) and average (26.5 kg/h) values are indicated as dashed and solid gray lines.

Figure 57 shows SOF measurements of VOCs in the crude oil part of the tank farm. Here the height of the column corresponds to the measured vertical column of alkanes (non-methane) and the arrow shows the wind direction (south-east in this case). The large columns downwind of the second tank from the left in the middle row (here referred to as tank 16) suggest the presence of a distinct leak at this tank. During the campaign, this tank showed large emissions during several days, see Table 40, and large variability range suggesting a dependence on operations. The refinery personnel and SCAQMD were notified of this finding and service personnel carried out an inspection showing that one of the valves was leaking. When the tank was filled with new product and the floating roof accordingly moved upwards, the displacement of VOC contaminated air between the internal floating roof and the external dome generated the large emissions through the malfunctioning vent gauge. The measurements illustrated in this figure were compared against DIAL measurements with very good agreement (see separate report by Pikelnaya et. al. (2016)).

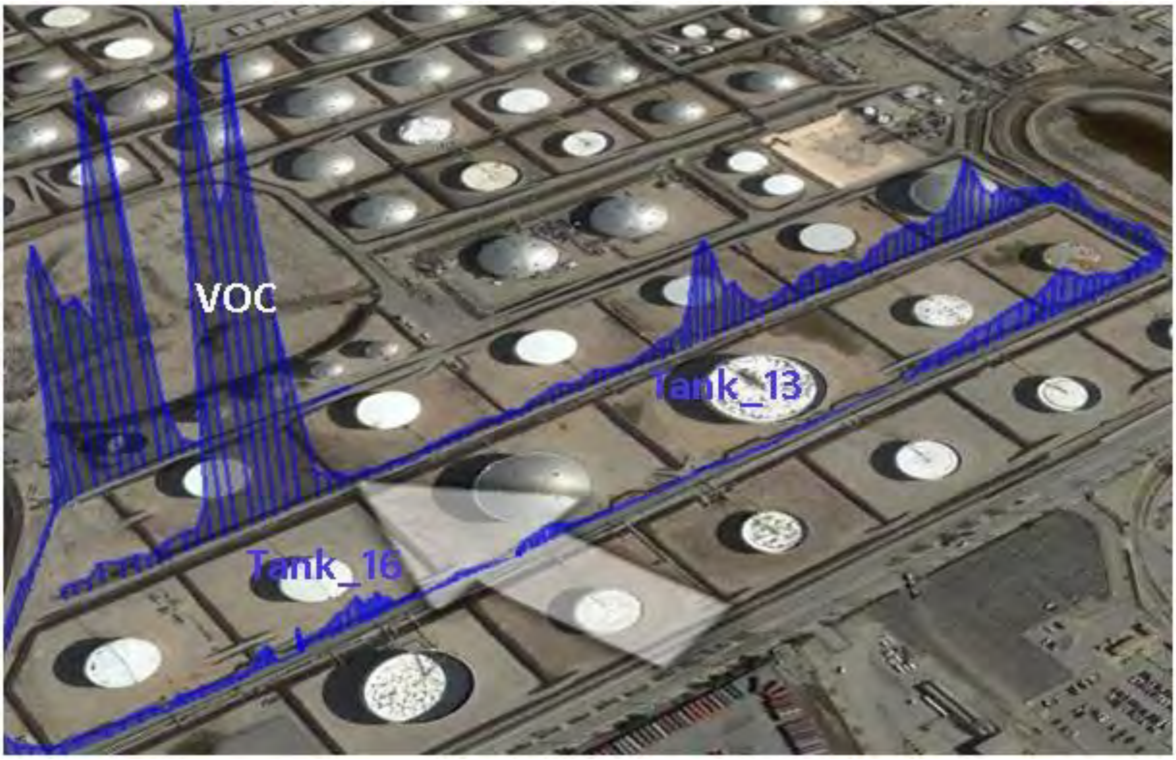

Figure 57. Measurements of VOCs with SOF in the crude oil part of the tank farm. Here the height of the blue columns corresponds to the amount of alkanes present in the column measured by SOF and the white arrow corresponds to the wind direction (south-east in this case).

Figure 57 also shows Tank_13 (two tanks right of tank 16 in the middle row) being a source of emissions – compare the clean upwind columns to the clear VOC plume downwind of tank 13 and 16 respectively. Table 40 and Table 41 include daily average emission data and the total average and median values from SOF measurements at tank 16 and tank 13 respectively.

Table 40. Summary of SOF alkane measurements for tank 16. *Single measurement.† Non-typical event with malfunctioning valve at tank roof on the 5 October 2015.

Day [yymmdd]	Time span [hhmmss-hhmmss]	No. of Transects	Emission Average±SD [kg/h]	Wind Speed Min-Max [m/s]	Wind Dir Min-Max [deg]
150928*	141036 -141127	1	28.0	4.9	294
150930*	135622 -135646	1	0.33	2.8	188
151001	133101 -141133	5	73.6±29.9	3.3-4.9	147-194
151002	123616 -133233	5	29.5±12.9	3.1-5.1	147-194
151005†	113438 -155044	42	326.6±151.4	3.1-6.2	144-204
151006*	151220 -151258	1	2.1	4.8	283
Average±SD	All days	(total 55)	259±134 (52%)	-	-
Median	All days	(total 55)	222	-	-
Average±SD	**Excluding 151005**	**(total 13)**	**42.0±33.6 (80%)**	**-**	**-**
Median	**Excluding 151005**	**(total 13)**	**41.5**	**-**	**-**

Table 41. Summary of SOF alkane measurements for tank 13. * Single measurement

Day [yymmdd]	**Time span** [hhmmss-hhmmss]	**No. of Transects**	**Emission Average±SD** [kg/h]	**Wind Speed Min-Max** [m/s]	**Wind Dir Min-Max** [deg]
150928*	141153 -141257	1	1.1	4.9	292
150930*	135449 -135542	1	12.9	12.9	194
151001	132928 -141655	5	22.9±10.5	3.4-4.9	154-190
151002	112139 -133118	11	16.1±8.5	2.1-5.1	139-194
151005	123245 -160628	14	27.5±12.0	4.0-7.7	166-205
Average±SD	**-**	**(total 32)**	**21.6±10.4 (48%)**	**-**	**-**
Median	**-**	**(total 32)**	**18.1**	**-**	**-**

Figure 58 and Figure 59 show the frequency distribution of the SOF alkane measurements at tank 13 and tank 16 respectively, for the week of on site measurements. As seen in the distributions, tank 16 emissions show a large spread, almost as two source distributions overlay with a secondary maximum and tail of observations above 250 kg/h corresponding to the atypical event with a malfunctioning valve at the tank roof during filling on October 5 as discussed previously. Tank 13 in Figure 58 showed a more typical tank emission distribution.

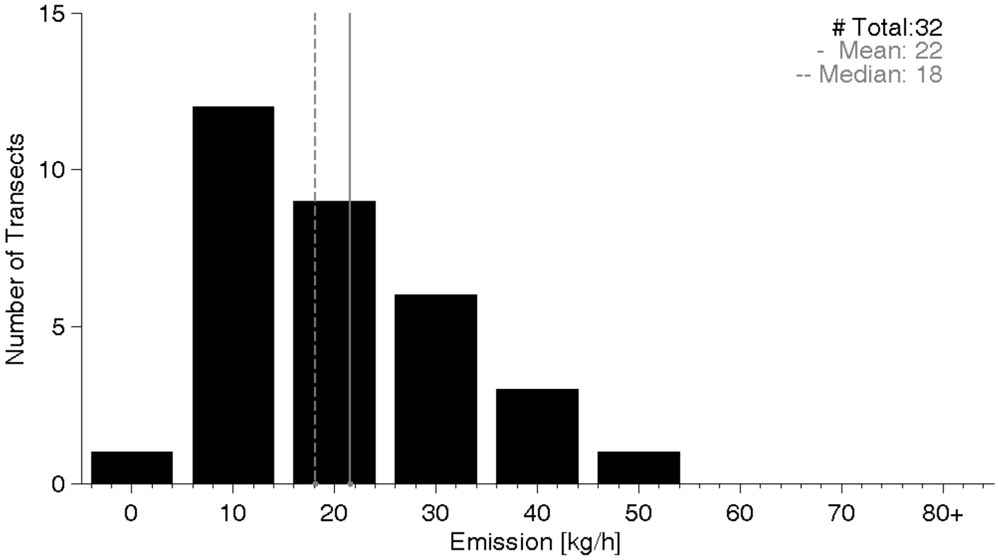

Figure 58. Histogram of all SOF measurements at Tank 13 during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

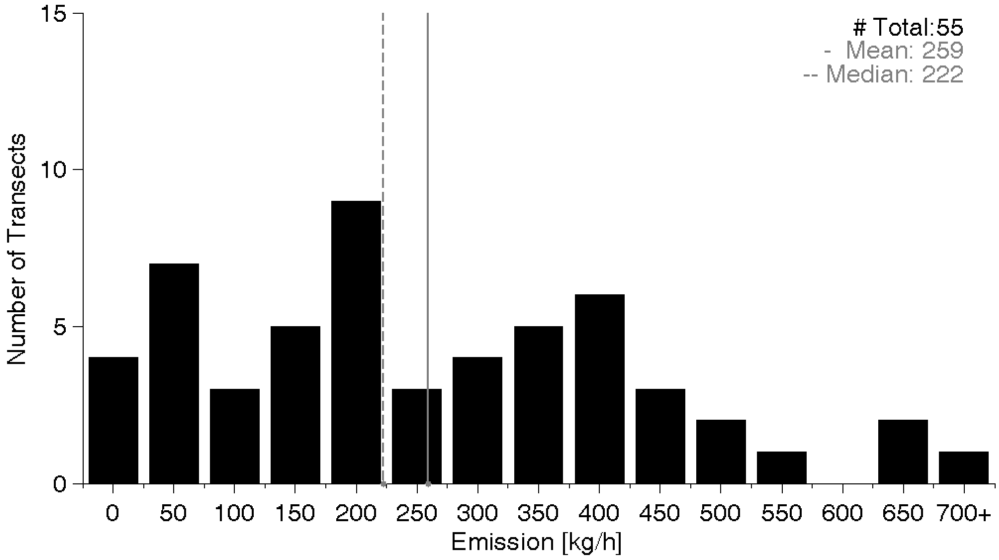

Figure 59. Histogram of all SOF measurements at Tank 16 during the SCAQMD survey 2015. The median and average values are indicated as dashed and solid gray lines.

The ground concentration of aromatic BTEX and alkanes across the refinery tank farm are shown in Figure 60 and Figure 61 respectively. The ratio of aromatics to alkanes was measured using MWDOAS and MeFTIR while driving through the tank park. Measurements were specifically concentrated on tanks 13, 16 and 502.

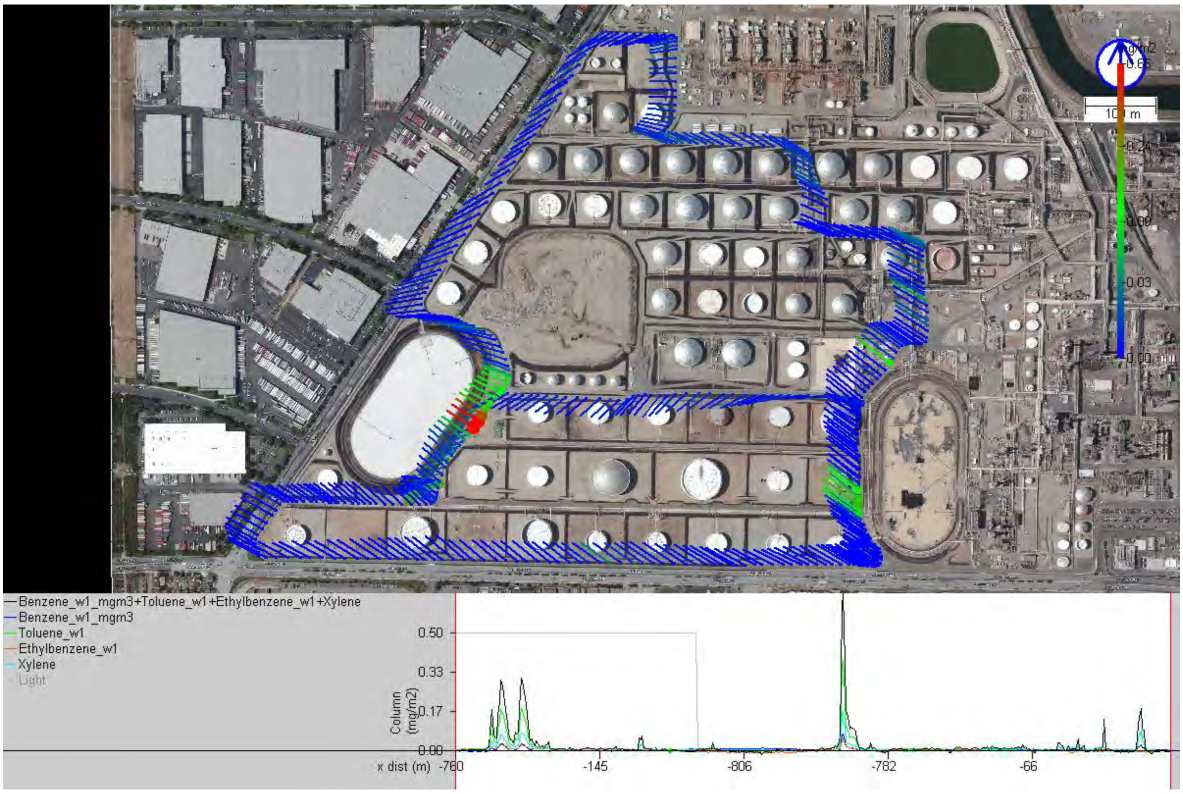

Figure 60. Aromatic VOC concentrations in mg/m^3 across the tank farm measured using MWDOAS. Bars are pointing towards the wind, hence in the direction of the source. North is upwards in the figure.

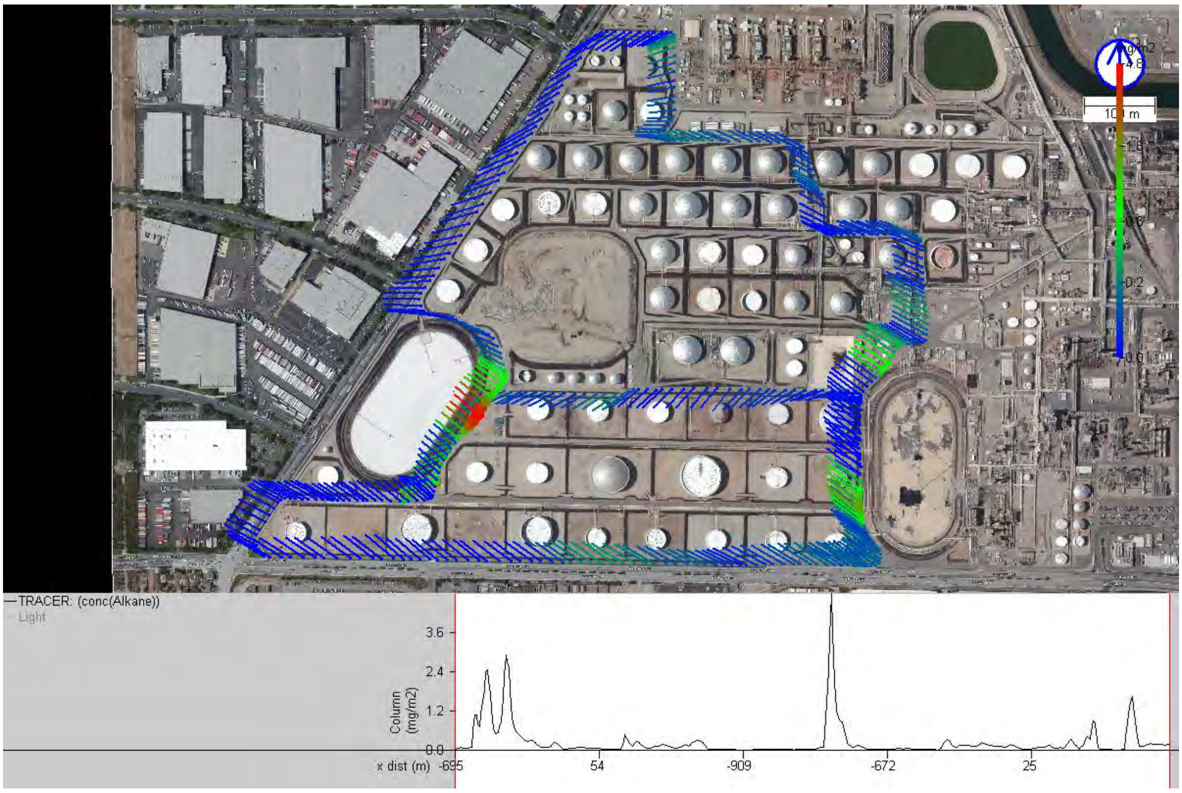

Figure 61. Alkane concentrations in mg/m^3 measured using MeFTIR across the tank farm. Bars are pointing towards the wind, hence in the direction of the source. North is upwards in the figure.

5.3 Further Leak search and Leak Detection

On site measurements with the real time geo-tagged result capabilities of the SOF + MeFTIR + MWDOAS techniques, as described in the previous section, are in a way a continuous leak search task. By driving the mobile lab on accessible roads on the upwind and downwind side of the different sources it's possible to rather quickly (within hours) build a concentration map of a whole tank farm with located hot spots of elevated concentrations/emissions. Repeating this several times makes it possible to judge whether an observed emission pattern seems recurring or just being an intermittent release (for the time frame of the measurements). Repeated measurements at a site also build confidence in what emission levels that are normally observed, and when an aberration is observed and should be alarmed to the operations department.

During the 8 days of on site measurements between 28 September and 7 October, two major atypical emission events were identified, and reported to the operations and SCAQMD representatives. Tank_16, has already been discussed previously where a malfunctioning vent at the external roof of the crude tank inferred atypical high concentration levels and emission rates downwind of the tank 5 October. This was observed both by the MeFTIR and SOF measurements, and an inspection by operations verified the vent being stuck open.

Another atypical leak was found in the southern part of the so called *Tanks_Northeast* area, see Figure 52. Passing on the road south of the area, elevated alkane concentrations was observed with about 70,000 ppb in contrast to ten to hundred ppb normally observed downwind the various tanks. The leak was discovered late in the day, short before working permits ended as well as the sun setting to low for continued work. SOF and MeFTIR measurements pointed out an area next to the ground in the vicinity of several pipe lines. A gas camera was brought in to visualize that gas was indeed emerging from the soil beneath the pipes. Tubing was also attached to the MeFTIR instrumentation for "walk around" leak search with the tubing sampling air from locations around the pipe lines and at the ground. Figure 62 shows a SOF measurement from the particular site. Six SOF measurements between 4 PM and 5 PM on 30 September estimated the leak to be on average 31 kg/h.

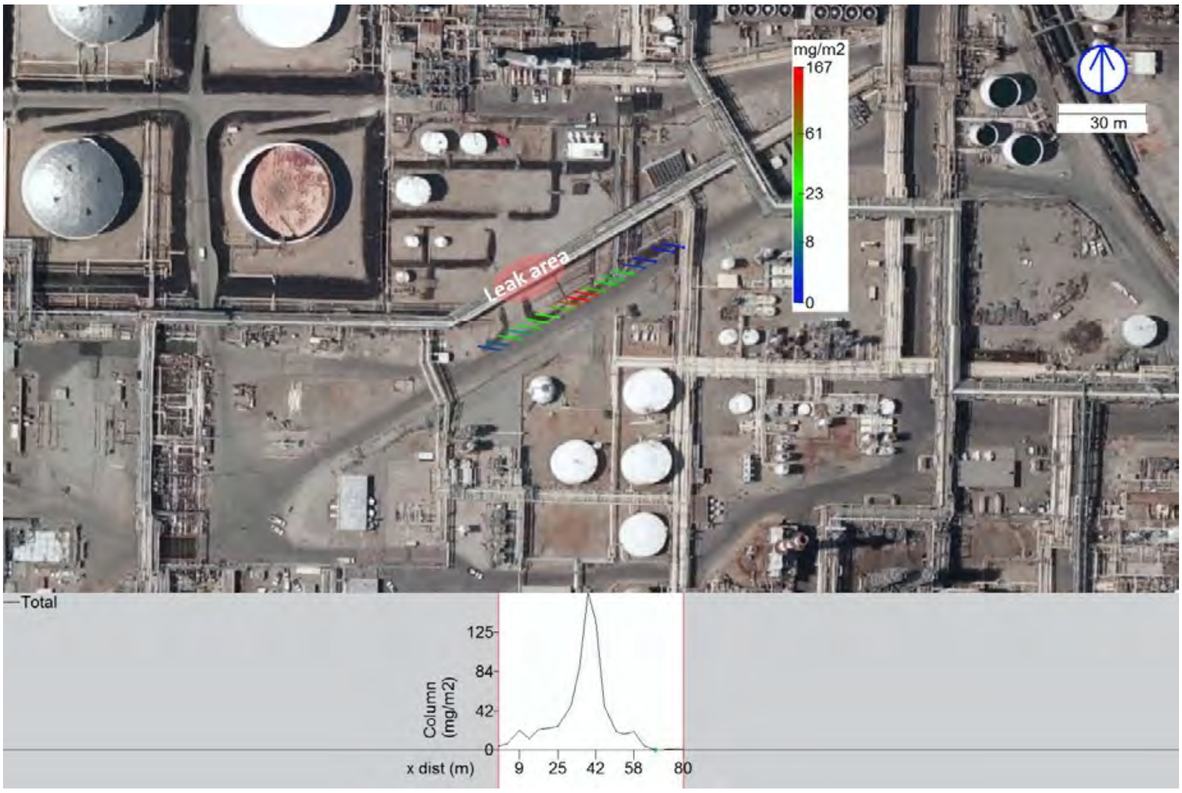

Figure 62. SOF measurement observing an atypical leak from the soil ground near a set of pipe lines. The leak area is indicated by a light-red area. The colored lines show observed alkane column (mg/m^2) with the lines pointing towards the wind and potential source. The graph beneath the picture shows integrated alkane column along the transect through the plume with traversed distance in meters.

Personnel from operations and SCAQMD were notified about the findings at once, and the source of emissions was further investigated by the refinery staff who immediately took appropriate actions. A leak, the size of a pinhole, was found in an alkane pipeline buried 30 cm below the ground. After the leak was repaired additional SOF and MeFTIR measurements were conducted to verify that the issue was resolved.

This case illustrates how mobile optical measurements and gas imaging information can be used to identify unknown leaks, and that immediate call upon and guidance of repair efforts can safely mitigate and suppress the risk of any further, potentially serious, complications. In general during the onsite measurements, working together with the experienced operations staff provided valuable input for interpreting the observed emissions and potential deviations from normal operations.

6 Discussion and Conclusion

Emission measurements of VOCs (alkanes, methane, and BTEX), SO_2 and NO_2 from six major refineries in the SCAB have been carried out by FluxSense Inc. using several state-of-the-art ORS techniques during a two and a half month campaign. The six refineries have a combined capacity of more than 900,000 barrels of crude oil per day and constitute an important stationary source of VOC emissions in Southern California.

For each refinery we compared the measured emission rates to the corresponding emission inventory values obtained by means of the US EPA AP-42 model (US-EPA 2013). The reported annual emissions have been divided by 12 to obtain average monthly emission rates, which were then compared to measured monthly median emissions obtained in this study. Thus, the comparisons are representative for September 2015 (the time-period when most of the measurements were performed).

An analysis of measured monthly emissions from each refinery normalized by the corresponding crude oil capacity is presented in Table 42. The overall alkane emission factor for all refineries in the SCAB (% of total emitted mass of alkanes to total capacity mass of crude oil) is 0.024%, ranging between 0.017 % and 0.045 % for the different facilities. This average emission factor is within 0.03 % and 0.1 %, a range observed from previous measurements conduced at well-run refineries in Europe (Kihlman *et al.* 2005; Mellqvist *et al.* 2009; INERIS 2010; Samuelsson *et al.* 2011). Thus, according to this data, the refineries in the SCAB are characterized by relatively low emissions compared to their capacity.

Table 42. Capacity normalized VOC (Alkanes+BTEX) emission factors * for the 2015 SCAQMD survey.

Measured Refineries 2015 Survey	**Crude Oil Capacity***		**Measured Monthly Emission** Alkanes + BTEX	**Emission Factor** Alkanes + BTEX
	[bbl/day]	Tons^1/mo	Tons^1/mo	[%]
Refinery A	257300	1086215	214	0.020%
Refinery B	139000**	586801**	59	0.045%
Refinery C			205	
Refinery D	104500	441156	132	0.030%
Refinery E	269000	1135608	201	0.018%
Refinery F	149500	631128	109	0.017%
Sum of all	**919300**	**3880908**	**919**	**0.024%**

*Crude capacity data is obtained from the 2016 California Energy Commission report. The overall emission factor is based on the sum of measured emissions for all refineries relative to the total capacity.

**Crude capacity for Refinery B and Refinery C are reported together since Refinery B processes the crude oil and Refinery C upgrades intermediate products to finished products.

^{1}Metric Tons

A comparison between the measured monthly emissions and the average monthly emissions from the inventories (i.e., annual inventory emission divided by 12) is presented in Table 43. For all major refineries in the SCAB, the ratio between measured and reported emissions for September 2015 (denoted as D in table 43) is 6.2 for VOCs, 1.5 for SO_2, and 0.83 for NO_x. For benzene this ratio is ~34, although the total measured benzene emissions were relatively small. Note that the inventories report NO_x (NO_2+NO), while only NO_2 is measured by the SkyDOAS. However, previous studies have shown that NO_2 typically constitutes 75 % or more of the NO_x found in the air around refineries (Rivera *et al.* 2010).

Table 43. Reported (*Rep*) average monthly emissions [metric tons per month] from the available inventory for the six SCAB refineries and measured emissions (*Meas*) for the 2015 SCAQMD survey. *D* denotes the ratio between measured and reported emissions (Meas/Rep). The overall discrepancy values (last row) are calculated from the total sum of reported and measured emissions, respectively. The comparisons are representative for September 2015.

Refineries	*Total VOC*			*SOx*			*NOx* [1]			*Benzene*		
2015 Survey	**Rep.**	**Meas.**	**D**	**Rep.**	**Meas.**	**D**	**Rep.**	**Meas.**	**D**	**Rep.**	**Meas.**	**D**
	Tot VOC	*Alk+ BTEX*		*SOx*	*SO_2*		*NOx*	*NO_2*				
	tons /mo	tons /mo	[]	tons /mo	tons /mo	[]	tons /mo	tons /mo	[]	tons /mo	tons /mo	[]
Refinery A	33	214	6.4	38	46	1.2	50	48	1.0	0.06	2.5	43
Refinery B	7	59	8.3	26	39	1.5	30	23	0.8	0.03	0.8	33
Refinery C	17	205	12	10	27	2.7	37	42	1.1	0.03	6.0	202
Refinery D	12	132	11	7	12	1.7	23	25	1.1	0.03	1.2	39
Refinery E	37	201	5.4	23	39	1.7	57	46	0.8	0.05	2.0	38
Refinery F	40	109	2.7	25	27	1.1	39	13	0.3	0.19	0.6	3.2
All refineries	**148**	**919**	**6.2**	**129**	**190**	**1.5**	**237**	**197**	**0.8**	**0.38**	**13**	**34**

[1] Nitrogen oxides (NO_x) are reported in inventories while only the NO_2 fraction was measured by SkyDOAS.

The comparison of measured emissions with annual inventory values presents a number of challenges. Firstly, it is important to know whether the studied refineries operated under typical conditions during the measurement campaign. Since operational data from the facilities is not available for this project, we estimated the average monthly emission rate at each site by dividing the reported annual emission inventory value for each facility by 12.

Secondly, it has to be established that a sufficient number of measurements have been conducted during the measurement period to eliminate the risk of disproportional influence from intermittent emissions due to tank cleaning, maintenance, flaring, etc. To address this point the frequency distributions of the measured emission (as shown in Figure 15) have been analyzed and taken into account in our calculations. As a result median measured emissions were used for comparison with inventories instead of average measured emissions, therefore reducing the sensitivity to outliers.

Thirdly, the effects of differences in meteorological conditions between September 2015 and the entire year need to be considered to establish how representative the emissions measured during the study were to the entire year. In our experience, tank emissions contribute approximately 2/3 of the total refinery emissions (Kihlman 2005). At the same time, emissions from tanks are also more affected by environmental parameters such as wind, temperature and solar insolation, than emissions from process units. Therefore, a sensitivity study for two types of crude oil tanks, external floating roof tank (EFRT) and internal floating roof tank (IFRT), utilizing the formulas in the AP-42 model was conducted. A very similar approach has been previously applied to evaluate seasonal variations of refinery emissions (Johansson *et al.* 2014b). During the measurement campaign, the average maximum daytime temperature was 5.4 °C higher than the 2015 average annual temperature of 19.6 °C (data from weatherunderground.com for Torrance Airport), while the 2015 monthly and annual average wind speeds were both 2.2 m/s (data from weatherunderground.com for Long Beach Airport). In addition, the monthly average solar radiation was 22 W/m^2 higher than the annual average of 226 W/m^2 (data from Torrance airport from the National Solar Radiation Database). According to AP-42 model, these differences in meteorology combined resulted in 11 % and 29 % higher modeled emissions for September 2015 than for the annual average for the IFRT and EFRT, respectively. These values are within the uncertainty of the SOF method.

Additionally, no dependency of measured emissions on temperature and wind speed was observed. Figure 63 illustrates that there was no obvious correlation between measured alkane emissions and wind speed or temperature at Refinery A. Therefore, the observed discrepancies between measured emissions and reported inventories (based on the AP-42 standard (US-EPA 2013)) are considerably higher than what can be explained by measurement uncertainties or short-term sampling alone.

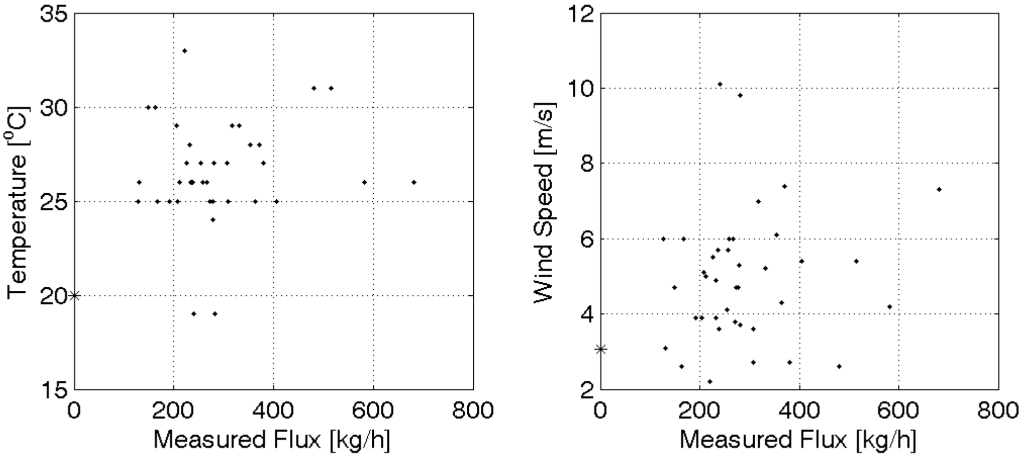

Figure 63. SOF emission data from Refinery A plotted against the corresponding local temperature and wind speed values (left and right plots, respectively). *Annual average values from the meteorological station at Torrance Airport (KTOA) 2015 [www.weatherunderground.com].

Refineries and tank farms are complex environments with a large number of installations and numerous potential emission sources (e.g. tank seals, valves, gauges, flares, vapor recovery units, etc.). Many of these components can show degrading performance over time, and to accurately account for the impact of non-ideal performance in emissions inventory reporting is, we believe, an impossible task. Nevertheless, EPA's AP-42 system provides valuable insights for a specific facility on the production and abatement techniques applied, and on what emission level the site could reach given ideal performance of all installations. Comparing measured emissions to ideal performance levels established by AP-42 could provide a basis for benchmarking of different refineries or sites.

OUTLOOK

Studies conducted in the SCAB, the Bay Area, Texas, and other places worldwide, show that field measurements provide a reliable way to determine actual emissions of VOCs and other pollutants from refineries and various industrial sites. Accurate estimates of VOC and other pollutant emissions from industrial sources are crucial for improving air quality models, to guide air pollution mitigation strategies, promote successful compliance strategies, and reduce exposure for nearby communities.

In our experience, the observed difference in fugitive VOC emissions between measured and inventory estimates is a general issue for the petroleum industry worldwide. We believe that a possible path forward could be to conduct monitoring in parallel with continued AP 42 based reporting, and to use the measurements to guide and verify the efficiency of the emission reduction efforts at the industrial sites.

Longer-term ORS studies spanning over different seasons could be conducted in order to alleviate concerns stemming from comparison of emissions measured over limited-time to annual emissions reported through the inventories. Additionally, future studies could combine ORS measurements and site-specific emission modeling performed for inventory calculations. A better dialog between scientists conducting the measurements and the facility operators could also be crucial to improve our understanding of how site activities may affect measured emissions.

Traditional Leak Detection and Repair (LDAR) is an important practice to control and limit unplanned VOC emissions from refineries and to identify potential leak sources. The ORS techniques used in this study have demonstrated their ability to quickly quantify and map refinery emissions and to identify potential air pollution sources within a facility. Using real time measurements, refinery personnel and air quality regulators can enhance LDAR programs by prioritizing LDAR activities. Addressing the most concerning issues first is important to reduce occupational risks for refinery workers, avoid public hazard exposures, and limit the economic losses due to unplanned evaporation of refinery products.

A continued path towards improved air quality involves a good understanding of current emission levels and sources. Repeated and systematic emission measurements will be an important tool for benchmarking industry’s environmental performance as well as for sustaining and verifying efficient emission improvement plans, ultimately resulting in cleaner air and a better environment.

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8 Acknowledgements

This work was funded by the South Coast Air Quality Management District (SCAQMD). We would like to acknowledge the important contributions by Dr. Laki Tisopulos, Dr. Andrea Polidori, Dr. Olga Pikelnaya and other SCAQMD staff. We also acknowledge the collaboration of Refinery A with SCAQMD, making it possible to carry out on site measurements.

9 Appendix A: Quality Assessments

Quality checks and measures are performed at several levels in order as indicated in Figure 2 and given below. On arrival, FluxSense personnel will power up the equipment, check operating parameters, and test the instruments. The purpose is to run operational checks to catch problems prior to field deployment and repair all malfunctioning equipment.

Quality Checks and Routines

PRIOR TO MEASUREMENTS:

Vehicle:
1. Checking vehicle status according to safety and performance
2. Mount warning lights and signs
3. Make sure that battery pack is fully charged
4. Make sure any loose items are stowed away securely

Instruments:
1. Turn on instruments and make sure that detectors are properly cooled
2. Optimize signals by optical alignment (SOF, SkyDOAS, MWDOAS, MEFTIR)
3. Cleaning mirrors and optics if necessary (SOF, SkyDOAS, MWDOAS)
4. Rotational alignment (SOF). Tolerance: ±2 mg/m^2 in any direction
5. Checking spectral resolution and response (SOF, SkyDOAS, MWDOAS, MEFTIR)
6. Take calibration spectra (SkyDOAS, MWDOAS)

GPS:
1. Checking that GPS information is available and reasonable
2. Check time synchronization of all instruments and computers

Wind:
1. Checking that the time difference of logger and computer and synchronize if necessary. Tolerance 1s.
2. Select an open flat surface at a representative location for the measurements
3. Erecting the wind mast vertically and secure it firmly
4. Directing sensor correctly (toward magnetic north) using a compass. Tolerance: ±5 deg
5. Put the LIDAR truck on level ground.
6. Check that wind information is available and reasonable.

DURING MEASUREMENTS:

1. Drive slowly and steadily to reduce vibration noise. Around 20-30 km/h for SOF/SkyDOAS and around 10-20 km/h for MWDOAS/MEFTIR (dependent on distance to source and the spatial resolution required)
2. Avoid shadows as far as possible during solar measurements (SOF, SkyDOAS).
3. Try boxing the facilities when possible or make relevant upwind/background measurements continuously.
4. Keep track of wind directions and measured columns/concentrations so that the entire plume from a facility is captured.
5. Always try to start new measurements outside the plume.

6. Aim for 3-5 transects with acceptable quality (See section on data analysis below) per facility and day and at least 1 upwind measurement (if not boxing).
7. Take notes and photos on interesting findings and events
8. Check the wind meter on a regular basis to make sure that it is operational

AFTER MEASUREMENTS:

1. Turn off instruments and download gas measurement data to external hard drive
2. Download data from wind mast logger and save to external hard drive
3. Download data from wind LIDAR and save to external hard drive
4. Dismount wind mast if not in safe location
5. Turn off wind LIDAR and store securely over night
6. Store Airmar data and measurement notes on external hard drive
7. Update survey documents and Google Earth maps accordingly
8. Charge vehicle, LIDAR and data logger batteries over night
9. Make sure that instruments are well protected inside the vehicle from rain/moisture

DATA ANALYSIS:

1. Discard transects with noise levels above the detection limits (see Table 1)
2. Discard transects with significant baseline variations
3. Discard transects with significant data gaps in the plume
4. Discard transects with extended vehicle stops
5. If incoming plumes are of significant magnitude compared to the outgoing plume (SOF and SkyDOAS) treat transects with extra care and require further statistics
6. Discard transects with average wind speeds below 1.5 m/s (SOF and SkyDOAS)
7. Discard transects with highly varying wind directions

Data Analysis, Interpretation, and Management

DATA REPORTING REQUIREMENTS:

A Draft and Final Report will be delivered to SCAQMD electronically (i.e., via file transfer protocol (FTP) or e-mail) in MS-WORD format no later than the established deliverable due date. After post-processing, validation and analysis, the data will be delivered to SCAQMD at the time of the final report.

DATA VALIDATION PROCEDURES:

Project personnel will maintain records that include sufficient information to reconstruct each final reported measurement from the variables originally gathered in the measurement process. This includes, but is not limited to, information (raw data, electronic files, and/or hard copy printouts) related to sampler calibration, sample collection, measurement instrument calibration, quality control checks of sampling or measurement equipment, "as collected" or “raw” measurement values, an audit trail for any modifications made to the "as collected" or “raw” measurement values, and traceability documentation for reference standards.

Difficulties encountered during sampling or analysis, such as interference between adjacent plumes, large upwind fluxes or highly variable wind fields will be documented in narratives that clearly indicate the affected measurements. All electronic versions of data sets should reflect the limitations associated with individual measurement values.

The data collected in the project will be made available in electronic format at the time of the final report. For all data we will produce ASCII tables with the geo-positioning and time. In addition kml files will be produced for the most useful data for Google Earth viewing.

To ensure high quality data an internal audit procedure of the data is carried out. In the project, gas columns obtained from SOF and mobile DOAS measurements are used to calculate gas fluxes through a procedure which includes manual checking of each measurement transect and manual choices of baselines etc (see previous section). In the audit procedure the completed transects will be reviewed by an independent experienced SOF-operator that was not involved in the actual data evaluation. At least one of the persons involved in the data processing must have been in the FluxSense mobile lab while the actual measurements were made

STATISTICAL PROCEDURES:

The final data will be presented as daily means and standard deviations for each facility together with histograms showing all individual measurements. The variability of the result will be a combination of measurement uncertainties, wind variability and actual variability in the emissions from the facility.

Extreme outliers are generally not excluded, unless non-typical conditions/operations at the facility are reported. In this case, the outliers will be reported separately so that these conditions/operations can be followed up.

More samples will provide a closer estimate of the actual emissions. In reality, the number of measurement will be a trade-off between acceptable statistics and available time and conditions for making the measurement and time sharing between other measurements. The aim is 3-5 transects with acceptable quality per facility and day during at least four days. If boxing is not performed, at least 1 representative upwind measurement per facility should be made.

DATA SUMMARY AND ANALYSIS:

The data will be post processed with the spectral retrieval programs QESOF (SOF) and QDOAS (mobile DOAS). This will give time series of column concentrations, positions and solar angles stored in ASCII-files. These files are loaded into custom software, SOF-Report, used to calculate fluxes.

Wind LIDAR data will be processed using the output from Leosphere WindCube system. Data files are saved as ASCII-files.

The weather mast will be connected to a real time data logger and will be periodically downloaded to a computer. The data logger samples the input voltage of each instrument at a set time interval, digitizes it, and stores the data sequentially into a record.

ASCII tables with time stamped geo positioned data will be produced. In addition kml files will be produced for viewing the data in Google Earth. The data will also be retained for a minimum of 5 years at FluxSense.

DATA STORAGE REQUIREMENTS:

The spectra from the spectroscopic measurements (SOF, SkyDOAS, MEFTIR, MWDOAS) are directly saved to the hard drive of the computer used to operate these instruments. At the end of each measurement day, all new such data will be copied to an external hard drive by the operator. Approximately 1 GB of data will be produced per measurements day.

10 Appendix B: Wind Plots

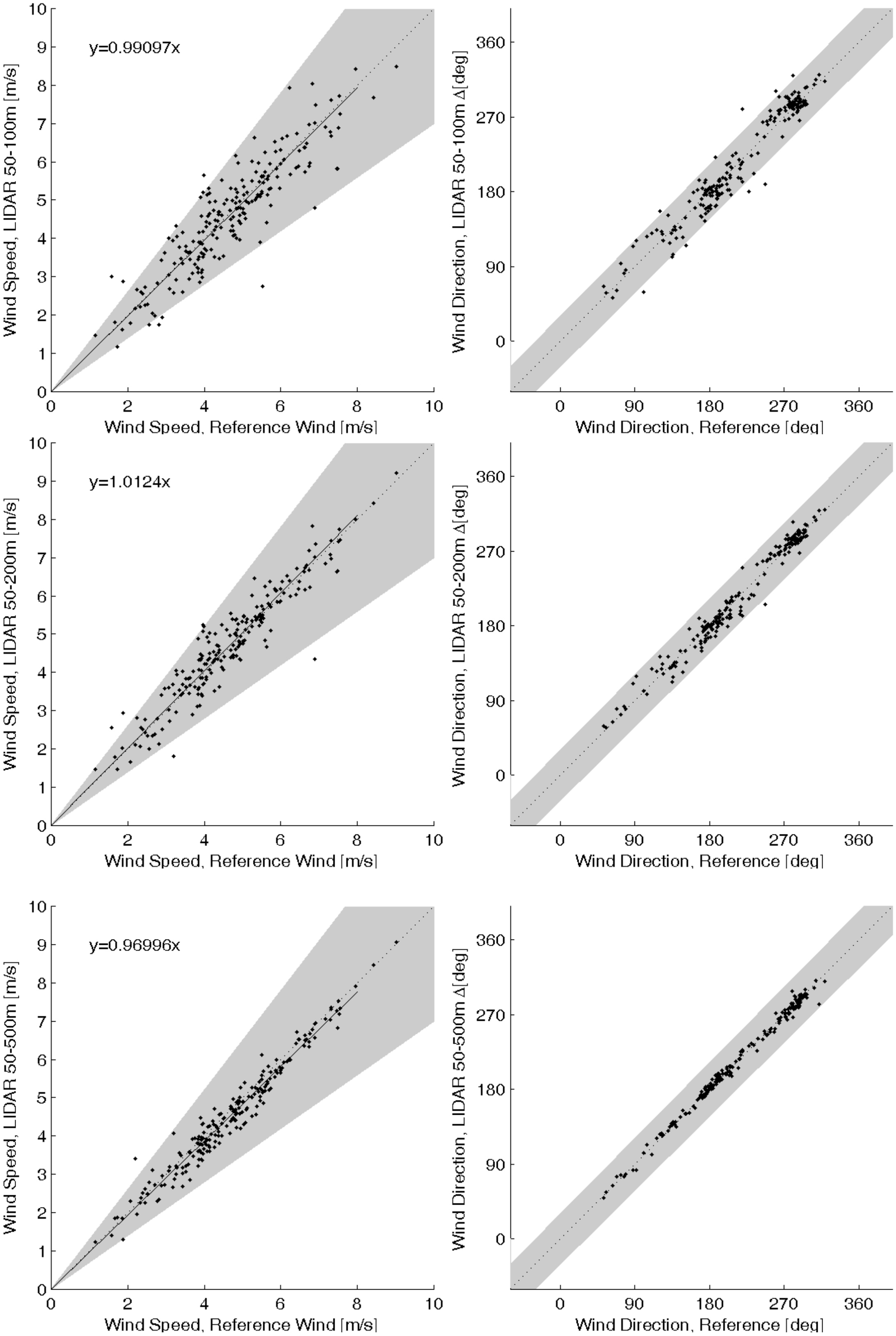


Figure 64. Wind LIDAR data for different altitude ranges versus the reference LIDAR wind (50-400m) during the calibration period 2-6 October 2016 at LIDAR site L1 (10 min average from 10AM to 5PM) . The shaded areas indicate ±30% relative deviation from reference wind speed (left panels) and ±30° deviation from reference wind direction (right panels). Fitted least squares are shown as solid lines.

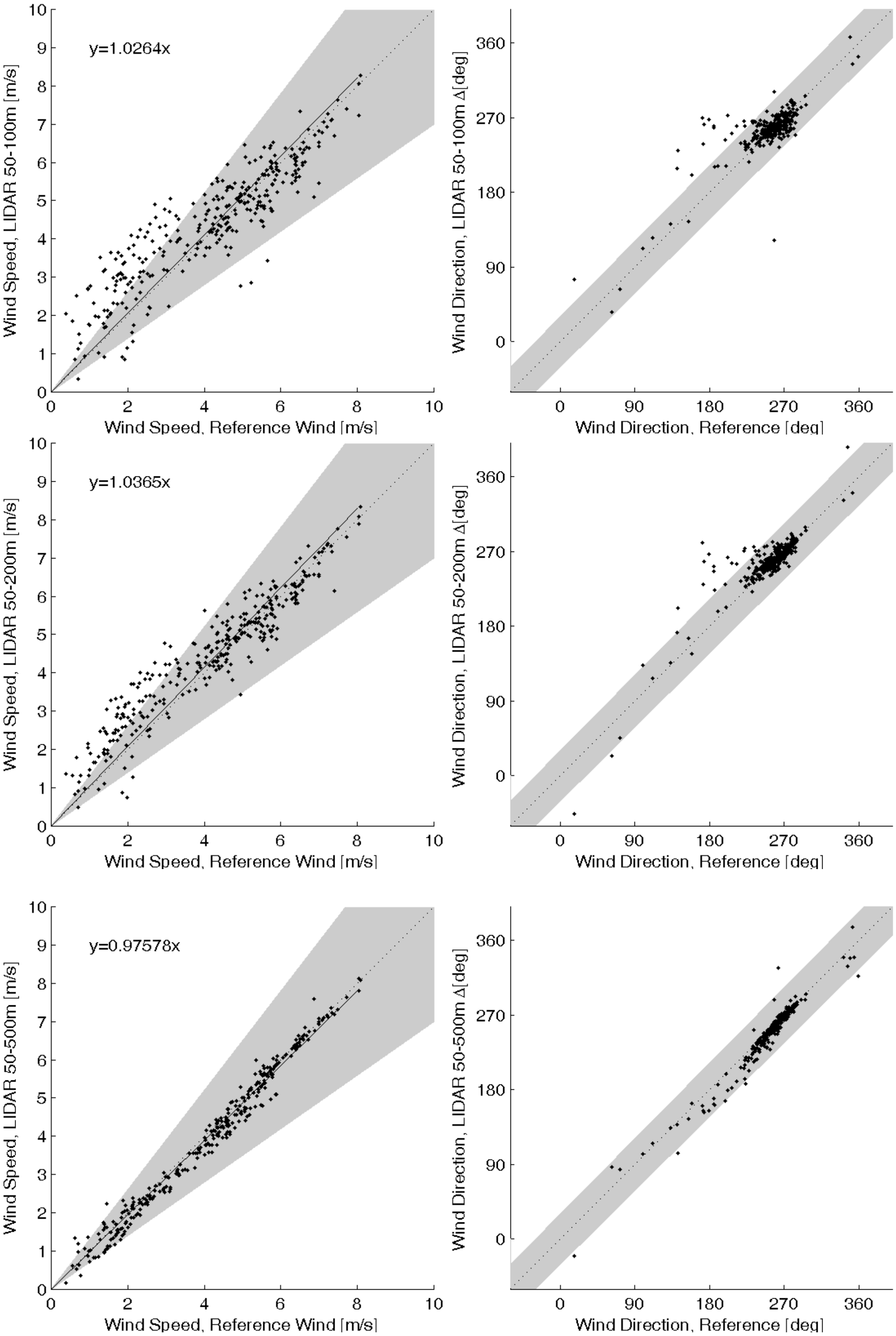


Figure 65. Wind LIDAR data for different altitude ranges versus the reference LIDAR wind (50-400m) during the calibration period 9-16 October 2016 at LIDAR site L4 (10 min average from 10AM to 5PM). The shaded areas indicate ±30% relative deviation from reference wind speed (left panels) and ±30° deviation from reference wind direction (right panels). Fitted least squares are shown as solid lines.

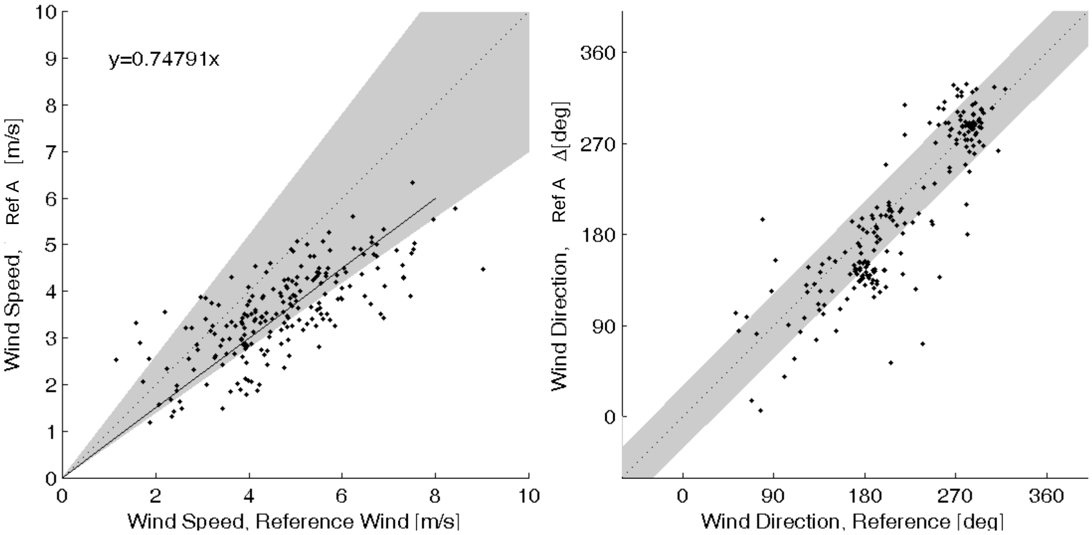


Figure 66. Refinery A´s 10m wind mast data versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM) during the calibration period 2-6 October 2016 at LIDAR site L1. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

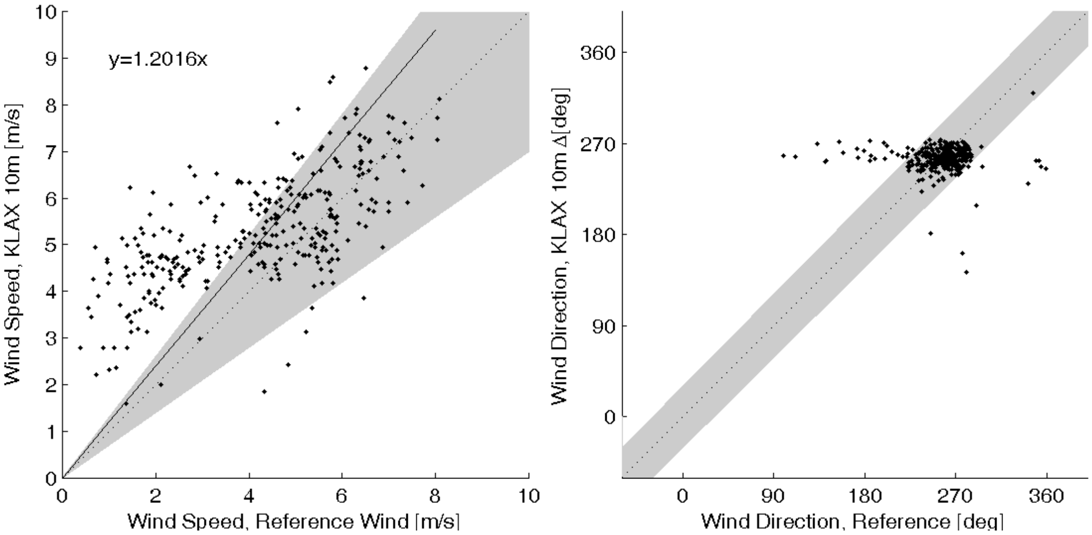


Figure 67. ASOS Met station at Los Angeles International Airport-KLAX versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM)during the calibration period 9-16 October 2016 at LIDAR site L3. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

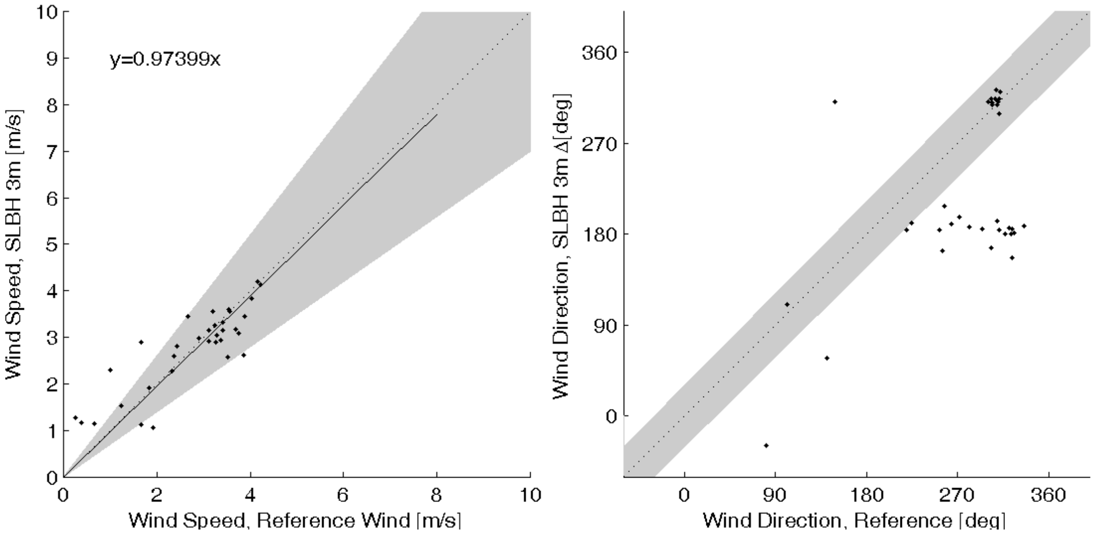


Figure 68. SCAQMD Met station at South Long Beach (SLBH) versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM)during the calibration 18 October 2016 at LIDAR site L2. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

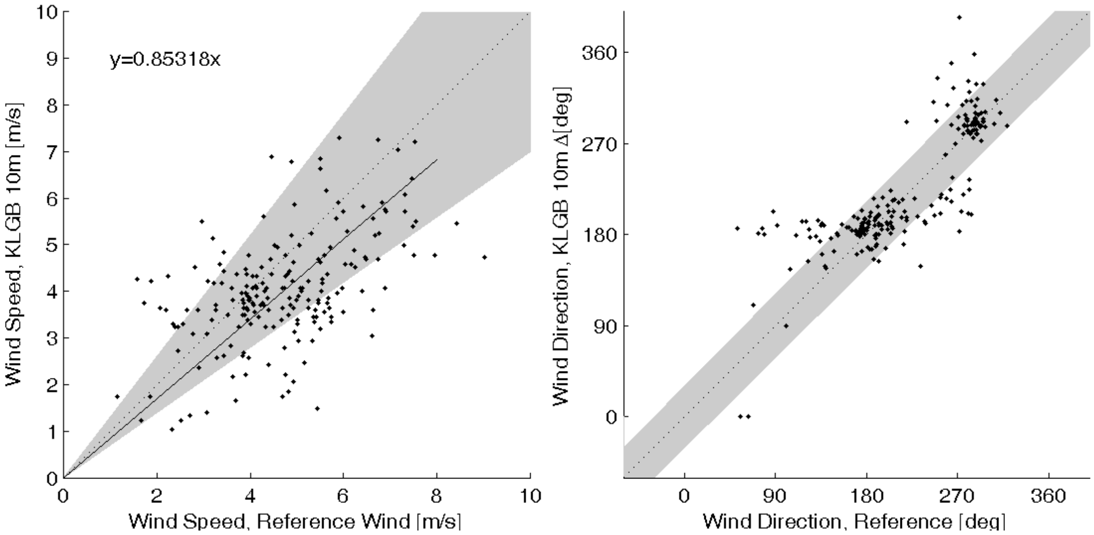


Figure 69. ASOS Met station at Long Beach Airport (KLGB) versus the reference LIDAR wind (50-400m) (10 min average from 10AM to 5PM)during the calibration period 2-6 October 2016 at LIDAR site L1. The shaded areas indicate ±30% relative deviation from reference wind speed (left panel) and ±30° deviation from reference wind direction (right panel). Fitted least squares are shown as solid lines.

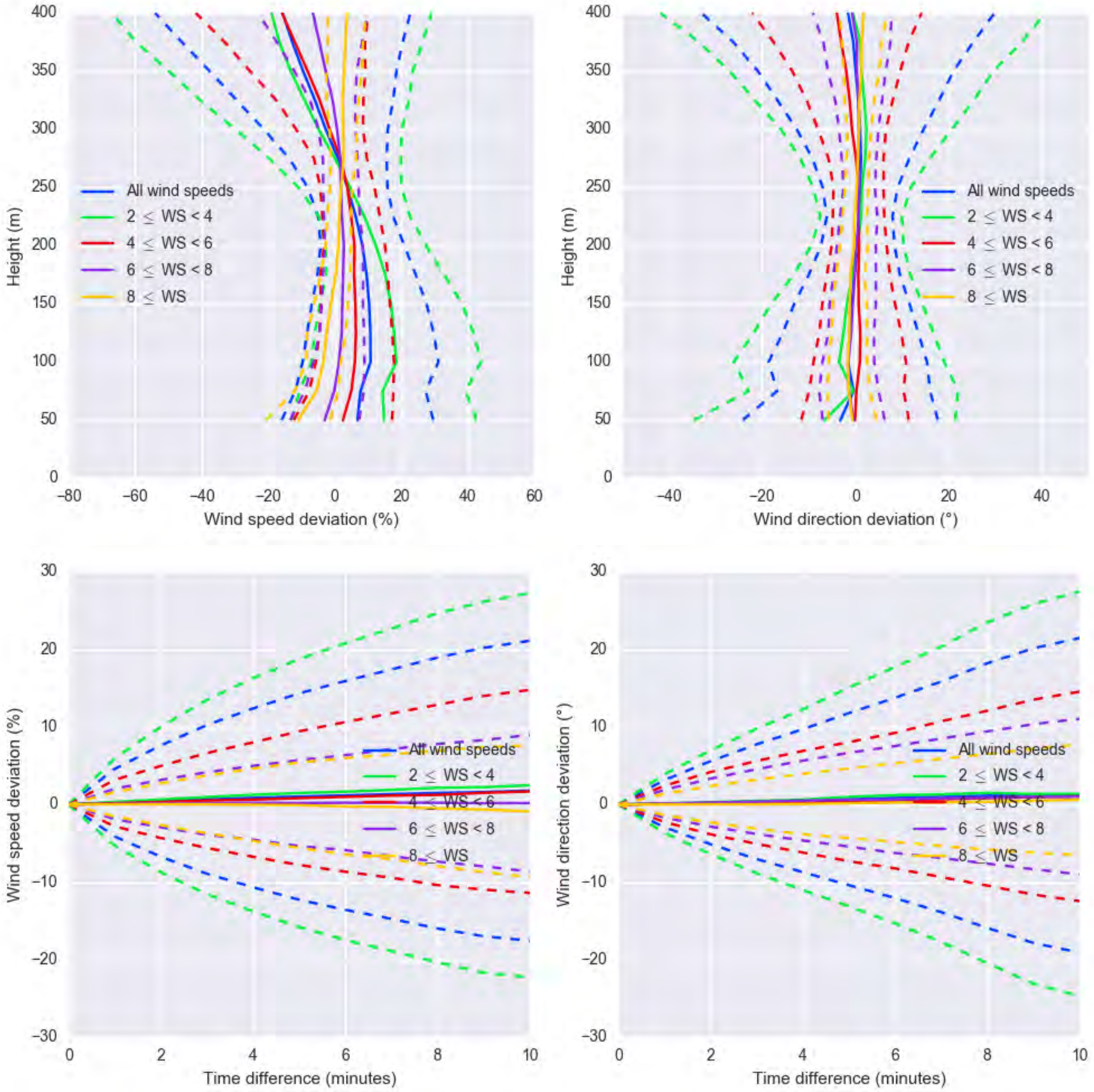


Figure 70. Wind LIDAR 10-min data for the entire SCAQMD survey 2015. Average (solid lines) and 1σ deviations (dashed lines). Top row panels show altitude information and the lower row shows time dependence. Different colors represent different wind speed ranges.

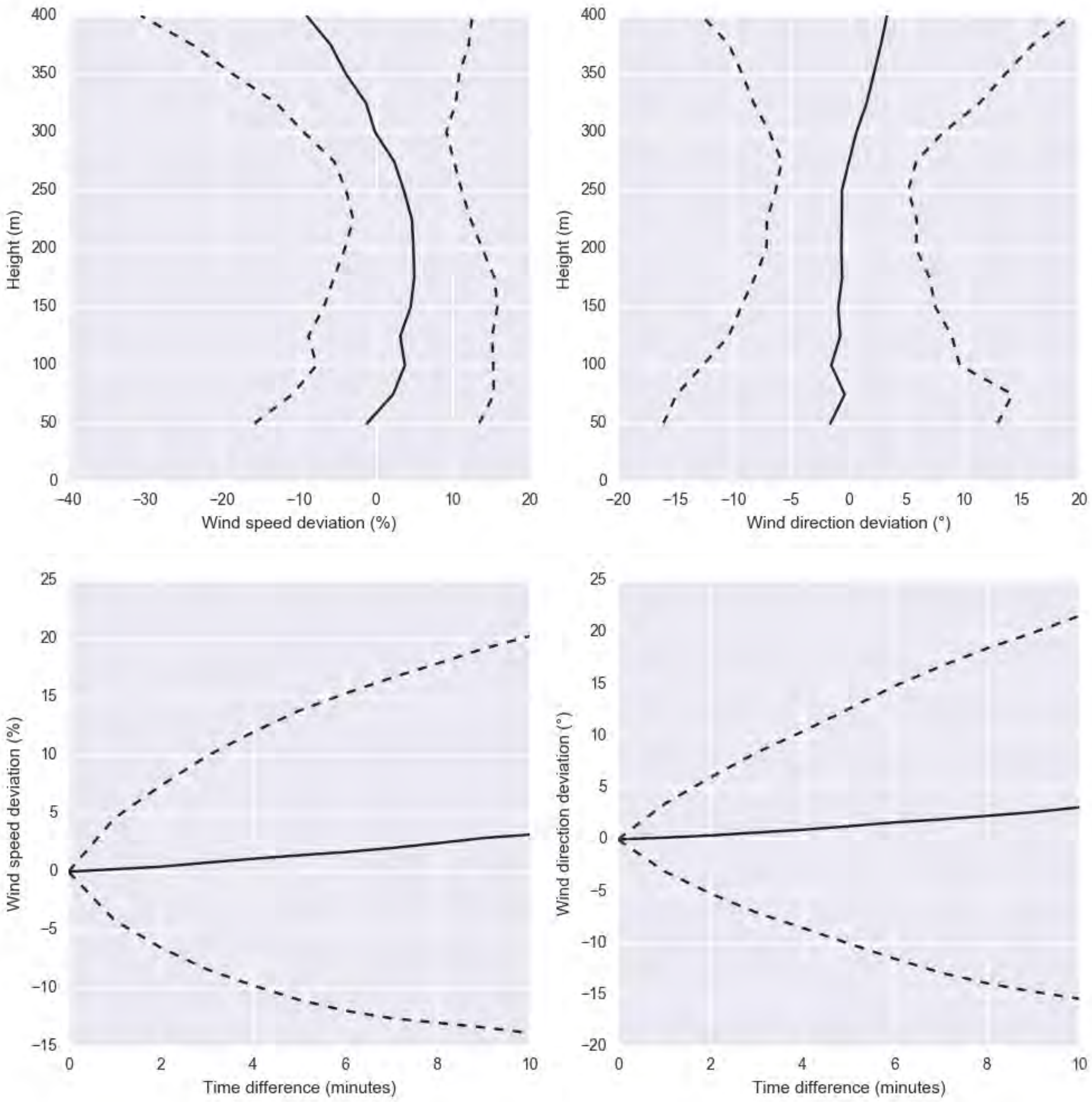


Figure 71. Wind LIDAR 10-min data at L1. Wind data averages (solid lines) and 1σ deviations (dashed lines) for the calibration period (9-16 Oct) during the SCAQMD survey 2015. Top row panels show altitude information and the lower row shows time dependence.

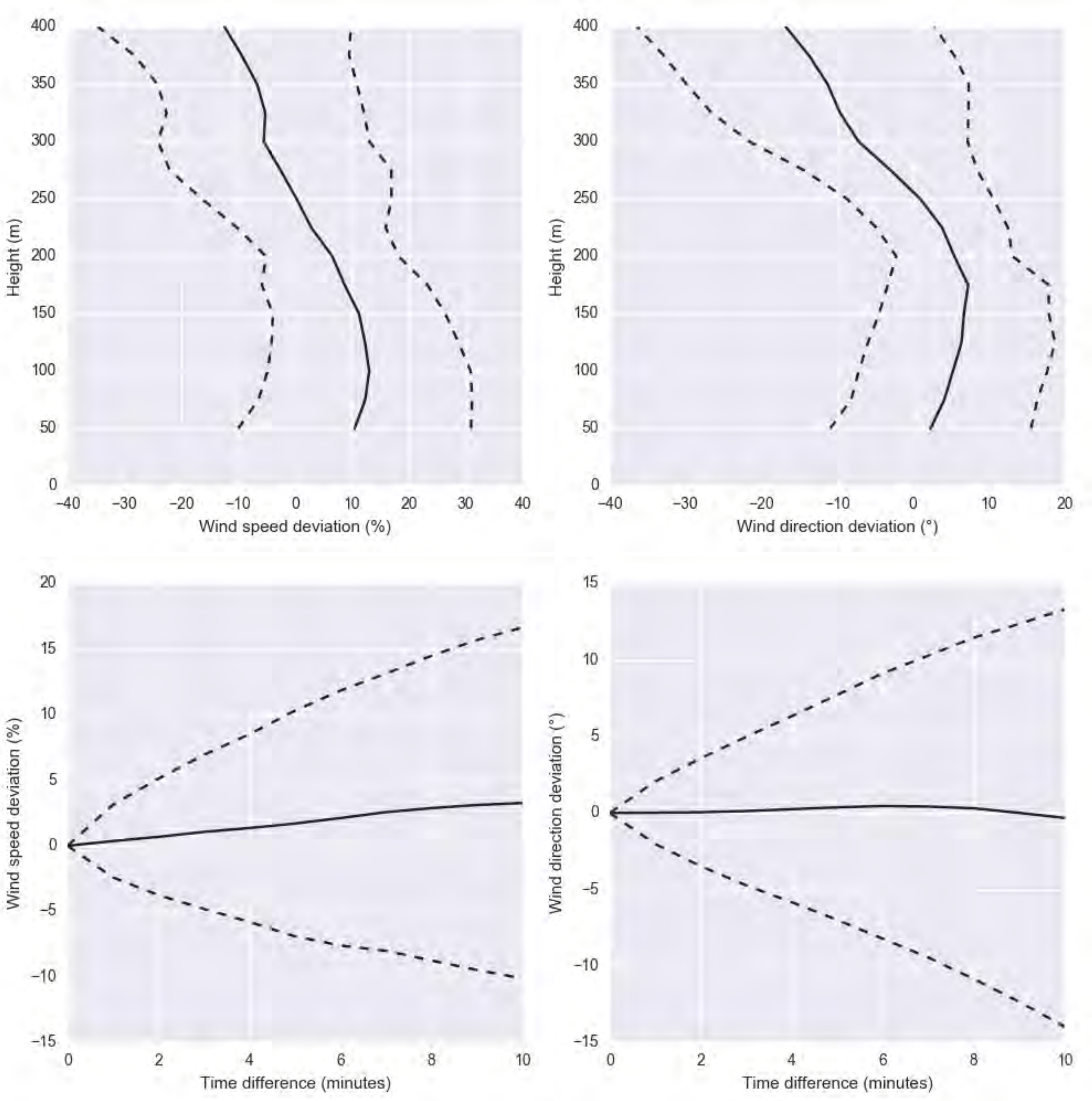
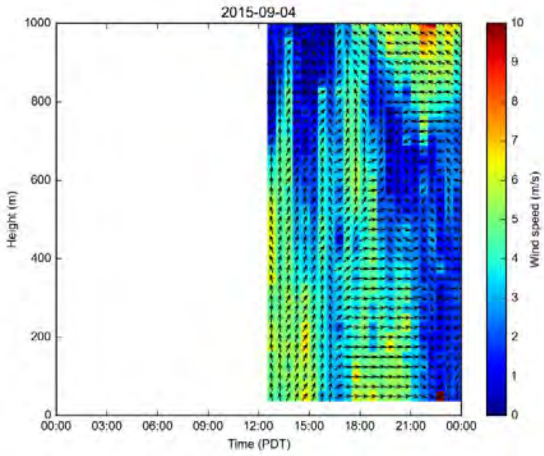


Figure 72. Wind LIDAR 10-min data at L4. Wind data averages (solid lines) and 1σ deviations (dashed lines) for the calibration period (2-6 Oct) during the SCAQMD survey 2015. Top row panels show altitude information and the lower row shows time dependence.

Figure 73. Wind LIDAR data (30 minute averages) from 50 to 1000 m for all measurement daysin this project. Arrows indicate wind direction and color wind speed (0-10 m/s). White gaps when no data available due to limited back scatter signal or other reason. **All panels below**.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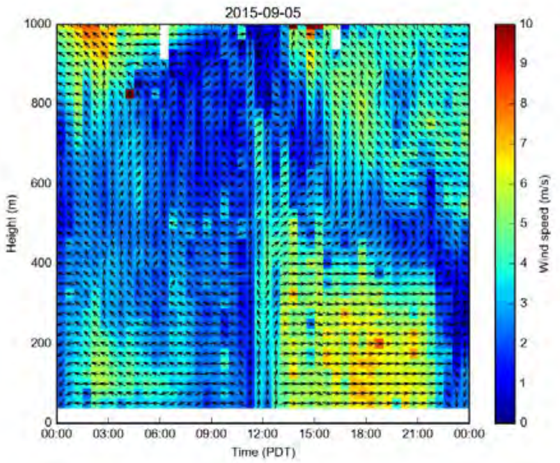
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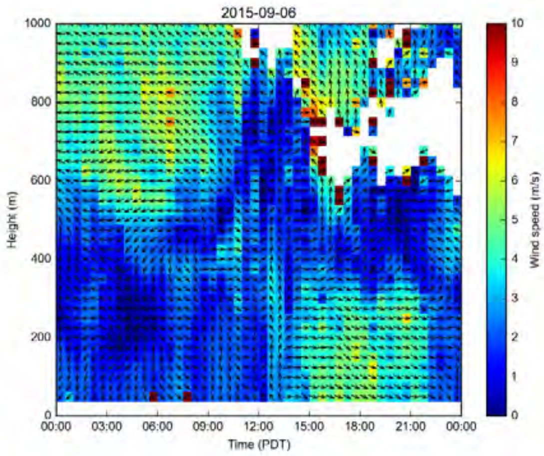
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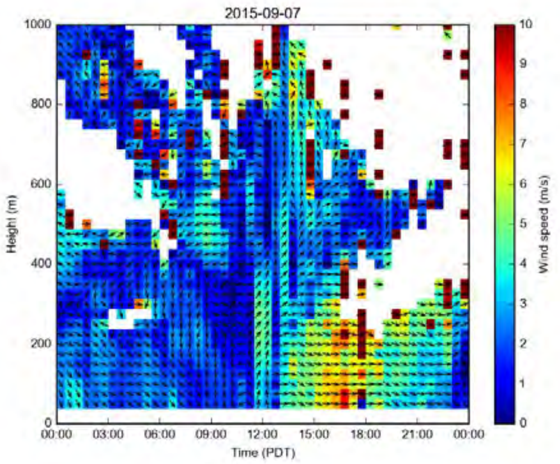
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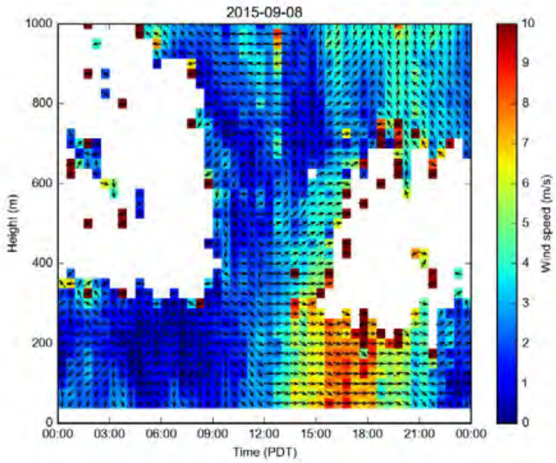
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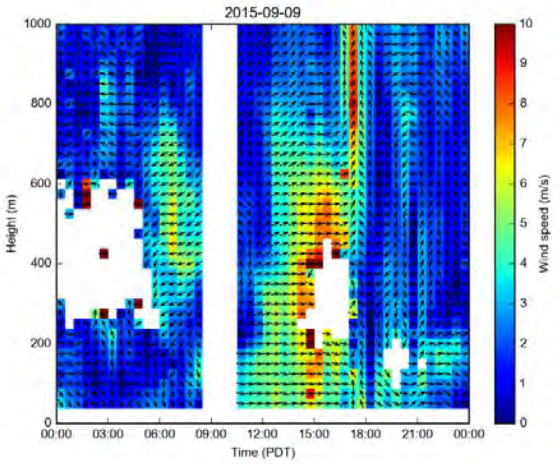
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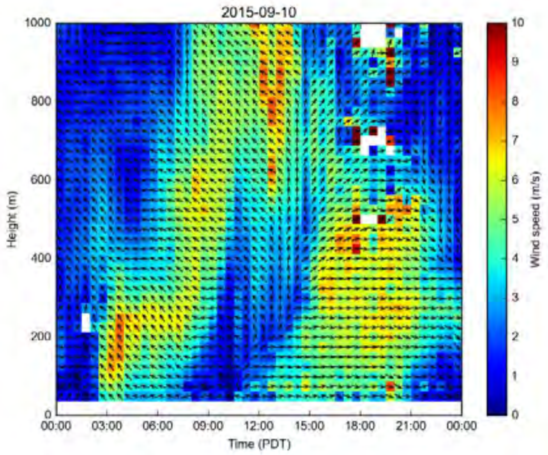
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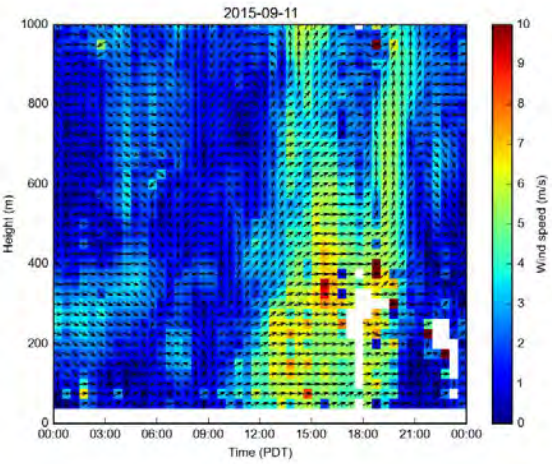
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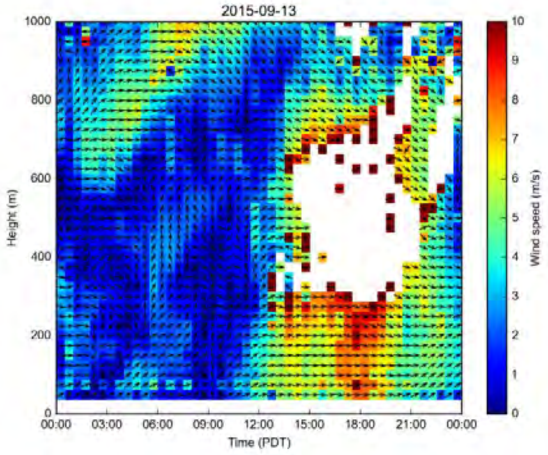
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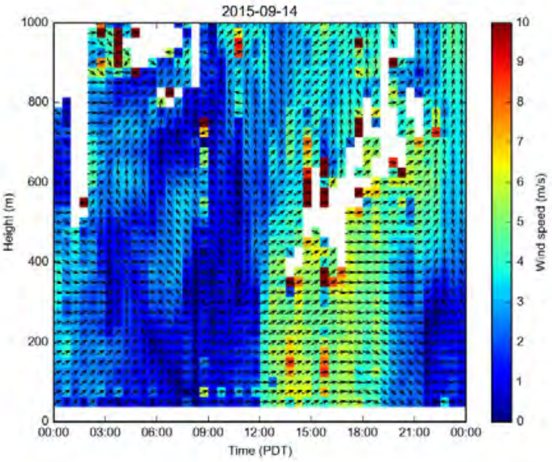
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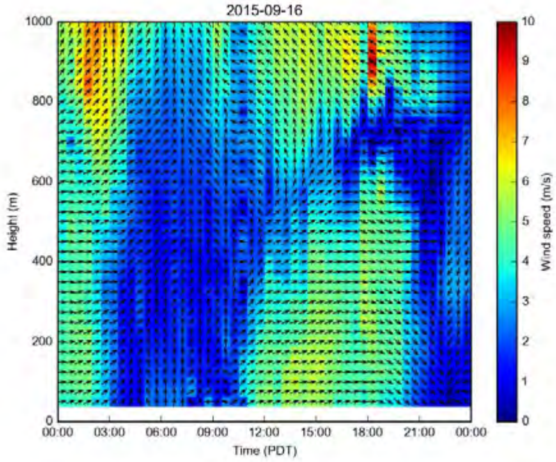
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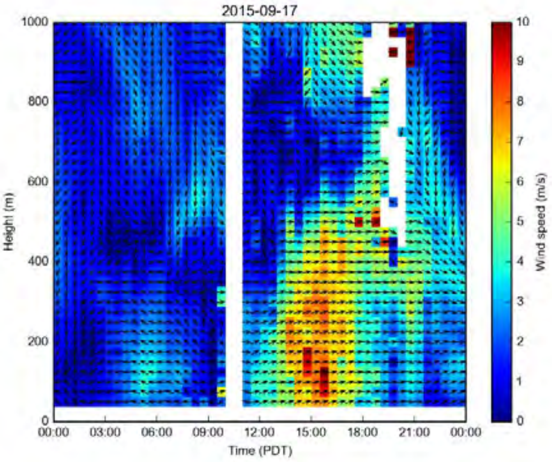
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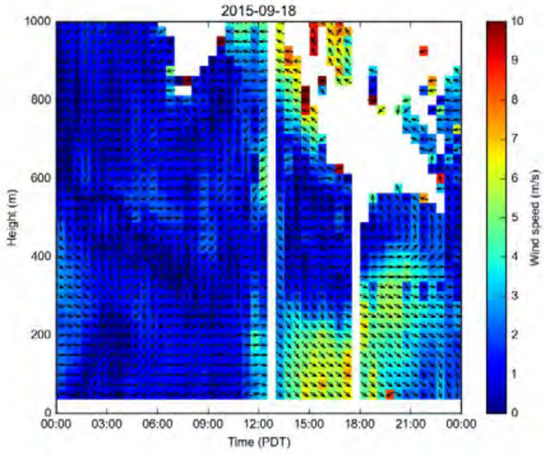
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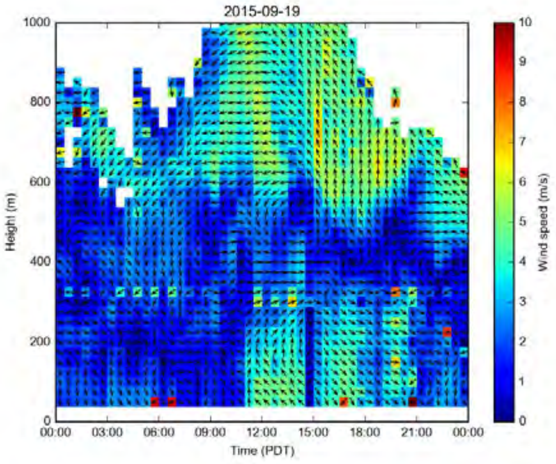
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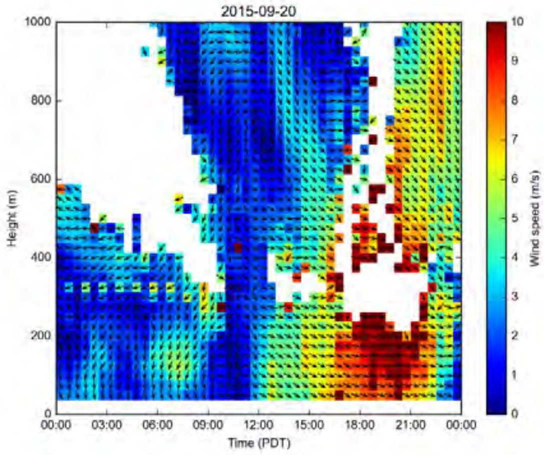
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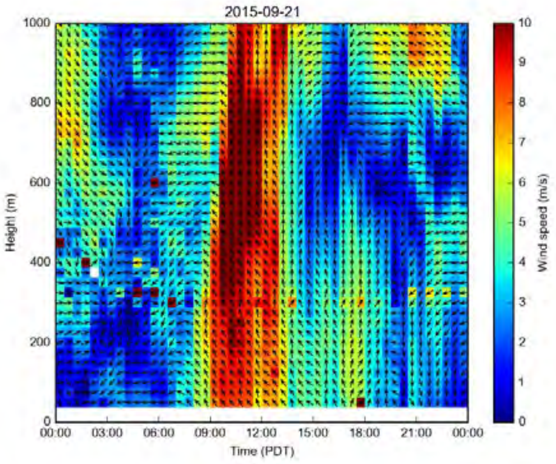
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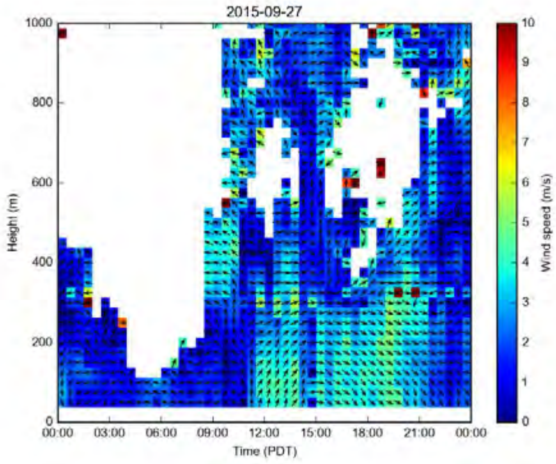
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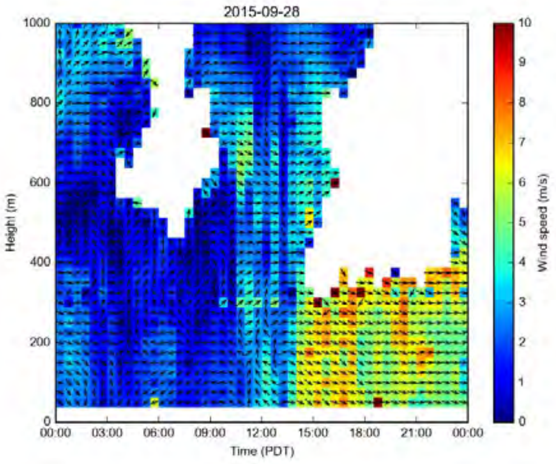
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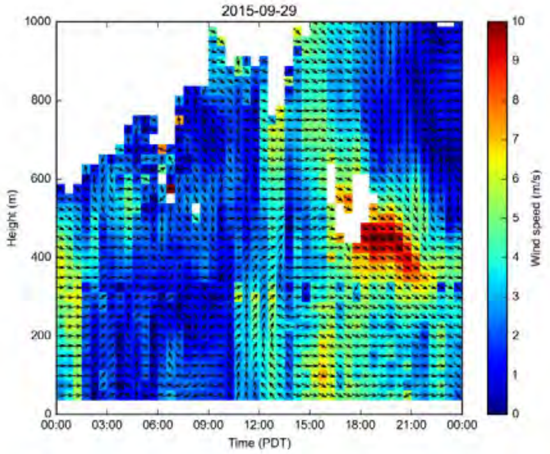
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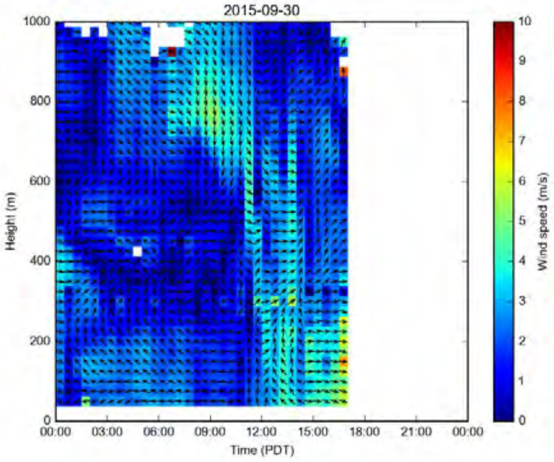
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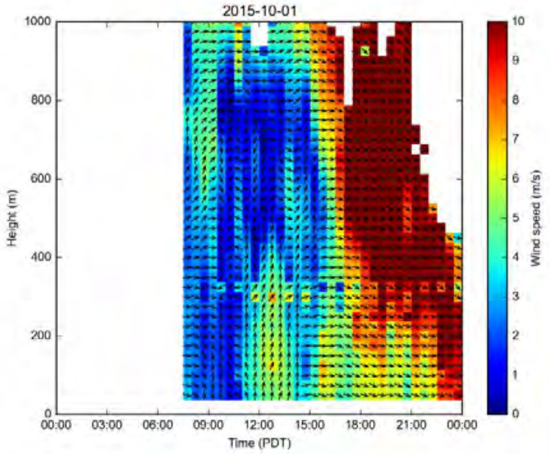
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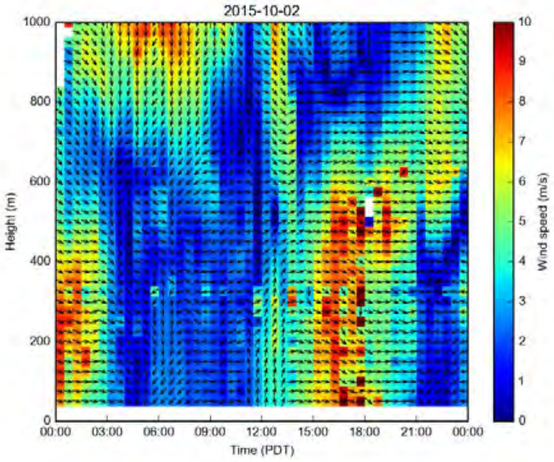
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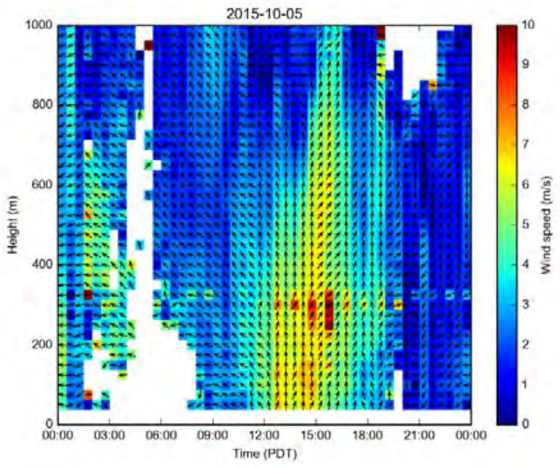
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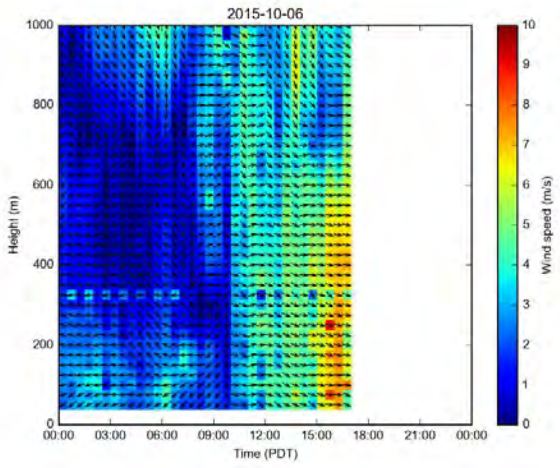
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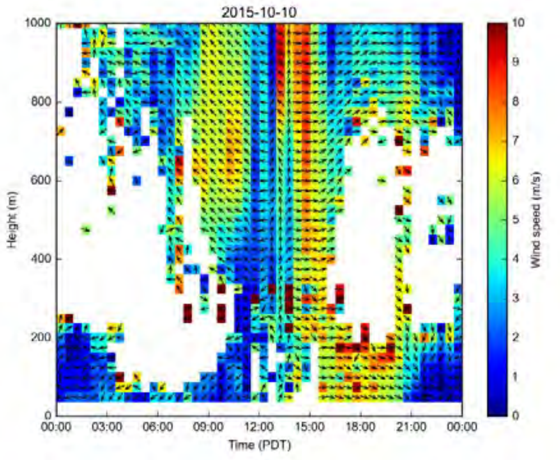
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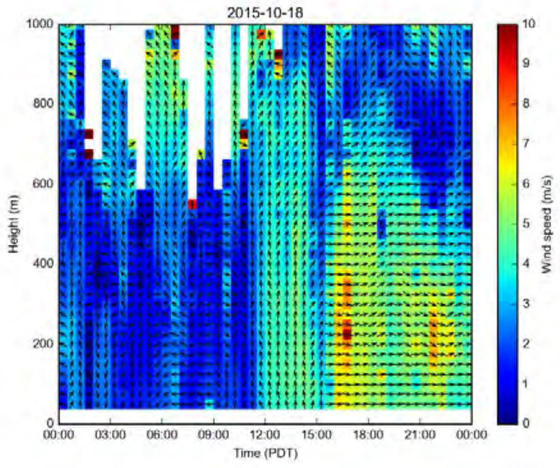
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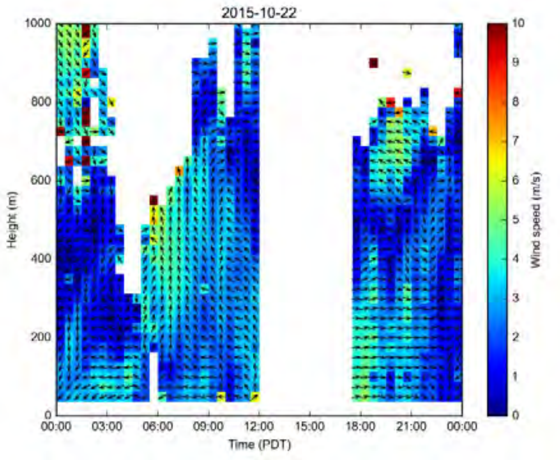
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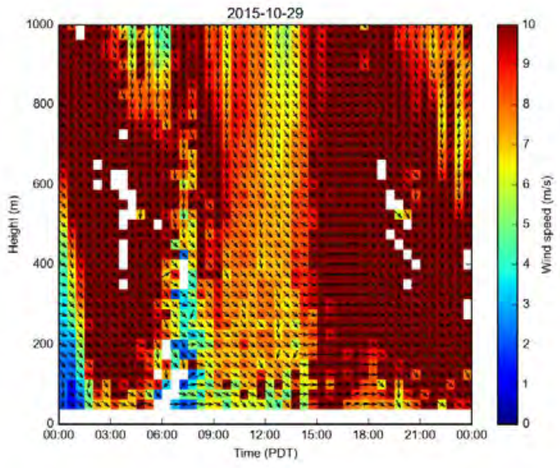
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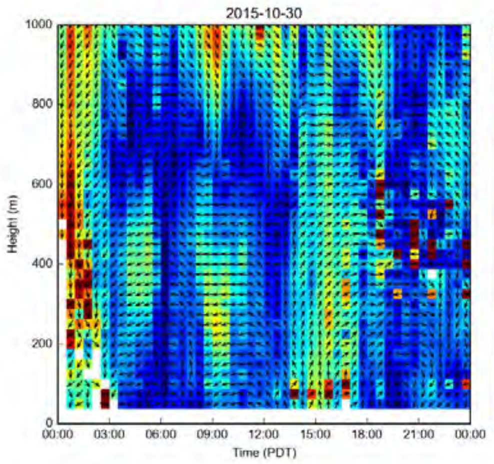
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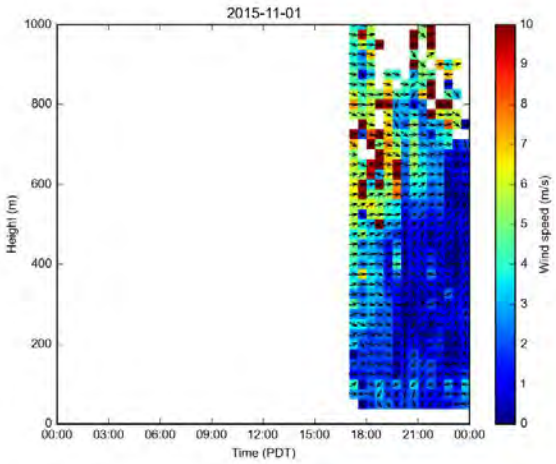
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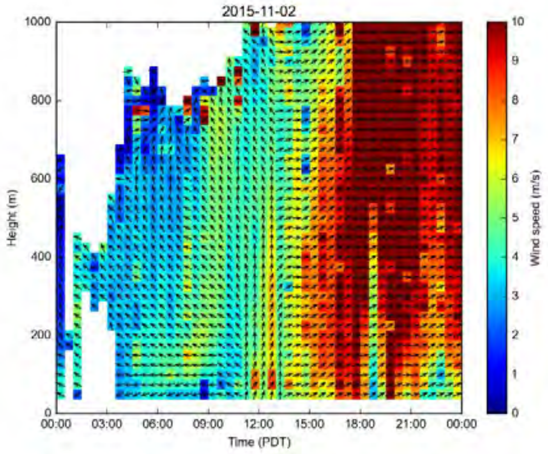
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AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2013JD020485

Special Section:
Study of Houston Atmospheric Radical Precursors (SHARP)

Key Points:
- Total VOC, SO2 and NO2 emission fluxes are measured from industries in Houston
- Reported VOC emissions are typically underestimated by an order of magnitude
- Meteorological variations cannot alone explain VOC emission discrepancies

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Emission measurements of alkenes, alkanes, SO_2, and NO_2 from stationary sources in Southeast Texas over a 5 year period using SOF and mobile DOAS

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Abstract A mobile platform for flux measurements of VOCs (alkanes and alkenes), SO_2, and NO_2 emissions using the Solar Occultation Flux (SOF) method and mobile differential optical absorption spectroscopy (DOAS) was used in four different studies to measure industrial emissions. The studies were carried out in several large conglomerates of oil refineries and petrochemical industries in Southeast and East Texas in 2006, 2009, 2011, and 2012. The measured alkane emissions from the Houston Ship Channel (HSC) have been fairly stable between 2006 and 2011, averaging about 11,500 kg/h, while the alkene emissions have shown greater variations. The ethene and propene emissions measured from the HSC were 1511 kg/h and 878 kg/h, respectively, in 2006, while dropping to roughly 600 kg/h for both species in 2009 and 2011. The results were compared to annual inventory emissions, showing that measured VOC emissions were typically 5–15 times higher, while for SO_2 and NO_2 the ratio was typically 0.5–2. AP-42 emission factors were used to estimate meteorological effects on alkane emissions from tanks, showing that these emissions may have been up to 35–45% higher during the studies than the annual average. A more focused study of alkene emissions from a petrochemical complex in Longview in 2012 identified two upset episodes, and the elevation of the total emissions during the measurement period due to the upsets was estimated to be approximately 20%. Both meteorological and upset effects were small compared to the factor of 5–15, suggesting that VOC emissions are systematically and substantially underestimated in current emission inventories.

1. Introduction

The Houston-Galveston-Brazoria area, which includes eight counties in the vicinity of Houston, Texas, is a nonattainment area for the 2008 National Ambient Air Quality Standard for ozone. Ground-level ozone is formed through a chemical process in the atmosphere, fueled by sunlight and emissions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Many large metropolitan areas in the U.S. have trouble meeting ozone standards since urban areas generally have a high concentration of anthropogenic sources of VOCs and NO_x. However, the Houston area is special due to its high concentration of refineries and petrochemical industries. These industries are primarily associated with VOC emissions but also have a significant NO_x contribution.

Measurements during the 2000 TexAQS (Texas Air Quality Study) and the 2006 TexAQS II indicated that the best emission inventories available at the time significantly underestimate industrial VOC emissions in Houston [*Kleinman et al.*, 2002; *Karl et al.*, 2003; *Ryerson et al.*, 2003; *Wert et al.*, 2003; *Jobson et al.*, 2004; *De Gouw et al.*, 2009; *Parrish et al.*, 2009; *Mellqvist et al.*, 2010b; *Washenfelder et al.*, 2010]. Several studies also concluded that industrial VOC emissions contribute significantly to ozone formation [*Kleinman et al.*, 2002; *Ryerson et al.*, 2003; *Wert et al.*, 2003; *Jobson et al.*, 2004; *Gilman et al.*, 2009; *Kim et al.*, 2011].

Industries are required to report the emissions from their activities to the state governments according to guidelines from the United States Environmental Protection Agency (EPA). The industries typically estimate their emissions with emission factors calculated using methods and formulas described in *AP-42*, *Compilation of Air Pollutant Emission Factors* [*United States Environmental Protection Agency* (*USEPA*), 2013]. VOC emissions from refineries and petrochemical industries are typically dominated by evaporative losses from storage tanks and process equipment. NO_x and SO_2 emissions, on the other hand, primarily come from external

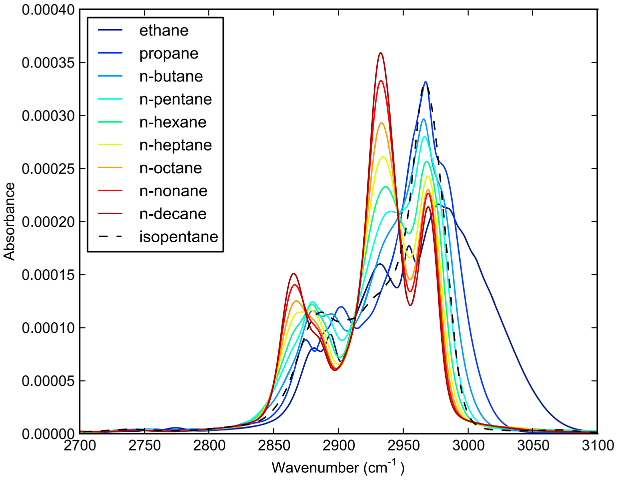

Figure 1. Absorbance spectra for 1 mg/m^2 of each of the *n*-alkanes from ethane to *n*-decane and isopentane degraded to 8 cm^{-1} spectral resolution.

combustion sources. This difference in types of emission sources makes VOC emission estimates inherently less reliable. External combustion is generally intentional and takes place in a limited number of places in a facility, often under controlled conditions with emissions released through flue gas channels which can be monitored to verify emission. Flares are an exception though. Estimates of SO_2 emissions from combustion are arguably even more reliable due to sulfur mass balance constraints; i.e., they are limited by the amount of sulfur in the burnt fuel. Evaporative losses of VOCs, on the other hand, can potentially occur in every unit in which petroleum products are stored, processed, or transported. Units that are malfunctioning, in need of maintenance, or irregularly operated can have drastically elevated emissions without giving any other indication. These types of irregular emissions can remain unnoticed if measurements of diffuse emissions are not made. Methods for quantitatively measuring these types of VOC emissions exist but are intrinsically more difficult due to the diffuse nature and the large number (tens of thousands) of potential sources. Estimates of VOC emissions from refineries and petrochemical industries are therefore rarely verified by quantitative measurements. Since reported total VOC emissions from a facility are typically a very small fraction (typically in the order of 0.01–0.02%) of its throughput, emissions would remain insignificant in any type of mass balance even if they were many times larger than reported.

In this paper we present measurements of VOCs, SO_2, and NO_2 from four campaigns in Southeast and East Texas carried out during 2006, 2009, 2011, and 2012. Additionally, a Solar Occultation Flux (SOF) spectral evaluation routine for alkanes is presented in detail and evaluated on the basis of its ability to quantify alkane mass columns in typical VOC mixtures from refineries. The measurement results are compared to emissions reported to the State of Texas Air Reporting System (STARS), and the representativeness of the results is discussed in relation to meteorological conditions, based on the use of the AP-42 emission factors.

2. Methods

All emission measurements presented in this article are based on the two methods, Solar Occultation Flux (SOF) and mobile DOAS (differential optical absorption spectroscopy). Both of them are based on the same principles for measuring total fluxes, instead of just concentrations, of industrial emission plumes. They take advantage of the ability of open path absorption spectroscopy methods to measure column concentrations. An emission flux is calculated from a series of column concentrations measured while traversing a plume crosswind together with some form of wind velocity measurement. The difference between the methods is mainly in the spectroscopy. SOF [*Mellqvist et al.*, 2010b] is based on infrared measurements of direct sunlight, while mobile DOAS [*Galle et al.*, 2002] is based on UV measurements of scattered sunlight.

2.1. Solar Occultation Flux

The Solar Occultation Flux method (SOF) is based on infrared measurements of direct sunlight from a mobile platform, typically a small truck, using a Fourier transform infrared (FTIR) spectrometer with a solar tracker.

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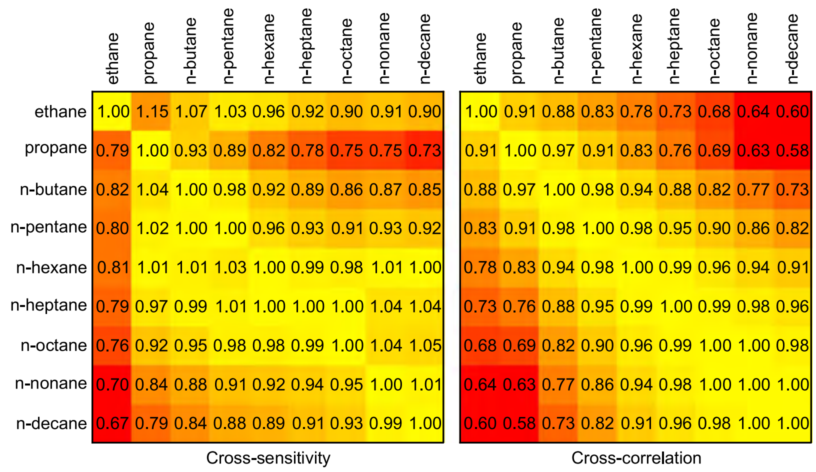

Cross-sensitivity

	ethane	propane	n-butane	n-pentane	n-hexane	n-heptane	n-octane	n-nonane	n-decane
ethane	1.00	1.15	1.07	1.03	0.96	0.92	0.90	0.91	0.90
propane	0.79	1.00	0.93	0.89	0.82	0.78	0.75	0.75	0.73
n-butane	0.82	1.04	1.00	0.98	0.92	0.89	0.86	0.87	0.85
n-pentane	0.80	1.02	1.00	1.00	0.96	0.93	0.91	0.93	0.92
n-hexane	0.81	1.01	1.01	1.03	1.00	0.99	0.98	1.01	1.00
n-heptane	0.79	0.97	0.99	1.01	1.00	1.00	1.00	1.04	1.04
n-octane	0.76	0.92	0.95	0.98	0.98	0.99	1.00	1.04	1.05
n-nonane	0.70	0.84	0.88	0.91	0.92	0.94	0.95	1.00	1.01
n-decane	0.67	0.79	0.84	0.88	0.89	0.91	0.93	0.99	1.00

Cross-correlation

	ethane	propane	n-butane	n-pentane	n-hexane	n-heptane	n-octane	n-nonane	n-decane
ethane	1.00	0.91	0.88	0.83	0.78	0.73	0.68	0.64	0.60
propane	0.91	1.00	0.97	0.91	0.83	0.76	0.69	0.63	0.58
n-butane	0.88	0.97	1.00	0.98	0.94	0.88	0.82	0.77	0.73
n-pentane	0.83	0.91	0.98	1.00	0.98	0.95	0.90	0.86	0.82
n-hexane	0.78	0.83	0.94	0.98	1.00	0.99	0.96	0.94	0.91
n-heptane	0.73	0.76	0.88	0.95	0.99	1.00	0.99	0.98	0.96
n-octane	0.68	0.69	0.82	0.90	0.96	0.99	1.00	1.00	0.98
n-nonane	0.64	0.63	0.77	0.86	0.94	0.98	1.00	1.00	1.00
n-decane	0.60	0.58	0.73	0.82	0.91	0.96	0.98	1.00	1.00

Figure 2. Cross sensitivity and cross correlation between each pair of *n*-alkanes from ethane to *n*-decane. The cross sensitivity is the ratio of the evaluated mass column to the true mass column, when evaluating the species on the *y* scale as the species on the *x* scale in a simple linear least squares retrieval in the interval 2700–3005 cm^{-1}. The cross correlation is the correlation coefficient between the two absorbance spectra in the same interval.

The solar tracker continuously guides the sunlight into the spectrometer as the truck moves and turns, and infrared spectra are recorded consecutively. These spectra are evaluated for absorption by molecular species in the industrial emission plume. A detailed description of the principles for SOF measurements and its application for measurements of ethene and propene is given in *Mellqvist et al*. [2010b].

In addition to ethene and propene, this study focuses on SOF measurements of alkanes. The evaluation of ethene and propene are based on narrow absorption lines in the interval 900–1000 cm^{-1} which are very specific to each species, while the alkane evaluation is based on a much broader absorption band in the region 2700–3000 cm^{-1}. This is called the C-H stretch band, since it corresponds to vibrational excitations of carbon-hydrogen bonds. Since C-H bonds are present in most VOCs, they typically have absorption features in this band. Figure 1 shows the absorbance spectra for all *n*-alkanes from ethane to decane downgraded to a spectral resolution of 8 cm^{-1}, which is typically used for these measurements. They are all fairly similar, and most of the variations are among the shorter alkanes, while the shape seems to almost converge the longer the carbon chain gets. Additionally, all alkanes have almost the same total absorption, i.e., the area under each absorbance spectra, for equal mass columns. These properties make it possible to approximate the combined absorption of any mix of alkanes fairly well with the combination of just a few of their absorbance spectra, and this combination will also approximate the total mass column of the alkane mix. This is important because the number of absorption spectra included in a spectral fitting routine has to be limited to avoid numerical instability, overfitting, and sensitivity to noise. To determine which absorption spectra to include in the evaluation, their similarities were quantified by pairwise calculation of cross sensitivity, i.e., how well the mass column of one alkane is approximated by a simple linear least squares fit to the absorbance spectrum of the other, and cross correlation. The cross sensitivity is a measure of how well a species approximates the mass column of another species in a spectral evaluation, while cross correlation is a measure of how good the spectral fit would be. In a spectral evaluation with several species included, absorption by another species is most likely to be approximated by the species it has high cross correlation with, since the spectral evaluation strives to optimize the spectral fit. The result of this is presented in Figure 2. This confirms the picture that the largest variations are among the shorter alkanes, while the longer ones are more similar to each other. For this reason it is more important to include the absorbance spectra of several shorter alkanes in the spectral fitting routine, while a single long alkane is sufficient to approximate the rest of them. This is also additionally motivated by the fact that gaseous emissions are typically dominated by shorter alkanes since they are more volatile. Accurate determination of alkane columns is further complicated by the presence of branched alkanes and cycloalkanes, which diverge slightly more in cross sensitivity from straight alkanes of similar carbon number. Isopentane is also included in Figure 1 as an example of this, showing that it is fairly similar in shape to straight alkanes but with somewhat lower total absorption, i.e., the area under the graph. However,

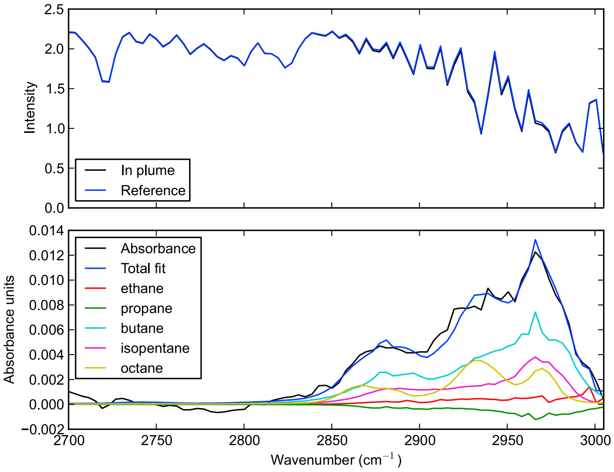

Figure 3. (top) SOF spectrum measured in a VOC plume and a reference spectrum measured outside of the plume. (bottom) Absorbance in the plume relative to the reference, fitted absorbance, and the fitted components of ethane, propane, butane, isopentane, and octane.

since the fraction of branched alkanes and cycloalkanes in VOC emissions from petroleum industries is typically low, the error of fitting them as straight alkanes is fairly limited.

A combination of ethane, propane, *n*-butane, isopentane, and *n*-octane was chosen to be included in the spectral fitting routine for the alkane measurements in this paper. The inclusion of isopentane was motivated by its relatively high abundance in VOC emissions compared to other branched alkanes and cycloalkanes. Absorption spectra for these species from the Pacific Northwest National Laboratories database [*Sharpe et al.*, 2004] were downgraded to 8 cm^{-1} resolution and were fitted by multivariate regression to the absorbance in the interval 2700–3005 cm^{-1}. Absorption spectra for water and methane, synthesized with line parameters from the HITRAN database [*Rothman et al.*, 2005], were also included in the fitting routine, which was performed in the QESOF software [*Kihlman*, 2005]. The total alkane mass column was calculated as the sum of the fitted mass columns of all the included alkanes. Figure 3 shows an example of a spectral fit and the alkane components fitted. The 8 cm^{-1} spectral resolution was empirically determined to be a good compromise between measurement signal-to-noise, sampling time, and sensitivity to spectral interference from other species.

In order to validate the accuracy of the alkane mass columns determined by this spectral fitting routine, data [*Texas Commission on Environmental Quality* (*TCEQ*), 2013] from an automated gas chromatograph in a Continuous Ambient Monitoring Station (CAMS), C169 located close to the Houston Ship Channel (HSC) (29.7062492°, −95.2611301°) and operated by TCEQ (Texas Commission on Environmental Quality), were used to approximate typical refinery VOC compositions in Houston. Data from September 2006, the time of the first measurement campaign, was filtered for hourly averages where wind speed was above 1.4 m/s and wind direction was in the interval 69°–87°. In these wind directions the emissions from refineries in the HSC should dominate the VOC concentrations measured at CAMS 169. Seven such instances were found during September 2006. For each of these instances an artificial solar spectrum was synthesized with absorption by different VOCs in the proportions measured by the auto-GC. These spectra were downgraded to the resolution of the spectral retrieval, 8 cm^{-1}, and evaluated by the spectral fitting routine described above. The evaluated alkane mass columns were then compared to that used for synthesizing the solar spectra. The results of this are presented in Table 1. The evaluated alkane mass overestimated the true alkane mass by 3–7%, which is small compared to the uncertainty in flux calculations due to wind speed uncertainty. This overestimation is due to a combination of the errors of fitting all alkanes to a finite set and the spectral interference from other VOCs with weaker absorption in the same region.

Methane is typically treated separately from other VOC emissions because it has much lower ozone formation potential. Fortunately, the alkane evaluation routine described above has low sensitivity to methane. Methane has absorption in this band but primarily in narrow lines. Because of the relatively high background concentration of methane, these lines are practically depleted of light after passing through the full atmospheric column. This is illustrated in Figure 4. Due to the nonlinearity of Beer-Lamberts law at such strong

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Table 1. VOC Composition in the Plume Downwind of a Large Refinery Complex in the HSC During Seven Episodes in the 2006 Study as Measured by an Auto-GC at CAMS 169[a]

		Date and Time						
	Molar mass	2 Sep 2006, 19:00	4 Sep 2006, 17:00	9 Sep 2006, 21:00	9 Sep 2006, 22:00	20 Sep 2006, 11:00	20 Sep 2006, 12:00	26 Sep 2006, 16:00
Wind speed (m/s)		1.70	1.43	2.28	1.88	2.55	2.86	1.43
Wind direction (deg)		76	72	87	86	69	76	77
Units	g/mole	ppbv	ppbv	ppbv	ppbv	ppbv	ppbv	ppbv
Alkanes								
Ethane	30.1	17.93	2.59	3.46	4.59	10.51	7.52	3.64
Propane	44.1	20.20	1.23	1.71	2.22	9.40	4.84	2.09
n-Butane	58.1	12.85	1.14	0.87	0.58	8.74	4.97	1.07
i-Butane	58.1	4.87	0.37	0.68	0.60	3.84	2.41	1.03
cyc-Pentane	70.1	1.01	0.09	0.16	0.04	0.43	0.23	0.05
i-Pentane	72.2	16.07	1.35	1.43	0.47	6.69	4.17	0.74
n-Pentane	72.2	12.52	0.80	0.94	0.24	4.23	2.37	0.42
cyc-Hexane	84.2	2.17	0.09	0.14	0.04	0.49	0.24	0.04
2,2-Dimethylbutane	86.2	0.33	0.04	0.08	0.03	0.20	0.11	0.02
n-Hexane	86.2	2.40	0.18	0.48	0.14	1.21	0.71	0.19
3-me-Hexane	100.2	0.45	0.05	0.14	0.05	0.32	0.22	0.05
n-Heptane	100.2	0.65	0.05	0.13	0.04	0.33	0.21	0.04
n-Octane	114.2	0.31	0.04	0.09	0.02	0.19	0.11	0.03
i-Octane	114.2	0.36	0.10	0.18	0.08	0.58	0.24	0.08
n-Nonane	128.2	0.07	0.01	0.02	0.01	0.05	0.03	0.01
n-Decane	142.2	0.04	0.01	0.02	0.03	0.05	0.03	0.01
Alkenes								
Ethylene	28.0	4.16	0.46	0.75	0.50	1.96	1.51	0.66
Propylene	42.1	3.94	0.24	0.99	0.92	1.66	0.90	0.42
1,3-Butadiene	54.1	0.44	0.40	0.16	0.18	0.12	0.12	0.48
t-2-Butene	56.1	0.68	0.13	0.09	0.07	0.12	0.10	0.12
1-Butene	56.1	0.65	0.14	0.06	0.03	0.36	0.20	0.09
c-2-Butene	56.1	0.52	0.07	0.06	0.04	0.09	0.07	0.07
Isoprene	68.1	0.20	0.24	0.01	0.01	0.22	0.10	0.10
t-2-Pentene	70.1	0.69	0.04	0.07	0.02	0.08	0.05	0.02
1-Pentene	70.1	1.07	0.06	0.05	0.02	0.12	0.08	0.03
c-2-Pentene	70.1	0.32	0.02	0.04	0.01	0.04	0.03	0.01
Styrene	104.1	0.07	0.00	0.29	3.58	0.02	0.11	0.16
Aromatics								
Benzene	78.1	0.82	0.12	0.21	0.11	0.64	0.57	0.22
Toluene	92.1	2.40	0.26	0.49	0.27	0.70	0.54	0.41
m + *p*-Xylene	106.1	0.42	0.07	0.24	0.10	0.25	0.17	0.17
o-Xylene	106.1	0.13	0.02	0.10	0.10	0.10	0.08	0.06
Ethylbenzene	106.1	0.18	0.03	0.10	0.09	0.09	0.06	0.07
Mass fractions								
Alkanes		84.7%	76.4%	71.1%	44.0%	87.9%	85.3%	70.4%
Alkenes		9.4%	15.5%	15.5%	48.9%	6.6%	7.6%	16.3%
Aromatics		5.9%	8.1%	13.4%	7.0%	5.4%	7.1%	13.4%
Retrieved/true alkane mass		1.044	1.051	1.062	1.058	1.035	1.036	1.065

[a] The uncertainty of the alkane spectral retrieval has been estimated by applying it to solar spectra with absorption by VOCs added synthetically proportionally to the measured concentrations. The mass ratios between the evaluated alkane columns and the total alkane columns added synthetically are given at the bottom of the table. The mass fractions of alkanes, alkenes, and aromatics are also presented to give an overview of the composition.

absorption, the apparent absorption of additional methane at 8 cm^{-1} resolution is approximately a factor of 17 lower than it would be without the atmospheric methane background column. The absorption spectrum of methane is still included in the alkane spectral fitting routine but mainly to improve the spectral fit and not to quantify methane. Quantitative measurement of atmospheric methane using solar FTIR is possible but generally requires high-resolution measurements [*Angelbratt et al.*, 2011].

2.2. Mobile DOAS

For mobile DOAS measurements UV spectra of solar light scattered in the atmosphere are measured with a UV spectrometer, typically a Czerny-Turner spectrometer with a CCD detector. The spectrometer is typically connected

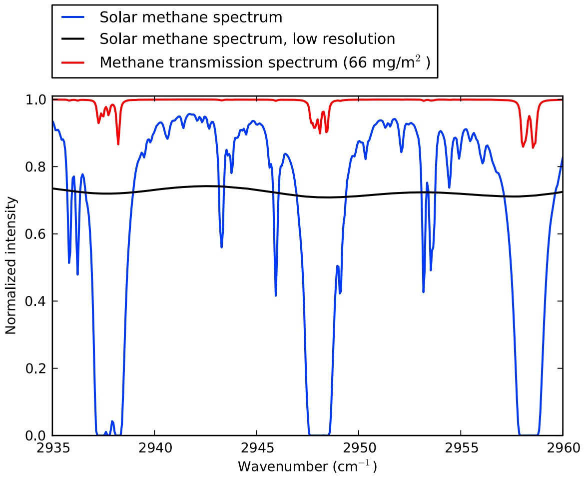

Figure 4. High-resolution solar spectrum (blue) after passing through the full atmospheric methane column and the same solar spectrum downgraded to a resolution of 8 cm^{-1} (black). Although not obvious from the low-resolution spectrum, the strong absorption lines are depleted of light.

with a light guide to a zenith-looking telescope. The principles for mobile DOAS measurements are described in detail by *Galle et al.* [2002], *Johansson et al.* [2008, 2009], *Rivera et al.* [2009, 2010], and *Johansson et al.* [2014] together with its application for measuring SO_2 and NO_2 in *Johansson et al.* [2008] and *Rivera et al.* [2009, 2010] as well as formaldehyde (HCHO) in *Johansson et al.* [2008, 2009], *Rivera et al.* [2010], and *Johansson et al.* [2014].

The measurements in 2009, 2011, and 2012 used a 303 mm focal length Czerny-Turner spectrometer (ANDOR Shamrock 303i) with a 1024 × 255 pixel, thermoelectrically cooled CCD detector (Newton DU920N-BU2) which was connected with a liquid light guide, 3 mm in diameter, to a zenith-looking quartz telescope with a 75 mm diameter and a 20 mrad field of view. The holographic grating used (1800 grooves/mm) together with a 300 μm entrance slit gave a 0.63 nm spectral resolution in the 309–351 nm wavelength region that the CCD was set to cover. The telescope was equipped with an optical band pass filter (Hoya), blocking wavelengths above 380 nm to reduce stray light in the spectrometer. This is a highly light-sensitive DOAS system originally developed for airborne measurements of ship emissions using downward looking DOAS [*Berg et al.*, 2012]. This was the same system and setup as in *Johansson et al.* [2014], and NO_2 was evaluated with the same spectral fitting routine as formaldehyde in that paper. This routine involved fitting cross sections for HCHO [*Cantrell et al.*, 1990], NO_2 [*Vandaele et al.*, 1998], O_3 [*Burrows et al.*, 1999], $(O_2)_2$ collision complex [*Hermans et al.*, 1999], a ring spectrum, and a polynomial of order 3 in the 324–350 nm spectral window. Wavelength calibration of the spectrometer was made with respect to the Fraunhofer lines present in all solar spectra. SO_2 was also evaluated from the same spectra using a 310–325 nm spectral window where SO_2 [*Bogumil et al.*, 2003], O_3 [*Burrows et al.*, 1999], a ring spectrum, and a polynomial of order 3 were fitted. Apart from spectral window and cross sections fitted, the two routines were identical. The QDOAS software [*Fayt*, 2011] was used for the wavelength calibration, degradation of cross sections, ring spectrum synthesis, and spectral fitting. Further details of the NO_2/HCHO evaluation routine can be found in *Johansson et al.* [2014]. During the 2006 study, a commercial mini-DOAS system was used instead of the one described above. This system collected less light and therefore required longer exposure times to achieve the same accuracy. The mobile DOAS results from this study was previously published in *Rivera et al.* [2010] together with a complete description of the system used.

2.3. Wind Measurements

Accurate wind information is of major importance for flux calculations for both SOF and mobile DOAS. Even though considerable effort is put into obtaining high-quality wind measurements, wind uncertainty is typically the largest error source for flux measurements. Measurements of wind height profiles throughout the boundary layer were taken during all four campaigns using GPS tracking radiosondes launched with helium balloons. Since the number of radiosonde launches on a given measurement day varied between five and zero, profiles derived from these launches were not available sufficiently close in time to the measurement

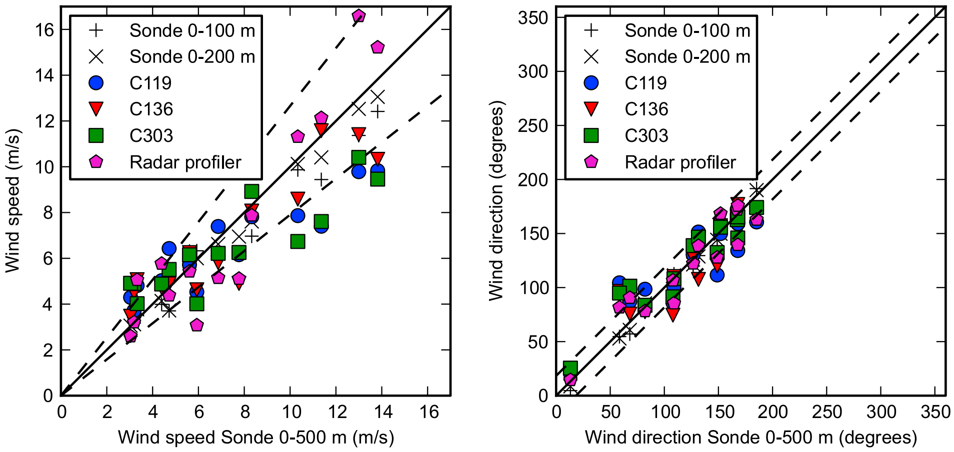

Figure 5. Comparison of different wind measurements in the Beaumont/Port Arthur area during the 2011 study. For each radiosonde launch the wind profile averages from ground up to 100 m and 200 m and simultaneous rescaled measurements at the ground stations C119, C136, and C303 and from a local radar profiler are plotted against the profile average from ground up to 500 m. The solid line represents perfect agreement, and the dashed lines show plus/minus the average of the standard deviations of the differences (relative differences for the wind speed) between the ground sources and the radiosonde profile average.

transects. Hence, the radiosonde data were complemented by wind measurements from local ground sites, mainly from the TCEQ-operated network of Continuous Ambient Monitoring Stations (CAMS) [*TCEQ*, 2013]. Ground wind speed data were normalized to radiosonde measurements to compensate for systematic wind speed differences as a function of height. Average winds over the first 500 m (350 m for the 2012 Longview study) of the wind profiles were used both for flux calculations and for normalization of ground wind data, as described in *Mellqvist et al*. [2010b]. Flux calculations were made using height profile averages when available sufficiently close in time to the measurement transect and normalized ground wind data for other cases. The variations between the different wind data sets were used to estimate the wind uncertainty. This is not a measurement uncertainty but rather the uncertainty due to the variation in the wind on the spatial and temporal scales that the wind measurements differ from the time and place of the column measurements. As an example, Figure 5 shows a comparison between height profile averages and simultaneous normalized ground wind measurements from CAMS sites in the Beaumont/Port Arthur area during the 2011 study. The estimated wind uncertainties based on these comparisons are presented in Table 2 for the different studies. The range of uncertainties given represents the 1σ variabilities of a number of ground wind stations compared to sonde profile averages. The estimated uncertainties were similar in most years, with the exception of 2012 in Longview, where especially the wind direction uncertainty was larger. This was suspected to have been at least partly caused by measurement errors in some of the ground wind measurements.

2.4. Emission Inventories

Emission inventory data were extracted from the STARS (State of Texas Air Reporting System) emission inventory for comparison to the measured emission rates. Emissions are reported to STARS by the industries on an annual basis and are typically based on calculations using emission factor formulas such as found in *AP-42*, *Compilation of Air Pollutant Emission Factors* [*USEPA*, 2013]. Data for 2006, 2009, and 2011 was extracted, and total emissions of the species of interest were computed as the sum of all point source emissions within each studied area. Emission inventories were not yet available for 2012. Speciation in the emission inventories did not perfectly match the speciation of the measurements. For comparison with the SOF alkane measurements, all emissions speciated as either alkanes or alcohols were added, as well as unspeciated VOCs and vaguely speciated VOCs, such as "crude oil" and "naphtha." Alcohols were included since they typically

Table 2. Wind Speed and Wind Direction Uncertainties for the Four Studies as Estimated From the Variation Between Sonde Profile Averages and Normalized Ground Wind Measurements

Year	Wind Speed Uncertainty	Wind Direction Uncertainty
2006	15–27%	11–33°
2009	11–29%	10–26°
2011	16–30%	11–23°
2012	25–34%	30–34°

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Table 3. Total Number of Sites and Sources and Total Reported Average Emissions in the Emission Inventories for Harris County for All Measured Species and for the Years of the Studies

	Number of Sites			Number of Sources			Total Emissions (kg/h)		
Species	2006	2009	2011	2006	2009	2011	2006	2009	2011
Alkanes	261	262	266	10,052	8,398	8,822	1,597	1,224	1,293
Ethene	49	41	51	1,055	798	830	123	104	88
Propene	50	46	53	1,148	844	853	179	102	92
NO_x	228	234	240	2,449	2,255	2,331	3,241	1,877	1,664
SO_2	203	207	210	2,192	1,957	2,011	2,730	2,004	1,256

have absorption cross sections similar in shape and strength to alkanes in the C-H stretch spectral region. The unspeciated and vaguely speciated VOCs were included since they are probably dominated by alkanes in general but may contain some species that the alkane measurements are not sensitive to. NO_x emissions are reported to the inventories, while only NO_2 is measured with mobile DOAS. According to airborne measurement carried out in parallel to the SOF measurements during the 2006 study [*Rivera et al.*, 2010], the typical NO_2/NO_x ratio was 0.75, which suggests that measured NO_2 emissions should be expected to be on average 25% lower than the reported emissions. The measured emissions of ethene, propene, and SO_2 were all possible to compare directly to the equivalent inventory species. Table 3 shows the total number of industrial sites and point sources within those sites reporting emissions of the species of interest to the inventories for Harris County, which contains all of the HSC and parts of Mont Belvieu, in 2006, 2009, and 2011. Alkane emissions (including alcohols and unspeciated VOC) are the most common, and almost every site reports something in this category, while ethene and propene are significantly less common. The number of point sources has stayed relatively constant, although there seems to have been a noticeable dip from 2006 to 2009. To what extent this represents changes in operations, as opposed to changes in reporting procedures, is not known.

The emissions are reported on an annual basis so even when converted to kg/h they should be thought of as annual average emissions. Since there can be large variations in emissions from a source within a year, instantaneous emissions cannot be expected to always match the annual average emissions. However, since each area contains a large number of sources in several independently operated facilities and measurements have been performed on multiple days and in different years, the measured emission should at least be expected to be roughly the same as the reported annual average emissions on average.

3. Results

The measurement results in this article were aggregated from four different studies of industrial emissions performed in Southeast and East Texas in the period 2006–2012. A map of the region is shown in Figure 6. The first study was a part of the Second Texas Air Quality Study (TexAQS II) [*Parrish et al.*, 2009], and measurements lasted from August to September 2006. This study tried to cover as many refinery and petrochemical industry areas in the Greater Houston area as possible. As a result, the total number of measurements for each area was fairly low. An example of an alkane measurement series from this study is shown in Figure 7. This measurement was performed on 25 September 2006 in Houston Ship Channel, and separate plumes from a large number of facilities can easily be distinguished in the northerly wind. The second study was a part of the Study of Houston Atmospheric Radical Precursors [*Lefer*, 2009], and measurements lasted from April to June 2009. In this study, the measurements were focused on three areas: the HSC, Mont Belvieu, and Texas City. This allowed for a larger number of measurements, spread over more days, to be collected. Figure 8 shows an example of a combined alkane and alkene measurement series from this study. This measurement was performed in Mont Belvieu on 5 June 2009, and three separate plumes are detected. The simultaneous measurements of alkane, ethene, and propene suggest that they are only partly coemitted, and especially propene seems to have a separate source. The third study, lasting from April to May 2011, was a stand-alone field study covering the same areas as in 2009, as well as the Beaumont/Port Arthur area. A single day of measurements was also conducted at a petrochemical complex in Longview. An example of an alkane measurement series from this study is shown in Figure 9. This measurement was performed on 3 May 2011 and covered a number of the largest alkane emission sources in the Beaumont/Port Arthur area but not all of them. The fourth study was performed during May 2012 and was focused entirely on the

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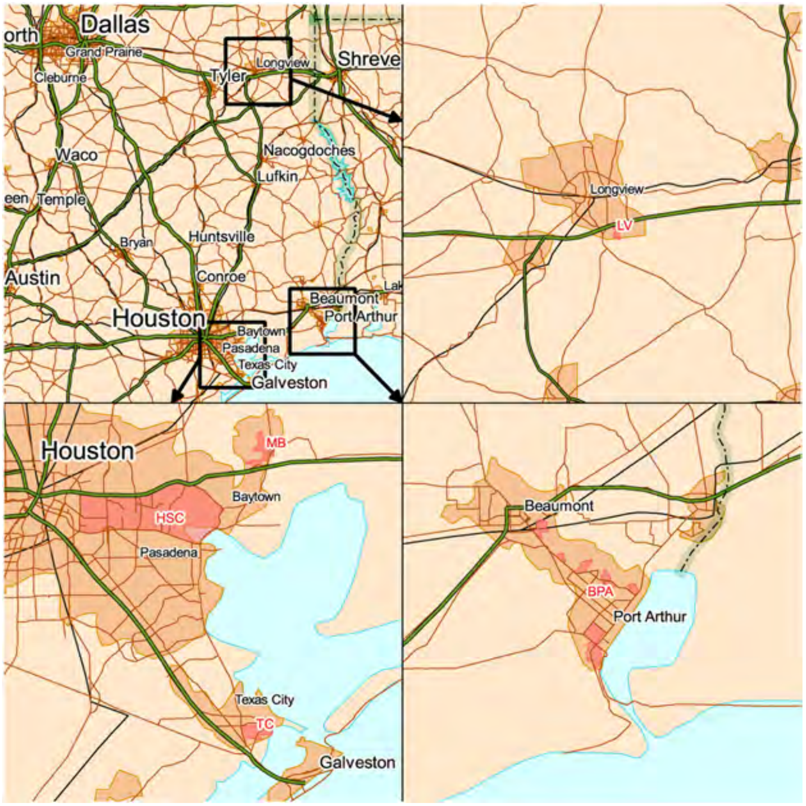

Figure 6. Map of Southeastern and Eastern Texas with zoomed in boxes around the areas studied. The areas are marked in red and denoted by their abbreviated names.

petrochemical complex in Longview. This allowed for a comprehensive set of measurements to be collected, giving a clearer picture of day-to-day variations. Figure 10 shows an example of a combined alkene and NO_2 measurement series from this study. This measurement was performed at the petrochemical complex on 7 May 2012. The measurement series for ethene and propene are closely correlated, but there is a clear spatial

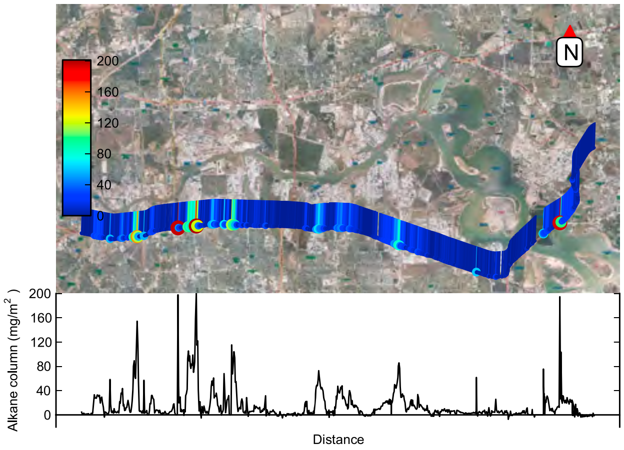

Figure 7. Alkane measurement transect covering all of the Houston Ship Channel (HSC) performed on 25 September 2006. Each measurement is indicated on the map with a circle and a line. The size and color of the circle indicates the magnitude of the alkane column measured, and the line indicates the direction the wind is blowing from. Below the map is a plot of the alkane column as a function of crosswind distance. This transect provided one alkane flux measurement for the HSC area.

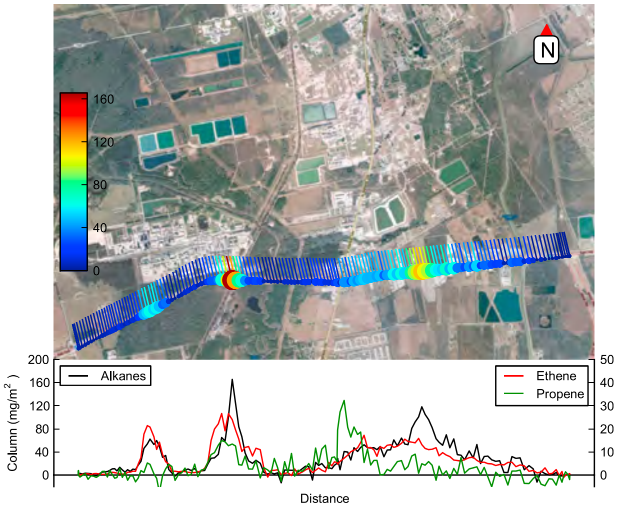

Figure 8. Measurement transect of alkanes, ethene, and propene covering all of Mont Belvieu performed on 5 June 2009. Each measurement is indicated on the map with a circle and a line. The size and color of the circle indicates the magnitude of the alkane column measured, and the line indicates the direction the wind is blowing from. Below the map is a plot of the columns of all species as a function of crosswind distance. This transect provided one flux measurement each for alkanes, ethene, and propene from Mont Belvieu.

separation between them and the NO_2 plume. However, this is most likely primarily caused by the different measurement angles of SOF and mobile DOAS. Ethene and propene are measured with SOF, which measures along the path of the direct sunlight, while NO_2 is measured with mobile DOAS, which measures in the zenith direction. This measurement was made in the morning when the sun was fairly low and in the east, which makes the alkene plume appear further to the west. Detailed results from all four studies are presented in *Mellqvist et al.* [2010b, 2007, 2010a] and *Johansson et al.* [2011, 2012].

The measurement results from all these studies have been aggregated to give an overview and enable comparison over time and between the different areas. These aggregated results are presented in Table 4

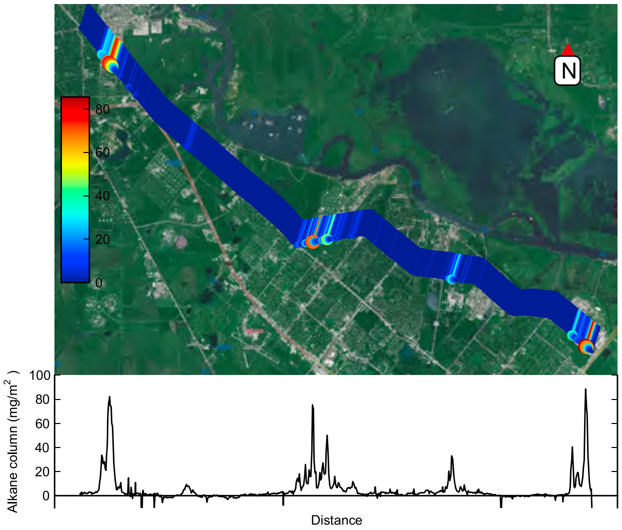

Figure 9. Alkane measurement transect covering a number of industries in the Beaumont/Port Arthur area performed on 3 May 2011. Each measurement is indicated on the map with a circle and a line. The size and color of the circle indicates the magnitude of the alkane column measured, and the line indicates the direction the wind is blowing from. Below the map is a plot of the alkane column as a function of crosswind distance. This transect provided one alkane flux measurement each for five subareas in Beaumont/Port Arthur.

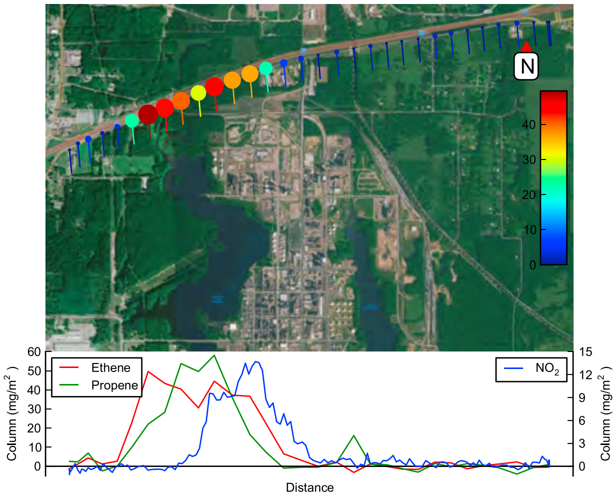

Figure 10. Measurement transect of ethene, propene, and NO_2 covering the petrochemical complex in Longview performed on 7 May 2012. Each measurement is indicated on the map with a circle and a line. The size and color of the circle indicates the magnitude of the ethene column measured, and the line indicates the direction the wind is blowing from. Below the map is a plot of the columns of all species as a function of crosswind distance. This transect provided a flux measurement each for ethene, propene, and NO_2 from Longview.

together with annual average emissions reported to the emission inventories for the corresponding areas. For each area, species and year, the table shows the total number of measurements, mean and standard deviation of the emission flux measured, and the reported annual average emission. In some cases, total emissions for an area was calculated as a sum of emissions from subareas and the number of flux measurements were not the same for all subareas. For these cases, mean emissions from the subareas were summed, standard deviations were root-sum-squared, and the number of total flux measurements is given as a range from the lowest number of measurements on a subarea to the highest. Reported emissions are the sum of the annual routine emissions for all point sources within an area, converted to average hourly emissions.

Many emissions seem to have been quite stable over the years. The mean total alkane emissions from the HSC have been within ±10% of 11,500 kg/h for all three studies. At the same time there are some large differences from year to year. The total propene emissions from the HSC, for example, were approximately 1500 kg/h in 2006 but dropped to roughly 600 kg/h in 2009 and 2011. However, as described in more detail in *Mellqvist et al*. [2010b], the variability in the propene emissions measured from the HSC in 2006 was exceptionally large, indicating temporary upset emissions. Despite some significant variations from year to year and from area to area, there is a clear pattern of measured VOC emissions (alkanes, ethene, and propene) exceeding reported emissions with almost an order of magnitude on average, while no similar pattern exists for SO_2 and NO_2. This pattern is highlighted in Figure 11, where the ratios between measured emissions and reported annual average emissions have been plotted for each year, species, and area. Reported emissions for 2011 were used for the 2012 ratios, since 2012 data were not yet available. Most ratios for SO_2 and NO_2 emissions are gathered fairly close to 1, while the ratios for alkanes, ethene, and propene are mostly within the interval of 5–10. There are of course differences between the areas and the years, but they are generally dwarfed by the difference between the species. The most striking exceptions to the overall pattern are the SO_2 emissions from Texas City. The reported SO_2 emissions from Texas City have steadily declined during the period of these studies, but no such decrease has been observed in the measurements. Instead, the measured mean emissions increased from 2009 to 2011, giving a measured to reported ratio of almost 12 in 2011. However, all SO_2 measurements in Texas City in 2011 were performed during a single day, which makes this comparison very sensitive to short-term variations. The unusually large discrepancy in 2011 SO_2 emissions from Texas City might be attributable to large nonroutine emissions during that single day. A large proportion of reported SO_2 emissions in Texas City are attributed to flares, which might have significant variability. Measurement with Multi-Axis DOAS [*Stutz et al*., 2011] were performed in parallel with the mobile DOAS measurements during the 2009 study and estimated the average SO_2 emissions during the period to be 510 kg/h, approximately halfway between the mobile DOAS result and the reported annual emissions.

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Table 4. Summary of All Total Flux Measurements for Each Area, Species, and Year[a]

Area	Species	2006				2009				2011				2012			
		N	Mean	Std	EI	*N*	Mean	Std	EI	*N*	Mean	Std	EI	*N*	Mean	Std	EI
Houston Ship Channel	Ethene	4	878	152	63	6	614	284	67	4–14	612	168	53	-	-	-	-
	Propene	3	1,511	529	149	4	642	108	70	1–9	563[b]	294	63	-	-	-	-
	Alkanes	3	12,276	3,491	1,208	3	10,522	2,032	814	5	11,569	2,598	894	-	-	-	-
	SO_2	3	2,277	1,056	2,570	10–23	3,364	821	1,784	18–25	2,329	466	1,228	-	-	-	-
	NO_2	9	2,460	885	2,303	-	-	-	-	5–16	1,830	330	1,103	-	-	-	-
Mont Belvieu	Ethene	6	443	139	82	23	444	174	59	6–9	545	284	47	-	-	-	-
	Propene	3	489	231	37	17	303	189	25	1	58[b]	-	25	-	-	-	-
	Alkanes	1	874	-	177	13	1,575	704	221	3	1,319	280	127	-	-	-	-
	NO_2	-	-	-	-	2–35	168	39	174	2	305	29	155	-	-	-	-
Texas City	Ethene	3	83	12	7	11	122	41	4	7–9	177	48	2	-	-	-	-
	Propene	ND	ND	ND	9	3	54	22	7	5	56[b]	9	6	-	-	-	-
	Alkanes	6	3,010	572	447	12	2,422	288	288	7	2,342	805	242	-	-	-	-
	SO_2	-	-	-	-	17–37	834	298	297	25–26	1,285	428	109	-	-	-	-
	NO_2	11	460	150	452	10	283	30	351	15–16	492	71	352	-	-	-	-
Beaumont and Port Arthur	Ethene	-	-	-	-	-	-	-	-	4–7	178	35	18	-	-	-	-
	Propene	-	-	-	-	-	-	-	-	1–5	53[b]	6	18	-	-	-	-
	Alkanes	-	-	-	-	-	-	-	-	1–12	7,413	1,448	407	-	-	-	-
	SO_2	-	-	-	-	-	-	-	-	3–22	1,612	447	2,377	-	-	-	-
	NO_2	-	-	-	-	-	-	-	-	3–18	1,422	268	965	-	-	-	-
Longview	Ethene	-	-	-	-	-	-	-	-	9	452	191	127	67	249	130	-
	Propene	-	-	-	-	-	-	-	-	8	282	59	32	60	211	122	-
	NO_2	-	-	-	-	-	-	-	-	4	176	51	231	92	118	33	-

[a] The table gives the number of measurements (N), the mean and standard deviation of the measured fluxes (Mean and Std), and the annual average emissions reported to the emission inventories (EI). All numbers are in kg/h except N, the number of measurements. A range given for N indicates that the mean emissions were calculated as the sum of the mean emissions from a number of subareas. N is the range of the number of measurements for each subarea. The standard deviation was calculated as the root-sum-square of the standard deviations of the subareas for these cases.

[b] Instrumental problems during parts of the 2011 campaign resulted in fewer propene measurements with larger uncertainty.

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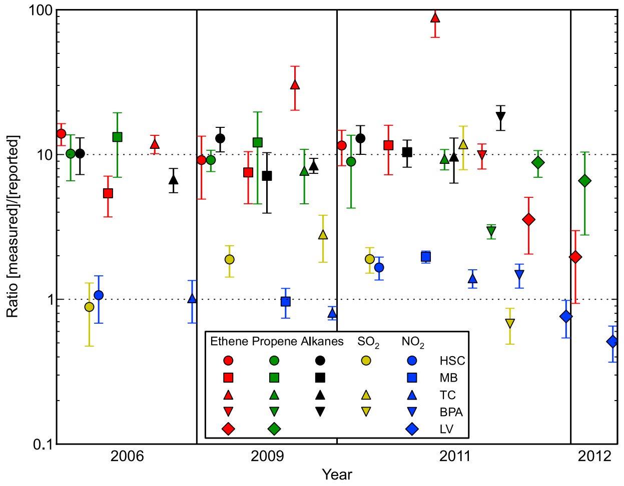

Figure 11. Ratios of emissions measured with SOF and mobile DOAS to annual average emissions reported to State of Texas Air Reporting System (STARS) for each year, species, and area. The markers indicate the ratio of the mean of all flux measurements to the reported emissions, while the error bars indicate ratio of the mean plus/minus one standard deviation to the reported emissions. The error bars only represent the variation in the flux measurements and not the uncertainty in measurements or in reported emissions. The *x* scale only indicates the year of the measurements; the *x* position within a year has no meaning. Reported emissions for 2011 were used for the 2012 ratios since 2012 data were not yet available.

Since the Longview study in 2012 was focused on only a single industrial complex, an unusually large number of measurements were performed. In total, 67 measurements of ethene emissions, 60 of propene emissions, and 92 of NO_2 emissions were performed on 8 different days in a 9 day period. This gives a fairly detailed picture of how much total emissions from an industry varies during a week. The histograms in Figure 12 show the distribution of fluxes for all measurements of these three species. During the measurement period, two episodes with atypical emissions were identified. On the afternoon of May 7, ethene emissions were significantly elevated after having been at more typical levels earlier in the day. Similarly, propene emissions were elevated during May 10. These elevated emissions were suspected to be due to upsets or irregular operation. The measurements from these episodes are shown separately in the histograms in Figure 12. Excluding these two episodes, the variability of the measured fluxes is fairly small for all three species. For ethene the average emission of all SOF transects is 205 ± 57 kg/h, excluding the presumed upset. Similarly, the average propene emission is 172 ± 77 kg/h without presumed upset emissions. No upset episodes were identified for the NO_2 emissions. The average NO_2 emission during the whole study was 118 ± 33 kg/h. The flux distributions for ethene and NO_2, with the identified upset for ethene excluded, are approximately Gaussian in shape with standard deviations of about 30% of the mean. Measurement variability of this magnitude is often intrinsic to local wind field variability not captured by the wind measurements and not necessarily indicative of the true emission variability. The propene flux distribution, on the other hand, is a bit more irregular with larger variability, even after excluding the identified upset episode. This is probably more than can be explained by wind variability alone, indicating that propene emissions were less constant during the period, although still relatively stable. This study suggests that apart from isolated upset episodes, the total emissions from a petrochemical complex like this is fairly stable on the time scale of slightly more than a week. The average emissions for all transects, including the upset episodes, were 249 ± 130 kg/h for ethene and 211 ± 122 kg/h for propene, which is 21% and 22% higher than without the upset episodes. This is only a single site and a fairly limited period, but if it is taken to be representative of typical conditions, it would indicate that nonroutine emissions account for a relatively small part of total annual emissions, even though they can dominate the momentaneous emissions at times. This conclusion is also compatible with the broad patterns of the measurements in other areas presented in this study, even though the lower number of measurements in those areas makes it more difficult to clearly separate routine emissions from upset events. A notable example to this pattern, however, is the 2006 propene measurement in the HSC, which indicated huge variations in emissions over short time periods. This may, however, have been a rare event, since nothing similar has been seen after that.

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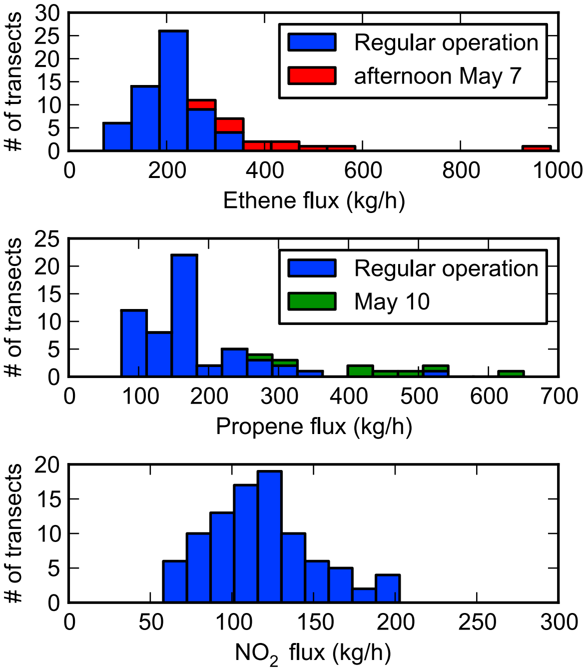

Figure 12. Histograms showing the distribution of all flux measurements of ethene, propene, and NO_2 during 2012. Ethene emissions were significantly elevated during the afternoon on 7 May, and similarly, propene emissions were higher than usual on 10 May. Fluxes measured during these episodes are plotted as separated additive histograms.

4. Discussion

4.1. Measurement Uncertainty

The main uncertainty associated with SOF and mobile DOAS flux measurements generally comes from the uncertainty in the wind field. Uncertainties for the measured wind speeds and wind directions were estimated from comparisons of wind profile averages to normalized ground wind measurements. The estimated uncertainties are given in Table 2. Since the calculated flux is proportional to the wind speed, the uncertainty of the wind speed carries over to the flux proportionally. For the wind direction uncertainty, however, the impact on the flux is not linear and also depends on how orthogonal the measurement transect is to the wind direction. To estimate the flux uncertainty due to wind direction uncertainty, measurement situations were simulated with wind errors drawn from a normal distribution based on the estimated wind direction uncertainties, and the average absolute flux error was calculated from a large number of simulations. This was done for 90° and 75° angles between the transect and wind direction to represent the typical range of measurement scenarios and for the estimated wind direction uncertainties of all four studies. The results are given in Table 5. This uncertainty estimate is somewhat conservative, since large wind direction errors can usually be avoided by estimating the wind direction from geometric constraints, i.e., the approximate locations of the sources and where the plume was detected. For the 2012 study, the comparisons of wind profile averages to normalized ground wind measurements gave unusually large wind direction uncertainty estimates, but the simple measurement geometry with only one large industrial complex enabled the actual wind direction uncertainty to be significantly limited by geometrical constraints. To avoid a needlessly conservative uncertainty estimate in this case, wind errors were restricted to a maximum of ±15° in the simulations for this study.

The cross-section uncertainties are generally well established by the experimentalists who have measured them. The infrared cross sections for the VOCs have an uncertainty of 3–3.5% [*Sharpe et al.*, 2004], while the UV cross sections have uncertainties of 2.8% for SO_2 [*Bogumil et al.*, 2003] and 4% for NO_2 [*Vandaele et al.*, 1998]. Additionally, retrieval errors of 10–20% have been estimated for the different species. This is the combined effect of instrument and retrieval stability on the total columns for a plume transect [*Mellqvist et al.*, 2010b]. For the alkane retrieval this also includes the 6% mass retrieval uncertainty established above. All these uncertainty sources have been combined by root-sum-square to a composite flux measurement

Table 5. Error Budget for the Flux Measurements During the Different Studies[a]

			Alkanes	Ethene	Propene	SO_2	NO_2
Cross-Section Uncertainty			3.5%	3.5%	3.5%	2.8%	4%
Retrieval Error			12%	10%	10%, 20%	10%	10%
Year	Wind Speed	Wind Direction	Composite Flux Measurement Uncertainty				
2006	15–27%	8–12%	21–32%	20–31%	26–36%	20–31%	20–31%
2009	11–29%	7–10%	18–33%	17–32%	24–37%	17–32%	17–33%
2011	16–30%	5–8%	21–33%	20–33%	26–37%	20–33%	20–33%
2012	25–34%	4–12%	28–38%	27–38%	32–41%	27–38%	28–38%

[a] The cross-section uncertainties and estimated retrieval errors depend mainly on the species, while the wind speed and wind direction errors have been estimated separately for each year but apply equally to all species. These four error sources are combined by root-sum-square to a composite flux measurement uncertainty for each species and year. The highest and lowest composite uncertainties in the ranges given were calculated using the lowest and highest uncertainties for both wind speed and direction.

uncertainty range for each species and study. The maximum and minimum for each range were calculated using the maximum and minimum uncertainties of both wind speed and wind direction. These are given in Table 5. In most cases, the composite uncertainty is approximately 20–35%. The high retrieval error estimated for propene (20%) was due to instrumental problems that were primarily present during the 2009 and 2011 studies. These problems primarily affected measurements of small propene columns. Many of the propene measurements actually had a lower retrieval error than this, but 20% was used in the composite errors in Table 5.

4.2. Representativeness of Measurements

In Table 4 and Figure 11, the results of the SOF and mobile DOAS measurements are compared to reported annual average emissions. The relevance of this comparison depends on whether measurements during shorter periods, a few weeks in these cases, can be expected to be representative for the average emissions over a full year. One argument against this is that temporary emissions or upsets, which only last a limited time period, may be overrepresented in the SOF measurements. Examples of this include emissions occurring during tank cleaning operations, ship loading, flaring, and accidental releases. This type of events occurs rather frequently and might typically last for 1–24 h. Hence, it is likely that some of the SOF measurements include emissions from such events. This type of event is likely to be the explanation for upset emission identified in the Longview measurements in 2012, as illustrated in Figure 12. This example showed that it is possible to discriminate between such upsets and average emissions if a large number of measurements are performed but that the influence of the upset emissions was relatively small on the estimated average emissions.

The industrial areas studied in this paper consist of a large number of independent sites, especially the HSC, and short-term upsets should occur in at least some of the sites during each transect. On the other hand, it is unlikely that they occur in a large fraction of them at the same time, and hence the relative elevation of the total emissions from all of them will be much smaller than for the sites where the upset occurs. The fact that the emissions, for instance, of alkanes from the HSC, show relatively small variations from transect to transect and over several years, as shown in Table 4, indicates that the SOF measurements are representative for long time periods and that the impact of longer term upset emissions is averaged out. On the other hand, this was not the case for the 2006 propene measurements in the HSC, where the emission showed large temporal variability that was attributed to flaring activity in petrochemical plants [*Mellqvist et al.*, 2010b]. These emissions decreased in the later years and have since been more stable. This shows that upsets can have a significant impact on total emissions in some cases and that measurements over longer periods or repeated studies over several years might be needed to make such distinctions.

Another potential reason why the measurements presented in this paper might not be representative for the annual average emissions is that there might be systematic differences in meteorological conditions between the measurement periods and the whole years that could have a large effect on the emission rates of some facilities. All four studies were conducted during the warmer half of the year, during daytime and in clear conditions. All these factors would be expected to contribute to higher than average ambient temperature and solar insolation. Wind speeds might also have been unrepresentative during the studies, which might have caused higher than average emissions. The emission sources most sensitive to meteorological conditions are probably storage tanks for crude oil and for refined products. Ambient temperature and solar

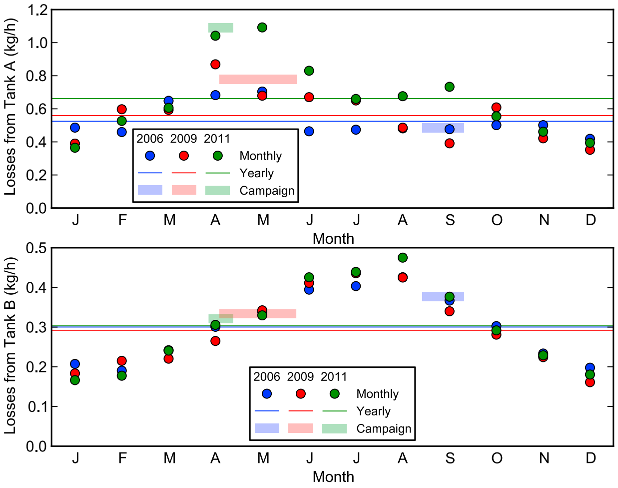

Figure 13. Emission rates from Tank A (external floating roof tank with crude oil) and Tank B (internal floating roof tank with gasoline) calculated using emission factor formulas and meteorological data averaged over different time periods. Circles indicate emissions calculated using monthly averages, and bars indicate emissions calculated using averages over the campaign periods, as well as the extent of these campaigns. Yearly averages of the monthly emissions were calculated and indicated with horizontal lines.

insolation affect the liquid surface temperature of the product in tanks which in turn affect the vapor pressure and thereby evaporation. Wind speed primarily affects losses in external floating roof tanks. Ethene, propene, and other products that are gaseous under ambient conditions are stored in pressurized tanks, which should not be expected to have losses significantly affected by meteorology. Temperatures and pressures of feedstocks and products in process steps are typically monitored and regulated and thereby not significantly affected by ambient conditions. Effects of ambient temperatures, solar radiation, and wind speed are included in the formulas for estimation of storage tank losses in *AP-42*, *Compilation of Air Pollutant Emission Factors* [*USEPA*, 2013], EPA's primary compilation of emission factor information, which most emission estimates reported to the emission inventories are based on. To estimate the effects of the differences in meteorological conditions, the campaign periods, and the entire years, formulas from *AP-42* were used to estimate the emissions from an external floating roof tank storing crude oil (Tank A) and from an internal floating roof tank storing gasoline (Tank B). These were chosen to represent the most typical tanks with significantly meteorology-affected emissions. Emissions from these tanks were estimated on a monthly basis using monthly averages of the hourly meteorology data. The meteorological data consisted of measurements of ambient temperature, solar radiation and wind speed from the TCEQ monitoring station C1015 [*TCEQ*, 2013]. Annual average emissions were calculated as the average of monthly emissions for all months in each year. Average emissions during each campaign were calculated using averages of the meteorological data for the duration of the campaign. Figure 13 shows the effects of using meteorological data from these different periods in 2006, 2009, and 2011 on calculated emissions from Tank A and Tank B. Meteorological data were missing from C1015 for October and November 2011, so average values for the same months in 2006 and 2009 were used instead. For Tank B the intrayear variations in emissions are quite similar from year to year, while for Tank A there are larger differences between the years, and especially 2011 stands out. The reason for this is that, according to the AP-42 emission factors, emissions from external floating roof tanks are sensitive to wind speed, while emissions from internal floating roof tanks are unaffected by wind. During the summer half of 2011, winds speeds were significantly higher than during the same periods in 2006 and 2009, especially in April and May. For this reason, the calculated emissions from Tank A for the campaign period were approximately 65% higher than the annual average, while for 2009 it was only 39% higher and for 2006 it was 8% lower. For Tank B the corresponding differences were smaller: 26%, 14%, and 6% higher during the campaign periods in 2006, 2009, and 2011, respectively.

The differences in calculated emissions presented in Figure 13 are only the seasonal variations. There are of course also day-to-day variations and differences between daytime and nighttime. Assessing these variations

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using the *AP-42* formulas requires applying the formulas on time scales of single days or even hours or at least to averages of meteorological from nonconsecutive time periods on such scales. This is not how the formulas in *AP-42* are typically applied and not what they were designed for. Instead, emissions are typically calculated using monthly or even annual averages. Since the campaign periods were of similar time scales as months, the campaign averages in Figure 13 are probably comparable to monthly averages. To estimate the variations on shorter time scales, the *AP-42* formulas have been applied to averages of meteorological data from daytime hours (9:00–18:00 CDT) on the days in each campaign when SOF measurements were made. Applying the formulas in this way is likely to give overestimated differences compared to averages for the whole campaign, primarily because the surface temperature in a tank might not follow changes in ambient temperature and solar radiation on the scale of hours or days in the same way as it does on the time scale of months or years. There might be memory effects from the ambient temperatures and solar radiation in previous hours or days, which are likely to be averaged out over a month. The differences given by applying the formulas like this can, however, be thought of as upper estimates of actual differences. Table 6 shows the differences between the daytime averages of the SOF measurement days and whole campaign averages for ambient temperature, solar radiation, and wind speed, and the differences to the calculated emissions from Tank A and Tank B from using averages of measurement days instead of campaign averages. These effects are shown for each meteorological parameter separately as well as the combined effect. Additionally, the last two columns show the differences between campaign averages and annual averages (as shown in Figure 13), as well as the total effect of both seasonal and shorter term variations. The total effect typically adds up to 35–45% for both tanks, with the exception of Tank A in 2011. This exceptionally large effect was due to the strong winds during the campaign. The winds were so strong that the campaign average was outside the applicable range of the *AP-42* formulas, 0–15 mph, and hence there was no extra effect due to the short-term variations.

The calculated total effects should be considered as upper estimates, since they assume that there are no memory effects from the cooler nighttime conditions suppressing the daytime emissions. Assuming that storage tanks represent roughly two thirds of the emissions from typical refineries [*Kihlman*, 2005] and that emissions from process steps are not significantly affected by meteorological conditions, the total meteorological effects estimated above indicate that the alkane emissions measured from refineries in this paper may be 20–30% higher than the annual average.

Table 6. Average Temperatures, Solar Radiations, and Wind Speeds During the Whole Campaigns Compared to Daytime (9–18) on the SOF-Measurement Days and the Estimated Effects of These Differences in Meteorology on Tank Emissions of Alkanes From an External Floating Roof Tank Storing Crude Oil (A) and From an Internal Floating Roof Tank Storing Gasoline (B)[a]

Year	Tank	Mean Temperature Campaign (°C)	Mean Temperature Measurement Days (°C)	Effect of Temperature Difference on Emissions	Mean Solar Radiation Campaign (W/m^2)	Mean Solar Radiation Measurement Days (W/m^2)	Effect of Solar Radiation Difference on Emissions	Mean Wind Speed Campaign (m/s)	Mean Wind Speed Measurement Days (m/s)	Effect of Wind Speed Difference on Emissions	Combined Effect on Emissions	Difference Between Campaign and Year	Total Difference Between Measurement Days and Year
2006	A	27.3	26.5	−2.2%	208	677	8.3%	3.8	4.8	40.3%	49.0%	−7.9%	37.2%
	B			−4.2%			17.0%			0.0%	11.5%	25.5%	39.9%
2009	A	24.9	26.3	4.6%	248	712	8.9%	5.4	4.9	−14.2%	−2.5%	39.2%	35.7%
	B			7.8%			15.5%			0.0%	25.4%	14.3%	43.3%
2011	A	24.2	26.1	6.7%	232	649	8.2%	7	7.5	0.0%	15.6%	64.5%	90.2%
	B			10.8%			13.5%			0.0%	26.7%	6.0%	34.3%

[a] Combined with the effect of whole campaign averages versus annual averages (as shown in Figure 13), the total elevation of alkane emissions due to the meteorological conditions during the measurements is estimated.

Neither meteorological effects nor elevated emissions due to upset events seem to be even close in magnitude to the discrepancies between measurements and emission inventories, and hence these discrepancies most likely represent an underestimation of the continuous routine emissions by the inventories.

5. Conclusions

Total emissions of alkanes, ethene, propene, SO_2, and NO_2 from a number of large industrial areas dominated by refineries and petrochemical industries were measured during four measurement campaigns in the period 2006–2012. The measurement error analysis indicates uncertainties typical within 20–35%. In comparison to annual average emissions reported to emission inventories, the VOCs (alkanes, ethene, and propene) stood out with measured emissions typically exceeding reported emissions by factor of 5–15, while measured SO_2 and NO_2 emissions were much closer to reported emissions. A tank model analysis of the effect of wind speed, solar radiation, and ambient temperature on tank emissions shows that the alkane emissions measured from tanks in this study may have been up to 35–45% higher than the annual average, and in 2011 that effect may have been even larger for crude oil tanks due to exceptionally strong winds. These meteorological effects are not nearly large enough to explain the discrepancies between SOF measurements and emission inventories, and they are also not applicable to process emissions and alkene emissions from petrochemical industries. A detailed study of alkene emissions from a petrochemical complex in Longview indicated that upset emissions can cause an increase in total emissions on the order of 20% compared to the continuous routine emissions. Upset emissions are of course highly irregular by nature, but the relatively limited variation in the other VOC emission measurements presented confirms the notion that total emissions are typically dominated by routine emissions rather than by upset emissions.

Since neither upset emissions nor meteorological effects can account for the large emission discrepancies, the conclusion from these results is that current emission inventories, based on emission factor calculations, systematically fail to quantify continuous industrial VOC emissions and that reliable estimates of these emissions can currently only be obtained from measurements.

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The American Lung Association assumes sole responsibility for the content of the American Lung Association “State of the Air® 2017.”

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Fighting for Air

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The State of the Air 2017

The "State of the Air 2017" found continued improvement in air quality in 2013-2015 in ozone and year-round particle pollution, but an unrelenting increase in dangerous spikes in particle pollution. These trends demonstrate the continued need to support and enforce the Clean Air Act to protect the nation from unhealthy air.

The "State of the Air 2017" report shows that cleaning up pollution continues successfully in much of the nation. In the 25 cities with the worst ozone and year-round particle pollution, the majority saw improvements from last year. Many again reached their lowest levels ever of these widespread air pollutants.

Yet, even as most cities experienced strong improvement, too many cities suffered worse episodes of unhealthy air. While most of the nation has much cleaner air quality than even a decade ago, many cities reported their highest number of unhealthy days since the report began, including some that experienced extreme weather events.

> "State of the Air 2017" shows that more than four in 10 people had unhealthy air quality in their communities.

The "State of the Air 2017" report shows that, even with continued improvement, too many people in the United States live where the air is unhealthy for them to breathe. Despite that continued need and the nation's progress, some people seek to weaken the Clean Air Act, the public health law that has driven the cuts in pollution since 1970, and to undermine the ability of the nation to fight for healthy air.

The "State of the Air 2017" report looks at levels of ozone and particle pollution found in official monitoring sites across the United States in 2013, 2014 and 2015. The report uses the most current quality-assured nationwide data available for these analyses.

The report examines particle pollution ($PM_{2.5}$) in two different ways: averaged year-round (annual average) and over short-term levels (24-hour). For both ozone and short-term particle pollution, the analysis uses a weighted average number of days that allows recognition of places with higher levels of pollution. For the year-round particle pollution rankings, the report uses averages calculated and reported by the U.S. Environmental Protection Agency (EPA). For comparison, the "State of the Air 2016" report covered data from 2012, 2013 and 2014.[1]

Overall Trends

The "State of the Air 2017" found continued improvement in air quality in 2013-2015 in ozone and year-round particle pollution, but an unrelenting increase in dangerous spikes in particle pollution. The number of people exposed to unhealthy levels of air pollution dropped to more than 125 million people, from 166 million in the years covered in the 2016 report (2012-2014).

> Four in 10 people live where the air is unhealthy.

Overall, **the best progress came in the continued reduction of ozone and year-round particle pollution,** thanks to cleaner power plants and increased use of cleaner vehicles and engines. Continued progress to cleaner air remains crucial to reduce the risk of premature death, asthma attacks and lung cancer. However, a changing climate is making it harder to protect human health.

Nearly four in 10 people (38.9 percent) in the United States live in counties that have unhealthful levels of either ozone or particle pollution. More than 125 million Americans live in 204 counties where they are exposed to unhealthful levels of air pollution in the form of either ozone or short-term or year-round levels of particles.

> Still, this represents a major improvement: One-quarter fewer people now live where the air quality hit unhealthy levels.

Still, this represents a major improvement: **One-quarter fewer people now live where the air quality hit unhealthy levels in 2013-2015** than in the 2016 report. In last year's report, covering 2012-2014, more than 166 million Americans lived in counties with unhealthful levels of air pollution.

More than 18 million people (5.6 percent) live in 12 counties with unhealthful levels of all three: ozone and short-term and year-round particle pollution. This is nearly 1.9 million fewer people than in the 2016 report when approximately 6.3 percent were exposed. However, we continue to lack data on particle pollution in all or parts of two states.

> Los Angeles improved over last year and again had its best ozone report in the history of the "State of the Air."

Los Angeles remains the city with the worst ozone pollution as it has for nearly the entire history of the report. **Bakersfield, CA, maintains its rank as the city with the worst short-term particle pollution,** while **Visalia-Porterfield-Hanford, CA,** moved for the first time to rank as the **most-polluted city for year-round particle pollution.**

The "State of the Air 2017" report shows the sustained success of the Clean Air Act, continuing to clean up pollution in much of the nation, as it nearly completes its fifth decade of service. Many cities reported fewer days of high ozone and lower levels of year-round particle pollution. Several cities again reported their cleanest years ever during this period, while others had their worst periods of air pollution.

Thanks to the provisions in the Clean Air Act, the United States has continued to **reduce ozone and particle pollution** as well as other pollutants for decades. Figure 1 from EPA shows that since 1970, the air has gotten cleaner while the population, the economy, energy use and miles driven increased greatly. As the economy continues to grow, overall air emissions that create the six most-widespread pollutants continue to drop.

Comparison of Growth Areas and Emissions, 1970–2015

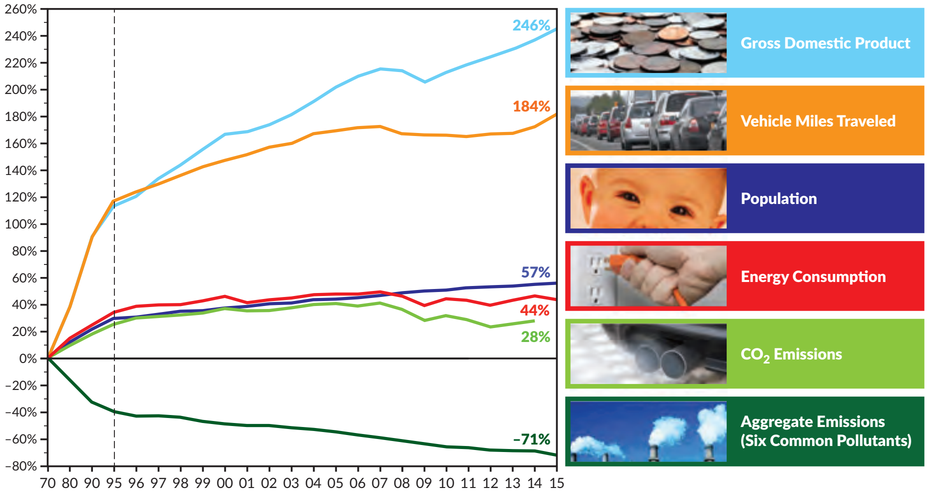

Figure 1: Air pollution emissions continue to drop steadily since 1970 thanks to the Clean Air Act. As the economy continues to grow, emissions that cause ozone and particle pollution continue to drop. Source: U.S. EPA, Air Trends: Air Quality National Summary, 2017.

The Clean Air Act must remain intact and enforced to enable the nation to continue to protect all Americans from the dangers of air pollution. This law has driven improvements in air quality for 47 years, as shown in Figure 1. Since first issued in 2000, the "State of the Air" reports have also documented these improvements, as shown in trend charts for counties and cities available at www.stateoftheair.org. The nation must ensure that the Clean Air Act's tools remain in place, funded and followed.

The "State of the Air 2017" report adds to the evidence that a changing climate in making it harder to protect human health. While most of the nation has much cleaner air quality than even a decade ago, a few cities reported their worst number of unhealthy days since the report began, including many that experienced wildfire smoke.

As climate change continues, cleaning up these pollutants will become ever more challenging. Climate change poses many threats to human health, including worsened air quality and extreme weather events. The nation must continue to reduce emissions that worsen climate.

Ozone Pollution

Twenty of the 25 cities with the worst ozone pollution reduced the number of high-ozone days they experienced each year, improving over the previous report. Twelve experienced their best ozone seasons ever during 2013-2015, reaching their lowest weighted average number of days of unhealthy levels each year.

Los Angeles remains at the top of this list as it has for all but one of the 18 reports. Los Angeles also continues its success at cleaning up ozone, dropping its average number of unhealthy days to its lowest level ever.

Also **experiencing their fewest high-ozone days on average were 10 other cities** among the 25 most polluted by ozone. They include Bakersfield, CA; Visalia-Porterville-Hanford, CA; Modesto-Merced, CA; Sacramento, CA; Las Vegas; Dallas-Fort Worth; El Centro, CA; San Jose-San Francisco; Philadelphia; and Chico, CA.

Nine others improved, though not reaching their lowest level: Fresno-Madera, CA; Phoenix; Denver-Aurora, CO; El Centro, CA; Fort Collins, CO; El Paso-Las Cruces, TX-NM; San Antonio; Hartford, CT; Sheboygan, WI. One city—Redding-Red Bluff, CA—had the same number of unhealthy ozone days on average in this year's report.

Four cities suffered more high-ozone days on average than in last year's report: San Diego; Houston; Salt Lake City; and Baton Rouge, LA.

These comparisons are all based on the Air Quality Index adopted with the 2015 ozone standard. Although EPA has yet to designate any places for cleanup based on that standard, it remains the current official national ambient air quality standard.

Regional differences. Cities in the West and Southwest continue to dominate the most ozone-polluted list. California retains its historic challenge with seven of the 10 most polluted metropolitan areas in that state and 11 of the worst 25. California's weather and geography complicate the strong effort the state continues to make to reduce emissions. The Southwest continues to fill most of the remaining slots, with nine of the 25 most ozone-polluted cities. Texas has four cities in the 25 most-polluted list: Houston, Dallas-Fort Worth, El Paso and San Antonio. Colorado has two: Denver and Fort Collins. Arizona, Nevada and Utah each have one. The Northeast also has three metro areas on the list, two of which cover parts of multiple states: New York City, Philadelphia, and Hanford, CT. The Midwest has only Sheboygan, WI. in the 25 most-polluted list. The only southern city to remain on the list is Baton Rouge, LA.

Those changes reflect changes seen in the past two reports, where increased oil and gas extraction especially in the Southwest and cleanup of power plants in the eastern U.S. have shifted the cities that experienced the greatest number of unhealthy air days.

Year-round Particles

Twelve cities improved to their lowest levels of year-round particle pollution.

Fifteen of the 25 cities with the highest year-round particle pollution reduced their levels, including 12 that reached or matched their lowest levels ever in 2013-2015. The 10 most polluted remain the only metropolitan areas in the nation that fail to meet the official national limits on annual fine particle pollution.

Eight of the 25 cities suffered higher annual particle pollution levels, including Visalia-Porterfield-Hanford, CA, the city that ranked as the most polluted for year-round levels. In addition to Visalia, three other California cities—Bakersfield; San Jose-San Francisco; and San Luis Obispo—and two other cities in the western states—Medford-Grants Pass, OR, and Fairbanks, AK—had worse year-round levels. The two remaining cities with higher year-round average levels were in the east: Johnstown-Somerset, PA and New York City metro area. San Luis Obispo reached its worst level ever.

Two cities in the list of the 25 most-polluted maintained the same level as in the 2016 report: Cleveland and Houston.

Regional differences. Much of the eastern and middle parts of the country have improved significantly since the report first started to track these fine particles. Much of that improvement came from reducing emissions from coal-fired power plants, as well as benefiting from nationwide cleanup of diesel engines. However, the western states' burden of so much wildfire smoke and high inversions seems to have moved from just being a short-term problem to adding to the burden year-round. Cities in California's San Joaquin valley were hit hard, as were other locations where particle pollution is usually limited to short spikes, including Fairbanks, AK, and Medford-Grants Pass, OR.

Data remain missing in all of Illinois, most of Tennessee and parts of Maine. That means that millions of people, including in large cities Chicago, Memphis and St. Louis (which is missing suburban counties in Illinois), cannot know how much particulate matter they are breathing.

Short-Term Particle Pollution

Bakersfield, CA retains its ranking as the most polluted city for spikes in particle pollution in this report, as it had in the 2016 report and in four other reports since 2010. Unfortunately, Bakersfield suffered more unhealthy days on average in this year's report.

Eight cities suffered their highest number of spikes in particle pollution since the reporting began.

Fifteen of the 25 most-polluted cities had more days with higher episodes of particle pollution, including eight that suffered their most days since the report started and one that maintained its worst report ever.

Cities recording their worst short-term particle episodes in 2013-2015 concentrated in the western states: Visalia-Porterfield-Hanford, CA; Fairbanks, AK; San Jose-San Francisco; Reno, NV; El Centro, CA; Lancaster, PN; Anchorage, AK; and Bend-Redmond-Prineville, OR, marking that city's first time on this list.

Seven other western cities recorded more unhealthy days than in the previous report: Bakersfield, CA; Salt Lake City, UT; Logan, UT-ID; Los Angeles; Sacramento, CA; Seattle-Tacoma, WA; and Medford-Grants Pass, OR.

Fortunately, **eight cities improved with fewer days of spikes in particle levels** in 2013-2015 than in 2012-2014. Six of these are western cities: Fresno-Madera, CA; Modesto-Merced, CA; Missoula, MT; Yakima, WA; Eugene, OR; and Phoenix, AZ. Two cities in Pennsylvania also improved: Harrisburg-York-Lebanon; and notably, Pittsburgh. Pittsburgh, which had been ranked the most polluted city in the same category in the 2008 report, experienced its fewest unhealthy days ever in 2013-2015.

Philadelphia and South Bend, IN recorded the same number of days in this year's report as in last year's report. However, as noted above, that kept South Bend stuck at its worst average number of unhealthy particle pollution days.

Regional differences. Locations with many days of spikes shows the burden of **concentrated smoke from wildfires, brushfires and wood-burning devices**. For example, Reno, NV, suffered wildfires, and Logan, UT-ID; Eugene, OR, and Fairbanks and Anchorage, AK, rely heavily on wood burning devices for heat. Wildfires have increased, in part, from drought and heat enhanced by climate change. Inversions trap particles in place behind mountains and ridgelines. For example, inversions in the San Joaquin Valley in California and in the Wasatch Ridge in Utah contributed to high pollution days in both states.

Cleanest Cities

Six cities ranked on all three cleanest cities lists in 2013-2015. These cities had zero high ozone or high particle pollution days, and were among the 25 cities with the lowest year-round particle levels. Five have repeated their ranking on this list, but Wilmington, NC, joins this list for the first time. Listed alphabetically below, these six cities are:

Burlington-South Burlington, VT
Cape Coral-Fort Myers-Naples, FL
Elmira-Corning, NY
Honolulu, HI
Palm Bay-Melbourne-Titusville, FL
Wilmington, NC

Eleven other cities ranked among the cleanest cities for both year-round and short-term levels of particle pollution. That means they had no days in the unhealthy level for short-term particle pollution and were on the list of the cleanest cities for year-round particle pollution. They are:

Bangor, ME
Casper, WY
Colorado Springs, CO
Farmington, NM
Homosassa Springs, FL
Lakeland Winter Haven, FL
North Port Sarasota, FL
Orlando-Deltona-Daytona Beach, FL
Pueblo-Canon City, CO
Sierra Vista-Douglas, AZ
Syracuse-Auburn, NY

Twenty-three other cities ranked among the cleanest for ozone and short-term particle pollution. That means they had no days in the unhealthy level for ozone or short-term particle pollution. They are:

Bellingham, WA
Brunswick, GA
Charlottesville, VA
Columbia-Orangeburg-Newberry, SC
Des Moines-Ames-West Des Moines, IA
Dothan-Enterprise-Ozark, AL
Eau Claire-Menomonie, WI
Fayetteville-Springdale-Rogers, AK-MO
Florence, SC
Florence-Muscle Shoals, AL
Gadsden, AL
Gainesville-Lake City, FL
Greenville-Washington, NC
Harrisonburg-Staunton-Waynesboro, VA
Jackson-Vicksburg-Brookhaven, MS
La Crosse-Onalaska, WI-MN
McAllen-Edinburg, TX
Monroe-Ruston-Bastrop, LA
Rome-Summerville, GA
Savannah-Hinesville-Statesboro, GA
Springfield-Branson, MO
Tuscaloosa, AL
Waterloo-Cedar Falls, IA

Two cities ranked on both lists for ozone and year-round particle pollution levels. Fargo-Wahpeton, ND-MN and Salinas, CA had no days in the unhealthy level for ozone pollution and were on the list of the cleanest cities for year-round particle pollution.

People at Risk

Looking at the nation as a whole, the **"State of the Air 2017" shows that, even with ongoing improvement, too many people in the United States live where the air is unhealthy for them to breathe.**

Nearly four in 10 people (38.9 percent) in the United States live in counties that have unhealthful levels of either ozone or particle pollution. More than 125 million Americans live in 204 counties where they breathe unhealthful levels of air pollution in the form of either ozone or short-term or year-round levels of particles.

This represents a major improvement: One-quarter fewer people now live where the air quality hit unhealthy levels in 2013-2015 than in the 2016 report. In last year's report, covering 2012-2014, more than 166 million Americans lived in counties with unhealthful levels of air pollution.

This improvement reflects continued progress in reducing harmful air pollution under the Clean Air Act. Progress would have been greater if climate change had not helped to create conditions that can worsen air quality.

More than one-third (36 percent) of the people in the United States live in areas with unhealthy levels of ozone pollution, but that is far fewer in 2013-2015 than in the previous report. Approximately 116.5 million people live in 161 counties that earned an F for ozone this year's report, a significant drop from the approximately 162.9 million who lived in counties earning an F in 2012-2014.

Nearly 19.9 million people (6.2 percent) suffered from unhealthy year-round levels of particle pollution in 2013-2015. These people lived in 18 counties where the annual average concentration of particle pollution was too high. Although still too high, fewer people face those dangerous year-round concentrations during this period than in last year's report. That report covered 2012-2014 when approximately 22.8 million people lived where monitors recorded unhealthy levels of year-round particle pollution.

More than 13 percent of people in the United States—more than 43 million—live in an area with too many days with unhealthful levels of particle pollution. Slightly fewer people lived where those episodes of unhealthy spikes in particle pollution in 2013-2015, despite many cities reaching their worst number of spikes since the report began. The total population exposed to unhealthy air dropped slightly to 43.03 million, down from 44.97 million in the 2016 report. Some counties with large populations had fewer high days, so they no longer received an F, while smaller population counties had more high pollution days. Those shifts resulted in slight changes to the population totals.

More than 18 million people (5.6 percent) live in 12 counties with unhealthful levels of all three: ozone and short-term and year-round particle pollution. This is nearly 1.9 million fewer people than in the 2016 report when approximately 6.3 percent were exposed. However, data on particle pollution remains missing in all or parts of three states.

More than 18 million people in the U.S. live in counties where the outdoor air failed all three tests.

With the risks from airborne pollution so great, the Lung Association seeks to inform people who may be in danger. Many people are at greater risk because of their age or because they have asthma or other chronic lung disease, cardiovascular disease or diabetes. The following list identifies the numbers of people in each at-risk group. Because of the missing data on particle pollution in Illinois, Tennessee and Maine, the numbers of people living in counties that fail all three tests may be actually higher.

Older and Younger—Nearly 16.7 million adults age 65 and over and more than 29.5 million children under 18 years old live in counties that received an F for at least one pollutant. More than 2.3 million seniors and more than 4.3 million children live in counties failing all three tests.

People with Asthma—Nearly 2.5 million children and nearly 8.3 million adults with asthma live in counties of the United States that received an F for at least one pollutant. Nearly 322,000 children and close to 1.1 million adults with asthma live in counties failing all three tests.

Chronic Obstructive Pulmonary Disease (COPD)—More than 5.1 million people with COPD live in counties that received an F for at least one pollutant. More than 575,000 people with COPD live in counties failing all three tests.

Lung Cancer—More than 68,000 people with lung cancer live in counties that received an F for at least one pollutant. More than 8,000 people with lung cancer live in counties failing all three tests.

Cardiovascular Disease—More than 7.1 million people with cardiovascular diseases live in counties that received an F for at least one pollutant; more than 88,000 people live in counties failing all three tests.

Diabetes—Nearly 3.3 million people with diabetes live in counties that received an F for either short-term or year-round particle pollution; more than 1.3 million live in counties failing both tests. Having diabetes increases the risk of harm from particle pollution.

Poverty—More than 17.7 million people with incomes meeting the federal poverty definition live in counties that received an F for at least one pollutant. Nearly 3.2 million people in poverty live in counties failing all three tests. Evidence shows that people who have low incomes may face higher risk from air pollution.

What Needs to Be Done

Our nation has made significant strides in cleaning up our air, as the progress in the 18 years of this report has shown. Stopping or retreating cannot be an option. Our nation's historic, legal commitment to protect the health of millions of Americans requires more work to reduce the burden of air pollution. Cleaning up air pollution requires a strong and coordinated effort on the part of our federal and state leaders. The President, the EPA administrator, members of Congress, governors and state leaders all have a key role to play. These leaders must support steps to improve the air we breathe so that it does not cause or worsen lung disease. The American Lung Association urges our nation's leaders to stand up for public health and take these important steps to improve the air we all breathe.

Protect the Clean Air Act

Our nation's continued air quality improvement shown in the "State of the Air 2017" report is possible only because of the Clean Air Act, a strong public health law put in place by an overwhelming bipartisan majority in Congress more than 45 years ago. Congress wrote the Clean Air Act to set up science-based, technology-fostering steps to protect public health by reducing pollution. Under the Clean Air Act, Congress directed that the EPA and each state take steps to clean up the air. As the "State of the Air 2017" report documents, those steps have reduced ozone and particle pollution in much of the nation.

Unfortunately, some in Congress seek changes to the Clean Air Act that would dismantle key provisions of the law and threaten progress made over nearly five decades. To protect the lives and health of millions of Americans, Congress must protect the Clean Air Act—making certain it remains strong, fully implemented and enforced.

> Congress must make certain that the Clean Air Act remains strong, fully implemented and enforced.

Fight Climate Change by Reducing Carbon Pollution from Power Plants

Power plants comprise the largest stationary source of carbon pollution in the United States. The electric sector contributed 30 percent of all energy-related carbon dioxide (CO_2) emissions in 2014.[2] Scientists tell us that carbon pollution contributes to a warming climate, enhancing conditions for ozone formation and making it harder to reduce this lethal pollutant. Climate change also leads to particle pollution from increased droughts and wildfires. Taking steps to reduce carbon pollution from electricity generation will also reduce ozone and particle pollution from these plants at the same time. EPA's analysis shows that these co-benefits can prevent up to 3,600 premature deaths and up to 90,000 asthma attacks in children in 2030. The American Lung Association calls on governors to direct their states to develop strong plans to reduce carbon pollution from power plants and protect public health.

In 2015, EPA adopted the Clean Power Plan, a flexible, practical tool kit for the states to reduce carbon pollution from power plants approximately 32 percent (below 2005 levels) by 2030. States can choose a variety of ways to cut carbon pollution with the Clean Power Plan. They can choose to require cleaner fuels for existing utilities, improve energy efficiency, produce more clean energy and partner with other states to jointly reduce carbon pollution. In February 2015, the Supreme Court issued a stay on the plan, putting EPA's enforcement of the plan on a temporary hold while the courts hear the case.

Even before the lower court released its decision on the Clean Power Plan, President Trump issued an Executive Order directing EPA Administrator Scott Pruitt to roll back the plan. However, the Lung Association and others will continue to fight to secure reductions in carbon dioxide emissions from power plants and other sources.

Retain the Clean Vehicle Emissions Standards.

Transportation produces more than one quarter of the nation's greenhouse gases that worsen climate change.[3] In 2012, EPA and the National Highway Traffic Safety Administration announced new standards for reducing greenhouse gas emissions from cars, SUVs and light-duty trucks in model years 2017-2025. The emissions standards would reduce 2 billion metric tons of carbon dioxide emissions over the lifetime of the vehicles and would improve fuel efficiency. EPA committed to doing an interim review after the initial phase was in place to see if the longer-term standards for 2012-2025 should still be in place. In January 2017, EPA announced that it had completed its mid-term review and that these emissions standards were appropriate and achievable by the automobile industry for model years 2022-2025. However, in March 2017, EPA Administrator Scott Pruitt and Transportation Secretary Elaine Chao announced the reconsideration of the final determination and reopened EPA's review.

The Lung Association opposed the decision to reopen the review, as EPA had taken an extensive, in-depth examination with public comments before reaching their conclusion. Based on the evidence EPA found before, the Lung Association expects EPA to conclude, again, that the targets should remain in place.

Reduce Emissions from Existing and New Oil and Gas Operations

Oil and gas production wells, processing plants, transmission pipelines and storage units have long emitted harmful gases including methane, volatile organic compounds and other pollutants. As noted earlier, this report found high levels of unhealthy ozone in places where oil and gas production has expanded in the last few years. In May 2016, EPA adopted health-protective standards to reduce harmful emissions of these gases from new and modified sources within the oil and natural gas industry.

However, that action did not affect emissions from the existing oil and gas infrastructure. In November 2016, EPA requested essential information from the oil and gas industry about the location and size of their facilities. Gathering this information is a required step for EPA to eventually limit harmful emissions from these existing sources. The industry objected and, unfortunately, in March 2017, the EPA withdrew its request to the updated information on their facilities, with the explanation that the administrator needed to review the request. The Lung Association calls on the administrator to move forward and set strong pollution control standards for existing oil and gas operations.

These standards would not only help to mitigate climate change and its associated health risks by curtailing emissions of methane—an especially potent greenhouse gas—but would also limit emissions of major precursors to ozone, as well as other toxic and carcinogenic air pollutants, benefiting public health in communities across the country.

Improve the Air Pollution Monitoring Network

The grades in this report come from information from the nationwide air pollution-monitoring network. That network forms the infrastructure for healthy air. States and local governments use monitors to accurately measure the amount of air pollution in the community.

Less than one-third of all counties have ozone or particle pollution monitors, seriously limiting the ability to adequately detect and track the levels of harmful air pollution. Unfortunately, funds for existing air pollution monitors have been cut across the nation. More monitoring is needed near roadways to measure the highest levels of exposures from air pollution related to traffic. Communities that have expanded oil and gas extraction operations need more monitoring.

The President has proposed to cut EPA's budget by 31 percent, including dramatic cuts for state air pollution grants that fund monitoring. With such challenges to our monitoring infrastructure, it may be harder for the nation to ensure accurate, reliable quality data in the future.

What You Can Do

You can do a great deal to help reduce air pollution outdoors. Here's how to speak up and step up:

Speak up for Healthy Air Protections.

Send a message to Congress and to the White House: Protect the Clean Air Act! Urge the President and Congress to support cleaner, healthier air and oppose measures to block or delay the cleanup of air pollution. The President and all members of Congress should support and protect the Clean Air Act.

Tell Congress to support adequate funds for the EPA to implement and enforce the Clean Air Act. EPA works with the states to make sure that the pollution is cleaned up, but they need the resources to do that work.

Tell EPA to follow the law to protect your health. EPA is required to follow the Clean Air Act, completing regular reviews of the science and putting in place steps to clean up sources of pollution to provide that protection. That includes taking steps to reduce pollution that causes climate change. You can provide comments to EPA at public hearings or in writing online. Sign up for more information about times when your voice is needed at www.FightingForAir.org.

Share your story. Do you or any member of your family have a personal reason to fight for healthier, cleaner air? Go to www.FightingForAir.org to let us know how healthy air affects you. Your story helps us remind decision makers what is at stake when it comes to clean air.

Get involved locally. Participate in state and local efforts to clean up air pollution and address climate change. To find your local air pollution control agency, go to www.4cleanair.org.

Step up to Curb Pollution in Your Community.

Drive less. Combine trips, walk, bike, carpool or vanpool, and use buses, subways or other alternatives to driving. Vehicle emissions are a major source of air pollution. Support community plans that provide ways to get around that don't require a car, such as more sidewalks, bike trails and transit systems.

Use less electricity. Turn out the lights and use energy-efficient appliances. Generating electricity is one of the biggest sources of pollution, particularly in the eastern United States.

Don't burn wood or trash. Burning firewood and trash is among the largest sources of particle pollution in many parts of the country. If you must use a fireplace or stove for heat, convert your woodstove to natural gas, which has far fewer polluting emissions. Compost and recycle as much as possible and dispose of other waste properly; don't burn it. Support efforts in your community to ban outdoor burning of construction and yard wastes. Avoid the use of outdoor hydronic heaters, also called outdoor wood boilers, which are frequently much more polluting than woodstoves.

Make sure your local school system requires clean school buses, which includes replacing or retrofitting old school buses with filters and other equipment to reduce emissions. Make sure your local schools don't idle their buses, a step that can immediately reduce emissions.

1 A complete discussion of the sources of data and the methodology is included in Methodology.

2 U.S. Environmental Protection Agency. *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2014.* Washington, DC: U.S. EPA, 2016. EPA 430-R-16-002.

3 EPA, 2016.

People at Risk from Short-Term Particle Pollution (24-Hour $PM_{2.5}$)

	Chronic Diseases							Age Groups			
In Counties where the Grades were:	Adult Asthma	Pediatric Asthma	COPD	Lung Cancer	CV Disease	Diabetes	Poverty	Under 18	65 and Over	Total Population	Number of Counties
Grade A (0.0)	5,992,655	1,802,928	4,289,711	53,062	5,519,300	6,813,373	12,296,314	19,154,928	12,637,796	85,841,453	288
Grade B (0.3-0.9)	2,487,361	710,302	1,707,641	22,079	2,257,763	2,798,334	5,296,773	8,482,854	5,136,291	36,961,630	111
Grade C (1.0-2.0)	1,497,678	418,793	1,017,268	13,031	1,354,796	1,698,140	3,133,628	5,062,225	3,014,053	21,607,181	54
Grade D (2.1-3.2)	1,034,136	260,265	627,358	8,067	847,006	1,130,589	2,203,289	3,452,500	2,064,381	15,344,010	23
Grade F (3.3+)	2,758,254	821,980	1,571,574	20,540	2,256,027	3,140,522	6,585,074	10,434,818	5,634,316	43,036,931	69
National Population in Counties with $PM_{2.5}$ Monitors	15,156,120	4,405,144	10,236,303	129,977	13,557,088	17,166,636	32,430,455	51,249,670	31,374,325	223,082,364	636

People at Risk from Year-Round Particle Pollution (Annual $PM_{2.5}$)

	Chronic Diseases							Age Groups			
In Counties where the Grades were:	Adult Asthma	Pediatric Asthma	COPD	Lung Cancer	CV Disease	Diabetes	Poverty	Under 18	65 and Over	Total Population	Number of Counties
Pass	11,727,392	3,421,296	7,938,618	100,393	10,429,084	13,115,687	24,212,629	38,997,449	23,983,876	170,682,208	468
Fail	1,215,259	349,400	673,296	9,220	1,011,474	1,495,671	3,455,844	4,738,182	2,612,834	19,870,106	18
National Population in Counties with $PM_{2.5}$ Monitors	15,156,120	4,405,144	10,236,303	129,977	13,557,088	17,166,636	32,430,455	51,249,670	31,374,325	223,082,364	636

People at Risk from Ozone

	Chronic Diseases					Age Groups			
In Counties where the Grades were:	Adult Asthma	Pediatric Asthma	COPD	CV Disease	Poverty	Under 18	65 and Over	Total Population	Number of Counties
Grade A (0.0)	2,135,734	592,588	1,591,631	2,084,164	4,515,103	7,034,893	4,934,132	31,578,049	218
Grade B (0.3-0.9)	1,866,933	547,662	1,429,515	1,831,132	4,001,141	6,187,522	4,137,336	27,423,560	159
Grade C (1.0-2.0)	2,625,700	740,239	1,949,579	2,496,364	4,762,756	8,192,247	5,655,800	36,787,108	167
Grade D (2.1-3.2)	1,752,575	487,238	1,199,321	1,527,279	3,307,983	5,233,129	3,456,203	23,537,106	62
Grade F (3.3+)	7,629,719	2,304,667	4,743,298	6,576,087	16,529,442	27,566,927	15,417,092	116,502,119	161
National Population in Counties with Ozone Monitors	16,218,750	4,732,885	11,069,317	14,726,495	33,546,429	54,859,943	34,098,150	238,804,343	803

Note: *The State of the Air 2017* covers the period 2013-2015. The Appendix provides a full discussion of the methodology.

People at Risk In 25 U.S. Cities Most Polluted by Short-Term Particle Pollution (24-hour $PM_{2.5}$)

2017 Rank[1]	Metropolitan Statistical Areas	Total Population[2]	Under 18[3]	65 and Over[3]	Pediatric Asthma [4,6]	Adult Asthma[5,6]	COPD[7]	Lung Cancer[8]	CV Disease[9]	Diabetes[10]	Poverty[11]
1	Bakersfield, CA	882,176	257,727	88,992	18,417	47,777	23,732	384	36,297	57,322	185,990
2	Visalia-Porterville-Hanford, CA	610,828	185,471	63,293	13,253	32,579	16,291	266	24,985	39,208	154,039
2	Fresno-Madera, CA	1,129,859	322,159	132,448	23,021	62,047	31,883	490	49,778	77,435	274,927
4	Modesto-Merced, CA	806,843	226,215	95,841	16,165	44,619	23,071	350	36,214	56,432	171,672
5	Fairbanks, AK	99,631	24,116	8,349	2,045	7,139	2,756	56	3,943	4,891	7,671
6	San Jose-San Francisco-Oakland, CA	8,713,914	1,877,655	1,214,016	134,173	526,751	280,172	3,779	448,510	696,765	933,311
7	Salt Lake City-Provo-Orem, UT	2,467,709	757,422	231,853	53,789	154,727	60,714	653	90,218	115,839	255,652
8	Logan, UT-ID	133,857	41,508	12,489	3,008	8,322	3,200	38	4,693	5,854	19,910
9	Los Angeles-Long Beach, CA	18,679,763	4,383,662	2,376,130	313,246	1,099,027	571,985	8,096	902,929	1,409,515	2,928,894
10	Reno-Carson City-Fernley, NV	605,706	131,049	102,549	7,661	38,311	33,137	356	39,626	49,111	81,422
11	El Centro, CA	180,191	51,119	22,442	3,653	9,934	5,187	78	8,178	12,647	41,685
12	Lancaster, PA	536,624	128,793	89,727	14,397	41,751	28,456	353	38,439	42,053	55,725
13	Missoula, MT	114,181	22,154	16,172	1,404	8,203	4,628	66	5,905	6,350	17,461
14	Sacramento-Roseville, CA	2,544,026	593,452	374,195	42,407	150,701	81,902	1,102	132,685	204,433	379,600
14	Anchorage, AK	399,790	101,387	38,009	8,596	27,941	11,714	223	17,279	21,498	34,981
16	Yakima, WA	248,830	74,063	32,662	4,838	16,416	10,504	138	13,029	14,296	46,794
17	Pittsburgh-New Castle-Weirton, PA-OH-WV	2,648,605	509,215	497,830	56,223	218,112	158,026	1,748	213,287	232,472	327,752
17	Seattle-Tacoma, WA	4,602,591	1,000,111	626,375	65,324	339,697	216,668	2,557	263,773	293,479	482,638
19	Medford-Grants Pass, OR	297,312	60,886	65,587	5,714	26,407	14,726	167	21,709	28,402	58,695
20	Philadelphia-Reading-Camden, PA-NJ-DE-MD	7,183,479	1,592,239	1,085,893	162,777	525,438	349,693	4,605	470,916	542,896	916,171
21	South Bend-Elkhart-Mishawaka, IN-MI	725,065	178,459	113,087	13,523	56,107	43,911	511	54,707	62,712	109,079
21	Harrisburg-York-Lebanon, PA	1,247,235	272,926	209,814	30,509	99,682	68,539	820	92,638	101,485	126,887
23	Eugene, OR	362,895	68,799	64,973	6,456	33,296	16,555	204	23,240	31,518	67,777
24	Phoenix-Mesa-Scottsdale, AZ	4,574,531	1,127,596	670,488	122,981	324,484	214,829	2,233	264,628	340,926	727,788
25	Bend-Redmond-Prineville, OR	196,898	41,110	38,464	3,858	17,521	9,377	111	13,392	17,982	26,721

Notes:

1. Cities are ranked using the highest weighted average for any county within that Combined Metropolitan Statistical Area or Metropolitan Statistical Area.
2. **Total Population** represents the at-risk populations for all counties within the respective Combined Metropolitan Statistical Area or Metropolitan Statistical Area.
3. Those **under 18** and **65 and over** are vulnerable to $PM_{2.5}$ and are, therefore, included. They should not be used as population denominators for disease estimates.
4. **Pediatric asthma** estimates are for those under 18 years of age and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
5. **Adult asthma** estimates are for those 18 years and older and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
6. Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.
7. **COPD** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
8. **Lung cancer** estimates are the number of new cases diagnosed in 2013 .
9. **CV disease** is cardiovascular disease and estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
10. **Diabetes** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
11. **Poverty** estimates come from the U.S. Census Bureau and are for all ages.

People at Risk In 25 U.S. Cities Most Polluted by Year-Round Particle Pollution (Annual $PM_{2.5}$)

2017 Rank[1]	Metropolitan Statistical Areas	Total Population[2]	Under 18[3]	65 and Over[3]	Pediatric Asthma [4,6]	Adult Asthma[5,6]	COPD[7]	Lung Cancer[8]	CV Disease[9]	Diabetes[10]	Poverty[11]
1	Visalia-Porterville-Hanford, CA	610,828	185,471	63,293	13,253	32,579	16,291	266	24,985	39,208	154,039
2	Bakersfield, CA	882,176	257,727	88,992	18,417	47,777	23,732	384	36,297	57,322	185,990
3	Fresno-Madera, CA	1,129,859	322,159	132,448	23,021	62,047	31,883	490	49,778	77,435	274,927
4	San Jose-San Francisco-Oakland, CA	8,713,914	1,877,655	1,214,016	134,173	526,751	280,172	3,779	448,510	696,765	933,311
5	Los Angeles-Long Beach, CA	18,679,763	4,383,662	2,376,130	313,246	1,099,027	571,985	8,096	902,929	1,409,515	2,928,894
6	Modesto-Merced, CA	806,843	226,215	95,841	16,165	44,619	23,071	350	36,214	56,432	171,672
7	El Centro, CA	180,191	51,119	22,442	3,653	9,934	5,187	78	8,178	12,647	41,685
8	Pittsburgh-New Castle-Weirton, PA-OH-WV	2,648,605	509,215	497,830	56,223	218,112	158,026	1,748	213,287	232,472	327,752
9	Cleveland-Akron-Canton, OH	3,493,596	756,784	597,001	54,482	274,623	222,765	2,401	263,764	312,145	497,987
10	San Luis Obispo-Paso Robles-Arroyo Grande, CA	281,401	50,837	51,231	3,633	17,910	10,097	122	16,633	25,113	38,448
11	Medford-Grants Pass, OR	297,312	60,886	65,587	5,714	26,407	14,726	167	21,709	28,402	58,695
11	Philadelphia-Reading-Camden, PA-NJ-DE-MD	7,183,479	1,592,239	1,085,893	162,777	525,438	349,693	4,605	470,916	542,896	916,171
13	Indianapolis-Carmel-Muncie, IN	2,372,530	583,997	313,675	43,916	184,825	139,575	1,738	171,702	200,542	329,297
13	Louisville/Jefferson County—Elizabethtown—Madison, KY-IN	1,504,559	346,616	219,919	35,200	133,941	130,160	1,365	133,904	150,903	200,814
13	Johnstown-Somerset, PA	211,933	40,095	44,363	4,482	17,358	12,999	140	18,031	19,502	29,615
16	Houston-The Woodlands, TX	6,855,069	1,829,561	703,418	144,776	382,312	248,754	3,705	381,501	552,311	988,741
17	Fairbanks, AK	99,631	24,116	8,349	2,045	7,139	2,756	56	3,943	4,891	7,671
18	Detroit-Warren-Ann Arbor, MI	5,319,913	1,196,787	801,027	92,712	424,024	314,167	3,379	372,872	436,925	847,421
18	Altoona, PA	125,593	25,939	24,852	2,900	10,102	7,381	82	10,174	11,031	18,616
20	Lancaster, PA	536,624	128,793	89,727	14,397	41,751	28,456	353	38,439	42,053	55,725
20	Cincinnati-Wilmington-Maysville, OH-KY-IN	2,216,735	531,163	311,427	42,406	176,287	145,299	1,650	160,014	188,672	287,495
22	Birmingham-Hoover-Talladega, AL	1,360,082	312,528	209,403	41,245	103,803	110,714	933	116,412	141,142	222,890
22	Harrisburg-York-Lebanon, PA	1,247,235	272,926	209,814	30,509	99,682	68,539	820	92,638	101,485	126,887
22	New York-Newark, NY-NJ-CT-PA	23,723,696	5,178,719	3,461,559	505,108	1,708,629	1,001,947	14,302	1,340,765	1,727,386	3,178,139
25	Erie-Meadville, PA	364,529	78,960	61,087	8,827	29,248	19,931	240	26,881	29,464	57,949

Notes:

1. Cities are ranked using the highest weighted average for any county within that Combined Metropolitan Statistical Area or Metropolitan Statistical Area.
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4. **Pediatric asthma** estimates are for those under 18 years of age and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
5. **Adult asthma** estimates are for those 18 years and older and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
6. Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.
7. **COPD** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
8. **Lung cancer** estimates are the number of new cases diagnosed in 2013 .
8. **CV disease** is cardiovascular disease and estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
9. **Diabetes** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
10. **Poverty** estimates come from the U.S. Census Bureau and are for all ages.

People at Risk In 25 Most Ozone-Polluted Cities

2017 Rank[1]	Metropolitan Statistical Areas	Total Population[2]	Under 18[3]	65 and Over[3]	Pediatric Asthma [4,6]	Adult Asthma[5,6]	COPD[7]	CV Disease[8]	Poverty[9]
1	Los Angeles-Long Beach, CA	18,679,763	4,383,662	2,376,130	313,246	1,099,027	571,985	8,096	1,409,515
2	Bakersfield, CA	882,176	257,727	88,992	18,417	47,777	23,732	384	57,322
3	Fresno-Madera, CA	1,129,859	322,159	132,448	23,021	62,047	31,883	490	77,435
4	Visalia-Porterville-Hanford, CA	610,828	185,471	63,293	13,253	32,579	16,291	266	39,208
5	Phoenix-Mesa-Scottsdale, AZ	4,574,531	1,127,596	670,488	122,981	324,484	214,829	2,233	340,926
6	Modesto-Merced, CA	806,843	226,215	95,841	16,165	44,619	23,071	350	56,432
7	San Diego-Carlsbad, CA	3,299,521	728,037	431,999	52,024	197,708	102,514	1,433	250,288
8	Sacramento-Roseville, CA	2,544,026	593,452	374,195	42,407	150,701	81,902	1,102	204,433
9	New York-Newark, NY-NJ-CT-PA	23,723,696	5,178,719	3,461,559	505,108	1,708,629	1,001,947	14,302	1,727,386
10	Las Vegas-Henderson, NV-AZ	2,362,015	543,472	358,944	33,670	149,068	120,361	1,367	179,273
11	Denver-Aurora, CO	3,418,876	802,008	408,996	68,001	237,472	108,795	1,453	169,116
12	Houston-The Woodlands, TX	6,855,069	1,829,561	703,418	144,776	382,312	248,754	3,705	552,311
13	Dallas-Fort Worth, TX-OK	7,538,055	1,990,630	826,555	157,759	422,482	282,033	4,071	625,563
14	El Centro, CA	180,191	51,119	22,442	3,653	9,934	5,187	78	12,647
15	Fort Collins, CO	333,577	67,793	47,570	5,748	24,144	11,356	142	17,585
16	El Paso-Las Cruces, TX-NM	1,053,267	288,219	129,282	23,423	61,859	39,643	538	84,514
17	Redding-Red Bluff, CA	242,841	53,749	47,109	3,841	14,771	8,761	105	22,350
18	San Jose-San Francisco-Oakland, CA	8,713,914	1,877,655	1,214,016	134,173	526,751	280,172	3,779	696,765
19	San Antonio-New Braunfels, TX	2,384,075	612,614	296,086	48,477	134,762	91,254	1,286	202,041
20	Salt Lake City-Provo-Orem, UT	2,467,709	757,422	231,853	53,789	154,727	60,714	653	115,839
21	Hartford-West Hartford, CT	1,483,187	305,454	239,202	35,791	123,794	60,395	936	109,140
22	Baton Rouge, LA	830,480	197,739	105,468	17,303	51,764	45,903	579	76,252
22	Philadelphia-Reading-Camden, PA-NJ-DE-MD	7,183,479	1,592,239	1,085,893	162,777	525,438	349,693	4,605	542,896
24	Sheboygan, WI	115,569	26,084	19,254	1,917	8,460	4,412	69	7,810
25	Chico, CA	225,411	45,348	39,543	3,240	13,978	7,812	98	19,274

Notes:

1. Cities are ranked using the highest weighted average for any county within that Combined Metropolitan Statistical Area or Metropolitan Statistical Area.
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4. **Pediatric asthma** estimates are for those under 18 years of age and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
5. **Adult asthma** estimates are for those 18 years and older and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
6. Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.
7. **COPD** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
8. **CV disease** is cardiovascular disease and estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
9. **Poverty** estimates come from the U.S. Census Bureau and are for all ages.

People at Risk in 25 Counties Most Polluted by Short-Term Particle Pollution (24-hour $PM_{2.5}$)

				At-Risk Groups									High $PM_{2.5}$ Days in Unhealthy Ranges, 2013–2015	
2017 Rank[1]	County	ST	Total Population[2]	Under 18[3]	65 and Over[3]	Pediatric Asthma[4,6]	Adult Asthma[5,6]	COPD[7]	Lung Cancer[8]	CV Disease[8]	Diabetes[9]	Poverty[10]	Weighted Avg.[11]	Grade[12]
1	Kern	CA	882,176	257,727	88,992	18,417	47,777	23,732	384	36,297	57,322	185,990	52.7	F
2	Fresno	CA	974,861	279,544	112,074	19,976	53,384	27,289	423	42,457	66,139	241,669	41.2	F
2	Kings	CA	150,965	41,435	14,146	2,961	8,357	4,026	66	6,015	9,555	30,117	41.2	F
4	Stanislaus	CA	538,388	146,063	67,324	10,437	30,189	15,817	233	25,049	38,935	103,646	29.8	F
5	Fairbanks North Star Borough	AK	99,631	24,116	8,349	2,045	7,139	2,756	56	3,943	4,891	7,671	25.8	F
6	Madera	CA	154,998	42,615	20,374	3,045	8,663	4,595	67	7,321	11,296	33,258	24.7	F
7	San Joaquin	CA	726,106	199,894	87,579	14,284	40,454	21,053	315	33,228	51,852	124,606	22.8	F
8	Salt Lake	UT	1,107,314	311,386	109,258	22,113	72,084	28,671	293	42,720	54,993	117,311	21.7	F
9	Cache	UT	120,783	37,123	10,685	2,636	7,531	2,768	32	4,057	5,140	18,657	20.2	F
10	Merced	CA	268,455	80,152	28,517	5,727	14,430	7,254	117	11,165	17,497	68,026	19.5	F
11	Shoshone	ID	12,432	2,464	2,772	209	909	576	6	892	988	2,577	16.8	F
12	Utah	UT	575,205	198,953	42,066	14,129	33,832	12,002	152	17,123	21,908	70,537	15.5	F
13	Lemhi	ID	7,735	1,398	2,193	119	574	398	4	642	694	1,347	14.3	F
14	Riverside	CA	2,361,026	612,848	320,086	43,793	134,810	71,829	1,024	114,813	177,144	377,244	14.0	F
15	Douglas	NV	47,710	8,500	12,234	497	3,145	3,277	28	4,072	4,863	4,459	13.3	F
16	Franklin	ID	13,074	4,385	1,804	372	791	432	6	636	714	1,253	12.7	F
17	Tulare	CA	459,863	144,036	49,147	10,292	24,222	12,265	200	18,970	29,653	123,922	12.5	F
17	Ravalli	MT	41,373	8,214	9,904	521	2,901	2,193	24	3,088	3,060	6,129	12.5	F
19	Plumas	CA	18,409	3,149	4,729	225	1,206	785	8	1,395	2,065	2,503	11.3	F
20	Weber	UT	243,645	70,325	27,606	4,994	15,725	6,546	64	10,045	12,791	29,768	11.0	F
20	Santa Cruz	CA	274,146	54,183	38,794	3,872	16,944	8,989	119	14,364	22,322	40,480	11.0	F
22	Los Angeles	CA	10,170,292	2,279,839	1,277,335	162,912	606,055	312,736	4,407	490,888	767,731	1,675,802	10.5	F
23	Inyo	CA	18,260	3,769	4,044	269	1,139	706	8	1,227	1,827	2,222	9.7	F
23	Lincoln	MT	19,052	3,491	4,903	221	1,360	1,072	11	1,523	1,499	3,817	9.7	F
25	Washoe	NV	446,903	99,275	67,548	5,804	28,100	23,194	263	27,431	34,367	61,017	9.5	F

Notes:

1. Counties are ranked by weighted average. See note 11 below.
2. **Total Population** represents the at-risk populations in counties with PM2.5 monitors.
3. Those **under 18** and **65 and over** are vulnerable to PM2.5 and are, therefore, included. They should not be used as population denominators for disease estimates.
4. **Pediatric asthma** estimates are for those under 18 years of age and represent the estimated number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
5. **Adult asthma** estimates are for those 18 years and older and represent the estimated number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
6. Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.
7. **COPD** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
8. **Lung cancer** estimates are the number of new cases diagnosed in 2013 .
9. **CV disease** is cardiovascular disease and estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
10. **Diabetes** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
11. **Poverty** estimates come from the U.S. Census Bureau and are for all ages.
12. The **Weighted Average** was derived by counting the number of days in each unhealthful range (orange, red, purple, maroon) in each year (2013-2015), multiplying the total in each range by the assigned standard weights (i.e., 1 for orange, 1.5 for red, 2.0 for purple, 2.5 for maroon), and calculating the average.
13. **Grade** is assigned by weighted average as follows: A=0.0, B=0.3-0.9, C=1.0-2.0, D=2.1-3.2, F=3.3+.

People at Risk In 25 Counties Most Polluted by Year-Round Particle Pollution (Annual $PM_{2.5}$)

				At-Risk Groups									$PM_{2.5}$ Annual, 2013–2015	
2017 Rank[1]	County	ST	Total Population[2]	Under 18[3]	65 and Over[3]	Pediatric Asthma[4,6]	Adult Asthma[5,6]	COPD[7]	Lung Cancer[8]	CV Disease[9]	Diabetes[10]	Poverty[11]	Design Value[12]	Pass/ Grade[13]
1	Kings	CA	150,965	41,435	14,146	2,961	8,357	4,026	66	6,015	9,555	30,117	22.2	Fail
2	Kern	CA	882,176	257,727	88,992	18,417	47,777	23,732	384	36,297	57,322	185,990	20.8	Fail
3	Tulare	CA	459,863	144,036	49,147	10,292	24,222	12,265	200	18,970	29,653	123,922	17.6	Fail
4	Fresno	CA	974,861	279,544	112,074	19,976	53,384	27,289	423	42,457	66,139	241,669	15.4	Fail
5	Madera	CA	154,998	42,615	20,374	3,045	8,663	4,595	67	7,321	11,296	33,258	15.2	Fail
6	Plumas	CA	18,409	3,149	4,729	225	1,206	785	8	1,395	2,065	2,503	14.9	Fail
7	San Joaquin	CA	726,106	199,894	87,579	14,284	40,454	21,053	315	33,228	51,852	124,606	14.2	Fail
8	Riverside	CA	2,361,026	612,848	320,086	43,793	134,810	71,829	1,024	114,813	177,144	377,244	14.1	Fail
9	Stanislaus	CA	538,388	146,063	67,324	10,437	30,189	15,817	233	25,049	38,935	103,646	13.8	Fail
10	Shoshone	ID	12,432	2,464	2,772	209	909	576	6	892	988	2,577	13.7	Fail
11	Imperial	CA	180,191	51,119	22,442	3,653	9,934	5,187	78	8,178	12,647	41,685	13.1	Fail
12	Lemhi	ID	7,735	1,398	2,193	119	574	398	4	642	694	1,347	12.7	Fail
13	Allegheny	PA	1,230,459	233,675	217,210	26,121	102,088	69,398	807	93,646	102,520	145,454	12.6	Fail
14	Merced	CA	268,455	80,152	28,517	5,727	14,430	7,254	117	11,165	17,497	68,026	12.5	Fail
15	Cuyahoga	OH	1,255,921	268,170	210,832	19,306	99,147	79,368	861	93,526	110,646	224,256	12.4	Fail
16	Los Angeles	CA	10,170,292	2,279,839	1,277,335	162,912	606,055	312,736	4,407	490,888	767,731	1,675,802	12.3	Fail
17	San Luis Obispo	CA	281,401	50,837	51,231	3,633	17,910	10,097	122	16,633	25,113	38,448	12.1	Fail
17	Hawaii	HI	196,428	43,217	35,851	4,291	15,151	6,892	99	10,359	13,874	35,294	12.1	Fail
19	San Bernardino	CA	2,128,133	572,173	228,666	40,886	119,170	59,986	923	92,725	146,418	394,031	12.0	Pass
20	Jackson	OR	212,567	44,332	44,244	4,160	18,855	10,252	119	14,926	19,715	40,427	11.8	Pass
20	Philadelphia	PA	1,567,442	346,932	198,475	38,782	127,499	74,034	1,024	94,862	106,183	385,781	11.8	Pass
22	Lincoln	MT	19,052	3,491	4,903	221	1,360	1,072	11	1,523	1,499	3,817	11.7	Pass
22	Marion	IN	939,020	234,220	108,060	17,613	73,292	52,169	686	63,121	75,137	189,323	11.7	Pass
22	Jefferson	KY	763,623	171,811	113,444	18,636	70,483	70,948	727	70,423	78,758	115,246	11.7	Pass
22	Cambria	PA	136,411	26,377	28,534	2,949	11,114	8,324	90	11,550	12,488	19,450	11.7	Pass
22	Washington	PA	208,261	41,143	40,169	4,599	16,954	12,373	137	17,016	18,497	20,501	11.7	Pass

Notes:

1. Counties are ranked by Design Value. See note 11 below.
2. **Total Population** represents the at-risk populations in counties with $PM_{2.5}$ monitors.
3. Those under 18 and 65 and over are vulnerable to $PM_{2.5}$ and are, therefore, included. They should not be used as population denominators for disease estimates.
4. **Pediatric asthma** estimates are for those under 18 years of age and represent the estimated number of people who had asthma in 2014 based on state rates (BRFSS) applied to population estimates (U.S. Census).
5. **Adult asthma** estimates are for those 18 years and older and represent the estimated number of people who had asthma in 2014 based on state rates (BRFSS) applied to population estimates (U.S. Census).
6. Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.
7. **COPD** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
8. **Lung cancer** estimates are the number of new cases diagnosed in 2013 .
9. **CV disease** is cardiovascular disease and estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
10. **Diabetes** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
11. **Poverty** estimates come from the U.S. Census Bureau and are for all ages.
12. The **Design Value** is the calculated concentration of a pollutant based on the form of the Annual $PM_{2.5}$ National Ambient Air Quality Standard, and is used by EPA to determine whether the air quality in a county meets the current (2012) standard (U.S. EPA).
13. **Grades** are based on EPA's determination of meeting or failure to meet the NAAQS for annual $PM_{2.5}$ levels during 2012-2014. Counties meeting the NAAQS received grades of Pass; counties not meeting the NAAQS received grades of Fail.

People at Risk in 25 Most Ozone-Polluted Counties

				At-Risk Groups							High Ozone Days in Unhealthy Ranges, 2013–2015	
2017 Rank[1]	County	ST	Total Population[2]	Under 18[3]	65 and Over[3]	Pediatric Asthma[4,6]	Adult Asthma[5,6]	COPD[7]	CV Disease[8]	Poverty[9]	Weighted Avg.[10]	Grade[11]
1	San Bernardino	CA	2,128,133	572,173	228,666	40,886	119,170	59,986	92,725	394,031	142.3	F
2	Riverside	CA	2,361,026	612,848	320,086	43,793	134,810	71,829	114,813	377,244	122.0	F
3	Los Angeles	CA	10,170,292	2,279,839	1,277,335	162,912	606,055	312,736	490,888	1,675,802	108.3	F
4	Kern	CA	882,176	257,727	88,992	18,417	47,777	23,732	36,297	185,990	100.5	F
5	Fresno	CA	974,861	279,544	112,074	19,976	53,384	27,289	42,457	241,669	92.8	F
6	Tulare	CA	459,863	144,036	49,147	10,292	24,222	12,265	18,970	123,922	92.5	F
7	Madera	CA	154,998	42,615	20,374	3,045	8,663	4,595	7,321	33,258	46.8	F
8	Kings	CA	150,965	41,435	14,146	2,961	8,357	4,026	6,015	30,117	44.5	F
9	Maricopa	AZ	4,167,947	1,030,669	592,961	112,410	295,494	193,792	237,849	667,637	34.7	F
10	Uintah	UT	37,928	12,923	3,410	918	2,262	889	1,322	3,733	34.0	F
11	Merced	CA	268,455	80,152	28,517	5,727	14,430	7,254	11,165	68,026	33.3	F
12	San Diego	CA	3,299,521	728,037	431,999	52,024	197,708	102,514	161,074	445,948	31.2	F
13	El Dorado	CA	184,452	37,919	34,393	2,710	11,424	6,776	11,581	16,634	31.0	F
14	Stanislaus	CA	538,388	146,063	67,324	10,437	30,189	15,817	25,049	103,646	30.0	F
15	Sacramento	CA	1,501,335	361,617	198,168	25,840	87,748	46,278	73,651	250,325	26.0	F
16	Nevada	CA	98,877	17,428	24,201	1,245	6,422	4,090	7,193	12,137	25.7	F
17	Fairfield	CT	948,053	220,906	137,799	25,884	76,395	36,729	51,524	83,612	24.0	F
18	Clark	NV	2,114,801	498,564	290,001	29,147	130,554	103,810	121,424	321,755	23.8	F
19	Jefferson	CO	565,524	116,627	85,287	9,889	40,386	20,708	29,549	44,068	23.7	F
20	Harris	TX	4,538,028	1,224,413	428,697	96,889	252,264	158,961	240,522	744,712	23.3	F
21	Tarrant	TX	1,982,498	533,475	208,355	42,215	110,194	72,657	111,992	255,993	23.2	F
21	Denton	TX	780,612	201,646	70,965	15,957	44,046	27,885	42,057	61,186	23.2	F
23	Imperial	CA	180,191	51,119	22,442	3,653	9,934	5,187	8,178	41,685	22.5	F
24	Duchesne	UT	20,862	7,230	2,283	513	1,236	517	802	2,247	21.3	F
25	Larimer	CO	333,577	67,793	47,570	5,748	24,144	11,356	16,259	39,648	19.7	F

Notes:

1. Counties are ranked by weighted average. See note 10 below.
2. **Total Population** represents the at-risk populations in counties with $PM_{2.5}$ monitors.
3. Those **under 18** and **65 and over** are vulnerable to $PM_{2.5}$ and are, therefore, included. They should not be used as population denominators for disease estimates.
4. **Pediatric asthma** estimates are for those under 18 years of age and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
5. **Adult asthma** estimates are for those 18 years and older and represent the **estimated** number of people who had asthma in 2015 based on state rates (BRFSS) applied to population estimates (U.S. Census).
6. Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.
7. **COPD** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
8. **CV disease** is cardiovascular disease and estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to population estimates (U.S. Census).
9. **Poverty** estimates come from the U.S. Census Bureau and are for all ages.
10. The **Weighted Average** was derived by counting the number of days in each unhealthful range (orange, red, purple) in each year (2013-2015), multiplying the total in each range by the assigned standard weights (i.e., 1 for orange, 1.5 for red, 2.0 for purple), and calculating the average.
11. Grade is assigned by weighted average as follows: A=0.0, B=0.3-0.9, C=1.0-2.0, D=2.1-3.2, F=3.3+.

Cleanest U.S. Cities for Short-Term Particle Pollution (24-hour PM$_{2.5}$)[1]

Metropolitan Statistical Area	Population
Albany-Schenectady, NY	1,173,891
Alexandria, LA	154,484
Asheville-Brevard, NC	480,051
Atlanta—Athens-Clarke County—Sandy Springs, GA	6,365,108
Augusta-Richmond County, GA-SC	590,146
Austin-Round Rock, TX	2,000,860
Bangor, ME	152,692
Beckley, WV	122,507
Bellingham, WA	212,284
Birmingham-Hoover-Talladega, AL	1,360,082
Bowling Green-Glasgow, KY	221,915
Brunswick, GA	116,003
Buffalo-Cheektowaga, NY	1,213,152
Burlington-South Burlington, VT	217,042
Cape Coral-Fort Myers-Naples, FL	1,059,287
Casper, WY	82,178
Charleston-Huntington-Ashland, WV-OH-KY	693,726
Charlotte-Concord, NC-SC	2,583,956
Charlottesville, VA	229,514
Chattanooga-Cleveland-Dalton, TN-GA-AL	950,005
Colorado Springs, CO	697,856
Columbia-Orangeburg-Newberry, SC	937,288
Columbus-Auburn-Opelika, GA-AL	504,865
Columbus-Marion-Zanesville, OH	2,424,831
Corpus Christi-Kingsville-Alice, TX	526,068
Des Moines-Ames-West Des Moines, IA	782,390
Dothan-Enterprise-Ozark, AL	248,947
Eau Claire-Menomonie, WI	210,133
Edwards-Glenwood Springs, CO	129,487
Elmira-Corning, NY	184,702
Erie-Meadville, PA	364,529
Evansville, IN-KY	315,693
Farmington, NM	118,737
Fayetteville-Lumberton-Laurinburg, NC	546,215
Fayetteville-Springdale-Rogers, AR-MO	513,559
Florence, SC	206,448
Florence-Muscle Shoals, AL	146,950
Fort Smith, AR-OK	280,241
Gadsden, AL	103,057
Gainesville-Lake City, FL	345,511
Goldsboro, NC	124,132
Grand Island, NE	85,066
Greensboro—Winston-Salem—High Point, NC	1,642,506
Greenville-Washington, NC	223,493
Gulfport-Biloxi-Pascagoula, MS	389,255
Harrisonburg-Staunton-Waynesboro, VA	251,352
Homosassa Springs, FL	141,058
Hot Springs-Malvern, AR	130,603
Houma-Thibodaux, LA	212,297
Huntsville-Decatur-Albertville, AL	763,287
Jackson-Vicksburg-Brookhaven, MS	670,061
La Crosse-Onalaska, WI-MN	136,985
Lafayette-Opelousas-Morgan City, LA	627,146
Lake Charles-Jennings, LA	237,044
Lakeland-Winter Haven, FL	650,092
Lansing-East Lansing-Owosso, MI	540,895
Lexington-Fayette—Richmond—Frankfort, KY	723,849
Lima-Van Wert-Celina, OH	219,831
Longview-Marshall, TX	284,527
Lynchburg, VA	259,950
McAllen-Edinburg, TX	906,099
Milwaukee-Racine-Waukesha, WI	2,046,692
Mobile-Daphne-Fairhope, AL	619,104
Monroe-Ruston-Bastrop, LA	253,407
Montgomery, AL	373,792
Morgantown-Fairmont, WV	195,101
New Orleans-Metairie-Hammond, LA-MS	1,493,205
North Port-Sarasota, FL	977,491
Oklahoma City-Shawnee, OK	1,430,327
Orlando-Deltona-Daytona Beach, FL	3,129,308
Owensboro, KY	117,463
Palm Bay-Melbourne-Titusville, FL	568,088
Parkersburg-Marietta-Vienna, WV-OH	153,444
Pensacola-Ferry Pass, FL-AL	515,832
Pittsfield, MA	127,828
Pueblo-Cañon City, CO	210,283
Richmond, VA	1,271,334
Rochester-Batavia-Seneca Falls, NY	1,175,724
Rome-Summerville, GA	121,426
Saginaw-Midland-Bay City, MI	382,598
Salisbury, MD-DE	395,300
San Antonio-New Braunfels, TX	2,384,075
Santa Maria-Santa Barbara, CA	444,769
Savannah-Hinesville-Statesboro, GA	532,048
Scranton—Wilkes-Barre—Hazleton, PA	558,166
Sierra Vista-Douglas, AZ	126,427
Springfield-Branson, MO	541,991
Springfield-Greenfield Town, MA	702,583
St. George, UT	155,602
Syracuse-Auburn, NY	738,746
Tampa-St. Petersburg-Clearwater, FL	2,975,225
Texarkana, TX-AR	149,769
Tulsa-Muskogee-Bartlesville, OK	1,151,172
Tuscaloosa, AL	239,908
Urban Honolulu, HI	998,714
Valdosta, GA	142,875
Virginia Beach-Norfolk, VA-NC	1,828,187
Waterloo-Cedar Falls, IA	170,612
Wilmington, NC	277,969

Note:

1. Monitors in these cities reported no days when PM$_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the 2006 NAAQS.

Top 25 Cleanest U.S. Cities for Year-Round Particle Pollution (Annual $PM_{2.5}$)[1]

Rank[2]	Design Value[3]	Metropolitan Statistical Area	Population
1	4.1	Cheyenne, WY	97,121
1	4.1	Farmington, NM	118,737
3	4.6	Casper, WY	82,178
4	4.8	Kahului-Wailuku-Lahaina, HI	164,726
5	5.3	Bismarck, ND	129,517
6	5.4	Urban Honolulu, HI	998,714
7	5.6	Palm Bay-Melbourne-Titusville, FL	568,088
8	5.7	Colorado Springs, CO	697,856
8	5.7	Elmira-Corning, NY	184,702
10	5.8	Pueblo-Cañon City, CO	210,283
11	5.9	Cape Coral-Fort Myers-Naples, FL	1,059,287
12	6.0	Miami-Fort Lauderdale-Port St. Lucie, FL	6,654,565
13	6.1	North Port-Sarasota, FL	977,491
14	6.2	Redding-Red Bluff, CA	242,841
14	6.2	Homosassa Springs, FL	141,058
14	6.2	Orlando-Deltona-Daytona Beach, FL	3,129,308
17	6.3	Salinas, CA	433,898
17	6.3	Burlington-South Burlington, VT	217,042
19	6.4	Fargo-Wahpeton, ND-MN	256,634
19	6.4	Yuma, AZ	204,275
19	6.4	Bangor, ME	152,692
19	6.4	Syracuse-Auburn, NY	738,746
23	6.5	Lakeland-Winter Haven, FL	650,092
23	6.5	Sierra Vista-Douglas, AZ	126,427
23	6.5	Wilmington, NC	277,969

Notes:

1 This list represents cities with the lowest levels of annual $PM_{2.5}$ air pollution.

2. Cities are ranked by using the highest design value for any county within that metropolitan area.

3. The **Design Value** is the calculated concentration of a pollutant based on the form of the Annual $PM_{2.5}$ National Ambient Air Quality Standard, and is used by EPA to determine whether the air quality in a county meets the current (2012) standard (U.S. EPA).

Cleanest U.S. Cities for Ozone Air Pollution[1]

Metropolitan Statistical Area	Population
Bellingham, WA	212,284
Blacksburg-Christiansburg-Radford, VA	181,747
Brownsville-Harlingen-Raymondville, TX	444,059
Brunswick, GA	116,003
Burlington-South Burlington, VT	217,042
Cape Coral-Fort Myers-Naples, FL	1,059,287
Cedar Rapids-Iowa City, IA	432,538
Charleston-North Charleston, SC	744,526
Charlottesville, VA	229,514
Columbia-Moberly-Mexico, MO	226,174
Columbia-Orangeburg-Newberry, SC	937,288
Decatur, IL	107,303
Des Moines-Ames-West Des Moines, IA	782,390
Dothan-Enterprise-Ozark, AL	248,947
Eau Claire-Menomonie, WI	210,133
Elmira-Corning, NY	184,702
Fairbanks, AK	99,631
Fargo-Wahpeton, ND-MN	256,634
Fayetteville-Springdale-Rogers, AR-MO	513,559
Florence, SC	206,448
Florence-Muscle Shoals, AL	146,950
Fort Wayne-Huntington-Auburn, IN	626,124
Gadsden, AL	103,057
Gainesville-Lake City, FL	345,511
Greenville-Washington, NC	223,493
Harrisonburg-Staunton-Waynesboro, VA	251,352
Hickory-Lenoir, NC	407,499
Idaho Falls-Rexburg-Blackfoot, ID	235,829
Ithaca-Cortland, NY	153,420
Jackson-Vicksburg-Brookhaven, MS	670,061
Jefferson City, MO	151,145
Johnson City-Kingsport-Bristol, TN-VA	507,768
La Crosse-Onalaska, WI-MN	136,985
Lincoln-Beatrice, NE	345,478
McAllen-Edinburg, TX	906,099
Missoula, MT	114,181
Monroe-Ruston-Bastrop, LA	253,407
New Bern-Morehead City, NC	195,124
Ocala, FL	343,254
Palm Bay-Melbourne-Titusville, FL	568,088
Peoria-Canton, IL	413,717
Quincy-Hannibal, IL-MO	116,296
Rapid City-Spearfish, SD	168,961
Roanoke, VA	314,560
Rochester-Austin, MN	252,989
Rome-Summerville, GA	121,426
Salinas, CA	433,898
Savannah-Hinesville-Statesboro, GA	532,048
Sebring, FL	99,491
Sioux City-Vermillion, IA-SD-NE	183,033
Sioux Falls, SD	251,854
Springfield-Branson, MO	541,991
Springfield-Jacksonville-Lincoln, IL	314,212
Steamboat Springs-Craig, CO	37,067
Tallahassee-Bainbridge, FL-GA	405,098
Terre Haute, IN	171,019
Tuscaloosa, AL	239,908
Urban Honolulu, HI	998,714
Utica-Rome, NY	295,600
Waterloo-Cedar Falls, IA	170,612
Williamsport-Lock Haven, PA	155,489
Wilmington, NC	277,969

Notes:

1. This list represents cities with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Cleanest Counties for Short-Term Particle Pollution (24-hour $PM_{2.5}$)[1]

County	State	MSAs and Respective CSA[2]
Baldwin	AL	Mobile-Daphne-Fairhope, AL
Clay	AL	
Colbert	AL	Florence-Muscle Shoals, AL
DeKalb	AL	Huntsville-Decatur-Albertville, AL
Etowah	AL	Gadsden, AL
Houston	AL	Dothan-Enterprise-Ozark, AL
Jefferson	AL	Birmingham-Hoover-Talladega, AL
Madison	AL	Huntsville-Decatur-Albertville, AL
Mobile	AL	Mobile-Daphne-Fairhope, AL
Montgomery	AL	Montgomery, AL
Morgan	AL	Huntsville-Decatur-Albertville, AL
Russell	AL	Columbus-Auburn-Opelika, GA-AL
Shelby	AL	Birmingham-Hoover-Talladega, AL
Talladega	AL	Birmingham-Hoover-Talladega, AL
Tuscaloosa	AL	Tuscaloosa, AL
Arkansas	AR	
Ashley	AR	
Garland	AR	Hot Springs-Malvern, AR
Jackson	AR	
Polk	AR	
Union	AR	
Washington	AR	Fayetteville-Springdale-Rogers, AR-MO
Cochise	AZ	Sierra Vista-Douglas, AZ
Mohave	AZ	Las Vegas-Henderson, NV-AZ
Pima	AZ	Tucson-Nogales, AZ
San Benito	CA	San Jose-San Francisco-Oakland, CA
Santa Barbara	CA	Santa Maria-Santa Barbara, CA
Sonoma	CA	San Jose-San Francisco-Oakland, CA
Ventura	CA	Los Angeles-Long Beach, CA
Yolo	CA	Sacramento-Roseville, CA
Arapahoe	CO	Denver-Aurora, CO
El Paso	CO	Colorado Springs, CO
Garfield	CO	Edwards-Glenwood Springs, CO
La Plata	CO	
Montezuma	CO	
Pueblo	CO	Pueblo-Cañon City, CO
Rio Blanco	CO	
Hartford	CT	Hartford-West Hartford, CT
Litchfield	CT	New York-Newark, NY-NJ-CT-PA
District of Columbia	DC	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Kent	DE	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Sussex	DE	Salisbury, MD-DE
Alachua	FL	Gainesville-Lake City, FL
Brevard	FL	Palm Bay-Melbourne-Titusville, FL
Broward	FL	Miami-Fort Lauderdale-Port St. Lucie, FL
Citrus	FL	Homosassa Springs, FL
Escambia	FL	Pensacola-Ferry Pass, FL-AL
Hillsborough	FL	Tampa-St. Petersburg-Clearwater, FL
Lee	FL	Cape Coral-Fort Myers-Naples, FL
Orange	FL	Orlando-Deltona-Daytona Beach, FL
Palm Beach	FL	Miami-Fort Lauderdale-Port St. Lucie, FL
Pinellas	FL	Tampa-St. Petersburg-Clearwater, FL
Polk	FL	Lakeland-Winter Haven, FL
Sarasota	FL	North Port-Sarasota, FL
Seminole	FL	Orlando-Deltona-Daytona Beach, FL
Volusia	FL	Orlando-Deltona-Daytona Beach, FL
Chatham	GA	Savannah-Hinesville-Statesboro, GA
Clarke	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Clayton	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Cobb	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
DeKalb	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Floyd	GA	Rome-Summerville, GA
Fulton	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Glynn	GA	Brunswick, GA
Gwinnett	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Hall	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Houston	GA	Macon-Bibb County—Warner Robins, GA
Lowndes	GA	Valdosta, GA
Muscogee	GA	Columbus-Auburn-Opelika, GA-AL
Paulding	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Richmond	GA	Augusta-Richmond County, GA-SC
Walker	GA	Chattanooga-Cleveland-Dalton, TN-GA-AL
Washington	GA	
Honolulu	HI	Urban Honolulu, HI
Kauai	HI	
Black Hawk	IA	Waterloo-Cedar Falls, IA
Delaware	IA	
Lee	IA	
Palo Alto	IA	
Polk	IA	Des Moines-Ames-West Des Moines, IA
Van Buren	IA	
Dubois	IN	

Notes:

1. Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the current (2006) standard (U.S. EPA).
2. MSA and CSA are terms used by the U.S. Office of Management and Budget for statistical purposes. MSA stands for Metropolitan Statisical Area and includes one or more counties. CSA stands for Combined Statistical Area and may include multiple MSAs and individual counties.

Cleanest Counties for Short-Term Particle Pollution (24-hour $PM_{2.5}$)[1] (cont.)

County	State	MSAs and Respective CSA[2]
Greene	IN	
Spencer	IN	
Vanderburgh	IN	Evansville, IN-KY
Johnson	KS	Kansas City-Overland Park-Kansas City, MO-KS
Bell	KY	
Boyd	KY	Charleston-Huntington-Ashland, WV-OH-KY
Campbell	KY	Cincinnati-Wilmington-Maysville, OH-KY-IN
Carter	KY	
Christian	KY	Clarksville, TN-KY
Daviess	KY	Owensboro, KY
Fayette	KY	Lexington-Fayette—Richmond—Frankfort, KY
Hardin	KY	Louisville/Jefferson County—Elizabethtown—Madison, KY-IN
Henderson	KY	Evansville, IN-KY
Madison	KY	Lexington-Fayette—Richmond—Frankfort, KY
McCracken	KY	Paducah-Mayfield, KY-IL
Perry	KY	
Pulaski	KY	
Warren	KY	Bowling Green-Glasgow, KY
Calcasieu Parish	LA	Lake Charles-Jennings, LA
Iberville Parish	LA	Baton Rouge, LA
Jefferson Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Lafayette Parish	LA	Lafayette-Opelousas-Morgan City, LA
Ouachita Parish	LA	Monroe-Ruston-Bastrop, LA
Rapides Parish	LA	Alexandria, LA
St. Bernard Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Tangipahoa Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Terrebonne Parish	LA	Houma-Thibodaux, LA
West Baton Rouge Parish	LA	Baton Rouge, LA
Berkshire	MA	Pittsfield, MA
Bristol	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Essex	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Hampden	MA	Springfield-Greenfield Town, MA
Plymouth	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Suffolk	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Worcester	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Anne Arundel	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Baltimore	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Dorchester	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Garrett	MD	
Harford	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Kent	MD	
Montgomery	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Prince George's	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Penobscot	ME	Bangor, ME
Allegan	MI	Grand Rapids-Wyoming-Muskegon, MI
Bay	MI	Saginaw-Midland-Bay City, MI
Berrien	MI	South Bend-Elkhart-Mishawaka, IN-MI
Chippewa	MI	
Ingham	MI	Lansing-East Lansing-Owosso, MI
Lenawee	MI	Detroit-Warren-Ann Arbor, MI
Missaukee	MI	
Washtenaw	MI	Detroit-Warren-Ann Arbor, MI
Dakota	MN	Minneapolis-St. Paul, MN-WI
Scott	MN	Minneapolis-St. Paul, MN-WI
Wright	MN	Minneapolis-St. Paul, MN-WI
Cedar	MO	
Greene	MO	Springfield-Branson, MO
Grenada	MS	
Hancock	MS	Gulfport-Biloxi-Pascagoula, MS
Harrison	MS	Gulfport-Biloxi-Pascagoula, MS
Hinds	MS	Jackson-Vicksburg-Brookhaven, MS
Jackson	MS	Gulfport-Biloxi-Pascagoula, MS
Alamance	NC	Greensboro—Winston-Salem—High Point, NC
Buncombe	NC	Asheville-Brevard, NC
Caswell	NC	
Catawba	NC	Hickory-Lenoir, NC
Cumberland	NC	Fayetteville-Lumberton-Laurinburg, NC
Davidson	NC	Greensboro—Winston-Salem—High Point, NC
Duplin	NC	
Durham	NC	Raleigh-Durham-Chapel Hill, NC
Forsyth	NC	Greensboro—Winston-Salem—High Point, NC
Gaston	NC	Charlotte-Concord, NC-SC
Guilford	NC	Greensboro—Winston-Salem—High Point, NC
Haywood	NC	Asheville-Brevard, NC
Jackson	NC	
Johnston	NC	Raleigh-Durham-Chapel Hill, NC
Martin	NC	
Mecklenburg	NC	Charlotte-Concord, NC-SC
Mitchell	NC	
Montgomery	NC	
New Hanover	NC	Wilmington, NC
Pitt	NC	Greenville-Washington, NC
Rowan	NC	Charlotte-Concord, NC-SC
Swain	NC	

Notes:

1. Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the current (2006) standard (U.S. EPA).
2. MSA and CSA are terms used by the U.S. Office of Management and Budget for statistical purposes. MSA stands for Metropolitan Statisical Area and includes one or more counties. CSA stands for Combined Statistical Area and may include multiple MSAs and individual counties.

Cleanest Counties for Short-Term Particle Pollution (24-hour $PM_{2.5}$)[1] (cont.)

County	State	MSAs and Respective CSA[2]
Wayne	NC	Goldsboro, NC
Hall	NE	Grand Island, NE
Scotts Bluff	NE	
Belknap	NH	Boston-Worcester-Providence, MA-RI-NH-CT
Grafton	NH	
Hillsborough	NH	Boston-Worcester-Providence, MA-RI-NH-CT
Rockingham	NH	Boston-Worcester-Providence, MA-RI-NH-CT
Atlantic	NJ	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Bergen	NJ	New York-Newark, NY-NJ-CT-PA
Gloucester	NJ	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Mercer	NJ	New York-Newark, NY-NJ-CT-PA
Middlesex	NJ	New York-Newark, NY-NJ-CT-PA
Morris	NJ	New York-Newark, NY-NJ-CT-PA
Passaic	NJ	New York-Newark, NY-NJ-CT-PA
Warren	NJ	New York-Newark, NY-NJ-CT-PA
San Juan	NM	Farmington, NM
Albany	NY	Albany-Schenectady, NY
Bronx	NY	New York-Newark, NY-NJ-CT-PA
Chautauqua	NY	
Erie	NY	Buffalo-Cheektowaga, NY
Essex	NY	
Kings	NY	New York-Newark, NY-NJ-CT-PA
Monroe	NY	Rochester-Batavia-Seneca Falls, NY
New York	NY	New York-Newark, NY-NJ-CT-PA
Onondaga	NY	Syracuse-Auburn, NY
Orange	NY	New York-Newark, NY-NJ-CT-PA
Queens	NY	New York-Newark, NY-NJ-CT-PA
Richmond	NY	New York-Newark, NY-NJ-CT-PA
Steuben	NY	Elmira-Corning, NY
Suffolk	NY	New York-Newark, NY-NJ-CT-PA
Allen	OH	Lima-Van Wert-Celina, OH
Athens	OH	
Butler	OH	Cincinnati-Wilmington-Maysville, OH-KY-IN
Clark	OH	Dayton-Springfield-Sidney, OH
Franklin	OH	Columbus-Marion-Zanesville, OH
Greene	OH	Dayton-Springfield-Sidney, OH
Lake	OH	Cleveland-Akron-Canton, OH
Lawrence	OH	Charleston-Huntington-Ashland, WV-OH-KY
Lorain	OH	Cleveland-Akron-Canton, OH
Mahoning	OH	Youngstown-Warren, OH-PA
Medina	OH	Cleveland-Akron-Canton, OH
Portage	OH	Cleveland-Akron-Canton, OH
Preble	OH	
Scioto	OH	Charleston-Huntington-Ashland, WV-OH-KY
Trumbull	OH	Youngstown-Warren, OH-PA
Oklahoma	OK	Oklahoma City-Shawnee, OK
Sequoyah	OK	Fort Smith, AR-OK
Tulsa	OK	Tulsa-Muskogee-Bartlesville, OK
Armstrong	PA	Pittsburgh-New Castle-Weirton, PA-OH-WV
Erie	PA	Erie-Meadville, PA
Lackawanna	PA	Scranton—Wilkes-Barre—Hazleton, PA
Monroe	PA	New York-Newark, NY-NJ-CT-PA
Westmoreland	PA	Pittsburgh-New Castle-Weirton, PA-OH-WV
Kent	RI	Boston-Worcester-Providence, MA-RI-NH-CT
Washington	RI	Boston-Worcester-Providence, MA-RI-NH-CT
Chesterfield	SC	
Edgefield	SC	Augusta-Richmond County, GA-SC
Florence	SC	Florence, SC
Lexington	SC	Columbia-Orangeburg-Newberry, SC
Richland	SC	Columbia-Orangeburg-Newberry, SC
Spartanburg	SC	Greenville-Spartanburg-Anderson, SC
Brown	SD	
Hamilton	TN	Chattanooga-Cleveland-Dalton, TN-GA-AL
McMinn	TN	Chattanooga-Cleveland-Dalton, TN-GA-AL
Bexar	TX	San Antonio-New Braunfels, TX
Bowie	TX	Texarkana, TX-AR
Ellis	TX	Dallas-Fort Worth, TX-OK
Galveston	TX	Houston-The Woodlands, TX
Harrison	TX	Longview-Marshall, TX
Hidalgo	TX	McAllen-Edinburg, TX
Nueces	TX	Corpus Christi-Kingsville-Alice, TX
Travis	TX	Austin-Round Rock, TX
Washington	UT	St. George, UT
Albemarle	VA	Charlottesville, VA
Arlington	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Bristol City	VA	Johnson City-Kingsport-Bristol, TN-VA
Charles City	VA	Richmond, VA
Chesterfield	VA	Richmond, VA
Fairfax	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Hampton City	VA	Virginia Beach-Norfolk, VA-NC
Henrico	VA	Richmond, VA
Loudoun	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Lynchburg City	VA	Lynchburg, VA
Norfolk City	VA	Virginia Beach-Norfolk, VA-NC
Page	VA	
Rockingham	VA	Harrisonburg-Staunton-Waynesboro, VA

Notes:

1. Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the current (2006) standard (U.S. EPA).
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Cleanest Counties for Short-Term Particle Pollution (24-hour $PM_{2.5}$)[1] (cont.)

County	State	MSAs and Respective CSA[2]
Salem City	VA	Roanoke, VA
Virginia Beach City	VA	Virginia Beach-Norfolk, VA-NC
Bennington	VT	
Chittenden	VT	Burlington-South Burlington, VT
Kitsap	WA	Seattle-Tacoma, WA
Skagit	WA	Seattle-Tacoma, WA
Whatcom	WA	Bellingham, WA
Ashland	WI	
Dodge	WI	Milwaukee-Racine-Waukesha, WI
Eau Claire	WI	Eau Claire-Menomonie, WI
Forest	WI	
Grant	WI	
La Crosse	WI	La Crosse-Onalaska, WI-MN
Milwaukee	WI	Milwaukee-Racine-Waukesha, WI
Ozaukee	WI	Milwaukee-Racine-Waukesha, WI
Sauk	WI	Madison-Janesville-Beloit, WI
Taylor	WI	
Vilas	WI	
Waukesha	WI	Milwaukee-Racine-Waukesha, WI
Brooke	WV	Pittsburgh-New Castle-Weirton, PA-OH-WV
Cabell	WV	Charleston-Huntington-Ashland, WV-OH-KY
Hancock	WV	Pittsburgh-New Castle-Weirton, PA-OH-WV
Harrison	WV	
Kanawha	WV	Charleston-Huntington-Ashland, WV-OH-KY
Marion	WV	Morgantown-Fairmont, WV
Marshall	WV	Wheeling, WV-OH
Monongalia	WV	Morgantown-Fairmont, WV
Raleigh	WV	Beckley, WV
Wood	WV	Parkersburg-Marietta-Vienna, WV-OH
Albany	WY	
Carbon	WY	
Natrona	WY	Casper, WY
Park	WY	
Sublette	WY	
Sweetwater	WY	
Teton	WY	

Notes:

1. Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the current (2006) standard (U.S. EPA).
2. MSA and CSA are terms used by the U.S. Office of Management and Budget for statistical purposes. MSA stands for Metropolitan Statistical Area and includes one or more counties. CSA stands for Combined Statistical Area and may include multiple MSAs and individual counties.

Top 25 Cleanest Counties for Year-Round Particle Pollution (Annual $PM_{2.5}$)[1]

2017 Rank[2]	County	State	Design Value[3]
1	Custer	SD	3.2
2	McKenzie	ND	3.4
3	Kauai	HI	3.9
3	Lake	CA	4.0
4	San Juan	NM	4.1
4	Laramie	WY	4.1
4	Essex	NY	4.1
4	Park	WY	4.1
9	Campbell	WY	4.2
10	Albany	WY	4.3
11	Fergus	MT	4.5
12	Natrona	WY	4.6
13	Jackson	SD	4.7
13	Teton	WY	4.7
15	Sweetwater	WY	4.8
15	Lake	MN	4.8
15	Maui	HI	4.8
18	Kent	RI	4.9
18	Oliver	ND	4.9
18	Phillips	MT	4.9
18	Billings	ND	4.9
22	San Benito	CA	5.0
22	Vilas	WI	5.0
22	Sublette	WY	5.0
22	Belknap	NH	5.0

Notes:

1. This list represents counties with the lowest levels of monitored long term $PM_{2.5}$ air pollution.
2. Counties are ranked by Design Value.
3. The Design Value is the calculated concentration of a pollutant based on the form of the Annual PM2.5 National Ambient Air Quality Standard, and is used by EPA to determine whether the air quality in a county meets the current (2012) standard (U.S. EPA).

Cleanest Counties for Ozone Air Pollution[1]

County	State	Metropolitan Statistical Area
Denali Borough	AK	
Fairbanks North Star Borough	AK	Fairbanks, AK
Colbert	AL	Florence-Muscle Shoals, AL
Etowah	AL	Gadsden, AL
Houston	AL	Dothan-Enterprise-Ozark, AL
Madison	AL	Huntsville-Decatur-Albertville, AL
Morgan	AL	Huntsville-Decatur-Albertville, AL
Sumter	AL	
Tuscaloosa	AL	Tuscaloosa, AL
Newton	AR	
Polk	AR	
Washington	AR	Fayetteville-Springdale-Rogers, AR-MO
Colusa	CA	
Humboldt	CA	
Lake	CA	
Marin	CA	San Jose-San Francisco-Oakland, CA
Mendocino	CA	
Monterey	CA	Salinas, CA
San Francisco	CA	San Jose-San Francisco-Oakland, CA
Santa Cruz	CA	San Jose-San Francisco-Oakland, CA
Sonoma	CA	San Jose-San Francisco-Oakland, CA
Moffat	CO	Steamboat Springs-Craig, CO
Montezuma	CO	
Alachua	FL	Gainesville-Lake City, FL
Baker	FL	Jacksonville-St. Marys-Palatka, FL-GA
Brevard	FL	Palm Bay-Melbourne-Titusville, FL
Collier	FL	Cape Coral-Fort Myers-Naples, FL
Columbia	FL	Gainesville-Lake City, FL
Flagler	FL	Orlando-Deltona-Daytona Beach, FL
Highlands	FL	Sebring, FL
Holmes	FL	
Lee	FL	Cape Coral-Fort Myers-Naples, FL
Leon	FL	Tallahassee-Bainbridge, FL-GA
Liberty	FL	
Marion	FL	Ocala, FL
Seminole	FL	Orlando-Deltona-Daytona Beach, FL
Wakulla	FL	Tallahassee-Bainbridge, FL-GA
Chatham	GA	Savannah-Hinesville-Statesboro, GA
Chattooga	GA	Rome-Summerville, GA
Clarke	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Columbia	GA	Augusta-Richmond County, GA-SC
Glynn	GA	Brunswick, GA
Muscogee	GA	Columbus-Auburn-Opelika, GA-AL
Paulding	GA	Atlanta—Athens-Clarke County—Sandy Springs, GA
Richmond	GA	Augusta-Richmond County, GA-SC
Sumter	GA	
Honolulu	HI	Urban Honolulu, HI
Bremer	IA	Waterloo-Cedar Falls, IA
Linn	IA	Cedar Rapids-Iowa City, IA
Polk	IA	Des Moines-Ames-West Des Moines, IA
Scott	IA	Davenport-Moline, IA-IL
Story	IA	Des Moines-Ames-West Des Moines, IA
Van Buren	IA	
Warren	IA	Des Moines-Ames-West Des Moines, IA
Butte	ID	Idaho Falls-Rexburg-Blackfoot, ID
Adams	IL	Quincy-Hannibal, IL-MO
Clark	IL	
Effingham	IL	
Hamilton	IL	
Macon	IL	Decatur, IL
Macoupin	IL	St. Louis-St. Charles-Farmington, MO-IL
Peoria	IL	Peoria-Canton, IL
Sangamon	IL	Springfield-Jacksonville-Lincoln, IL
Will	IL	Chicago-Naperville, IL-IN-WI
Allen	IN	Fort Wayne-Huntington-Auburn, IN
Delaware	IN	Indianapolis-Carmel-Muncie, IN
Elkhart	IN	South Bend-Elkhart-Mishawaka, IN-MI
Hamilton	IN	Indianapolis-Carmel-Muncie, IN
Hancock	IN	Indianapolis-Carmel-Muncie, IN
Hendricks	IN	Indianapolis-Carmel-Muncie, IN
Huntington	IN	Fort Wayne-Huntington-Auburn, IN
Johnson	IN	Indianapolis-Carmel-Muncie, IN
Knox	IN	
Madison	IN	Indianapolis-Carmel-Muncie, IN
Morgan	IN	Indianapolis-Carmel-Muncie, IN
Shelby	IN	Indianapolis-Carmel-Muncie, IN
Vigo	IN	Terre Haute, IN
Johnson	KS	Kansas City-Overland Park-Kansas City, MO-KS
Trego	KS	
Bell	KY	
Carter	KY	
Morgan	KY	
Perry	KY	
Pike	KY	
Pulaski	KY	
Warren	KY	Bowling Green-Glasgow, KY
Ouachita Parish	LA	Monroe-Ruston-Bastrop, LA
Androscoggin	ME	Portland-Lewiston-South Portland, ME
Aroostook	ME	
Oxford	ME	
Chippewa	MI	
Becker	MN	
Crow Wing	MN	

Notes:

1. This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Cleanest Counties for Ozone Air Pollution[1] (cont.)

County	State	Metropolitan Statistical Area
Goodhue	MN	Minneapolis-St. Paul, MN-WI
Hennepin	MN	Minneapolis-St. Paul, MN-WI
Lake	MN	
Mille Lacs	MN	Minneapolis-St. Paul, MN-WI
Olmsted	MN	Rochester-Austin, MN
St. Louis	MN	Duluth, MN-WI
Stearns	MN	Minneapolis-St. Paul, MN-WI
Washington	MN	Minneapolis-St. Paul, MN-WI
Boone	MO	Columbia-Moberly-Mexico, MO
Callaway	MO	Jefferson City, MO
Cass	MO	Kansas City-Overland Park-Kansas City, MO-KS
Greene	MO	Springfield-Branson, MO
Taney	MO	Springfield-Branson, MO
Hinds	MS	Jackson-Vicksburg-Brookhaven, MS
Lauderdale	MS	
Fergus	MT	
Flathead	MT	
Lewis and Clark	MT	
Missoula	MT	Missoula, MT
Phillips	MT	
Powder River	MT	
Richland	MT	
Rosebud	MT	
Alexander	NC	Hickory-Lenoir, NC
Avery	NC	
Buncombe	NC	Asheville-Brevard, NC
Caldwell	NC	Hickory-Lenoir, NC
Carteret	NC	New Bern-Morehead City, NC
Chatham	NC	Raleigh-Durham-Chapel Hill, NC
Durham	NC	Raleigh-Durham-Chapel Hill, NC
Franklin	NC	Raleigh-Durham-Chapel Hill, NC
Granville	NC	Raleigh-Durham-Chapel Hill, NC
Johnston	NC	Raleigh-Durham-Chapel Hill, NC
Lenoir	NC	
Macon	NC	
Martin	NC	
Montgomery	NC	
New Hanover	NC	Wilmington, NC
Pitt	NC	Greenville-Washington, NC
Swain	NC	
Billings	ND	
Burke	ND	
Burleigh	ND	Bismarck, ND
Cass	ND	Fargo-Wahpeton, ND-MN
McKenzie	ND	
Mercer	ND	
Williams	ND	

County	State	Metropolitan Statistical Area
Knox	NE	
Lancaster	NE	Lincoln-Beatrice, NE
Belknap	NH	Boston-Worcester-Providence, MA-RI-NH-CT
Sandoval	NM	Albuquerque-Santa Fe-Las Vegas, NM
Santa Fe	NM	Albuquerque-Santa Fe-Las Vegas, NM
Albany	NY	Albany-Schenectady, NY
Hamilton	NY	
Herkimer	NY	Utica-Rome, NY
Monroe	NY	Rochester-Batavia-Seneca Falls, NY
Onondaga	NY	Syracuse-Auburn, NY
Steuben	NY	Elmira-Corning, NY
Tompkins	NY	Ithaca-Cortland, NY
Lorain	OH	Cleveland-Akron-Canton, OH
Portage	OH	Cleveland-Akron-Canton, OH
Summit	OH	Cleveland-Akron-Canton, OH
Caddo	OK	
Columbia	OR	Portland-Vancouver-Salem, OR-WA
Bradford	PA	
Clearfield	PA	State College-DuBois, PA
Lycoming	PA	Williamsport-Lock Haven, PA
Abbeville	SC	Greenville-Spartanburg-Anderson, SC
Aiken	SC	Augusta-Richmond County, GA-SC
Anderson	SC	Greenville-Spartanburg-Anderson, SC
Berkeley	SC	Charleston-North Charleston, SC
Charleston	SC	Charleston-North Charleston, SC
Chesterfield	SC	
Colleton	SC	
Darlington	SC	Florence, SC
Oconee	SC	Greenville-Spartanburg-Anderson, SC
Pickens	SC	Greenville-Spartanburg-Anderson, SC
Richland	SC	Columbia-Orangeburg-Newberry, SC
York	SC	Charlotte-Concord, NC-SC
Brookings	SD	
Custer	SD	Rapid City-Spearfish, SD
Jackson	SD	
Meade	SD	Rapid City-Spearfish, SD
Minnehaha	SD	Sioux Falls, SD
Union	SD	Sioux City-Vermillion, IA-SD-NE
Anderson	TN	Knoxville-Morristown-Sevierville, TN
Claiborne	TN	
DeKalb	TN	
Sevier	TN	Knoxville-Morristown-Sevierville, TN
Sullivan	TN	Johnson City-Kingsport-Bristol, TN-VA
Wilson	TN	Nashville-Davidson—Murfreesboro, TN
Brewster	TX	
Cameron	TX	Brownsville-Harlingen-Raymondville, TX
Hidalgo	TX	McAllen-Edinburg, TX
Albemarle	VA	Charlottesville, VA

Notes:

1. This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Cleanest Counties for Ozone Air Pollution[1] (cont.)

County	State	Metropolitan Statistical Area
Caroline	VA	Richmond, VA
Chesterfield	VA	Richmond, VA
Fauquier	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Frederick	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Giles	VA	Blacksburg-Christiansburg-Radford, VA
Madison	VA	
Page	VA	
Roanoke	VA	Roanoke, VA
Rockbridge	VA	
Rockingham	VA	Harrisonburg-Staunton-Waynesboro, VA
Wythe	VA	
Chittenden	VT	Burlington-South Burlington, VT
Clallam	WA	
Pierce	WA	Seattle-Tacoma, WA
Skagit	WA	Seattle-Tacoma, WA
Thurston	WA	Seattle-Tacoma, WA
Whatcom	WA	Bellingham, WA
Ashland	WI	
Eau Claire	WI	Eau Claire-Menomonie, WI
Forest	WI	
La Crosse	WI	La Crosse-Onalaska, WI-MN
Taylor	WI	
Berkeley	WV	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Gilmer	WV	
Greenbrier	WV	
Big Horn	WY	
Campbell	WY	
Fremont	WY	
Teton	WY	
Weston	WY	

Notes:

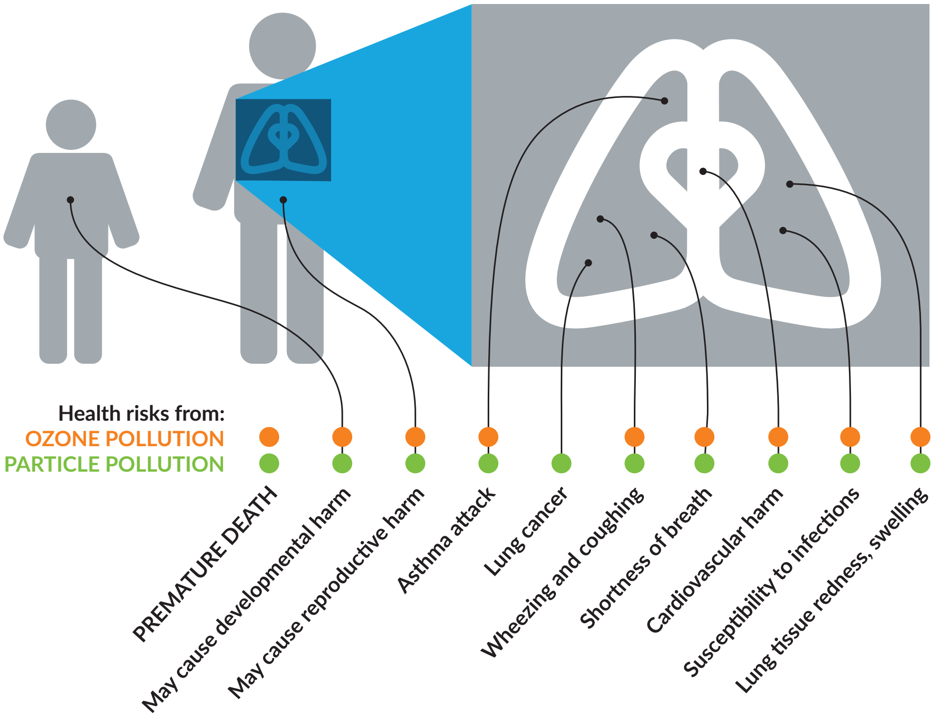
1. This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Health Effects of Ozone and Particle Pollution

Two types of air pollution dominate in the U.S.: ozone and particle pollution.[1] These two pollutants threaten the health and the lives of millions of Americans. Thanks to the Clean Air Act, the U.S. has far less of both pollutants now than in the past. Still, more than 125 million people live in counties where monitors show unhealthy levels of one or both—meaning the air a family breathes could shorten life or cause lung cancer.

So what are ozone and particle pollution?

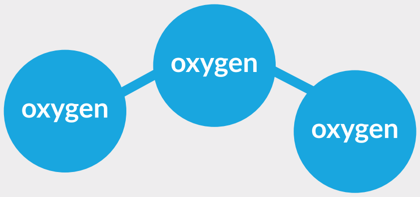
Air pollution remains a major danger to the health of children and adults.



Ozone Pollution

It may be hard to imagine that pollution could be invisible, but ozone is. The most widespread pollutant in the U.S. is also one of the most dangerous.

Scientists have studied the effects of ozone on health for decades. Hundreds of research studies have confirmed that ozone harms people at levels currently found in the United States. In the last few years, we've learned that it can also be deadly.



Ozone (O_3) is a gas molecule composed of three oxygen atoms.

What Is Ozone?

Ozone (O_3) is a gas molecule composed of three oxygen atoms. Often called "smog," ozone is harmful to breathe. Ozone aggressively attacks lung tissue by reacting chemically with it.

The ozone layer found high in the upper atmosphere (the stratosphere) shields us from much of the sun's ultraviolet radiation. However, ozone air pollution at ground level where we can breathe it (in the troposphere) causes serious health problems.

Where Does Ozone Come From?

Ozone develops in the atmosphere from gases that come out of tailpipes, smokestacks and many other sources. When these gases come in contact with sunlight, they react and form ozone smog.

The essential raw ingredients for ozone come from nitrogen oxides (NO_x); hydrocarbons, also called volatile organic compounds (VOCs); and carbon monoxide (CO). They are produced primarily when fossil fuels like gasoline, oil or coal are burned or when some chemicals, like solvents, evaporate. NOx is emitted from power plants, motor vehicles and other sources of high-heat combustion. VOCs are emitted from motor vehicles, chemical plants, refineries, factories, gas stations, paint and other sources. CO is also primarily emitted from motor vehicles.[2]

When gases that come out of tailpipes and smokestacks come in contact with sunlight, they react and form ozone smog.

If the ingredients are present under the right conditions, they react to form ozone. And because the reaction takes place in the atmosphere, the ozone often shows up downwind of the sources of the original gases. In addition, winds can carry ozone far from where it began.

You may have wondered why "ozone action day" warnings are sometimes followed by recommendations to avoid activities such as mowing your lawn or driving your car. Lawn mower exhaust and gasoline vapors are VOCs that could turn into ozone in the heat and sun.

Who Is at Risk from Breathing Ozone?

Anyone who spends time outdoors where ozone pollution levels are high may be at risk. Five groups of people are especially vulnerable to the effects of breathing ozone:

- children and teens;[3]
- anyone 65 and older;[4]
- people who work or exercise outdoors;[5]
- people with existing lung diseases, such as asthma and chronic obstructive pulmonary disease (also known as COPD, which includes emphysema and chronic bronchitis);[6] and
- people with cardiovascular disease.[7]

In addition, some evidence suggests that other groups—including women, people who suffer from obesity and people with low incomes—may also face higher risk from ozone.[8] More research is needed to confirm these findings.

A major new study found evidence that people with lung cancer faced greater risk from ozone and other outdoor air pollutants. The 2016 study tracked the air pollution levels from 1988 to 2011 that more than 350,000 cancer patients in California experienced. The researchers found that the ozone and other air pollutants shortened their survival.[9]

The impact on your health can depend on many factors, however. For example, the risks would be greater if ozone levels are higher, if you are breathing faster because you're working outdoors or if you spend more time outdoors.

Lifeguards in Galveston, Texas, provided evidence of the impact of even short-term exposure to ozone on healthy, active adults in a study published in 2008. Testing the breathing capacity of these outdoor workers several times a day, researchers found that many lifeguards had greater obstruction in their airways when ozone levels were high. Because of this research, Galveston became the first city in the nation to install an air quality warning flag system on the beach.[10]

How Ozone Pollution Harms Your Health

Premature death. Breathing ozone can shorten your life. Strong evidence exists of the deadly impact of ozone in large studies conducted in cities across the U.S., in Europe and in Asia. Researchers repeatedly found that the risk of premature death increased with higher levels of ozone.[11] Newer research has confirmed that ozone increased the risk of premature death even when other pollutants also exist.[12]

Immediate breathing problems. Many areas in the United States produce enough ozone during the summer months to cause health problems that can be felt right away. Immediate problems—in addition to increased risk of premature death—include:

- shortness of breath, wheezing and coughing;
- asthma attacks;
- increased risk of respiratory infections;
- increased susceptibility to pulmonary inflammation; and
- increased need for people with lung diseases, like asthma or chronic obstructive pulmonary disease (COPD), to receive medical treatment and to go to the hospital.[13]

Cardiovascular effects. Inhaling ozone may affect the heart as well as the lungs. A 2006 study linked exposures to high ozone levels for as little as one hour to a particular type of cardiac arrhythmia that itself increases the risk of premature death and stroke.[14] A French study found that exposure to elevated ozone levels for one to two days increased the risk of heart attacks for middle-aged adults without heart disease.[15] Several studies around the world have found increased risk of hospital admissions or emergency department visits for cardiovascular disease.[16]

Long-term exposure risks. New studies warn of serious effects from breathing ozone over longer periods. With more long-term data, scientists are finding that long-term exposure—that is, for periods longer than eight hours, including days, months or years—may increase the risk of onset of asthma or early death.

- Examining the records from a long-term national database, researchers found a higher risk of death from respiratory diseases associated with increases in ozone.[17]
- New York researchers looking at hospital records for children's asthma found that the risk of admission to hospitals for asthma increased with chronic exposure to ozone. Younger children and children from low-income families were more likely than other children to need hospital admissions even during the same time periods.[18]
- California researchers analyzing data from their long-term Southern California Children's Health Study found that some children with certain genes were more likely to develop asthma as adolescents in response to the variations in ozone levels in their communities.[19]
- Studies link lower birth weight and decreased lung function in newborns to ozone levels in their community.[20] This research provides increasing evidence that ozone may harm newborns.

Breathing other pollutants in the air may make your lungs more responsive to ozone—and breathing ozone may increase your body's response to other pollutants. For example, research warns that breathing sulfur dioxide and nitrogen oxide—two pollutants common in the eastern U.S.—can make the lungs react more strongly than to just breathing ozone alone. Breathing ozone may also increase the response to allergens in people with allergies. A large study published in 2009 found that children were more likely to suffer from hay fever and respiratory allergies when ozone and $PM_{2.5}$ levels were high.[21]

Research shows lower level of ozone causes harm. The EPA released their latest complete review of the current research on ozone pollution in February 2013.[22] The EPA had engaged a panel of expert scientists, the Clean Air Scientific Advisory Committee, to help them assess the evidence; in particular, they examined research published between 2006 and 2012. The experts on the Committee and EPA concluded that ozone pollution posed multiple, serious threats to health. Their findings are highlighted in the box on the next page.

EPA Concludes Ozone Pollution Poses Serious Health Threats

- Causes respiratory harm (e.g., worsened asthma, worsened COPD, inflammation)
- Likely to cause early death (both short-term and long-term exposure)
- Likely to cause cardiovascular harm (e.g., heart attacks, strokes, heart disease, congestive heart failure)
- May cause harm to the central nervous system
- May cause reproductive and developmental harm

—U.S. Environmental Protection Agency, *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*, 2013. EPA/600/R-10/076F.

Based on that review, the EPA set more protective limits, called national ambient air quality standards, on ozone pollution in October 2015. These official limits drive the cleanup of ozone pollution nationwide. The Clean Air Act requires EPA to review the standards every five years to make sure that they protect the health of the public.

Particle Pollution

Ever look at dirty truck exhaust?

The dirty, smoky part of that stream of exhaust is made of particle pollution. Overwhelming evidence shows that particle pollution—like that coming from that exhaust smoke—can kill. Particle pollution can increase the risk of heart disease, lung cancer and asthma attacks and can interfere with the growth and work of the lungs.

What Is Particle Pollution?

Particle pollution refers to a mix of very tiny solid and liquid particles that are in the air we breathe. But nothing about particle pollution is simple. And it is so dangerous, it can shorten your life.

Particle pollution refers to a mix of very tiny solid and liquid particles that are in the air we breathe. But nothing about particle pollution is simple. And it is so dangerous, it can shorten your life.

Size matters. Particles themselves are different sizes. Some are one-tenth the diameter of a strand of hair. Many are even tinier; some are so small they can only be seen with an electron microscope. Because of their size, you can't see the individual particles. You can only see the haze that forms when millions of particles blur the spread of sunlight.

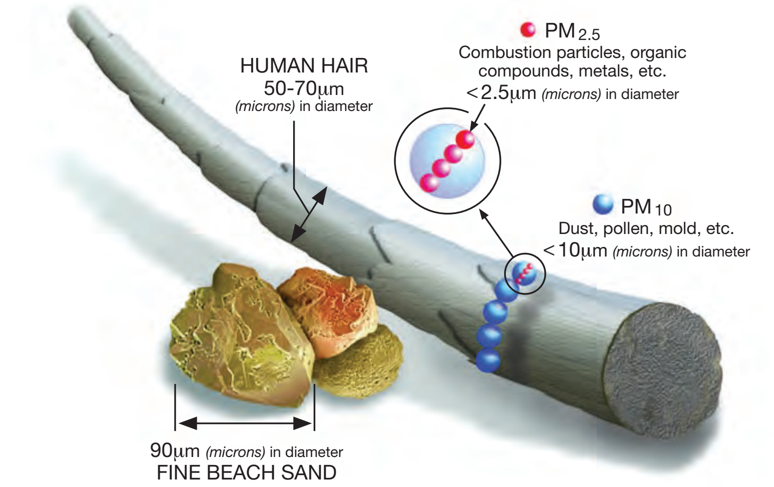


Image courtesy of the U.S. EPA

The differences in size make a big difference in how they affect us. Our natural defenses help us to cough or sneeze larger particles out of our bodies. But those defenses don't keep out smaller particles, those that are smaller than 10 microns (or micrometers) in diameter, or about one-seventh the diameter of a single human hair. These particles get trapped in the lungs, while the smallest are so minute that they can pass through the lungs into the bloodstream, just like the essential oxygen molecules we need to survive.

Researchers categorize particles according to size, grouping them as coarse, fine and ultrafine. Coarse particles fall between 2.5 microns and 10 microns in diameter and are called $PM_{10-2.5}$. Fine particles are 2.5 microns in diameter or smaller and are called $PM_{2.5}$. Ultrafine particles are smaller than 0.1 micron in diameter[23] and are small enough to pass through the lung tissue into the blood stream, circulating like the oxygen molecules themselves. No matter what the size, particles can harm your health.

"A mixture of mixtures." Because particles form in so many different ways, they can be composed of many different compounds. Although we often think of particles as solids, not all are. Some are completely liquid; others are solids suspended in liquids. As the EPA puts it, particles are really "a mixture of mixtures."[24]

The mixtures differ between the eastern and western United States and in different times of the year. For example, the Midwest, Southeast and Northeast states have more sulfate particles than the West on average, largely due to the high levels of sulfur dioxide emitted by large, coal-fired power plants. By contrast, nitrate particles from motor vehicle exhaust form a larger proportion of the unhealthful mix in the winter in the Northeast, Southern California, the Northwest and North Central U.S.[25]

Who Is at Risk?

Anyone who lives where particle pollution levels are high is at risk. Some people face higher risk, however. People at the greatest risk from particle pollution exposure include:

- Infants, children and teens;[26]
- People over 65 years of age;[27]
- People with lung disease such as asthma and chronic obstructive pulmonary disease (COPD), which includes chronic bronchitis and emphysema;
- People with heart disease[28] or diabetes;[29]
- People with low incomes;[30] and
- People who work or are active outdoors.[31]

Diabetics face increased risk at least in part because of their higher risk for cardiovascular disease.[32]

People with lung cancer also appear to be at higher risk from particle pollution, according to the 2016 study of more than 350,000 patients in California. Researchers looked at the exposure they experienced between 1988 and 2011 and found that where higher concentrations of particle pollution existed, people with lung cancer had shorter life spans.[33]

What Can Particles Do to Your Health?

Particle pollution can be very dangerous to breathe. Breathing particle pollution may trigger illness, hospitalization and premature death, risks that are showing up in new studies that validate earlier research.

Breathing particle pollution may trigger illness, hospitalization and premature death.

Thanks to steps taken to reduce particle pollution, good news is growing from researchers who study the drop in year-round levels of particle pollution.

Looking at air quality in 545 counties in the U.S. between 2000 and 2007, researchers found that people had approximately four months added to their life expectancy on average due to cleaner air. Women and people who lived in urban and densely populated counties benefited the most.[34]

Another long-term study of six U.S. cities tracked from 1974 to 2009 added more evidence of the benefits. Their findings suggest that cleaning up particle pollution had almost immediate health benefits. They estimated that the U.S. could prevent approximately 34,000 premature deaths a year if the nation could lower annual levels of particle pollution by 1 µg/m^3.[35]

Other researchers estimated that reductions in air pollution can be expected to produce rapid improvements in public health, with fewer deaths occurring within the first two years after reductions.[36]

These studies add to the growing research that cleaning up air pollution improves life and health.

Short-Term Exposure Can Be Deadly

First and foremost, short-term exposure to particle pollution can kill. Peaks or spikes in particle pollution can last for hours to days. Deaths can occur on the very day that particle levels are high, or within one to two months afterward. Particle pollution does not just make people die a few days earlier than they might otherwise—these are deaths that would not have occurred if the air were cleaner.[37]

Even low levels of particles can be deadly. A 2016 study found that people age 65 and older in New England faced a higher risk of premature death from particle pollution, even in places that met current standards for short-term particle pollution.[38] Another study in 2017 looked more closely at Boston and found a similar higher risk of premature death from particle pollution in a city that meets current limits on short-term particle pollution.[39]

Particle pollution also diminishes lung function, causes greater use of asthma medications and increased rates of school absenteeism, emergency room visits and hospital admissions. Other adverse effects include coughing, wheezing, cardiac arrhythmias and heart attacks. According to extensive research, short-term increases in particle pollution have been linked to:

- death from respiratory and cardiovascular causes, including strokes;[40, 41, 42, 43]
- increased mortality in infants and young children;[44]
- increased numbers of heart attacks, especially among the elderly and in people with heart conditions;[45]
- inflammation of lung tissue in young, healthy adults;[46]
- increased hospitalization for cardiovascular disease, including strokes and congestive heart failure;[47, 48, 49]
- increased emergency room visits for patients suffering from acute respiratory ailments;[50]
- increased hospitalization for asthma among children;[51, 52, 53] and
- increased severity of asthma attacks in children.[54]

Again, the impact of even short-term exposure to particle pollution on healthy adults was demonstrated in the Galveston lifeguard study. In addition to the harmful effects of ozone pollution, lifeguards had reduced lung volume at the end of the day when fine particle levels were high.[55]

Year-Round Exposure

Breathing high levels of particle pollution day in and day out can also be deadly, as landmark studies in the 1990s conclusively showed[56] and as other studies confirmed.[57] Chronic exposure to particle pollution can shorten life by one to three years.[58] Recent research has confirmed that long-term exposure to particle pollution still kills, even with the declining levels in the U.S. since 2000 [59] and even in areas, such as New England, that currently meet the official limit, or standard, for year-round particle pollution.[60]

In late 2013, the International Agency for Research on Cancer, part of the World Health Organization, concluded that particle pollution could cause lung cancer. The IARC reviewed the most recent research and reported that the risk of lung cancer increases as the particle levels rise.[61]

In late 2013, the World Health Organization concluded that particle pollution could cause lung cancer.

Year-round exposure to particle pollution has also been linked to:

- increased hospitalization for asthma attacks for children living near roads with heavy truck or trailer traffic;[62, 63]
- slowed lung function growth in children and teenagers;[64, 65]
- development of asthma in children up to age 14;[66]
- significant damage to the small airways of the lungs;[67]
- increased risk of death from cardiovascular disease;[68] and
- increased risk of lower birth weight and infant mortality.[69]

Research into the health risks of 65,000 women over age 50 found that those who lived in areas with higher levels of particle pollution faced a much greater risk of dying from heart disease than had been previously estimated. Even women who lived within the same city faced differing risks depending on the annual levels of pollution in their neighborhood.[70]

New research has found evidence that long-term exposure to particle pollution may increase the risk of developing diabetes. Two independent reviews of published research found that particle pollution may increase the risk of developing type 2 diabetes mellitus.[71]

Scientists have found links between particle pollution and mental health concerns. A study of 27,000 residents in Seoul, Korea, found that breathing particle pollution over a long time increased the risk of major depressive disorder. The risk was higher for those who also had a chronic disease such as asthma, COPD, or diabetes.[72] Older adults suffered more symptoms of depression and anxiety when particle pollution was higher in a large study looking at data from community living groups across the United States. Those who lived in lower socioeconomic situations or who had a history of respiratory illness or heart disease were more likely to have anxiety symptoms.[73]

The EPA completed their most recent review of the current research on particle pollution in December 2009.[74] The EPA had engaged a panel of expert scientists, the Clean Air Scientific Advisory Committee, to help them assess the evidence. The EPA concluded that particle pollution caused multiple, serious threats to health. Their findings are highlighted in the box below.

EPA Concludes Fine Particle Pollution Poses Serious Health Threats

- Causes early death (both short-term and long-term exposure)
- Causes cardiovascular harm (e.g., heart attacks, strokes, heart disease, congestive heart failure)
- Likely to cause respiratory harm (e.g., worsened asthma, worsened COPD, inflammation)
- May cause cancer
- May cause reproductive and developmental harm

—U.S. Environmental Protection Agency, *Integrated Science Assessment for Particulate Matter*, December 2009. EPA 600/R-08/139F

Where Does Particle Pollution Come From?

Particle pollution is produced through two separate processes—mechanical and chemical.

Mechanical processes break down bigger bits into smaller bits with the material remaining essentially the same, only becoming smaller. Mechanical processes primarily create coarse particles.[75] Dust storms, construction and demolition, mining operations, and agriculture are among the activities that produce coarse particles. Tire, brake pad and road wear can also create coarse particles. Bacteria, pollen, mold, and plant and animal debris are also included as coarse particles.[76]

By contrast, chemical processes in the atmosphere create most of the tiniest fine and ultrafine particles. Combustion sources burn fuels and emit gases. These gases can vaporize and then condense to become a particle of the same chemical compound. Or they can react with other gases or particles in the atmosphere to form a particle of a different chemical compound. Particles formed by this latter process come from the reaction of elemental carbon (soot), heavy metals, sulfur dioxide (SO_2), nitrogen oxides (NO_x) and volatile organic compounds with water and other compounds in the atmosphere.[77] Burning fossil fuels in factories, power plants, steel mills, smelters, diesel- and gasoline-powered motor vehicles (cars and trucks) and equipment generate a large part of the raw materials for fine particles. So does burning wood in residential fireplaces and wood stoves or burning agricultural fields or forests.

Chemical processes in the atmosphere create most of the tiniest particles.

Are Some Particles More Dangerous Than Others?

With so many sources of particles, researchers want to know if some particles pose greater risk than others. Researchers are exploring possible differences in health effects of the sizes of particles and particles from different sources, such as diesel particles from trucks and buses or sulfates from coal-fired power plants. Recent studies have tried to answer this question. So far, the answers are complicated.

Each particle may have many different components. The building blocks of each can include several biological and chemical components. Bacteria, pollen and other biological ingredients can combine in the particle with chemical agents, such as heavy metals, elemental carbon, dust and secondary species like sulfates and nitrates. These combinations mean that particles can have complex effects on the body.[78]

Some studies have found different kinds of particles may have greater risk for different health outcomes.

- For example, one 2015 study found that particles from burning fossil fuels, including coal-burning and diesel emissions, increased the risk of dying prematurely from ischemic heart disease, but that particles from wind-blown soil and biomass combustion did not.[79]
- Another recent study looked at older adults in Connecticut and Massachusetts and found that breathing black carbon, calcium and road dust particles was more likely to send them to the hospital for cardiovascular and respiratory problems than other particles.[80]
- Some of the same researchers found that when they looked at the risk of low birthweight for newborns in the Northeast and Mid-Atlantic states, different particles harmed some groups more than others.[81]

Other studies have identified the challenges of exploring all the kinds of particles and their health effects with the limited monitoring across the nation.[82] Some particles serve as carriers for other chemicals that are also toxic, and the combination may worsen the impact.[83, 84]

The best evidence shows that having less of all types of particles in the air leads to better health and longer lives.

Focusing on Children's Health

Children face special risks from air pollution because their lungs are growing and because they are so active.

Just like the arms and legs, the largest portion of a child's lungs will grow long after he or she is born. Eighty percent of their tiny air sacs develop after birth. Those sacs, called the alveoli, are where the life-sustaining transfer of oxygen to the blood takes place. The lungs and their alveoli aren't fully grown until children become adults.[85] In addition, the body's defenses that help adults fight off infections are still developing in young bodies.[86] Children have more respiratory infections than adults, which also seems to increase their susceptibility to air pollution.[87]

Furthermore, children don't behave like adults, and their behavior also affects their vulnerability. They are outside for longer periods and are usually more active when outdoors. Consequently, they inhale more polluted outdoor air than adults typically do.[88]

Air Pollution Affects Children Before They Are Born

Several studies have found air pollution linked to harm to children while they are still in the womb. A large study in California found that higher particle pollution levels increased the risk of preterm birth.[89] Pregnant women exposed to even low levels of particle pollution had higher risk factors for preterm birth in a Boston study.[90] Preterm births occurred more frequently when particle pollution spiked, as an Australian study found, even when they controlled for other risk factors.[91]

> The largest portion of a child's lungs will grow long after he or she is born.

Air Pollution Increases Risk of Underdeveloped Lungs

The Southern California Children's Health study looked at the long-term effects of particle pollution on teenagers. Tracking 1,759 children who were between ages 10 and 18 from 1993 to 2001, researchers found that those who grew up in more polluted areas face the increased risk of having underdeveloped lungs, which may never recover to their full capacity. The average drop in lung function was 20 percent below what was expected for the child's age, similar to the impact of growing up in a home with parents who smoked.[92]

Community health studies are pointing to less obvious, but serious effects from year-round exposure to ozone, especially for children. Scientists followed 500 Yale University students and determined that living just four years in a region with high levels of ozone and related co-pollutants was associated with diminished lung function and frequent reports of respiratory symptoms.[93] A much larger study of 3,300 schoolchildren in Southern California found reduced lung function in girls with asthma and boys who spent more time outdoors in areas with high levels of ozone.[94]

Cleaning Up Pollution Can Reduce Risk to Children

There is also real-world evidence that reducing air pollution can help protect children.

A 2015 follow-up to that Southern California Children's Health study showed that reducing pollution could improve children's health. This time they tracked a different group of 863 children living in the same area, but growing up between 2007 and 2011, when the air in Southern California was much cleaner. They compared these children to those who had been part of their earlier studies when the air was dirtier. Children growing up in the cleaner air had much greater lung function, a benefit that may help them throughout their lives. As the researchers noted, their study suggested that "all children have the potential to benefit from improvements in air quality." [95]

In Switzerland, particle pollution dropped during a period in the 1990s. Researchers there tracked 9,000 children over a nine-year period, following their respiratory symptoms. After taking other factors such as family characteristics and indoor air pollution into account, the researchers noted that during the years with less pollution, the children had fewer episodes of chronic cough, bronchitis, common cold and conjunctivitis symptoms.[96]

Disparities in the Impact of Air Pollution

The burden of air pollution is not evenly shared. Poorer people and some racial and ethnic groups are among those who often face higher exposure to pollutants and who may experience greater responses to such pollution. Many studies have explored the differences in harm from air pollution to racial or ethnic groups and people who are in a low socioeconomic position, have less education, or live nearer to major sources,[97] including a workshop the American Lung Association held in 2001 that focused on urban air pollution and health inequities.[98]

Many studies have looked at differences in the impact on premature death. Results have varied widely, particularly for effects between racial groups. Some studies have found no differences among races,[99] while others found greater responsiveness for whites and Hispanics, but not African Americans,[100] or for African Americans but not other races or ethnic groups.[101] Other researchers have found greater risk for African Americans from hazardous air pollutants, including those pollutants that also come from traffic sources.[102]

> Poorer people and some racial and ethnic groups often face higher exposure and greater responses to pollution.

Socioeconomic position has been more consistently associated with greater harm from air pollution. Multiple large studies show evidence of that link. Low socioeconomic status consistently increased the risk of premature death from fine particle pollution among 13.2 million Medicare recipients studied in the largest examination of particle pollution mortality nationwide.[103] In the 2008 study that found greater risk for premature death for African Americans, researchers also found greater risk for people living in areas with higher unemployment or higher use of public transportation.[104] A 2008 study of Washington, DC, found that while poor air quality and worsened asthma went hand in hand in areas where Medicaid enrollment was high, the areas with the highest Medicaid enrollment did not always have the strongest association of high air pollution and asthma attacks.[105] A 2016 study of New Jersey residents found that the risk of dying early from long-term exposure to particle pollution was higher in communities with larger African-American populations, lower home values and lower median income.[106] However, two other studies in France have found no association with lower income and asthma attacks.[107]

Scientists have speculated that there are three broad reasons why disparities may exist. First, groups may face greater exposure to pollution because of factors ranging from racism to class bias to housing market dynamics and land costs. For example, pollution sources may be located near disadvantaged communities, increasing exposure to harmful pollutants. Second, low social position may make some groups more susceptible to health threats because of factors related to their disadvantage. Lack of access to health care, grocery stores and good jobs; poorer job opportunities; dirtier workplaces or higher traffic exposure are among the factors that could handicap groups and increase the risk of harm. Finally, existing health conditions, behaviors or traits may predispose some groups to greater risk. For example, diabetics are among the groups most at risk from air pollutants, and the elderly, African Americans, Mexican Americans and people living near a central city have higher incidence of diabetes.[108]

Communities of color also may be more likely to live in counties with higher levels of pollution. Non-Hispanic blacks and Hispanics were more likely to live in counties that had worse problems with particle pollution, researchers found in a 2011 analysis. Non-Hispanic blacks were also more likely to live in counties with worse ozone pollution. Income groups, by contrast, differed little in these exposures. However, since few rural counties have monitors, the primarily older, non-Hispanic white residents of those counties lack information about the air quality in their communities.[109]

Unemployed people, those with low income or low education and non-Hispanic blacks were found to be more likely to live in areas with higher exposures to particle pollution in a 2012 study. However, the different racial/ethnic and income groups were often breathing very different kinds of particles; the different composition and structure of these particles may have different health impacts.[110]

Highways May Be Especially Dangerous for Breathing

Being in heavy traffic or living near a road may be even more dangerous than being in other places in a community. Growing evidence shows that the vehicle emissions coming directly from those highways may be higher than in the community as a whole, increasing the risk of harm to people who live or work near busy roads.

The number of people living "next to a busy road" may include 30 to 45 percent of the urban population in North America, according to the most recent review of the evidence. In January 2010, the Health Effects Institute published a major review of the evidence by a panel of expert scientists. The panel looked at over 700 studies from around the world, examining the health effects. They concluded that traffic pollution causes asthma attacks in children, and may cause a wide range of other effects including the onset of childhood asthma, impaired lung function, premature death and death from cardiovascular diseases, and cardiovascular morbidity. The area most affected, they concluded, was roughly 0.2 to 0.3 miles (300 to 500 meters) from the highway.[111]

Children and teenagers are among the most vulnerable—though not the only ones at risk. A Danish study found that long-term exposure to traffic air pollution may increase the risk of developing chronic obstructive pulmonary disease (COPD). They found that those most at risk were people who already had asthma or diabetes.[112] Studies have found increased risk of premature death from living near a major highway or an urban road.[113] Another study found an increase in risk of heart attacks from being in traffic, whether driving or taking public transportation.[114] Urban women in a Boston study experienced decreased lung function associated with traffic-related pollution.[115]

Adults living closer to the road—within 300 meters—may risk dementia. In 2017, a study of residents of Ontario, Canada, found that those who lived close to heavy traffic had a higher risk of dementia, though not for Parkinson's disease or multiple sclerosis. Researchers found the strongest association among those who lived closest to the roads (less than 50 meters), who had never moved and who lived in major cities.[116]
A study of older men in 2011 also found that long-term exposure to traffic pollution increased their risk of having poor cognition.[117]

How to Protect Yourself from Ozone and Particle Pollution

To minimize your exposure to ozone and particle pollution:

- Pay attention to forecasts for high air pollution days to know when to take precautions;
- Avoid exercising near high-traffic areas;
- Avoid exercising outdoors when pollution levels are high, or substitute an activity that requires less exertion;
- Do not let anyone smoke indoors and support measures to make all places smokefree; and
- Reduce the use of fireplaces and wood-burning stoves.

Bottom line: Help yourself and everyone else breathe easier. Support national, state and local efforts to clean up sources of pollution. Your life and the life of someone you love may depend on it.

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1 Ozone and particle pollution are the most widespread, but they aren't the only serious air pollutants. Others include carbon monoxide, lead, nitrogen dioxide, and sulfur dioxide, as well as scores of toxins such as mercury, arsenic, benzene, formaldehyde, and acid gases. However, the monitoring networks are not as widespread nationwide for the other pollutants.

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Statistical Methodology: The Air Quality Data

Data Sources

The data on air quality throughout the United States were obtained from the U.S. Environmental Protection Agency's Air Quality System (AQS), formerly called Aerometric Information Retrieval System (AIRS) database. The American Lung Association contracted with Dr. Allen S. Lefohn, A.S.L. & Associates, Helena, Montana, to characterize the hourly averaged ozone concentration information and the 24-hour averaged $PM_{2.5}$ concentration information for the three-year period for 2013-2015 for each monitoring site.

Design values for the annual $PM_{2.5}$ concentrations by county for the period 2013-2015 came from data posted on July 29, 2016, at the U.S. Environmental Protection Agency's website at https://www.epa.gov/sites/production/files/2016-07/pm25_designvalues_20132015_final_07_29_16.xlsx.

Ozone Data Analysis

The 2013, 2014 and 2015 AQS hourly ozone data were used to calculate the daily 8-hour maximum concentration for each ozone-monitoring site. The hourly averaged ozone data were downloaded on August 11, 2016, following the close of the authorized period for quality review and assurance certification of data. Only the hourly average ozone concentrations derived from FRM and FEM monitors were used in the analysis. The data were considered for a three-year period for the same reason that the EPA uses three years of data to determine compliance with the ozone standard: to prevent a situation in any single year, where anomalies of weather or other factors create air pollution levels, which inaccurately reflect the normal conditions. The highest 8-hour daily maximum concentration in each county for 2013, 2014 and 2015, based on the EPA-defined ozone season, was identified.

The current national ambient air quality standard for ozone is 70 parts per billion (ppb) measured over eight hours. The EPA's Air Quality Index reflects the 70 ppb standard. A.S.L. & Associates prepared a table by county that summarized, for each of the three years, the number of days the ozone level was within the ranges identified by the EPA based on the EPA Air Quality Index:

8-hour Ozone Concentration	Air Quality Index Levels
0 – 54 ppb	🟩 Good (Green)
55 – 70 ppb	🟨 Moderate (Yellow)
71 – 85 ppb	🟧 Unhealthy for Sensitive Groups (Orange)
86 – 105 ppb	🟥 Unhealthy (Red)
106 – 200 ppb	🟪 Very Unhealthy (Purple)
>201 ppb	🟫 Hazardous (Maroon)

The goal of this report was to identify the number of days that 8-hour daily maximum concentrations in each county occurred within the defined ranges. This approach provided an indication of the level of pollution for all monitored days, not just those days that fell under the requirements for attaining the national ambient air quality standards. Therefore, no data capture criteria were applied to eliminate monitoring sites or to require a number of valid days for the ozone season.

The daily maximum 8-hour average concentration for a given day is derived from the highest of the 17 consecutive 8-hour averages beginning with the 8-hour period from 7:00 a.m. to 3:00 p.m. and ending with the 8-hour period from 11:00 p.m. to 7:00 a.m. the following day. This follows the process EPA uses for the current ozone standard adopted in 2015, but differs from the form used under the previous 0.075 ppm 8-hour average ozone standard that was established in 2008. All valid days of data within the ozone season were used in the analysis. However, for computing an 8-hour average, at least 75 percent of the hourly concentrations (i.e., 6-8 hours) had to be available for the 8-hour period. In addition, an 8-hour daily maximum average was identified if valid 8-hour averages were available for at least 75 percent of possible hours in the day (i.e., at least 13 of the possible 17 8-hour averages). Because the EPA includes days with inadequate data (i.e., not 75 percent complete) if the standard value is exceeded, our data capture methodology also included the site's 8-hour value if at least one valid 8-hr period were available and it was 71 ppb or higher.

As instructed by the Lung Association, A.S.L. & Associates included the exceptional and natural events that were identified in the database and identified for the Lung Association the dates and monitoring sites that experienced such events. Some data have been flagged by the state or local air pollution control agency to indicate that they had raised issues with EPA about those data. For each day across all sites within a specific county, the highest daily maximum 8-hour average ozone concentration was recorded and then the results were summarized by county for the number of days the ozone levels were within the ranges identified above.

Following receipt of the above information, the American Lung Association identified the number of days each county, with at least one ozone monitor, experienced air quality designated as orange (Unhealthy for Sensitive Groups), red (Unhealthy) or purple (Very Unhealthy).

Short-Term Particle Pollution Data Analysis

A.S.L. & Associates identified the maximum daily 24-hour AQS PM$_{2.5}$ concentration for each county in 2013, 2014 and 2015 with monitoring information. The 24-hour PM$_{2.5}$ data were downloaded on August 10, 2016, following the close of the authorized period for quality review and assurance certification of data. In addition, hourly averaged PM$_{2.5}$ concentration data were characterized into 24-hour average PM$_{2.5}$ values by the EPA and provided to A.S.L. & Associates. Using these results, A.S.L. & Associates prepared a table by county that summarized, for each of the three years, the number of days the maximum of the daily PM$_{2.5}$ concentration was within the ranges identified by the EPA based on the EPA Air Quality Index, as adopted by the EPA on December 14, 2012:

24-hour PM$_{2.5}$ Concentration	Air Quality Index Levels
0.0 mg/m^3 to 12.0 mg/m^3	🟩 Good (Green)
12.1 mg/m^3 to 35.4 mg/m^3	🟨 Moderate (Yellow)
35.5 mg/m^3 to 55.4 mg/m^3	🟧 Unhealthy for Sensitive Groups (Orange)
55.5 mg/m^3 to 150.4 mg/m^3	🟥 Unhealthy (Red)
150.5 mg/m^3 to 250.4 mg/m^3	🟪 Very Unhealthy (Purple)
greater than or equal to 250.5 mg/m^3	🟫 Hazardous (Maroon)

All previous data collected for 24-hour average PM$_{2.5}$ were characterized using the AQI thresholds listed above.

The goal of this report was to identify the number of days that the maximum in each county of the daily PM$_{2.5}$ concentration occurred within the defined ranges. This approach provided an indication of the level of pollution for all monitored days, not just those days that fell under the requirements for attaining the national ambient air quality standards. Therefore, no data capture criteria were used to eliminate monitoring sites. Both 24-hour averaged PM data, as well as hourly averaged PM data averaged over 24 hours were used. Included in the analysis are data collected using only FRM and FEM methods, which reported hourly and 24-hour averaged data. As instructed by the Lung Association, A.S.L. & Associates included the exceptional and natural events that were identified in the database and identified for the Lung Association the dates and monitoring sites that experienced such events. Some data have been flagged by the state or local air pollution control agency to indicate that they had raised issues with EPA about those data. For each day across all sites within a specific county, the highest daily maximum 24-h $PM_{2.5}$ concentration was recorded and then the results were summarized by county for the number of days the concentration levels were within the ranges identified on the chart on the preceding page.

Following receipt of the above information, the American Lung Association identified the number of days each county, with at least one $PM_{2.5}$ monitor, experienced air quality designated as orange (Unhealthy for Sensitive Groups), red (Unhealthy), purple (Very Unhealthy) or maroon (Hazardous).

Description of County Grading System

Ozone and Short-Term Particle Pollution (24-hour $PM_{2.5}$)

The grades for ozone and short-term particle pollution (24-hour $PM_{2.5}$) were based on a weighted average for each county. To determine the weighted average, the Lung Association followed these steps:

1. First, assigned weighting factors to each category of the Air Quality Index. The number of orange days experienced by each county received a factor of 1; red days, a factor of 1.5; purple days, a factor of 2; and maroon days, a factor of 2.5. This allowed days where the air pollution levels were higher to receive greater weight.
2. Next, multiplied the total number of days within each category by their assigned factor, and then summed all the categories to calculate a total.
3. Finally, divided the total by three to determine the weighted average, since the monitoring data were collected over a three-year period.

The weighted average determined each county's grades for ozone and 24-hour $PM_{2.5}$.

- All counties with a weighted average of zero (corresponding to no exceedances of the standard over the three-year period) were given a grade of "A."
- For ozone, an "F" grade was set to generally correlate with the number of unhealthy air days that would place a county in nonattainment for the ozone standard.
- For short-term particle pollution, fewer unhealthy air days are required for an F than for nonattainment under the $PM_{2.5}$ standard. The national air quality standard is set to allow 2 percent of the days during the three years to exceed 35 $\mu g/m^3$ (called a "98th percentile" form) before violating the standard. That would be roughly 21 unhealthy days in three years. The grading used in this report would allow only about 1 percent of the days to be over 35 $\mu g/m^3$ (called a "99th percentile" form) of the $PM_{2.5}$. The American Lung Association supports using the tighter limits in a 99th percentile form as a more appropriate standard that is intended to protect the public from short-term spikes in pollution.

Grading System

Grade	Weighted Average	Approximate Number of Allowable Orange/Red/Purple/Maroon days
A	0.0	None
B	0.3 to 0.9	1 to 2 orange days with no red
C	1.0 to 2.0	3 to 6 days over the standard: 3 to 5 orange with no more than 1 red OR 6 orange with no red
D	2.1 to 3.2	7 to 9 days over the standard: 7 total (including up to 2 red) to 9 orange with no red
F	3.3 or higher	9 days or more over the standard: 10 orange days or 9 total including at least 1 or more red, purple or maroon

Weighted averages allow comparisons to be drawn based on severity of air pollution. For example, if one county had nine orange days and no red days, it would earn a weighted average of 3.0 and a D grade. However, another county that had only eight orange days but also two red days, which signify days with more serious air pollution, would receive a F. That second county would have a weighted average of 3.7.

Note that this system differs significantly from the methodology the EPA uses to determine violations of both the ozone and the 24-hour $PM_{2.5}$ standards. The EPA determines whether a county violates the standard based on the fourth maximum daily 8-hour ozone reading each year averaged over three years. Multiple days of unhealthy air beyond the highest four in each year are not considered. By contrast, the system used in this report recognizes when a community's air quality repeatedly results in unhealthy air throughout the three years. Consequently, some counties will receive grades of "F" in this report, showing repeated instances of unhealthy air, while still meeting the EPA's 2015 ozone standard. The American Lung Association's position is that the evidence shows that the 2015 ozone standard, although stronger than the 2008 standard, still fails to adequately protect public health.

The Lung Association calculates the population at risk from these pollutants based on the population from the entire county where the monitor is located and the largest metropolitan area that contains that county. Not only do people from that county or metropolitan area circulate within the county and the metropolitan area, the air pollution circulates to that monitor through the county and metropolitan area.

Counties were ranked by weighted average. Metropolitan areas were ranked by the highest weighted average among the counties within a given Metropolitan Statistical Area as of 2015 as defined by the White House Office of Management and Budget (OMB).

Year-Round Particle Pollution (Annual $PM_{2.5}$)

Since no comparable Air Quality Index exists for year-round particle pollution (annual $PM_{2.5}$), the grading was based on the 2012 National Ambient Air Quality Standard for annual $PM_{2.5}$ of 12 $\mu g/m^3$. Counties that EPA listed as being at or below 12 $\mu g/m^3$ were given grades of "Pass." Counties EPA listed as being at or above 12.1 $\mu g/m^3$ were given grades of "Fail." Where insufficient data existed for EPA to determine a design value, those counties received a grade of "Incomplete."

EPA officially recognized that data collected in all Illinois counties, in some Maine counties and in most Tennessee counties were processed in certain laboratories where quality control issues meant that available data could not be considered for development of an official design value. For short-term and annual particle pollution, those counties received a grade of "Incomplete."

Design value is the calculated concentration of a pollutant based on the form of the national ambient air quality standard and is used by EPA to determine whether or not the air quality in a county meets the standard. Counties were ranked by design value. Metropolitan areas were ranked by the highest design value among the counties within a given Metropolitan Statistical Area as of 2015 as defined by the OMB.

The Lung Association received critical assistance from members of the National Association of Clean Air Agencies and the Association of Air Pollution Control Agencies. With their assistance, all state and local agencies were provided the opportunity to review and comment on the data in draft tabular form. The Lung Association reviewed all discrepancies with the agencies and, if needed, with Dr. Lefohn at A.S.L. & Associates. Questions about the annual PM design values were discussed with EPA; however, the Lung Association made final decisions to grade counties as "Incomplete" where EPA considered $PM_{2.5}$ data to have inadequate quality assurance. The American Lung Association wishes to express its continued appreciation to the state and local air directors for their willingness to assist in ensuring that the characterized data used in this report are correct.

Calculations of Populations at Risk

Presently county-specific measurements of the number of persons with chronic conditions are not generally available. In order to assess the magnitude of chronic conditions at the state and county levels, we have employed a synthetic estimation technique originally developed by the U.S. Census Bureau. This method uses age-specific national and state estimates of self-reported conditions to project disease prevalence to the county level. The exception to this is poverty, for which estimates are available at the county level.

Population Estimates

The Lung Association includes the total county population in discussions of populations at risk from exposure to pollution in each county. The Lung Association uses that conservative count based on several factors: the recognized limited number and locations of monitors in most counties and metropolitan areas; the movement of the population both in daily activities, including outdoor activities, such as exercise or work; and the transport of emission from sources into and across the county to reach the monitor.

The U.S. Census Bureau estimated data on the total population of each county in the United States for 2015. The Census Bureau also estimated the age-specific breakdown of the population and how many individuals were living in poverty by county. These estimates are the best information on population demographics available between decennial censuses.

Poverty estimates came from the Census Bureau's Small Area Income and Poverty Estimates (SAIPE) program. The program does not use direct counts or estimates from sample surveys, as these methods would not provide sufficient data for all counties. Instead, a model based on estimates of income or poverty from the Annual Social and Economic Supplement (ASEC) to the Current Population Survey (CPS) is used to develop estimates for all states and counties.

Prevalence Estimates

Chronic Obstructive Pulmonary Disease, Cardiovascular Disease, Asthma and Diabetes. In 2015, the Behavioral Risk Factor Surveillance System (BRFSS) survey found that approximately 21.6 million (8.9 percent) of adults residing in the United States and 8.5 percent of children from 30 states and Washington, D.C., reported currently having asthma. Among adults in the Unites States in 2015, 15.5 million (6.3 percent) had ever been diagnosed with chronic obstructive pulmonary disease (COPD), 20.4 million (8.4

percent) had ever been diagnosed with cardiovascular disease and 25.6 million (10.4 percent) had ever been diagnosed with diabetes.

The prevalence estimate for pediatric asthma is calculated for those younger than 18 years. Local area prevalence of pediatric asthma is estimated by applying 2015 state prevalence rates, or if not available, the national rate from the BRFSS to pediatric county-level resident populations obtained from the U.S. Census Bureau website. Pediatric asthma data from the 2015 BRFSS were available for thirty states and Washington D.C., from the 2014 BRFSS for seven states, from the 2013 BRFSS for one state, from the 2012 BRFSS for two states, from the 2011 BRFSS for one state, and national data were used for the nine states[1] that had no data available. Data from earlier years were not used due to changes in the 2011 survey methodology.

The prevalence estimate for COPD, cardiovascular disease, adult asthma and diabetes is calculated for those aged 18-44 years, 45-64 years and 65 years and older. Local area prevalence for these diseases is estimated by applying age-specific state prevalence rates from the 2015 BRFSS to age-specific county-level resident populations obtained from the U.S. Census Bureau website. Cardiovascular disease included ever having been diagnosed with a heart attack, angina or coronary heart disease, or stroke.

Incidence Estimates

Lung Cancer. State- and gender-specific lung cancer incidence rates for 2013 were obtained from StateCancerProfiles.gov, a system that provides access to statistics from both the National Cancer Institute's Surveillance, Epidemiology and End Results (SEER) program and the Center for Disease Control and Prevention's National Program of Cancer Registries.

Local area incidence of lung cancer is estimated by applying 2013 age-adjusted and sex-specific incidence rates to 2015 county populations obtained from the U.S. Census Bureau. Thereafter, the incidence estimates for each county within a state are summed to determine overall incidence. Estimates for Nevada are based on 2010 rates.

Limitations of Estimates. Since the statistics presented by the BRFSS and SAIPE are based on a sample, they will differ (due to random sampling variability) from figures that would be derived from a complete census or case registry of people in the U.S. with these diseases. The results are also subject to reporting, non-response and processing errors. These types of errors are kept to a minimum by methods built into the survey.

Additionally, a major limitation of the BRFSS is that the information collected represents self-reports of medically diagnosed conditions, which may underestimate disease prevalence since not all individuals with these conditions have been properly diagnosed. However, the BRFSS is the best available source for information on the magnitude of chronic disease at the state level. The conditions covered in the survey may vary considerably in the accuracy and completeness with which they are reported.

Local estimates of chronic diseases are scaled in direct proportion to the base population of the county and its age distribution. No adjustments are made for other factors that may affect local prevalence (e.g., local prevalence of cigarette smokers or occupational exposures) since the health surveys that obtain such data are rarely conducted on the county level. Because the estimates do not account for geographic differences in the prevalence of chronic and acute diseases, the sum of the estimates for each of the counties in the United States may not exactly reflect the national or state estimates derived from the BRFSS.

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[1] 2014: Alabama, Kentucky, Maryland, North Carolina, Tennessee, Washington, West Virginia. 2013: Arizona. 2012: North Dakota and Wyoming. 2011: Iowa. National: Alaska, Arkansas, Colorado, Delaware, Florida, Idaho, South Carolina, South Dakota and Virginia.

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State Table Notes

A full explanation of the sources of data and methodology is in **Methodology**.

Notes for all state data tables

1. **Total Population** is based on 2015 U.S. Census and represents the at-risk populations in counties with ozone or $PM_{2.5}$ pollution monitors; it does not represent the entire state's sensitive populations.
2. **Those 18 & under** and **65 & over** are vulnerable to ozone and $PM_{2.5}$. Do not use them as population denominators for disease estimates—that will lead to incorrect estimates.
3. **Pediatric asthma** estimates are for those under 18 years of age and represent the estimated number of people who had asthma in 2015 based on the state rates when available or national rates when not (Behavioral Risk Factor Surveillance System, or BRFSS), applied to county population estimates (U.S. Census).
4. **Adult asthma** estimates are for those 18 years and older and represent the estimated number of people who had asthma during 2015 based on state rates (BRFSS) applied to county population estimates (U.S. Census).
5. **COPD** estimates are for adults 18 and over who had ever been diagnosed with chronic obstructive pulmonary disease, which includes chronic bronchitis and emphysema, based on state rates (BRFSS) applied to county population estimates (U.S. Census).
6. **Lung cancer** estimates are for all ages and represent the estimated number of people diagnosed with lung cancer in 2013 based on state rates (StateCancerProfiles.gov) applied to county population estimates (U.S. Census).
7. **Cardiovascular disease** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to county population estimates (U.S. Census). CV disease includes coronary heart disease, stroke, and heart attack.
8. **Diabetes** estimates are for adults 18 and over who have been diagnosed within their lifetime based on state rates (BRFSS) applied to county population estimates (U.S. Census).
9. **Poverty** estimates include all ages and come from the U.S. Census Bureau's Small Area Income and Poverty Estimates program. The estimates are derived from a model using estimates of income or poverty from the Annual Social and Economic Supplement and the Current Population Survey, 2015.
10. Adding across rows does not produce valid estimates. Adding the at risk categories (asthma, COPD, poverty, etc.) will double-count people who fall into more than one category.

Notes for all state grades tables.

1. Not all counties have monitors for either ozone or particle pollution. If a county does not have a monitor, that county's name is not on the list in these tables. The decision about monitors in the county is made by the state and the U.S. Environmental Protection Agency, not by the American Lung Association.
2. **INC** (Incomplete) indicates that monitoring is underway for that pollutant in that county, but that the data are incomplete for all three years. Those counties are not graded. For particle pollution, some states collected data, but experienced laboratory quality issues that meant the data could not be used for assessing pollution levels.
3. **DNC** (Data Not Collected) indicates that data on that particular pollutant are not collected in that county.
4. The **Weighted Average (Wgt. Avg)** was derived by adding the three years of individual level data (2013-2015), multiplying the sums of each level by the assigned standard weights (i.e. 1=orange, 1.5=red, 2.0=purple and 2.5=maroon) and calculating the average. Grades are assigned based on the weighted averages as follows: A=0.0, B=0.3-0.9, C=1.0-2.0, D=2.1-3.2, F=3.3+.
5. The Design Value is the calculated concentration of a pollutant based on the form of the National Ambient Air Quality Standard, and is used by EPA to determine whether the air quality in a county meets the standard. The numbers refer to micrograms per cubic meter, or $\mu g/m^3$. Design values for the annual $PM_{2.5}$ concentrations by county for the period 2013-2015 are as posted on July 26, 2016 at EPA's website at https://www.epa.gov/air-trends/air-quality-design-values. The 2013-2015 design values were compared to the 2012 National Ambient Air Quality Standard for Annual $PM_{2.5}$, particularly to the EPA's assessment of data quality required, as discussed on EPA's website at https://www.epa.gov/pm-pollution/2012-national-ambient-air-quality-standards-naaqs-particulate-matter-pm. Many design values are missing because state data did not meet quality requirements.
6. The annual average National Ambient Air Quality Standard for $PM_{2.5}$ is 12 $\mu g/m^3$ as of December 14, 2012. Counties with design values of 12 or lower received a grade of "Pass." Counties with design values of 12.1 or higher received a grade of "Fail."

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	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Baldwin	203,709	44,719	39,062	5,902	15,709	17,599	140	19,344	23,202	25,941
Clay	13,555	2,897	2,700	382	1,053	1,194	9	1,322	1,585	2,436
Colbert	54,354	11,698	10,232	1,544	4,217	4,700	37	5,139	6,174	9,732
DeKalb	71,130	17,539	11,383	2,315	5,306	5,730	49	6,101	7,372	14,481
Elmore	81,468	18,601	11,693	2,455	6,234	6,536	56	6,769	8,234	10,609
Etowah	103,057	22,585	18,278	2,981	7,961	8,752	71	9,456	11,391	19,146
Houston	104,173	24,547	17,147	3,240	7,880	8,515	71	9,090	10,969	18,829
Jefferson	660,367	152,511	96,633	20,127	50,335	52,865	451	54,982	66,751	115,897
Madison	353,089	78,771	49,684	10,396	27,236	28,736	243	29,667	36,236	45,877
Mobile	415,395	99,154	62,039	13,086	31,333	33,139	284	34,686	42,050	75,204
Montgomery	226,519	54,083	31,018	7,137	17,089	17,578	155	18,045	21,919	49,457
Morgan	119,565	27,527	19,529	3,633	9,117	9,914	82	10,564	12,787	19,250
Russell	59,660	15,352	7,574	2,026	4,396	4,501	41	4,579	5,584	13,575
Shelby	208,713	50,382	28,101	6,649	15,723	16,505	143	16,969	20,742	17,558
Sumter	13,103	2,553	2,197	337	1,043	1,101	9	1,164	1,401	4,073
Talladega	80,862	17,686	13,396	2,334	6,258	6,803	56	7,248	8,773	17,439
Tuscaloosa	203,976	42,579	24,553	5,619	15,992	15,511	140	15,316	18,631	38,704
Totals	**2,972,695**	**683,184**	**445,219**	**90,161**	**226,882**	**239,679**	**2,038**	**250,441**	**303,801**	**498,208**

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	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Baldwin	3	0	0	1.0	C	0	0	0	0.0	A	8.6	PASS
Clay	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.4	PASS
Colbert	0	0	0	0.0	A	0	0	0	0.0	A	8.9	PASS
DeKalb	1	0	0	0.3	B	0	0	0	0.0	A	9.2	PASS
Elmore	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Etowah	0	0	0	0.0	A	0	0	0	0.0	A	9.2	PASS
Houston	0	0	0	0.0	A	0	0	0	0.0	A	8.1	PASS
Jefferson	11	0	0	3.7	F	0	0	0	0.0	A	11.0	PASS
Madison	0	0	0	0.0	A	0	0	0	0.0	A	8.6	PASS
Mobile	7	0	0	2.3	D	0	0	0	0.0	A	8.6	PASS
Montgomery	1	0	0	0.3	B	0	0	0	0.0	A	9.3	PASS
Morgan	0	0	0	0.0	A	0	0	0	0.0	A	8.9	PASS
Russell	2	0	0	0.7	B	0	0	0	0.0	A	10.0	PASS
Shelby	4	0	0	1.3	C	0	0	0	0.0	A	INC	INC
Sumter	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Talladega	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.5	PASS
Tuscaloosa	0	0	0	0.0	A	0	0	0	0.0	A	9.0	PASS

ALASKA

American Lung Association in Alaska

www.lung.org/alaska

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Anchorage Municipality	298,695	73,959	28,001	6,271	21,084	8,706	166	12,779	15,881	25,305
Denali Borough	1,919	352	173	30	145	64	1	93	122	124
Fairbanks North Star Borough	99,631	24,116	8,349	2,045	7,139	2,756	56	3,943	4,891	7,671
Juneau City and Borough	32,756	7,216	3,594	612	2,372	1,060	18	1,597	1,992	2,542
Kenai Peninsula Borough	58,059	13,343	8,604	1,131	4,123	2,057	32	3,275	3,960	6,488
Matanuska-Susitna Borough	101,095	27,428	10,008	2,326	6,857	3,008	57	4,500	5,618	9,676
Totals	**592,155**	**146,414**	**58,729**	**12,414**	**41,720**	**17,651**	**331**	**26,188**	**32,463**	**51,806**

ALASKA

American Lung Association in Alaska

www.lung.org/alaska

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
Borough	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Anchorage Municipality	DNC	DNC	DNC	DNC	DNC	0	1	0	0.5	B	5.7	PASS
Denali Borough	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fairbanks North Star Borough	0	0	0	0.0	A	26	33	1	25.8	F	11.5	PASS
Juneau City and Borough	DNC	DNC	DNC	DNC	DNC	3	0	0	1.0	C	6.8	PASS
Kenai Peninsula Borough	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Matanuska-Susitna Borough	INC	INC	INC	INC	INC	20	2	0	7.7	F	7.1	PASS

ARIZONA

American Lung Association in Arizona

www.lung.org/arizona

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Apache	71,474	20,658	9,977	2,253	4,804	3,242	35	4,004	5,188	26,788
Cochise	126,427	28,038	26,125	3,058	9,240	6,964	62	8,939	11,020	20,439
Coconino	139,097	29,757	15,930	3,245	10,261	6,029	68	7,138	9,491	25,133
Gila	53,159	10,845	14,609	1,183	3,977	3,438	26	4,568	5,456	11,089
La Paz	20,152	3,451	7,491	376	1,545	1,505	10	2,069	2,342	4,398
Maricopa	4,167,947	1,030,669	592,961	112,410	295,494	193,792	2,033	237,849	307,832	667,637
Mohave	204,737	37,506	56,716	4,091	15,719	13,467	100	17,851	21,373	34,720
Navajo	108,277	29,874	17,825	3,258	7,398	5,271	53	6,633	8,407	29,810
Pima	1,010,025	218,540	185,865	23,835	74,267	52,701	492	66,528	83,206	184,628
Pinal	406,584	96,927	77,527	10,571	28,991	21,037	200	26,779	33,093	60,151
Santa Cruz	46,461	12,919	7,668	1,409	3,167	2,267	23	2,855	3,620	11,295
Yavapai	222,255	38,024	64,634	4,147	17,332	15,160	108	20,183	24,097	32,978
Yuma	204,275	52,433	36,813	5,719	14,162	9,995	100	12,659	15,606	41,159
Totals	**6,780,870**	**1,609,641**	**1,114,141**	**175,556**	**486,357**	**334,869**	**3,310**	**418,057**	**530,731**	**1,150,225**

ARIZONA

American Lung Association in Arizona

www.lung.org/arizona

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Apache	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Cochise	7	0	0	2.3	D	0	0	0	0.0	A	6.5	PASS
Coconino	11	0	0	3.7	F	INC	INC	INC	INC	INC	INC	INC
Gila	20	0	0	6.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
La Paz	12	0	0	4.0	F	INC	INC	INC	INC	INC	INC	INC
Maricopa	101	2	0	34.7	F	7	3	1	4.5	F	10.0	PASS
Mohave	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Navajo	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pima	7	0	0	2.3	D	0	0	0	0.0	A	5.5	PASS
Pinal	25	0	0	8.3	F	8	0	0	2.7	D	7.7	PASS
Santa Cruz	DNC	DNC	DNC	DNC	DNC	7	3	0	3.8	F	9.1	PASS
Yavapai	7	0	0	2.3	D	INC	INC	INC	INC	INC	INC	INC
Yuma	20	2	0	7.7	F	1	1	0	0.8	B	6.4	PASS

ARKANSAS

American Lung Association in Arkansas

www.lung.org/arkansas

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Arkansas	18,433	4,255	3,280	361	1,443	1,447	15	1,668	1,897	3,748
Ashley	20,838	4,889	3,929	415	1,619	1,641	17	1,919	2,167	4,040
Clark	22,633	4,334	3,638	367	1,824	1,666	18	1,823	2,082	4,466
Crittenden	48,963	13,578	6,133	1,151	3,608	3,380	39	3,647	4,267	12,473
Garland	97,177	20,122	21,427	1,706	7,785	8,111	78	9,762	10,867	18,354
Jackson	17,338	3,488	2,948	296	1,405	1,366	14	1,541	1,764	4,150
Newton	7,913	1,563	1,976	133	643	698	6	866	955	1,894
Polk	20,216	4,766	4,438	404	1,562	1,647	16	2,000	2,220	4,869
Pulaski	392,664	92,607	55,006	7,852	30,450	28,558	315	31,092	36,114	74,375
Union	40,144	9,591	6,842	813	3,111	3,095	32	3,542	4,043	7,800
Washington	225,477	56,325	24,743	4,776	16,954	14,630	183	14,926	17,610	36,600
Totals	**911,796**	**215,518**	**134,360**	**18,273**	**70,403**	**66,239**	**733**	**72,787**	**83,988**	**172,769**

ARKANSAS

American Lung Association in Arkansas

www.lung.org/arkansas

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Arkansas	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.1	PASS
Ashley	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.6	PASS
Clark	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Crittenden	1	0	0	0.3	B	1	0	0	0.3	B	9.4	PASS
Garland	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.0	PASS
Jackson	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.9	PASS
Newton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Polk	0	0	0	0.0	A	0	0	0	0.0	A	9.2	PASS
Pulaski	4	0	0	1.3	C	1	0	0	0.3	B	10.7	PASS
Union	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.1	PASS
Washington	0	0	0	0.0	A	0	0	0	0.0	A	8.6	PASS

CALIFORNIA

American Lung Association in California

www.lung.org/california

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Alameda	1,638,215	346,302	208,711	24,746	99,232	51,297	709	80,675	126,353	184,716
Amador	37,001	5,654	9,539	404	2,475	1,589	16	2,803	4,144	4,404
Butte	225,411	45,348	39,543	3,240	13,978	7,812	98	12,787	19,274	47,269
Calaveras	44,828	7,795	11,595	557	2,929	1,912	19	3,403	5,033	5,781
Colusa	21,482	5,958	2,889	426	1,198	646	9	1,042	1,611	2,800
Contra Costa	1,126,745	261,320	164,504	18,673	66,864	36,598	488	59,728	92,596	114,123
El Dorado	184,452	37,919	34,393	2,710	11,424	6,776	80	11,581	17,709	16,634
Fresno	974,861	279,544	112,074	19,976	53,384	27,289	423	42,457	66,139	241,669
Glenn	28,017	7,491	4,220	535	1,590	883	12	1,447	2,214	5,105
Humboldt	135,727	26,518	21,791	1,895	8,447	4,603	59	7,444	11,365	27,616
Imperial	180,191	51,119	22,442	3,653	9,934	5,187	78	8,178	12,647	41,685
Inyo	18,260	3,769	4,044	269	1,139	706	8	1,227	1,827	2,222
Kern	882,176	257,727	88,992	18,417	47,777	23,732	384	36,297	57,322	185,990
Kings	150,965	41,435	14,146	2,961	8,357	4,026	66	6,015	9,555	30,117
Lake	64,591	13,267	13,778	948	4,025	2,473	28	4,282	6,420	13,006
Los Angeles	10,170,292	2,279,839	1,277,335	162,912	606,055	312,736	4,407	490,888	767,731	1,675,802
Madera	154,998	42,615	20,374	3,045	8,663	4,595	67	7,321	11,296	33,258
Marin	261,221	53,520	52,327	3,824	16,244	9,837	113	16,960	25,706	19,100
Mariposa	17,531	2,875	4,421	205	1,157	744	8	1,316	1,952	2,627
Mendocino	87,649	18,982	17,382	1,356	5,368	3,203	38	5,454	8,187	17,508
Merced	268,455	80,152	28,517	5,727	14,430	7,254	117	11,165	17,497	68,026
Monterey	433,898	114,387	53,530	8,174	24,563	12,728	189	19,992	31,075	63,732
Napa	142,456	30,661	24,821	2,191	8,688	4,953	62	8,241	12,528	13,960
Nevada	98,877	17,428	24,201	1,245	6,422	4,090	43	7,193	10,664	12,137
Orange	3,169,776	716,153	430,447	51,175	188,995	100,412	1,374	160,772	250,372	398,428
Placer	375,391	84,957	69,332	6,071	22,644	13,266	162	22,400	33,857	32,093
Plumas	18,409	3,149	4,729	225	1,206	785	8	1,395	2,065	2,503
Riverside	2,361,026	612,848	320,086	43,793	134,810	71,829	1,024	114,813	177,144	377,244
Sacramento	1,501,335	361,617	198,168	25,840	87,748	46,278	650	73,651	114,506	250,325
San Benito	58,792	15,631	6,957	1,117	3,316	1,731	26	2,748	4,328	5,454
San Bernardino	2,128,133	572,173	228,666	40,886	119,170	59,986	923	92,725	146,418	394,031
San Diego	3,299,521	728,037	431,999	52,024	197,708	102,514	1,433	161,074	250,288	445,948
San Francisco	864,816	115,963	126,593	8,286	57,569	29,633	376	46,201	71,392	105,244
San Joaquin	726,106	199,894	87,579	14,284	40,454	21,053	315	33,228	51,852	124,606
San Luis Obispo	281,401	50,837	51,231	3,633	17,910	10,097	122	16,633	25,113	38,448
San Mateo	765,135	162,283	114,498	11,596	46,568	25,369	331	41,231	63,775	63,663
Santa Barbara	444,769	99,537	63,670	7,113	26,618	14,037	193	22,203	33,995	66,475
Santa Clara	1,918,044	436,397	239,977	31,184	113,823	59,008	833	93,034	145,834	156,430

CALIFORNIA (cont.)

American Lung Association in California

www.lung.org/california

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Santa Cruz	274,146	54,183	38,794	3,872	16,944	8,989	119	14,364	22,322	40,480
Shasta	179,533	38,620	35,628	2,760	11,015	6,564	78	11,166	16,752	33,556
Siskiyou	43,554	8,813	10,231	630	2,737	1,734	19	3,039	4,503	9,725
Solano	436,092	99,381	61,524	7,102	25,974	13,988	189	22,587	35,069	50,972
Sonoma	502,146	102,120	87,731	7,297	31,075	17,715	217	29,511	45,011	54,563
Stanislaus	538,388	146,063	67,324	10,437	30,189	15,817	233	25,049	38,935	103,646
Sutter	96,463	25,170	14,342	1,799	5,517	3,029	42	4,928	7,539	16,721
Tehama	63,308	15,129	11,481	1,081	3,756	2,197	27	3,705	5,598	14,073
Trinity	13,069	2,207	3,209	158	856	549	6	970	1,445	2,523
Tulare	459,863	144,036	49,147	10,292	24,222	12,265	200	18,970	29,653	123,922
Tuolumne	53,709	8,959	12,976	640	3,523	2,209	23	3,851	5,703	7,305
Ventura	850,536	202,649	119,596	14,481	49,997	27,022	369	43,731	67,850	83,389
Yolo	213,016	45,741	24,994	3,269	12,808	6,335	92	9,602	14,965	35,877
Totals	**38,984,776**	**9,084,172**	**5,166,478**	**649,133**	**2,301,495**	**1,210,079**	**16,906**	**1,921,480**	**2,987,129**	**5,866,931**

CALIFORNIA

American Lung Association in California

www.lung.org/california

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Alameda	19	0	0	6.3	F	11	0	0	3.7	F	10.8	PASS
Amador	20	0	0	6.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Butte	23	1	0	8.2	F	4	1	0	1.8	C	9.3	PASS
Calaveras	23	1	0	8.2	F	2	1	1	1.8	C	8.6	PASS
Colusa	0	0	0	0.0	A	3	1	0	1.5	C	7.6	PASS
Contra Costa	13	0	0	4.3	F	3	0	0	1.0	C	10.5	PASS
El Dorado	87	4	0	31.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fresno	215	41	1	92.8	F	68	37	0	41.2	F	15.4	FAIL
Glenn	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Humboldt	0	0	0	0.0	A	4	0	0	1.3	C	INC	INC
Imperial	63	3	0	22.5	F	22	4	0	9.3	F	13.1	FAIL
Inyo	9	0	0	3.0	D	6	14	1	9.7	F	7.6	PASS
Kern	232	45	1	100.5	F	81	50	1	52.7	F	20.8	FAIL
Kings	120	9	0	44.5	F	65	39	0	41.2	F	22.2	FAIL
Lake	0	0	0	0.0	A	0	1	0	0.5	B	4.0	PASS
Los Angeles	202	78	3	108.3	F	27	3	0	10.5	F	12.3	FAIL
Madera	124	11	0	46.8	F	47	18	0	24.7	F	15.2	FAIL
Marin	0	0	0	0.0	A	5	0	0	1.7	C	10.0	PASS
Mariposa	49	0	0	16.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mendocino	0	0	0	0.0	A	2	2	0	1.7	C	INC	INC
Merced	94	4	0	33.3	F	48	7	0	19.5	F	12.5	FAIL
Monterey	0	0	0	0.0	A	1	0	0	0.3	B	6.3	PASS
Napa	2	0	0	0.7	B	2	0	0	0.7	B	11.4	PASS
Nevada	74	2	0	25.7	F	1	1	0	0.8	B	5.3	PASS
Orange	26	4	0	10.7	F	8	0	0	2.7	D	7.8	PASS
Placer	49	5	0	18.8	F	5	6	1	5.3	F	7.8	PASS
Plumas	DNC	DNC	DNC	DNC	DNC	31	2	0	11.3	F	14.9	FAIL
Riverside	243	82	0	122.0	F	36	4	0	14.0	F	14.1	FAIL
Sacramento	72	4	0	26.0	F	23	0	0	7.7	F	10.2	PASS
San Benito	9	0	0	3.0	D	0	0	0	0.0	A	5.0	PASS
San Bernardino	220	126	9	142.3	F	18	0	0	6.0	F	12.0	PASS
San Diego	92	1	0	31.2	F	4	2	0	2.3	D	10.0	PASS
San Francisco	0	0	0	0.0	A	2	0	0	0.7	B	8.4	PASS
San Joaquin	39	2	0	14.0	F	52	11	0	22.8	F	14.2	FAIL
San Luis Obispo	21	0	0	7.0	F	7	0	0	2.3	D	12.1	FAIL
San Mateo	2	0	0	0.7	B	3	0	0	1.0	C	7.8	PASS

CALIFORNIA (cont.)

American Lung Association in California

www.lung.org/california

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Santa Barbara	8	2	0	3.7	F	0	0	0	0.0	A	7.7	PASS
Santa Clara	13	0	0	4.3	F	9	2	0	4.0	F	10.2	PASS
Santa Cruz	0	0	0	0.0	A	33	0	0	11.0	F	5.6	PASS
Shasta	16	0	0	5.3	F	0	1	0	0.5	B	6.2	PASS
Siskiyou	1	0	0	0.3	B	4	2	0	2.3	D	INC	INC
Solano	4	0	0	1.3	C	14	0	0	4.7	F	9.8	PASS
Sonoma	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Stanislaus	84	4	0	30.0	F	64	17	0	29.8	F	13.8	FAIL
Sutter	19	1	0	6.8	F	3	0	0	1.0	C	9.1	PASS
Tehama	42	1	0	14.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Trinity	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Tulare	226	33	1	92.5	F	18	13	0	12.5	F	17.6	FAIL
Tuolumne	29	0	0	9.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ventura	37	1	0	12.8	F	0	0	0	0.0	A	9.4	PASS
Yolo	4	0	0	1.3	C	0	0	0	0.0	A	7.0	PASS

COLORADO

American Lung Association in Colorado

www.lung.org/colorado

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Adams	491,337	135,138	47,987	11,458	32,466	13,882	209	19,244	21,576	61,980
Arapahoe	631,096	153,148	76,968	12,985	43,314	20,195	268	28,436	31,401	57,651
Boulder	319,372	63,682	40,331	5,399	23,227	10,580	136	14,899	16,431	38,046
Chaffee	18,658	2,848	4,366	241	1,409	858	8	1,275	1,329	2,006
Clear Creek	9,303	1,472	1,743	125	695	408	4	585	637	880
Denver	682,545	140,671	74,815	11,927	49,657	20,404	290	28,558	31,559	105,275
Douglas	322,387	89,885	33,895	7,621	20,957	9,951	137	13,757	15,563	10,917
El Paso	674,471	167,331	79,908	14,188	46,093	20,905	287	29,453	32,453	72,201
Garfield	58,095	14,941	6,534	1,267	3,902	1,825	25	2,543	2,846	5,909
Gunnison	16,067	2,807	1,851	238	1,211	515	7	718	799	1,892
Jackson	1,356	237	296	20	99	61	1	89	94	189
Jefferson	565,524	116,627	85,287	9,889	40,386	20,708	240	29,549	32,231	44,068
La Plata	54,688	10,531	8,129	893	3,981	1,996	23	2,843	3,105	4,993
Larimer	333,577	67,793	47,570	5,748	24,144	11,356	142	16,259	17,585	39,648
Mesa	148,513	33,122	25,879	2,808	10,389	5,551	63	8,110	8,600	20,326
Moffat	12,937	3,317	1,719	281	865	438	6	619	682	1,496
Montezuma	26,168	5,909	5,169	501	1,807	1,067	11	1,570	1,656	4,994
Park	16,510	2,744	2,844	233	1,215	723	7	1,023	1,136	1,511
Pitkin	17,787	2,772	2,908	235	1,347	707	8	1,008	1,101	1,243
Pueblo	163,591	37,836	28,497	3,208	11,311	6,102	69	8,917	9,456	31,501
Rio Blanco	6,571	1,561	916	132	452	224	3	319	348	607
San Miguel	7,879	1,444	929	122	579	277	3	382	434	865
Weld	285,174	76,551	32,528	6,491	18,940	8,642	121	12,144	13,430	31,531
Totals	**4,863,606**	**1,132,367**	**611,069**	**96,012**	**338,444**	**157,371**	**2,067**	**222,301**	**244,450**	**539,729**

COLORADO

American Lung Association in Colorado

www.lung.org/colorado

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adams	19	0	0	6.3	F	2	0	0	0.7	B	INC	INC
Arapahoe	21	0	0	7.0	F	0	0	0	0.0	A	6.3	PASS
Boulder	25	1	0	8.8	F	2	0	0	0.7	B	7.0	PASS
Chaffee	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clear Creek	32	3	0	12.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Denver	8	0	0	2.7	D	9	1	0	3.5	F	7.5	PASS
Douglas	41	3	0	15.2	F	1	0	0	0.3	B	5.5	PASS
El Paso	11	0	0	3.7	F	0	0	0	0.0	A	5.7	PASS
Garfield	2	0	0	0.7	B	0	0	0	0.0	A	INC	INC
Gunnison	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jackson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	62	6	0	23.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
La Plata	7	0	0	2.3	D	0	0	0	0.0	A	INC	INC
Larimer	56	2	0	19.7	F	2	1	0	1.2	C	6.8	PASS
Mesa	1	0	0	0.3	B	4	0	0	1.3	C	7.4	PASS
Moffat	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Montezuma	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Park	5	0	0	1.7	C	INC	INC	INC	INC	INC	INC	INC
Pitkin	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pueblo	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	5.8	PASS
Rio Blanco	9	4	1	5.7	F	0	0	0	0.0	A	8.2	PASS
San Miguel	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Weld	19	0	0	6.3	F	2	0	0	0.7	B	7.8	PASS

CONNECTICUT

American Lung Association in Connecticut

www.lung.org/connecticut

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Fairfield	948,053	220,906	137,799	25,884	76,395	36,729	598	51,524	66,675	83,612
Hartford	895,841	192,728	142,573	22,583	73,932	35,966	565	51,006	64,973	96,763
Litchfield	183,603	35,040	34,949	4,106	15,442	8,423	116	12,149	15,281	13,383
Middlesex	164,063	30,985	29,944	3,631	13,892	7,288	103	10,464	13,197	10,744
New Haven	859,470	178,891	137,053	20,961	71,618	34,597	542	49,032	62,466	112,801
New London	271,863	54,507	44,994	6,387	22,836	11,233	172	15,975	20,290	28,760
Tolland	151,420	27,234	21,691	3,191	13,134	5,907	96	8,209	10,681	9,593
Windham	116,573	23,768	17,803	2,785	9,752	4,697	74	6,602	8,518	12,211
Totals	**3,590,886**	**764,059**	**566,806**	**89,528**	**297,001**	**144,841**	**2,265**	**204,962**	**262,081**	**367,867**

CONNECTICUT

American Lung Association in Connecticut

www.lung.org/connecticut

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Fairfield	51	14	0	24.0	F	2	0	0	0.7	B	9.4	PASS
Hartford	23	1	0	8.2	F	0	0	0	0.0	A	7.3	PASS
Litchfield	11	0	0	3.7	F	0	0	0	0.0	A	5.2	PASS
Middlesex	28	3	0	10.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
New Haven	28	6	0	12.3	F	3	0	0	1.0	C	8.7	PASS
New London	15	4	0	7.0	F	1	0	0	0.3	B	INC	INC
Tolland	22	0	0	7.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Windham	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC

DELAWARE

American Lung Association in Delaware

www.lung.org/delaware

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Kent	173,533	40,353	27,752	3,421	12,327	9,164	122	12,038	14,468	23,947
New Castle	556,779	122,224	78,983	10,363	40,396	29,290	391	37,276	46,136	65,503
Sussex	215,622	41,809	53,780	3,545	16,172	13,976	152	19,956	22,909	26,205
Totals	**945,934**	**204,386**	**160,515**	**17,330**	**68,894**	**52,430**	**665**	**69,271**	**83,513**	**115,655**

DELAWARE

American Lung Association in Delaware

www.lung.org/delaware

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Kent	1	0	0	0.3	B	0	0	0	0.0	A	8.1	PASS
New Castle	17	1	0	6.2	F	9	1	0	3.5	F	9.6	PASS
Sussex	8	0	0	2.7	D	0	0	0	0.0	A	8.4	PASS

DISTRICT OF COLUMBIA

American Lung Association in the District of Columbia

www.lung.org/districtofcolumbia

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
District of Columbia	672,228	118,107	77,004	10,175	59,002	28,305	375	37,044	46,280	113,185
Totals	**672,228**	**118,107**	**77,004**	**10,175**	**59,002**	**28,305**	**375**	**37,044**	**46,280**	**113,185**

DISTRICT OF COLUMBIA

American Lung Association in the District of Columbia

www.lung.org/districtofcolumbia

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
District of Columbia	10	0	0	3.3	F	0	0	0	0.0	A	9.2	PASS

FLORIDA

American Lung Association in Florida

www.lung.org/florida

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Alachua	259,964	46,861	33,506	3,973	16,007	11,918	155	15,044	18,257	52,258
Baker	27,420	6,769	3,636	574	1,567	1,313	16	1,700	2,073	4,189
Bay	181,635	39,234	29,823	3,327	10,763	9,517	108	12,574	15,154	29,301
Brevard	568,088	105,472	130,247	8,943	34,825	35,230	338	48,315	57,294	75,268
Broward	1,896,425	407,683	296,906	34,567	112,749	98,583	1,128	129,582	156,814	263,607
Citrus	141,058	21,032	50,225	1,783	8,877	10,724	84	15,432	17,779	24,249
Collier	357,305	63,956	107,485	5,423	21,743	24,126	213	34,140	39,548	48,198
Columbia	68,348	14,889	12,005	1,262	4,035	3,664	41	4,882	5,858	12,413
Duval	913,010	207,260	119,785	17,573	53,462	43,566	543	56,074	68,376	142,660
Escambia	311,003	64,885	50,304	5,502	18,556	15,977	186	21,003	25,283	44,835
Flagler	105,392	18,778	30,717	1,592	6,449	7,144	63	10,072	11,729	12,213
Highlands	99,491	17,476	33,952	1,482	6,037	7,096	59	10,196	11,699	22,419
Hillsborough	1,349,050	311,084	180,904	26,376	78,572	64,466	803	83,213	101,279	209,040
Holmes	19,324	3,848	3,762	326	1,166	1,091	12	1,468	1,752	4,535
Indian River	147,919	25,425	45,664	2,156	9,095	10,294	88	14,601	16,934	19,051
Lake	325,875	64,420	85,204	5,462	19,489	20,536	194	28,638	33,475	41,272
Lee	701,982	129,382	189,043	10,970	42,657	45,196	418	63,130	73,716	110,398
Leon	286,272	54,381	33,957	4,611	17,445	12,742	170	15,951	19,452	59,366
Liberty	8,331	1,609	1,004	136	510	400	5	508	624	1,422
Manatee	363,369	69,687	94,063	5,909	21,940	23,107	216	32,165	37,697	53,080
Marion	343,254	64,096	97,002	5,435	20,749	22,493	204	31,619	36,781	62,271
Martin	156,283	26,273	46,400	2,228	9,690	10,828	93	15,280	17,805	17,125
Miami-Dade	2,693,117	552,280	420,642	46,827	161,793	138,709	1,602	181,691	219,597	529,850
Okaloosa	198,664	43,993	30,682	3,730	11,671	9,957	119	13,045	15,737	21,966
Orange	1,288,126	290,689	141,831	24,647	75,573	57,410	768	72,218	88,804	196,882
Osceola	323,993	80,769	41,928	6,848	18,388	14,891	193	19,170	23,316	59,226
Palm Beach	1,422,789	276,718	326,763	23,462	85,823	85,174	846	116,804	137,780	189,355
Pasco	497,909	101,714	112,844	8,624	29,705	29,645	296	40,664	48,023	71,760
Pinellas	949,827	159,853	222,148	13,554	59,433	59,907	564	82,129	97,345	127,287
Polk	650,092	147,812	128,029	12,533	37,680	35,383	387	47,818	56,748	109,907
Santa Rosa	167,040	37,266	24,872	3,160	9,842	8,520	100	11,153	13,538	19,681
Sarasota	405,549	59,816	140,193	5,072	25,580	30,252	241	43,364	50,014	38,874
Seminole	449,144	95,641	66,050	8,109	26,795	22,857	267	29,808	36,207	51,205
St. Lucie	298,563	61,111	68,766	5,182	17,789	17,857	178	24,544	28,946	48,570
Volusia	517,887	92,727	122,495	7,862	31,901	32,178	308	44,218	52,234	82,326
Wakulla	31,535	6,596	4,347	559	1,896	1,599	19	2,072	2,532	4,623
Totals	**18,525,033**	**3,771,485**	**3,527,184**	**319,778**	**1,110,252**	**1,024,351**	**11,026**	**1,374,285**	**1,640,200**	**2,860,682**

FLORIDA

American Lung Association in Florida

www.lung.org/florida

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Alachua	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Baker	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bay	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Brevard	0	0	0	0.0	A	0	0	0	0.0	A	5.6	PASS
Broward	2	0	0	0.7	B	0	0	0	0.0	A	INC	INC
Citrus	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	6.2	PASS
Collier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Columbia	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Duval	4	0	0	1.3	C	1	0	0	0.3	B	7.7	PASS
Escambia	5	0	0	1.7	C	0	0	0	0.0	A	7.7	PASS
Flagler	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Highlands	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hillsborough	10	0	0	3.3	F	0	0	0	0.0	A	7.8	PASS
Holmes	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Indian River	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lake	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lee	0	0	0	0.0	A	0	0	0	0.0	A	5.9	PASS
Leon	0	0	0	0.0	A	0	1	0	0.5	B	8.3	PASS
Liberty	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Manatee	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Marion	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Martin	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Miami-Dade	2	0	0	0.7	B	1	0	0	0.3	B	6.0	PASS
Okaloosa	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Orange	3	0	0	1.0	C	0	0	0	0.0	A	6.2	PASS
Osceola	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Palm Beach	3	0	0	1.0	C	0	0	0	0.0	A	5.3	PASS
Pasco	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pinellas	4	0	0	1.3	C	0	0	0	0.0	A	6.5	PASS
Polk	2	0	0	0.7	B	0	0	0	0.0	A	6.5	PASS
Santa Rosa	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sarasota	6	0	0	2.0	C	0	0	0	0.0	A	6.1	PASS
Seminole	0	0	0	0.0	A	0	0	0	0.0	A	6.1	PASS
St. Lucie	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Volusia	1	0	0	0.3	B	0	0	0	0.0	A	6.1	PASS
Wakulla	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC

GEORGIA

American Lung Association in Georgia

www.lung.org/georgia

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Bibb	153,721	38,331	22,157	4,261	10,747	8,295	101	11,020	13,528	39,343
Chatham	286,956	63,320	40,041	7,038	20,576	15,162	189	20,027	24,437	48,579
Chattooga	24,922	5,646	4,126	628	1,807	1,455	17	1,949	2,400	4,781
Clarke	123,912	21,518	12,223	2,392	9,081	5,512	81	7,032	8,370	42,773
Clayton	273,955	77,100	23,396	8,570	18,229	12,585	179	16,189	19,824	62,452
Cobb	741,334	182,064	81,302	20,237	52,131	37,970	488	49,492	60,804	83,213
Columbia	144,052	37,251	17,316	4,140	9,969	7,447	95	9,777	12,018	13,355
Coweta	138,427	35,281	17,659	3,922	9,689	7,436	91	9,804	12,086	14,976
Dawson	23,312	4,936	4,330	549	1,738	1,461	15	1,971	2,435	2,800
DeKalb	734,871	173,901	78,499	19,329	51,950	36,932	482	47,985	58,756	128,675
Dougherty	91,332	22,653	12,926	2,518	6,368	4,841	60	6,420	7,865	25,847
Douglas	140,733	37,540	15,015	4,173	9,654	7,098	92	9,256	11,392	19,638
Floyd	96,504	22,599	15,526	2,512	6,893	5,458	64	7,300	8,966	18,060
Fulton	1,010,562	231,537	108,711	25,736	71,920	50,682	666	65,813	80,451	156,705
Glynn	83,579	19,122	15,181	2,125	6,058	5,027	55	6,784	8,357	14,999
Gwinnett	895,823	247,554	79,872	27,516	60,468	42,829	592	55,273	67,944	112,026
Hall	193,535	50,521	27,256	5,615	13,315	10,249	128	13,608	16,702	32,263
Henry	217,739	57,991	23,693	6,446	14,976	11,108	143	14,506	17,871	21,377
Houston	150,033	38,453	18,150	4,274	10,384	7,705	99	10,116	12,416	22,510
Lowndes	112,865	28,087	12,987	3,122	7,710	5,316	75	6,935	8,405	28,460
Murray	39,565	10,027	5,446	1,115	2,766	2,143	26	2,839	3,494	6,960
Muscogee	200,579	48,646	24,713	5,407	13,983	10,088	133	13,232	16,148	42,678
Paulding	152,238	41,773	15,125	4,643	10,311	7,452	100	9,678	11,899	13,326
Pike	17,941	4,379	2,688	487	1,280	1,026	12	1,367	1,688	2,074
Richmond	201,793	47,511	26,108	5,281	14,261	10,493	133	13,808	16,888	46,401
Rockdale	88,856	22,656	11,700	2,518	6,237	4,853	58	6,414	7,916	14,009
Sumter	30,779	7,285	4,783	810	2,179	1,690	20	2,254	2,762	8,970
Walker	68,066	15,176	11,539	1,687	4,973	4,048	45	5,430	6,692	12,485
Washington	20,816	4,586	3,374	510	1,525	1,224	14	1,636	2,016	4,969
Wilkinson	9,155	2,095	1,670	233	670	568	6	767	949	1,891
Totals	**6,467,955**	**1,599,539**	**737,512**	**177,790**	**451,848**	**328,152**	**4,259**	**428,684**	**525,480**	**1,046,595**

GEORGIA

American Lung Association in Georgia

www.lung.org/georgia

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Bibb	2	0	0	0.7	B	1	0	0	0.3	B	10.2	PASS
Chatham	0	0	0	0.0	A	0	0	0	0.0	A	8.9	PASS
Chattooga	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clarke	0	0	0	0.0	A	0	0	0	0.0	A	9.5	PASS
Clayton	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	10.0	PASS
Cobb	5	0	0	1.7	C	0	0	0	0.0	A	9.6	PASS
Columbia	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Coweta	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dawson	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
DeKalb	8	0	0	2.7	D	0	0	0	0.0	A	9.4	PASS
Dougherty	DNC	DNC	DNC	DNC	DNC	7	0	0	2.3	D	9.8	PASS
Douglas	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Floyd	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.9	PASS
Fulton	17	3	0	7.2	F	0	0	0	0.0	A	10.5	PASS
Glynn	0	0	0	0.0	A	0	0	0	0.0	A	8.0	PASS
Gwinnett	6	1	0	2.5	D	0	0	0	0.0	A	9.0	PASS
Hall	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.4	PASS
Henry	11	1	0	4.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Houston	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.9	PASS
Lowndes	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.5	PASS
Murray	1	1	0	0.8	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Muscogee	0	0	0	0.0	A	0	0	0	0.0	A	9.6	PASS
Paulding	0	0	0	0.0	A	0	0	0	0.0	A	8.2	PASS
Pike	4	1	0	1.8	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Richmond	0	0	0	0.0	A	0	0	0	0.0	A	9.5	PASS
Rockdale	14	0	0	4.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sumter	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Walker	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.9	PASS
Washington	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.2	PASS
Wilkinson	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	10.0	PASS

HAWAII

American Lung Association in Hawaii

www.lung.org/hawaii

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Hawaii	196,428	43,217	35,851	4,291	15,151	6,892	99	10,359	13,874	35,294
Honolulu	998,714	214,852	161,966	21,333	79,203	33,353	505	47,503	64,243	88,536
Kauai	71,735	16,019	12,902	1,591	5,515	2,500	36	3,748	5,026	7,928
Maui	164,637	36,745	26,166	3,649	12,794	5,586	83	8,155	11,097	17,333
Totals	**1,431,514**	**310,833**	**236,885**	**30,864**	**112,663**	**48,331**	**724**	**69,765**	**94,239**	**149,091**

HAWAII

American Lung Association in Hawaii

www.lung.org/hawaii

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Hawaii	DNC	DNC	DNC	DNC	DNC	2	0	0	0.7	B	12.1	FAIL
Honolulu	0	0	0	0.0	A	0	0	0	0.0	A	5.4	PASS
Kauai	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	3.9	PASS
Maui	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	4.8	PASS

IDAHO

American Lung Association in Idaho

www.lung.org/idaho

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Ada	434,211	107,568	56,644	9,121	29,849	15,427	205	21,998	25,165	49,369
Bannock	83,744	22,302	11,020	1,891	5,594	2,864	40	4,112	4,655	18,179
Benewah	9,052	2,003	1,973	170	643	409	4	634	702	1,614
Butte	2,501	624	512	53	171	107	1	165	183	394
Canyon	207,478	61,522	26,566	5,216	13,298	6,883	98	9,906	11,224	32,329
Franklin	13,074	4,385	1,804	372	791	432	6	636	714	1,253
Jerome	22,814	7,115	2,811	603	1,434	748	11	1,073	1,224	3,577
Lemhi	7,735	1,398	2,193	119	574	398	4	642	694	1,347
Shoshone	12,432	2,464	2,772	209	909	576	6	892	988	2,577
Totals	**793,041**	**209,381**	**106,295**	**17,753**	**53,263**	**27,843**	**375**	**40,057**	**45,548**	**110,639**

IDAHO

American Lung Association in Idaho

www.lung.org/idaho

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Ada	6	1	0	2.5	D	INC	INC	INC	INC	INC	INC	INC
Bannock	DNC	DNC	DNC	DNC	DNC	3	1	0	1.5	C	7.3	PASS
Benewah	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Butte	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Canyon	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Franklin	DNC	DNC	DNC	DNC	DNC	20	12	0	12.7	F	INC	INC
Jerome	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Lemhi	DNC	DNC	DNC	DNC	DNC	34	6	0	14.3	F	12.7	FAIL
Shoshone	DNC	DNC	DNC	DNC	DNC	43	5	0	16.8	F	13.7	FAIL

ILLINOIS

American Lung Association in Illinois

www.lung.org/illinois

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Adams	67,013	15,213	12,711	1,125	4,300	3,243	43	4,879	5,821	8,674
Champaign	208,861	39,693	23,639	2,935	14,382	8,428	135	10,735	13,579	38,751
Clark	15,979	3,632	3,029	269	1,024	782	10	1,178	1,408	2,171
Cook	5,238,216	1,175,147	692,946	86,906	341,993	224,961	3,377	306,619	381,122	833,241
DuPage	933,736	216,777	129,486	16,031	60,047	41,707	603	58,108	72,050	65,538
Effingham	34,371	8,103	5,870	599	2,187	1,608	22	2,362	2,852	3,313
Hamilton	8,200	1,815	1,678	134	528	413	5	633	750	1,055
Jersey	22,372	4,762	4,016	352	1,463	1,095	14	1,620	1,954	2,455
Jo Daviess	22,086	4,271	5,552	316	1,460	1,232	14	1,978	2,301	2,060
Kane	530,847	141,342	64,659	10,453	32,725	21,999	344	29,962	37,481	56,882
Lake	703,910	176,512	88,880	13,054	44,232	30,322	456	41,581	52,009	61,899
Macon	107,303	23,914	19,664	1,769	6,933	5,160	69	7,683	9,211	18,784
Macoupin	46,045	9,770	8,897	723	3,007	2,302	30	3,469	4,148	6,192
Madison	266,209	59,077	42,437	4,369	17,297	12,351	172	17,738	21,641	33,734
McHenry	307,343	75,431	38,883	5,578	19,422	13,535	199	18,604	23,327	24,659
McLean	173,166	38,016	20,468	2,811	11,432	7,115	112	9,355	11,766	18,969
Peoria	186,221	44,415	28,650	3,285	11,867	8,285	120	11,823	14,415	28,269
Randolph	32,852	6,300	5,782	466	2,214	1,602	22	2,336	2,826	4,049
Rock Island	146,133	32,595	26,190	2,410	9,450	6,954	94	10,290	12,363	18,596
Sangamon	198,712	45,433	31,830	3,360	12,791	9,198	128	13,260	16,158	29,798
St. Clair	264,052	63,022	37,645	4,661	16,833	11,705	170	16,430	20,263	42,464
Will	687,263	179,235	79,991	13,255	42,712	28,544	445	38,444	48,427	53,883
Winnebago	287,078	68,062	46,023	5,033	18,270	13,182	185	19,061	23,193	41,541
Totals	**10,487,968**	**2,432,537**	**1,418,926**	**179,893**	**676,570**	**455,721**	**6,771**	**628,146**	**779,067**	**1,396,977**

ILLINOIS

American Lung Association in Illinois

www.lung.org/illinois

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adams	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Champaign	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Clark	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cook	17	1	0	6.2	F	INC	INC	INC	INC	INC	INC	INC
DuPage	3	0	0	1.0	C	INC	INC	INC	INC	INC	INC	INC
Effingham	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hamilton	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Jersey	3	1	0	1.5	C	INC	INC	INC	INC	INC	INC	INC
Jo Daviess	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kane	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Lake	15	0	0	5.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Macon	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Macoupin	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Madison	22	0	0	7.3	F	INC	INC	INC	INC	INC	INC	INC
McHenry	5	0	0	1.7	C	INC	INC	INC	INC	INC	INC	INC
McLean	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Peoria	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Randolph	4	0	0	1.3	C	INC	INC	INC	INC	INC	INC	INC
Rock Island	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Sangamon	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
St. Clair	4	0	0	1.3	C	INC	INC	INC	INC	INC	INC	INC
Will	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Winnebago	3	0	0	1.0	C	INC	INC	INC	INC	INC	INC	INC

INDIANA

American Lung Association in Indiana

www.lung.org/indiana

				AT-RISK GROUPS						
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Allen	368,450	96,167	49,434	7,232	28,100	21,417	270	26,495	30,756	52,689
Bartholomew	81,162	19,533	12,282	1,469	6,334	4,972	60	6,242	7,129	9,462
Boone	63,344	17,002	8,084	1,279	4,779	3,735	46	4,561	5,364	3,734
Brown	14,977	2,893	3,272	218	1,215	1,145	11	1,489	1,632	1,688
Carroll	19,856	4,508	3,604	339	1,561	1,347	15	1,723	1,925	1,855
Clark	115,371	26,683	16,811	2,007	9,130	7,129	85	8,860	10,229	11,832
Delaware	116,852	22,109	18,947	1,663	9,771	7,248	85	9,213	10,402	24,820
Dubois	42,461	10,185	6,962	766	3,296	2,768	31	3,490	3,961	3,179
Elkhart	203,474	56,889	27,717	4,278	15,101	11,658	149	14,513	16,730	27,906
Floyd	76,778	17,795	11,459	1,338	6,056	4,879	56	6,060	6,995	8,502
Greene	32,441	7,205	5,983	542	2,565	2,222	24	2,847	3,175	4,710
Hamilton	309,697	87,329	33,758	6,567	23,072	17,116	227	20,525	24,634	14,366
Hancock	72,520	17,226	11,199	1,295	5,665	4,640	53	5,797	6,648	4,272
Hendricks	158,192	40,662	20,089	3,058	12,146	9,245	116	11,296	13,285	8,477
Henry	48,985	10,256	8,982	771	3,945	3,337	36	4,274	4,771	6,636
Howard	82,556	18,761	15,225	1,411	6,489	5,535	60	7,127	7,911	13,724
Huntington	36,630	8,072	5,967	607	2,924	2,386	27	3,005	3,418	3,832
Jackson	44,069	10,778	6,811	810	3,414	2,742	32	3,447	3,929	5,250
Johnson	149,633	37,532	21,118	2,822	11,549	8,924	110	11,099	12,807	11,720
Knox	37,927	8,005	6,383	602	3,067	2,439	28	3,102	3,494	6,735
Lake	487,865	118,118	73,176	8,882	37,969	30,309	357	37,867	43,453	79,740
LaPorte	110,884	24,277	17,940	1,826	8,873	7,209	82	9,068	10,327	16,294
Madison	129,723	28,550	22,366	2,147	10,340	8,494	95	10,823	12,157	20,636
Marion	939,020	234,220	108,060	17,613	73,292	52,169	686	63,121	75,137	189,323
Monroe	144,705	23,002	16,832	1,730	12,779	7,869	106	9,570	11,380	30,425
Montgomery	38,227	8,829	6,489	664	3,003	2,491	28	3,166	3,564	4,543
Morgan	69,648	16,261	10,890	1,223	5,462	4,557	51	5,682	6,526	7,814
Perry	19,347	3,996	3,346	300	1,570	1,287	14	1,635	1,843	2,341
Porter	167,688	37,980	24,962	2,856	13,333	10,585	123	13,158	15,182	18,931
Posey	25,512	5,795	4,202	436	2,012	1,715	19	2,151	2,455	2,442
Shelby	44,478	10,203	7,078	767	3,507	2,912	33	3,644	4,170	5,205
Spencer	20,715	4,658	3,820	350	1,630	1,429	15	1,828	2,041	1,931
St. Joseph	268,441	64,242	39,260	4,831	21,028	16,236	196	20,287	23,296	42,922
Tippecanoe	185,826	38,439	19,501	2,891	15,485	9,570	137	11,530	13,844	32,336
Vanderburgh	181,877	39,873	28,248	2,998	14,597	11,442	133	14,364	16,408	30,123
Vigo	107,896	22,180	16,090	1,668	8,853	6,580	80	8,240	9,450	20,027

INDIANA (cont.)

American Lung Association in Indiana

www.lung.org/indiana

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Wabash	32,138	6,905	6,374	519	2,560	2,213	24	2,882	3,160	3,625
Warrick	61,897	15,119	10,247	1,137	4,776	3,992	45	5,057	5,713	4,546
Whitley	33,406	7,743	5,457	582	2,622	2,194	25	2,759	3,140	2,598
Totals	**5,144,668**	**1,229,980**	**718,425**	**92,492**	**403,873**	**308,133**	**3,770**	**381,995**	**442,441**	**741,191**

INDIANA

American Lung Association in Indiana

www.lung.org/indiana

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Allen	0	0	0	0.0	A	7	1	0	2.8	D	10.2	PASS
Bartholomew	3	0	0	1.0	C	INC	INC	INC	INC	INC	INC	INC
Boone	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Brown	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carroll	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clark	4	1	0	1.8	C	1	0	0	0.3	B	11.4	PASS
Delaware	0	0	0	0.0	A	2	0	0	0.7	B	9.7	PASS
Dubois	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	10.6	PASS
Elkhart	0	0	0	0.0	A	16	0	0	5.3	F	10.4	PASS
Floyd	6	0	0	2.0	C	1	0	0	0.3	B	10.0	PASS
Greene	3	0	0	1.0	C	0	0	0	0.0	A	9.5	PASS
Hamilton	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Hancock	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hendricks	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Henry	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	9.1	PASS
Howard	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Huntington	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jackson	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Johnson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Knox	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lake	5	0	0	1.7	C	8	2	0	3.7	F	11.0	PASS
LaPorte	8	0	0	2.7	D	2	0	0	0.7	B	9.5	PASS
Madison	0	0	0	0.0	A	3	0	0	1.0	C	9.6	PASS
Marion	4	0	0	1.3	C	10	1	0	3.8	F	11.7	PASS
Monroe	DNC	DNC	DNC	DNC	DNC	0	1	0	0.5	B	9.4	PASS
Montgomery	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Morgan	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Perry	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Porter	8	0	0	2.7	D	2	2	0	1.7	C	10.0	PASS
Posey	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Shelby	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Spencer	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	10.1	PASS
St. Joseph	3	0	0	1.0	C	5	1	0	2.2	D	9.7	PASS
Tippecanoe	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	9.8	PASS
Vanderburgh	13	0	0	4.3	F	0	0	0	0.0	A	10.7	PASS

INDIANA (cont.)

American Lung Association in Indiana

www.lung.org/indiana

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Vigo	0	0	0	0.0	A	2	1	0	1.2	C	10.3	PASS
Wabash	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Warrick	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Whitley	DNC	DNC	DNC	DNC	DNC	3	0	0	1.0	C	9.3	PASS

IOWA

American Lung Association in Iowa

www.lung.org/iowa

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Black Hawk	133,455	28,752	20,236	1,655	7,985	5,680	85	7,289	8,473	18,161
Bremer	24,722	5,422	4,661	312	1,462	1,149	16	1,548	1,757	1,791
Clinton	47,768	10,950	8,898	630	2,797	2,264	30	3,074	3,522	6,263
Delaware	17,403	4,134	3,170	238	1,010	823	11	1,119	1,288	1,743
Harrison	14,265	3,214	2,800	185	838	696	9	955	1,089	1,385
Johnson	144,251	29,208	15,003	1,681	8,840	5,358	92	6,265	7,568	24,908
Lee	35,089	7,594	6,698	437	2,088	1,693	22	2,301	2,633	5,358
Linn	219,916	52,166	32,289	3,003	12,826	9,353	140	12,093	14,166	23,524
Montgomery	10,234	2,280	2,172	131	601	515	6	716	809	1,339
Muscatine	43,011	10,915	6,676	628	2,450	1,857	27	2,445	2,847	4,871
Palo Alto	9,133	2,053	1,974	118	533	450	6	626	701	1,013
Polk	467,711	117,819	55,946	6,782	26,886	18,343	297	22,854	27,333	54,557
Pottawattamie	93,671	22,256	14,930	1,281	5,452	4,145	59	5,466	6,361	12,293
Scott	172,126	41,195	25,490	2,371	10,013	7,375	109	9,575	11,219	20,823
Story	96,021	16,276	10,417	937	6,112	3,587	62	4,132	4,950	15,717
Van Buren	7,344	1,697	1,534	98	427	365	5	508	575	1,154
Warren	48,626	12,180	7,409	701	2,785	2,097	31	2,750	3,212	3,641
Woodbury	102,782	26,929	14,335	1,550	5,802	4,192	65	5,397	6,331	13,957
Totals	**1,687,528**	**395,040**	**234,638**	**22,738**	**98,908**	**69,942**	**1,071**	**89,112**	**104,835**	**212,498**

IOWA

American Lung Association in Iowa

www.lung.org/iowa

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Black Hawk	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.0	PASS
Bremer	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clinton	1	0	0	0.3	B	3	0	0	1.0	C	10.2	PASS
Delaware	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.7	PASS
Harrison	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Johnson	DNC	DNC	DNC	DNC	DNC	2	0	0	0.7	B	8.8	PASS
Lee	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	10.0	PASS
Linn	0	0	0	0.0	A	3	0	0	1.0	C	9.3	PASS
Montgomery	1	0	0	0.3	B	1	0	0	0.3	B	7.6	PASS
Muscatine	DNC	DNC	DNC	DNC	DNC	11	0	0	3.7	F	10.4	PASS
Palo Alto	1	0	0	0.3	B	0	0	0	0.0	A	7.8	PASS
Polk	0	0	0	0.0	A	0	0	0	0.0	A	8.3	PASS
Pottawattamie	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	9.0	PASS
Scott	0	0	0	0.0	A	5	0	0	1.7	C	10.1	PASS
Story	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Van Buren	0	0	0	0.0	A	0	0	0	0.0	A	8.0	PASS
Warren	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Woodbury	DNC	DNC	DNC	DNC	DNC	3	0	0	1.0	C	8.4	PASS

KANSAS

American Lung Association in Kansas

www.lung.org/kansas

AT-RISK GROUPS

County	Total Population	Under 18	65 & Over	Lung Diseases: Pediatric Asthma	Lung Diseases: Adult Asthma	Lung Diseases: COPD	Lung Diseases: Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Johnson	580,159	145,597	76,022	12,903	37,954	26,585	365	33,371	41,203	31,474
Leavenworth	79,315	19,050	10,365	1,688	5,263	3,650	51	4,566	5,647	7,817
Linn	9,536	2,198	2,004	195	636	525	6	724	844	1,318
Neosho	16,346	4,044	3,030	358	1,067	835	10	1,127	1,330	2,995
Riley	75,247	13,025	6,256	1,154	5,394	2,707	48	2,986	3,925	15,560
Sedgwick	511,574	134,499	67,228	11,919	32,879	22,839	322	28,782	35,402	76,898
Shawnee	178,725	43,262	29,471	3,834	11,780	8,832	112	11,604	13,921	24,840
Sumner	23,535	5,821	4,135	516	1,540	1,200	15	1,600	1,904	2,701
Trego	2,927	545	707	48	206	177	2	248	286	298
Wyandotte	163,369	45,889	18,586	4,067	10,260	6,858	103	8,433	10,532	35,442
Totals	**1,640,733**	**413,930**	**217,804**	**36,682**	**106,979**	**74,210**	**1,033**	**93,440**	**114,993**	**199,343**

KANSAS

American Lung Association in Kansas

www.lung.org/kansas

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Johnson	0	0	0	0.0	A	0	0	0	0.0	A	7.7	PASS
Leavenworth	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Linn	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Neosho	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Riley	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sedgwick	8	0	0	2.7	D	1	0	0	0.3	B	9.2	PASS
Shawnee	1	0	0	0.3	B	1	0	0	0.3	B	8.0	PASS
Sumner	5	0	0	1.7	C	1	0	0	0.3	B	7.8	PASS
Trego	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wyandotte	1	0	0	0.3	B	1	0	0	0.3	B	9.2	PASS

KENTUCKY

American Lung Association in Kentucky

www.lung.org/kentucky

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Bell	27,337	5,809	4,852	630	2,552	2,718	26	2,784	3,050	11,772
Boone	127,712	34,843	14,808	3,779	11,106	10,927	122	10,493	12,018	10,304
Boyd	48,325	10,186	8,823	1,105	4,517	4,859	46	5,003	5,463	9,440
Bullitt	78,702	17,953	11,116	1,947	7,241	7,392	75	7,275	8,195	7,504
Campbell	92,066	20,046	13,096	2,174	8,588	8,562	88	8,414	9,476	12,805
Carter	27,158	6,102	4,620	662	2,498	2,635	26	2,685	2,952	5,203
Christian	73,309	20,014	8,410	2,171	6,384	5,498	71	5,242	5,985	13,750
Daviess	99,259	24,141	16,079	2,619	8,918	9,312	95	9,442	10,412	14,405
Edmonson	12,007	2,276	2,407	247	1,150	1,253	11	1,308	1,415	2,376
Fayette	314,488	66,246	37,689	7,186	29,741	26,994	300	25,619	29,457	57,637
Greenup	36,068	7,867	7,046	853	3,331	3,676	34	3,843	4,155	5,973
Hancock	8,692	2,186	1,479	237	771	830	8	851	932	1,189
Hardin	106,439	26,333	13,901	2,856	9,563	9,441	102	9,199	10,422	15,424
Henderson	46,407	10,857	7,419	1,178	4,223	4,445	44	4,484	4,966	7,688
Jefferson	763,623	171,811	113,444	18,636	70,483	70,948	727	70,423	78,758	115,246
Jessamine	51,961	12,805	7,098	1,389	4,670	4,648	49	4,565	5,143	9,129
Livingston	9,316	1,920	1,909	208	872	996	9	1,047	1,129	1,404
Madison	87,824	18,551	11,491	2,012	8,284	7,689	84	7,420	8,436	14,873
McCracken	65,018	14,201	12,169	1,540	6,012	6,528	62	6,767	7,355	9,671
Morgan	13,275	2,552	1,954	277	1,279	1,280	13	1,259	1,417	3,577
Oldham	64,875	16,641	7,791	1,805	5,765	5,842	63	5,627	6,441	3,688
Perry	27,565	6,064	4,404	658	2,555	2,682	26	2,696	2,994	7,675
Pike	61,792	13,066	10,260	1,417	5,786	6,128	59	6,192	6,852	15,082
Pulaski	63,782	14,325	11,539	1,554	5,856	6,331	61	6,528	7,122	14,448
Simpson	18,006	4,378	2,864	475	1,619	1,694	17	1,712	1,893	2,820
Trigg	14,233	3,061	3,072	332	1,315	1,519	14	1,618	1,729	2,129
Warren	122,851	27,678	15,030	3,002	11,394	10,379	117	9,920	11,347	20,992
Washington	12,063	2,761	2,102	299	1,102	1,184	12	1,213	1,329	1,992
Totals	**2,474,153**	**564,673**	**356,872**	**61,249**	**227,576**	**226,390**	**2,361**	**223,628**	**250,845**	**398,196**

KENTUCKY

American Lung Association in Kentucky

www.lung.org/kentucky

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Bell	0	0	0	0.0	A	0	0	0	0.0	A	8.9	PASS
Boone	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Boyd	5	0	0	1.7	C	0	0	0	0.0	A	9.1	PASS
Bullitt	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Campbell	13	0	0	4.3	F	0	0	0	0.0	A	9.5	PASS
Carter	0	0	0	0.0	A	0	0	0	0.0	A	7.6	PASS
Christian	1	0	0	0.3	B	0	0	0	0.0	A	9.7	PASS
Daviess	1	0	0	0.3	B	0	0	0	0.0	A	10.3	PASS
Edmonson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fayette	4	0	0	1.3	C	0	0	0	0.0	A	9.1	PASS
Greenup	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hancock	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hardin	1	0	0	0.3	B	0	0	0	0.0	A	9.8	PASS
Henderson	2	0	0	0.7	B	0	0	0	0.0	A	10.3	PASS
Jefferson	6	4	0	4.0	F	2	1	0	1.2	C	11.7	PASS
Jessamine	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Livingston	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Madison	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.1	PASS
McCracken	1	0	0	0.3	B	0	0	0	0.0	A	INC	INC
Morgan	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Oldham	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Perry	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Pike	0	0	0	0.0	A	3	0	0	1.0	C	8.0	PASS
Pulaski	0	0	0	0.0	A	0	0	0	0.0	A	8.7	PASS
Simpson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Trigg	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Warren	0	0	0	0.0	A	0	0	0	0.0	A	9.1	PASS
Washington	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC

LOUISIANA

American Lung Association in Louisiana

www.lung.org/louisiana

	AT-RISK GROUPS									
				Lung Diseases						
Parish	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Disease**	**Cardiovascular Diabetes**	**Poverty**	
Ascension Parish	119,455	32,905	12,536	2,879	7,071	6,217	83	8,674	10,209	12,695
Bossier Parish	125,175	31,423	16,527	2,750	7,674	6,838	87	9,879	11,416	17,765
Caddo Parish	251,460	61,152	38,375	5,351	15,547	14,636	174	21,587	24,857	54,405
Calcasieu Parish	198,788	49,384	27,852	4,321	12,205	11,288	139	16,419	19,009	34,103
East Baton Rouge Parish	446,753	101,773	57,272	8,906	28,269	24,506	310	35,101	40,586	80,662
Iberville Parish	33,095	7,047	4,648	617	2,126	1,971	23	2,841	3,307	6,538
Jefferson Parish	436,275	94,962	67,695	8,310	27,857	26,432	304	38,811	44,859	70,484
Lafayette Parish	240,098	57,778	27,678	5,056	14,923	12,910	167	18,189	21,229	39,876
Lafourche Parish	98,325	23,175	13,797	2,028	6,135	5,703	69	8,266	9,598	13,612
Livingston Parish	137,788	36,109	16,505	3,160	8,310	7,428	96	10,560	12,325	18,356
Orleans Parish	389,617	79,432	48,658	6,951	25,384	22,147	270	31,364	36,545	90,849
Ouachita Parish	156,761	39,935	21,430	3,494	9,553	8,692	109	12,628	14,594	34,836
Pointe Coupee Parish	22,251	5,032	4,156	440	1,402	1,439	15	2,180	2,502	4,264
Rapides Parish	132,141	33,075	20,183	2,894	8,087	7,698	92	11,361	13,098	27,768
St. Bernard Parish	45,408	12,355	4,547	1,081	2,703	2,319	32	3,215	3,783	9,179
St. Charles Parish	52,812	13,348	6,346	1,168	3,215	2,989	37	4,226	4,979	6,147
St. James Parish	21,567	5,009	3,347	438	1,349	1,317	15	1,934	2,245	3,902
St. John the Baptist Parish	43,626	10,928	5,681	956	2,666	2,489	30	3,567	4,172	8,829
St. Martin Parish	53,835	13,320	7,326	1,166	3,305	3,098	38	4,472	5,211	9,693
St. Tammany Parish	250,088	60,805	38,533	5,321	15,417	15,091	174	22,189	25,742	31,138
Tangipahoa Parish	128,755	31,859	16,932	2,788	7,924	7,133	90	10,276	11,915	30,092
Terrebonne Parish	113,972	29,354	14,655	2,569	6,910	6,320	80	9,073	10,567	22,587
West Baton Rouge Parish	25,490	6,258	3,120	548	1,570	1,421	18	2,017	2,361	3,754
Totals	**3,523,535**	**836,418**	**477,799**	**73,190**	**219,602**	**200,084**	**2,452**	**288,828**	**335,109**	**631,534**

LOUISIANA

American Lung Association in Louisiana

www.lung.org/louisiana

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
Parish	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Ascension Parish	6	1	0	2.5	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bossier Parish	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Caddo Parish	1	0	0	0.3	B	1	0	0	0.3	B	10.3	PASS
Calcasieu Parish	8	1	0	3.2	D	0	0	0	0.0	A	7.2	PASS
East Baton Rouge Parish	21	4	0	9.0	F	1	0	0	0.3	B	8.8	PASS
Iberville Parish	13	0	0	4.3	F	0	0	0	0.0	A	8.7	PASS
Jefferson Parish	7	0	0	2.3	D	0	0	0	0.0	A	7.9	PASS
Lafayette Parish	2	0	0	0.7	B	0	0	0	0.0	A	7.8	PASS
Lafourche Parish	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Livingston Parish	11	0	0	3.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Orleans Parish	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Ouachita Parish	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Pointe Coupee Parish	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rapides Parish	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.4	PASS
St. Bernard Parish	6	0	0	2.0	C	0	0	0	0.0	A	9.0	PASS
St. Charles Parish	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. James Parish	2	1	0	1.2	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. John the Baptist Parish	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Martin Parish	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Tammany Parish	9	1	0	3.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tangipahoa Parish	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.6	PASS
Terrebonne Parish	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.2	PASS
West Baton Rouge Parish	5	0	0	1.7	C	0	0	0	0.0	A	8.9	PASS

MAINE

American Lung Association in Maine

www.lung.org/maine

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Androscoggin	107,233	23,468	17,615	2,271	9,491	6,529	82	7,587	7,883	15,668
Aroostook	68,628	12,778	15,032	1,237	6,197	4,798	52	5,829	5,875	12,342
Cumberland	289,977	56,068	49,183	5,426	26,504	18,210	220	21,155	21,985	30,030
Hancock	54,659	9,551	12,084	924	5,007	3,874	42	4,704	4,742	6,136
Kennebec	119,980	23,627	21,154	2,286	10,873	7,728	91	9,084	9,366	15,229
Knox	39,855	7,333	9,143	710	3,595	2,830	30	3,460	3,471	4,393
Oxford	57,202	11,150	11,363	1,079	5,145	3,883	44	4,666	4,739	9,579
Penobscot	152,692	28,318	26,256	2,740	14,095	9,622	116	11,160	11,609	24,822
Sagadahoc	35,149	6,793	7,136	657	3,165	2,383	27	2,865	2,909	3,915
Washington	31,625	5,998	7,145	580	2,834	2,230	24	2,724	2,735	5,779
York	201,169	39,427	37,449	3,815	18,177	13,211	153	15,665	16,055	16,376
Totals	**1,158,169**	**224,511**	**213,560**	**21,726**	**105,082**	**75,298**	**880**	**88,899**	**91,369**	**144,269**

MAINE

American Lung Association in Maine

www.lung.org/maine

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Androscoggin	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Aroostook	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Cumberland	7	0	0	2.3	D	INC	INC	INC	INC	INC	INC	INC
Hancock	6	0	0	2.0	C	INC	INC	INC	INC	INC	INC	INC
Kennebec	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Knox	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Oxford	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Penobscot	1	0	0	0.3	B	0	0	0	0.0	A	6.4	PASS
Sagadahoc	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washington	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
York	12	0	0	4.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MARYLAND

American Lung Association in Maryland

www.lung.org/maryland

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Anne Arundel	564,195	126,843	77,478	12,264	38,806	26,664	325	33,851	44,294	32,769
Baltimore	831,128	179,387	133,926	17,344	57,577	40,725	477	54,155	68,882	73,955
Baltimore City	621,849	131,353	77,919	12,700	43,408	28,201	357	34,916	45,727	135,850
Calvert	90,595	21,516	12,259	2,080	6,168	4,414	52	5,556	7,420	5,315
Carroll	167,627	37,047	26,540	3,582	11,612	8,518	97	11,173	14,536	10,235
Cecil	102,382	23,808	14,590	2,302	6,991	4,975	59	6,367	8,371	10,109
Charles	156,118	38,264	17,904	3,700	10,517	7,125	90	8,625	11,679	10,943
Dorchester	32,384	6,896	6,546	667	2,245	1,721	19	2,441	3,020	5,781
Frederick	245,322	58,104	32,623	5,618	16,659	11,593	141	14,594	19,310	17,749
Garrett	29,460	5,704	6,094	552	2,093	1,606	17	2,275	2,818	3,921
Harford	250,290	56,808	37,682	5,493	17,181	12,287	144	15,974	20,770	19,384
Howard	313,414	76,590	39,680	7,405	21,083	14,520	181	18,081	24,056	16,350
Kent	19,787	3,304	5,013	319	1,438	1,136	11	1,716	2,035	2,723
Montgomery	1,040,116	243,491	146,195	23,542	70,668	49,115	598	62,958	82,042	77,657
Prince George's	909,535	204,375	106,712	19,760	62,662	41,217	523	50,108	66,913	83,988
Washington	149,585	33,184	24,253	3,208	10,296	7,382	87	9,831	12,543	16,984
Totals	**5,523,787**	**1,246,674**	**765,414**	**120,537**	**379,403**	**261,199**	**3,178**	**332,622**	**434,417**	**523,713**

MARYLAND

American Lung Association in Maryland

www.lung.org/maryland

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Anne Arundel	9	0	0	3.0	D	0	0	0	0.0	A	9.3	PASS
Baltimore	20	0	0	6.7	F	0	0	0	0.0	A	9.8	PASS
Baltimore City	6	0	0	2.0	C	1	0	0	0.3	B	9.6	PASS
Calvert	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carroll	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cecil	13	1	0	4.8	F	1	0	0	0.3	B	9.4	PASS
Charles	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dorchester	3	0	0	1.0	C	0	0	0	0.0	A	7.9	PASS
Frederick	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Garrett	1	0	0	0.3	B	0	0	0	0.0	A	6.6	PASS
Harford	13	1	0	4.8	F	0	0	0	0.0	A	9.4	PASS
Howard	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Kent	10	0	0	3.3	F	0	0	0	0.0	A	8.8	PASS
Montgomery	6	0	0	2.0	C	0	0	0	0.0	A	8.9	PASS
Prince George's	16	1	0	5.8	F	0	0	0	0.0	A	9.4	PASS
Washington	4	0	0	1.3	C	3	0	0	1.0	C	9.4	PASS

MASSACHUSETTS

American Lung Association in Massachusetts

www.lung.org/massachusetts

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Barnstable	214,333	33,534	61,137	4,053	17,645	12,686	136	19,120	21,136	16,030
Berkshire	127,828	22,400	27,597	2,707	10,567	6,708	81	9,544	10,858	17,453
Bristol	556,772	116,624	89,109	14,095	45,031	25,669	353	34,497	40,355	68,378
Dukes	17,299	3,158	3,617	382	1,419	905	11	1,282	1,469	1,456
Essex	776,043	169,296	123,799	20,461	62,022	35,610	491	47,962	56,131	87,669
Franklin	70,601	12,653	13,439	1,529	5,860	3,595	45	4,986	5,782	8,221
Hampden	470,690	105,014	72,932	12,692	37,479	21,025	298	28,133	32,860	77,818
Hampshire	161,292	24,587	24,700	2,972	14,134	7,399	102	9,645	11,270	21,232
Middlesex	1,585,139	322,638	226,108	38,994	130,333	70,034	1,004	91,480	107,969	116,761
Norfolk	696,023	149,465	111,124	18,065	55,890	31,991	440	43,046	50,370	48,042
Plymouth	510,393	113,432	85,389	13,710	40,386	23,953	323	32,672	38,155	48,231
Suffolk	778,121	133,727	86,473	16,162	67,807	31,251	493	37,909	45,273	144,867
Worcester	818,963	178,270	118,261	21,546	65,911	36,609	519	48,272	57,168	95,500
Totals	**6,783,497**	**1,384,798**	**1,043,685**	**167,368**	**554,483**	**307,435**	**4,295**	**408,549**	**478,798**	**751,658**

MASSACHUSETTS

American Lung Association in Massachusetts

www.lung.org/massachusetts

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Barnstable	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Berkshire	INC	INC	INC	INC	INC	0	0	0	0.0	A	6.8	PASS
Bristol	9	2	0	4.0	F	0	0	0	0.0	A	6.9	PASS
Dukes	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Essex	14	0	0	4.7	F	0	0	0	0.0	A	6.3	PASS
Franklin	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Hampden	7	0	0	2.3	D	0	0	0	0.0	A	7.3	PASS
Hampshire	6	0	0	2.0	C	INC	INC	INC	INC	INC	INC	INC
Middlesex	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Norfolk	7	1	0	2.8	D	INC	INC	INC	INC	INC	INC	INC
Plymouth	INC	INC	INC	INC	INC	0	0	0	0.0	A	INC	INC
Suffolk	6	0	0	2.0	C	0	0	0	0.0	A	7.7	PASS
Worcester	3	0	0	1.0	C	0	0	0	0.0	A	6.9	PASS

MICHIGAN

American Lung Association in Michigan

www.lung.org/michigan

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Allegan	114,625	28,179	17,738	2,183	8,866	6,785	73	8,142	9,463	12,668
Bay	105,659	21,934	19,842	1,699	8,544	6,759	67	8,346	9,546	15,161
Benzie	17,457	3,257	4,301	252	1,431	1,258	11	1,633	1,811	1,810
Berrien	154,636	34,521	28,115	2,674	12,265	9,639	98	11,873	13,603	25,854
Cass	51,657	10,899	10,254	844	4,145	3,399	33	4,247	4,817	7,530
Chippewa	38,033	7,100	6,330	550	3,181	2,316	25	2,775	3,242	6,502
Clinton	77,390	17,667	12,207	1,369	6,127	4,660	49	5,587	6,501	7,632
Genesee	410,849	95,474	65,992	7,396	32,345	24,536	261	29,550	34,316	83,172
Huron	31,883	6,218	7,574	482	2,590	2,254	20	2,911	3,238	3,662
Ingham	286,085	57,692	35,094	4,469	23,751	15,154	182	17,099	20,836	56,310
Kalamazoo	260,263	57,149	36,023	4,427	21,016	14,218	166	16,530	19,732	40,161
Kent	636,369	158,665	79,581	12,291	49,439	34,080	405	39,215	46,957	90,457
Lenawee	98,573	21,365	17,053	1,655	7,903	6,083	63	7,405	8,546	13,388
Macomb	864,840	187,442	137,131	14,521	69,546	52,417	549	62,721	73,101	99,879
Manistee	24,461	4,357	5,816	338	2,031	1,750	16	2,250	2,510	3,465
Mason	28,783	5,963	6,234	462	2,313	1,938	18	2,463	2,768	4,745
Missaukee	14,903	3,400	2,922	263	1,170	958	10	1,199	1,359	2,576
Monroe	149,568	33,218	24,353	2,573	11,919	9,249	95	11,143	12,913	15,717
Muskegon	172,790	40,701	26,801	3,153	13,565	10,150	110	12,149	14,167	26,695
Oakland	1,242,304	270,694	192,577	20,970	99,794	75,210	789	89,638	104,668	114,976
Ottawa	279,955	69,191	37,983	5,360	21,771	15,170	178	17,716	21,041	23,266
Schoolcraft	8,173	1,440	2,031	112	678	606	5	785	870	1,273
St. Clair	159,875	34,557	27,456	2,677	12,812	10,129	102	12,313	14,186	20,195
Tuscola	53,777	11,360	10,174	880	4,323	3,483	34	4,310	4,917	8,200
Washtenaw	358,880	69,537	44,917	5,387	30,063	19,495	228	22,065	26,801	48,525
Wayne	1,759,335	423,146	248,327	32,780	137,680	99,824	1,116	117,427	138,457	430,851
Wexford	33,003	7,725	5,915	598	2,580	2,048	21	2,522	2,888	4,827
Totals	**7,434,126**	**1,682,851**	**1,112,741**	**130,366**	**591,847**	**433,567**	**4,725**	**514,016**	**603,256**	**1,169,497**

MICHIGAN

American Lung Association in Michigan

www.lung.org/michigan

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Allegan	17	2	0	6.7	F	0	0	0	0.0	A	8.1	PASS
Bay	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.8	PASS
Benzie	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Berrien	14	0	0	4.7	F	0	0	0	0.0	A	8.2	PASS
Cass	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Chippewa	0	0	0	0.0	A	0	0	0	0.0	A	6.1	PASS
Clinton	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Genesee	5	0	0	1.7	C	1	0	0	0.3	B	8.2	PASS
Huron	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ingham	1	0	0	0.3	B	0	0	0	0.0	A	8.5	PASS
Kalamazoo	3	0	0	1.0	C	1	0	0	0.3	B	9.0	PASS
Kent	6	0	0	2.0	C	0	1	0	0.5	B	9.4	PASS
Lenawee	4	0	0	1.3	C	0	0	0	0.0	A	8.4	PASS
Macomb	15	0	0	5.0	F	0	1	0	0.5	B	8.9	PASS
Manistee	5	0	0	1.7	C	1	0	0	0.3	B	6.3	PASS
Mason	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Missaukee	2	0	0	0.7	B	0	0	0	0.0	A	5.6	PASS
Monroe	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	INC	INC
Muskegon	17	1	0	6.2	F	INC	INC	INC	INC	INC	INC	INC
Oakland	8	0	0	2.7	D	1	0	0	0.3	B	9.0	PASS
Ottawa	7	0	0	2.3	D	INC	INC	INC	INC	INC	INC	INC
Schoolcraft	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Clair	19	0	0	6.3	F	1	0	0	0.3	B	9.1	PASS
Tuscola	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washtenaw	5	0	0	1.7	C	0	0	0	0.0	A	9.2	PASS
Wayne	9	0	0	3.0	D	4	0	0	1.3	C	11.4	PASS
Wexford	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MINNESOTA

American Lung Association in Minnesota

www.lung.org/minnesota

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Anoka	344,151	83,424	42,705	5,248	19,301	11,354	198	16,473	19,048	24,058
Becker	33,386	8,227	6,532	518	1,834	1,277	19	2,020	2,185	3,728
Beltrami	45,672	11,516	6,826	724	2,541	1,509	26	2,252	2,515	7,081
Carlton	35,569	8,059	5,945	507	2,021	1,304	21	1,991	2,211	3,658
Crow Wing	63,428	13,940	13,464	877	3,604	2,552	36	4,072	4,371	6,500
Dakota	414,686	102,866	52,466	6,471	23,088	13,629	238	19,853	22,860	29,191
Goodhue	46,435	10,438	8,789	657	2,628	1,793	27	2,805	3,063	4,042
Hennepin	1,223,149	271,399	157,112	17,074	70,967	40,122	702	57,856	66,595	130,801
Lake	10,631	1,986	2,655	125	623	476	6	779	823	1,024
Lyon	25,673	6,424	3,787	404	1,428	857	15	1,279	1,435	3,009
Mille Lacs	25,788	6,154	4,744	387	1,437	966	15	1,505	1,644	3,125
Olmsted	151,436	37,346	21,771	2,349	8,453	5,084	87	7,554	8,523	13,255
Ramsey	538,133	125,750	71,450	7,911	30,770	17,476	309	25,385	28,983	78,920
Scott	141,660	40,341	13,602	2,538	7,549	4,150	81	5,802	6,891	7,203
St. Louis	200,431	38,344	35,413	2,412	11,947	7,587	115	11,579	12,809	25,821
Stearns	154,708	35,283	21,287	2,220	8,908	5,096	89	7,441	8,458	19,939
Washington	251,597	62,864	33,651	3,955	13,922	8,474	144	12,499	14,289	12,744
Winona	50,885	9,338	7,888	587	3,102	1,786	29	2,634	2,960	5,953
Wright	131,311	37,511	15,260	2,360	6,963	4,029	76	5,824	6,733	6,629
Totals	**3,888,729**	**911,210**	**525,347**	**57,325**	**221,085**	**129,523**	**2,234**	**189,602**	**216,396**	**386,681**

MINNESOTA

American Lung Association in Minnesota

www.lung.org/minnesota

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Anoka	3	0	0	1.0	C	1	0	0	0.3	B	6.8	PASS
Becker	0	0	0	0.0	A	2	0	0	0.7	B	INC	INC
Beltrami	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Carlton	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Crow Wing	0	0	0	0.0	A	2	0	0	0.7	B	5.1	PASS
Dakota	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.0	PASS
Goodhue	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hennepin	0	0	0	0.0	A	1	0	0	0.3	B	8.1	PASS
Lake	0	0	0	0.0	A	1	0	0	0.3	B	4.8	PASS
Lyon	4	0	0	1.3	C	1	0	0	0.3	B	6.3	PASS
Mille Lacs	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Olmsted	0	0	0	0.0	A	2	0	0	0.7	B	7.3	PASS
Ramsey	DNC	DNC	DNC	DNC	DNC	3	0	0	1.0	C	9.3	PASS
Scott	1	0	0	0.3	B	0	0	0	0.0	A	7.8	PASS
St. Louis	0	0	0	0.0	A	1	0	0	0.3	B	7.5	PASS
Stearns	0	0	0	0.0	A	0	1	0	0.5	B	6.1	PASS
Washington	0	0	0	0.0	A	2	0	0	0.7	B	8.4	PASS
Winona	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Wright	1	0	0	0.3	B	0	0	0	0.0	A	6.6	PASS

MISSISSIPPI

American Lung Association in Mississippi

www.lung.org/mississippi

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Bolivar	33,322	8,403	4,779	747	1,929	1,892	26	2,762	3,604	11,380
DeSoto	173,323	45,833	21,065	4,073	9,912	9,623	135	13,634	18,017	17,169
Forrest	75,944	17,548	9,980	1,560	4,495	4,171	59	5,962	7,867	19,355
Grenada	21,578	5,133	3,658	456	1,278	1,331	17	1,999	2,572	4,539
Hancock	46,420	10,185	8,158	905	2,827	3,005	36	4,513	5,802	9,574
Harrison	201,410	48,920	27,525	4,348	11,829	11,575	157	16,684	21,885	43,019
Hinds	242,891	60,755	30,353	5,400	14,123	13,542	187	19,229	25,403	63,361
Jackson	141,425	34,092	20,634	3,030	8,356	8,445	110	12,307	16,048	22,511
Lauderdale	78,524	18,824	12,320	1,673	4,632	4,689	61	6,938	8,991	16,497
Lee	85,300	21,934	12,457	1,949	4,920	4,933	66	7,227	9,407	14,640
Yalobusha	12,447	2,895	2,301	257	742	789	10	1,204	1,538	2,747
Totals	**1,112,584**	**274,522**	**153,230**	**24,398**	**65,043**	**63,994**	**864**	**92,458**	**121,133**	**224,792**

MISSISSIPPI

American Lung Association in Mississippi

www.lung.org/mississippi

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bolivar	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
DeSoto	2	0	0	0.7	B	1	0	0	0.3	B	9.3	PASS
Forrest	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	10.0	PASS
Grenada	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.1	PASS
Hancock	2	0	0	0.7	B	0	0	0	0.0	A	8.6	PASS
Harrison	7	0	0	2.3	D	0	0	0	0.0	A	8.8	PASS
Hinds	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Jackson	8	0	0	2.7	D	0	0	0	0.0	A	9.2	PASS
Lauderdale	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lee	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Yalobusha	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MISSOURI

American Lung Association in Missouri

www.lung.org/missouri

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Andrew	17,296	3,984	3,022	345	1,272	1,174	13	1,521	1,633	1,612
Boone	174,974	35,803	18,998	3,096	13,586	10,170	131	11,594	12,960	29,347
Buchanan	89,100	20,210	13,356	1,748	6,634	5,710	67	7,113	7,733	14,578
Callaway	44,834	9,507	6,539	822	3,402	2,924	34	3,617	3,954	5,672
Cass	101,603	25,189	16,118	2,178	7,325	6,577	76	8,377	9,052	9,241
Cedar	13,934	3,246	3,352	281	1,012	1,014	10	1,408	1,458	2,727
Clay	235,637	58,322	30,934	5,044	17,111	14,431	176	17,614	19,358	18,212
Clinton	20,609	4,876	3,628	422	1,503	1,392	16	1,809	1,939	2,094
Greene	288,072	60,311	45,016	5,216	21,990	18,438	216	22,908	24,764	48,993
Jackson	687,623	165,286	95,014	14,295	50,363	42,820	514	52,688	57,659	119,421
Jasper	118,596	30,156	16,783	2,608	8,530	7,230	89	8,946	9,735	18,467
Jefferson	224,124	53,406	30,911	4,619	16,414	14,345	168	17,751	19,493	23,221
Lincoln	54,696	14,267	6,951	1,234	3,893	3,353	41	4,105	4,529	6,089
Monroe	8,583	1,912	1,839	165	633	620	6	838	882	1,182
Perry	19,183	4,604	3,242	398	1,395	1,271	14	1,637	1,759	2,088
St. Charles	385,590	93,004	52,662	8,043	28,177	24,240	289	29,863	32,763	23,775
St. Louis	1,003,362	223,088	169,017	19,294	74,774	67,336	748	86,170	92,819	101,692
St. Louis City	315,685	63,437	36,569	5,486	24,494	19,411	236	22,709	25,343	78,089
Ste. Genevieve	17,919	4,035	3,118	349	1,325	1,237	13	1,603	1,726	1,914
Taney	54,592	11,646	11,028	1,007	4,102	3,801	41	5,033	5,313	8,483
Totals	**3,876,012**	**886,289**	**568,097**	**76,650**	**287,936**	**247,496**	**2,899**	**307,306**	**334,871**	**516,897**

MISSOURI

American Lung Association in Missouri

www.lung.org/missouri

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Andrew	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Boone	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Buchanan	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	10.5	PASS
Callaway	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cass	0	0	0	0.0	A	1	0	0	0.3	B	9.4	PASS
Cedar	1	0	0	0.3	B	0	0	0	0.0	A	7.9	PASS
Clay	13	0	0	4.3	F	1	0	0	0.3	B	8.6	PASS
Clinton	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Jackson	DNC	DNC	DNC	DNC	DNC	3	0	0	1.0	C	9.1	PASS
Jasper	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	10	0	0	3.3	F	3	0	0	1.0	C	10.6	PASS
Lincoln	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Monroe	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Perry	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Charles	15	1	0	5.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Louis	11	0	0	3.7	F	3	0	0	1.0	C	10.7	PASS
St. Louis City	2	0	0	0.7	B	7	1	0	2.8	D	11.0	PASS
Ste. Genevieve	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Taney	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MONTANA

American Lung Association in Montana

www.lung.org/montana

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Fergus	11,427	2,337	2,685	148	794	587	7	825	817	1,515
Flathead	96,165	21,452	17,068	1,360	6,633	4,416	56	5,933	6,135	13,270
Lewis and Clark	66,418	14,379	11,234	912	4,630	3,002	38	3,992	4,165	7,903
Lincoln	19,052	3,491	4,903	221	1,360	1,072	11	1,523	1,499	3,817
Missoula	114,181	22,154	16,172	1,404	8,203	4,628	66	5,905	6,350	17,461
Phillips	4,169	965	865	61	282	204	2	283	285	673
Powder River	1,773	302	435	19	129	99	1	139	138	185
Ravalli	41,373	8,214	9,904	521	2,901	2,193	24	3,088	3,060	6,129
Richland	11,960	3,091	1,504	196	796	466	7	594	643	835
Rosebud	9,398	2,763	1,326	175	593	373	5	490	517	1,750
Silver Bow	34,622	7,092	6,107	450	2,442	1,575	20	2,103	2,181	5,614
Yellowstone	157,048	36,826	24,786	2,335	10,690	6,650	91	8,761	9,193	15,995
Totals	**567,586**	**123,066**	**96,989**	**7,802**	**39,452**	**25,264**	**328**	**33,634**	**34,983**	**75,147**

MONTANA

American Lung Association in Montana

www.lung.org/montana

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Fergus	0	0	0	0.0	A	7	3	0	3.8	F	4.5	PASS
Flathead	0	0	0	0.0	A	9	9	0	7.5	F	9.3	PASS
Lewis and Clark	0	0	0	0.0	A	12	5	0	6.5	F	8.3	PASS
Lincoln	DNC	DNC	DNC	DNC	DNC	9	12	1	9.7	F	11.7	PASS
Missoula	0	0	0	0.0	A	9	11	0	8.5	F	10.4	PASS
Phillips	0	0	0	0.0	A	5	4	0	3.7	F	4.9	PASS
Powder River	0	0	0	0.0	A	5	1	0	2.2	D	6.2	PASS
Ravalli	DNC	DNC	DNC	DNC	DNC	17	11	2	12.5	F	9.4	PASS
Richland	0	0	0	0.0	A	4	3	0	2.8	D	7.0	PASS
Rosebud	0	0	0	0.0	A	4	1	0	1.8	C	5.4	PASS
Silver Bow	DNC	DNC	DNC	DNC	DNC	10	7	0	6.8	F	9.7	PASS
Yellowstone	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC

NEBRASKA

American Lung Association in Nebraska

www.lung.org/nebraska

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Douglas	550,064	142,366	64,743	9,416	29,437	20,470	338	27,534	32,882	77,869
Hall	61,680	16,673	8,902	1,103	3,241	2,456	38	3,402	3,973	8,182
Knox	8,543	2,077	2,039	137	462	438	5	646	720	1,141
Lancaster	306,468	70,379	38,425	4,655	17,054	11,578	189	15,724	18,567	39,383
Sarpy	175,692	49,226	18,645	3,256	9,137	6,234	108	8,293	9,997	10,095
Scotts Bluff	36,261	8,957	6,543	592	1,960	1,615	22	2,296	2,628	5,364
Washington	20,248	4,864	3,361	322	1,105	911	12	1,267	1,482	1,328
Totals	**1,158,956**	**294,542**	**142,658**	**19,480**	**62,396**	**43,703**	**713**	**59,162**	**70,249**	**143,362**

NEBRASKA

American Lung Association in Nebraska

www.lung.org/nebraska

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Douglas	2	0	0	0.7	B	4	0	0	1.3	C	9.1	PASS
Hall	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	6.8	PASS
Knox	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lancaster	0	0	0	0.0	A	1	0	0	0.3	B	7.5	PASS
Sarpy	DNC	DNC	DNC	DNC	DNC	3	0	0	1.0	C	INC	INC
Scotts Bluff	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	5.3	PASS
Washington	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	7.5	PASS

NEVADA

American Lung Association in Nevada

www.lung.org/nevada

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Carson City	54,521	11,140	10,792	651	3,492	3,226	32	3,913	4,779	8,457
Churchill	24,200	5,626	4,425	329	1,492	1,341	14	1,613	1,978	3,115
Clark	2,114,801	498,564	290,001	29,147	130,554	103,810	1,242	121,424	153,343	321,755
Douglas	47,710	8,500	12,234	497	3,145	3,277	28	4,072	4,863	4,459
Elko	51,935	14,459	5,043	845	3,058	2,226	31	2,562	3,328	5,065
Lyon	52,585	11,634	10,816	680	3,293	3,136	31	3,827	4,647	7,180
Washoe	446,903	99,275	67,548	5,804	28,100	23,194	263	27,431	34,367	61,017
White Pine	9,811	2,088	1,511	122	625	518	6	614	769	1,198
Totals	**2,802,466**	**651,286**	**402,370**	**38,075**	**173,759**	**140,729**	**1,647**	**165,456**	**208,074**	**412,246**

NEVADA

American Lung Association in Nevada

www.lung.org/nevada

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Carson City	1	0	0	0.3	B	8	10	1	8.3	F	INC	INC
Churchill	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clark	64	5	0	23.8	F	5	1	0	2.2	D	10.1	PASS
Douglas	DNC	DNC	DNC	DNC	DNC	13	10	6	13.3	F	INC	INC
Elko	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lyon	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washoe	18	0	0	6.0	F	18	7	0	9.5	F	9.6	PASS
White Pine	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NEW HAMPSHIRE

American Lung Association in New Hampshire

www.lung.org/newhampshire

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Belknap	60,641	11,714	12,451	845	4,872	3,532	40	4,079	4,424	5,217
Cheshire	75,909	13,972	13,574	1,008	6,283	4,172	50	4,648	5,073	7,064
Coos	31,212	5,412	7,018	390	2,554	1,910	21	2,236	2,410	4,792
Grafton	89,320	15,033	16,667	1,084	7,546	5,007	59	5,588	6,065	9,245
Hillsborough	406,678	87,109	58,512	6,283	32,660	20,524	267	22,154	24,704	31,984
Merrimack	147,994	28,984	24,880	2,091	12,059	7,973	97	8,834	9,732	11,691
Rockingham	301,777	61,163	47,679	4,412	24,310	16,094	198	17,762	19,803	15,687
Totals	**1,113,531**	**223,387**	**180,781**	**16,113**	**90,285**	**59,212**	**731**	**65,301**	**72,211**	**85,680**

NEW HAMPSHIRE

American Lung Association in New Hampshire

www.lung.org/newhampshire

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Belknap	0	0	0	0.0	A	0	0	0	0.0	A	5.0	PASS
Cheshire	1	0	0	0.3	B	3	1	0	1.5	C	8.8	PASS
Coos	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Grafton	1	0	0	0.3	B	0	0	0	0.0	A	6.3	PASS
Hillsborough	4	0	0	1.3	C	0	0	0	0.0	A	6.3	PASS
Merrimack	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC
Rockingham	9	0	0	3.0	D	0	0	0	0.0	A	8.2	PASS

NEW JERSEY

American Lung Association in New Jersey

www.lung.org/newjersey

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Atlantic	274,219	60,077	44,800	5,175	15,459	10,901	160	15,917	19,885	37,923
Bergen	938,506	201,430	152,403	17,351	53,224	37,421	548	54,597	68,269	65,906
Camden	510,923	118,125	74,538	10,175	28,407	19,173	298	27,507	34,471	65,805
Cumberland	155,854	36,694	21,848	3,161	8,621	5,673	92	8,040	10,063	24,740
Essex	797,434	191,077	100,634	16,459	43,951	28,153	466	39,512	49,773	131,125
Gloucester	291,479	65,857	42,653	5,673	16,321	11,115	170	16,027	20,133	22,086
Hudson	674,836	136,696	73,318	11,775	39,100	22,716	395	30,321	38,252	117,828
Hunterdon	125,488	25,973	20,477	2,237	7,191	5,243	73	7,794	9,827	6,046
Mercer	371,398	80,663	52,076	6,948	21,047	13,868	217	19,699	24,736	39,354
Middlesex	840,900	183,992	115,274	15,849	47,569	31,018	492	43,846	55,073	69,660
Monmouth	628,715	138,218	100,935	11,906	35,431	25,248	368	37,103	46,557	46,641
Morris	499,509	109,736	78,501	9,452	28,166	19,849	292	29,039	36,453	25,917
Ocean	588,721	138,514	130,156	11,931	32,235	25,767	344	39,159	48,012	63,101
Passaic	510,916	124,017	68,264	10,682	28,014	18,301	299	25,890	32,510	86,457
Union	555,786	131,997	73,670	11,370	30,698	20,137	325	28,577	35,981	58,384
Warren	106,869	22,141	17,629	1,907	6,119	4,382	62	6,452	8,093	8,040
Totals	**7,871,553**	**1,765,207**	**1,167,176**	**152,050**	**441,554**	**298,964**	**4,602**	**429,480**	**538,088**	**869,013**

NEW JERSEY

American Lung Association in New Jersey

www.lung.org/newjersey

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Atlantic	4	1	0	1.8	C	0	0	0	0.0	A	8.1	PASS
Bergen	22	0	0	7.3	F	0	0	0	0.0	A	9.1	PASS
Camden	18	1	0	6.5	F	1	0	0	0.3	B	10.4	PASS
Cumberland	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Essex	10	0	0	3.3	F	2	0	0	0.7	B	8.9	PASS
Gloucester	12	0	0	4.0	F	0	0	0	0.0	A	8.9	PASS
Hudson	21	2	0	8.0	F	1	0	0	0.3	B	10.8	PASS
Hunterdon	10	0	0	3.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mercer	19	0	0	6.3	F	0	0	0	0.0	A	8.6	PASS
Middlesex	13	1	0	4.8	F	0	0	0	0.0	A	8.0	PASS
Monmouth	9	2	0	4.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Morris	10	0	0	3.3	F	0	0	0	0.0	A	7.1	PASS
Ocean	15	1	0	5.5	F	1	0	0	0.3	B	7.7	PASS
Passaic	9	0	0	3.0	D	0	0	0	0.0	A	8.9	PASS
Union	DNC	DNC	DNC	DNC	DNC	5	0	0	1.7	C	10.4	PASS
Warren	3	0	0	1.0	C	0	0	0	0.0	A	8.3	PASS

NEW MEXICO

American Lung Association in New Mexico

www.lung.org/newmexico

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Bernalillo	676,685	153,390	99,360	13,882	51,620	30,839	271	40,308	58,573	126,614
Doña Ana	214,295	54,119	31,444	4,898	15,811	9,174	86	12,034	17,463	53,968
Eddy	57,578	15,216	8,022	1,377	4,178	2,504	23	3,272	4,755	7,015
Grant	28,609	5,929	7,226	537	2,238	1,607	11	2,263	3,077	5,753
Lea	71,180	21,611	7,399	1,956	4,891	2,679	29	3,388	5,077	9,875
Luna	24,518	6,385	5,121	578	1,790	1,200	10	1,661	2,296	7,395
Rio Arriba	39,465	9,489	6,793	859	2,956	1,926	16	2,581	3,662	9,486
San Juan	118,737	31,403	16,654	2,842	8,614	5,179	48	6,774	9,836	22,047
Sandoval	139,394	33,821	22,113	3,061	10,410	6,576	56	8,716	12,494	15,572
Santa Fe	148,686	28,477	31,050	2,577	11,852	8,108	59	11,065	15,447	19,165
Valencia	75,737	18,383	12,106	1,664	5,655	3,590	30	4,764	6,821	14,643
Totals	**1,594,884**	**378,223**	**247,288**	**34,231**	**120,014**	**73,384**	**639**	**96,827**	**139,501**	**291,533**

NEW MEXICO

American Lung Association in New Mexico

www.lung.org/newmexico

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bernalillo	7	0	0	2.3	D	1	0	0	0.3	B	7.5	PASS
Doña Ana	47	1	0	16.2	F	0	1	0	0.5	B	5.6	PASS
Eddy	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Grant	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lea	3	0	0	1.0	C	1	1	0	0.8	B	7.8	PASS
Luna	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rio Arriba	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
San Juan	6	0	0	2.0	C	0	0	0	0.0	A	4.1	PASS
Sandoval	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Santa Fe	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Valencia	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NEW YORK

American Lung Association in New York

www.lung.org/newyork

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Albany	309,381	58,304	48,270	5,820	25,045	14,222	187	18,365	24,127	36,827
Bronx	1,455,444	368,977	166,281	36,829	108,973	56,592	878	71,058	95,629	430,291
Chautauqua	130,779	26,957	24,195	2,691	10,265	6,506	79	8,608	11,130	21,630
Dutchess	295,754	58,429	47,326	5,832	23,510	14,221	179	18,470	24,379	28,978
Erie	922,578	189,903	154,748	18,955	72,679	43,998	558	57,512	75,126	139,581
Essex	38,478	6,501	8,240	649	3,148	2,108	23	2,824	3,617	4,418
Franklin	50,660	10,048	7,766	1,003	4,038	2,354	31	3,040	4,017	8,234
Hamilton	4,712	684	1,305	68	391	302	3	416	523	523
Herkimer	63,100	13,267	12,133	1,324	4,915	3,204	38	4,262	5,493	7,806
Jefferson	117,635	28,751	14,843	2,870	8,938	4,605	72	5,833	7,723	15,718
Kings	2,636,735	612,433	325,578	61,129	203,249	105,485	1,591	133,122	177,651	581,684
Monroe	749,600	159,513	119,145	15,922	58,648	34,647	453	45,035	59,058	107,747
New York	1,644,518	240,380	240,185	23,993	141,186	73,158	992	92,935	122,646	280,715
Niagara	212,652	43,176	37,547	4,310	16,742	10,569	129	13,900	18,134	32,421
Onondaga	468,463	101,865	73,407	10,168	36,408	21,602	283	28,054	36,875	66,114
Orange	377,647	97,462	48,796	9,728	27,867	15,918	229	20,341	27,220	44,395
Oswego	120,146	25,897	17,842	2,585	9,349	5,539	73	7,150	9,490	19,996
Putnam	99,042	20,747	15,070	2,071	7,722	4,803	60	6,219	8,298	5,897
Queens	2,339,150	476,985	323,755	47,610	185,952	102,666	1,415	130,999	174,342	320,712
Richmond	474,558	104,847	71,216	10,465	36,723	21,600	287	27,926	36,907	66,586
Rockland	326,037	90,294	49,160	9,013	23,402	14,047	197	18,331	23,965	44,933
Saratoga	226,249	47,460	36,846	4,737	17,692	10,863	137	14,164	18,634	14,149
Steuben	97,631	21,597	17,601	2,156	7,504	4,813	59	6,364	8,257	14,745
Suffolk	1,501,587	329,288	234,551	32,867	116,081	70,497	910	91,598	120,920	114,849
Tompkins	104,926	15,703	13,350	1,567	9,018	4,342	64	5,415	7,221	18,480
Wayne	91,446	20,039	15,562	2,000	7,042	4,489	55	5,894	7,727	11,008
Westchester	976,396	221,464	154,130	22,105	74,826	45,276	591	58,954	77,491	96,580
Totals	**15,835,304**	**3,390,971**	**2,278,848**	**338,465**	**1,241,312**	**698,426**	**9,575**	**896,789**	**1,186,604**	**2,535,017**

NEW YORK

American Lung Association in New York

www.lung.org/newyork

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Albany	0	0	0	0.0	A	0	0	0	0.0	A	7.4	PASS
Bronx	14	0	0	4.7	F	0	0	0	0.0	A	9.4	PASS
Chautauqua	8	0	0	2.7	D	0	0	0	0.0	A	INC	INC
Dutchess	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Erie	9	0	0	3.0	D	0	0	0	0.0	A	8.6	PASS
Essex	1	0	0	0.3	B	0	0	0	0.0	A	4.1	PASS
Franklin	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hamilton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Herkimer	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kings	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.1	PASS
Monroe	0	0	0	0.0	A	0	0	0	0.0	A	7.2	PASS
New York	8	0	0	2.7	D	0	0	0	0.0	A	11.0	PASS
Niagara	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC
Onondaga	0	0	0	0.0	A	0	0	0	0.0	A	6.4	PASS
Orange	4	0	0	1.3	C	0	0	0	0.0	A	7.2	PASS
Oswego	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Putnam	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Queens	11	0	0	3.7	F	0	0	0	0.0	A	8.1	PASS
Richmond	18	2	0	7.0	F	0	0	0	0.0	A	INC	INC
Rockland	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Saratoga	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Steuben	0	0	0	0.0	A	0	0	0	0.0	A	5.7	PASS
Suffolk	22	2	0	8.3	F	0	0	0	0.0	A	7.5	PASS
Tompkins	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wayne	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Westchester	18	1	0	6.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NORTH CAROLINA

American Lung Association in North Carolina

www.lung.org/northcarolina

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Alamance	158,276	36,006	25,967	4,138	10,049	9,404	111	11,839	13,568	29,039
Alexander	37,325	7,735	7,268	889	2,439	2,402	27	3,142	3,539	5,555
Avery	17,689	2,743	3,691	315	1,229	1,186	13	1,554	1,741	2,997
Buncombe	253,178	48,656	47,089	5,591	16,815	15,971	178	20,538	23,256	37,433
Caldwell	81,287	17,004	14,831	1,954	5,301	5,202	57	6,696	7,622	12,963
Carteret	68,879	12,577	15,542	1,445	4,653	4,789	49	6,461	7,177	9,370
Caswell	22,941	4,390	4,658	504	1,532	1,542	16	2,029	2,285	4,353
Catawba	155,056	35,211	25,759	4,046	9,865	9,408	109	11,889	13,637	23,050
Chatham	70,928	14,114	17,716	1,622	4,698	4,963	50	6,923	7,548	8,111
Cumberland	323,838	82,868	36,625	9,523	19,664	16,254	228	18,698	22,260	59,320
Davidson	164,622	36,952	28,400	4,246	10,520	10,193	116	12,997	14,858	22,977
Davie	41,753	9,023	8,180	1,037	2,703	2,725	29	3,581	4,037	5,080
Duplin	59,159	14,471	9,762	1,663	3,676	3,487	42	4,424	5,056	14,603
Durham	300,952	65,360	34,465	7,511	19,232	15,910	211	18,150	21,740	49,310
Edgecombe	54,150	12,476	9,504	1,434	3,433	3,321	38	4,262	4,849	14,742
Forsyth	369,019	87,172	54,419	10,017	23,139	21,137	258	25,965	30,134	64,966
Franklin	63,710	14,466	9,945	1,662	4,054	3,839	45	4,777	5,532	9,909
Gaston	213,442	48,942	32,838	5,624	13,524	12,603	150	15,625	18,086	36,243
Graham	8,616	1,836	1,961	211	560	575	6	786	864	1,783
Granville	58,674	12,289	9,341	1,412	3,820	3,628	42	4,512	5,230	8,786
Guilford	517,600	117,471	73,066	13,499	32,807	29,322	362	35,488	41,440	78,783
Haywood	59,868	11,001	14,384	1,264	4,038	4,188	42	5,752	6,320	10,436
Jackson	41,265	7,064	7,473	812	2,801	2,531	29	3,206	3,634	7,879
Johnston	185,660	48,767	23,545	5,604	11,240	10,152	131	12,131	14,323	23,887
Lee	59,660	14,874	9,190	1,709	3,680	3,419	42	4,267	4,914	10,044
Lenoir	58,106	13,143	10,623	1,510	3,706	3,626	41	4,695	5,319	13,069
Lincoln	81,035	17,661	13,178	2,030	5,223	5,027	57	6,304	7,283	10,774
Macon	34,201	6,475	9,163	744	2,293	2,453	24	3,478	3,757	5,719
Martin	23,357	4,761	5,018	547	1,537	1,577	16	2,114	2,357	5,213
McDowell	44,989	9,263	8,484	1,064	2,945	2,888	32	3,744	4,240	8,183
Mecklenburg	1,034,070	251,972	106,570	28,956	63,888	52,936	726	59,508	72,056	145,693
Mitchell	15,246	2,815	3,644	323	1,028	1,073	11	1,471	1,620	2,516
Montgomery	27,548	6,329	5,233	727	1,748	1,717	19	2,249	2,529	5,296
New Hanover	220,358	42,336	35,679	4,865	14,586	13,082	155	16,201	18,628	36,967
Person	39,259	8,509	7,046	978	2,536	2,486	28	3,195	3,640	6,317
Pitt	175,842	38,695	20,590	4,447	11,183	9,139	123	10,466	12,467	43,954

NORTH CAROLINA (cont.)

American Lung Association in North Carolina

www.lung.org/northcarolina

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Robeson	134,197	34,605	18,170	3,977	8,167	7,318	94	8,857	10,348	39,785
Rockingham	91,758	19,184	17,184	2,205	5,989	5,938	64	7,694	8,733	16,699
Rowan	139,142	31,310	23,306	3,598	8,871	8,407	98	10,636	12,177	23,342
Swain	14,434	3,222	2,727	370	922	889	10	1,160	1,304	2,295
Union	222,742	62,453	25,941	7,177	13,169	11,899	157	14,033	16,727	21,397
Wake	1,024,198	253,184	105,510	29,095	63,063	53,124	721	59,937	72,654	111,299
Watauga	52,906	6,990	7,728	803	3,739	3,045	37	3,581	4,183	11,956
Wayne	124,132	29,833	18,567	3,428	7,740	7,069	88	8,725	10,092	22,267
Yancey	17,587	3,332	4,208	383	1,178	1,225	12	1,683	1,849	3,359
Totals	**6,962,654**	**1,609,540**	**974,188**	**184,962**	**438,984**	**393,069**	**4,893**	**475,422**	**555,616**	**1,087,719**

NORTH CAROLINA

American Lung Association in North Carolina

www.lung.org/northcarolina

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Alamance	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Alexander	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Avery	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Buncombe	0	0	0	0.0	A	0	0	0	0.0	A	7.7	PASS
Caldwell	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carteret	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Caswell	1	0	0	0.3	B	0	0	0	0.0	A	8.8	PASS
Catawba	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.9	PASS
Chatham	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Cumberland	1	0	0	0.3	B	0	0	0	0.0	A	8.5	PASS
Davidson	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.2	PASS
Davie	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Duplin	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.3	PASS
Durham	0	0	0	0.0	A	0	0	0	0.0	A	8.3	PASS
Edgecombe	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Forsyth	5	0	0	1.7	C	0	0	0	0.0	A	8.5	PASS
Franklin	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Gaston	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Graham	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Granville	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Guilford	2	0	0	0.7	B	0	0	0	0.0	A	8.4	PASS
Haywood	2	0	0	0.7	B	0	0	0	0.0	A	8.2	PASS
Jackson	2	0	0	0.7	B	0	0	0	0.0	A	7.3	PASS
Johnston	0	0	0	0.0	A	0	0	0	0.0	A	7.3	PASS
Lee	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Lenoir	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Lincoln	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Macon	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Martin	0	0	0	0.0	A	0	0	0	0.0	A	6.9	PASS
McDowell	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	8.4	PASS
Mecklenburg	13	0	0	4.3	F	0	0	0	0.0	A	9.0	PASS
Mitchell	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Montgomery	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
New Hanover	0	0	0	0.0	A	0	0	0	0.0	A	6.5	PASS
Person	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pitt	0	0	0	0.0	A	0	0	0	0.0	A	7.3	PASS

NORTH CAROLINA (cont.)

American Lung Association in North Carolina

www.lung.org/northcarolina

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Robeson	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Rockingham	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rowan	2	0	0	0.7	B	0	0	0	0.0	A	8.7	PASS
Swain	0	0	0	0.0	A	0	0	0	0.0	A	7.6	PASS
Union	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wake	1	0	0	0.3	B	2	0	0	0.7	B	10.7	PASS
Watauga	DNC	DNC	DNC	DNC	DNC	0	1	0	0.5	B	6.7	PASS
Wayne	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Yancey	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NORTH DAKOTA

American Lung Association in North Dakota

www.lung.org/northdakota

AT-RISK GROUPS

County	Total Population	Under 18	65 & Over	Lung Diseases: Pediatric Asthma	Lung Diseases: Adult Asthma	Lung Diseases: COPD	Lung Diseases: Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Billings	936	173	163	11	69	42	1	62	72	66
Burke	2,308	562	401	37	159	98	1	149	169	192
Burleigh	92,991	21,222	13,612	1,381	6,465	3,702	54	5,307	6,195	8,048
Cass	171,512	38,045	18,870	2,475	11,893	6,161	99	7,969	9,723	17,733
Dunn	4,646	1,076	636	70	323	184	3	264	311	452
McKenzie	12,826	3,854	942	251	802	400	7	505	638	1,061
Mercer	8,853	2,011	1,502	131	624	383	5	588	672	630
Oliver	1,846	435	356	28	129	84	1	134	150	187
Williams	35,294	9,399	3,013	612	2,311	1,163	21	1,474	1,843	2,713
Totals	**331,212**	**76,777**	**39,495**	**4,995**	**22,774**	**12,215**	**192**	**16,451**	**19,775**	**31,082**

NORTH DAKOTA

American Lung Association in North Dakota

www.lung.org/northdakota

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Billings	0	0	0	0.0	A	3	1	0	1.5	C	4.9	PASS
Burke	0	0	0	0.0	A	5	4	0	3.7	F	5.5	PASS
Burleigh	0	0	0	0.0	A	6	1	0	2.5	D	5.3	PASS
Cass	0	0	0	0.0	A	4	0	0	1.3	C	6.4	PASS
Dunn	1	0	0	0.3	B	10	1	0	3.8	F	5.1	PASS
McKenzie	0	0	0	0.0	A	4	2	0	2.3	D	3.4	PASS
Mercer	0	0	0	0.0	A	5	2	0	2.7	D	5.5	PASS
Oliver	1	0	0	0.3	B	6	1	0	2.5	D	4.9	PASS
Williams	0	0	0	0.0	A	7	2	0	3.3	F	6.9	PASS

OHIO

American Lung Association in Ohio

www.lung.org/ohio

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Allen	104,425	24,346	17,055	1,753	8,035	6,376	72	7,507	8,857	15,229
Ashtabula	98,632	22,120	17,501	1,592	7,671	6,382	68	7,634	9,028	17,636
Athens	65,886	9,882	7,559	711	5,658	3,636	45	3,860	4,586	17,573
Belmont	69,154	13,189	13,339	949	5,601	4,681	48	5,645	6,629	9,524
Butler	376,353	90,328	51,037	6,503	28,834	21,736	259	24,687	29,593	52,356
Clark	135,959	30,897	24,918	2,224	10,513	8,720	93	10,504	12,315	20,019
Clermont	201,973	48,113	29,391	3,464	15,505	12,247	139	14,130	16,999	19,052
Clinton	41,917	9,921	6,529	714	3,217	2,554	29	2,983	3,551	5,513
Cuyahoga	1,255,921	268,170	210,832	19,306	99,147	79,368	861	93,526	110,646	224,256
Delaware	193,013	52,718	23,146	3,795	14,185	10,754	133	12,061	14,687	8,353
Fayette	28,679	6,849	4,866	493	2,189	1,783	20	2,121	2,502	4,575
Franklin	1,251,722	295,725	138,531	21,290	96,685	67,131	861	72,955	88,119	208,972
Geauga	94,102	22,331	17,501	1,608	7,188	6,237	65	7,563	8,957	6,298
Greene	164,427	34,044	26,323	2,451	13,098	10,146	113	11,809	13,961	19,772
Hamilton	807,598	187,937	116,074	13,530	62,391	47,619	554	54,606	65,154	130,935
Jefferson	67,347	13,199	13,329	950	5,414	4,584	46	5,566	6,523	11,547
Knox	61,061	14,158	10,223	1,019	4,704	3,770	42	4,461	5,257	8,510
Lake	229,245	47,536	42,296	3,422	18,209	15,263	158	18,324	21,649	18,884
Lawrence	61,109	13,547	10,753	975	4,767	3,907	42	4,660	5,495	12,680
Licking	170,570	40,213	26,543	2,895	13,109	10,454	117	12,208	14,558	20,933
Lorain	305,147	68,903	51,233	4,960	23,715	19,284	210	22,810	27,050	39,833
Lucas	433,689	100,612	65,018	7,243	33,505	25,953	298	30,017	35,721	82,814
Madison	44,094	9,215	6,244	663	3,518	2,685	31	3,055	3,676	3,614
Mahoning	231,900	47,425	45,088	3,414	18,446	15,530	159	18,829	22,053	37,640
Medina	176,395	40,862	28,428	2,942	13,627	11,121	122	13,076	15,628	12,287
Miami	104,224	24,089	18,432	1,734	8,029	6,632	72	7,939	9,354	10,992
Montgomery	532,258	119,127	90,442	8,576	41,422	33,149	365	39,253	46,195	91,879
Noble	14,326	2,646	3,478	190	1,162	1,086	10	1,372	1,597	1,741
Portage	162,275	31,122	24,393	2,241	13,204	9,990	112	11,433	13,617	20,927
Preble	41,329	9,520	7,350	685	3,187	2,653	28	3,180	3,754	5,160
Scioto	76,825	16,922	13,094	1,218	6,006	4,801	53	5,683	6,687	16,881
Stark	375,165	81,870	67,972	5,894	29,375	24,258	258	29,084	34,211	48,889
Summit	541,968	116,666	89,731	8,399	42,718	34,297	372	40,333	47,877	76,554
Trumbull	203,751	42,580	40,561	3,065	16,103	13,752	140	16,777	19,626	35,069
Warren	224,469	57,543	30,240	4,143	16,843	13,101	155	14,960	18,078	11,375
Washington	61,112	12,223	12,007	880	4,888	4,128	42	5,010	5,868	8,906
Wood	129,730	26,801	18,693	1,929	10,356	7,572	89	8,603	10,167	14,385
Totals	**9,137,750**	**2,053,349**	**1,420,150**	**147,824**	**712,220**	**557,341**	**6,285**	**648,226**	**770,225**	**1,351,563**

OHIO

American Lung Association in Ohio

www.lung.org/ohio

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Allen	4	0	0	1.3	C	0	0	0	0.0	A	INC	INC
Ashtabula	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Athens	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.8	PASS
Belmont	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Butler	11	0	0	3.7	F	0	0	0	0.0	A	10.9	PASS
Clark	11	0	0	3.7	F	0	0	0	0.0	A	9.7	PASS
Clermont	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clinton	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cuyahoga	9	1	0	3.5	F	3	0	0	1.0	C	12.4	FAIL
Delaware	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fayette	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Franklin	16	0	0	5.3	F	0	0	0	0.0	A	10.1	PASS
Geauga	9	0	0	3.0	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	6	0	0	2.0	C	0	0	0	0.0	A	9.3	PASS
Hamilton	16	1	0	5.8	F	1	0	0	0.3	B	11.2	PASS
Jefferson	3	0	0	1.0	C	4	0	0	1.3	C	10.8	PASS
Knox	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lake	16	0	0	5.3	F	0	0	0	0.0	A	8.5	PASS
Lawrence	4	0	0	1.3	C	0	0	0	0.0	A	8.0	PASS
Licking	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lorain	0	0	0	0.0	A	0	0	0	0.0	A	8.7	PASS
Lucas	5	0	0	1.7	C	1	0	0	0.3	B	10.1	PASS
Madison	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mahoning	1	0	0	0.3	B	0	0	0	0.0	A	10.6	PASS
Medina	1	0	0	0.3	B	0	0	0	0.0	A	9.3	PASS
Miami	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Montgomery	5	0	0	1.7	C	1	0	0	0.3	B	INC	INC
Noble	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Portage	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Preble	2	0	0	0.7	B	0	0	0	0.0	A	9.1	PASS
Scioto	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.6	PASS
Stark	11	0	0	3.7	F	1	0	0	0.3	B	11.6	PASS
Summit	0	0	0	0.0	A	1	0	0	0.3	B	11.2	PASS
Trumbull	5	0	0	1.7	C	0	0	0	0.0	A	INC	INC
Warren	11	0	0	3.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washington	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wood	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC

OKLAHOMA

American Lung Association in Oklahoma

www.lung.org/oklahoma

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Adair	22,004	5,835	3,271	594	1,556	1,443	15	1,787	1,962	6,197
Bryan	44,884	10,515	7,768	1,070	3,274	3,053	31	3,842	4,138	7,924
Caddo	29,343	7,495	4,653	762	2,096	1,958	21	2,446	2,664	5,828
Canadian	133,378	35,367	16,305	3,598	9,419	8,213	94	9,750	10,969	12,844
Cherokee	48,447	11,088	7,479	1,128	3,559	3,184	34	3,896	4,265	10,023
Cleveland	274,458	60,824	33,816	6,188	20,371	17,047	193	19,823	22,387	30,190
Comanche	124,648	30,129	14,223	3,065	9,013	7,439	88	8,556	9,727	17,201
Cotton	5,996	1,418	1,115	144	441	435	4	561	602	995
Creek	70,892	17,030	12,230	1,732	5,181	4,988	50	6,332	6,850	10,927
Dewey	4,995	1,336	952	136	350	349	3	455	482	640
Jefferson	6,276	1,506	1,247	153	458	461	4	603	640	1,216
Johnston	10,980	2,552	2,029	260	807	784	8	1,004	1,076	2,276
Kay	45,366	11,477	8,310	1,168	3,238	3,140	32	4,034	4,306	8,261
Lincoln	35,042	8,681	6,031	883	2,542	2,473	25	3,151	3,409	5,097
Love	9,870	2,477	1,834	252	706	688	7	887	945	1,213
Mayes	40,887	9,954	7,040	1,013	2,976	2,867	29	3,641	3,938	7,471
McClain	38,066	9,807	5,679	998	2,723	2,530	27	3,133	3,445	4,040
Oklahoma	776,864	199,953	98,327	20,341	55,262	47,978	544	57,019	63,883	123,515
Ottawa	31,981	7,992	5,750	813	2,289	2,193	22	2,800	2,996	7,103
Pittsburg	44,610	10,011	8,213	1,018	3,313	3,195	31	4,082	4,381	7,163
Pottawatomie	71,875	17,434	11,470	1,774	5,213	4,824	50	6,002	6,541	11,672
Sequoyah	41,153	9,726	7,162	989	3,021	2,905	29	3,689	3,987	9,934
Tulsa	639,242	163,049	84,306	16,587	45,693	40,342	447	48,432	54,032	99,650
Totals	**2,551,257**	**635,656**	**349,210**	**64,665**	**183,501**	**162,489**	**1,789**	**195,925**	**217,626**	**391,380**

OKLAHOMA

American Lung Association in Oklahoma

www.lung.org/oklahoma

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Adair	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bryan	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Caddo	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Canadian	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cherokee	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cleveland	4	0	0	1.3	C	INC	INC	INC	INC	INC	INC	INC
Comanche	7	0	0	2.3	D	INC	INC	INC	INC	INC	INC	INC
Cotton	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Creek	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dewey	4	0	0	1.3	C	INC	INC	INC	INC	INC	INC	INC
Jefferson	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Johnston	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kay	5	0	0	1.7	C	3	0	0	1.0	C	INC	INC
Lincoln	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Love	INC	INC	INC	INC	INC	1	1	0	0.8	B	INC	INC
Mayes	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
McClain	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Oklahoma	15	0	0	5.0	F	0	0	0	0.0	A	8.6	PASS
Ottawa	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pittsburg	5	0	0	1.7	C	2	0	0	0.7	B	8.8	PASS
Pottawatomie	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sequoyah	1	0	0	0.3	B	0	0	0	0.0	A	8.9	PASS
Tulsa	12	0	0	4.0	F	0	0	0	0.0	A	8.8	PASS

OREGON

American Lung Association in Oregon

www.lung.org/oregon

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Clackamas	401,515	88,343	67,006	8,291	35,479	18,252	226	25,041	34,780	37,507
Columbia	49,600	10,906	8,810	1,023	4,368	2,336	28	3,237	4,469	6,595
Crook	21,630	4,183	5,347	393	1,935	1,143	12	1,719	2,217	3,423
Deschutes	175,268	36,927	33,117	3,465	15,586	8,234	99	11,673	15,765	23,298
Harney	7,200	1,476	1,642	139	638	366	4	541	708	1,147
Jackson	212,567	44,332	44,244	4,160	18,855	10,252	119	14,926	19,715	40,427
Josephine	84,745	16,554	21,343	1,554	7,553	4,474	48	6,783	8,687	18,268
Klamath	66,016	14,286	13,086	1,341	5,811	3,122	37	4,495	5,994	12,966
Lake	7,829	1,456	1,844	137	709	412	4	609	798	1,374
Lane	362,895	68,799	64,973	6,456	33,296	16,555	204	23,240	31,518	69,999
Marion	330,700	83,148	48,905	7,803	28,173	13,540	186	18,453	25,643	53,817
Multnomah	790,294	154,609	96,666	14,509	73,114	31,912	444	41,027	59,635	121,528
Umatilla	76,531	19,800	11,009	1,858	6,461	3,107	43	4,207	5,881	13,860
Washington	574,326	137,564	70,107	12,910	50,119	22,712	323	29,388	42,614	59,471
Totals	**3,161,116**	**682,383**	**488,099**	**64,038**	**282,096**	**136,418**	**1,778**	**185,339**	**258,424**	**463,680**

OREGON

American Lung Association in Oregon

www.lung.org/oregon

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Clackamas	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Columbia	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Crook	DNC	DNC	DNC	DNC	DNC	8	3	0	4.2	F	9.9	PASS
Deschutes	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Harney	DNC	DNC	DNC	DNC	DNC	7	1	0	2.8	D	9.1	PASS
Jackson	1	1	0	0.8	B	11	3	1	5.8	F	11.8	PASS
Josephine	DNC	DNC	DNC	DNC	DNC	2	1	0	1.2	C	9.2	PASS
Klamath	DNC	DNC	DNC	DNC	DNC	10	3	0	4.8	F	10.3	PASS
Lake	DNC	DNC	DNC	DNC	DNC	13	9	0	8.8	F	10.6	PASS
Lane	4	0	0	1.3	C	14	1	0	5.2	F	9.6	PASS
Marion	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Multnomah	1	0	0	0.3	B	3	1	0	1.5	C	7.4	PASS
Umatilla	3	0	0	1.0	C	5	2	0	2.7	D	INC	INC
Washington	1	0	0	0.3	B	6	1	0	2.5	D	8.0	PASS

PENNSYLVANIA

American Lung Association in Pennsylvania

www.lung.org/pennsylvania

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Adams	102,295	21,070	19,261	2,355	8,250	5,971	67	8,193	8,914	8,365
Allegheny	1,230,459	233,675	217,210	26,121	102,088	69,398	807	93,646	102,520	145,454
Armstrong	67,052	13,037	13,867	1,457	5,448	4,137	44	5,751	6,223	8,334
Beaver	168,871	33,153	33,941	3,706	13,729	10,208	111	14,116	15,302	21,668
Berks	415,271	94,450	67,198	10,558	32,891	22,274	273	29,968	32,895	50,814
Blair	125,593	25,939	24,852	2,900	10,102	7,381	82	10,174	11,031	18,616
Bradford	61,281	13,427	12,190	1,501	4,832	3,639	40	5,048	5,465	7,881
Bucks	627,367	132,377	107,816	14,798	50,440	35,909	412	48,892	53,504	39,001
Cambria	136,411	26,377	28,534	2,949	11,114	8,324	90	11,550	12,488	19,450
Centre	160,580	24,411	20,365	2,729	14,328	7,762	107	9,715	10,961	22,716
Chester	515,939	120,162	77,227	13,432	40,664	27,246	339	36,441	40,187	30,147
Clearfield	80,994	14,976	15,660	1,674	6,708	4,835	54	6,630	7,213	12,487
Cumberland	246,338	50,023	42,941	5,592	20,103	13,677	162	18,463	20,208	17,149
Dauphin	272,983	61,299	42,684	6,852	21,743	14,543	179	19,477	21,436	36,332
Delaware	563,894	125,524	86,401	14,032	45,114	29,719	369	39,628	43,687	56,493
Elk	30,872	6,030	6,463	674	2,499	1,936	20	2,702	2,921	2,821
Erie	278,045	60,598	44,847	6,774	22,329	14,928	183	20,015	21,996	45,339
Franklin	153,638	34,945	28,517	3,906	12,067	8,644	101	11,848	12,880	14,258
Greene	37,519	7,221	6,584	807	3,100	2,129	25	2,878	3,151	5,200
Indiana	86,966	15,860	15,277	1,773	7,302	4,848	57	6,505	7,130	14,789
Lackawanna	211,917	42,598	40,519	4,762	17,222	12,291	139	16,831	18,302	31,144
Lancaster	536,624	128,793	89,727	14,397	41,751	28,456	353	38,439	42,053	55,725
Lawrence	88,082	17,798	17,902	1,990	7,102	5,314	58	7,365	7,973	15,015
Lebanon	137,067	31,439	25,574	3,514	10,736	7,699	90	10,559	11,473	15,464
Lehigh	360,685	82,249	58,165	9,194	28,575	19,173	237	25,744	28,267	42,456
Luzerne	318,449	62,459	61,036	6,982	26,033	18,616	209	25,496	27,732	46,457
Lycoming	116,048	23,833	20,789	2,664	9,415	6,552	76	8,898	9,717	16,377
Mercer	114,234	22,901	23,137	2,560	9,243	6,836	75	9,451	10,236	15,242
Monroe	166,397	34,257	25,870	3,829	13,551	9,240	109	12,406	13,675	20,559
Montgomery	819,264	178,455	137,266	19,949	65,556	45,144	538	61,016	66,866	52,939
Northampton	300,813	61,413	53,683	6,865	24,435	17,070	198	23,194	25,338	25,559
Perry	45,685	9,948	7,509	1,112	3,651	2,553	30	3,457	3,792	4,322
Philadelphia	1,567,442	346,932	198,475	38,782	127,499	74,034	1,024	94,862	106,183	385,781
Somerset	75,522	13,718	15,829	1,533	6,244	4,675	50	6,482	7,015	10,165
Tioga	41,877	8,324	8,398	930	3,401	2,486	28	3,428	3,716	5,233
Washington	208,261	41,143	40,169	4,599	16,954	12,373	137	17,016	18,497	20,501
Westmoreland	357,956	67,000	75,735	7,490	29,318	22,397	235	31,186	33,713	39,587
York	442,867	99,147	71,845	11,083	35,199	24,097	291	32,488	35,662	45,255
Totals	**11,271,558**	**2,386,961**	**1,883,463**	**266,826**	**910,734**	**616,511**	**7,400**	**829,957**	**910,319**	**1,425,095**

PENNSYLVANIA

American Lung Association in Pennsylvania

www.lung.org/pennsylvania

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Adams	3	0	0	1.0	C	3	0	0	1.0	C	9.6	PASS
Allegheny	20	1	0	7.2	F	15	2	0	6.0	F	12.6	FAIL
Armstrong	11	1	0	4.2	F	0	0	0	0.0	A	11.1	PASS
Beaver	14	1	0	5.2	F	1	0	0	0.3	B	10.8	PASS
Berks	8	0	0	2.7	D	17	0	0	5.7	F	10.2	PASS
Blair	4	0	0	1.3	C	3	0	0	1.0	C	11.4	PASS
Bradford	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bucks	24	2	0	9.0	F	13	0	0	4.3	F	10.2	PASS
Cambria	3	0	0	1.0	C	2	0	0	0.7	B	11.7	PASS
Centre	2	0	0	0.7	B	2	0	0	0.7	B	8.6	PASS
Chester	6	1	0	2.5	D	2	0	0	0.7	B	10.0	PASS
Clearfield	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cumberland	DNC	DNC	DNC	DNC	DNC	12	0	0	4.0	F	10.1	PASS
Dauphin	6	0	0	2.0	C	15	0	0	5.0	F	11.0	PASS
Delaware	15	0	0	5.0	F	3	0	0	1.0	C	11.6	PASS
Elk	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Erie	3	0	0	1.0	C	0	0	0	0.0	A	10.8	PASS
Franklin	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Indiana	10	1	0	3.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lackawanna	4	0	0	1.3	C	0	0	0	0.0	A	INC	INC
Lancaster	5	0	0	1.7	C	26	1	0	9.2	F	11.2	PASS
Lawrence	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lebanon	15	0	0	5.0	F	16	0	0	5.3	F	INC	INC
Lehigh	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Luzerne	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lycoming	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mercer	9	0	0	3.0	D	0	1	0	0.5	B	9.7	PASS
Monroe	2	0	0	0.7	B	0	0	0	0.0	A	8.7	PASS
Montgomery	14	0	0	4.7	F	4	0	0	1.3	C	9.0	PASS
Northampton	4	0	0	1.3	C	11	0	0	3.7	F	10.0	PASS
Perry	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Philadelphia	21	3	0	8.5	F	9	0	0	3.0	D	11.8	PASS
Somerset	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tioga	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Washington	11	0	0	3.7	F	1	0	0	0.3	B	11.7	PASS
Westmoreland	7	0	0	2.3	D	0	0	0	0.0	A	9.8	PASS
York	9	0	0	3.0	D	6	0	0	2.0	C	10.1	PASS

RHODE ISLAND

American Lung Association in Rhode Island

www.lung.org/rhodeisland

AT-RISK GROUPS

County	Total Population	Under 18	65 & Over	Lung Diseases: Pediatric Asthma	Lung Diseases: Adult Asthma	Lung Diseases: COPD	Lung Diseases: Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Kent	164,801	31,665	29,398	3,101	14,638	8,784	117	10,569	12,804	14,250
Providence	633,473	132,542	91,356	12,982	55,645	29,827	449	35,158	42,350	104,385
Washington	126,517	22,283	23,507	2,183	11,447	6,849	90	8,290	9,985	11,912
Totals	**924,791**	**186,490**	**144,261**	**18,266**	**81,730**	**45,460**	**655**	**54,017**	**65,138**	**130,547**

RHODE ISLAND

American Lung Association in Rhode Island

www.lung.org/rhodeisland

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Kent	8	1	0	3.2	D	0	0	0	0.0	A	4.9	PASS
Providence	10	1	0	3.8	F	1	1	0	0.8	B	8.1	PASS
Washington	16	1	0	5.8	F	0	0	0	0.0	A	5.1	PASS

SOUTH CAROLINA

American Lung Association in South Carolina

www.lung.org/southcarolina

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Abbeville	24,932	5,332	4,973	452	1,621	1,530	16	2,100	2,554	4,617
Aiken	165,829	36,383	29,985	3,085	10,685	9,783	109	13,223	16,185	29,497
Anderson	194,692	45,054	33,829	3,820	12,344	11,213	128	15,093	18,504	32,807
Berkeley	202,786	49,143	25,819	4,167	12,568	10,415	134	13,345	16,679	25,852
Charleston	389,262	78,207	57,844	6,631	25,386	21,392	255	27,842	34,524	56,459
Cherokee	56,194	13,378	8,734	1,134	3,526	3,110	37	4,114	5,081	11,195
Chesterfield	46,017	10,586	7,528	898	2,937	2,656	30	3,540	4,366	10,653
Colleton	37,731	8,550	7,241	725	2,418	2,277	25	3,114	3,796	8,601
Darlington	67,548	15,405	11,535	1,306	4,310	3,911	44	5,246	6,446	14,194
Edgefield	26,514	5,036	4,394	427	1,777	1,585	18	2,099	2,595	4,459
Florence	138,900	33,464	21,513	2,837	8,670	7,614	90	10,074	12,433	27,558
Greenville	491,863	115,082	71,724	9,758	30,913	26,554	323	34,724	43,049	66,299
Lexington	281,833	66,209	41,223	5,614	17,775	15,468	185	20,257	25,138	36,805
Oconee	75,713	15,209	16,645	1,290	5,009	4,846	50	6,745	8,156	13,493
Pickens	121,691	23,855	18,905	2,023	7,956	6,702	80	8,773	10,836	20,751
Richland	407,051	88,453	47,511	7,500	25,787	20,235	267	25,368	31,886	59,495
Spartanburg	297,302	69,835	45,633	5,921	18,703	16,355	195	21,578	26,665	43,326
York	251,195	61,836	33,653	5,243	15,602	13,338	165	17,268	21,538	30,789
Totals	**3,277,053**	**741,017**	**488,689**	**62,830**	**207,986**	**178,985**	**2,150**	**234,503**	**290,433**	**496,850**

SOUTH CAROLINA

American Lung Association in South Carolina

www.lung.org/southcarolina

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Abbeville	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Aiken	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Anderson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Berkeley	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Charleston	0	0	0	0.0	A	1	0	0	0.3	B	7.9	PASS
Cherokee	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Chesterfield	0	0	0	0.0	A	0	0	0	0.0	A	7.9	PASS
Colleton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Darlington	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Edgefield	1	0	0	0.3	B	0	0	0	0.0	A	8.4	PASS
Florence	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.7	PASS
Greenville	1	0	0	0.3	B	2	0	0	0.7	B	9.2	PASS
Lexington	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.3	PASS
Oconee	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Pickens	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Richland	0	0	0	0.0	A	0	0	0	0.0	A	9.0	PASS
Spartanburg	1	0	0	0.3	B	0	0	0	0.0	A	8.8	PASS
York	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC

SOUTH DAKOTA

American Lung Association in South Dakota

www.lung.org/southdakota

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Brookings	33,897	6,856	3,643	581	2,312	1,215	21	1,707	1,964	4,419
Brown	38,785	9,206	6,242	781	2,477	1,671	24	2,579	2,772	3,846
Codington	27,939	6,862	4,415	582	1,761	1,199	17	1,850	1,994	2,976
Custer	8,446	1,380	2,234	117	581	497	5	826	837	873
Hughes	17,555	4,206	2,734	357	1,113	759	11	1,168	1,265	1,821
Jackson	3,321	1,116	452	95	185	123	2	188	203	1,067
Meade	26,986	6,396	3,833	542	1,729	1,105	17	1,667	1,829	2,598
Minnehaha	185,197	46,279	23,258	3,924	11,663	7,218	113	10,689	11,947	21,865
Pennington	108,702	25,681	17,633	2,177	6,946	4,719	67	7,295	7,836	12,946
Union	14,909	3,644	2,394	309	936	657	9	1,017	1,097	942
Totals	**465,737**	**111,626**	**66,838**	**9,465**	**29,703**	**19,163**	**285**	**28,987**	**31,745**	**53,353**

SOUTH DAKOTA

American Lung Association in South Dakota

www.lung.org/southdakota

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Brookings	0	0	0	0.0	A	2	0	0	0.7	B	INC	INC
Brown	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	6.6	PASS
Codington	DNC	DNC	DNC	DNC	DNC	1	0	0	0.3	B	7.1	PASS
Custer	0	0	0	0.0	A	2	0	0	0.7	B	3.2	PASS
Hughes	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Jackson	0	0	0	0.0	A	2	0	0	0.7	B	4.7	PASS
Meade	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Minnehaha	0	0	0	0.0	A	3	0	0	1.0	C	8.3	PASS
Pennington	DNC	DNC	DNC	DNC	DNC	2	0	0	0.7	B	7.8	PASS
Union	0	0	0	0.0	A	3	0	0	1.0	C	8.5	PASS

TENNESSEE

American Lung Association in Tennessee

www.lung.org/tennessee

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Anderson	75,749	15,904	14,578	1,549	5,382	6,163	57	7,382	8,189	14,721
Blount	127,253	26,593	24,050	2,590	9,052	10,324	97	12,324	13,704	16,388
Claiborne	31,709	6,219	6,001	606	2,285	2,576	24	3,069	3,415	6,575
Davidson	678,889	145,277	76,326	14,149	46,887	45,604	514	50,248	58,858	111,678
DeKalb	19,182	4,223	3,473	411	1,343	1,518	15	1,803	2,011	3,814
Dyer	37,893	9,170	6,385	893	2,572	2,856	29	3,371	3,776	8,374
Hamilton	354,098	74,599	57,953	7,265	24,920	26,989	268	31,502	35,529	52,287
Jefferson	53,240	10,896	10,271	1,061	3,801	4,330	40	5,184	5,750	8,627
Knox	451,324	96,191	66,821	9,368	31,513	33,063	343	38,002	43,287	68,679
Lawrence	42,564	10,676	7,487	1,040	2,858	3,222	32	3,837	4,270	7,931
Loudon	51,130	10,141	12,833	988	3,693	4,513	39	5,653	6,075	6,804
Madison	97,610	22,374	15,115	2,179	6,713	7,242	74	8,408	9,521	16,874
Maury	87,757	20,627	13,377	2,009	6,004	6,508	67	7,544	8,558	11,432
McMinn	52,639	11,338	10,008	1,104	3,714	4,249	40	5,085	5,644	11,864
Meigs	11,830	2,461	2,407	240	846	988	9	1,194	1,317	2,351
Montgomery	193,479	52,142	16,996	5,078	12,300	11,310	148	12,142	14,451	25,378
Putnam	74,553	15,787	12,232	1,538	5,194	5,498	57	6,430	7,225	14,166
Roane	52,753	10,283	11,475	1,001	3,845	4,582	40	5,579	6,125	9,180
Sevier	95,946	20,280	17,553	1,975	6,800	7,694	73	9,139	10,197	13,806
Shelby	938,069	237,852	113,176	23,165	62,228	63,837	709	71,647	83,069	186,186
Sullivan	156,791	30,977	32,448	3,017	11,325	13,169	119	15,927	17,548	25,241
Sumner	175,989	42,434	26,488	4,133	11,963	13,003	134	15,057	17,099	17,557
Williamson	211,672	59,107	25,560	5,757	13,764	14,807	161	16,702	19,368	10,548
Wilson	128,911	30,931	19,198	3,012	8,798	9,604	98	11,097	12,629	10,676
Totals	**4,201,030**	**966,482**	**602,211**	**94,128**	**287,800**	**303,651**	**3,187**	**348,325**	**397,614**	**661,137**

TENNESSEE

American Lung Association in Tennessee

www.lung.org/tennessee

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Anderson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Blount	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC
Claiborne	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Davidson	4	0	0	1.3	C	INC	INC	INC	INC	INC	INC	INC
DeKalb	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dyer	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Hamilton	5	0	0	1.7	C	0	0	0	0.0	A	9.0	PASS
Jefferson	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Knox	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC
Lawrence	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Loudon	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC
Madison	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Maury	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
McMinn	INC	INC	INC	INC	INC	0	0	0	0.0	A	8.6	PASS
Meigs	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Montgomery	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Putnam	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Roane	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Sevier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Shelby	8	0	0	2.7	D	INC	INC	INC	INC	INC	INC	INC
Sullivan	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Sumner	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC
Williamson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wilson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC

TEXAS

American Lung Association in Texas

www.lung.org/texas

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Bell	334,941	93,147	33,942	7,371	18,436	11,419	181	17,333	24,804	51,728
Bexar	1,897,753	494,269	218,139	39,112	106,843	70,076	1,023	108,644	154,343	288,976
Bowie	93,389	22,169	14,727	1,754	5,411	3,976	51	6,461	8,867	16,170
Brazoria	346,312	92,721	38,491	7,337	19,276	12,985	188	20,194	29,003	35,519
Brewster	9,145	1,752	1,878	139	561	448	5	752	1,004	1,349
Cameron	422,156	132,069	54,064	10,451	22,076	15,253	227	24,295	33,605	133,508
Collin	914,127	246,271	92,102	19,488	50,752	33,687	493	51,814	75,532	59,993
Dallas	2,553,385	682,485	252,270	54,006	142,402	90,900	1,377	138,406	200,959	451,795
Denton	780,612	201,646	70,965	15,957	44,046	27,885	421	42,057	62,008	61,186
El Paso	835,593	233,304	97,233	18,462	45,852	30,316	450	47,241	66,708	165,987
Ellis	163,632	44,077	19,927	3,488	9,080	6,354	88	10,033	14,265	17,580
Galveston	322,225	79,179	42,148	6,266	18,452	13,130	174	20,870	29,546	44,355
Gregg	124,108	32,020	17,698	2,534	6,999	4,996	67	8,024	11,115	20,438
Harris	4,538,028	1,224,413	428,697	96,889	252,264	158,961	2,452	240,522	350,940	744,712
Harrison	66,746	16,910	10,327	1,338	3,783	2,825	36	4,602	6,340	12,036
Hidalgo	842,304	281,203	90,076	22,252	42,759	27,637	453	42,854	60,247	259,506
Hood	55,423	11,607	13,395	918	3,319	2,893	30	5,004	6,519	5,364
Hunt	89,844	21,419	13,951	1,695	5,194	3,868	48	6,290	8,692	14,418
Jefferson	254,308	60,384	34,403	4,778	14,740	10,306	138	16,368	22,964	40,306
Johnson	159,990	41,857	21,591	3,312	8,971	6,439	87	10,300	14,450	17,955
Kaufman	114,690	31,704	13,801	2,509	6,304	4,385	62	6,917	9,825	14,824
McLennan	245,671	60,939	33,372	4,822	14,060	9,608	132	15,226	21,150	46,949
Montgomery	537,559	143,545	66,131	11,359	29,920	21,043	290	33,281	47,307	53,837
Navarro	48,323	12,673	7,978	1,003	2,706	2,070	26	3,411	4,643	9,312
Nueces	359,715	90,534	47,578	7,164	20,468	14,191	194	22,497	31,521	70,336
Orange	84,260	20,854	12,913	1,650	4,813	3,582	45	5,824	8,049	13,443
Parker	126,042	30,860	19,085	2,442	7,217	5,459	68	8,882	12,369	11,680
Polk	46,972	9,604	9,187	760	2,833	2,277	26	3,813	5,142	7,304
Randall	130,269	31,609	17,919	2,501	7,503	5,223	70	8,308	11,583	10,887
Rockwall	90,861	24,947	11,026	1,974	5,004	3,533	49	5,590	7,958	5,403
Smith	222,936	55,137	35,076	4,363	12,754	9,316	120	15,144	20,694	34,786
Tarrant	1,982,498	533,475	208,355	42,215	110,194	72,657	1,068	111,992	161,771	255,993
Travis	1,176,558	267,942	102,528	21,203	69,258	41,330	638	61,060	90,267	152,195
Victoria	92,382	23,834	13,673	1,886	5,210	3,756	50	6,064	8,350	12,329
Webb	269,721	91,421	23,938	7,234	13,588	8,425	145	12,741	18,399	81,276
Totals	**20,332,478**	**5,441,980**	**2,188,584**	**430,631**	**1,133,050**	**741,209**	**10,973**	**1,142,813**	**1,640,941**	**3,223,435**

TEXAS

American Lung Association in Texas

www.lung.org/texas

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bell	11	0	0	3.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bexar	31	5	0	12.8	F	0	0	0	0.0	A	8.5	PASS
Bowie	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.8	PASS
Brazoria	19	8	0	10.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Brewster	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cameron	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Collin	28	0	0	9.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dallas	32	1	0	11.2	F	1	0	0	0.3	B	10.2	PASS
Denton	59	7	0	23.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
El Paso	18	0	0	6.0	F	8	2	0	3.7	F	9.9	PASS
Ellis	11	0	0	3.7	F	0	0	0	0.0	A	9.3	PASS
Galveston	20	3	0	8.2	F	0	0	0	0.0	A	INC	INC
Gregg	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Harris	47	14	1	23.3	F	3	0	0	1.0	C	11.6	PASS
Harrison	4	0	0	1.3	C	0	0	0	0.0	A	9.0	PASS
Hidalgo	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Hood	13	4	0	6.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hunt	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	18	1	0	6.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Johnson	20	1	0	7.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kaufman	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
McLennan	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Montgomery	15	0	0	5.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Navarro	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Nueces	3	0	0	1.0	C	0	0	0	0.0	A	10.1	PASS
Orange	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Parker	34	0	0	11.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Polk	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Randall	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rockwall	17	0	0	5.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Smith	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tarrant	59	7	0	23.2	F	1	0	0	0.3	B	10.0	PASS
Travis	14	0	0	4.7	F	0	0	0	0.0	A	9.2	PASS
Victoria	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Webb	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC

UTAH

American Lung Association in Utah

www.lung.org/utah

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Box Elder	52,097	16,873	6,463	1,198	3,204	1,406	14	2,220	2,804	4,345
Cache	120,783	37,123	10,685	2,636	7,531	2,768	32	4,057	5,140	18,657
Carbon	20,479	5,456	3,241	387	1,370	637	5	1,040	1,297	3,247
Daggett	1,109	254	235	18	78	40	0	69	84	84
Davis	336,043	111,031	31,398	7,885	20,377	8,120	89	12,138	15,590	23,138
Duchesne	20,862	7,230	2,283	513	1,236	517	6	802	1,014	2,247
Garfield	5,009	1,233	1,025	88	346	178	1	304	374	543
Salt Lake	1,107,314	311,386	109,258	22,113	72,084	28,671	293	42,720	54,993	117,311
San Juan	15,772	5,071	1,853	360	974	425	4	662	844	4,397
Tooele	62,952	21,418	5,557	1,521	3,763	1,497	17	2,220	2,871	4,493
Uintah	37,928	12,923	3,410	918	2,262	889	10	1,322	1,697	3,733
Utah	575,205	198,953	42,066	14,129	33,832	12,002	152	17,123	21,908	70,537
Washington	155,602	43,096	31,425	3,061	10,259	5,108	41	8,826	10,649	20,252
Weber	243,645	70,325	27,606	4,994	15,725	6,546	64	10,045	12,791	29,768
Totals	**2,754,800**	**842,372**	**276,505**	**59,822**	**173,040**	**68,805**	**729**	**103,548**	**132,056**	**302,752**

UTAH

American Lung Association in Utah

www.lung.org/utah

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Box Elder	8	0	0	2.7	D	7	1	0	2.8	D	7.5	PASS
Cache	3	0	0	1.0	C	38	15	0	20.2	F	9.1	PASS
Carbon	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Daggett	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Davis	14	0	0	4.7	F	16	0	0	5.3	F	7.8	PASS
Duchesne	21	22	5	21.3	F	INC	INC	INC	INC	INC	INC	INC
Garfield	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Salt Lake	38	0	0	12.7	F	47	12	0	21.7	F	9.0	PASS
San Juan	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tooele	9	0	0	3.0	D	INC	INC	INC	INC	INC	INC	INC
Uintah	30	24	18	34.0	F	INC	INC	INC	INC	INC	INC	INC
Utah	27	0	0	9.0	F	24	15	0	15.5	F	9.0	PASS
Washington	6	0	0	2.0	C	0	0	0	0.0	A	INC	INC
Weber	18	1	0	6.5	F	24	6	0	11.0	F	INC	INC

VERMONT

American Lung Association in Vermont

www.lung.org/vermont

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Bennington	36,317	6,999	7,896	725	3,205	1,980	22	2,673	2,666	4,102
Chittenden	161,382	29,797	22,049	3,086	14,815	7,330	96	8,926	9,526	15,695
Rutland	59,736	10,817	12,005	1,120	5,377	3,204	36	4,247	4,301	6,560
Totals	**257,435**	**47,613**	**41,950**	**4,930**	**23,397**	**12,514**	**153**	**15,846**	**16,493**	**26,357**

VERMONT

American Lung Association in Vermont

www.lung.org/vermont

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bennington	1	0	0	0.3	B	0	0	0	0.0	A	6.2	PASS
Chittenden	0	0	0	0.0	A	0	0	0	0.0	A	6.3	PASS
Rutland	DNC	DNC	DNC	DNC	DNC	6	0	0	2.0	C	8.7	PASS

VIRGINIA

American Lung Association in Virginia

www.lung.org/virginia

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Albemarle	105,703	21,846	18,063	1,852	6,674	5,025	63	6,684	9,069	9,462
Alexandria City	153,511	27,554	15,874	2,336	10,006	6,410	91	7,896	10,885	13,832
Arlington	229,164	40,006	21,698	3,392	15,031	9,204	137	11,139	15,335	16,031
Bristol City	17,141	3,408	3,413	289	1,094	868	10	1,179	1,593	3,260
Caroline	29,984	7,130	4,670	605	1,817	1,373	18	1,818	2,480	3,531
Charles City	7,040	1,100	1,557	93	473	402	4	554	754	814
Chesterfield	335,687	81,561	44,925	6,915	20,191	14,765	199	19,183	26,357	22,942
Fairfax	1,142,234	271,539	136,327	23,023	69,150	48,796	680	62,353	85,991	69,985
Fauquier	68,782	16,340	10,588	1,385	4,167	3,231	41	4,286	5,880	4,646
Frederick	83,199	19,427	13,087	1,647	5,070	3,865	50	5,124	7,000	6,342
Giles	16,708	3,416	3,426	290	1,058	865	10	1,185	1,603	1,751
Hampton City	136,454	29,445	19,217	2,497	8,509	6,064	81	7,858	10,733	20,072
Hanover	103,227	23,125	16,704	1,961	6,367	4,957	61	6,601	9,037	6,268
Henrico	325,155	75,430	46,015	6,396	19,852	14,479	192	18,876	25,832	30,037
Loudoun	375,629	109,247	31,044	9,263	21,135	13,961	224	17,211	23,976	13,953
Lynchburg City	79,812	15,534	11,277	1,317	5,119	3,390	47	4,330	5,846	15,975
Madison	13,134	2,726	2,759	231	829	690	8	950	1,286	1,351
Norfolk City	246,393	49,439	25,062	4,192	15,658	9,727	148	11,908	16,313	45,756
Page	23,726	4,791	4,822	406	1,507	1,232	14	1,684	2,282	3,532
Prince Edward	22,952	3,702	3,609	314	1,533	1,054	14	1,364	1,843	4,172
Prince William	451,721	125,637	39,298	10,653	25,879	17,061	269	21,074	29,283	29,925
Richmond City	220,289	40,012	25,506	3,393	14,329	9,365	130	11,694	16,040	50,763
Roanoke	94,409	19,582	19,014	1,660	5,958	4,834	56	6,603	8,935	6,744
Roanoke City	99,897	22,184	15,144	1,881	6,180	4,558	59	5,985	8,166	20,913
Rockbridge	22,354	3,881	5,538	329	1,472	1,274	13	1,784	2,400	2,834
Rockingham	78,593	17,492	14,401	1,483	4,863	3,831	47	5,173	7,016	8,422
Salem City	25,432	4,918	4,476	417	1,633	1,240	15	1,653	2,244	2,391
Stafford	142,003	37,700	13,452	3,197	8,277	5,610	85	7,005	9,733	7,448
Suffolk City	88,161	21,858	11,713	1,853	5,268	3,833	52	4,976	6,831	11,370
Virginia Beach City	452,745	102,144	57,630	8,661	27,869	19,333	269	24,736	33,881	36,451
Wythe	29,119	5,837	5,864	495	1,853	1,507	17	2,056	2,786	4,163
Totals	**5,220,358**	**1,208,011**	**646,173**	**102,425**	**318,821**	**222,804**	**3,102**	**284,920**	**391,408**	**475,136**

VIRGINIA

American Lung Association in Virginia

www.lung.org/virginia

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Albemarle	0	0	0	0.0	A	0	0	0	0.0	A	7.4	PASS
Alexandria City	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Arlington	11	1	0	4.2	F	0	0	0	0.0	A	8.9	PASS
Bristol City	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.2	PASS
Caroline	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Charles City	4	0	0	1.3	C	0	0	0	0.0	A	7.7	PASS
Chesterfield	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Fairfax	6	0	0	2.0	C	0	0	0	0.0	A	8.2	PASS
Fauquier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Frederick	0	0	0	0.0	A	1	0	0	0.3	B	9.0	PASS
Giles	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hampton City	2	0	0	0.7	B	0	0	0	0.0	A	7.3	PASS
Hanover	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Henrico	3	0	0	1.0	C	0	0	0	0.0	A	8.0	PASS
Loudoun	7	0	0	2.3	D	0	0	0	0.0	A	8.7	PASS
Lynchburg City	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.4	PASS
Madison	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Norfolk City	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.7	PASS
Page	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Prince Edward	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Prince William	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Richmond City	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Roanoke	0	0	0	0.0	A	1	0	0	0.3	B	INC	INC
Roanoke City	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Rockbridge	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rockingham	0	0	0	0.0	A	0	0	0	0.0	A	8.5	PASS
Salem City	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.5	PASS
Stafford	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Suffolk City	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Virginia Beach City	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	7.9	PASS
Wythe	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC

WASHINGTON

American Lung Association in Washington

www.lung.org/washington

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Benton	190,309	50,899	26,210	3,325	13,172	8,583	106	10,631	11,734	26,824
Chelan	75,644	18,190	13,547	1,188	5,459	3,797	42	4,953	5,333	9,458
Clallam	73,486	12,880	20,298	841	5,803	4,522	41	6,419	6,630	11,195
Clark	459,495	114,536	65,323	7,481	32,661	21,440	255	26,573	29,368	48,401
King	2,117,125	438,574	263,386	28,646	157,724	97,651	1,176	116,316	130,619	205,336
Kitsap	260,131	53,941	42,954	3,523	19,521	13,074	145	16,577	18,085	24,950
Kittitas	43,269	7,689	6,540	502	3,314	2,060	24	2,556	2,781	8,190
Pierce	843,954	201,220	110,163	13,143	60,558	38,426	469	46,643	51,946	102,917
Skagit	121,846	27,143	23,517	1,773	9,000	6,344	68	8,382	8,962	17,965
Snohomish	772,501	177,236	96,213	11,577	56,362	35,894	429	42,913	48,418	71,017
Spokane	490,945	109,896	74,486	7,178	35,959	23,541	273	29,445	32,284	74,144
Thurston	269,536	58,760	42,752	3,838	19,931	13,225	150	16,672	18,229	32,458
Whatcom	212,284	42,086	33,919	2,749	15,982	10,360	118	13,054	14,194	29,802
Yakima	248,830	74,063	32,662	4,838	16,416	10,504	138	13,029	14,296	46,794
Totals	**6,179,355**	**1,387,113**	**851,970**	**90,602**	**451,863**	**289,421**	**3,432**	**354,163**	**392,878**	**709,451**

WASHINGTON

American Lung Association in Washington

www.lung.org/washington

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Benton	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Chelan	DNC	DNC	DNC	DNC	DNC	2	2	0	1.7	C	INC	INC
Clallam	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clark	1	0	0	0.3	B	4	2	0	2.3	D	INC	INC
King	8	0	0	2.7	D	7	0	0	2.3	D	6.7	PASS
Kitsap	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Kittitas	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC
Pierce	0	0	0	0.0	A	13	1	0	4.8	F	7.5	PASS
Skagit	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Snohomish	DNC	DNC	DNC	DNC	DNC	15	2	0	6.0	F	8.1	PASS
Spokane	1	0	0	0.3	B	5	0	0	1.7	C	INC	INC
Thurston	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Whatcom	0	0	0	0.0	A	0	0	0	0.0	A	7.0	PASS
Yakima	DNC	DNC	DNC	DNC	DNC	17	1	0	6.2	F	9.1	PASS

WEST VIRGINIA

American Lung Association in West Virginia

www.lung.org/westvirginia

	AT-RISK GROUPS									
				Lung Diseases						
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardiovascular Disease	Diabetes	Poverty
Berkeley	111,901	26,911	15,243	2,534	9,221	10,805	91	10,968	11,588	13,823
Brooke	23,350	4,124	5,158	388	2,096	2,682	19	2,901	2,960	3,338
Cabell	96,844	19,614	16,756	1,847	8,326	9,800	78	10,149	10,561	18,776
Gilmer	8,518	1,193	1,310	112	786	877	7	877	929	1,650
Greenbrier	35,516	6,979	7,789	657	3,114	4,013	29	4,354	4,437	6,629
Hancock	29,815	5,781	6,177	544	2,628	3,371	24	3,629	3,718	4,032
Harrison	68,714	14,900	12,499	1,403	5,855	7,237	56	7,643	7,901	10,861
Kanawha	188,332	38,490	35,175	3,624	16,307	20,209	152	21,378	22,079	30,529
Marion	56,925	11,532	10,481	1,086	4,917	5,964	46	6,266	6,482	8,899
Marshall	31,978	6,368	6,457	600	2,796	3,555	26	3,813	3,913	3,965
Monongalia	104,236	16,820	11,513	1,584	9,288	9,493	85	8,956	9,755	19,051
Ohio	43,066	8,330	8,520	784	3,775	4,692	35	4,991	5,135	5,711
Raleigh	77,510	16,482	14,532	1,552	6,623	8,139	63	8,606	8,878	14,676
Tucker	6,966	1,219	1,620	115	628	821	6	897	911	1,165
Wood	86,452	18,498	16,258	1,742	7,401	9,235	70	9,804	10,108	14,793
Totals	**970,123**	**197,241**	**169,488**	**18,570**	**83,761**	**100,893**	**785**	**105,231**	**109,355**	**157,898**

WEST VIRGINIA

American Lung Association in West Virginia

www.lung.org/westvirginia

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Berkeley	0	0	0	0.0	A	1	0	0	0.3	B	10.3	PASS
Brooke	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	11.2	PASS
Cabell	2	0	0	0.7	B	0	0	0	0.0	A	9.2	PASS
Gilmer	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greenbrier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hancock	6	0	0	2.0	C	0	0	0	0.0	A	INC	INC
Harrison	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.8	PASS
Kanawha	3	0	0	1.0	C	0	0	0	0.0	A	9.6	PASS
Marion	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	9.4	PASS
Marshall	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	10.7	PASS
Monongalia	3	0	0	1.0	C	0	0	0	0.0	A	8.6	PASS
Ohio	4	0	0	1.3	C	1	0	0	0.3	B	10.3	PASS
Raleigh	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	INC	INC
Tucker	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wood	6	0	0	2.0	C	0	0	0	0.0	A	9.4	PASS

WISCONSIN

American Lung Association in Wisconsin

www.lung.org/wisconsin

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Ashland	15,843	3,542	2,833	260	1,157	621	10	996	1,100	2,616
Brown	258,718	62,681	34,930	4,606	18,884	8,819	155	13,713	15,620	27,979
Columbia	56,743	12,579	9,524	924	4,170	2,190	34	3,470	3,876	4,908
Dane	523,643	109,975	64,580	8,081	40,551	16,979	314	26,290	30,144	57,411
Dodge	88,502	18,187	14,761	1,336	6,664	3,427	53	5,421	6,066	7,157
Door	27,554	4,529	7,601	333	2,084	1,370	16	2,313	2,427	2,317
Eau Claire	102,105	20,961	14,721	1,540	7,907	3,459	61	5,497	6,148	13,260
Fond du Lac	101,973	22,331	17,318	1,641	7,537	3,913	61	6,233	6,928	9,248
Forest	9,057	1,823	2,016	134	670	394	5	651	698	1,284
Grant	52,250	10,640	8,626	782	4,010	1,884	31	3,043	3,347	6,622
Jefferson	84,559	18,608	13,050	1,367	6,291	3,118	51	4,903	5,520	7,534
Kenosha	168,437	40,321	21,512	2,963	12,345	5,738	101	8,805	10,154	20,812
Kewaunee	20,366	4,483	3,922	329	1,482	833	12	1,346	1,474	1,652
La Crosse	118,212	23,826	17,986	1,751	9,144	4,151	71	6,615	7,372	16,248
Manitowoc	79,806	16,743	15,197	1,230	5,887	3,292	48	5,289	5,825	8,466
Marathon	135,868	31,458	22,337	2,312	9,891	5,104	81	8,108	9,037	12,675
Milwaukee	957,735	233,159	118,711	17,132	70,675	30,571	572	47,491	54,244	189,827
Outagamie	183,245	43,882	24,843	3,224	13,390	6,343	110	9,829	11,229	16,225
Ozaukee	87,850	19,169	15,833	1,409	6,435	3,525	53	5,625	6,236	4,488
Racine	195,080	46,202	29,573	3,395	14,155	7,136	117	11,184	12,626	23,505
Rock	161,448	38,325	24,969	2,816	11,732	5,853	97	9,248	10,366	21,946
Sauk	63,642	14,520	11,094	1,067	4,639	2,441	38	3,914	4,323	7,340
Sheboygan	115,569	26,084	19,254	1,917	8,460	4,412	69	7,000	7,810	10,167
Taylor	20,455	4,832	3,821	355	1,456	822	12	1,323	1,454	2,491
Vilas	21,387	3,623	6,283	266	1,590	1,100	13	1,872	1,949	2,829
Walworth	102,804	22,330	16,304	1,641	7,679	3,802	62	6,018	6,736	12,374
Waukesha	396,488	87,705	67,598	6,444	29,037	15,576	237	24,644	27,546	18,401
Totals	**4,149,339**	**942,518**	**609,197**	**69,255**	**307,919**	**146,872**	**2,484**	**230,839**	**260,254**	**509,782**

WISCONSIN

American Lung Association in Wisconsin

www.lung.org/wisconsin

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Ashland	0	0	0	0.0	A	0	0	0	0.0	A	5.1	PASS
Brown	3	0	0	1.0	C	1	0	0	0.3	B	8.2	PASS
Columbia	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dane	1	0	0	0.3	B	1	0	0	0.3	B	9.0	PASS
Dodge	7	0	0	2.3	D	0	0	0	0.0	A	8.0	PASS
Door	9	0	0	3.0	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Eau Claire	0	0	0	0.0	A	0	0	0	0.0	A	7.5	PASS
Fond du Lac	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Forest	0	0	0	0.0	A	0	0	0	0.0	A	INC	INC
Grant	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	8.3	PASS
Jefferson	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kenosha	24	0	0	8.0	F	0	1	0	0.5	B	8.5	PASS
Kewaunee	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
La Crosse	0	0	0	0.0	A	0	0	0	0.0	A	8.0	PASS
Manitowoc	12	0	0	4.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Marathon	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Milwaukee	10	0	0	3.3	F	0	0	0	0.0	A	9.7	PASS
Outagamie	3	0	0	1.0	C	1	0	0	0.3	B	8.0	PASS
Ozaukee	15	0	0	5.0	F	0	0	0	0.0	A	7.6	PASS
Racine	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rock	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sauk	3	0	0	1.0	C	0	0	0	0.0	A	7.2	PASS
Sheboygan	25	1	0	8.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Taylor	0	0	0	0.0	A	0	0	0	0.0	A	6.5	PASS
Vilas	1	0	0	0.3	B	0	0	0	0.0	A	5.0	PASS
Walworth	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Waukesha	3	0	0	1.0	C	0	0	0	0.0	A	9.8	PASS

WYOMING

American Lung Association in Wyoming

www.lung.org/wyoming

	AT-RISK GROUPS									
				Lung Diseases						
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**Cardiovascular Disease**	**Diabetes**	**Poverty**
Albany	37,956	6,264	3,881	538	2,526	1,852	15	1,790	1,902	7,181
Big Horn	12,022	3,083	2,363	265	715	740	5	837	876	1,437
Campbell	49,220	13,816	3,674	1,187	2,812	2,173	19	2,132	2,473	3,668
Carbon	15,559	3,677	2,241	316	947	865	6	927	1,010	1,682
Converse	14,236	3,652	2,020	314	844	781	6	840	920	1,205
Fremont	40,315	10,278	6,773	883	2,399	2,335	16	2,573	2,747	5,071
Goshen	13,383	2,695	2,823	232	856	878	5	990	1,031	1,852
Laramie	97,121	22,812	14,266	1,960	5,929	5,384	38	5,765	6,216	10,084
Natrona	82,178	19,800	10,804	1,701	4,972	4,371	32	4,607	5,031	8,827
Park	29,228	5,898	6,063	507	1,867	1,924	11	2,170	2,282	2,739
Sheridan	30,009	6,456	5,731	555	1,883	1,893	12	2,113	2,242	2,777
Sublette	9,899	2,383	1,348	205	599	547	4	584	647	605
Sweetwater	44,626	11,984	4,474	1,030	2,597	2,140	18	2,180	2,451	3,744
Teton	23,125	4,349	3,001	374	1,496	1,280	9	1,331	1,464	1,516
Uinta	20,822	6,141	2,432	528	1,169	1,029	8	1,082	1,201	2,030
Weston	7,234	1,570	1,331	135	453	451	3	501	536	675
Totals	**526,933**	**124,858**	**73,225**	**10,727**	**32,063**	**28,641**	**208**	**30,421**	**33,029**	**55,093**

WYOMING

American Lung Association in Wyoming

www.lung.org/wyoming

	HIGH OZONE DAYS 2013–2015					HIGH PARTICLE POLLUTION DAYS 2013–2015						
						24-Hour					Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Albany	2	0	0	0.7	B	0	0	0	0.0	A	4.3	PASS
Big Horn	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC
Campbell	0	0	0	0.0	A	1	0	0	0.3	B	4.2	PASS
Carbon	1	0	0	0.3	B	0	0	0	0.0	A	INC	INC
Converse	2	0	0	0.7	B	3	0	0	1.0	C	INC	INC
Fremont	0	0	0	0.0	A	1	0	0	0.3	B	6.9	PASS
Goshen	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Laramie	3	0	0	1.0	C	0	1	0	0.5	B	4.1	PASS
Natrona	2	0	0	0.7	B	0	0	0	0.0	A	4.6	PASS
Park	DNC	DNC	DNC	DNC	DNC	0	0	0	0.0	A	4.1	PASS
Sheridan	DNC	DNC	DNC	DNC	DNC	2	0	0	0.7	B	6.9	PASS
Sublette	1	0	0	0.3	B	0	0	0	0.0	A	5.0	PASS
Sweetwater	4	0	0	1.3	C	0	0	0	0.0	A	4.8	PASS
Teton	0	0	0	0.0	A	0	0	0	0.0	A	4.7	PASS
Uinta	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Weston	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC

We will breathe easier when the air in every
American community is clean and healthy.

We will breathe easier when people are free from the addictive
grip of tobacco and the debilitating effects of lung disease.

We will breathe easier when the air in our public spaces and
workplaces is clear of secondhand smoke.

We will breathe easier when children no longer
battle airborne poisons or fear an asthma attack.

Until then, we are fighting for air.

About the American Lung Association

The American Lung Association is the leading organization working to save lives by improving lung health and preventing lung disease, through research, education and advocacy. The work of the American Lung Association is focused on four strategic imperatives: to defeat lung cancer; to improve the air we breathe; to reduce the burden of lung disease on individuals and their families; and to eliminate tobacco use and tobacco-related diseases. For more information about the American Lung Association, a holder of the Better Business Bureau Wise Giving Guide Seal, or to support the work it does, call 1-800-LUNGUSA (1-800-586-4872) or visit: www.Lung.org.

AMERICAN LUNG ASSOCIATION®

South Coast
Air Quality Management District
21865 Copley Drive, Diamond Bar, CA 91765-4182
(909) 396-2000 • www.aqmd.gov

SUBJECT: **NOTICE OF COMPLETION OF A DRAFT ENVIRONMENTAL IMPACT REPORT**

PROJECT TITLE: **PHILLIPS 66 LOS ANGELES REFINERY ULTRA LOW SULFUR DIESEL PROJECT**

In accordance with the California Environmental Quality Act (CEQA), the South Coast Air Quality Management District (SCAQMD) is the Lead Agency and has prepared a Draft Environmental Impact Report (EIR) for the project identified above. The Draft EIR includes a project description and analysis of potential adverse environmental impacts that could be generated from the proposed project. The purpose of this letter, the attached Notice of Completion (NOC) and Draft EIR is to allow public agencies and the public the opportunity to obtain, review and comment on the environmental analysis contained in the Draft EIR.

This letter, the attached NOC, and Draft EIR are not SCAQMD applications or forms requiring a response from you. Their purpose is simply to provide information to you on the above project. If the project has no bearing on you or your organization, no action on your part is necessary. The project's description, location, and potential adverse environmental impacts are summarized in the NOC.

Copies of the Draft EIR and other relevant documents may be obtained at the SCAQMD's Public Information Center located at SCAQMD Headquarters: 21865 Copley Drive, Diamond Bar, CA 91765. Copies of these documents can also be obtained by calling (909) 396-2039 or accessing the SCAQMD's CEQA website at http://www.aqmd.gov/home/library/documents-support-material/lead-agency-permit-projects/permit-project-documents---year-2014. Comments focusing on your area of expertise, your agency's area of jurisdiction, or issues relative to the environmental analysis should be addressed to Jeff Inabinet at the address shown above, or sent by FAX to (909) 396-3324 or by email to jinabinet@aqmd.gov. Comments must be received no later than 5:00 p.m. on November 13, 2014. In any written correspondence, please include the name, email address, and phone number of the contact person for your organization.

Project Applicant: Phillips 66

Date: September 26, 2014

Signature: Michael Krause

Michael Krause
Program Supervisor, CEQA Section
Planning, Rules, and Area Sources
(909) 396-2706

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
21865 Copley Drive, Diamond Bar, CA 91765-4182
NOTICE OF COMPLETION OF DRAFT ENVIRONMENTAL IMPACT REPORT (EIR)

Project Title:
Phillips 66 Los Angeles Refinery Ultra Low Sulfur Diesel Project

Project Location:
Phillips 66 Wilmington Refinery is located at 1660 West Anaheim Street, Wilmington, California, 90744

Description of Nature, Purpose, and Beneficiaries of Project:
The project includes the following activities: 1) modifications to Hydrotreater Unit 90; 2) replacement of an existing charge heater with a functionally identical replacement heater; 3) installation of a Selective Catalytic Reduction Unit to control NOx emissions from the replacement heater, with aqueous ammonia supplied from an existing aqueous ammonia storage tank; 4) demolition of an existing cooling tower and replacement with a new cooling tower of the same capacity; 5) minor modifications to the mid barrel handling and shipping system; 6) minor modifications to the hydrogen distribution system including new hydrogen distribution piping; and 7) modifications to one storage tank to allow a change of service (i.e., contents). In response to the court's decision on the 2004 Final Negative Declaration and Addendum, an EIR is required for the ConocoPhillips ULSD Project to address the air quality setting and operational air quality impacts from the proposed project.

Lead Agency:	**Division:**
South Coast Air Quality Management District	Planning, Rules, and Area Sources

Draft EIR and all supporting documentation are available at:

SCAQMD Headquarters 21865 Copley Drive Diamond Bar, CA 91765	**or by calling** (909) 396-2039

Draft EIR is available by accessing the SCAQMD's website at:
http://www.aqmd.gov/home/library/documents-support-material/lead-agency-permit-projects/permit-project-documents---year-2014

The Public Notice of Completion is provided through the following:

☑ Los Angeles Times and The Daily Breeze (September 30, 2014) ☑ SCAQMD Website
☑ SCAQMD Public Information Center ☑ Interested Parties ☑ SCAQMD Mailing List

Draft EIR 45-Day Review Period:
September 30, 2014 through November 13, 2014

Send CEQA Comments to:	**Phone:**	**Email:**	**Fax:**
Mr. Jeff Inabinet	(909) 396-2453	jinabinet@aqmd.gov	(909) 396-3324

September, 2014 **SCH No. 2004011095**

PHILLIPS 66
LOS ANGELES REFINERY

ULTRA LOW SULFUR DIESEL PROJECT

DRAFT
ENVIRONMENTAL IMPACT REPORT

Executive Officer
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Planning, Rule Development, and Area Sources
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Susan Nakamura

Submitted to:
SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Prepared by:
ENVIRONMENTAL AUDIT, INC.

Reviewed by: Michael Krause – Program Supervisor
Jeff Inabinet – Air Quality Specialist
Barbara Baird – Chief Deputy Counsel
Veera Tyagi – Senior Deputy District Counsel

PHILLIPS 66 LOS ANGELES REFINERY

ULTRA LOW SULFUR DIESEL PROJECT

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1.0 INTRODUCTION AND EXECUTIVE SUMMARY

1.1 INTRODUCTION

In 2004 the ConocoPhillips Los Angeles Refinery (Refinery) first proposed modifications to produce Ultra Low Sulfur Diesel (ULSD) to comply with the federal, state and SCAQMD regulations that limit the sulfur content of diesel fuels. Pursuant to the California Environmental Quality Act (CEQA), the South Coast Air Quality Management District (SCAQMD), as lead agency for the project, prepared a Final Negative Declaration and Addendum for the proposed ULSD modifications in 2004. However, a Draft Environmental Impact Report (EIR) is now being prepared for the Project because a decision of the California Supreme Court that found certain deficiencies in the previously prepared CEQA documents for the Phillips 66 ULSD Project and required the preparation of an EIR. However, the court did allow the project to proceed. Since the time of the ULSD Project approval, the ConocoPhillips owners changed the company's name to Phillips 66 and this is how the company will be referred to throughout the remainder of this document.

In Los Angeles, heavy-duty trucks and buses contributed more than a quarter of the nitrogen oxide (NOx) emissions and 14 percent of the particulate matter less than 2.5 microns in diameter (PM2.5) emissions from all mobile sources in 2004. The emission-control devices to reduce emissions from these heavy duty engines are sensitive to sulfur, thus regulatory requirements mandate that the amount of sulfur in the diesel fuel is reduced to increase performance of the control devices. Furthermore, reducing the sulfur content of diesel fuel leads to a reduction of sulfur oxides (SOx) and particulate sulfate emissions from mobile sources that use ULSD.

The United States Environmental Protection Agency (U.S. EPA) developed regulations that required refiners to sell highway diesel fuel that would meet a maximum sulfur standard of 15 parts per million by weight (ppmw) starting in 2006. In order to meet these deadlines, refineries needed to make equipment modifications and conuct performance testing in advance. Similarly, California's Air Resources Board (CARB) developed a Diesel Risk Reduction Plan to minimize exposure to cancer risks associated with diesel particulate matter and required a reduction in the sulfur content in fuel to reduce particulate emissions from vehicles that use the fuel starting in June 2006. Finally, the SCAQMD approved Rule 431.2 which required a reduction in sulfur content in diesel fuel used in stationary sources to a limit of 15 parts per million by weight (ppmw) starting in June 2006. The Phillips 66 ULSD Project was needed to comply with all of these federal, state, and local rules and requirements.

During litigation challenging the SCAQMD's approval and environmental analysis of the ULSD Project, the petitioners sought a preliminary injunction (or stay) to prevent Project construction during the pendency of the lawsuits; however, the Superior Court denied these requests. Based on denial of the preliminary injunction or stay, the Refinery modifications included as part of the ULSD Project were completed. As a result, Phillips 66 has been producing ULSD at its Los Angeles Refinery since 2006, as required by the applicable ULSD rules and regulations identified above.

1.2 PREVIOUS CEQA DOCUMENTS

The activities associated with the ULSD Project were evaluated in the CEQA documents described below.

Notice of Intent to Adopt a Negative Declaration, ConocoPhillips Los Angeles Refinery, Ultra Low Sulfur Diesel Project (January 2004)

The Notice of Intent (NOI) to Adopt a Negative Declaration was released for a 30-day public review and comment period on January 22, 2004. The Negative Declaration evaluated the potential adverse impacts on the following environmental topics: aesthetics, agriculture resources, air quality, biological resources, cultural resources, energy, geology and soils, hazards and hazardous materials, hydrology and water quality, land use and planning, mineral resources, noise, population and housing, public services, recreation, solid and hazardous waste, and transportation/circulation. No significant adverse impacts were identified for any of these environmental resources, therefore, no mitigation measures or alternatives were incorporated into the 2004 Draft Negative Declaration.

2004 Final Negative Declaration for the ConocoPhillips Los Angeles Refinery Ultra Low Sulfur Diesel Project, June 2004

The 2004 Final Negative Declaration included applicable changes to the text of the Draft Negative Declaration and the responses to comments received during the public review and comment period.

The SCAQMD received two comment letters on the Draft Negative Declaration during the public comment period and one letter was received after the close of the public comment period. Comments from all three comment letters were responded to and, along with the comment letters, were presented in Appendix C of the 2004 Final Negative Declaration. The 2004 Final Negative Declaration was certified on June 18, 2004 (SCH 2004011095). No significant impacts on the environment were identified, therefore, no mitigation measures or alternatives were incorporated into the 2004 Final Negative Declaration (SCAQMD, 2004).

Addendum to the Final Negative Declaration for the ConocoPhillips Los Angeles Refinery Ultra Low Sulfur Diesel Project, September 2004

After the certification of the Final Negative Declaration, Phillips 66 proceeded with detailed engineering design for the ULSD Project. In the course of the detailed engineering work, the company updated the fugitive component counts (e.g., valves, flanges, pumps, etc.) for the Project. To account for the changes resulting from the revised number of fugitive components, an Addendum to the 2004 Final Negative Declaration was prepared. An addendum was the appropriate document because there were no Project changes or changes to the 2004 Final Negative Declaration that warrant the preparation of a subsequent CEQA document pursuant to CEQA Guidelines §15162. On September 21, 2004, the Addendum was certified and the 2004 Final Negative Declaration was re-certified.

<u>The Notice of Intent to Adopt Draft Subsequent Negative Declaration for the ConocoPhillips Los Angeles Refinery Ultra Low Sulfur Diesel Project, June 2005</u>

Subsequent to certification of the 2004 Addendum, SCAQMD staff concluded that best available control technology (BACT) for replacement charge heater B-401 was selective catalytic reduction (SCR) which was not evaluated in earlier CEQA documents for the project. Based on this modification to the Phillips 66 USLD Project, it was determined that a subsequent CEQA document pursuant to CEQA Guidelines §15162 should be prepared. A NOI to Adopt a Draft Subsequent Negative Declaration was released for a 30-day public review and comment period beginning on June 21, 2005 and ending on July 20, 2005. The Draft Subsequent Negative Declaration evaluated changes to the ULSD Project that included the installation of a SCR unit for NOx control on replacement charge heater B-401. The NOI evaluated the potential adverse impacts on the following environmental topics: aesthetics, agriculture resources, air quality, biological resources, cultural resources, energy, geology and soils, hazards and hazardous materials, hydrology and water quality, land use and planning, mineral resources, noise, population and housing, public services, recreation, solid and hazardous waste, and transportation/circulation. No significant adverse impacts were identified for any of these environmental resources, therefore, no mitigation measures or alternatives were required in the 2005 Draft Subsequent Negative Declaration.

<u>2005 Final Subsequent Negative Declaration for the ConocoPhillips Los Angeles Refinery Ultra Low Sulfur Diesel Project, October 2005</u>

The 2005 Final Subsequent Negative Declaration included applicable changes to the text of the Draft Negative Declaration and the responses to comments received during the public review and comment period.

The SCAQMD received two comment letters on the Draft Subsequent Negative Declaration during the public comment period and one letter was received after the close of the public comment period. Additional comments were received as part of a request for a public hearing under SCAQMD Regulation XII filed after the close of the public comment period. Responses to all four comment letters were prepared, and the comment letters and responses were presented in

Appendix C of the 2005 Final Subsequent Negative Declaration. The 2005 Final Subsequent Negative Declaration was certified on October 3, 2005 (SCH 2004011095).

Following the close of the public comment period on the Draft Subsequent Negative Declaration, the Governing Board of the SCAQMD received two petitions requesting hearings pursuant to SCAQMD Regulation XII, which were ultimately denied by the Governing Board. SCAQMD was under no legal requirement to respond to the assertions made in the petitions or the materials submitted as exhibits to the petitions for the Regulation XII hearing. Nonetheless, the SCAQMD elected to include clarifications and updates to issues raised in the Regulation XII petitions and supporting materials in the Final Subsequent Negative Declaration. The Project changes associated with the SCR and the clarifications and updates of issues raised in the Regulation XII petitions did not identify any new significant adverse impacts or show that previously identified impacts would be substantially worse. Conclusions made in the 2004 Negative Declaration also did not change (SCAQMD, 2005a).

<u>Notice of Preparation of Draft Environmental Impact Report, ConocoPhillips Los Angeles Refinery Ultra Low Sulfur Diesel Project, March 2012</u>

A Notice of Preparation (NOP) of a Draft EIR was prepared and circulated to the public on March 28, 2012 through April 26, 2012. No comments were received on the NOP. A copy of the NOP is included in Appendix A of this EIR.

Following completion of the CEQA documents, the SCAQMD issued permits to construct/operate to Phillips 66 for the construction of the ULSD Project components.

1.3 LEGAL HISTORY OF THE ULSD PROJECT

On July 16, 2004, two lawsuits were filed challenging the SCAQMD's certification of the 2004 Final Negative Declaration and approval of an SCAQMD permit for the ULSD Project (California Superior Court, Los Angeles County, Case Nos. BS091275 and BS091276). These lawsuits asserted that, among other things, an EIR should have been prepared to review the impacts associated with the Phillips 66 ULSD Project. The petitioners sought a preliminary injunction or stay to prevent Project construction during the pendency of the lawsuits; however, the court denied these requests. The lawsuits were amended following certification of the 2005 Subsequent Negative Declaration to add claims associated with that CEQA document and associated air permits issued by the SCAQMD. The trial occurred in two phases. Phase I challenged the SCAQMD’s decision to prepare the 2004 Negative Declaration and 2004 Addendum. The Phase 2 trial was held a year later and challenged the Subsequent Negative Declaration, as well as SCAQMD’s decision not to apply its Regulation XVII permitting program. Following each trial, the Los Angeles Superior Court concluded that the SCAQMD was correct on all counts. More specifically, the court concluded that the 2004 Final Negative

Declaration, the 2004 Addendum, and the 2005 Final Subsequent Negative Declaration all complied with CEQA and that the permitting decisions complied with law. On June 29, 2006, the Superior Court entered Judgment. The plaintiffs filed notices of appeal in August 2006.

On appeal, plaintiffs argued substantial evidence supported a fair argument that the Project would have a significant environmental impact on air quality, requiring the SCAQMD to prepare an EIR. On January 16, 2008, the Court of Appeal upheld the decision of the Superior Court on all claims but one. In the Court's opinion, an improper baseline was used to evaluate air quality impacts during project operations. It concluded that the potential increased use of existing equipment should have been evaluated as part of the ULSD Project, not as part of the baseline, and, that if the proper baseline had been used, there would be substantial evidence supporting a fair argument of significant NOx emissions from the ULSD Project, requiring the preparation of an EIR. The SCAQMD filed a Petition for Review to the California Supreme Court on February 25, 2008, in which Phillips 66 joined. The Petition sought review only of the portion of the Appellate Court's decision concerning baseline for evaluation of operational air quality impacts from the ULSD Project, and no other portion of the opinion was challenged by any party. On April 16, 2008, the Supreme Court granted review of the case.

On March 15, 2010, the Supreme Court concluded that the potential environmental impacts of a proposed Project must be compared to the environmental conditions that exist at the time the CEQA analysis was commenced, not the level of development or activity that would be allowed under existing permits or approvals. Because the ULSD Project may require increased utilization of existing permitted boilers and other steam generating equipment, the court concluded it was inconsistent with CEQA to use the maximum permitted operating capacity of this utility equipment as the baseline against which to compare NOx emissions from the proposed Project, rather than an estimate of the actual NOx emissions from the equipment under current operating conditions. The court determined that an inappropriate baseline was used and required SCAQMD to prepare an EIR for the Phillips 66 ULSD Project to respond to the findings the Supreme Court.

The Supreme Court left to the discretion of the SCAQMD the methodology for estimating the "actual existing levels of emissions" from the utility equipment. The Court explained:

> "The District and Phillips 66 emphasized that refinery operations are highly complex and that these operations, including the steam generation system, vary greatly with the season, crude oil supplies, market conditions, and other factors. . .
>
> "We do not attempt here to answer any technical questions as to how existing refinery operations should be measured for baseline purposes in this case or how similar baseline conditions should be measured in future cases. CEQA Guidelines section 15125 (Cal. Code Regs., tit. 14, § 15125, subd. (a) directs that the lead agency 'normally' use a measure of physical conditions 'at the time the notice of

> preparation [of an EIR] is published, or if no notice of preparation is published, at the time environmental analysis is commenced.' But, as one appellate court observed, 'the date for establishing baseline cannot be a rigid one. Environmental conditions may vary from year to year and in some cases it is necessary to consider conditions over a range of time periods.' . . . In some circumstances, peak impacts or recurring periods of resource scarcity may be as important environmentally as average conditions. Where environmental conditions are expected to change quickly during the period of environmental review for reasons other than the proposed project, project effects might reasonably be compared to predicted conditions at the expected date of approval, rather than to conditions at the time analysis is begun. . . A temporary lull or spike in operations that happens to occur at the time environmental review for a new project begins should not depress or elevate the baseline; overreliance on short term activity averages might encourage companies to temporarily increase operations artificially, simply in order to establish a higher baseline.
>
> "Neither CEQA nor the CEQA Guidelines mandates a uniform, inflexible rule for determination of the existing conditions baseline. Rather, the agency enjoys the discretion to decide, in the first instance, exactly how the existing physical conditions without the project can most realistically be measured, subject to review, as with all CEQA factual determinations, for support by substantial evidence."

The Court observed that the SCAQMD had previously calculated NOx emissions from the ULSD Project. However, it also stated that the SCAQMD is not required to use the same measurement method in the EIR that was used in the Negative Declaration. "Whatever method the District uses, however, the comparison must be between existing physical conditions without the Diesel Project and the conditions expected to be produced by the project." Because the project has already been constructed and currently operating, the analysis in the EIR has the advantage of actual data.

Finally, it should be noted that neither the Court of Appeal decision nor the Supreme Court decision invalidated any aspect of the prior CEQA documents except for the baseline used in the analysis of air quality impacts from Project operation. Other aspects of the prior CEQA documents that were challenged in the litigation, were rejected by the trial court, and the trial court's rulings were upheld on appeal. Thus, this EIR will focus only in the Air Quality analysis with regard to potential NOx emissions from the operation of the ULSD Project.

1.4 SCOPE AND CONTENT

Based on the court's decision on the previous CEQA documents for the Phillips 66 ULSD, the SCAQMD as the lead agency is required to prepare an EIR for the Phillips 66 ULSD Project. As a result, a Notice of Preparation of a Draft EIR for the ULSD Project was circulated for a 30-day review period on March 23, 2012. See Appendix A of the NOP.

No court decision invalidated any aspect of the prior CEQA documents except for the baseline used in the air quality impacts analysis for Project operations. With respect to analysis of air quality impacts from ULSD Project construction in particular, the litigation challenged the emissions estimates and the emissions factors applied to various construction activities and equipment, but the trial court found that the analysis in the prior CEQA documents was sound, and this aspect of the trial court decisions was not appealed. Similarly, other aspects of the prior CEQA documents that were challenged in the litigation were rejected by the trial court, and the trial court's rulings were upheld on appeal. Therefore, the Draft EIR for the Phillips 66 ULSD Project focuses on the issues directed by the court and is therefore limited to air quality setting and impacts from Project operations.

Because the SCAQMD is required to prepare an EIR, this document includes all relevant components required for preparation of an EIR (CEQA Guidelines §15120 through §15131) including, but not limited to, an executive summary, project description, existing setting, impacts, cumulative impacts, and an alternatives analysis.

1.5 LEAD AGENCY AND RESPONSIBLE AGENCIES

CEQA requires the evaluation of environmental impacts for proposed "projects" and requires the identification and implementation of feasible methods to reduce, avoid, or eliminate significant adverse impacts from these projects. The Phillips 66 ULSD Project constitutes a "project" as defined by CEQA. To fulfill the purpose and intent of CEQA, the SCAQMD is the "lead agency" for the Phillips 66 ULSD Project.

The lead agency is the public agency that has the principal responsibility for carrying out or approving a project that may have a significant effect upon the environment (Public Resources Code §21067). Because the SCAQMD has the greatest responsibility for supervising or approving the ULSD Project as a whole and because the SCAQMD has acted as the lead agency for previous CEQA documents for the ULSD Project, it was determined that the SCAQMD continues to be the most appropriate public agency to act as lead agency for the Phillips 66 ULSD Project (CEQA Guidelines § 15051(b)).

CEQA Guidelines §15381 defines a "responsible agency" as: "a public agency which proposes to carry out or approve a project, for which a Lead Agency is preparing or has prepared an EIR, SEIR, or Negative Declaration. For purposes of CEQA, responsible agencies include all public agencies other than the lead agency that have discretionary approval authority over the project."

The agency that had discretionary authority over the ULSD Project was the SCAQMD. The other public agency that had ministerial permitting authority, and was a responsible agency for certain actions associated with the ULSD Project at the Phillips 66 Los Angeles Refinery's Wilmington Plant was the City of Los Angeles.

No trustee agencies as defined by CEQA Guidelines §15386 have been identified with respect to the ULSD Project. However, notice of the ULSD Project has been sent to the Office of Planning and Research pursuant to Public Resources Code §21080.4 for distribution in the event trustee or other responsible agencies are identified.

1.6 INTENDED USES OF THE EIR

The Draft EIR is intended to be a decision-making tool that provides full disclosure of the environmental consequences associated with implementing the ULSD Project. Additionally, CEQA Guidelines §15124(d)(1) requires a public agency to identify the following specific types of intended uses:

- A list of the agencies that are expected to use the Draft EIR in their decision-making;
- A list of permits and other approvals required to implement the project; and,
- A list of related environmental review and consultation requirements required by federal, state, or local laws, regulations, or policies.

To the extent that local public agencies, such as cities, are responsible for making land use and planning decisions related to the ULSD Project, they relied on CEQA documents prepared by the SCAQMD during their decision-making process. It should be noted that the permits required for the ULSD Project have already been issued, including SCAQMD and City of Los Angeles permits, and the ULSD Project modifications have already been implemented. The court decisions did not rescind the permits associated with the ULSD Project. Therefore, the purpose of this EIR is to respond to the findings of the Supreme Court that requires a revised baseline analysis to evaluate operational air quality impacts of the ULSD Project.

1.7 AREAS OF CONTROVERSY

In accordance with CEQA Guidelines §15123(b)(2), the areas of controversy known to the lead agency, including issues raised by agencies and the public, shall be identified in the CEQA document. "Controversy" is defined as a difference in opinion or a dispute. As shown in Section 1.3, Legal History of the ULSD Project, the CEQA documents associated with the ULSD Project have been the subject of lawsuits challenging the SCAQMD's certification of the documents. Although other aspects of prior CEQA documents were challenged in the litigation, the main area of controversy was the proper baseline for analysis of operational air quality impacts from ULSD Project operations. The Supreme Court concluded that the environmental impacts of a proposed project must be compared to the environmental conditions that exist at the time CEQA analysis is commenced, not the level of development or activity that would be allowed under existing permits or approvals. Therefore, the SCAQMD has prepared this EIR to respond to the decision of the Supreme Court.

1.8 EXECUTIVE SUMMARY - CHAPTER 2: PROJECT DESCRIPTION

The ULSD Project at the Phillips 66 Los Angeles Refinery had two major components: (1) revamp the Mid-Barrel Hydrotreater Unit 90 to improve the hydrotreating reaction to meet the required diesel sulfur level; and (2) modify the Mid-barrel handling and logistics to segregate diesel from higher sulfur jet fuel. The Project also improved hydrogen distribution at the Wilmington Plant; and improved control of the Crude Unit heavy gas oil distillation cutpoint at the Carson Plant. A summary of the components of the ULSD Project is provided below.

Mid-Barrel Hydrotreater Unit 90 Modifications: Changes to Unit 90 included modifying the reactor loop to replace the existing reactors with two new larger reactors, and installation of new heat exchangers.

Charge Heater Modifications: The reactor charge heater B-201 was removed from service and replaced with a functionally identical replacement heater referred to as B-401, which included low NOx burners and a SCR Unit for NOx control to meet SCAQMD Best Available Control Technology requirements.

SCR Unit: SCR units control NOx emissions by injecting aqueous ammonia into the exhaust gas stream upstream of a catalyst. The aqueous ammonia used in the SCR Unit consists of 30 percent ammonia. Aqueous ammonia is supplied to the SCR's vaporizer system from an existing aqueous ammonia storage tank, so no new storage tank was required. A back-up supply consisting of two 150-pound cylinders of anhydrous ammonia was installed as part of the aqueous ammonia vaporization skid at heater B-401.

Cooling Tower: The cooling tower E-221 was demolished to make room for the new reactors and charge heater and was replaced in a different location.

Mid Barrel Handling and Shipping Modifications: Modifications to Mid-barrel handling and shipping at the Wilmington Plant improved segregation of ULSD and jet fuel. These modifications included a new ULSD shipping pump (the existing pump that previously shipped both diesel and jet fuel continues to be used to ship jet fuel); two new pumps for handling jet and diesel blendstocks; and one new sample pump and associated piping to create separate facilities for handling jet and diesel fuel.

Hydrogen System: The hydrogen distribution piping was changed to enable the exclusive use of high purity hydrogen at Unit 90 for maximizing hydrogen partial pressure at the reactor inlet. New piping was needed to properly distribute reformer hydrogen to other Refinery processes not requiring continued use of high purity hydrogen.

Storage Tank Modifications: As part of the ULSD Project, the service (contents) of Storage Tank 331 at the Wilmington Plant was changed into jet/diesel.

Crude Unit DU-5 at the Carson Plant: The Project scope included temperature monitoring equipment and modifications to flow control valves in order to improve crude distillation operations and minimize the high sulfur portion of the distilled crude routed to Unit 90. Maintenance workers performed the minor modifications (add pre-manufactured thermocouples and modify existing control valves) that were required to the unit. These changes did not result in physical impacts to the environment (air emissions, noise, traffic, etc.) so the environmental evaluation in this EIR is limited to the project activities at the Wilmington Plant (CEQA Guidelines §15064(d)(1)).

1.9 EXECUTIVE SUMMARY – CHAPTER 3: ENVIRONMENTAL SETTING, IMPACTS AND MITIGATION MEASURES

INTRODUCTION

The California Supreme Court decision invalidated only that aspect of the prior CEQA documents relating to the baseline used in the air quality impacts analysis for project operations. No other conclusions from the prior analysis that the ULSD Project would not significantly adversely affect any non-air quality environmental topics, was invalidated. In particular, the California Supreme Court concluded that the environmental impacts of a proposed Project must be compared to the environmental conditions that exist at the time the CEQA analysis is commenced, not the level of development or activity that would be allowed under existing permits or approvals. The Supreme Court left to the discretion of the SCAQMD the methodology for estimating the "actual existing levels of emissions" from the utility equipment, recognizing that refinery operations are highly complex and that these operations, including the steam generation, vary greatly with the season, crude oil supplies, market conditions and other factors. The Supreme Court concluded that "(w)hatever method the District uses, however, the comparison must be between existing physical conditions without the Diesel Project and the conditions expected to be produced by the project."

Environmental review for the ULSD Project began in early January 2004, when the 2004 Negative Declaration was prepared and published. Construction of the ULSD Project began in 2005 and was completed in 2006. The ULSD Project went through start-up and de-bugging procedures in April 2006 and was fully operational starting in May 2006. Thus, the 2002-2003 time period is considered to be the pre-ULSD Project or baseline conditions for Refinery operations as this represents the timeframe during the environmental analysis development for the ULSD Project prior to the construction and operation of the ULSD Project. This approach is consistent with CEQA Guidelines §15125, which indicates that an EIR must include a description of the physical environmental conditions in the vicinity of the project as they exist at the time the notice of preparation is published, or if no notice of preparation is published, at the time environmental analysis is commenced.

Since the ULSD Project went through start-up and de-bugging procedures in April 2006, the "post-project" period is considered to be May 2006 and thereafter. For the purposes of evaluating air quality impacts from the ULSD Project, the "post-project" period for the ULSD Project is May 2006 through April 2008. This period length was selected in order to compare an equivalent period of time, two years of operation, to the baseline conditions, which were developed using two years (2002 – 2003) of historical data. A two year period allows the data to reflect the various changes in operation such as shut down for maintenance, market demands, etc. Where available data did not precisely match these pre- and post-Project periods, the impact analysis relies on the best available match.

AIR QUALITY SETTING

The Phillips 66 Los Angeles Refinery is located within the SCAQMD jurisdiction which consists of the four-county South Coast Air Basin (Basin), including Orange, and the non-desert portions of Los Angles, Riverside, and San Bernardino counties, the Riverside County portions of the Salton Sea Air Basin (SSAB), and the Mojave Desert Air Basin (MDAB). The Basin is bounded by the Pacific Ocean to the west and the San Gabriel, San Bernardino, and San Jacinto mountain ranges to the north and east.

The climate in the Basin generally is characterized by sparse winter rainfall and hot summers tempered by cool ocean breezes. The mild climatological pattern is interrupted infrequently by periods of extremely hot weather, winter storms, and Santa Ana winds. Temperature affects the air quality of the region in several ways. Local winds are the result of temperature differences between the relatively stable ocean air and the uneven heating and cooling that takes place in the Basin due to a wide variation in topography. Temperature also has a major effect on vertical mixing height and affects chemical and photochemical reaction times.

The sources of air contaminants in the Basin vary by pollutant but generally include on-road mobile sources (e.g., automobiles, trucks and buses), other off-road mobile sources (e.g., airplanes, ships, trains, construction equipment, etc.), stationary sources (e.g., fuel combustion, petroleum production and marketing, and other industrial processes), and solvent evaporation (e.g., consumer products and architectural coatings). Mobile sources are responsible for a large portion of the total Basin emissions of several pollutants.

Health-based air quality standards have been established by the U.S. EPA and the CARB for ozone, carbon monoxide (CO), NOx, particulate matter less than ten microns in diameter (PM10), PM2.5, SOx, and lead. California also has established standards for sulfate, visibility, hydrogen sulfide, and vinyl chloride. The Basin, including the Project area, is classified as attainment for both the state and federal standards for CO, NOx, SOx, sulfates, and lead and the state standard for sulfates. The Basin is currently designated as non-attainment for PM2.5 and ozone for both state and federal standards. The Basin has met the PM10 standard and U.S. EPA has proposed approval of the PM10 attainment designation.

When the ULSD Project was proposed and implemented, the SCAQMD was promulgating rules and regulations identified as control measures in the 2003 Air Quality Management Plan (AQMP). Subsequently, the SCAQMD adopted the 2007 AQMP and promulgated rules and regulations identified as control measures in that Plan. As a result of implementing AQMP control measures as rules or regulations, there have been substantial improvements in air quality since 2004 when the ULSD Project originally underwent an environmental analysis pursuant to CEQA. In December 2012, the SCAQMD adopted the 2012 AQMP and has already begun the process of promulgating rules to ensure attainment of the federal 24-hour PM2.5 standard.

The Project site is located within the SCAQMD's South Coastal Los Angeles County monitoring area. The area has shown a general improvement in air quality with decreasing or consistent concentrations of most pollutants. Air quality in the South Coastal Los Angeles County monitoring area complies with the state and federal ambient air quality standards for CO, NOx, SOx, lead, and sulfate. The air quality in the project area is also in compliance with the federal eight-hour ozone standard, the federal 24-hour PM10 standard, and the federal 24-hour and annual average PM2.5 standards. However, the air quality in the South Coastal Los Angeles County area is not in compliance with the state 24-hour PM10 and PM2.5 standards.

ENVIRONMENTAL IMPACTS

Based on the court’s decision on the previous CEQA documents for the Phillips 66 ULSD, the EIR focuses on the issues as directed by the court and is limited to air quality setting, discussed in the previous section, and air quality impacts from ULSD Project operations. An impact is considered significant under CEQA if it leads to a "substantial, or potentially substantial, adverse change in the environment." A summary of the ULSD Project impacts is provided in Table 1-1.

The baseline for the ULSD Project was Refinery operations in years 2002-2003 (pre-Project), which reflects the physical environmental setting at the time the environmental review of the ULSD Project began. The Project was constructed in 2005 and became operational in April 2006. Therefore, Project impacts were evaluated for April 2006 through December 2008 (post-Project). Since the ULSD Project has been built and is operational, the Project impacts are based on actual operational information as opposed to the engineering estimates that were used in previous CEQA documents.

The ULSD Project resulted in emission changes at the Wilmington Refinery. These emission changes included increased fugitive components (i.e., increases in VOC emissions), replacement heater B-401 (i.e., decreases in CO and NOx emissions, and minor increases in VOC, SOx, PM10 and PM2.5 emissions), and storage tank 331 modifications (i.e., increases in VOC emissions). It was unltimately determined that the

ULSD Project did not result in an increase in steam generation or result in an emission increase associated with steam generation. This conclusion is further explained and analyzed in Ch. 3 of this EIR. The ULSD Project resulted in indirect (off-site) emissions associated with increases in hydrogen production, electricity demand, and truck transport. Daily operational emissions are summarized in Table 3.3-7 and compared to the SCAQMD daily operational significance thresholds to determine impact significance. As demonstrated in the table, operation of the ULSD Project is not expected to exceed any significance thresholds. Therefore, the air quality impacts associated with operational emissions from the ULSD Project are less than significant.

A health risk assessment (HRA) was performed to determine if emissions of TACs generated by the ULSD Project would exceed the SCAQMD thresholds of significance for cancer risk and hazard indices, thus resulting in significant health impacts. The incremental cancer risk for the ULSD Project is 7.65×10^{-8} or 0.08 per million for the residents (MEIR) and 9.20×10^{-9} or about 0.01 per million for the workers (MEIW). The incremental chronic risk is 0.0008 and the incremental acute risk is 0.0001. The cancer risks for the TACs emitted from the ULSD Project are below the significance threshold of ten per million and chronic and acute hazard indices are below the 1.0 thresholds. Therefore, the cancer risk and hazard index thresholds are not considered to be significant and no significant health impacts are associated with the ULSD Project.

No significant air quality impacts have been identified and no mitigation measures are required for the ULSD Project. However, the SCAQMD will impose AQ-1, which contains specific reporting requirements, to ensure that the Refinery operations are consistent with the assumptions upon which the air quality analysis is based.

TABLE 1-1

Summary of Environmental Impacts, Mitigation Measures, and Residual Impacts

IMPACT	MITIGATION MEASURES	RESIDUAL IMPACT
Operational emissions of criteria pollutants are less than significant for CO, VOC, NOx, SOx, PM10, and PM2.5.	None Required. However, the SCAQMD will impose AQ-1, which contains specific reporting requirements for fuel usage, to ensure that the refinery operations are consistent with the assumptions upon which the air quality analysis is based.	Operational emissions are expected to be less than significant CO, VOC, NOx, SOx, PM10, and PM2.5.
An ambient air quality screening analysis indicates that the Project emissions on NO_2, PM10, and PM2.5 will be below ambient air quality standards and are less than significant.	None required.	Project emissions of NO_2, PM10, and PM2.5 will be below ambient air quality standards and are less than significant.
The cancer risk due to the operation of the ULSD Project is expected to be less than the significance criterion of 10 per million, so that Project impacts are less than significant.	None required.	Cancer risk impacts are less than significant.
The ULSD Project impacts associated with exposure to non-carcinogenic compounds are expected to be less than significant. The chronic hazard index and the acute hazard index are both below 1.0.	None required.	No significant non-carcinogenic health impacts are expected.

1.10 EXECUTIVE SUMMARY – CHAPTER 4: CUMULATIVE IMPACTS

INTRODUCTION

The cumulative impact analysis focuses on whether the air quality impacts of the ULSD Project are cumulatively considerable within the context of impacts caused by other past, present, or reasonably foreseeable future projects. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. This cumulative impact analysis considers other related projects or projects causing related impacts within a geographic scope of approximately one mile from the Phillips 66 Wilmington Plant.

PROJECTS CONSIDERED IN CUMULATIVE IMPACT ANALYSIS

The Project is located within the existing Phillips 66 Wilmington Plant, in the southwest portion of Los Angeles County within Southern California. The area has been used as a Refinery for nearly a century and a number of other industrial facilities are located nearby including petroleum storage facilities, warehouses and the Port of Los Angeles. A total of 43 of these projects (approved or proposed) have been identified within the general vicinity of the Project that could contribute to cumulative impacts.

Local impacts were assumed to include projects which would occur within the same timeframe as the construction and operation of the ULSD Project (about 2002 until 2012) and which are within a one-mile radius of the Refinery site. Impacts to most environmental resources are generally localized in nature (e.g., air quality, noise, and traffic). Consequently, there is sufficient distance between projects located over one mile away from the Wilmington Plant to avoid cumulative impacts.

OPERATIONAL AIR QUALITY EMISSION IMPACTS

The ULSD Project operational emissions are substantially less than the SCAQMD project-specific significance thresholds. Therefore, project-specific air quality impacts associated with operational emissions from the ULSD Project are not considered to be a cumulatively considerable contribution to significant adverse cumulative air quality impacts, pursuant to CEQA Guidelines §15130 (A).

Other related projects at the Refinery included the construction of air pollution control equipment to reduce PM10 and NOx from the Phillips 66 Refinery. Therefore, the cumulative air quality impacts from the Refinery during this period were beneficial.

Other off-site cumulative projects could result in significant operational air quality impacts. However, as already noted above operational emissions from the ULSD Project are substantially less than the applicable project-specific operational significance thresholds and cumulative Refinery projects have resulted in a net reduction in emissions.

Therefore, operational emissions associated with the ULSD Project are not considered a cumulatively significant contribution to significant adverse cumulative air quality impacts, pursuant to CEQA Guidelines §15130 (A).

TOXIC AIR CONTAMINANT IMPACTS

The impacts from TACs are localized impacts. For example, impacts from exposures to TACs decline by approximately 90 percent at 300 to 500 feet from the emissions source (SCAQMD, 2005). Most related projects are located at greater than 500 feet from the Phillips 66 Refinery or are projects that would not result in increases in TACs, such that potential TAC impacts would not overlap with the ULSD Project. The ULSD Project impacts on health effects associated with exposure to TACs are expected to be substantially below the SCAQMD's cancer risk and hazard index significance thresholds and, therefore, less than significant.

Other cumulative projects could result in increased localized emissions of TACs. However, as noted above, TAC emissions from the ULSD Project are substantially less than the applicable project-specific operational significance thresholds. Therefore, cumulative impacts of TACs on health are expected to be less than significant.

LEVEL OF SIGNIFICANCE AFTER MITIGATION

The project-specific air quality impacts due to operational activities do not exceed the SCAQMD significance thresholds, are not considered to be cumulatively considerable, and do not contribute to significant adverse cumulative operational air quality impacts. The project-specific TAC health impacts are not significant, are also not considered to be cumulatively considerable, and do not generate significant adverse cumulative TAC impacts.

CEQA Guideline §15130(a) indicates that an EIR shall discuss cumulative impacts of a project when the project's incremental effect is cumulatively considerable. Where a lead agency is examining a project with an incremental effect that is not cumulatively considerable, a lead agency need not consider the effect significant, but must briefly describe the basis for concluding that the incremental effect is not cumulatively considerable. Therefore, the Project's contribution to operational air emissions, including toxic air contaminant emissions, is not cumulatively considerable and thus not cumulatively significant because the environmental conditions would essentially be the same whether or not the ULSD Project is implemented (CEQA Guidelines §15130). This conclusion is consistent with CEQA Guidelines §15064(h)(4), which states, "The mere existence of cumulative impacts caused by other projects alone shall not constitute substantial evidence that the proposed project's incremental effects are cumulatively considerable".

1.11 EXECUTIVE SUMMARY – CHAPTER 5: ALTERNATIVES ANALYSIS

INTRODUCTION

This EIR provides a discussion of alternatives to the ULSD Project as required by CEQA. According to the CEQA Guidelines, alternatives should include realistic measures to attain the basic objectives of the proposed project and provide means for evaluating the comparative merits of each alternative. In addition, though the range of alternatives must be sufficient to permit a reasoned choice, they need not include every conceivable project alternative. Alternatives presented in this chapter were developed by reviewing alternative options to reduce the sulfur content of feed-stocks in order to obtain more CARB-compliant diesel blending stocks. The rationale for selecting specific components of the proposed project on which to focus the alternatives analysis rests on CEQA's requirements to present a range of reasonable project alternatives that could feasibly attain the basic objectives of the project, while generating fewer or less severe adverse environmental impacts. The objectives of the Project are to produce ULSD that complies with the diesel sulfur content standards set by the SCAQMD, CARB, and U.S. EPA, and to insure that adequate supplies of ULSD are available to meet future demand within current permitted limits.

ALTERNATIVES REJECTED AS INFEASIBLE

In accordance with CEQA Guidelines, a CEQA document should identify any alternatives that were considered by the lead agency, but were rejected as infeasible during the scoping process and briefly explain the reason underlying the lead agency's determination. An alternative location for the ULSD Project has been rejected because it would not accomplish Project objectives and also because it is not feasible. To produce compliant diesel fuel at an alternative location would require the development of an entirely new refinery in an alternative location. This would require substantially more equipment and construction, be very costly, and potentially generate substantially greater impacts in many environmental categories than the ULSD Project. It also would require years of lead time to engineer, obtain permits and approvals, and construct. There is uncertainty the necessary permits would be approved in a timely manner. Therefore, an alternative site for the Project is not considered to be feasible.

The purchase of low sulfur feedstocks from off-site locations was also determined to be not feasible. Rather than reducing the sulfur content of diesel at the Phillips 66 Wilmington Plant, low sulfur blending components could be purchased by Phillips 66, transported to the Refinery, and blended with its manufactured streams. This alternative is rejected as infeasible because it is unlikely that sufficient quantities of low sulfur feedstocks within California would be available for purchase. The option of importing foreign feedstocks from outside of California would potentially generate significant adverse environmental impacts to more environmental topic areas or make existing impacts substantially worse because of the increase in marine vessels visits that would result in an increase in marine vessel emissions, which is inconsistent with the purpose of an alternatives analysis.

DESCRIPTION OF PROJECT ALTERNATIVES

Alternative 1 - No Project Alternative: The No Project Alternative would not allow the Wilmington Plant to produce diesel fuel that complies with the U.S. EPA, CARB, and SCAQMD mandates for ultra low sulfur diesel (15 ppmw sulfur). Sufficient quantities of low sulfur feedstocks are not available to offset the ULSD produced under the Phillips 66 ULSD Project; however, low sulfur feedstocks may be occasionally available for purchase. Under the No Project, additional quantities of low sulfur feedstocks may be delivered via marine vessel to the marine terminal/Refinery. Nonetheless, under the No Project Alternative, Phillips 66 would produce little, if any, ULSD resulting in a decrease in ULSD in California. Dince all diesel fuel sold in California is required to have low sulfur content, the No Project would affect availability of diesel fuel that could have adverse effects on implementing other development projects (e.g., reduction of PM from DPFs.)

Alternative 2 – New S-Zorb Unit: Alternative 2 would use S-Zorb technology, which is an alternative hydrotreating technology, to produce ULSD. Alternative 2 would require replacement of the existing Unit 90 Hydrotreater and the construction of a new S-Zorb hydrotreating unit including the following equipment: feed filter and feed surge drum, reactor charge pump, reactor feed/effluent exchanger, reactor charge heater, reactor, reactor effluent filter, product separators, stabilizer, recycle hydrogen compressor, sorbent flow equipment (including reducer, reactor, and reactor receiver), regenerator feed drum, regenerator, and regenerator receiver. The S-Zorb hydrotreating process was developed by Phillips Petroleum Company and has been installed in one refinery. However, in operation, the S-Zorb has been less efficient than traditional hydrotreaters, and has never been used to commercially hydrotreat diesel fuels. Therefore, the current feasibility of this technology is questionable.

Alternative 3 – High Pressure Hydrotreating: Alternative 3 would use high pressure hydrotreating to not only produce ULSD, but also to reduce aromatic content below requirements to produce CARB compliant diesel. Alternative 3 would replace the existing Unit 90 Hydtrotreater with a new 1200 psig hydrotreater. However, Alternative 3 would require either a new hydrogen plant or the purchase of hydrogen from a third party. No other modifications are anticipated to the existing units at the Wilmington Plant.

AIR QUALITY IMPACTS FROM THE PROJECT ALTERNATIVES COMPARED TO THE ULSD PROJECT

The No Project Alternative (Alternative 1) would eliminate the less than significant air quality impacts from the ULSD Project at the Wilmington Plant associated with the project. Other less than significant impacts identified in the previous CEQA documents for the ULSD Project (e.g., hazard and noise impacts) would also be eliminated at the

Wilmington Plant. However, Alternative 1 would increase operational emission and not achieve the objectives of the ULSD Project to continue producing diesel fuel that meets U.S. EPA, CARB, and SCAQMD ULSD requirements, and is therefore not a feasible option since Phillips 66 must comply with regulatory requirements and meeting future demand. Alternative 1 is also expected to generate additional marine vessel emissions, resulting in greater emissions than the ULSD Project.

Alternatives 2, and 3 would achieve the Project objectives of producing ULSD but would generate greater and potentially significant impacts to air quality impacts and TAC impacts as compared to the ULSD Project.

Based on the analysis in Chapter 5, Alternatives 1, 2, and 3 would potentially generate greater air quality impacts than the ULSD Project. Therefore, the ULSD Project is considered the environmentally superior alternative because it generates air quality impacts that would be less than the air quality impacts generated by Alternatives 1, 2 and 3.

1.12 EXECUTIVE SUMMARY – CHAPTER 6: REFERENCES

Information on references cited (including organizations and persons consulted) is presented in Chapters 6.

1.13 EXECUTIVE SUMMARY – CHAPTER 7: ACRONYMS AND GLOSSARY

Information on the acronyms and glossary are presented in Chapter 7.

CHAPTER 2

PROJECT DESCRIPTION

2.0 PROJECT DESCRIPTION

2.1 INTRODUCTION

The Phillips 66 Los Angeles Refinery first proposed modifications to produce Ultra Low Sulfur Diesel (ULSD) in 2004 to comply with the federal, state, and SCAQMD regulations that limit the sulfur content of diesel fuels. As the lead agency, pursuant to the California Environmental Quality Act (CEQA), the South Coast Air Quality Management District (SCAQMD) prepared a Negative Declaration, an Addendum, and a Subsequent Negative Declaration for the required modifications.

Following legal challenge, the California Supreme Court concluded that there were certain deficiencies in previously prepared CEQA documents for the Phillips 66 ULSD Project and required the SCAQMD to prepare an EIR to analyze the air quality impacts of the Project. The decision by the California Supreme Court resulted in decertification of the previously prepared CEQA documents but did not require that the issuance of required permits for the project be set aside. As a result, a Draft EIR is now being prepared for the ULSD Project as required by the California Supreme Court to correct deficiencies identified in the Court's decision and satisfy the court's request. However, the Refinery modifications proposed as part of the ULSD Project have been completed and Phillips 66 has been producing ULSD at its Los Angeles Refinery since 2006, as required by federal, state, and SCAQMD ULSD regulations.

2.2 PROJECT OBJECTIVES

The Phillips 66 ULSD Project was needed to comply with federal, state and SCAQMD regulations that limit the sulfur content of diesel fuels. Reducing the sulfur content of diesel fuel results in a reduction of SOx and particulate sulfate emissions from sources (such as vehicles and trucks) that use the fuel. The objectives of the ULSD Project are as follows:

- Reduce the sulfur content of diesel fuel produced at the Phillips 66 Los Angeles Refinery to reduce SOx and sulfate emissions from mobile sources in the basin.
- Reduce the sulfur content of diesel fuel produced at the Phillips 66 Los Angeles Refinery, which allows widespread use of particulate filters to reduce PM emissions that would otherwise fail if diesel fuel with a higher sulfur content is used.
- Comply with SCAQMD's Rule 431.2 which requires a reduction in sulfur content in diesel fuel used in stationary sources to 15 ppmw.
- Comply with CARB's 2000 Diesel Risk Reduction Plan to reduce risk exposure from diesel particulate matter.
- To ensure that adequate supplies of ULSD are available to meet future demand.

- Comply with the U.S. EPA's diesel fuel standards that required refiners to sell highway diesel fuel that meets a maximum sulfur standard of 15 ppmw.

2.3 PROJECT LOCATION

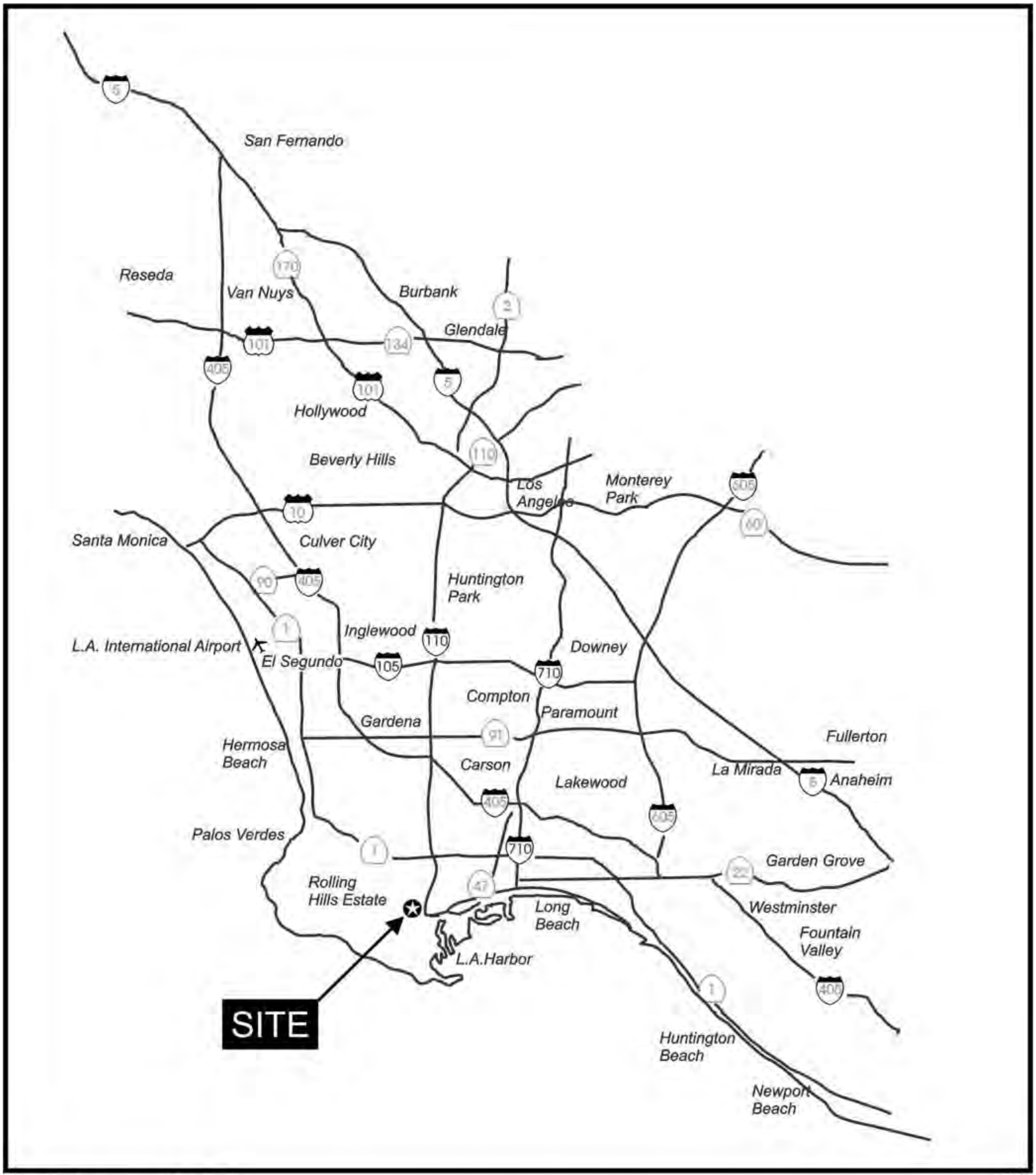
The Phillips 66 Los Angeles Refinery operates at two different sites in the South Coast Air Basin, which is a subarea of the SCAQMD's area of jurisdiction. One of the sites is located in the City of Carson (Carson Plant) and the other site is in the City of Los Angeles in the Wilmington community (Wilmington Plant). The Phillips 66 Wilmington Plant consists of approximately 400 acres and is located in Los Angeles County at 1660 West Anaheim Street, Wilmington, California (see Figures 2-1 and 2-2). The eastern part of the Wilmington Plant borders a residential area, a roofing materials plant, and a portion of the Harbor 110 Freeway. The northern portion of the site borders Harbor Lake Park, Harbor College, Harbor Golf Course, and a small residential area. The western part of the site borders Gaffey Street including a firing range, vacant fields, recreational fields, and a U.S. Navy fuel storage facility. Finally, the southern portion of the site shares a border with a warehouse facility. The ULSD Project occurs primarily at the Wilmington Plant, and only minor modifications were required at the Carson Plant.

The Carson Plant is bounded on the north by Sepulveda Boulevard; on the west by Wilmington Avenue; on the south by railroad tracks; and on the east by Alameda Boulevard. Property to the north of the Carson Plant is occupied by another refinery. The western boundary of the Carson Plant borders a shipping and container storage facility. Property across Wilmington Boulevard includes a residential neighborhood to the northwest and commercial uses to the southwest. Land uses to the south of the Carson Plant are heavy industrial. Land south of Lomita Avenue is dominated by port-related activities. Land east of Alameda Street is occupied by a storage tank farm and the Tesoro Refinery.

2.4 LAND USE AND ZONING

The ULSD project occurs primarily at the Phillips 66 Wilmington Plant, with minor modifications occurring at the Carson Plant. The project modifications to the Wilmington Plant have been developed entirely within the existing Wilmington Plant property boundaries. The nature of the overall function and products produced at the Wilmington Plant remains the same. Land use on the Wilmington Plant property is designated by the City of Los Angeles as M3, which is heavy industrial zoning. The ULSD project is consistent with the land use designation of heavy industry and manufacturing. No new land was required for the ULSD project and no zoning and/or land use changes were required as part of the ULSD project.

Land use at the Wilmington Plant, and in the surrounding vicinity, is consistent with the City of Los Angeles General Plan land use designations. The Land Use element of the General Plan currently in place was adopted in December 1992. No revisions to the Land Use element have occurred since December 1992.

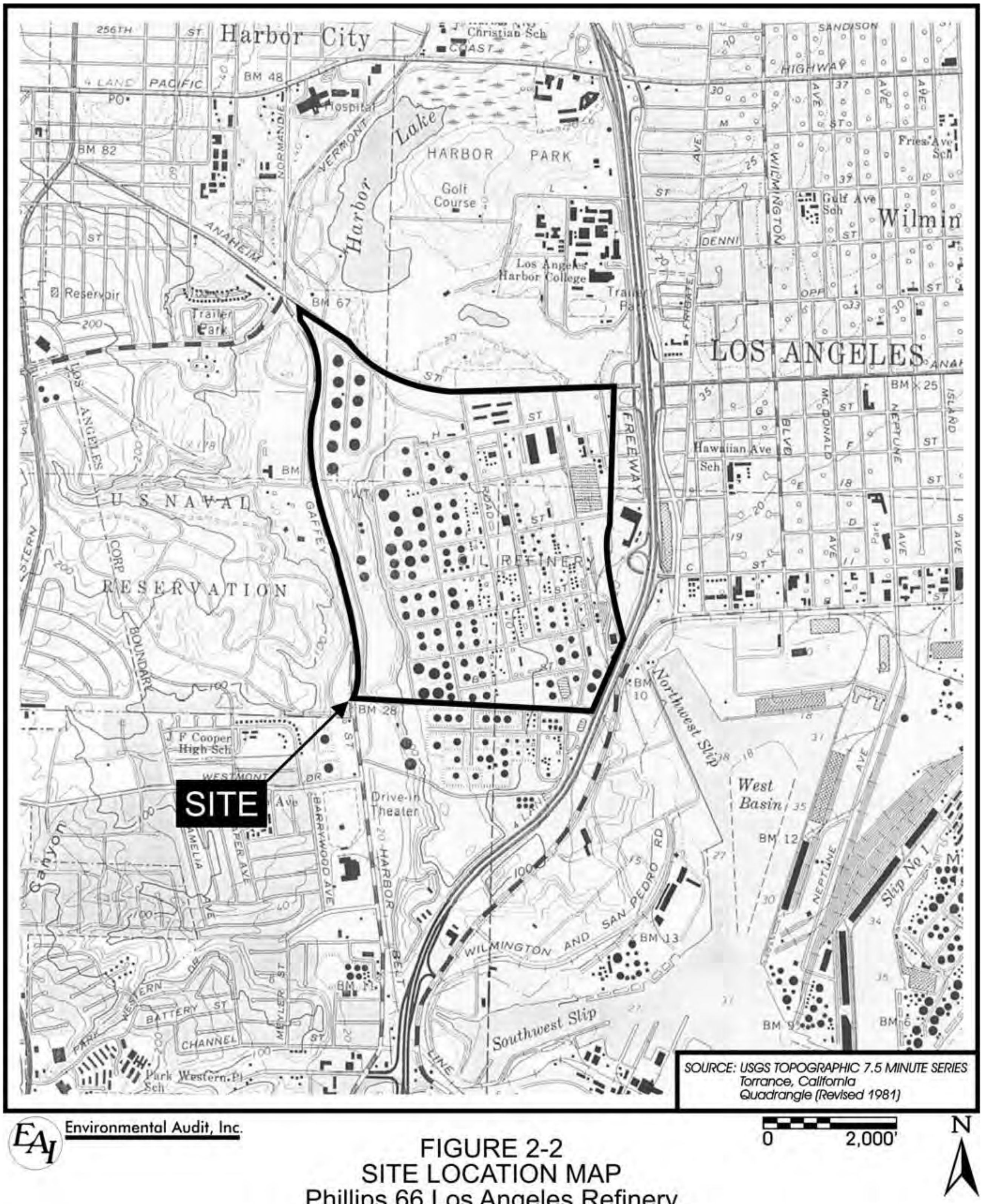


Environmental Audit, Inc.

FIGURE 2-1
REGIONAL MAP
Phillips 66 Wilmington Plant

Project No. 2696

N:\2696\RegionalMap (rev.2).cdr



SOURCE: USGS TOPOGRAPHIC 7.5 MINUTE SERIES
Torrance, California
Quadrangle (Revised 1981)

Environmental Audit, Inc.

FIGURE 2-2
SITE LOCATION MAP
Phillips 66 Los Angeles Refinery
Wilmington Plant

Project No. 2696

N:\2696\Site Location Map (rev.2).cdr

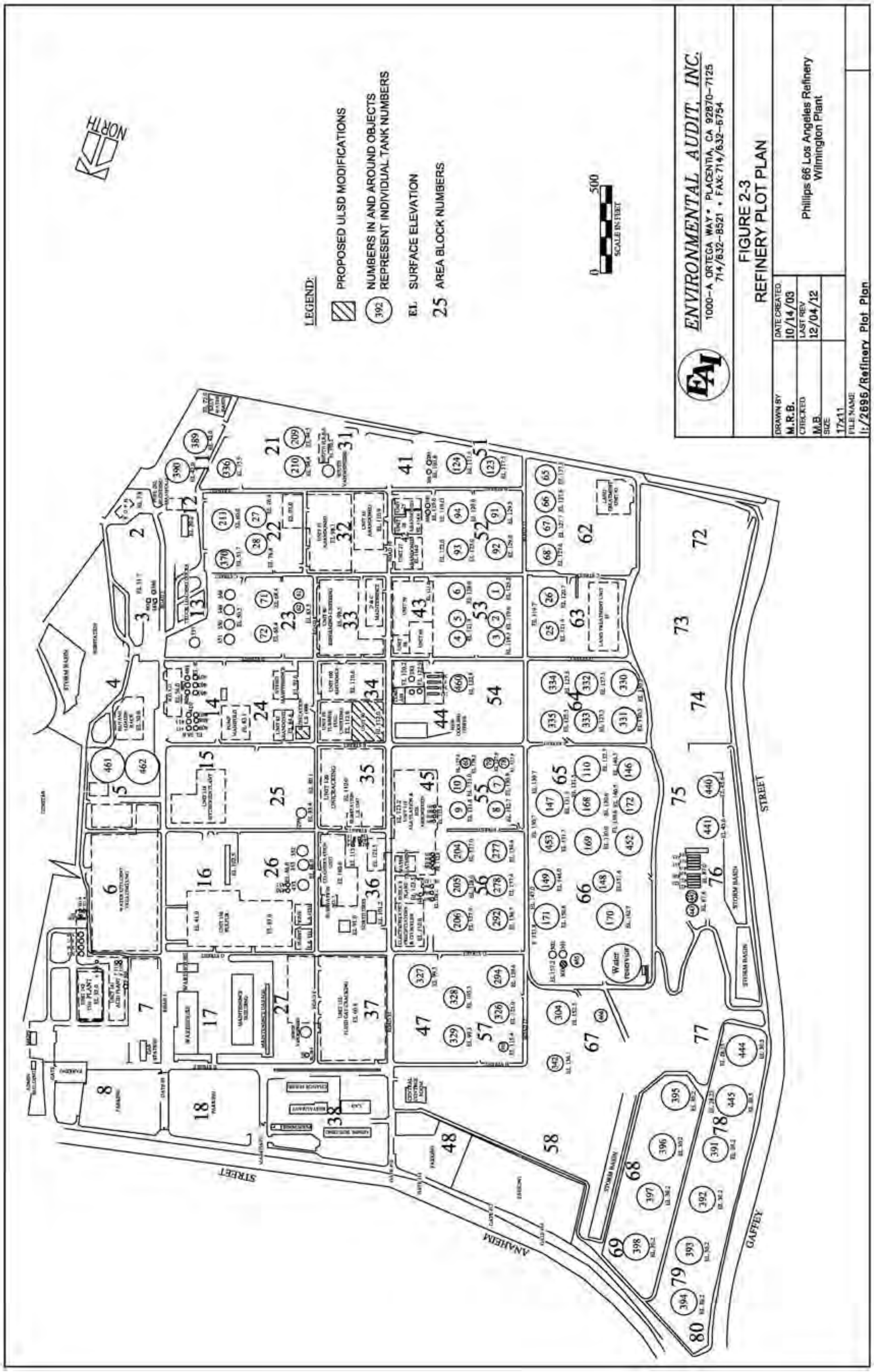
The ULSD modifications to the Carson Plant occurred entirely within the existing Carson Plant property boundaries. The nature of the overall function and products produced at the Carson Plant remains the same. The Carson Plant is designated as MH, Manufacturing Heavy land use zoning and all the surrounding land uses are heavy industrial, including other refinery facilities, tank farms, and transportation corridors. The ULSD project was and continues to be consistent with the current land use designation of heavy industry and manufacturing. No new property was acquired for the Carson Plant as part of the ULSD project. The ULSD project did not trigger changes to the zoning designations at the project sites.

2.5 EXISTING REFINERY CONFIGURATION AND OPERATION

Crude oil is a mixture of hydrocarbon compounds and relatively small amounts of other materials, such as oxygen, nitrogen, sulfur, salt, and water. Petroleum refining is a coordinated arrangement of manufacturing processes designed to produce physical and chemical changes in the crude oil to remove most of the non-hydrocarbon substances, break the crude oil into its various components, and blend them into various useful products. The overall refining process uses four kinds of techniques: (1) separation, including distilling hydrocarbon liquids into gases, gasoline, diesel fuel oil, and heavier residual materials; (2) cracking or breaking large hydrocarbon molecules into smaller ones by thermal or catalytic processes; (3) reforming using heat and catalysts to rearrange the chemical structure of a particular oil stream to improve its quality; and (4) combining by chemically combining two or more hydrocarbons to produce high-grade gasoline. The Phillips 66 Los Angeles Refinery produces a variety of products including gasoline, jet fuel, diesel fuel, petroleum gases, sulfuric acid, petroleum coke, and sulfur.

2.6 ULSD PROJECT DESCRIPTION

The ULSD Project at the Phillips 66 Los Angeles Refinery is comprised of two major components: (1) revamp the Mid-Barrel Hydrotreater Unit 90 to improve the hydrotreating reaction to comply with the required diesel sulfur content level; and (2) modify the Mid-barrel handling and logistics to segregate diesel from higher sulfur jet fuel; as well as several associated minor modifications. The Project also improves hydrogen distribution at the Wilmington Plant; and improves control of the Crude Unit heavy gas oil distillation cutpoint at the Carson Plant. The locations of equipment modified as part of the ULSD Project at the Wilmington Plant are shown in Figure 2-3. The main components of the ULSD Project are described in more detail in the following subsections.


NORTH
LEGEND:
PROPOSED ULSD MODIFICATIONS
392 NUMBERS IN AND AROUND OBJECTS REPRESENT INDIVIDUAL TANK NUMBERS
EL SURFACE ELEVATION
25 AREA BLOCK NUMBERS
0 500
SCALE IN FEET
ENVIRONMENTAL AUDIT, INC.
1000-A ORTEGA WAY • PLACENTIA, CA 92870-7125
714/632-8521 • FAX 714/632-6754
FIGURE 2-3
REFINERY PLOT PLAN
Phillips 66 Los Angeles Refinery Wilmington Plant
DRAWN BY M.R.B.
CHECKED M.B.
SIZE 17x11
DATE CREATED 10/14/03
LAST REV 12/04/12
FILE NAME I:/2695/Refinery Plot Plan
STREET
ANAHEIM
GAFFEY
STREET
STORM BASIN
Water reservoir

Mid-Barrel Hydrotreater Unit 90 Modifications

The 2004 Final Negative Declaration included an analysis of changes to Unit 90 including modifying the reactor loop to replace the existing reactors with two new larger reactors oriented in series. The reactor effluent exchanger train was replaced with new exchangers to improve heat recovery and minimize pressure drop. The Project did not increase the maximum throughput capacity of Unit 90.

The existing recycle gas compressor was modified to double its capacity by replacing the compressor internals with a larger rotor. The recycle gas scrubber required tray replacement to handle the increase in the recycle gas rate.

Charge Heater Modifications

The 2004 Final Negative Declaration included an analysis of the reactor charge heater B-201 which was removed from service, demolished, and replaced with a functionally identical replacement heater referred to as B-401. The heater had to be replaced to reduce the pressure drop through the tubes at the higher reactor inlet pressure, and to ensure the heater would meet the current American Petroleum Institute Standard No. 560, Fired Heaters for General Refinery Services, at all expected firing rates. Consistent with current SCAQMD policy, the air quality permit was updated to indicate the equipment's maximum design rating. Best Available Control Technology (BACT) for the new heater was determined to be low NOx burners and a SCR Unit for NOx control[1]. NOx emissions from replacement charge heater B-401 were limited to a concentration of five ppmv. BACT for CO and SOx control was 10 ppmv CO and 40 ppm total reduced sulfur, respectively. Heater B-401 and the SCR Unit were installed adjacent to the new reactors in Unit 90 (see 2-3, Block 34).

SCR Unit

As indicated above, SCR technology is considered to be BACT and is required to reduce NOx emissions from the new charge heater B-401 that replaced the existing charge heater B-201, which was analyzed in the 2005 Final Subsequent Negative Declaration. SCR units control NOx emissions by injecting aqueous ammonia into the exhaust gas stream upstream of a catalyst. The aqueous ammonia used in the SCR Unit consists of 30 percent ammonia. NOx, ammonia, and oxygen react on the surface of the catalyst to form nitrogen and water. The catalyst is made from a metallic oxide (vanadium pentoxide) with NOx control efficiencies expected to be approximately 90 percent or more. The NOx concentration downstream from the SCR Unit is limited to five parts per million.

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[1] As analyzed in the 2004 Final Negative Declaration, ultra low NOx burners were originally considered to be BACT for the ULSD Project. However, upon further engineering review by SCAQMD staff, it was concluded that SCR in addition to low NOx burners constituted BACT for the Project. As a result, the 2005 Final Subsequent Negative Declaration was prepared to analyze the change in BACT from ultra low NOx burners to low NOx burners and SCR.

Aqueous ammonia is supplied to the SCR's vaporizer system from an aqueous ammonia storage tank that already existed at the site before implementing the ULSD Project, so no new storage tank was required. In addition, no physical modifications were required to the existing storage tank. The annual throughput of the existing aqueous ammonia tank increased slightly, but this did not cause an increase in emissions because the tank is pressurized with a vapor balanced system for filling. A back-up supply consisting of two 150-pound cylinders of anhydrous ammonia was installed as part of the aqueous ammonia vaporization skid at heater B-401. This back-up ammonia supply is manually activated only if the normal aqueous ammonia supply fails. The back-up ammonia cylinders require re-inspection under Department of Transportation requirements every ten years; therefore, the ammonia cylinders are replaced at least every ten years.

Anhydrous ammonia cylinders are also used as an emergency backup ammonia supply on other existing SCR Units at the Wilmington Plant. The anhydrous ammonia cylinders are supplied by a local company that supplies a variety of products to the Refinery, including ammonia and other products. The company makes weekly deliveries to the Wilmington Plant.

Cooling Tower

The existing cooling tower E-221 was demolished and replaced with a new cooling tower of the same capacity as part of the ULSD Project, but at a different location at the Refinery, which was analyzed in the 2004 Final Negative Declaration. Demolishing existing cooling tower E-221 and relocating the new cooling tower was also necessary to make room for the new reactors and charge heater.

Mid Barrel Handling and Shipping Modifications

Before implementing the ULSD Project, common pipeline facilities were used to transport jet and diesel fuels from the Wilmington Plant to the Phillips 66 Torrance Tank Farm (an existing tank farm in Torrance used to distribute finished product). The sulfur content of jet fuel is much higher than that of ULSD. Improved handling and shipping modifications were needed so that ULSD would not be contaminated with higher sulfur jet fuel, which could cause ULSD to exceed the 15 ppmw sulfur limit.

Modifications to Mid-barrel handling and shipping at the Wilmington Plant improved segregation of ULSD and jet fuel and were analyzed in the 2004 Final Negative Declaration. These modifications included a new ULSD shipping pump (the existing pump that previously shipped both diesel and jet fuel continues to be used to ship jet fuel); two new pumps for handling jet and diesel blendstocks; one new sample pump and associated piping to create separate facilities for handling jet and diesel fuel. The ULSD Project did not change the total combined quantity of diesel and jet fuel handled. Therefore, while there is a new shipping pump to handle the ULSD, there has been a corresponding reduction in use of the existing pump, which no longer is used to ship diesel.

Hydrogen System

The 2004 Final Negative Declaration included an analysis of changes to the hydrogen distribution piping which enabled the exclusive use of high purity hydrogen at Unit 90 for maximizing hydrogen partial pressure at the reactor inlet. New piping was installed to properly distribute reformer hydrogen to other refinery processes not requiring continuous use of high purity hydrogen.

Storage Tank Modifications

As part of the ULSD Project, the service (contents) of Storage Tank 331 at the Wilmington Plant was changed to jet/diesel, which was analyzed in the 2004 Final Negative Declaration. Tank 331 is an existing storage tank that had been empty for more than two years before implementing the ULSD Project. Tank 331 had been permitted previously by the SCAQMD, and the permit allowed storage of jet/diesel; therefore, no physical or permit modifications were required for this tank.

Crude Unit DU-5 at the Carson Plant

The Carson Plant processes straightrun diesel or heavy gas oil feed in the Unit 90, which contains sulfur species that are some of the most difficult to hydrotreat. To reduce sulfur content in the feed and maintain a desirable catalyst life, the crude column needed to be capable of controlling the temperature between 650 and 700°F. The ULSD Project included the installation of temperature monitoring equipment (thermocouples) and flow control valves in order to improve crude distillation operations and minimize the high sulfur portion of the distilled crude routed to Unit 90. This allowed the crude column to be operated on advanced computer control within the existing Crude Unit throughput capacity rate.

The 2004 Final Negative Declaration ULSD Project included an analysis of the physical modifications associated with the changes at the Carson Plant, which were concluded to be very minor. No major construction activities were required and these changes were incorporated into a normally scheduled refinery turnaround (i.e., refinery shutdown for routine maintenance) or into regular, ongoing maintenance activities. Maintenance workers performed the minor installation of pre-manufactured equipment (thermocouples and modify existing control valves) that were required to the unit. These changes did not result in physical impacts to any environmental topic identified in the environmental checklist in Chapter 2 of the 2004 Final Negative Declaration, so the environmental evaluation in this EIR is limited to the Wilmington Plant (CEQA Guidelines §15064(d)(1)).

2.7 CONSTRUCTION OF THE PROJECT

The construction schedule for ULSD project at the Wilmington Plant took place from approximately third quarter of 2005 and was completed in April 2006. Because the construction activities have already occurred and the court decision was based on operational air quality impacts, no further discussion of construction is warranted or necessary.

2.8 OPERATION OF THE PROJECT

The ULSD construction period concluded in April 2006 and the ULSD refinery modifications have been operating since that time. The ULSD project did not result in an increase in the permanent work force at the Refinery, and incrementally increased truck traffic at the Wilmington Plant only by a maximum of one truck per day of 30 percent aqueous ammonia. Additional truck trips associated with catalyst replacement are infrequent (e.g., once every 2-3 years for Unit 90 catalyst and once every 5-10 years for SCR catalyst). For the peak day operations, it was assumed that one ammonia truck and four catalyst trucks would be required.

2.9 PERMITS AND APPROVALS

The ULSD project required permits to construct/operate from the SCAQMD and building permits from the City of Los Angeles.

CHAPTER 3

ENVIRONMENTAL SETTING, IMPACTS AND MITIGATION MEASURES

Introduction
Air Quality

3.0 ENVIRONMENTAL SETTING, IMPACTS AND MITIGATION MEASURES

3.1 INTRODUCTION

The California Supreme Court decision invalidated the baseline used in the air quality impacts analysis for project operations, but did not invalidate any other aspect of the prior CEQA documents, including the conclusions that the ULSD Project would not significantly adversely affect any non-air quality environmental topics.

In particular, the California Supreme Court concluded that the environmental impacts of a proposed project must be compared to the environmental conditions that exist at the time the CEQA analysis is commenced, not the level of development or activity that would be allowed under existing permits or approvals not previously evaluated in a CEQA analysis. The Supreme Court left to the discretion of the SCAQMD the methodology for estimating the "actual existing levels of emissions" from the utility equipment, recognizing that refinery operations are highly complex and that these operations, including the steam generation, vary greatly with the season, crude oil supplies, market conditions and other factors. The Supreme Court concluded that "(w)hatever method the District uses, however, the comparison must be between existing physical conditions without the Diesel Project and the conditions expected to be produced by the project."

Other aspects of the prior CEQA documents were challenged in the litigation, but those challenges were rejected by the trial court, and the trial court's rulings were upheld on appeal. Therefore, the Draft EIR for the Phillips 66 ULSD Project focuses on the issues as directed by the court and is limited to establishing the air quality setting, i.e., baseline, and air quality impacts from project operations. The analysis of construction emissions is not affected by the decision on environmental baseline. Construction emissions were part of the litigation and the courts determined that the analysis was adequate. Therefore, no further construction emission analysis is required. Further, construction emissions do not impact air quality operational impacts because they occur sequentially and the ULSD Project construction emissions did not overlap with the ULSD operational emissions. The current air quality setting, air quality impacts from operations, and mitigation measures for the ULSD project operations are presented and evaluated in this Chapter.

Environmental review for the ULSD project began in early January 2004, when the 2004 Negative Declaration was prepared, published, and approved. Construction of the project began in 2005 and was completed in 2006. The ULSD project went through start-up and de-bugging procedures in April 2006 and was fully operational starting in May 2006. The 2002-2003 time period is considered to be the pre-ULSD Project or baseline conditions for Refinery operations as this represents the timeframe during the environmental analysis development for the ULSD Project and was prior to the construction and operation of the ULSD Project. This approach is consistent with CEQA Guidelines §15125, which indicates that an EIR must include a description of the physical environmental conditions in the vicinity of the project as they exist at the time the notice of preparation is published, or if no notice of preparation is published, at the time environmental analysis is commenced.

Because the ULSD Project went through start-up and de-bugging procedures in April 2006, the "post-project" period is considered to be May 2006 and thereafter. For the purposes of evaluating air quality impacts from the ULSD Project, the "post-project" period for the ULSD project is May 2006 through April 2008. This period length was selected in order to compare an equivalent period of time, two years of operation to the baseline conditions, which were developed using two years (2002 – 2003) of historical data. Where available data did not precisely match these pre- and post-project periods, the impact analysis relies on the best available match.

3.2 AIR QUALITY SETTING

3.2.1 WEATHER CONDITIONS

The Phillips 66 Los Angeles Refinery is located within the SCAQMD jurisdiction (referred to hereafter as the district). The district consists of the four-county South Coast Air Basin (Basin), that includes Orange, and the non-desert portions of Los Angles, Riverside, and San Bernardino counties, the Riverside County portions of the Salton Sea Air Basin (SSAB), and the Mojave Desert Air Basin (MDAB). The Basin is bounded by the Pacific Ocean to the west and the San Gabriel, San Bernardino, and San Jacinto mountain ranges to the north and east. The following subsections summarize general weather conditions in the Basin.

3.2.1.1 Meteorological Conditions

The climate in the Basin generally is characterized by sparse winter rainfall and hot summers tempered by cool ocean breezes. A temperature inversion, a warm layer of air that traps the cool marine air layer underneath it and prevents vertical mixing, is the prime factor that allows contaminants to accumulate in the Basin. The mild climatological pattern is interrupted infrequently by periods of extremely hot weather, winter storms, and Santa Ana winds. The climate of the area is not unique, but the high concentration of mobile and stationary sources of air contaminants in the western portion of the Basin, in addition to the mountains, which surround the perimeter of the Basin, contribute to poor air quality in the region.

3.2.1.2 Temperature and Rainfall

Temperature affects the air quality of the region in several ways. Local winds are the result of temperature differences between the relatively stable ocean air and the uneven heating and cooling that takes place in the Basin due to a wide variation in topography. Temperature also has a major effect on vertical mixing height and affects chemical and photochemical reaction times. The annual average temperatures vary little throughout the

Basin, averaging 75°F. The coastal areas show little variation in temperature on a year round basis due to the moderating effect of the marine influence. On average, August is the warmest month while January is the coolest month. Most of the annual rainfall in the Basin falls between November and April. Annual average rainfall varies from nine inches in Riverside to 14 inches in downtown Los Angeles.

3.2.1.3 Wind Flow Patterns

Wind flow patterns play an important role in the transport of air pollutants in the Basin. The winds flow from offshore and blow eastward during the daytime hours. In summer, the sea breeze starts in mid-morning, peaks at 10-15 miles per hour, and subsides after sundown. There is a calm period until about midnight. At that time, the land breeze begins from the northwest, typically becoming calm again about sunrise. In winter, the same general wind flow patterns exist except that summer wind speeds average slightly higher than winter wind speeds. This pattern of low wind speeds is a major factor that allows the pollutants to accumulate in the Basin.

The normal wind patterns in the Basin are interrupted by the unstable air accompanying the passing storms during the winter and infrequent strong northeasterly Santa Ana wind flows from the mountains and deserts north of the Basin.

3.2.2 EXISTING AIR QUALITY

Local air quality in the Basin is monitored by the SCAQMD, which operates a network of monitoring stations throughout the Basin. CARB operates additional monitoring stations.

3.2.2.1 Criteria Pollutants

The sources of air contaminants in the Basin vary by pollutant but generally include on-road mobile sources (e.g., automobiles, trucks and buses), other off-road mobile sources (e.g., airplanes, ships, trains, construction equipment, etc.), stationary sources (e.g., fuel combustion, petroleum production and marketing, and other industrial processes), and solvent evaporation (e.g., consumer products and architectural coatings). Mobile sources are responsible for a large portion of the total Basin emissions of several pollutants (SCAQMD, 2012b)

Criteria air pollutants are those pollutants for which the federal and state governments have established ambient air quality standards or criteria for outdoor concentrations in order to protect public health with a margin of safety. The current health-based federal and state ambient air quality standards are shown in Table 3-1. (Note that the following ambient air quality standards have changed since the 2002-2003 timeframe: state 1-hour NO_2 standard, federal one-hour SO_2 standard, and the state and federal PM2.5 standards.) National Ambient Air Quality Standards (NAAQS) were first authorized by the federal Clean Air Act (CAA) of 1970 and were promulgated by the U.S. EPA in 1971. California Ambient Air Quality Standards were authorized by the state legislature in 1967 and promulgated by CARB in 1969. Air quality of a region is considered to be in attainment of the standards if the measured concentrations of air pollutants are continuously equal to or less than the air quality standards over the previous three-year period.

TABLE 3.1-1

Ambient Air Quality Standards

Air Pollutant	State Standard Concentration/ Averaging Time	Federal Primary Standard Concentration/ Averaging Time	Most Relevant Effects
Ozone	0.09 ppm (180 ug/m^3), 1-hr. avg. 0.070 ppm (137 ug/m^3), 8-hr	0.075 ppm (147 ug/m^3), 8-hr avg.	(a) Short-term exposures: (1) Pulmonary function decrements and localized lung edema (2) Risk to public health implied by alterations in pulmonary morphology and host defense in animals; (b) Long-term exposures: Risk to public health implied by altered connective tissue metabolism and pulmonary morphology in animals after long-term exposures and pulmonary function decrements in chronically exposed humans; (c) Vegetation damage; (d) Property damage
Carbon Monoxide	20 ppm (23 mg/m^3), 1-hr avg. 9.0 ppm (10 mg/m^3), 8-hr avg.	35 ppm (40 mg/m^3), 1-hr avg. 9 ppm (10 mg/m^3), 8-hr avg.	(a) Aggravation of angina pectoris and other coronary heart disease; (b) Decreased exercise tolerance in persons with vascular disease and lung disease; (c) Impairment of central nervous system functions; (d) Possible increased risk to fetuses
Nitrogen Dioxide	0.18 ppm (339 ug/m^3), 1-hr avg. 0.03 ppm (57 ug/m^3), ann. avg.	0.100 ppm (188 ug/m^3), 1-hr avg.(1) 0.053 ppm (100 ug/m^3), ann. avg.	(a) Potential to aggravate chronic respiratory disease and respiratory symptoms in sensitive groups; (b) Risk to public health implied by pulmonary and extra-pulmonary biochemical and cellular changes and pulmonary structural changes; (c) Contribution to atmospheric discoloration
Sulfur Dioxide	0.25 ppm (655 ug/m^3), 1-hr. avg. 0.04 ppm (105 ug/m^3), 24-hr avg.	75 ppb (196 ug/m^3), 1-hr avg.(2) 0.5 ppm, 3-hr avg. (secondary)	Bronchoconstriction accompanied by symptoms which may include wheezing, shortness of breath and chest tightness, during exercise or physical activity in persons with asthma
Suspended Particulate Matter (PM10)	50 µg/ m^3, 24-hr avg. 20 µg/m^3, ann. arithmetic mean	150 µg/ m^3, 24-hr avg.	(a) Excess deaths from short-term exposures and exacerbation of symptoms in sensitive patients with respiratory disease; (b) Excess seasonal declines in pulmonary function in children
Suspended Particulate Matter (PM2.5)	12 µg/ m^3, ann. Arithmetic mean	35 µg/ m^3, 24-hr avg. 15.0 µg/ m^3, annual arithmetic mean	Decreased lung function from exposures and exacerbation of symptoms in sensitive patients with respiratory disease; elderly; children.
Sulfates	25 µg/ m^3, 24-hr avg.	Not Federal Standard	(a) Decrease in ventilatory function; (b) Aggravation of asthmatic symptoms; (c) Aggravation of cardio-pulmonary disease; (d) Vegetation damage; (e) Degradation of visibility; (f) Property damage
Lead	1.5 µg/ m^3, 30-day avg.	1.5 µg/ m^3, calendar quarter 0.15 µg/ m^3, rolling 3-month avg.	(a) Increased body burden; (b) Impairment of blood formation and nerve conduction
Visibility-Reducing Particles	In sufficient amount to give an extinction coefficient >0.23 inverse kilometers (visual range to less than 10 miles) with relative humidity less than 70%, 8-hour average (10am – 6pm PST)	Not Federal Standard	Nephelometry and AISI Tape Sampler; instrumental measurement on days when relative humidity is less than 70 percent
Hydrogen Sulfide	0.03 ppm (42 ug/m^3), 1-hr avg.	Not Federal Standard	Breathing H2S at levels above the standard will result in exposure to a very disagreeable odor.
Vinyl Chloride	0.01 ppm (26 ug/m^3), 24-hour avg.	Not Federal Standard	Short-term exposure to high levels of vinyl chloride in air causes central nervous system effects, such as dizziness, drowsiness, and headaches. Long-term exposure to vinyl chloride through inhalation and oral exposure causes in liver damage. Cancer is a major concern from exposure to vinyl chloride via inhalation. Vinyl chloride exposure has been shown to increase the risk of angiosarcoma, a rare form of liver cancer in humans.

Footnotes:

(1) To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average at each monitor within an area must not exceed 0.100 ppm. The U.S. EPA established a new 1-hour NO$_2$ standard effective April 7, 2010.

(2) Based on the 3-year average of the 99th percentile of the 1-hour daily maximum concentrations. The U.S. EPA revised the SO2 federal standard by establishing the new 1-hour standard of 75 ppb and revoking the existing annual (0.03 ppm) and 24-hour (0.14 ppm) standards, effective August 2, 2010.

Health-based air quality standards have been established by the U.S. EPA and the CARB for ozone, CO, NO_2, PM10, PM2.5, SO_2, and lead. The California standards are generally more stringent than the federal air quality standards. California also has established standards for sulfate, visibility, hydrogen sulfide, and vinyl chloride. Hydrogen sulfide and vinyl chloride currently are not monitored in the Basin because they are not a regional air quality problem, but are generally associated with localized emission sources. In addition, vinyl chloride emissions have been associated primarily with sources such as landfills. Because landfills in the district are subject to SCAQMD Rule 1150.1, which contains stringent requirements for landfill gas collection and control, potentially vinyl chloride emissions are below the level of detection. The Basin, including the project area, is classified as attainment for both the state and federal standards for CO, NO_2, SO_2, sulfates, and lead and the state standard for sulfates. The Basin is currently designated as non-attainment for PM2.5 and ozone for both state and federal standards. The Basin has met the federal 24 hour PM10 standard and U.S. EPA has proposed approval of the attainment.

3.2.2.2 Air Quality Management Plans

When the ULSD Project was proposed and implemented, the SCAQMD was promulgating rules and regulations identified as control measures in the 2003 AQMP. Subsequently, the SCAQMD adopted the 2007 AQMP and promulgated rules and regulations identified as control measures in that Plan. As a result of implementing AQMP control measures as rules or regulations, there have been substantial improvements in air quality since 2004 when the ULSD Project originally underwent an environmental analysis pursuant to CEQA. In December 2012, the SCAQMD adopted the 2012 AQMP and has already begun the process of promulgating rules to demonstrate attainment of the federal 24-hour PM2.5 standard. The main components of these three AQMPs are summarized in the following subsections.

3.2.2.2.1 SCAQMD 2003 AQMP

The 2003 AQMP was approved and adopted by the SCAQMD in August 2003. The 2003 AQMP was never fully approved by the U.S. EPA as part of the State Implementation Plan (SIP). The 2003 AQMP was initially partially approved and partially disapproved by EPA. The 2003 AQMP addressed the following control strategies:

- Attain the federal PM10 ambient air quality standard for the South Coast Air Basin and Coachella Valley - these portions were approved by the U.S. EPA; in both areas, the ozone attainment demonstration was disapproved after the CARB withdrew its measures;
- Attain the federal one-hour ozone standard;

- Implement remaining 1997/1999 control measures not yet implemented;
- Revise the Post-1996 VOC Rate-of-Progress Plan and SIP for CO;
- Because U.S. EPA was in the process of adopting ambient air quality standards for PM2.5, include an initial analysis of emission reductions necessary to attain the PM2.5 and eight-hour ozone standards; etc.; and

In addition to the above strategies, as required by CARB, emissions inventories developed for the 2003 AQMP used 1997 as the base year. Future projected emissions incorporate rules and regulations adopted by U.S. EPA, CARB and SCAQMD from 1997 to October 2002. Information necessary to produce an emission inventory for the Basin is obtained from the SCAQMD and other governmental agencies including: CARB, California Department of Transportation (CalTrans), and SCAG. The inventories only include anthropogenic sources (i.e., those associated with human activity) (SCAQMD, 2003).

The 2003 AQMP revisions to the SCAQMD's CO Plan also served two purposes: it replaced the 1997 attainment demonstration and it provided the basis for a CO maintenance plan in the future.

3.2.2.2.2 SCAQMD 2007 AQMP

The SCAQMD Governing Board approved the 2007 AQMP on June 1, 2007. On September 27, 2007, CARB adopted the State Strategy for the 2007 State Implementation Plan and the 2007 South Coast Air Quality Management Plan as part of the SIP. The 2007 SIP was then forwarded to U.S. EPA for approval. The following summarize the major components of the 2007 AQMP:

- The most current air quality setting (e.g., 2005 data);
- Updated emission inventories using 2002 as the base year, which also incorporate measures adopted since adopting the 2003 AQMP;
- Updated emission inventories of stationary and mobile on-road and off-road sources;
- 2003 AQMP control measures not yet implemented (eight of the control measures originally contained in the 2003 AQMP were updated or revised for inclusion into the Draft 2007 AQMP);
- 24 new measures were incorporated into the 2007 AQMP based on replacing the SCAQMD's long-term control measures from the 2003 AQMP with more defined or new control measures and control measure adoption and implementation schedules;
- CARB's recommended control measures aimed at reducing emissions from sources that are primarily under State and federal jurisdiction, including on-road and off-road mobile sources, and consumer products;
- SCAG's regional transportation strategy and control measures; and

- Analysis of emission reductions necessary and attainment demonstrations to achieve the federal eight-hour ozone and PM2.5 air quality standards.

On November 22, 2010, U.S. EPA issued a notice of proposed partial approval and partial disapproval of the 2007 South Coast SIP for the 1997 Fine Particulate Matter Standards and the corresponding 2007 State Strategy. Specifically, U.S. EPA proposed approving the SIP's inventory and regional modeling analyses, but it also proposed disapproving the attainment demonstration because it relied too extensively on commitments to emission reductions in lieu of fully adopted, submitted, and SIP-approved rules. The notice also cited deficiencies in the SIP's contingency measures.

3.2.2.2.3 SCAQMD 2012 AQMP

The 2012 AQMP provides an updated air pollution control strategy to attain the 24-hour PM2.5 federal ambient air quality standard and to partially fulfill the 2007 AQMP Clean Air Act §182 (e)(5) reduction commitment. It was been developed as an integrated Plan taking into consideration: air quality, climate change, transportation, and energy needs. The 2012 AQMP focused on PM reductions to attain the federal 24-hour PM2.5 standard by 2014. The 2012 AQMP also includes ozone reduction strategies to make expeditious progress in attaining the state one-hour and eight-hour ozone standards and the federal eight-hour ozone standards (80 parts per billion (ppb) by 2023 and 75 ppb by 2032). The 2012 AQMP provides the strategy to meet the (revoked) one-hour federal ozone standard (by 2022). In particular, the ozone strategy approach relies heavily on NOx emission reductions, primarily from mobile sources, and identifies actions that can be taken in the next two to three years. The 2012 AQMP relies upon the most recent planning assumptions and the best available information such as CARB's latest EMFAC2011 for the on-road mobile source emissions inventory, CARB's OFF-ROAD 2011 model for the off-road mobile source emission inventory, the latest point source and improved area source inventories as well as the use of new episodes and air quality modeling analysis, and SCAG's forecast assumptions based on its recent 2012 Regional Transportation Plan. The 2012 AQMP includes the current and future air quality in the Coachella Valley. The 2012 AQMP also includes a discussion of ultra-fine particles, near roadway exposure and energy.

Based upon the modeling analysis described in the Program Environmental Impact Report for the 2012 AQMP, implementation of all control measures contained in the 2012 AQMP is anticipated to bring the district into compliance with the federal eight-hour ozone standard by 2023 and the state eight-hour ozone standard beyond 2023 (SCAQMD, 2012b).

3.2.2.3 Local Air Quality

The project site is located within the SCAQMD's South Coastal Los Angeles County monitoring area. Recent background air quality data for criteria pollutants for the South Coast Los Angeles County 1 Monitoring Station No. 072 is presented in Table 3.1-2. The area has shown a general improvement in air quality with decreasing or consistent concentrations of most pollutants (see Table 3.1-2). Air quality in the South Coastal Los Angeles County monitoring area complies with the state and federal ambient air quality standards for CO, NO_2, SO_2, lead, and sulfate.

TABLE 3.1-2

South Coastal Los Angeles County 1 Monitoring Station No. 072 (2001-2012) Maximum Observed Concentrations

Constituent		2001	2002	2003	2004	2005	2006
Ozone:	1-Hour (ppm)	0.091	0.084	0.099	0.090	0.126	0.17
	Days Exceeding Federal Standard	(0)	(0)	(0)	(0)	(1)	(12)
	Days Exceeding State Standard	(0)	(0)	(1)	(0)	(11)	(76)
	8-Hour (ppm)	0.070	0.065	0.071	0.075	0.103	0.122
	Days Exceeding Federal Standard	(0)	(0)	(0)	(0)	(3)	(53)
	Days Exceeding State Standard					(18)	(84)
Carbon Monoxide$^{a)}$:							
	1-Hour (ppm)	6	6	6	4	3	3
	8-Hour (ppm)	4.71	4.6	4.7	3.4	2.5	2.1
Nitrogen Dioxide$^{b)}$:							
	1-Hour (ppm)	0.13	0.13	0.14*	0.12	0.08	0.08
	Annual (ppm)	0.0308	0.0298	0.0288*	0.0280	0.0222	0.0199
PM10:	24-Hour$^{d,g)}$ (μg/m^3)	91	74	63	72	80	125
	Percent of Samples Exceeding Federal Standard	(0)	(0)	(0)	(0)	(0)	(0)
	Percent of Samples Exceeding State Standard	(17%)	(8.6%)	(6.6%)	(6.7%)	(31.7%)	(35.2%)
	Annual (μg/m^3)					39.2	45.0
	Geometric	34.8	34.1	(--)	(--)	--	68.5
	Arithmetic	37.4	35.9	32.8	33.	--	(0.3%)
PM2.5:	24-Hour$^{f,g)}$ (μg/m^3)	72.9	62.7	35.0	66.6	98.7	19.0
	Percent of Samples Exceeding Federal Standard	(0.3%)	(0%)	(0%)	(0.3%)	(1.2%)	
	Annual Arithmetic Mean (μg/m^3)	21.4	19.5	10.5	17.6	21.0	0.01
Sulfur Dioxide$^{c)}$:							
	1-Hour (ppm)	0.05	0.03	0.04	0.04	0.02	0.0013
	24-Hour (ppm)	0.012	0.008	0.006	0.012	0.011	0.01
	Annual Arithmetic Mean (ppm)	(--)	(--)	(--)	(--)	(--)	0.01
Lead$^{h)}$:	30-Day (μg/m^3)	0.05	0.03	0.10	0.02	0.02	10.8
	Quarter (μg/m^3)	0.04	0.02	0.05	0.01	0.02	(0%)
Sulfate$^{i)}$:	24-Hour (μg/m^3)	15.9	17.8	17.8	15.9	10.3	0.17
	State Standard	(0%)	(0%)	(0%)	(0%)	(0%)	(12)

Source: SCAQMD Air Quality Data Annual Summaries 2001-2012.

Notes: (%) = Percent of samples exceeding the federal or state standard, (--) = Pollutant not monitored, ppm = parts per million of air by volume, AAA = Annual Arithmetic Mean, μg/m^3 = micrograms per cubic meter. -- = Pollutant not monitored, * = Less than 12 months of data

TABLE 3.1-2 (cont.)

Constituent		2007	2008	2009	2010	2011	2012
Ozone:	1-Hour (ppm)	0.139	0.142	0.089	0.101	0.073	0.084
	Days Exceeding Federal Standard	(4)	(4)	(0)		(0)	(0)
	Days Exceeding State Standard	(66)	(65)	(0)	(1)	(0)	(0)
	8-Hour (ppm)	0.116	0.114	0.068	0.084	0.061	0.067
	Days Exceeding Federal Standard	(37)	(41)	(0)	(1)	(0)	(0)
	Days Exceeding State Standard	(88)	(94)	(0)	(1)	(0)	(0)
Carbon Monoxide [a]:							
	1-Hour (ppm)	4	3	3	3	--	--
	8-Hour (ppm)	2.9	2.0	2.2	2.1	2.6	2.2
Nitrogen Dioxide [b]:							
	1-Hour (ppm)	0.07	0.09	0.11	0.093*	0.106	0.077*
	Annual (ppm)	0.0206	0.0192	0.021	0.020*	0.018	0.021*
PM10 [d]:	24-Hour ($\mu g/m^3$)	120	115	62	44	43	45
	Percent of Samples Exceeding Federal Standard	(0)	(0)	(0)	(0)	(0)	(0)
	Percent of Samples Exceeding State Standard	(54%)	(41%)	(5.3%)[(b)]	(0%)	(0%)	(0%)
	Annual [e] ($\mu g/m^3$) (arithmetic mean)	54.8	46.6	30.5	22.0	24.2	23.3
PM2.5 [f]:	24-Hour ($\mu g/m^3$)	75.7	57.7	63.4	35.0	39.7	49.8
	Percent of Samples Exceeding Federal Standard	(1.0%)	(4.0%)	(1.6%)[(c)]	(0%)	(0.3%)	(1.1%)
	Annual Arithmetic Mean ($\mu g/m^3$)	19.1	16.4	13.0	10.5	11.0	10.4
Sulfur Dioxide [c]:							
	1-Hour (ppm)	0.02	0.01	0.02	.040*	0.015	0.022*
	24-Hour (ppm)	0.002	0.003	0.005	0.006*	0.011	0.014*
	Annual Arithmetic Mean (ppm)	0.0017	0.0009	(--)	(--)	(--)	(--)
Lead [h]:	30-Day ($\mu g/m^3$)	0.02	0.01	0.00	0.00	0.010	0.005
	Quarter ($\mu g/m^3$)	0.01	0.01	0.00	0.00	0.007	0.005
Sulfate [i]:	24-Hour ($\mu g/m^3$)	12.0	9.1	13.6	11.8	6.1	5.2
	State Standard	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)

Source: SCAQMD Air Quality Data Annual Summaries 2001-2012.

Notes: (%) = Percent of samples exceeding the federal or state standard, (--) = Pollutant not monitored, ppm = parts per million of air by volume, AAA = Annual Arithmetic Mean, $\mu g/m^3$ = micrograms per cubic meter. -- = Pollutant not monitored, * = Less than 12 months of data

a) - The federal 8-hour standard (8-hour average CO > 9 ppm) and state 8-hour standard (8-hour average CO > 9.0 ppm) were not exceeded. The federal and state 1-hour standards (35 ppm and 20 ppm) were not exceeded either.

b) - The NO_2 federal 1-hour standard is 100 ppb and the annual standard is annual arithmetic mean $NO_2 > 0.0534$ ppm (53.4 ppb). The state 1-hour and annual standards are
0.18 ppm (180 ppb) and 0.030 ppm (30 ppb).

c) - The federal SO_2 1-hour standard is 75 ppb (0.075 ppm). The state standards are 1-hour average $SO_2 > 0.25$ ppm (250 ppb) and 24-hour average $SO_2 > 0.04$ ppm (40 ppb).

d) - Federal Reference Method (FRM) PM10 samples were collected every 6 days at all sites except for Stations 4144 and 4157, where samples were collected every 3 days. PM10 statistics listed above are for the FRM data only. Federal Equivalent Method (FEM) PM10 continuous monitors were operated at some of the above locations. Max 24-hour average PM10 at sites with FEM

monitoring was 142 μg/m^3 , at Palm Springs in Coachella Valley. The FEM Basin's max was 104 μg/m^3 at Mira Loma.
e) - Federal annual PM10 standard (AAM > 50 μg/m^3) was revoked in 2006. State standard is annual average (AAM) > 20 μg/m^3
f) - PM2.5 samples were collected every 3 days at all sites except for station numbers 069, 072, 077, 087, 3176, 4144 and 4165, where samples were taken daily, and station number 5818 where samples were taken every 6 days. PM2.5 statistics listed above are for the FRM data only. FEM PM2.5 continuous monitoring instruments were operated at some of the above locations. Max 24-hour average PM2.5 concentration recorded at FEM sites was 79.0 μg/m^3 at Central LA. U.S. EPA has revised the annual PM2.5 standard from annual average (AAM) 15.0 μg/m^3 to 12.0 μg/m^3, effective March 18, 2013. State standard is annual average (AAM) > 12.0 μg/m^3.
g) - High PM10 and PM2.5 data samples excluded in accordance with the EPA Exceptional Event Regulation are as follows: PM10 (FEM) data recorded on August 9 (270 μg/m^3) and January 21 (207 μg/m^3) both at Indio; PM2.5 (FRM) at Azusa (39.6 μg/m^3) and Fontana (39.9 μg/m^3), both recorded on July 5.
h) – Federal lead standard is 3-months rolling average > 0.15 μg/m^3; state standard is monthly average ≥1.5 μg/m^3. Lead statistics listed above are for population-oriented sites only; standards were not exceeded at any of these sites.
i) – State sulfate standard is 24-hour ≥25 μg/m^3. There is no federal standard for sulfate.

The air quality in the area also is in compliance with the federal eight-hour ozone standard, the federal 24-hour PM10 standard, and the federal 24-hour and annual average PM2.5 standards. The air quality in the South Coast Los Angeles County area is not in compliance with the state 24-hour PM10 and PM2.5 standards (SCAQMD, 2012a).

3.2.2.4 Air Quality Monitoring

This section provides an overview of air quality in the district. It is the responsibility of the SCAQMD to ensure that state and federal ambient air quality standards are achieved and maintained in its geographical jurisdiction. Health-based air quality standards have been established by California and the federal government for the following criteria air pollutants: ozone, CO, NO_2, PM10, PM2.5, SO2, lead, and sulfate. These standards were established to protect sensitive receptors with a margin of safety from adverse health impacts due to exposure to air pollution. The California standards are more stringent than the federal standards and in the case of PM10 and SO2. California has also established standards for sulfates, visibility reducing particles, hydrogen sulfide, and vinyl chloride. The state and national ambient air quality standards for each of these pollutants and their effects on health are summarized in Table 3.1-1. The SCAQMD monitors levels of various criteria pollutants at 34 monitoring stations. The 2001-2012 air quality data from SCAQMD's monitoring stations are presented in Table 3.1-2.

3.2.2.4.1 Carbon Monoxide

CO is a colorless, odorless, relatively inert gas. It is a trace constituent in the unpolluted troposphere, and is produced by both natural processes and human activities. In remote areas far from human habitation, carbon monoxide occurs in the atmosphere at an average background concentration of 0.04 ppm, primarily as a result of natural processes such as forest fires and the oxidation of methane. Global atmospheric mixing of CO from urban and industrial sources creates higher background concentrations (up to 0.20 ppm) near urban areas. The major source of CO in urban areas is incomplete combustion of carbon-containing fuels, mainly gasoline.

CO is a primary pollutant, meaning that it is directly emitted into the air, not formed in the atmosphere by chemical reaction of precursors, as is the case with ozone and other secondary pollutants. Ambient concentrations of CO in the Basin exhibit large spatial and temporal variations due to variations in the rate at which CO is emitted and in the meteorological conditions that govern transport and dilution. Unlike ozone, CO tends to reach high concentrations in the fall and winter months. The highest concentrations frequently occur on weekdays at times consistent with rush hour traffic and late night during the coolest, most stable portion of the day.

In 2003, the SCAQMD monitored levels of various criteria pollutants at 32 monitoring stations. The Basin has technically met the CO standards since 2002. No exceedances of the CO standards occurred in 2004 and in 2005, CO concentrations did not exceed the standards anywhere in the Basin for the third consecutive year. As a result, in 2004, the SCAQMD formally requested the U.S. EPA to re-designate the Basin from non-attainment to attainment with the CO National Ambient Air Quality Standards. On February 24, 2007, U.S. EPA published in the Federal Register its proposed decision to re-designate the Basin from non-attainment to attainment for CO. The comment period on the re-designation proposal closed on March 16, 2007 with no comments received by the U.S. EPA. On May 11, 2007, U.S. EPA published in the Federal Register its final decision to approve the SCAQMD's request for re-designation from non-attainment to attainment for CO, effective June 11, 2007.

More recently, carbon monoxide concentrations were measured at 26 locations in the Basin and neighboring SSAB areas in 2012. Carbon monoxide concentrations did not exceed the standards between 2008 and 2012. The highest eight-hour average carbon monoxide concentration recorded (4.7 ppm in the South Central Los Angeles County area in 2011) was 52 percent of the federal eight-hour carbon monoxide standard of 9.0 ppm.

CO Health Effects: Individuals with a deficient blood supply to the heart are the most susceptible to the adverse effects of CO exposure. The effects observed include earlier onset of chest pain with exercise, and electrocardiograph changes indicative of worsening oxygen supply to the heart. Inhaled CO has no direct toxic effect on the lungs, but exerts its effect on tissues by interfering with oxygen transport by competing with oxygen to combine with hemoglobin present in the blood to form carboxyhemoglobin (COHb). Hence, conditions with an increased demand for oxygen supply can be adversely affected by exposure to CO. Individuals most at risk include patients with diseases involving heart and blood vessels, fetuses (unborn babies), and patients with chronic hypoxemia (oxygen deficiency) as seen in high altitudes.

Reductions in birth weight and impaired neurobehavioral development have been observed in animals chronically exposed to CO resulting in COHb levels similar to those observed in smokers. Recent studies have found increased risks for adverse birth outcomes with exposure to elevated CO levels. These include pre-term births and heart abnormalities.

3.2.2.4.2 Ozone

Ozone (O_3), a colorless gas with a sharp odor, is a highly reactive form of oxygen. Ozone is formed from atmospheric, photochemical reactions involving primarily NOx and VOCs, so it was not inventoried. High ozone concentrations exist naturally in the stratosphere. Some mixing of stratospheric ozone downward through the troposphere to the earth's surface does occur; however, the extent of ozone transport is limited. At the earth's surface in sites remote from urban areas ozone concentrations are normally very low (e.g., from 0.03 ppm to 0.05 ppm).

The district exceeded the federal health one-hour standard for ozone on 36 days in 2001, with maximum levels approximately 58 percent higher than the national ambient air quality standard. This represents the number of days a standard was exceeded anywhere in the district. In 2002, the district exceeded the federal health one-hour standard for ozone on 49 days, with maximum levels approximately 36 percent higher than the national ambient air quality standard (SCAQMD, 2003).

In 2005, the District regularly monitored ozone concentrations at 29 locations in the Basin and the SSAB. All areas monitored were below the stage 1 episode level (0.20 ppm), but the maximum concentrations in the Basin exceeded the health advisory level (0.15 ppm). Maximum ozone concentrations in the SSAB areas monitored by the SCAQMD were lower than in the Basin and were below the health advisory level (SCAQMD, 2007). The one-hour federal standard was not exceeded in areas along or near the coast, due in large part to the prevailing sea breeze which transports polluted air inland before high ozone concentrations can be reached.

In 2005, the location in the nation most frequently exceeding the federal standard levels for ozone was within the Basin. Also, five of the ten locations in the nation that most frequently exceeded the eight-hour average federal ozone standard level were located in the district. In 2005, the Basin exceeded the federal standards for ozone on a total of 84 days at one or more locations; this compares to 119 days in 2003 and 90 days in 2004 (based on the existing eight-hour average federal standard for ozone at the time).

The standard was exceeded most frequently in the Central San Bernardino Mountains extending from Central San Bernardino Valleys through the Riverside-San Bernardino area in the east, and in the Santa Clarita Valleys in the west. The Central San Bernardino Mountains area recorded the greatest number of exceedances of the state standard (80 days), one-hour and eight-hour federal standards (18 days and 69 days, respectively) and health advisory level (seven days). Similarly, maximum one-hour and eight-hour average ozone concentrations (0.182 ppm and 0.145 ppm, both recorded in Central San Bernardino Mountains areas) were 146 and 171 percent of the federal standard, respectively.

In 2010, the SCAQMD regularly monitored ozone concentrations at 29 locations in the Basin and SSAB. Maximum ozone concentrations for all areas monitored were below the stage 1 episode level (0.20 ppm) and below the health advisory level (0.15 ppm).

Maximum ozone concentrations in the SSAB areas monitored by the SCAQMD were lower than in the Basin and were below the health advisory level. Specifically, maximum one-hour and eight-hour average ozone concentrations were 0.143 ppm and 0.123 ppm, respectively (the maximum one-hour was recorded in the Central San Bernardino Valley 1 area, the eight-hour maximum was recorded in the Central San Bernardino Mountains area). The federal one-hour ozone standard was revoked and replaced by the eight-hour average ozone standard effective June 15, 2005. U.S. EPA has revised the federal eight-hour ozone standard from 0.84 ppm to 0.075 ppm, effective May 27, 2008. The maximum eight-hour concentration was 164 percent of the new federal standard. The maximum one-hour concentration was 159 percent of the one-hour state ozone standard of 0.09 ppm. The maximum eight-hour concentration was 175 percent of the eight-hour state ozone standard of 0.070 ppm.

In 2012, the former federal one-hour ozone standard of 0.124ppm was exceeded on 12 days. The current federal eight-hour standard for ozone of 0.075ppm was exceeded 111 days in 2012. The areas where the federal standards were exceeded the most frequently are in San Bernardino County and Metropolitan Riverside County. The maximum one-hour and eight-hour average ozone concentrations were recorded in the East San Gabriel Valley (0.147ppm(one-hour)) and Santa Clarita Valley and San Bernardino Mountain (0.112ppm(eight-hour)). These maximum concentrations for ozone represent 118 and 149 percent of the former federal one-hour standard and current eight-hour federal standard respectively. The current state one-hour (0.09ppm) and eight-hour (0.07ppm) were exceeded on 98 and 138 days respectively.

Ozone Health Effects: While ozone is beneficial in the stratosphere because it filters out skin-cancer-causing ultraviolet radiation, it is a highly reactive oxidant. It is this reactivity which accounts for its damaging effects on materials, plants, and human health at the earth's surface.

The propensity of ozone for reacting with organic materials causes it to be damaging to living cells and ambient ozone concentrations in the Basin are frequently sufficient to cause health effects. Ozone enters the human body primarily through the respiratory tract and causes respiratory irritation and discomfort, makes breathing more difficult during exercise, and reduces the respiratory system's ability to remove inhaled particles and fight infection.

Individuals exercising outdoors, children and people with preexisting lung disease, such as asthma and chronic pulmonary lung disease, are considered to be the most susceptible subgroups for ozone effects. Short-term exposures (lasting for a few hours) to ozone at levels typically observed in southern California can result in breathing pattern changes, reduction of breathing capacity, increased susceptibility to infections, inflammation of the lung tissue, and some immunological changes. In recent years, a correlation between elevated ambient ozone levels and increases in daily hospital admission rates, as well as mortality, has also been reported. An increased risk for asthma has been found in children who participate in multiple sports and live in high ozone communities. Elevated ozone levels are also associated with increased school absences.

Ozone exposure under exercising conditions is known to increase the severity of the abovementioned observed responses. Animal studies suggest that exposures to a combination of pollutants which include ozone may be more toxic than exposure to ozone alone. Although lung volume and resistance changes observed after a single exposure diminish with repeated exposures, biochemical and cellular changes appear to persist, which can lead to subsequent lung structural changes.

3.2.2.4.3 Nitrogen Dioxide

NO_2 is a reddish-brown gas with a bleach-like odor. Nitric oxide (NO) is a colorless gas, formed from the nitrogen (N_2) and oxygen (O_2) in air under conditions of high temperature and pressure which are generally present during combustion of fuels; NO reacts rapidly with the oxygen in air to form NO_2. NO_2 is responsible for the brownish tinge of polluted air. The two gases, NO and NO_2, are referred to collectively as NOx. In the presence of sunlight, NO_2 reacts to form nitric oxide and an oxygen atom. The oxygen atom can react further to form ozone, via a complex series of chemical reactions involving hydrocarbons. Nitrogen dioxide may also react to form nitric acid (HNO_3) which reacts further to form nitrates, components of PM2.5 and PM10.

The Basin has not exceeded the federal standard for nitrogen dioxide (0.0534 ppm) since 1991, when the Los Angeles County portion of the Basin recorded the last exceedance of the standard in any county within the United States.

In 2010, nitrogen dioxide concentrations were monitored at 24 locations. No area of the Basin or SSAB exceeded the federal or state standards for nitrogen dioxide. In 2010, the maximum annual average concentration was 26.2 ppb recorded in the Pomona/Walnut Valley area. Effective March 20, 2008, CARB revised the nitrogen dioxide one-hour standard from 0.25 ppm to 0.18 ppm and established a new annual standard of 0.30 ppm. In addition, U.S. EPA has established a new federal one-hour NO_2 standard of 100 ppb (98th percentile concentration), effective April 7, 2010. The highest one-hour average concentration recorded (97.0 ppb in Pomona/Walnut Valley) was 53 percent of the state one-hour standard and the highest annual average concentration recorded (26.2 ppb in Pomona/Walnut Valley) was 87 percent of the state annual average standard. NOx emission reductions continue to be necessary because it is a precursor to both ozone and PM (PM2.5 and PM10) concentrations.

Most recently, the maximum one-hour average NO_2 concentration in 2011 (110 ppb, measured in Central Los Angeles), in 2012 (98ppb, measured in South Coastal Los Angeles County) was 109 and 98 percent of the federal standard respectively, exceeding the concentration level, but not the 98th percentile form of the NAAQS.

NO_2 Health Effects: Population-based studies suggest that an increase in acute respiratory illness, including infections and respiratory symptoms in children (not infants), is associated with long-term exposures to NO_2 at levels found in homes with gas stoves, which are higher than ambient levels found in southern California. Increase in resistance to air flow and airway contraction is observed after short-term exposure to NO_2

in healthy subjects. Larger decreases in lung functions are observed in individuals with asthma and/or chronic obstructive pulmonary disease (e.g., chronic bronchitis, emphysema) than in healthy individuals, indicating a greater susceptibility of these sub-groups. More recent studies have found associations between NO_2 exposures and cardiopulmonary mortality, decreased lung function, respiratory symptoms and emergency room asthma visits.

In animals, exposure to levels of NO_2 considerably higher than ambient concentrations results in increased susceptibility to infections, possibly due to the observed changes in cells involved in maintaining immune functions. The severity of lung tissue damage associated with high levels of ozone exposure increases when animals are exposed to a combination of ozone and NO_2.

3.2.2.4.4 Sulfur Dioxide

Sulfur dioxide (SO_2) is a colorless gas with a sharp odor. It reacts in the air to form sulfuric acid ($H2SO_4$), which contributes to acid precipitation, and sulfates, which are components of PM10 and PM2.5. Most of the SO_2 emitted into the atmosphere is produced by burning sulfur-containing fuels.

No exceedances of federal or state standards for sulfur dioxide occurred in 2005 at any of the seven SCAQMD locations monitored. Though sulfur dioxide concentrations remain well below the standards, sulfur dioxide is a precursor to sulfate, which is a component of fine particulate matter, PM10, and PM2.5. The maximum concentration of federal 24-hour sulfur dioxide standard in 2005 occurred in Los Angeles County 1 area and was 0.012 ppm, which is nine percent of the standard. Sulfur dioxide was not measured at SSAB sites in 2005. Historical measurements showed concentrations to be well below standards and monitoring has been discontinued.

No exceedances of federal or state standards for sulfur dioxide occurred in 2010 at any of the seven district locations monitored. The maximum one-hour sulfur dioxide concentration was 40.0 ppb, as recorded in the South Coastal Los Angeles County 1 area. The maximum 24-hour sulfur dioxide concentration was 6.0 ppb, as recorded in South Coastal Los Angeles County 1 area. The U.S. EPA revised the federal sulfur dioxide standard by establishing a new one-hour standard of 0.075 ppm and revoking the existing annual arithmetic mean (0.03 ppm) and the 24-hour average (0.14 ppm), effective August 2, 2010. The state standards are 0.25 ppm for the one-hour average and 0.04 ppm for the 24-hour average.

No exceedances of federal or state standards for sulfur dioxide occurred in 2011 or 2012 at any of the eight district locations monitored. The maximum one-hour sulfur dioxide concentration was 51.3 in 2011, and 22.7 in 2012, as recorded in the Metropolitan Riverside County 1 and South Coastal LA County 3 area respectively. Though sulfur dioxide concentrations remain well below the standards, sulfur dioxide is a precursor to sulfate, which is a component of fine particulate matter, PM10, and PM2.5. Historical measurements showed concentrations to be well below standards and monitoring has been discontinued.

SO_2 Health Effects: Exposure of a few minutes to low levels of SO_2 can result in airway constriction in some asthmatics. All asthmatics are sensitive to the effects of SO_2. In asthmatics, increase in resistance to air flow, as well as reduction in breathing capacity leading to severe breathing difficulties, is observed after acute higher exposure to SO_2. In contrast, healthy individuals do not exhibit similar acute responses even after exposure to higher concentrations of SO_2.

Animal studies suggest that despite SO_2 being a respiratory irritant, it does not cause substantial lung injury at ambient concentrations. However, very high levels of exposure can cause lung edema (fluid accumulation), lung tissue damage, and sloughing off of cells lining the respiratory tract.

Some population-based studies indicate that the mortality and morbidity effects associated with fine particles show a similar association with ambient SO_2 levels. In these studies, efforts to separate the effects of SO_2 from those of fine particles have not been successful. It is not clear whether the two pollutants act synergistically or one pollutant alone is the predominant factor.

3.2.2.4.5 Particulate Matter (PM10 and PM2.5)

PM emissions, either PM10 or PM2.5, are formed by reaction of gaseous precursors, such as SO_2, sulfates, and ammonia in the atmosphere. NOx and VOCs also react to form nitrates and solid organic compounds, which are a significant fraction of PM10. PM emissions may also be directly emitted from fugitive dust sources such as re-entrained road dust, construction activities, farming operations and wind-blown dust (SCAQMD, 2003).

The federal annual PM10 standard was exceeded at only one location in the SCAQMD in 2005, Metropolitan Riverside County. The maximum PM10 concentration was 52 $\mu g/m^3$, which was 103 percent of the federal annual PM10 standard. In general, the highest PM10 concentrations were recorded in Riverside and San Bernardino counties in and around the Metropolitan Riverside County area and further inland in San Bernardino Valley areas. The federal 24-hour standard was not exceeded at any of the locations monitored in 2005. The much more stringent state standards were exceeded in most areas.

The SCAQMD began regular monitoring of PM2.5 in 1999 following the U.S. EPA's adoption of the national PM2.5 standards in 1997. In 2005, PM2.5 concentrations were monitored at 19 locations throughout the district. Maximum 24-hour average and annual average PM2.5 concentrations (132.7 µg/m3 recorded in East San Gabriel Valley area and 21.0 µg/m3 recorded in Metropolitan Riverside County area) were 203 and 139 percent of the federal 24-hour and annual average standards, respectively (SCAQMD, 2007).

The SCAQMD monitored PM10 concentrations at 21 locations in 2010. The federal 24-hour PM10 standard (150 µg/m3) was not exceeded at any of the locations monitored in 2010. The maximum 24-hour PM10 concentration of 107 µg/m3 was recorded in the Coachella Valley No. 2 area and was 71 percent of the federal standard and 214 percent of the much more stringent state 24-hour PM10 standard (50 µg/m3). The state 24-hour PM10 standard was exceeded at 12 of the 21 monitoring stations. The maximum annual average PM10 concentration of 42.3 µg/m3 was recorded in Mira Loma. The maximum annual average PM10 concentration in Mira Loma was 211 percent of the state standard. The federal annual PM10 standard has been revoked. The Basin has technically met the PM10 NAAQS and was redesignation for attainment for the federal PM10 standard in June 2013.

U.S. EPA revised the federal 24-hour PM2.5 standard from 65 µg/m3 to 35 µg/m3, effective December 17, 2006. In 2010, the maximum PM2.5 concentrations in the Basin exceeded the new federal 24-hour PM2.5 standard in all but six locations. The maximum 24-hour PM2.5 concentration of 54.2 µg/m3 was recorded in the Mira Loma area, which represents 154 percent of the federal standard of 35 µg/m3. The maximum annual average concentration of 15.2 µg/m3 was recorded in Mira Loma, which represents 101 percent of the federal standard of 15 µg/m3 and 126 percent of the state standard of 12 µg/m3.

In 2012, only one station in the Basin (Riverside County at Mira Loma) exceeded both the annual PM2.5 and the 98th percentile form of the 24-hour PM2.5 NAAQS. The maximum 24-hour average PM2.5 concentration (58.7 µg/m^3, measured in Central LA) and annual average concentration (15.06 µg/m^3, measured in Riverside Countyat Mira Loma) were 168 and 125 percent of the federal 24-hour and annual average standard concentrations, respectively. Basin-wide, the federal PM2.5 24-hour standard level was exceeded on 15 sampling days in 2012.

PM Health Effects: Of great concern to public health are the particles small enough to be inhaled into the deepest parts of the lung. Respirable particles (particulate matter less than about 10 micrometers in diameter) can accumulate in the respiratory system and aggravate health problems such as asthma, bronchitis and other lung diseases. Children, the elderly, exercising adults, and those suffering from asthma are especially vulnerable to adverse health effects of PM10 and PM2.5.

A consistent correlation between elevated ambient fine particulate matter (PM10 and PM2.5) levels and an increase in mortality rates, respiratory infections, number and severity of asthma attacks and the number of hospital admissions has been observed in different parts of the United States and various areas around the world. Studies have reported an association between long-term exposure to air pollution dominated by fine particles (PM2.5) and increased mortality, reduction in life-span, and an increased mortality from lung cancer.

Daily fluctuations in fine particulate matter concentration levels have also been related to hospital admissions for acute respiratory conditions, to school and kindergarten absences, to a decrease in respiratory function in normal children and to increased medication use in children and adults with asthma. Studies have also shown lung function growth in children is reduced with long-term exposure to particulate matter. In addition to children, the elderly, and people with pre-existing respiratory and/or cardiovascular disease appear to be more susceptible to the effects of PM10 and PM2.5.

3.2.2.4.6 Lead

Lead in the atmosphere is present as a mixture of a number of lead compounds. Leaded gasoline and lead smelters have been the main sources of lead emitted into the air. Due to requirements to phase out leaded gasoline, there was a dramatic reduction in atmospheric lead in the Basin over the past three decades.

The federal and state standards for lead were not exceeded in any area of the district in 2005. There have been no violations of the lead standards at the SCAQMD's regular air monitoring stations since 1982, primarily the result of removing lead from gasoline. The maximum quarterly average lead concentration (0.03 $\mu g/m^3$) was two percent of the federal standard. Additionally, special monitoring stations immediately adjacent to stationary sources of lead (e.g., lead smelting facilities) have not recorded exceedances of the standards in localized areas of the Basin since 1991 and 1994 for the federal and state standards, respectively. The maximum monthly and quarterly average lead concentration (0.44 $\mu g/m^3$ and 0.34 $\mu g/m^3$ in Central Los Angeles), measured at special monitoring sites immediately adjacent to stationary sources of lead were 29 and 23 percent of the state and federal standards, respectively. No lead data were obtained at SSAB and Orange County stations in 2005 and, because historical lead data showed concentrations in SSAB and Orange County areas to be well below the standard, measurements have been discontinued.

The old federal and current state standards for lead were not exceeded in any area of the district in 2010. The maximum quarterly average lead concentration (0.01 µg/m3 at monitoring stations in South San Gabriel Valley, South Central Los Angeles County, and Central San Bernardino Valley No. 2) was 0.7 percent of the old federal quarterly average lead standard (1.5 µg/m3). The maximum monthly average lead concentration (0.01 µg/m3 in South San Gabriel Valley and South Central Los Angeles County), measured at special monitoring sites immediately adjacent to stationary sources of lead was 0.7 percent of the state monthly average lead standard. No lead data were obtained at SSAB and Orange County stations in 2010. Because historical lead data showed concentrations in SSAB and Orange County areas to be well below the standard, measurements have been discontinued.

On November 12, 2008, U.S. EPA published new national ambient air quality standards for lead, which became effective January 12, 2010. The existing national lead standard, 1.5 µg/m3, was reduced to 0.15 µg/m3, averaged over a rolling three-month period. This designation was based on two source-specific monitors in Vernon and in the City of Industry exceeding the new standard in the 2007-2009 timeframe. As a result, U.S. EPA designated the Los Angeles County portion of the Basin (excluding the high desert areas, San Clemente and Santa Catalina Islands) as non-attainment for the new lead standard, effective December 31, 2010, primarily based on emissions from two battery recycling facilities. For the 2009-2012 timeframe, only one of these stations exceeded the standard (Vernon). The remainder of the Basin remained in attainment of the lead standard.

Lead Health Effects: Fetuses, infants, and children are more sensitive than others to the adverse effects of lead exposure. Exposure to low levels of lead can adversely affect the development and function of the central nervous system, leading to learning disorders, distractibility, inability to follow simple commands, and lower intelligence quotient. In adults, increased lead levels are associated with increased blood pressure.

Lead poisoning can cause anemia, lethargy, seizures, and death. It appears that there are no direct effects of lead on the respiratory system. Lead can be stored in the bone from early-age environmental exposure, and elevated blood lead levels can occur due to breakdown of bone tissue during pregnancy, hyperthyroidism (increased secretion of hormones from the thyroid gland), and osteoporosis (breakdown of bone tissue). Fetuses and breast-fed babies can be exposed to higher levels of lead because of previous environmental lead exposure of their mothers.

3.2.2.4.7 Sulfates

Sulfates are chemical compounds which contain the sulfate ion and are part of the mixture of solid materials which make up PM10. Most of the sulfates in the atmosphere are produced by oxidation of SO2. Oxidation of sulfur dioxide yields sulfur trioxide (SO_3) which reacts with water to form sulfuric acid, which contributes to acid deposition. The reaction of sulfuric acid with basic substances such as ammonia yields sulfates, a component of PM10 and PM2.5.

In 2005, the state sulfate standard was not exceeded anywhere in the Basin. The maximum 24-hour sulfate concentration occurred in South Central Los Angeles County and was 17.3 $\mu g/m^3$, which is 69 percent of the standard. No sulfate data were obtained at SSAB and Orange County stations in 2005. Historical sulfate data showed concentrations in the SSAB and Orange County areas to be well below the standard, and measurements have been discontinued.

In 2010, the state 24-hour sulfate standard (25 µg/m3) was not exceeded in any of the monitoring locations in the district. No sulfate data were obtained at SSAB and Orange County stations in 2010. Historical sulfate data showed sulfate concentrations in the SSAB and Orange County areas to be well below the standard; thus, measurements in these areas have been discontinued. There are no federal sulfate standards.

Sulfates Health Effects: Most of the health effects associated with fine particles and SO2 at ambient levels are also associated with SOx. Thus, both mortality and morbidity effects have been observed with an increase in ambient SOx concentrations. However, efforts to separate the effects of SOx from the effects of other pollutants have generally not been successful.

Clinical studies of asthmatics exposed to sulfuric acid suggest that adolescent asthmatics are possibly a subgroup susceptible to acid aerosol exposure. Animal studies suggest that acidic particles such as sulfuric acid aerosol and ammonium bisulfate are more toxic than non-acidic particles like ammonium sulfate. Whether the effects are attributable to acidity or to particles remains unresolved.

3.2.2.4.8 Vinyl Chloride

Vinyl chloride is a colorless, flammable gas at ambient temperature and pressure. At room temperature, vinyl chloride is a gas with a sickly sweet odor that is easily condensed. However, it is stored as a liquid. Due to the hazardous nature of vinyl chloride to human health there are no end products that use vinyl chloride in its monomer form. Vinyl chloride is a chemical intermediate, not a final product. It is an important industrial chemical chiefly used to produce polymer polyvinyl chloride (PVC). The process involves vinyl chloride liquid fed to polymerization reactors where it is converted from a monomer to a polymer PVC. The final product of the polymerization process is PVC in either a flake or pellet form. Billions of pounds of PVC are sold on the global market each year. From its flake or pellet form, PVC is sold to companies that heat and mold the PVC into end products such as PVC pipe and bottles.

In the past, vinyl chloride emissions have been associated primarily with sources such as landfills. Risks from exposure to vinyl chloride are considered to be a localized impacts rather than regional impacts. Because landfills in the district are subject to SCAQMD 1150.1, which contains stringent requirements for landfill gas collection and control, potential vinyl chloride emissions are below the level of detection. Therefore, the SCAQMD does not monitor for vinyl chloride at its monitoring stations.

Vinyl Chloride Health Effects: Vinyl chloride is highly toxic and is classified by the American Conference of Governmental Industrial Hygienists (ACGIH) as A1 (confirmed carcinogen in humans) and by the International Agency for Research on Cancer (IARC) as 1 (known to be a human carcinogen) (Air Gas, 2010).

3.2.2.4.9 Volatile Organic Compounds

It should be noted that there are no state or national ambient air quality standards for VOCs because they are not classified as criteria pollutants. VOCs are regulated, however, because limiting VOC emissions reduces the rate of photochemical reactions that contribute to the formation of ozone. VOCs are also transformed into organic aerosols in the atmosphere, contributing to higher PM10 and lower visibility levels.

Total organic gases (TOG) incorporates all gaseous compounds containing the element carbon with the exception of the inorganic compounds, CO, carbon dioxide (CO_2), carbonic acid, carbonates, and metallic carbides. VOC is a subset of TOG and does not include acetone, ethane, methane, methylene chloride, methyl chloroform, perchloroethylene, methyl acetate, p-chlorobenzotrifluoride, and a number of Freon-type gases, because these substances do not generally contribute to ozone formation. In the

2003 AQMP, the amount of VOC in TOG was calculated for each process primarily using species and size fraction profiles provided by CARB. Besides average annual day emissions that are reported for all criteria pollutants, summer planning inventories (VOC and NOx) were reported for ozone purposes.

VOC Health Effects: Although health-based standards have not been established for VOCs, health effects can occur from exposures to high concentrations of VOCs because of interference with oxygen uptake. In general, ambient VOC concentrations in the atmosphere are suspected to cause coughing, sneezing, headaches, weakness, laryngitis, and bronchitis, even at low concentrations. Some hydrocarbon components classified as VOC emissions are thought or known to be hazardous. Benzene, for example, one hydrocarbon component of VOC emissions, is known to be a human carcinogen.

3.2.2.4.10 Visibility

In 2005, annual average visibility at Rudiboux (Riverside), the worst case, was just over 10 miles (SCAQMD, 2012b). With the exception of Lake County, which is designated in attainment, all of the air districts in California are currently designated as unclassified with respect to the CAAQS for visibility reducing particles.

In Class-I wilderness areas, which typically have visual range measured in tens of miles the deciview metric is used to estimate an individual’s perception of visibility. The deciview index works inversely to visual range which is measured in miles or kilometers whereby a lower deciview is optimal. In the South Coast Air Basin, the Class-I areas are typically restricted to higher elevations (greater than 6,000 feet above sea level) or far downwind of the metropolitan emission source areas. Visibility in these areas is typically unrestricted due to regional haze despite being in close proximity to the urban setting. All of the Class-I wilderness areas reside in areas having average deciview values less than 20 with many portions of those areas having average deciview values less than 10. By contrast, Rubidoux, in the Basin has a deciview value exceeding 30. The closest Class-I area is the San Gabriel Wilderness area, located over 35 miles north of the Phillips 66 Wilmington Refinery.

3.2.2.5 Existing Refinery Criteria Pollutant Emissions

Operation of the existing Phillips 66 Los Angeles Refinery results in the emissions of criteria pollutants. The reported emissions of criteria air pollutants from the Refinery for the last 13 years are shown in Table 3.1-3. The emissions in Table 3.1-3 are based on actual operations as reported on annual emission reports to the SCAQMD (and not the maximum potential to emit allowed in permits).

TABLE 3.1-3

Phillips 66 Refinery
Reported Criteria Pollutant Emissions (tons/year)(1)

Reporting Period	CO	NOx	VOC	SOx	PM10
2000	716.5	744.7	219.6	728.9	199.7
2001	861.6	592.5	259.4	735.8	202.6
2002	921.8	651.4	238.3	638.7	201.8
2003	652.8	719.9	198.1	627.6	168.6
2004	674.9	638.0	187.1	486.0	170.1
2005	749.3	624.1	261.8	434.7	284.3
2006	790.8	616.8	297.0	410.1	271.8
2007	325.8	323.0	136.3	242.5	135.8
2008	596.3	702.3	266.1	271.0	241.0
2009	461.2	630.5	264.2	104.7	167.6
2010	431.7	554.4	244.5	101.6	155.6
2011	400.2	582.5	241.5	115.3	115.8
2012	344.2	498.5	242.3	128.2	126.2
2013	302.1	762.4	253.7	125.1	172.4

(1) The reported emissions include emission estimates of RECLAIM pollutants calculated pursuant to the missing data provisions included in SCAQMD Regulation XX.

3.2.2.6 Toxic Air Contaminants (TACs)

TACs are air pollutants which may cause or contribute to an increase in mortality or severe illness, or which may pose a potential hazard to human health. The California Health and Safety Code (§39655) defines a toxic air contaminant as an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health. Under California's TAC program (Assembly Bill 1807, Health and Safety Code §39650 et seq.), CARB, with the participation of the local air pollution control districts, evaluates and develops any needed control measures for air toxics. The general goal of regulatory agencies is to limit exposure to TACs to the maximum extent feasible.

Monitoring for TACs is limited compared to monitoring for criteria pollutants because toxic pollutant impacts are typically more localized than criteria pollutant impacts. CARB conducts air monitoring for a number of TACs every 12 days at approximately 20 sites throughout California. The ULSD Project is located closest to the North Long Beach station. A summary of the averaged monitoring data from the Long Beach station for various TACs is considered to be an appropriate estimate of the TAC concentration in the vicinity of the ULSD Project. Table 3.1-4 provides the TAC monitoring data from the Long Beach station for 2003 to show pre-project conditions. Table 3.1-5 provides the TAC monitoring data from the Long Beach station for 2011 to show post-project conditions. Comparison of the tables show a general increase in toxic monitored at the North Long Beach station over time.

TABLE 3.1-4

Ambient Air Quality Toxic Air Contaminants
North Long Beach Peak 24-Hour Concentration 2003

Pollutant	Annual Average	Pollutant	Annual Average
VOC's	**ppb/v(a)**		**ppb/v**
Acetaldehyde	1.06	Methyl Ethyl Ketone	0.13
Benzene	0.705	Methyl Tertiary Butyl Ether	0.45
1,3-Butadiene	0.142	Methylene Chloride	0.31
Carbon Tetrachloride	0.092	Perchloroethylene	0.076
Chloroform	0.05	Styrene	0.24
o-Dichlorobenzene	0.15	Toluene	2.1
p-Dichlorobenzene	0.2	Trichloroethylene	0.023
Ethyl Benzene	0.24	meta-Xylene	0.0
Formaldehyde	2.79	ortho-xylene	0.34
Methyl Chloroform	0.055		
PAH's	**nanograms/m(b)**		**nanograms/m(c)**
Benzo(a)pyrene	0.07	Benzo(k)fluoranthene	0.038
Benzo(b)fluoranthene	0.086	Dibenz(a,h)anthracene	0.026
Benzo(g,h,i)perylene	0.283	Indeno(1,2,3-cd)pyrene	0.121
Inorganic Compounds(c)	**nanograms/m(b)**		**nanograms/m(c)**
Aluminum	1,140.0	Nickel	7.4
Antimony	3.8	Phosphorus	40.8
Arsenic	0.0	Potassium	433.0
Barium	48.4	Rubidium	2.2
Bromine	9.1	Selenium	1.1
Calcium	912.0	Silicon	2,950.0
Chlorine	1,550.0	Strontium	11.5
Chromium	5.9	Sulfur	1,430.0
Cobalt	8.0	Tin	5.0
Copper	34.5	Titanium	98.3
Hexavalent Chromium	0.076(d)	Uranium	1.1
Iron	1,060.0	Vanadium	21.8
Lead	11.2	Yttrium	1.1
Manganese	19.6	Zinc	73.3
Mercury	1.7	Zirconium	5.1
Molybdenum	2.8		

Source: California ARB website: Annual Toxics Summaries by Monitoring Sites, http://www.arb.ca.gov/adam/toxics/sitesubstance.html

a) ppb/v = parts per billion by volume.
b) nanograms/m^3 = nanograms per cubic meter.
c) Data for Inorganic Compounds is from the year 2001-the most recent year with 12 consecutive months of monitoring data.
d) Data is from year 2002- the most recent year with 12 consecutive months of monitoring data.

TABLE 3.1-5
Ambient Air Quality Toxic Air Contaminants
North Long Beach Peak 24-Hour Concentration 2011

Pollutant	Peak 24-hour Concentration	Pollutant	Peak 24-hour Concentration
VOCs	**Ppbv**		**ppbv**
Acetaldehyde (b)	1.9	Ethyl Benzene	0.5
Acetone	11	Formaldehyde (b)	4.7
Acetonitrile	11	Methyl Bromide	0.06
Acrolein	1.0	Methyl Chloroform	0.02
Benzene	1.1	Methyl Ethyl Ketone (b)	0.7
1,3-Butadiene	0.33	Methyl Tertiary-Butyl Ether (f)	2.0
Carbon Disulfide (d)	1.1	Methylene Chloride	1.1
Carbon Tetrachloride	0.10	Perchloroethylene	0.09
Chloroform	0.09	Styrene	0.3
ortho-Dichlorobenzene(c)	0.15	Toluene	2.9
para-Dichlorobenzene(c)	0.15	Trichloroethylene	0.067
cis-1,3-Dichloropropene	0.05	ortho-Xylene	0.6
trans-1,3-Dichloropropene	0.05		
PAHs(e)	**nanograms/m(c)**		**nanograms/m(c)**
Benzo(a)pyrene	0.61	Benzo(k)fluoranthene	0.19
Benzo(b)fluoranthene	0.51	Dibenz(a,h)anthracene	0.18
Benzo(g,h,i)perylene	1.7	Indeno(1,2,3-cd)pyrene	0.64
Inorganic compounds	**nanograms/m(c)**		**nanograms/m(c)**
Aluminum (g)	2,100	Nickel (a)	4.5
Antimony (a)	9	Phosphorous (g)	61
Arsenic (a)	0.75	Platinum (a)	0.15
Barium (g)	91	Potassium6(g)	860
Bromine (g)	15	Rubidium(g)	4
Cadmium (a)	2.0	Selenium (a)	2.1
Calcium (g)	2,300	Silicon(g)	5,600
Chlorine (g)	6,900	Strontium (a)	25
Chromium (a)	7	Sulfur (a)	3,500
Cobalt (a)	0.75	Tin (a)	3.5
Copper (a)	68	Titanium (a)	85
Hexavalent Chromium (b)	0.11	Uranium(g)	2.0
Iron (a)	1,200	Vanadium (a)	10
Lead (a)	190	Yttrium(g)	3
Manganese (a)	46	Zinc (a)	250
Mercury (g)	4.0	Zirconium (a)	2.8
Molybdenum (a)	2.6		

Source: CARB, 2010. Annual Ambient Toxic Monitoring Sites, North Long Beach,

Notes: ppbv = parts per billion by volume; nanograms/m^3 = nanograms per cubic meter

(a) The most recent complete year data is from 2010

(b) The most recent complete year data is from 2009

(c) The most recent complete year data is from 2006

(d) The most recent complete year data is from 2005

(e) The most recent complete year data for PAHs is from 2004.

(f) The most recent complete year data is from 2003

(g) The most recent complete year data is from 2002

The SCAQMD measured TAC concentrations as part of its Multiple Air Toxic Exposure Study (MATES). The purpose of the study was to provide an estimate of exposure to TACs to individuals within the Basin. In a second study, MATES-II, the SCAQMD conducted air sampling at about 24 different sites for over 30 different TACs between April 1998 and March 1999. The SCAQMD recently concluded a third study, referred to as MATES-III, that includes monitoring for 21 TACs at ten fixed, and five temporary, sites within the Basin in neighborhoods near toxic emission sources or in areas where community members are concerned about health risks from air pollution. The scope of the monitoring was from April 2004 through March 2006. The MATES-III found about 94 percent of the cancer risk is attributed to emissions associated with mobile sources and about six percent of the cancer risk is attributed to toxics emitted from stationary sources (e.g., industrial sources). The results indicate that diesel exhaust is the major contributor to cancer risk, accounting for about 84 percent of the total. Compared to previous studies of air toxics in the Basin, the MATES-III study found a decreasing cancer risk for air toxics exposure, with the population-weighted risk down by eight percent from the analysis in MATES-II, which was based on monitoring in 1998 and 1999. The highest risks are found near the Port area, an area near central Los Angeles and near transportation corridors. The average carcinogenic risk in the Basin is about 1,200 per million people. This means that 1,200 people out of a million are susceptible to contracting cancer from exposure to the known TACs over a 70-year period of time (SCAQMD, 2008). Of the monitoring sites in the MATES-III study, the West Long Beach study site is the closest to the Refinery. The estimated cancer risk at the West Long Beach station was about 1,650 per million (SCAQMD, 2008). Areas near the ports had the highest cancer risk in the Basin, ranging from 1,100 to 3,700 per million. An area of elevated risk was also found near Central Los Angeles with risks ranging from 1,400 to 1,900 per million. The areas projected to have higher risk followed transportation corridors, including freeways and railways (SCAQMD, 2008).

CARB completed air monitoring between May 2001 and July 2002, at Wilmington Park Elementary school because of the location of the school in proximity to refineries and the ports (CARB, 2003). Monitoring was completed for over 50 air pollutants. The key findings of the study were the following: (1) the air quality around the Wilmington Park Elementary school is similar to other parts of the Los Angeles urban area; (2) the estimated cancer risk in Wilmington was 278 per million as compared to Long Beach with a cancer risk of 279 per million and downtown Los Angeles at 341 per million; (3) local meteorology patterns in Wilmington appear to favor dispersion of local air pollution; and (4) PM10 levels measured in Wilmington were noticeably higher than in nearby Long Beach (CARB, 2003).

3.2.3 REGULATORY BACKGROUND

Ambient air quality standards in California are the responsibility of, and have been established by, both the U.S. EPA and CARB. These standards have been set at concentrations which provide margins of safety for the protection of public health and welfare. Federal and state air quality standards are presented in Table 3.3-1. The SCAQMD has established levels of episodic criteria and has indicated measures that must be initiated to immediately reduce contaminant emissions when these levels are reached or exceeded. The federal, state, and local air quality regulations are identified below in further detail.

3.2.3.1 Federal Regulations

The U.S. EPA is responsible for setting and enforcing the NAAQS for ozone, CO, NO_2, SO_2, PM10, PM2.5, and lead. The U.S. EPA has jurisdiction over emissions sources that are under the authority of the federal government including aircraft, locomotives, and emission sources outside state waters (Outer Continental Shelf). The U.S. EPA also establishes emission standards for vehicles sold in states other than California. Automobiles sold in California must meet the stricter emission requirements of CARB.

The Federal CAA and its subsequent amendments form the basis for the national air pollution control effort. U.S. EPA is responsible for implementing most aspects of the CAA. Basic elements of the act include the NAAQS for major air pollutants, hazardous air pollutant standards, attainment plans, motor vehicle emission standards, stationary source emission standards and permits, acid rain control measures, stratospheric ozone protection, and enforcement provisions. The CAA delegates the enforcement of the federal standards to the states. In California, CARB and the local air agencies have shared responsibility for enforcing air pollution regulations, with the local air agencies having primary responsibility for regulation stationary emission sources. In the Basin, the SCAQMD has this responsibility.

3.2.3.1.1 State Implementation Plan

In areas that have not attained all NAAQSs, the CAA requires preparation of a SIP, detailing how the State will attain the NAAQS within mandated timeframes. In 2003, the SCAQMD and Southern California Association of Governments (SCAG) developed the 2003 Air Quality Management Plan (2003 AQMP), which upon approval by the SCAQMD and CARB was incorporated into the SIP. The focus of the 2003 AQMP was to demonstrate attainment of the federal PM10 standard by 2006 and the federal one-hour ozone standard by 2010, while making expeditious progress toward attainment of state standards. Since the Basin was close to attaining the federal CO standard, the 2003 AQMP also replaced the 1997 attainment demonstration for the federal CO standard, and provided a basis for a future maintenance plan for CO (SCAQMD, 2003). The SCAQMD and SCAG developed the 2007 AQMP for purposes of demonstrating compliance with the new NAAQS for PM2.5 and eight-hour ozone and other planning requirements, including compliance with the NAAQS for PM10 (SCAQMD, 2007). Since it will be more difficult to achieve the eight-hour ozone NAAQS compared to the one-hour NAAQS, the 2007 AQMP contains substantially more emission reduction measures compared to the 2003 AQMP. The SCAQMD adopted the 2007 AQMP in June 2007 (SCAQMD, 2007). On September 27, 2007, the CARB Board adopted the State Strategy for the 2007 State Implementation Plan and the 2007 South Coast AQMP as part of the SIP. The U.S. EPA approved the eight-hour SIP portion of the 2007 AQMP in 2011. The 2012 AQMP (approved by the SCAQMD Governing Board on December

7, 2012) demonstrates attainment of the federal 24 hour PM2.5 by 2014 and updates certain portions of the existing SIP, including the new 8-hour ozone control measures will be submitted into the SIP with commitments for corresponding emission reductions.

3.2.3.1.2 Emission Standards for Non-Road Diesel Engines

To reduce emissions from off-road diesel equipment other than marine vessels and locomotives, the U.S. EPA established a series of increasingly strict emission standards for new non-road diesel engines. Tier 1 standards were phased in from manufacture year 1996 to 2000, depending on the engine horsepower category. Tier 2 standards were phased in from 2001 to 2006. Tier 3 standards were phased in from 2006 to 2008. Tier 4 standards, which likely will require add-on emission control equipment to attain them, will be phased in from 2008 to 2015. The use of ULSD in mobile sources is required to achieve the non-diesel road engine standards as sulfur poisons some of the catalysts used in the Tier 4 technologies. These standards would apply to construction equipment, as well as other non-road diesel engines (Diesel Net, 2012).

3.2.3.1.3 Diesel Fuel Standards

On January 18, 2001, the U.S. EPA published a final rule on diesel fuels standards (40 CFR §§80, 500). The rule required refiners to begin selling highway diesel fuel that meets a maximum sulfur standard of 15 ppmw by June 1, 2006. The 2006 deadline was issued to ensure that adequate supplies of ULSD would be available to meet the demand in 2007, when all on-road, diesel-fuel vehicles were required to be equipped to run on ULSD fuel. In Los Angeles, heavy-duty trucks and busses contributed more than a quarter of the NOx emissions and 14 percent of the PM2.5 emissions from mobile sources. Pollution-control devices for heavy duty engines are sensitive to sulfur and would not work unless the amount of sulfur in the fuel was reduced (U.S. EPA, 2003). Therefore, the U.S. EPA implemented additional regulations to control sulfur in fuel and which ultimately led to particulate emissions controls on diesel fueled engines.

To reduce emissions from on-road, heavy-duty diesel trucks, U.S. EPA established a series of cleaner emission standards for new engines, starting in 1988. The U.S. EPA promulgated the 2007 Heavy Duty Highway Rule. The PM emission standard of 0.01 grams per horse power hour (g/hp-hr) was required for new vehicles beginning with the model year 2007. Also, the NOx and non-methane hydrocarbon (NMHC) standards of 0.20 g/hp-hr and 0.14 g/hp-hr, respectively, were phased in together between 2007 and 2010 on a percent-of-sales basis: 50 percent from 2007 to 2009 and 100 percent in 2010.

3.2.3.2 State Regulations

The CCAA adopted in 1988 mandates achievement of the maximum degree of emission reductions possible from vehicular and other mobile sources in order to attain the state ambient air quality standards by the earliest practical date. The CCAA requires non-attainment areas to achieve and maintain the state ambient air quality standards by the earliest practicable date and local air districts to develop plans for attaining the state ozone, CO, sulfur dioxide, and NO_2 standards. The CCAA also requires air districts to assess their progress toward attaining the air quality standards every three years. The triennial assessment is to report the extent of air quality improvement and the amounts of emission reductions achieved from control measures for the preceding three year period. The air districts must also review and revise attainment plans, if necessary, to correct for deficiencies in meeting progress, to incorporate new data or projections, to mitigate ozone transport, and to pursue the expeditious adoption of all feasible control measures.

CARB is responsible for ensuring implementation of the CCAA and federal CAA, and for regulating emissions from consumer products and motor vehicles. CARB has established CAAQS for all pollutants for which the federal government has established NAAQS and also has standards for sulfates, visibility, hydrogen sulfide, and vinyl chloride. California standards are generally more stringent than the NAAQS. CARB has established emission standards for vehicles sold in California and for various types of stationary equipment. Although CARB also has established fuel specifications to reduce vehicular emissions, it has no regulatory approval authority over the ULSD Project. Federal and state air quality standards are presented in Table 3.3-1.

3.2.3.2.1 California Diesel Fuel Regulations

CARB set sulfur limitations for diesel fuel sold in California for use in on-road and off-road motor vehicles and to fulfill CARB's 2000 Diesel Risk Reduction Plan. Harbor craft and intrastate locomotives were originally excluded from the rule, but were later included by a 2004 rule amendment. Under this rule, diesel fuel used in motor vehicles except harbor craft and intrastate locomotives had been limited to 500 ppm sulfur since 1993. The sulfur limit was reduced to 15 ppm effective September 1, 2006. Diesel fuel used in intrastate locomotives (switch locomotives) was limited to 15 ppm sulfur effective January 1, 2007.

3.2.3.2.2 Heavy Duty Diesel Truck Idling Regulation

This CARB rule affects heavy-duty diesel trucks in California starting February 1, 2005. The rule requires that heavy-duty trucks shall not idle for longer than five minutes at a time. However, truck idling for longer than five minutes while queuing is allowed if the queue is located beyond 100 feet from any homes or schools.

3.2.3.2.3 Statewide Portable Equipment Registration Program

The Portable Equipment Registration Program (PERP) established a uniform program to regulate portable engines and portable engine-driven equipment units. Once registered in the PERP, engines and equipment units may operate throughout California without the need to obtain individual permits from local air districts. The PERP applies to back-up electricity generators.

3.2.3.2.4 CARB Portable Diesel-Fueled Engines Air Toxic Control Measure

Effective September 12, 2007, all portable engines having a maximum rated horsepower of 50 bhp and greater and fueled with diesel must comply with this regulation and meet weighted fleet average PM emission standards. The first fleet standard compliance date is in 2013.

3.2.3.2.5 CARB In-Use Off-Road Diesel Vehicle Rule

In later July 2007, CARB adopted a rule that requires owners of off-road mobile equipment powered by diesel engines 25 hp or larger to meet the fleet average or BACT requirements for NOx and PM emissions by March 1 of each year. The rule is structured by fleet size: large, medium and small. Medium sized fleets receive deferred compliance, and small fleets are exempt from NOx requirements and also get deferred compliance.

The original Regulation for In-Use Off-Road Diesel Vehicles was adopted in April, 2008. CARB subsequently amended the regulation to delay the turnover of Tier 1 equipment meeting the NOx performance requirements of the regulation, and then to delay overall implementation of the equipment turnover compliance schedule in response to the economic downturn in 2008 and 2009.

3.2.3.2.6 CARB Surplus Off-Road Op-In for NOx

The Surplus Off-Road Opt-In for NOx (SOON) Program was originally adopted with the statewide Regulation for In-Use Off-Road Diesel Vehicles (Off-Road Rule) in 2008 and would apply to districts whose governing board elected to opt into to provision of the program. The SOON Program requires applicable fleets to meet a more stringent fleet-average NOx target than the statewide Off-Road Rule on a compliance schedule. The SCAQMD has opted into the SOON program and requires off-road equipment fleets to meet certain emissions Tier levels for NOx reduction.

3.2.3.2.7 CARB Statewide Bus and Truck Regulation

In December 2008, CARB adopted Statewide Bus and Truck Regulation that requires installation of PM retrofits on all heavy duty trucks beginning January 1, 2012 and replacement of older trucks starting January 1, 2015. By January 1, 2023, all vehicles need to have 2010 model year engines or equivalent.

3.2.3.2.8 Toxic Air Contaminants

California also has established a state air toxics program, California Toxic Air Contaminants Program (Tanner Bill) (AB1807), which was modified by the Revised Tanner Bill (AB2728). This program sets forth provisions to implement the national program for control of hazardous air pollutants.

The Air Toxic "Hot Spots" Information and Assessment Act (AB2588), as amended by Senate Bill 1731 (SB1731), requires operators of certain stationary sources to inventory air toxic emissions from their operations and, if directed to do so by the local air district, prepare a health risk assessment to determine the potential health impacts of such emissions. If the health impacts are determined to be "significant" (greater than 10 per one million exposures or non-cancer hazard index greater than 1.0), each facility operator must, upon approval of the health risk assessment, provide public notification to affected individuals.

3.2.3.3 Regional Regulations

The Basin is under the jurisdiction of the SCAQMD which has regulatory authority over stationary source air pollution control and limited authority over mobile sources. The SCAQMD is responsible for air quality planning in the Basin and development of the AQMP. The AQMP establishes the strategies that will be used to achieve compliance with NAAQS and CAAQS.

SCAQMD's Rule 431.2 (Sulfur Content of Liquid Fuels, amended on September 15, 2000) contained a sulfur limit requirement consistent with the one later adopted by the U.S. EPA. At the time, the sulfur limit for diesel fuel sold for use in California was 500 ppmw which was approved by CARB in 1988 (Title 13, CCR §22). Rule 431.2 required a reduction in the sulfur content of diesel used in both stationary and mobile sources to 15 ppmw starting mid-2006.

The SCAQMD generally regulates stationary sources of air pollutants. There were a number of SCAQMD regulations that applied to the ULSD Project including Regulation II – Permits, Regulation III – Fees, Regulation IV – Prohibitions, Regulation IX – New Source Performance Standards, Regulation X - National Emissions Standards for Hazardous Air Pollutants (NESHAPS) Regulations, Regulation XI – Source Specific Standards, Regulation XIII – New Source Review, Regulation XIV – New Source Review of Carcinogenic Air Contaminants (including Rule 1401, New Source Review of Toxic Air Contaminants and Rule 1403, Asbestos Emissions from Demolition/Renovation Activities), Regulation XVII – Prevention of Significant Deterioration, Regulation XX – Regional Clean Air Incentives Market (RECLAIM) Program, and Regulation XXX – Title V Permits. SCAQMD permits were required for the construction and operation of the ULSD Project at Phillips 66.

3.3 ENVIRONMENTAL IMPACTS

This section provides an analysis of potential adverse environmental impacts associated with the ULSD Project described in Chapter 2. Based on the court's decision on the previous CEQA documents for the Phillips 66 ULSD, the EIR focuses on the issues as directed by the court and is limited to air quality setting, discussed in the previous section, and air quality impacts from project operations. An impact is considered significant under CEQA if it leads to a "substantial, or potentially substantial, adverse change in the environment." Impacts from the project fall within one of the following categories:

Beneficial - Impacts would have a positive effect on the environment.

No impact - There would be no impact to the identified resource as a result of the proposed project.

Adverse but not significant - Some impacts may result from the project; however, they are judged to be insignificant. Impacts are frequently considered insignificant when the changes are minor relative to the size of the available resource base or would not change an existing resource.

Potentially significant but mitigation measures reduce impacts to insignificance - Significant impacts may occur; however, with proper and feasible mitigation the impacts can be reduced to insignificance.

Potentially significant and mitigation measures are not available to reduce impacts to insignificance - Impacts may occur that would be significant even after mitigation measures have been applied to lessen their severity or no mitigation measures are available.

3.3.1 SIGNIFICANCE CRITERIA

To determine whether or not air quality impacts from the ULSD Project are significant, impacts will be evaluated and compared to the significance criteria in Table 3.3-6. If impacts equal or exceed any of the criteria in Table 3.3-6, they will be considered significant.

The SCAQMD makes significance determinations for operational emissions based on the maximum or peak daily allowable emissions during the operational phase.

TABLE 3.3-6

Air Quality Significance Thresholds

Mass Daily Thresholds[a]		
Pollutant	**Construction[b]**	**Operation[c]**
NO_x	100 lbs/day	55 lbs/day
VOC	75 lbs/day	55 lbs/day
PM10	150 lbs/day	150 lbs/day
PM2.5	55 lbs/day	55 lbs/day
SOx	150 lbs/day	150 lbs/day
CO	550 lbs/day	550 lbs/day
Lead	3 lbs/day	3 lbs/day
Toxic Air Contaminants, Odor, and GHG Thresholds		
TACs (including carcinogens and non-carcinogens)	Maximum Incremental Cancer Risk ≥ 10 in 1 million Chronic and Acute Hazard Index ≥ 1.0 (project increment) Cancer Burden ≥ 0.5 excess cancer cases (in areas ≥ 1 in 1 million)	
Odor	Project creates an odor nuisance pursuant to SCAQMD Rule 402	
Ambient Air Quality for Criteria Pollutants[d]		
NO_2 1-hour average annual average	In attainment; significant if project causes or contributes to an exceedance of any standard: 0.18 ppm (state) 0.03 ppm (state) and 0.0534 ppm (federal)	
PM10 24-hour annual average	10.4 $\mu g/m^3$ (construction)[e] and 2.5 $\mu g/m^3$ (operation) 1.0 $\mu g/m^3$	
PM2.5 24-hour average	10.4 $\mu g/m^3$ (construction)[e] and 2.5 $\mu g/m^3$ (operation)	
SO_2 1-hour average 24-hour average	0.255 ppm (state) and 0.075 ppm federal – 99th percentile) 0.04 ppm (state)	
Sulfate 24-hour average	25 $\mu g/m^3$ (state)	
CO 1-hour average 8-hour average	In attainment; significant if project causes or contributes to an exceedance of any standard: 20 ppm (state) and 35 ppm (federal) 9.0 ppm (state/federal)	
Lead 30-day average Rolling 3-month average Quarterly average	1.5 $\mu g/m^3$ (state) 0.15$\mu g/m^3$ (federal) 1.5$\mu g/m^3$ (federal)	

a) Source: SCAQMD CEQA Handbook (SCAQMD, 1993)

b) Construction thresholds apply to both the SCAB and Coachella Valley (Salton Sea and Mojave Desert Air Basin)

c) For Coachella Valley, the mass daily thresholds for operation are the same as the construction thresholds.

d) Ambient air quality thresholds for criteria pollutants based on SCAQMD Rule 1303, Table A-2 unless otherwise stated.

e) Ambient air quality threshold based on SCAQMD Rule 403.

KEY: ppm = parts per million; $\mu g/m^3$ = microgram per cubic meter; lbs/day = pounds per day; MT/yr CO2eq = metric tons per year of CO_2 equivalents, ≥ greater than or equal to, > = greater than

3.3.2 OPERATIONAL EMISSION IMPACTS

3.3.2.1 Criteria Pollutant Emissions

The baseline for the ULSD Project was Refinery operations in 2002-2003 (pre-project), which reflects the existing environmental setting when the environmental analysis development of the ULSD project began. The project was constructed in 2005 and became operational in April 2006. Therefore, project impacts were evaluated for April 2006 through December 2008 (post-project). Where the data set does not directly match these pre- and post-project periods, data were matched as closely as possible. Because the ULSD Project has been built and is operational, the project impacts are based on actual as-built information where available, as opposed to the engineering estimates that were used in previous CEQA documents. The ULSD Project resulted in refinery modifications that included emission increases, as well as emission reductions.

Operational emissions from the ULSD Project are summarized in Table 3.3-7. Detailed emission calculations are provided in Appendix B. The operational emission calculations provided in previous ULSD CEQA documents have been updated and modified to include information on the Project as it was built and has been operated. Detailed baseline and post-project information on each component of the ULSD Project is described in the following paragraphs.

TABLE 3.3-7

ULSD Operational Emissions(1)

PROJECT COMPONENT	ULSD Project Emissions (lb/day)					
	CO	VOC	NOx	SOx	PM10	PM2.5
Fugitive Components	-	5.2	-	-	-	-
Replacement Heater(2)	-16.60	0.91	-25.54	1.69	0.98	0.98
Storage Tank 331	-	0.2	-	-	-	-
Hydrogen Production	2.28	2.28	3.50	0.10	2.73	2.73
Electricity Demand	3.7	0.2	21.3	2.2	0.7	0.7
Truck Transport	11.55	1.57	14.80	0.12	0.26	0.26
Steam Demand	0	0	0	0	0	0
TOTAL ULSD Project Emissions	**0.93**	**10.36**	**14.06**	**4.11**	**4.67**	**4.67**
SCAQMD Significance Thresholds	550	55	55	150	150	55
Significant?	NO	NO	NO	NO	NO	NO

(1) See Appendix B for detailed emission calculations. Differences in emissions in this table and Appendix B are due to rounding.
(2) A negative number indicates emission reductions.

Fugitive Emissions: Fugitive project components include pumps, compressors, valves, flanges, and process drains. The ULSD Project resulted in the installation of fugitive refinery components and the removal of others. The fugitive component emissions in previous CEQA documents were based on engineering estimates of the required changes in fugitive components. The emission estimates in this EIR are based on the actual as-built changes in fugitive component counts, including emission increases from the addition of new components and emission decreases associated with removal of older components. The Refinery is required to monitor fugitive components under SCAQMD Rule 1173 and maintains a database of components by unit. Therefore, the actual component counts installed as part of the ULSD Project were used to develop the fugitive emissions estimates. The ULSD Project resulted in a net emissions increase of about 5.2 pounds per day (lbs/day) VOC from fugitive components (valves, flanges, and process drains) (see Table 3.3-7 and Appendix B for detailed analysis).

Replacement Charge Heater: As part of the ULSD Project, Heater B-201 was removed from service and replaced with a new, functionally identical heater, B-401. Heater B-401 was equipped with low NOx burners and included the construction of an SCR Unit as BACT for NOx emissions. Baseline emissions from Heater B-201 were based on actual operating conditions for 2002 and 2003. The operating data for 2002 and 2003 were reviewed to determine the maximum emissions achieved by Heater B-201 during that timeframe.

The emissions from Heater B-401 (new heater) are based on the maximum potential to emit from the heater as estimated from the SCAQMD permit application. Heater B-401 was permitted to operate at a maximum fire duty of 34 million British Thermal Units per hour (mmBtu/hr). Therefore, the emissions from B-401 are based on the maximum potential to emit assuming the heater operates at 34 mmBtu/hr. Emissions of SOx, NOx, and CO are based on the SCAQMD permit limits for Heater B-401. Emissions of other criteria pollutants are based on SCAQMD-approved emission factors for combustion emissions. Heater B-401 is equipped with low NOx burners and an SCR Unit for NOx emission control. Therefore, maximum potential NOx emissions from Heater B-401 are less than Heater B-201 because of the additional pollution control (see Table 3.3-7 and Appendix B). CO emissions are also less because the SCAQMD established a reduced CO emission limit (10 ppm) based on BACT considerations.

Storage Tanks: As part of the ULSD Project, a storage tank (Tank 331) that was idle was put back into jet/diesel fuel service. Under the baseline conditions, Tank 331 was assumed to have no emissions as the tank was not in service. Emission increases associated with Tank 331 were estimated using the U.S. EPA TANKS model. The model bases emissions on the vapor pressure of material stored in the tank, tank diameter, volume, estimated throughput (or turnovers), and specific information on the type of construction (tank seals). The emissions from Tank 331 were estimated to be about 0.2 lb/day and no other changes to storage tanks occurred as part of the ULSD Project (see Table 3.3-7 and Appendix B). The SCAQMD Permit to Operate provides conditions to enforce tank operations and includes limitations on the tank throughput, material that can be stored, and the vapor pressure of material stored in the tank. Therefore, emissions are limited by permit conditions.

Hydrogen Production: Hydrotreaters use hydrogen in the presence of a catalyst to remove sulfur from feedstocks. The ULSD Project required increasing the size of the reaction vessel in Unit 90 thereby increasing the feed stock residence time, the amount of hydrogen consumed, and the amount of catalyst used in the reactor, resulting in a greater amount of sulfur removed from the feedstock. The blend stock produced by Unit 90, which now has a reduced sulfur content, is used to produce ultra low sulfur diesel. Therefore, the ULSD Project resulted in an increase in hydrogen demand, increasing the criteria pollutant emissions required to produce additional hydrogen.

The Refinery does not monitor hydrogen use in Unit 90 alone. The Refinery monitors the total hydrogen used in Unit 89 (jet hydrotreater) and Unit 90 (diesel hydrotreater) combined on an annual basis. The baseline hydrogen demand in Units 89 and 90 were based on monitoring data of hydrogen use in 2002-2003 for the two units combined. The ULSD Project was expected to increase hydrogen use in Unit 90. Conversely, no physical changes were made to Unit 89 during this period that would have increased its hydrogen use. Therefore, the total increase in hydrogen used by Units 89 and 90 combined between the pre-project and the post-project periods was attributed to the Unit 90 for ULSD project. The overall use of hydrogen increased over the baseline period by about 511 million standard cubic feet per year (mmscf/year) (see Appendix B). The analysis includes the conservative assumption that all of the increase in hydrogen use was attributed to the ULSD Project (Unit 90 hydrogen demand increase). The assumption is considered to be conservative because any increase in hydrogen demand compared to the baseline, regardless if it is from Unit 89 and/or Unit 90, is attributed to the ULSD Project. Although actual hydrogen demand varies on a daily basis, most of the increase in hydrogen came from a third party hydrogen supplier. The emission factors for the increased hydrogen production were based on the emission factors for a third party hydrogen supplier, as reported in the EIR for that facility (City of Carson, 1998). The emissions for increased hydrogen production are presented in Table 3.3-7, with detailed calculations in Appendix B.

Electrical Generation: The ULSD project resulted in the installation of additional equipment associated with the modifications to Unit 90. The installation of pumps, fans and air coolers resulted in an increase in electricity use at the Refinery (about 835 horsepower (HP)). In addition to the pumps, Phillips reactivated a 200 HP recycle gas compressor in Unit 89 (jet hydrotreater), as Unit 89 and Unit 90 could no longer share a compressor. Therefore, the total increase in electricity usage was 1,035 HP or about 18,623 kilowatt-hours per day. Emission increases associated with the increase in electricity use were calculated using emission factors in the SCAQMD CEQA Air Quality Handbook (SCAQMD, 1993) (see Appendix B for detailed analysis).

Trucks: The ULSD Project also resulted in an increase in trucks associated with the needed delivery of aqueous ammonia and an additional catalyst. A review of the activity associated with the delivery of aqueous ammonia and catalyst from the ULSD Project determined that the maximum truck deliveries per day were associated with the periodic change of catalyst in Unit 90, which resulted in a maximum of four truck trips per day over a two week period. The catalyst in Unit 90 has a life expectancy of two to three years, so catalyst replacement occurs once every two to three years. The catalyst in the SCR Unit has a life expectancy from five to ten years, so SCR catalyst replacement occurs once every five to ten years. The ULSD Project also resulted in an increase of one aqueous ammonia truck per year. Therefore, to determine the peak day emissions increase associated with new truck trips, it was assumed that maximum daily truck trips associated with the Unit 90 catalyst replacement and aqueous ammonia delivery would occur on the same day, resulting in a maximum of five trucks per day (see Table 3.3-7 and Appendix C). Truck trips are typically off-peak hour to minimize delivery time.

Steam Demand: Steam is used within a refinery for a variety of uses where energy (heat and/or power) are required. A large portion of steam used at the Wilmington Plant is generated in the refinery's four existing utility boilers (Boilers 4, 6, 7 and 8) and existing cogeneration unit by combusting refinery fuel gas and natural gas, which in turn produces air emissions. Therefore, the ULSD modifications were examined to assess whether the project has increased refinery steam demand in a way that has resulted in an increase in steam generation. Although specific equipment within Unit 90 requires more steam to operate following the ULSD modifications, this has not caused an increase in Refinery steam generation due to the refinery's integrated steam system. This is explained in further detail in the following sections. Because the generation of Refinery steam does not increase, the project emissions corresponding to steam demand does not increase and thus Table 3.3-7 lists zero emissions from steam demand

Refinery Steam Production and Demand Systems: Within a refinery, there is equipment that uses steam. Some refining units are both steam producers and consumers.

Refineries typically require steam at three different pressures (high pressure, medium pressure and low pressure). High pressure steam is normally generated in utility boilers and waste heat boilers in process units, and it is typically used to generate electrical power and to power turbine drivers in pumps, compressors and other machinery. High pressure steam also may be used for process heating in lieu of fired heaters. Medium pressure steam is usually obtained by recycling the exhaust from the turbines that use high pressure steam, by generating steam in process waste heat steam generators, and by direct pressure letdown from the high pressure system. Medium pressure steam is typically used in refineries in process heat exchangers, small turbine drivers, and ejectors used to maintain vacuum. Low pressure steam is used for process heat exchangers, tank heating, line tracing and miscellaneous services.(Lucas, 2000) Thus, refineries typically meet their steam requirements by (1) producing steam at different pressures, (2) reusing steam that has already lost some of its pressure, and (3) reducing the pressure of high pressure steam through let-down valves.

The Wilmington Plant operates an integrated steam system. The primary steam generators are four existing steam boilers and an existing cogeneration unit. As is typical for refineries, the Wilmington Plant uses steam at three different pressures: 400 pounds per square inch (psi) steam (high pressure system), 150 psi steam (medium pressure system), and 20 psi steam (low pressure system). Different equipment in the Refinery requires one or more of these different pressures of steam. However, the four steam boilers and cogeneration plant produce steam at only one pressure, 400 psi. There are two ways that 400 psi steam is reduced to 150 psi steam. First, a portion of the 400 psi steam passes through units requiring 400 psi steam, where some of the energy in the steam is put to work, and then the steam (now at lower pressure) is directed into the header for the 150 psi steam system. Second, some of the 400 psi steam passes to the 150 psi steam system directly through one of four letdown valves, where the pressure is deliberately reduced to maintain 150 psi (see Figure 3-1). The Refinery requires more 150 psi steam (to power~200 pieces of equipment) than it does 400 psi steam (to power~70 pieces of equipment). The Refinery also produces some 150 psi steam, but not enough to make up this shortfall. Therefore, the boilers and cogeneration plant always produce more 400 psi steam than is needed for the units that use 400 psi steam, and this additional 400 psi steam is reduced through letdown valves and sent to the 150 psi system.

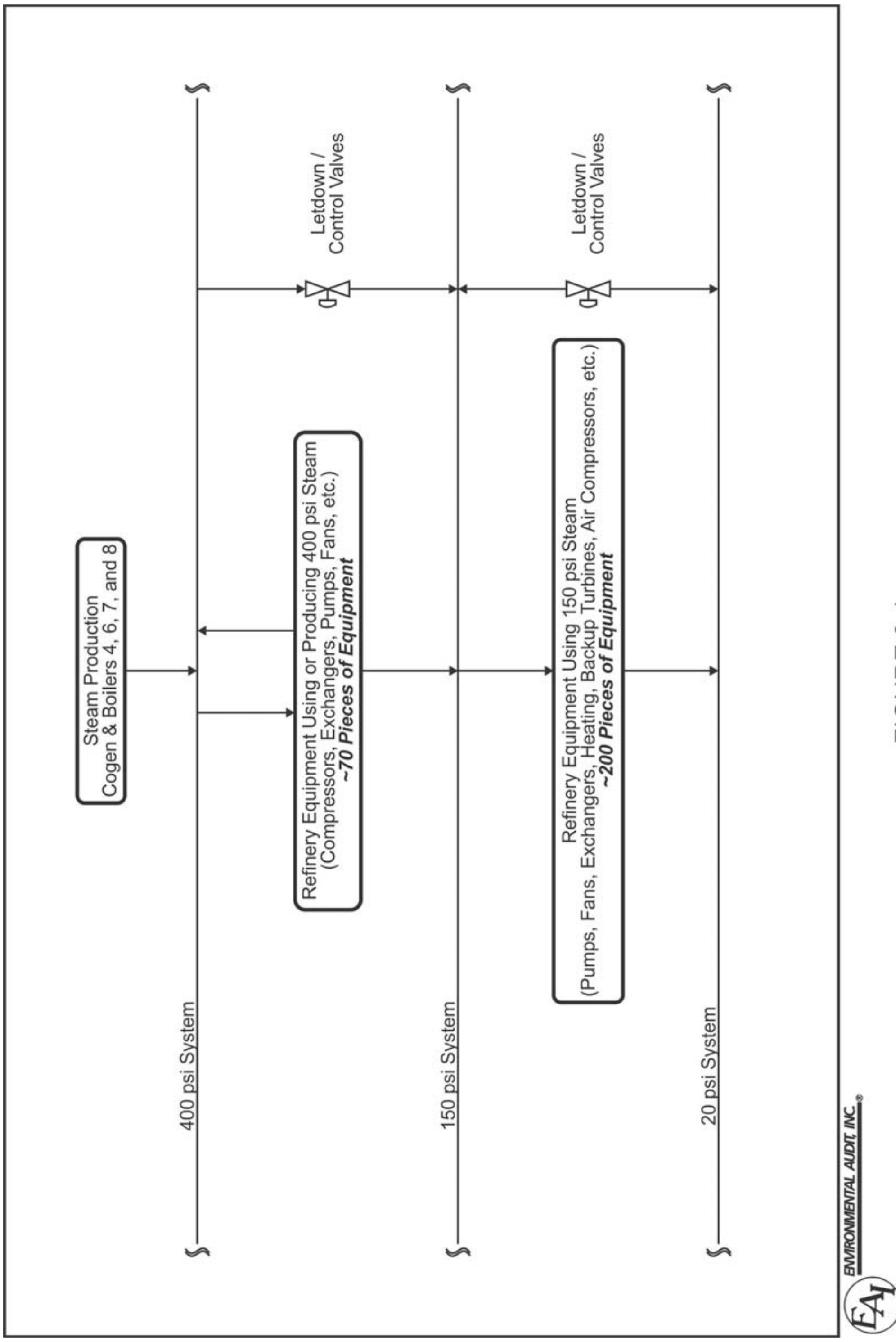


FIGURE 3-1
PHILLIPS 66 WILMINGTON PLANT STEAM SYSTEM

ENVIRONMENTAL AUDIT, INC.

Project No. 2696
N:\2696\Flow Diagram\Wilmington Plant Steam System (rev.4).cdr

Changes to Steam Demand and Generation from ULSD Project: Within Unit 90, steam is used to drive the recycle gas compressor. This compressor circulates the hydrogen rich gas used, in the presence of a catalyst, to remove sulfur and other impurities from the hydrocarbon streams. As part of the ULSD project, the existing recycle gas compressor GB-301 was modified to increase its capacity. The recycle gas compressor capacity doubled, but this did not result in a corresponding increase in steam generated by the boilers and cogeneration unit at the Wilmington plant. The following provides a summary of the steam demand associated with the ULSD Project and why this did not cause an increase in the overall steam generation at the Refinery.

Refinery steam system flow demonstrates why steam generation did not increase as a result of the ULSD project. The recycle gas compressor in Unit 90 uses predominantly 400 psi steam. Given the integration between the 400 psi and 150 psi steam systems, if Unit 90 requires more 400 psi steam, any increased demand for steam is met by merely diverting 400 psi steam from the letdown valves to Unit 90. Within Unit 90, the 400 psi steam is put to work in the recycle gas compressor, and then it is exhausted to the 150 psi steam header for use elsewhere in the refinery. Thus, energy in the 400 psi steam is used in Unit 90, instead of passing the excess 400 psi steam through the letdown valves to produce 150 psi steam. The same amount of 400 psi steam is produced by the four refinery steam boilers and cogeneration unit, but there is a shift in the allocation of steam between the two pathways to the 150 psi system. More of the steam passes through Unit 90 to get to the 150 psi system and less of the steam passes through letdown valves to get to the 150 psi system, but the same amount of steam is being generated. In other words, since the 150 psi system creates the demand for steam, the increase in steam for Unit 90 merely shifts the path of the steam to travel through Unit 90 as opposed to the letdown valve.

A comparison of steam production per barrel of Refinery throughput before and after the project corroborates the conclusion that the ULSD project did not cause an increase in refinery steam demand and generation. Using the fuel fired in the four boilers and cogeneration unit, the pre-project and post-project steam production was calculated as follow:

Pre-project (2002-2003): 147.9 MMbtu/1000 bbl feed
Post-project (2006-2008): 147.7 MMbtu/1000 bbl feed

This calculation demonstrates that the steam production per barrel of Refinery throughput did not increase as a result of the ULSD project. Due to the Refinery's integrated steam system with high, medium and low pressure steam, the added 400 psi steam required by Unit 90 did not require that additional 400 psi steam be produced. Rather, it merely affected the pathway for the 400 psi steam to reach the 150 psi steam system. A portion of the 400 psi steam that would otherwise have gone through the step-down valve instead went through Unit 90 and was then released into the 150 psi system.

Operational Criteria Emissions Summary: Daily operational emissions are summarized in Table 3.3-7, together with the SCAQMD daily operational significance thresholds. As demonstrated in the table, operation of the ULSD Project does not exceed any significance thresholds. Therefore, the air quality impacts associated with operational emissions from the ULSD Project are less than significant.

While the Draft EIR does not identify any significant air quality impacts, a mitigation measure is being proposed to ensure that the Refinery operations are consistent with the assumptions upon which the analysis is based.

AQ-1 For five years, the facility permit operator shall monitor and report the fuel usage (standard cubic feet of gas) and the Higher Heating Values (Btu/scf), on an annual basis, for each of the following equipment:

Boiler No. 4 (Device ID D684)
Boiler No. 6 (Device ID D688)
Boiler No. 7 (Device ID D686)
Boiler No. 8 (Device ID D687)
Gas Turbine (Device ID D828)
Turbine Exhaust Heat Recovery Boiler (Device ID D829)

Using the fuel usage and Higher Heating Value data for the above equipment, the facility operator shall calculate and report the annual fuel consumption per barrels of feed (mmBtu/1000 bbl feed). The facility permit operator shall explain any increase in the annual fuel consumption per barrels of feed compared to the previous reporting year. The first reporting year (calendar year 2014) shall be compared to the pre-project (2002-2003) amount of 147.9 MMBtu/1000 bbl feed. For any year in which the reported fuel consumption per barrel of feed exceeds the amount reported for the prior year, the annual report shall also state whether the increase was due in whole or part to the Ultra-Low Sulfur Diesel Project. If the report discloses an increase but states that it is not due to the Ultra-Low Sulfur Diesel Project, then the report shall also explain the cause(s) or circumstance(s) for the increase. The report shall be submitted no later than March 31 of each year (2015 through 2019) for the prior calendar year.

The operator shall, for not less than three years, keep records of the fuel usage and Higher Heating Values used to prepare the reports, and shall make the records available to District personnel upon request.

3.3.2.2 CO Hot Spots

The potential for high concentration of CO emissions associated with truck/vehicle traffic was considered and evaluated per the requirements of the SCAQMD CEQA Air Quality Handbook (SCAQMD, 1993). The Handbook indicates that any project that could negatively impact levels of service at local intersections may create a CO hot spot and should be evaluated. Operation of the ULSD Project did not result in an increase in permanent workers, did not result in an increase in peak hour traffic and, consequently, did not result in a change in level of service that could create a CO hot spot. Therefore, no significant adverse impacts to ambient air quality due to the traffic impact at the intersections in the vicinity of the ULSD Project occurred, so no mitigation is required.

3.3.2.3 Ambient Air Quality Impacts

SCAQMD Rule 1303 (b)(1) requires ambient air quality modeling for stationary sources of new or modified facilities for NOx, CO, and particulate matter to assure that the source will not cause or contribute to a violation of ambient air quality standards. The only component of the ULSD Project subject to ambient air quality modeling is the Replacement Heater B-401 as it is the only stationary source that generates NOx, CO, and particulate matter. The other sources of combustion emissions associated with the ULSD Project include hydrogen production, electricity demand, and truck transport. These sources are located off-site (electricity generation and hydrogen production) or are mobile sources that would occur throughout the Basin and do not overlap with the onsite stationary sources associated with the ULSD Project.

SCAQMD Rule 1303 provides a screening analysis to determine the potential for ambient air quality impacts in lieu of formal modeling. If emissions are less than the threshold emissions provided in Table A-1 of Rule 1303, the emissions would not impact ambient air quality and no further analysis is required. Table A-1 of SCAQMD Rule 1303 is based on the modeling of emissions from different sizes of combustion sources, so emissions less than the threshold emissions in the table would comply with ambient air quality standards and rule requirements. Table 3.3-9 compares the emissions of NOx, CO, and particulate matter to the threshold emissions developed in SCAQMD Rule 1303 Table A-1. For all pollutants, the ULSD Project emissions would be less than the Rule 1303 threshold emissions. Therefore, no significant ambient air quality impact is associated with the ULSD Project.

TABLE 3.3-9

Ambient Air Quality Analysis

	NOx	CO	PM10	PM2.5(1)
Project Emissions (lbs/day)	-25.52	-16.60	0.98	0.98
Project Emissions (lbs/hr) (2)	-1.06	-0.69	0.04	0.04
Screening Thresholds(lbs/hr)(3)	1.31	72.1	7.9	7.9
Significant?	No	No	No	No

(1) PM2.5 thresholds have not been developed for PM2.5 and are assumed to be the same as PM10.
(2) Based on 24 hours/day.
(3) SCAQMD Rule 1303, Appendix A, Screening Analysis, Table A-1 for 30-40 mmBtu/hr combustion sources.

3.3.2.4 Toxic Air Contaminant Impacts

A HRA was performed to determine if emissions of TACs generated by the ULSD Project would exceed the SCAQMD thresholds of significance for cancer risk and hazard indices, thus resulting in significant health impacts. The following subsections summarize the health risks associated with the ULSD Project. Details of the HRA are included in Appendix C. The worst-case project health risks have been determined by comparing the on-site health risks associated with Heater B-201 before the Project (baseline) with the health risks associated with Heater B-401 and the incremental increase in fugitive emissions from Unit 90 (post-Project) as a result of the ULSD Project.

3.3.2.4.1 HRA Methodology

The CARB Hotspots Analysis Reporting Program (HARP) model is the most appropriate model for determining the air quality impacts from the ULSD Project. The HARP model is well suited for refinery modeling since it can accommodate multiple sources and receptors. However, the HARP model utilizes the U.S. EPA Industrial Source Complex dispersion, which has been replaced by AERMOD as the preferred air dispersion model. This analysis utilizes AERMOD for the dispersion and loaded the concentration profiles into HARP using the HARP On-Ramp add-on. The health risks were evaluated in HARP using the SCAQMD *Risk Assessment Procedures for Rules 1401 and 212 Version 7.0* (July 2005). The model default values were modified to conform to the SCAQMD Supplemental Guidelines for Preparing Risk Assessment for AB2588 (SCAQMD, 2005b).

3.3.2.4.2 Hazard Identification

The ULSD Project generates various air contaminants. Some of these chemical compounds are potentially carcinogenic, toxic, or hazardous, depending on concentration or duration of exposure. Numerous federal, state, and local regulatory agencies have developed lists of TACs. The list of potentially-emitted substances considered in the preparation of the HRA for the proposed project is identified in Appendix A-I of the CARB AB2588 requirements and by OEHHA. The AB2588 TACs emitted from the proposed project are shown in Appendix C. Polycyclic aromatic hydrocarbons (PAHs) were speciated in this analysis. Health effects data are not available for all compounds. However, a total of 16 TACs were included in the air dispersion modeling (see Appendix C). For carcinogens, cancer potency slope factors were used to compute cancer risk through inhalation. If the carcinogen is a multi-pathway pollutant, a potency slope was used for estimation of risk from non-inhalation pathways. For non-cancer health effects, reference exposure levels (REL) and acceptable oral doses (for multi-pathway pollutants) were used. The non-carcinogenic hazard indices were computed for chronic and acute exposures with their respective toxicological endpoints shown.

3.3.2.4.3 Emission Estimations and Sources

The emissions estimates of TACs from the heaters are calculated using emission factors from a source test. Fugitive emissions are based on the refinery specific speciation of Unit 90. The emission factors used for emission sources are from the *2012 ConocoPhillips Company Los Angeles Refinery - Wilmington Plant AB 2588 Revision F 2006-2007* and *the 2001 Tosco Los Angeles Refinery Wilmington Plant AB2588 HRA*. The calculated TAC emissions are presented in Appendix C.

3.3.2.4.4 Baseline (Pre-Project) Health Risks

The results of the HRA are summarized in Table 3.3-10.

Cancer Risk Analysis: The baseline maximum cancer risk from Heater 201 for a maximum exposed individual resident (MEIR) is located approximately 260 east of the Refinery. The cancer risk is 7.35×10^{-8} or 0.07 in a million at the MEIR. Hexavalent chromium contributes approximately 75.5 percent of the calculated cancer risk at the MEIR. The inhalation pathway accounts for 84.4 percent of the cancer risk.

The baseline maximum exposed incremental cancer risk at an occupational exposure (MEIW) is located approximately 100 meters east of the Refinery. The incremental cancer risk is 1.89×10^{-8} or 0.02 in a million at the MEIW. Hexavalent chromium contributes approximately 67.7 percent of the calculated cancer risk at the MEIW. The inhalation pathway accounts for 75.7 percent of the cancer risk. Detailed cancer risk contributions by pathway and pollutants are presented in Appendix C.

TABLE 3.3-10

Health Risk Assessment Summary(1)

Health Risk	Maximum Exposed Individual Resident	Maximum Exposed Individual Worker	Maximum Chronic Hazard Index	Maximum Acute Hazard Index
Baseline Health Risks	7.35×10^{-8}	1.89×10^{-8}	0.00282	0.00012
Post-Project Health Risks	1.50×10^{-7}	2.81×10^{-8}	0.00366	0.00015
Project Incremental Health Risks	7.35×10^{-8}	9.20×10^{-9}	0.00084	0.000145
Significance Threshold	10×10^{-6}	10×10^{-6}	1.0	1.0
Significant?	No	No	No	No

(1) See Appendix C for more details on the HRA.

Non-Cancer Risk Analysis: The baseline maximum chronic hazard index (MCHI) total for Heater 201 for the respiratory system is 0.0028. The MCHI is located approximately 100 meters east of the Refinery. Arsenic contributes approximately 97.2 percent of the calculated MCHI.

The baseline maximum acute hazard index (MAHI) total for the central nervous system is 0.00012. The MAHI is located on the eastern boundary of the Refinery. Arsenic contributes approximately 90.3 percent of the calculated MAHI. Detailed contribution by pollutant to the acute hazard index for the maximum receptor locations are presented in Appendix C.

3.3.2.4.5 Post-Project Health Risk

Cancer Risk Analysis: The post-Project maximum cancer risk from Heater 401 and associated fugitives for the MEIR is located approximately 260 meters east of the Refinery. The cancer risk is 1.50×10^{-7} or 0.15 in a million at the MEIR. Hexavalent chromium contributes approximately 48.1 percent of the calculated cancer risk at the MEIR. The inhalation pathway accounts for 59.1 percent of the cancer risk.

The post-Project maximum exposed incremental cancer risk at the MEIW is located approximately 100 meters east of the Refinery. The incremental cancer risk is 2.81×10^{-8} or 0.03 in a million at the MEIW. Hexavalent chromium contributes approximately 58.7 percent of the calculated cancer risk at the MEIW. The inhalation pathway accounts for approximately 68 percent of the cancer risk. Detailed cancer risk contributions by pathway and pollutants are presented in Appendix C.

Non-Cancer Risk Analysis: The post-Project MCHI total for Heater 401 and associated fugitives for the respiratory system is 0.0037. The MCHI is located approximately 100 meters east of the Refinery. Arsenic contributes approximately 96.4 percent of the calculated MCHI. The post-Project MAHI total for the central nervous system is 0.0001. The MAHI is located at the northwestern boundary of the Refinery. Arsenic contributes approximately 90.3 percent of the calculated MAHI. Detailed contribution by pollutant to the acute hazard index for the maximum receptor location is presented in Appendix C.

3.3.2.4.6 Incremental Health Risk

As summarized in Table 3.3-10, the incremental cancer risk for the ULSD Project is 7.65 x 10^{-8} (0.15-0.07) or 0.08 per million at the MEIR and 9.20 x 10^{-9} (0.03-0.02) or about 0.01 per million at the MEIW. The incremental chronic risk is 0.0008 and the incremental acute risk is 0.0001. The cancer risks for the TACs emitted from the ULSD Project are below the significance threshold of ten per million and chronic and acute hazard indices are below the 1.0 thresholds. Therefore, the cancer risk and hazard index thresholds are not considered to be significant and no significant health impacts are associated with the ULSD Project.

3.3.3 MITIGATION MEASURES

No significant air quality impacts have been identified. Therefore, no mitigation measures are required for the ULSD Project. However, the SCAQMD will impose AQ-1, which contains specific reporting requirements, to ensure that the Refinery operations are consistent with the assumptions upon which the air quality analysis is based.

3.3.4 LEVEL OF SIGNIFICANCE

Air quality impacts associated with the ULSD Project are less than significant.

CHAPTER 4

CUMULATIVE IMPACTS

Introduction
Cumulative Air Quality Impacts

4.0 CUMULATIVE IMPACTS

4.1 INTRODUCTION

This chapter presents the requirements for analysis of the cumulative impacts, including the analysis of the potential for the ULSD Project, together with other past, present, and reasonably foreseeable future projects, to have significant cumulative effects. Following the presentation of the requirements related to cumulative impact analyses and a description of the related projects (Sections 4.1.1 and 4.1.2, respectively) and the analysis in Section 4.2 addresses cumulative air quality impacts. As per the Court's order, the required analysis of the ULSD Project is limited to operational air quality impacts. Therefore, the cumulative analysis is also limited to operational air quality impacts.

4.1.1 REQUIREMENTS FOR CUMULATIVE IMPACT ANALYSIS

State CEQA Guidelines (14 CCR §15130) require that an EIR include a reasonable analysis of the significant cumulative impacts of a proposed project. Cumulative impacts are defined by CEQA as "two or more individual effects which, when considered together, are considerable or which compound or increase other environmental impacts" (State CEQA Guidelines, §15355).

Cumulative impacts are further described as follows:

- The individual effects may be changes resulting from a single project or a number of separate projects.

- The cumulative impacts from several projects are the changes in the environment which result from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable future projects. Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time (State CEQA Guidelines, §15355[b]).

- As defined in §15355, a "cumulative impact" consists of an impact that is created as a result of the combination of the project evaluated in the EIR together with other projects causing related impacts. An EIR should not discuss impacts which do not result in part from the project evaluated in the EIR.

When considering whether or not a project contributes to cumulative impacts, it is also necessary to consider CEQA Guidelines §15064(h)(4), which states, "The mere existence of cumulative impacts caused by other projects alone shall not constitute substantial evidence that the proposed project's incremental effects are cumulatively considerable."

The following cumulative impact analysis focuses on whether the air quality impacts of the ULSD Project are cumulatively considerable within the context of impacts caused by other past, present, or reasonably foreseeable future projects. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. This cumulative impact analysis considers other related projects or projects causing related impacts within a geographic scope of approximately one mile from the Phillips 66 Wilmington Plant. One mile is the area of maximum localized air quality impacts.

For this Draft EIR, related projects with a potential to contribute to cumulative impacts were identified using the "list" approach, using a list of closely related projects that would be constructed in the cumulative geographic scope. The list of related projects or projects causing related impacts utilized in this analysis is provided in Table 4-1.

4.1.2 PROJECTS CONSIDERED IN CUMULATIVE IMPACT ANALYSIS

The Project is located within the existing Phillips 66 Wilmington Plant, in the southwest portion of Los Angeles County within Southern California. The Project area includes a mixture of industrial, commercial, transportation, and residential/institutional uses. The Project site itself is located in an existing Refinery in the Wilmington community within the City of Los Angeles. The area has been used as a Refinery for nearly a century and a number of other industrial facilities are located nearby including petroleum storage facilities, warehouses and the Port of Los Angeles. Interstate 110 is located within the vicinity of the Project, just east of the Refinery. Residential areas of Wilmington, San Pedro, and Rancho Palos Verdes are located adjacent to this industrial area.

A number of projects in the vicinity of the ULSD Project were contemporaneous with the ULSD Project, have occurred subsequent to the ULSD Project, or are reasonably foreseeable future projects. A total of 46 of these projects (approved or proposed) have been identified within the general vicinity of the ULSD Project that could contribute to cumulative impacts. The list of cumulative projects is provided in Table 4-1 and the corresponding locations are shown in Figure 4-1.

The analysis of impacts of the ULSD Project has been limited to operational air quality, so the cumulative air quality impact analysis is also limited to operational air quality. The region of analysis for cumulative air quality impacts is the South Coast Air Basin, but the analysis is focused on the communities adjacent to the ULSD Project and generally within one mile of the Wilmington Plant (including portions of Wilmington, Carson, San Pedro, Rancho Palos Verdes, Lomita and Harbor City) because that is the area of maximum localized air quality impacts and the influence of Project emissions decreases with distance from the Refinery.

TABLE 4-1

List of Cumulative Projects

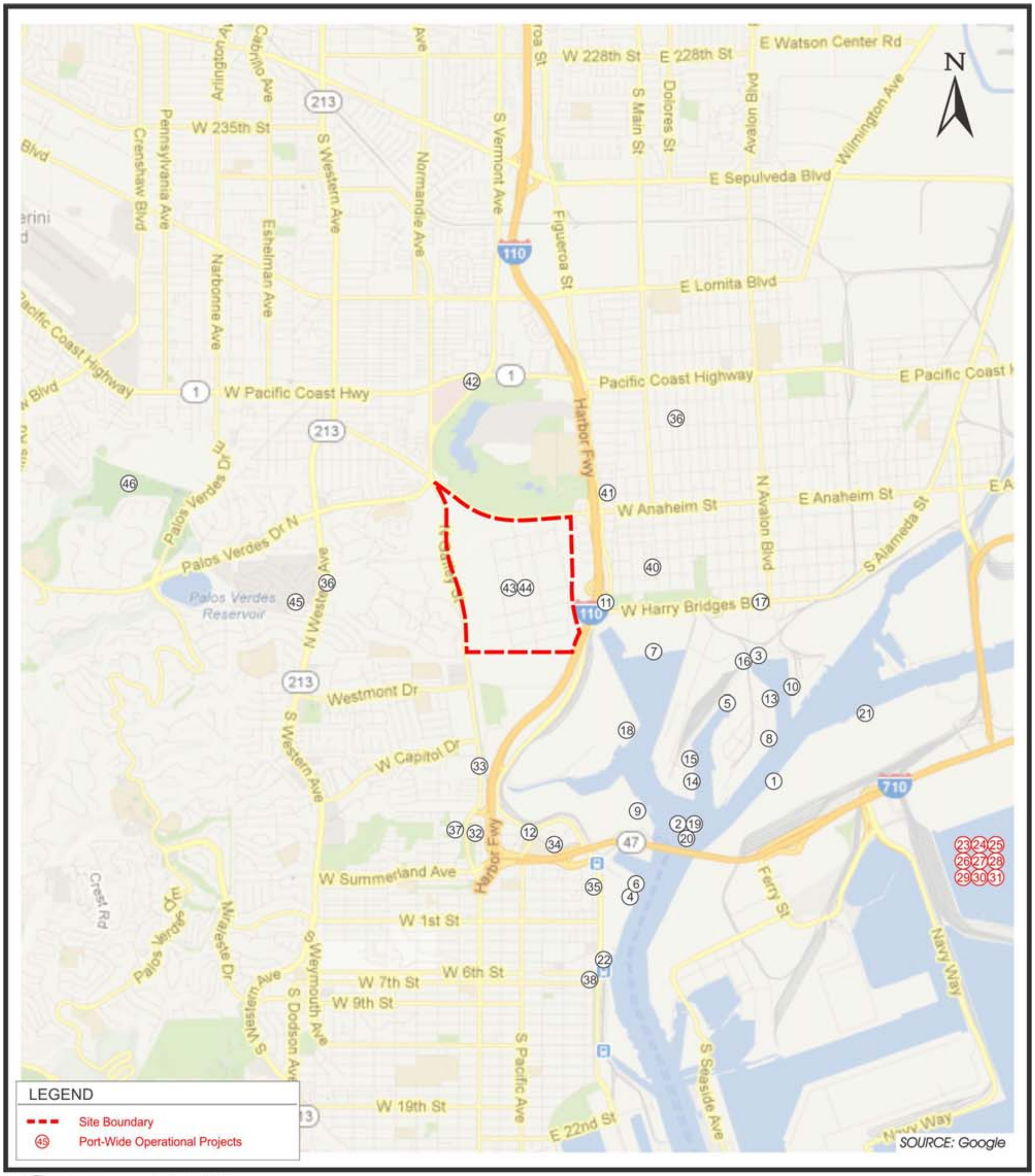
No. in Figure 4-1	Project Title and Location	Project Description	Project Status (Time Frame)
Port of Los Angeles Projects			
1	Berths 212-224 [YTI] Container Terminal Improvements Project	Wharf modifications at the YTI Marine Terminal Project involves wharf upgrades and backland reconfiguration, including new buildings.	Public review period for DEIS/DEIR to end June 16, 2014.
2	Port of Los Angeles Master Plan Update	Redevelopment of Fish Harbor, redevelopment of Terminal Island and consideration of on-dock rail expansion, and consolidation of San Pedro and Wilmington Waterfront districts.	FEIR published August 2013.
3	Wilmington Waterfront Development Project	The 94 acre proposed project site includes about 60 acres south of C street, north of Slip 5, east of Lagoon Avenue, and west of Broad Avenue. The major elements of the Project include pedestrian-oriented features, a Land Bridge park, and a waterfront promenade; new infrastructure for 150,000 sf of future industrial development; 70,000 sf of commercial/retail development; sustainable design elements; 1 acre Railroad Green Park; an observation tower; and transportation improvements. The proposed Project includes removal of the existing LADWP oil tanks. The proposed Project would also extend the Waterfront Red Car Line and California Coastal Trail along John S. Gibson Boulevard and Harry Bridges Boulevard, and potentially develop a 14,500 sf Red Car museum in the historic Berkin's Building complex.	FEIS/FEIR certified June 18, 2009.
4	From Bridge to Breakwater Master Development Plan for the San Pedro Waterfront and Promenade	The proposed project involves a 30-year, multiple phase, master development plan involving development projects and infrastructure improvements for approximately 418 acres. The project includes up to 9.64 acres of new water harbors, wharfs, piers, and floating docks for waterfront activities; creation of a 9.25 mile pedestrian promenade along the entire waterfront; creation of 4.50 miles of on-street bike, roller blade, and pedestrian paths; and approximately 171 acres of public open space areas, including new parks, beaches, recreational areas, landscaped areas, and promenades and plazas. The plan also includes approximately 182 acres of development parcels and 55.5 acres of public streets and sidewalks for up to approximately 1.5 million square feet of visitor-serving and maritime commercial retail, office, restaurants, recreational, and hotel uses. Harbor Boulevard would be realigned. The Red Car Line would be extended to Cabrillo Beach. Parking encompasses a series of surface parking lots and parking structures, spread throughout the project area.	NOP submitted September 8, 2005. FEIR certified September 9, 2009. Project ongoing.
5	Ultramar Inc. Marine Terminal Lease Renewal Project	Proposal to renew the lease between the Port of LA and Ultramar Inc., for continued operation of the marine terminal facilities at Berths 163-164, as well as associated tank farms and pipelines. Project includes upgrades to existing facilities to increase the proposed minimum throughput to 10 million barrels per year (mby), compared to the existing 7.5 mby minimum.	NOP submitted April 29, 2004. Currently on hold.

No. in Figure 4-1	Project Title and Location	Project Description	Project Status (Time Frame)
6	Waterfront Gateway Development Project	The project includes a waterfront Boardwalk along the nothern portion of Slip 93; an entry plaza near the intersection of Harbor Blvd. and Swinford St.; a 50-ft-wide Pedestrian Pkwy between Swinford St. and 5th St. along the east side of Harbor Blvd.; streetscape improvements on both sides of Harbor Blvd. between Swinford St. and 5th St.; intersection improvements along Harbor Blvd. at Swinford St, First Street, 5th Street; and streetscape improvements along First St. between Harbor Blvd. and Gaffey St.	Project complete.
7	Berth 136-147 (TraPac) Container Terminal Project	Element of the West Basin Transportation Improvement Projects. Expansion and redevelopment of the TraPac Container Terminal to 243 acres, including improvement of Harry Bridges Boulevard and a 30-acre landscaped area, relocation of an existing rail yard and construction of a new on-dock rail yard, and reconfiguration of wharves and backlands (includes filling of the Northwest Slip, dredging, and construction of new wharves.)	Construction started in 2009 and ongoing through 2016.
8	Berths 171-181, Pasha Marine Terminal Improvements Project	Redevelopment of existing facilities at Berths 171-181 as an Omni (multi-use) facility.	Project EIR on hold.
9	Berth 97-109 [China Shipping] Container Terminal Project	Development of the China Shipping Terminal Phase I, II, and III, including wharf construction, landfill and terminal construction, and backland development.	Project complete.
10	Berths 195-200A WWL Vehicle Services Americas, Inc. Project	Expansion of vehicle offloading processing, and operations, including cargo increase up to 220,000 vehicles per year and construction of two additional rail loading racks.	MND certified August 16, 2012.
11	C Street/ Figueroa Street Interchange	The C Street/Figueroa Street interchange would be redesigned to include an elevated ramp from Harry Bridges Boulevard to I-110 Freeway, over John S. Gibson Boulevard. There would be a minimum 15-ft clearance for vehicles traveling on John S. Gibson Boulevard. An additional extension would connect from Figueroa Street to the new elevated ramp, over Harry Bridges Boulevard.	MND certified June 21, 2012. Construction expected 2013 through 2016.
12	John S. Gibson Boulevard/I-110 Access Ramps and SR-47/I-110 Connector Improvement Project	Program may include C Street/ I-110 access ramp intersection improvements, I-110 NB Ramp/John S. Gibson Boulevard intersection improvements, and SR-47 on- and off-ramp at Front Street. These projects would reduce delays and emissions in the I-110/SR-47 area and improve safety and access.	MND certified April 5, 2012. Construction expected 2012-2015.
13	Berths 176-181 Break Bulk Terminal Redevelopment	This project would expand the break bulk terminal at Berths 176-181 by up to 8 acres, demolish an existing shed, replace an 700-foot section of wharf, and include additional wharf improvements along Berths 179-181.	Conceptual planning stage.
14	SSA Marine Outer Harbor Fruit Facility Relocation	Proposal to relocate the existing fruit import facility at 22nd and Miner to Berth 153.	On hold.
15	Crescent Warehouse Company Relocation	Relocate the operations of Crescent Warehouse Company from Port Warehouses 1, 6, 9, and 10 to an existing warehouse at Berth 153. Relocate Catalina Freight operations from Berth 184 to same building at Berth 153.	Project complete.

No. in Figure 4-1	Project Title and Location	Project Description	Project Status (Time Frame)
16	South Wilmington Grade Separation	An elevated grade separation would be constructed along a portion of Fries Avenue or Marine Avenue, over the existing rail line tracks, to eliminate vehicular traffic delays that would otherwise be caused by trains using the existing rail line and the new ICTF rail yard. The elevated grade would include a connection onto Water Street. There would be a minimum 24.5-ft clearance for railcars traveling under the grade separation.	Construction expected to be complete spring 2015.
17	Wilmington Waterfront Master Plan (Avalon Boulevard Corridor Project)	Planned development intended to provide waterfront access and promoting development specifically along Avalon Boulevard.	EIR certified June 18, 2009. Construction expected 2012 through 2014.
18	Berths 121-131 (Yang Ming) Container Terminal Improvements Project	Reconfiguration of wharves and backlands. Expansion and redevelopment of the Yang Ming Terminal.	Public review period for NOI/NOP ends May 25, 2014.
19	Port Transportation Master Plan	Port-wide transportation master plan for roadways in and around POLA facilities. Present and future traffic improvement needs are being determined, based on existing and projected traffic volumes. Some improvements under consideration include I-110/SR-47/Harbor Boulevard interchange improvements; south Wilmington grade separations; and additional traffic capacity analysis for the Vincent Thomas Bridge.	Conceptual planning document ongoing.
20	Channel Deepening Project	Dredging and sediment disposal. This project deepened the POLA Main Channel to a maximum depth of –53 ft mean lower low water (MLLW; lesser depths are considered as project alternatives) by approximately 4 were for up to 151 acres (61 hectares) of landfill biology, for new fill locations. The Additional Disposal Capacity Project would provide approximately 4 million cubic yards of disposal capacity needed to complete the Channel Deepening Project and maximize beneficial use of dredged material by constructing lands for eventual terminal development and provide environmental enhancements at various locations in the Port of Los Angeles.	Project complete.
21	Berths 206-209 Interim Container Terminal Reuse Project	Proposal to allow interim reuse of former Matson Terminal while implementing green terminal measures.	New EIR on hold.
22	POLA Charter School and Port Police Headquarters, San Pedro	Proposal to lease property for the POLA Charter School and to construct a Port Police Headquarters and office. 330 S. Centre Street, San Pedro.	Project complete.
Port of Los Angeles and/or Port of Long Beach Potential Port-Wide Operational Projects			
23	Navy Way/Seaside Avenue Interchange	Construction of a new flyover connector from northbound Navy Way to westbound Seaside Avenue. This improvement is part of the Ports Infrastructure Cargo Fee Program.	Conceptual planning stage.
24	Terminal Free Time	Port program to reduce container storage time and use gates at off-peak travel times.	Program in progress.
25	Extended Terminal Gates (Pier Pass)	Port program to use economic incentives to encourage cargo owners to use terminal gates during off-peak hours.	Program in progress.

No. in Figure 4-1	Project Title and Location	Project Description	Project Status (Time Frame)
26	Shuttle Train/Inland Container Yard	ACTA program to encourage rail shuttle service between the on-dock rail facilities at the ports and a rail facility in Colton (in the Inland Empire). The pilot program will consist of a daily train to and from Colton. The containers will be trucked between the Colton rail facility and the cargo owners' facility.	Preliminary study in progress.
27	Origin/Destination and Toll Study	Port study to identify the origin and destination of international containers in the Los Angeles area, to determine the location of warehouses and identify the routes truck drivers use to move containers to and from the ports. The bridges serving Terminal Island (Vincent Thomas, Gerald Desmond and Heim Bridge) are not currently designed to handle the trade volumes projected at the ports. The ports are conducting a toll study to explore potential funding sources for bridge replacement and truck driver behavior if tolls were assessed on the bridges.	Study in progress.
28	Virtual Container Yard	ACTA and Ports program to explore implementing a system that would match an empty container from an import move to one from an empty export move.	Conceptual planning phase.
29	Increased On-Dock Rail Usage	ACTA and Ports program with shipping lines and terminal operators to consolidate intermodal volume of the neighboring terminals to create larger trains to interior points, thereby reducing need for truck transportation.	Conceptual planning phase.
30	Optical Character Recognition	Ports terminals have implemented Optical Character Recognition technology, which eliminates the need to type container numbers in the computer system. This expedites the passage of trucks through terminal gates.	Conceptual planning phase.
31	Truck Driver Appointment System	Appointment system that provides a pre-notification to terminals regarding which containers are planned to be picked up.	Conceptual planning phase.
Community of San Pedro Projects			
32	San Pedro Community Plan Update	The Proposed San Pedro Community Plan includes changes in land use designations and zones that are intended to accommodate growth anticipated in the SCAG 2030 Forecast. The Plan aims at preserving existing single-family residential neighborhoods and accommodating a variety of housing opportunities near public transit, services, and amenities.	DEIR submitted August 10, 2012. Circulation period ended September 24, 2012.
33	Single Family Homes (Gaffey Street)	Project to construct 135 single-family homes on about 2 acres. 1427 N Gaffey Street (at Basin Street), San Pedro.	Construction on-going. Several homes have been occupied.
34	Mixed-use development, 281 W 8th Street	Project to construct 72 condominiums and 7,000 square feet retail. 281 West 8th Street (near Centre Street), San Pedro.	Under construction.
35	319 N. Harbor Boulevard	Construction of 94 unit residential condominiums.	Construction has not started.
36	Ponte Vista/Naval Site	Construct 1725 condominiums, 575 senior housing units, and 4 baseball fields at 26900 Western Avenue (near Green Hills Park), San Pedro. Rolling Hills Prep School being developed in an adjacent lot.	Under construction.

No. in Figure 4-1	Project Title and Location	Project Description	Project Status (Time Frame)
37	Cabrillo Avenue Extension	This project will widen Cabrillo Avenue to 36-ft of roadway and 9-ft of sidewalk from Miraflores Avenue to existing alley. It will also widen the existing alley to 25-ft and connect it to Channel Street by acquiring right-of-way.	Construction is expected to begin in August 2013, and to be completed by July 2014.
38	Pacific Corridors Redevelopment Project	Development of commercial/retail, manufacturing, and residential components. Construction underway of four housing developments and Welcome Park.	Expected completion in 2032.
Community of Wilmington Projects			
39	Distribution Center and Warehouse	Project to construct a 135,000-square foot distribution center and warehouse on a 240,000-square foot lot with 47 parking spaces at 755 East L Street (at McFarland Avenue) in Wilmington.	Construction has not started.
40	Dana Strand Public Housing Redevelopment Project	Project to construct 413 units of mixed-income affordable housing in four phases: Phase I - 120 rental units; Phase II - 116 rental units; Phase III - 100 senior units; Phase IV - 77 single family homes. The plans also include a day care center, lifelong learning center, parks and landscaped open space.	Phases I and II have been completed and are being leased. Phases III and IV are currently under development.
41	931 N. Frigate Avenue	Private school expansion for 72 student increase for a total of 350 students.	Construction has not started.
Community of Harbor City Projects			
42	Kaiser Permanente South Bay Master Plan	Project to construct a 303,000-square foot medical office building, 42,500 square feet of records center/ office/warehouse, and 260 hospital beds. 25825 Vermont Street, Harbor City (at PCH).	Project complete.
Projects in Wilmington/Carson			
43	ConocoPhillips Refinery Tank Replacement Project	ConocoPhillips operators are in the process of removing seven existing petroleum storage tanks and replacing them with six new tanks, four at the Carson Plant, and two new tanks at the Wilmington Plant.	ND certified July 2008.
44	Phillips 66 Los Angeles Refinery PM10 and NOx Reduction Projects	Proposed projects that will reduce particulate matter less than 10 microns in diameter and nitrogen oxide emissions at its existing Wilmington and Carson Plants. Modifications included new wet gas scrubber, wet electrostatic precipitator, and a selective catalytic reduction unit at the Wilmington Plant. A new selective catalytic reduction unit was also installed at the Carson Plant.	Project Complete.
City of Rancho Palos Verdes Projects			
45	Green Hills Master Plan Revision	Revision to the Green Hills Cemetery Master Plan, addressing ultimate build-out of the cemetery site over the next 30 to 50-years allowing up to a total of 643,259 cubic yards of grading.	Planning Comission approved on April 27, 2007.
City of Rolling Hills Estates Projects			
46	Chandler Rance / Rolling Hills Country Club Project	Project includes 114 new single family homes, a reconfigured 18-hole golf course, and a new approximately 61,000 square foot clubhouse and related facilities. The 228-acre project site is located on the existing sites of the Chandler Quarry and Rolling Hills Country Club.	City Council approved FEIR on July 26, 2011.



Environmental Audit, Inc.

FIGURE 4-1
CUMULATIVE PROJECTS LOCATION MAP
Phillips 66 ULSD Project

Project No. 2696

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Local impacts were assumed to include projects which would occur within the same timeframe as the ULSD Project (about 2002 until 2012) and which are within a one-mile radius of the Refinery site. These projects generally include other Refinery projects, port projects, and projects in near-by cities. Figure 4-1 identifies by number the location of each of the projects. The numbers are used to identify the related projects throughout the discussion of cumulative impacts. Impacts to most environmental resources are generally localized in nature (e.g., air quality, noise, and traffic). Consequently, there is sufficient distance between projects located over one mile away from the Wilmington Plant to avoid cumulative impacts.

The cumulative projects in Table 4-1 have been identified using databases from the Port of Los Angeles, State Clearinghouse, City of Los Angeles (including for the communities of San Pedro and Wilmington), County of Los Angeles, SCAQMD, City of Carson, City of Harbor City, City of Lomita, City of Rancho Palos Verdes, and City of Rolling Hills Estates.

No major changes were required at the Phillips 66 Carson Plant because the project modifications at the Carson Plant did not result in direct physical impacts to the environment (e.g., air emissions, noise, traffic, etc.) (CEQA Guidelines §15064(d)(1)) or indirect environmental impacts (CEQA Guidelines §15064(d)(2)), there were no environmental impacts associated with modifications at the Carson Plant to be evaluated in Chapter 3 of this EIR. For the same reason, since there were no physical impacts to the environment at the Carson Plant, the cumulative impacts analysis will be limited to the Wilmington Plant and projects within approximately one mile of the Wilmington Plant.

4.2 CUMULATIVE AIR QUALITY IMPACTS

4.2.1 OPERATIONAL EMISSION IMPACTS

The past, present, and reasonably foreseeable future projects would have a significant cumulative impact. However, the ULSD Project operational emissions are substantially less than the SCAQMD project-specific significance thresholds (see Table 3.3-7). Therefore, project-specific air quality impacts associated with operational emissions from the ULSD Project are not considered to be a cumulatively considerable contribution to significant adverse cumulative air quality impacts.

Table 4-2 presents the maximum estimated daily emissions from the ULSD project as a percentage of the CEQA significance thresholds. The contribution of the project to cumulative air quality is very small. The peak daily emissions of CO, SOx, PM10 and PM 2.5 are all well below 10 percent of the project-specific CEQA significance thresholds, and CO is less than one percent of the threshold. In addition, while the table shows that peak daily emissions of NOx are approximately one quarter of the project-specific significance threshold, a substantial part of these emissions are related to concurrent truck deliveries of ammonia and catalyst that might occur a maximum of one day every two to three years. The delivery of up to four truck trips per day of Unit 90 catalyst will occur for two weeks every two to three years, and the delivery of one truck per day of ammonia will occur once per year; both events are infrequent, and they may never occur at the same time. On all other days, the ULSD project will result in a net reduction in NOx emissions.

TABLE 4-2

ULSD Operational Emissions Cumulative Contribution

	CO	VOC	NOx	SOx	PM10	PM2.5
ULSD Project Emissions (lbs/day)(1)	**0.93**	**10.36**	**14.06**(2)	**4.11**	**4.67**	**4.67**
SCAQMD Significance Thresholds (lb/day)	550	55	55	150	150	55
Individually Significant?	NO	NO	NO	NO	NO	NO
Percentage of Significance Threshold	0.17	18.83	25.56	2.74	3.11	8.49
Cumulatively Considerable Contribution?	NO	NO	NO	NO	NO	NO

(1) See Table 3.3-7.
(2) See Appendix B for detailed emission calculations. Differences in emissions in this table and Appendix B are due to rounding.

Other related projects at the Refinery included the construction of air pollution control equipment to reduce PM10 and NOx from the Phillips 66 Refinery (No. 40). This project resulted in large emission decreases in NOx, SOx, and particulate matter from the installation of a wet gas scrubber on the Fluid Catalytic Cracking Unit and an SCR Unit on Boiler 7. Therefore, cumulative air quality impacts from Refinery projects were beneficial during this period.

Other off-site cumulative projects could result in significant operational air quality impacts including a number of Port projects, such as Berth 212-224 Container Terminal Improvements (#1), San Pedro Waterfront Promenade (#4), Waterfront Gateway Project (#6), Berth 136-147 TraPac Terminal (#7), Berths 97-109 - China Shipping (#9), Berths 195-200A WWL Vehicle Terminal (#10), and Berth 121-131 Yang Ming Terminal (#18). In addition, projects could provide air quality improvements by reducing traffic delays, such as the South Wilmington Grade Separation (#16), I-110/C Street/Figueroa Street Interchange (#11), Port Transportation Master Plan (#19), and Increased On-dock Rail Usage (#29). However, as already noted above operational emissions from the ULSD Project are substantially less than the applicable project-specific operational significance thresholds and cumulative Refinery projects have resulted in a net reduction in emissions. Therefore, operational emissions associated with the ULSD Project are not considered a cumulatively significant contribution to significant adverse cumulative air quality impacts.

4.2.2 TOXIC AIR CONTAMINANT IMPACTS

The impacts from TACs are localized impacts. For example, impacts from exposures to TACs decline by approximately 90 percent at 300 to 500 feet from the emissions source (SCAQMD, 2005). As indicated in Table 4-1, most related projects are located at greater than 500 feet from the Phillips 66 Refinery or are projects that would not result in increases in TACs, such that potential

TAC impacts would not overlap with the ULSD Project. The ULSD Project impacts on health effects associated with exposure to TACs are expected to be substantially below the SCAQMD's cancer risk and hazard index significance thresholds and, therefore, less than significant. The ULSD Project impacts on cancer risk to the MEIR and MEIW were estimated to be 7.35×10^{-8} (about 0.07 per million) and 9.20×10^{-9} (about 0.009 per million), respectively, which is well below the significance threshold of ten per million. The chronic health index and acute health index was estimated to be 0.0008 and 0.0001, respectively, which is well below the significance threshold of one (1.0). Therefore, the ULSD Project impacts are not considered to be cumulatively considerable and, therefore; are not expected to contribute to significant adverse cumulative TAC impacts.

Other off-site cumulative projects could result in significant TAC emissions, including a number of port projects such as Berth 212-224 Container Terminal Improvements (#1), San Pedro Waterfront Promenade (#4), Waterfront Gateway Project (#6), Berth 136-147 TraPac Terminal (#7), Berths 97-109 - China Shipping (#9), Berths 195-200A WWL Vehicle Terminal (#10), and Berth 121-131 Yang Ming Terminal (#18). In addition, projects could provide air quality improvements, including TAC emissions, by reducing traffic delays, such as the South Wilmington Grade Separation (#16), C Street/Figueroa Street Interchange (#11), Port Transportation Master Plan (#19), I-110/SR-47 Connector Improvement Program (#12), and Increased On-dock Rail Usage (#29). However, as already noted above TAC emissions from the ULSD Project are substantially less than the applicable project-specific health risk significance thresholds. Therefore, cumulative impacts of TACs on health risks are expected to be less than significant.

4.2.3 MITIGATION MEASURES

No significant air quality impacts have been identified. Therefore, no mitigation measures are required for the ULSD Project. However, the SCAQMD will impose AQ-1, which contains specific reporting requirements, to ensure that the Refinery operations are consistent with the assumptions upon which the air quality analysis is based.

4.2.4 LEVEL OF SIGNIFICANCE AFTER MITIGATION

The project-specific air quality impacts due to operational activities do not exceed the SCAQMD significance thresholds, are not considered to be cumulatively considerable, and do not contribute to significant adverse cumulative operational air quality impacts. The project-specific TAC health impacts are not significant, are also not considered to be cumulatively considerable, and do not generate significant adverse cumulative TAC impacts.

CEQA Guideline §15130(a) indicates that an EIR shall discuss cumulative impacts of a project when the project's incremental effect is cumulatively considerable. Where a lead agency is examining a project with an incremental effect that is not cumulatively considerable, a lead agency need not consider the effect significant, but must briefly describe the basis for concluding that the incremental effect is not cumulatively considerable. Therefore the project's contribution to operational air emissions, including toxic air contaminant emissions is not cumulatively considerable and thus not cumulatively significant because the environmental conditions would essentially be the same whether or not the ULSD Project is implemented (CEQA Guidelines §15130). This conclusion is consistent with CEQA Guidelines §15064(h)(4), which states, "The mere existence of cumulative impacts caused by other projects alone shall not constitute substantial evidence that the proposed project's incremental effects are cumulatively considerable".

CHAPTER 5

PROJECT ALTERNATIVES

5.0 PROJECT ALTERNATIVES

5.1 INTRODUCTION

This EIR provides a discussion of alternatives to the ULSD Project as required by CEQA. According to the CEQA guidelines, alternatives should include realistic measures to attain the basic objectives of the proposed project and provide means for evaluating the comparative merits of each alternative. In addition, though the range of alternatives must be sufficient to permit a reasoned choice, they need not include every conceivable project alternative (CEQA Guidelines, §15126.6(a)). The key issue is whether the selection and discussion of alternatives fosters informed decision making and public participation.

Alternatives presented in this chapter were developed by reviewing alternative options to reduce the sulfur content of feed-stocks in order to obtain more CARB-compliant diesel blending stocks. Because of the limited range of options for reducing sulfur content in feedstocks, each project alternative described below is similar to the ULSD Project in most respects. The rationale for selecting specific components of the Project on which to focus the alternatives analysis rests on CEQA's requirements to present a range of reasonable project alternatives that could feasibly attain the basic objectives of the project, while generating fewer or less severe adverse environmental impacts.

The objectives of the Project are to produce ULSD that complies with the diesel sulfur content standards set by the SCAQMD, CARB, and U.S. EPA, and to insure that adequate supplies of ULSD are available to meet future demand. With the exception of the "No-Project" alternative, the alternatives presented in this chapter involve modifications to aspects of the specific equipment or operations of the ULSD Project that would still allow the Refinery to meet the objectives of producing ULSD meeting U.S. EPA, CARB, and SCAQMD specifications for gasoline and diesel fuel.

Section 15126.6(f) of the CEQA Guidelines stipulates that the range of alternatives required in an EIR is governed by a rule of reason in that the EIR must discuss only those alternatives "necessary to permit a reasoned choice" and those that could feasibly attain most of the basic objectives of the Refinery. As discussed in Section 1.4, no court decision invalidated any aspect of the prior CEQA documents except for the baseline used in the air quality impacts analysis for Refinery operations. The Draft EIR for the Phillips 66 ULSD Project focuses on the issues as directed by the court and is limited to air quality setting and impacts from Refinery operations. Therefore, the alternatives analysis is also limited to air quality impacts from Refinery operations.

5.2 ALTERNATIVES REJECTED AS INFEASIBLE

In accordance with CEQA Guidelines §15126.6(c), a CEQA document should identify any alternatives that were considered by the lead agency, but were rejected as infeasible during the scoping process and briefly explain the reason underlying the lead agency's determination. CEQA Guidelines §15126.6(c) also states that among the factors that may be used to eliminate alternatives from detailed consideration in an EIR are: (1) failure to meet most of the basic project objectives;

(2) infeasibility; or (3) inability to avoid significant environmental impacts. Furthermore, CEQA Guidelines §15126.6(f)(2)(B) indicates that if the lead agency concludes that no feasible alternative locations for the project exist, it must disclose the reasons for this conclusion, and should include the reasons in the EIR. The objectives of the ULSD Project are as follows:

- Reduce the sulfur content of diesel fuel produced at the Phillips 66 Los Angeles Refinery to reduce SOx and sulfate emissions from mobile sources in the basin.
- Reduce the sulfur content of diesel fuel produced at the Phillips 66 Los Angeles Refinery, which allows widespread use of particulate filters to reduce PM emissions that would otherwise fail if diesel fuel with a higher sulfur content is used.
- Comply with SCAQMD's Rule 431.2 which requires a reduction in sulfur content in diesel fuel used in stationary sources to 15 ppmw.
- Comply with CARB's 2000 Diesel Risk Reduction Plan to reduce risk exposure from diesel particulate matter.
- To ensure that adequate supplies of ULSD are available to meet future demand.
- Comply with the U.S. EPA's diesel fuel standards that required refiners to sell highway diesel fuel that meets a maximum sulfur standard of 15 ppmw.

The following two sub-sections include descriptions of alternatives rejected as infeasible and the rationale for rejecting each alternative.

5.2.1 ALTERNATIVE SITES

CEQA Guidelines §15126.6(f)(2) includes consideration of an alternative location for a project if any significant effects of the project can be avoided or substantially lessened. An alternative location for the ULSD Project has been rejected because it would not accomplish Refinery objectives and also because it is not feasible. The objective of the ULSD Project was to modify the existing Refinery so that it can continue to produce diesel fuel meeting regulatory requirements, as those requirements have become more stringent over time. The Refinery operates as an integrated manufacturing complex in which raw materials, including crude oil, are put through a series of treatments in processing units to produce a range of different fuels and other products and by-products. In addition to processing units, the integrated plant requires ancillary equipment, utilities and infrastructure such as natural gas, water, and electric transmission infrastructures; petroleum product transportation infrastructure; emissions control and wastewater treatment systems. For example, a hydrotreater unit requires numerous services provided by the refinery, e.g., refinery fuel gas, flares, storage facilities, feedstocks, etc. Thus, it is not feasible to isolate the "ULSD" components of the Refinery and establish them at a separate location on an alternative site. To produce compliant diesel fuel at an alternative location would in fact require the development of an entirely new refinery in an alternative location. This would require substantially more equipment and construction, be very costly and potentially generate substantially greater impacts in many environmental categories (e.g., air quality, traffic and hazards) than the ULSD Project at the Refinery. It also would require years of lead time to engineer, obtain permits and approvals, and construct. In addition, there will be an uncertainty necessary permits would be approved in a timely manner. Therefore, an alternative site for the ULSD Project is not considered to be feasible.

5.2.2 PURCHASE OF LOW SULFUR FEEDSTOCKS

Rather than reducing the sulfur content of diesel at the Phillips 66 Wilmington Plant, low sulfur blending components could be purchased by Phillips 66, transported to the Refinery, and blended with its manufactured streams. This alternative would require: (1) that sufficient quantities of the appropriate blendstocks be available for purchase at an economic price; (2) that the required quantities can be delivered to the Refinery by marine vessel, railcar, truck or existing pipelines; and, (3) that the Refinery have sufficient tankage to store and handle the required quantities of imported blendstocks. Since the effective dates that the ULSD standards went into effect, existing refineries in California have been using all their low sulfur feedstocks to manufacture ULSD and maintain their own diesel output. Therefore, it is assumed that low sulfur feedstocks, if available, would be purchased from sources outside of California and transported to the Wilmington Plant via marine vessels, resulting in increased marine vessel emissions. Therefore, this alternative is rejected as infeasible because it is unlikely that sufficient quantities of low sulfur feedstocks within California would be available for purchase. The other option under this alternative of importing foreign feedstocks from outside of California would potentially generate significant adverse environmental impacts to more environmental topic areas or make existing impacts substantially worse, which is inconsistent with the objectives of an alternatives analysis.

5.3 DESCRIPTION OF THE PROJECT ALTERNATIVES

5.3.1 ALTERNATIVE 1 – NO PROJECT ALTERNATIVE

CEQA Guidelines§15126.6(e)(2) requires that the No Project Alternative "discuss the existing conditions at the time the notice of preparation is published, or if no notice of preparation is published, at the time environmental analysis is commenced, as well as what would be reasonably expected to occur in the foreseeable future if the project were not approved." For the ULSD Project and this EIR, the environmental baseline is considered to be the time that environmental analysis commenced which was generally the 2002-2003 timeframe, which will also serve as the basis for the analysis of the No Project Alternative. As noted earlier, the ULSD Project has been constructed and is operational. However, in order to provide an unbiased analysis of the No Project Alternative, the environmental analysis of this alternative will assume the 2002-2003 timeframe as if the ULSD Project had not been approved and built.

The No Project Alternative would not allow the Wilmington Plant to produce diesel fuel that complies with the U.S. EPA, CARB, and SCAQMD mandates for ultra low sulfur diesel (15 ppmw sulfur). Under this scenario, any excess high sulfur diesel material that could not be processed at either the FCC or Hydrocracker Units would have to be sold into the cutter/gas oil market and likely shipped outside of the country. This would mean that there would be increased marine shipments of higher sulfur material via marine vessel. It is expected that the Jet Fuel Hydrotreater Unit 89 would be shutdown. This alternative could require that additional facilities be installed, including a Vapor Recovery Unit at the Marine Terminal, to accommodate large and frequent marine shipments of high sulfur diesel material.

In addition, low sulfur diesel blendstocks could be shipped into the Refinery, if it could be found for purchase on the market. As discussed under Section 5.2.2, low sulfur feedstocks, if available, could be purchased from sources outside of California and transported to the Wilmington Plant via marine vessels. Sufficient quantities of low sulfur feedstocks are not available to offset the ULSD produced under the Phillips 66 ULSD Project; however, low sulfur feedstocks may be occasionally available for purchase. Under the No Project Alternative, additional quantities of low sulfur feedstocks may be delivered via marine vessel to the marine terminal/Refinery. Nonetheless, under the No Project Alternative, Phillips 66 would produce little, if any, ULSD, resulting in a decrease in ULSD in California.

5.3.2 ALTERNATIVE 2 – NEW S-ZORB UNIT

Alternative 2 would use S-Zorb technology, which is an alternative hydrotreating technology, to produce ULSD. S-Zorb involves similar technology to other hydrotreaters and includes a reactor, regenerator, and reducer. The main chemical reactions in the S-Zorb reactor are sulfur adsorption, olefin hydrogenation, and olefin hydroisomerization. The sorbent absorbs sulfur compounds from the feedstocks in the presence of hydrogen. Sorbent regeneration and reduction occur in the regenerator and reducer. S-Zorb removes sulfur by producing sulfur dioxide which would be fed to a sulfuric acid plant or treated by a control device. Traditional hydrotreaters treat feedstocks using a catalyst in the presence of hydrogen to produce hydrogen sulfide.

Under Alternative 2, the existing Unit 90 Hydrotreater would be replaced. Therefore, Alternative 2 would require the construction of a new S-Zorb hydrotreating unit including the following equipment: feed filter and feed surge drum, reactor charge pump, reactor feed/effluent exchanger, reactor charge heater, reactor, reactor effluent filter, product separators, stabilizer, recycle hydrogen compressor, sorbent flow equipment (including reducer, reactor, and reactor receiver), regenerator feed drum, regenerator, and regenerator receiver. Other Refinery modifications would be needed to process the sulfur dioxide bearing off-gas generated by the S-Zorb process.

The S-Zorb hydrotreating process was developed by Phillips Petroleum Company in the late 1990's and has been installed in one refinery for treating gasoline. S-Zorb has never been used to commercially hydrotreat diesel fuels, therefore, the current feasibility of this technology for producing ULSD is not proven.

5.3.3 ALTERNATIVE 3 – HIGH PRESSURE HYDROTREATING

Alternative 3 would use high pressure hydrotreating to not only reduce sulfur to meet ULSD requirements, but would also alter other properties of diesel fuel not required to meet ULSD specifications. Under Alternative 3, the existing Unit 90 Hydrotreater would be replaced. Alternative 3 would require the construction of an entirely new unit, a 1200 psig hydrotreater, instead of only modifying the existing medium pressure Unit 90. In addition, Alternative 3 would require either a new hydrogen plant or the purchase of additional hydrogen from a third party due to the more extensive hydrotreating of a high pressure unit, which is beyond that required to remove sulfur to ULSD levels. Alternative 3 would require substantially more construction activities as a new hydrotreating unit would be required and potentially a new hydrogen production unit, as compared to modification of an existing unit. Therefore, Alternative 3 would result in greater construction activities, higher emissions, higher hazard impacts and higher costs than the ULSD Project.

5.4 AIR QUALITY IMPACTS FROM THE PROJECT ALTERNATIVES COMPARED TO THE ULSD PROJECT

5.4.1 ALTERNATIVE 1 – NO PROJECT ALTERNATIVE

5.4.1.1 Air Quality

Air quality impacts associated with construction of the ULSD Project would be eliminated under Alternative 1. Construction emissions associated with the ULSD Project were considered less than significant for all pollutants in previous environmental analyses (SCAQMD, 2004 and 2005). Alternative 1 could require construction activities associated with additional vapor recovery at the marine terminal to transport greater quantities of low sulfur feed stocks. Construction activities required under the No Project Alternative are also expected to be less than significant.

The stationary source emissions associated with the operational phase of Alternative 1 would be less than the ULSD Project within the Basin since limited modifications would be required to the Refinery under Alternative 1. Although less than significant, the operational emissions associated with the ULSD Project identified in Table 3.3-7 would be eliminated.

Under Alternative 1, the Refinery would continue to produce gasoline, diesel and jet fuel range blending materials as a result of the crude refining process. Without the ULSD Project, these the diesel fuel blending materials would exceed sulfur limits and could generally not be sold in the United States. It is expected that additional quantities of high sulfur feed stocks (e.g., diesel fuel or diesel blending stocks) would be delivered to the marine terminals for transfer offshore to other countries. Therefore, the No Project Alternative would result in increased off-shore or rail transportation emissions associated with the transport of higher sulfur feedstocks, likely via marine vessel.

Under Alternative 1, it is also expected that additional quantities of low sulfur feed stocks (e.g., diesel fuel or diesel blending stocks) would be delivered to the marine terminal/Refinery, when found available for purchase on the market. The No Project Alternative could also result in increased ground transportation emissions associated with the transport of low sulfur feedstocks. The No Project Alternative is expected to result in additional transport of products using marine vessels, resulting in higher transportation emissions than under the ULSD Project. Therefore, air quality impacts under the No Project Alternative are expected to be greater than the ULSD Project and are expected to be significant.

Alternative 1 would eliminate the increased toxic air contaminant emissions from stationary sources associated with the ULSD Project and the associated health risks. The health risks associated with the ULSD Project (both carcinogenic and non-carcinogenic) were considered to be less than significant. However, under Alternative 1, there could be increased transportation of diesel fuel blendstocks to the terminals/Refinery along with the associated increased transportation emissions, including increased diesel particulate emissions and the related health risk associated with exposure to diesel particulate emissions. Because of the cancer risk associated with diesel particulates is high compared to the combustion of other fuel sources, it is expected that the toxic air contaminant impacts would be greater under Alternative 1 than the ULSD Project and potentially significant.

5.4.2 ALTERNATIVE 2 – NEW S-ZORB UNIT

5.4.2.1 Air Quality

Air quality impacts associated with construction under Alternative 2 would increase because Alternative 2 would require the construction of a new S-Zorb unit, which is essentially a new hydrotreater unit, as well as modifications to the Sulfuric Acid Plant. Under Alternative 2, the construction activities are expected to be greater than the peak construction activities associated with the ULSD Project, since an entire new unit would need to be constructed and demolition of existing facilities would likely be required. Based on this assumption, the construction emissions under Alternative 2 are expected to be significant for CO, VOC, NOx, PM10 and PM2.5

Operational air quality impacts generated by Alternative 2 are expected to be greater than operational air quality impacts from the ULSD Project because a new unit will be operated (rather than modifications to an existing unit). Alternative 2 is expected to have higher fugitive VOC emissions than the ULSD Project because the S-Zorb Unit is a more complicated unit than the Unit 90 Hydrotreater, and thus would require more fugitive components (pumps, valves, and flanges) than Unit 90. In addition, the S-Zorb Unit uses a fluidized catalyst to remove sulfur, which would create particulate emissions that would be discharged through a flue gas stack. A new charge heater would also be required but is expected to be the same size as the existing heater. Overall, the air quality impacts associated with Alternative 2 are expected to be greater than the ULSD Project, but still less than significant due to the SCAQMD requirement to use BACT.

Alternative 2 would result in an increase in fugitive and particulate emissions, resulting in increased toxic air contaminant emissions from the new unit and increased health risks. Therefore, the health risks associated with Alternative 2 are expected to be greater than the ULSD Project, but are still expected to be less than significant due to the use of BACT. The health risks associated with the ULSD Project (both carcinogenic and non-carcinogenic) were considered to be less than significant.

5.4.3 ALTERNATIVE 3 – HIGH PRESSURE HYDROTREATING

5.4.3.1 Air Quality

Air quality impacts associated with construction under Alternative 3 would increase compared to the proposed Project because of the additional construction activities required. Construction activities include the construction of the new Hydrotreater Unit and possibly a new Hydrogen

Plant. The construction activities are expected to be about four times greater than the peak construction activities associated with the ULSD Project. Based on this assumption, the construction emissions from construction activities would be significant for CO, VOC, NOx, PM10 and PM2.5.

Under Alternative 3 air quality impacts are expected to be greater in the operational phase due to the construction and operation of two new units compared to the ULSD Project. The operation of a new hydrogen plant and hydrotreater units would require additional heat sources so a new heater is expected to be required. The charge heater for the new Hydrotreater would be larger than the existing heater as more heat is required to operate the high pressure hydrotreater. Therefore, the air quality impacts associated with Alternative 3 are expected to be higher than the existing Unit 90 Hydrotreater in the proposed Project because of the need for additional hydrogen and increased firing of combustion sources. Overall, the air quality impacts associated with Alternative 3 are expected to be greater than the ULSD Project, but still less than significant due to the SCAQMD requirement to use BACT that reduces operational air quality impacts.

Alternative 3 would result in an increase in toxic air contaminant emissions from all of the new units and an increase in the associated health risks. Therefore, the health risks associated with Alternative 3 are expected to be greater than the ULSD Project, but are still expected to be less than significant due to the use of BACT that reduces operation toxic risk.

5.5 CONCLUSION

Table 5-1 compares the potential environmental impacts of the various alternatives relative to the ULSD Project.

The No Project Alternative (Alternative 1) would eliminate less than significant air quality impacts from the ULSD project. Other less than significant impacts identified in the previous CEQA documents for the ULSD Project (e.g., hazard and noise impacts) would also be eliminated at the Wilmington Plant. However, Alternative 1 would increase operational emissions and not achieve the objectives of the ULSD Project to modify the existing Refinery to continue producing diesel meeting U.S. EPA, CARB, and SCAQMD ULSD requirements. Additional marine vessel emissions under Alternative 1 will result in greater emissions than the ULSD Project.

Alternatives 2 and 3 would achieve the Project objectives of producing ULSD but would generate greater and potentially significant impacts to air quality impacts from construction and TAC impacts as compared to the ULSD Project.

Based on the analysis in Chapter 5, Alternatives 1, 2, and 3 have the potential to generate greater air quality impacts than the ULSD Project. Therefore, the ULSD Project is considered the environmentally superior alternative because it generates air quality impacts that would be less than the air quality impacts generated by Alternatives 1, 2 and 3.

TABLE 5-1

ENVIRONMENTAL IMPACTS OF ALTERNATIVES AS COMPARED TO ULSD PROJECT

ENVIRONMENTAL TOPIC	ULSD Project	Alternative 1[(1)]	Alternative 2[(1)]	Alternative 3[(1)]
Air Quality				
Construction	NS	NS(-)	S	S
Operation	NS	S(+)	NS(+)	NS(+)
Toxic Air Contaminants	NS	NS(+)	NS(+)	NS(+)

(1) See pages 5-4 through 5-6 for further details.

Notes:
S = Significant
NS = Not Significant
(-) = Potential impacts are less than the ULSD Project.
(+) = Potential impacts are greater than the ULSD Project.
(=) = Potential impacts are approximately the same as the ULSD Project.

CHAPTER 6

REFERENCES

6.0 REFERENCES

6.1 REFERENCES

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6.2 ORGANIZATIONS AND PERSONS CONSULTED

The CEQA statues and Guidelines require that organizations and persons consulted be provided in the EIR. The following organizations and persons have provided input into this document.

6.2.1 INDIVIDUALS AND ORGANIZATIONS

Phillips 66
Marshall Waller
Jimmy Greene

South Coast Air Quality Management District
Barbara Baird
Jeff Inabinet
Steve Smith
Veera Tyagi

6.3 LIST OF ENVIRONMENTAL IMPACT REPORT PREPARERS

South Coast Air Quality Management District
Diamond Bar, California

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CHAPTER 7

ACRONYMS AND GLOSSARY

Acronyms And Abbreviations
Glossary

CHAPTER 7.0

ACRONYMS AND GLOSSARY

ABBREVIATION	**DESCRIPTION**
2003 AQMP	2003 Air Quality Management Plan
AB	Assembly Bill
AB1807	California Toxic Air Contaminants Program (Tanner Bill)
AB2728	Revised Tanner Bill
AB2588	Air Toxic "Hot Spots" Information and Assessment Act
ACGIH	American Conference of Governmental Industrial Hygienists
AQMP	Air Quality Management Plan
BACT	Best Available Control Technology
Basin	South Coast Air Basin
CAA	Clean Air Act
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CCAA	California Clean Air Act
CEQA	California Environmental Quality Act
CO	carbon monoxide
CO_2	carbon dioxide
COHb	carboxyhemoglobin
EIR	Environmental Impact Report
g/hp-hr	grams per horse power hour
H_2SO_4	sulfuric acid
HARP	Hotspots Analysis Reporting Program
hp	horsepower
HRA	health risk assessment
HNO_3	nitric acid
IARC	International Agency for Research on Cancer
lbs/day	pounds per day
MATES	Multiple Air Toxic Exposure Study
MAHI	maximum acute hazard index
MCHI	maximum chronic hazard index
MDAB	Mojave Desert Air Basin
MEIR	maximum exposed individual resident
MEIW	Maximum Exposed Individual Worker
mmBtu/hr	million British Thermal Units per hour
mmscf/year	million standard cubic feet per year
N_2	nitrogen
NAAQS	National Ambient Air Quality Standards
NESHAPS	National Emission Standards for Hazardous Air Pollutants

NMHC	non-methane hydrocarbon
NOI	Notice of Intent
NO	nitric oxide
NOx	nitrogen oxide
O_2	oxygen
O_3	ozone
PAHs	polycyclic aromatic hydrocarbons
PERP	Portable Equipment Registration Program
PM10	particulate matter less than 10 microns in diameter
PM2.5	particulate matter less than 2.5 microns in diameter
Port	Port of Los Angeles
ppb	parts per billion
ppmw	parts per million by weight
psi	pounds per square inch
PMPU	Port of Los Angeles Master Plan Update
PVC	polymer polyvinyl chloride
RECLAIM	Regional Clean Air Incentives Market
Refinery	Phillips 66 Los Angeles Refinery
REL	reference exposure levels
SCAG	Southern California Association of Governments
SCAQMD	South Coast Air Quality Management District
SCR	Selective Catalytic Reduction
SIP	State Implementation Plan
SOON	Surplus Off-Road Opt-In for NOx
SO_2	sulfur dioxide
SO3	sulfur trioxide
SOx	sulfur oxide
SSAB	Salton Sea Air Basin
TAC	Toxic Air Contaminant
TOG	Total Organic Gases
ULSD	ultra low sulfur diesel
U.S. EPA	United States Environmental Protection Agency
ug/m^3	micrograms per cubic meter

GLOSSARY

TERM	DEFINITION
Alkylation	The reaction of low-molecular-weight olefins with an isoparafin to produce a saturated compound of high octane number.
Alkylate	The product of an alkylation process.
Aqueous	Formed from water, having a water base.
Aromatics	Hydrocarbons which contain one or more benzene rings.
Barrel	42 gallons.
Blending	One of the final operations in refining, in which two or more different components are mixed together to obtain the desired range of properties in the finished product.
Catalyst	A substance that promotes a chemical reaction to take place but which is not itself chemically changed.
Caustic Scrubber	Equipment used for the removal of potentially harmful gas emissions from various industrial processes through the application of a caustic scrubbing chemical which dissolves or destroys the harmful gases.
Cooling Tower	A cooling tower is a heat rejection device, which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Common applications for cooling towers are providing cooled water for manufacturing and electric power generation.
Condensate	Steam that has been condensed back into water by either raising its pressure or lowering its temperature
Cogeneration	A cogeneration unit is a unit that produces electricity.
Cracking	The process of breaking down higher molecular weight hydrocarbons to components with smaller molecular weights by the application of heat; cracking in the presence of a suitable

	catalyst produces an improvement in product yield and quality over simple thermal cracking.
Crude Oil	Crude oil is "unprocessed" oil, which has been extracted from the subsurface. It is also known as petroleum and varies in color, from clear to tar-black, and in viscosity, from water to almost solid.
Distillation	The process of heating a liquid to its boiling point and condensing and collecting the vapor.
Feedstock	Material used as a stream in the refining process.
Flares	Emergency equipment used to incinerate refinery gases during upset, startup, or shutdown conditions.
Flue Gas	Gases produced by burning fuels in a furnace, heater or boiler.
Heat exchanger	Process equipment used to transfer heat from one medium to another.
Heater	Process equipment used to raise the temperature of refinery streams processing.
Hydrocarbon	Organic compound containing hydrogen and carbon, commonly occurring in petroleum, natural gas, and coal.
Hydrotreater	A machine that treats hydrocarbons.
Hydrotreating	A process to catalytically stabilize petroleum products of feedstocks by reacting them with hydrogen.
Isomerization	The rearrangement of straight-chain hydrocarbon molecules to form branch chain products; normal butane may be isomerized to provide a portion of the isobutane feed needed for the alkylation process.
Liquefied Petroleum Gas (LPG)	Liquefied light end gases often used for home heating and cooking; this gas is usually 95 percent propane, the remainder being split between ethane and butane.
Naphtha	A crude distillation unit cut in the range of C_7-420^o; naphthas are subdivided – according to the actual crude distillation cuts - into light, intermediate, heavy, and very heavy virgin naphthas; a typical crude distillation operation would be:

C$_7$-160^o - light naphtha
160-280^o - intermediate naphtha
280-330^o - heavy naphtha
330-420^o - very heavy naphtha

Natural Gas	A mixture of hydrocarbon gases that occurs with petroleum deposits, principally methane together with varying quantities of ethane, propane, butane, and other gases.
Octane	Measurement of the burning quality of the gasoline; reflects the Suitability of gasoline to perform in internal combustion engines smoothly without letting the engine knock or ping.
Olefins	Hydrocarbons that contain at least two carbons joined by double bonds; olefins do not naturally occur in crude oils but are formed during the processing.
Pentane	Colorless, flammable isomeric hydrocarbon, derived from petroleum and used as a solvent.
Reactor	Vessels in which desired reactions take place.
Refinery gas (fuel gas)	Gas produced from refinery operations used primarily for combustion in refinery heaters and boilers.
Reformate	One of the products from a reformer; a reformed naptha; the naptha is then upgraded in octane by means of catalytic or thermal reforming process.
Reformulated gasoline	New gasoline required under the federal Clean Air Act and California Air Resources Board to reduce emissions.
Reid Vapor Pressure	The vapor pressure of a product determined in a volume of air four times greater than the liquid volume at 100^{o}F; Reid vapor pressure (RVP) is an indication of the vapor-lock tendency of a motor gasoline, as well as explosion and evaporation hazards.
Selective Catalyst Reduction	An air pollution control technology that uses a catalyst to remove nitrogen oxides from flue gas.
Stripper or Splitter	Refinery equipment used to separate two components in a feed stream; examples include sour water strippers and naphtha splitters.

APPENDIX A

NOTICE OF PREPARATION

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South Coast
Air Quality Management District
21865 Copley Drive, Diamond Bar, CA 91765-4182
(909) 396-2000 • www.aqmd.gov

SUBJECT: NOTICE OF PREPARATION OF DRAFT ENVIRONMENTAL IMPACT REPORT

PROJECT TITLE: CONOCOPHILLIPS LOS ANGELES REFINERY ULTRA LOW SULFUR DIESEL PROJECT

In accordance with the California Environmental Quality Act (CEQA), the South Coast Air Quality Management District (SCAQMD) is the Lead Agency and will prepare a Draft Environmental Impact Report (EIR) for the project identified above.

The ConocoPhillips Los Angeles Refinery first proposed modifications to produce Ultra Low Sulfur Diesel (ULSD) in 2004 and, pursuant to CEQA, the SCAQMD prepared CEQA documents for the proposed modifications. A Draft EIR is now being prepared for the Project because a decision by the California Supreme Court found certain deficiencies in previously prepared CEQA documents for the ConocoPhillips ULSD Project. Specifically, the court invalidated the baseline used in the previous air quality impact analysis. Therefore, the Draft EIR for the ULSD Project will address the air quality setting and air quality impacts associated with the ULSD Project. Additional information on the legal history of the ULSD project is attached to this cover letter.

The Notice of Preparation (NOP) normally serves two purposes: to solicit information on the scope of the environmental analysis for the ULSD Project and notify the public that the SCAQMD will prepare a Draft EIR to further assess air quality impacts that may have resulted from implementing the ULSD Project. However, as explained above and in the attached pages, in response to a California Supreme Court decision on previous CEQA documents for the ULSD project, the analysis will focus only on the air quality setting and impacts from the project.

The attached NOP is not an SCAQMD application or form requiring a response from you. The purpose of the NOP is simply to provide information to you on the above project. If the ULSD Project has no bearing on you or your organization, no action on your part is necessary. The project's description and location are described in the attached NOP.

Comments focusing on your area of expertise, your agency's area of jurisdiction, or issues relative to the air quality setting and impacts analysis should be addressed to Mr. Jeff Inabinet at the address shown above, sent by FAX to (909) 396-3324, or e-mailed to jinabinet@aqmd.gov. Comments must be received no later than 5:00 p.m. on April 26, 2012. Please include the name and phone number of the contact person for your organization.

Project Applicant: ConocoPhillips Los Angeles Refinery

Date: March 23, 2012 **Signature:** Steve Smith

Steve Smith, Ph.D.
Program Supervisor
Planning, Rule Development and Area Sources

Reference: California Code of Regulations, Title 14, Sections 15082, 15103, and 15375

LEGAL HISTORY OF THE CONOCOPHILLIPS ULSD PROJECT

On July 16, 2004, two lawsuits were filed challenging the SCAQMD's certification of the 2004 Final Negative Declaration and Addendum and approval of an SCAQMD permit for the ULSD Project (California Superior Court, Los Angeles County, Case Nos. BS091275 and BS091276). These lawsuits asserted that, among other things, an environmental impact report should have been prepared to review the impacts associated with the ConocoPhillips ULSD Project. The petitioners sought a preliminary injunction or stay to prevent Project construction during the pendency of the lawsuits; however, the court denied these requests. The lawsuits were amended following certification of a 2005 Subsequent Negative Declaration to add claims associated with that CEQA document and associated air permits issued by the SCAQMD. The trial occurred in two phases. Phase I challenged the SCAQMD’s decision to prepare the Negative Declaration and Addendum. The Phase II trial was held a year later and challenged the Subsequent Negative Declaration, as well as SCAQMD’s decision not to apply its Regulation XVII permitting program. Following each trial, the Los Angeles Superior Court concluded that the SCAQMD was correct on all counts. More specifically, the court concluded that the 2004 Final Negative Declaration, the 2004 Addendum, and the 2005 Final Subsequent Negative Declaration all complied with CEQA and that the permitting decisions complied with law. On June 29, 2006, the Superior Court entered Judgment. CBE and Valdez et al. filed notices of appeal in August 2006.

On appeal, plaintiffs argued substantial evidence that supported a fair argument that the Project would have a significant environmental impact on air quality, requiring the SCAQMD to prepare an EIR. On January 16, 2008, the Court of Appeal upheld the decision of the Superior Court on all claims but one. In the Court’s opinion, an improper baseline was used to evaluate air quality impacts during operations. It concluded that the increased use of existing equipment should have been evaluated as part of the ULSD Project, not as part of the baseline, and, that if the proper baseline had been used, there was substantial evidence supporting a fair argument of significant NOx emissions, requiring preparation of an EIR. The SCAQMD filed a Petition for Review to the California Supreme Court on February 25, 2008, in which ConocoPhillips joined. The Petition sought review only of the portion of the Appellate Court’s decision concerning baseline for evaluation of air quality impacts, and no other portion of the opinion was challenged by any party. On April 16, 2008, the Supreme Court granted review of the case.

On March 15, 2010, the Supreme Court concluded that the environmental impacts of a proposed Project must be compared to the environmental conditions that exist at the time the CEQA analysis is commenced, not the level of development or activity that would be allowed under existing permits or approvals. Because the ULSD Project may require increased utilization of existing boilers and other steam generating equipment, it was inconsistent with CEQA to use the maximum permitted operating capacity of this utility equipment as the baseline against which to compare NOx emissions from the proposed Project, rather than an estimate of the actual NOx emissions from the equipment under current operating conditions. Therefore, the SCAQMD is preparing an EIR for the ConocoPhillips ULSD Project to respond to the findings of the Supreme Court.

The Supreme Court left to the discretion of the SCAQMD the methodology for estimating the “actual existing levels of emissions” from the utility equipment. The Court explained:

> “The District and ConocoPhillips emphasized that refinery operations are highly complex and that these operations, including the steam generation system, vary greatly with the season, crude oil supplies, market conditions, and other factors. . . .

> "We do not attempt here to answer any technical questions as to how existing refinery operations should be measured for baseline purposes in this case or how similar baseline conditions should be measured in future cases. CEQA Guidelines section 15125 (Cal. Code Regs., tit. 14, § 15125, subd. (a) directs that the lead agency 'normally' use a measure of physical conditions 'at the time the notice of preparation [of an EIR] is published, or if no notice of preparation is published, at the time environmental analysis is commenced.' But, as one appellate court observed, 'the date for establishing baseline cannot be a rigid one. Environmental conditions may vary from year to year and in some cases it is necessary to consider conditions over a range of time periods.' . . . In some circumstances, peak impacts or recurring periods of resource scarcity may be as important environmentally as average conditions. Where environmental conditions are expected to change quickly during the period of environmental review for reasons other than the proposed project, project effects might reasonably be compared to predicted conditions at the expected date of approval, rather than to conditions at the time analysis is begun. . . A temporary lull or spike in operations that happens to occur at the time environmental review for a new project begins should not depress or elevate the baseline; overreliance on short term activity averages might encourage companies to temporarily increase operations artificially, simply in order to establish a higher baseline.
>
> "Neither CEQA nor the CEQA Guidelines mandates a uniform, inflexible rule for determination of the existing conditions baseline. Rather, the agency enjoys the discretion to decide, in the first instance, exactly how the existing physical conditions without the project can most realistically be measured, subject to review, as with all CEQA factual determinations, for support by substantial evidence."

The Court observed that the SCAQMD had previously calculated NOx emissions from the proposed ULSD Project. However, it also stated that the SCAQMD is not required to use the same measurement method in the EIR that was used in the Negative Declaration. "Whatever method the District uses, however, the comparison must be between existing physical conditions without the Diesel Project and the conditions expected to be produced by the project."

It should be noted that neither the Court of Appeal decision nor the Supreme Court decision invalidated any aspect of the prior CEQA documents except for the baseline used in the air quality impacts analysis. Other aspects of the prior CEQA documents were challenged in the litigation, but those challenges were rejected by the trial court, and the trial court's rulings were upheld on appeal. Therefore, the Draft EIR for the ULSD Project will be focused on the issues as directed by the court and will be limited to air quality setting and impacts from project operations.

The Refinery modifications proposed as part of the ULSD Project have been completed and ConocoPhillips has been producing ULSD at its Los Angeles Refinery since 2006, as required by these regulations. However, applying the court's decision, an EIR is required for the ConocoPhillips ULSD Project to address air quality impacts from the proposed project. Thus, the SCAQMD need not evaluate further impacts to other environmental topic areas from the project. Consequently, the SCAQMD will not prepare an initial study and has begun preparing the EIR in response to direction by the Court.

PROJECT OBJECTIVES

The project objectives for the ConocoPhillips ULSD Project were developed to comply with federal, state and SCAQMD regulations that limit the sulfur content of diesel fuels and are included below as part of this notice. Reducing the sulfur content of diesel fuel leads to a reduction of sulfur oxides (SOx) and particulate sulfate emissions from sources (such as vehicles and trucks) that use the fuel. The objectives of the ULSD Project are the following:

- Reduce the sulfur content of diesel fuel produced at the Los Angeles Refinery.
- Comply with SCAQMD's Rule 431.2 which required a reduction in sulfur content in diesel fuel used in stationary sources to 15 ppmw.
- Comply with CARB's 2000 Diesel Risk Reduction Plan to reduce exposure to diesel particulate matter.
- Comply with the U.S. EPA's diesel fuel standards that required refiners to sell highway diesel fuel that meets a maximum sulfur standard of 15 ppmw.

PUBLIC RESOURCES CODE §21092.6 – LIST RELATING TO HAZARDOUS WASTE

Government Code §65962.5 refers to the "Hazardous Waste and Substances Site List", which is a list of facilities that may be subject to the Resource Conservation and Recovery Act (RCRA) corrective action program. Neither the ConocoPhillips Wilmington Plant nor the Carson Plant are included on the list prepared by the Department of Toxic Substances Control (DTSC) pursuant to Government Code §65962.5 (DTSC, 2012). Nonetheless, the ConocoPhillips Carson Plant is included on a list of RCRA-permitted sites that require corrective action as identified by DTSC (DTSC, 2012). Furthermore, both plants are subject to corrective action under the "Spills, Leaks, Investigation & Cleanup (SLIC) Program" administered by the Los Angeles Regional Water Quality Control Board pursuant to California Water Code §13304. In order to provide full public disclosure per CEQA (Public Resources Code §21092.6) with regard to corrective actions required by local agency, the following information is provided:

Applicant:	**ConocoPhillips Carson Plant**
Address:	1520 East Sepulveda Boulevard, Carson, CA 90745
Phone:	(310) 522-9300
Address of Site:	1520 East Sepulveda Boulevard, Carson, CA 90745
Local Agency:	City of Carson
Assessor's Book:	7315-002-021
List:	DTSC and SLIC Corrective Action
SLIC Case No:	0232

Applicant:	**ConocoPhillips Wilmington Plant**
Address:	1660 West Anaheim Street, Wilmington, CA 90748
Phone:	(310) 952-6000
Address of Site:	1660 West Anaheim Street, Wilmington, CA 90748
Local Agency:	City of Los Angeles
Assessor's Book:	7412-015-003; 7412-022-008, 009 & 010; 7412-024-033 & 006; 7412-025-008
List:	SLIC Corrective Action
SLIC Case No:	0231

CONCLUSION

No court decision invalidated any aspect of the prior CEQA documents except for the baseline used in the air quality impacts analysis for project operations. Other aspects of the prior CEQA documents were challenged in the litigation, but those challenges were rejected by the trial court, and the trial court's rulings were upheld on appeal. Therefore, the analysis of impacts in the Draft EIR for the ULSD Project will be limited to air quality setting and impacts from project operations, as directed by the court.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
21865 Copley Drive, Diamond Bar, California 91765-4182

NOTICE OF PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT REPORT

Project Title:
ConocoPhillips Los Angeles Refinery Ultra Low Sulfur Diesel Project

Project Location:
The ConocoPhillips Los Angeles Refinery operates at two locations: the ConocoPhillips Carson Plant is located at 1520 East Sepulveda Boulevard, Carson, California, 90745. The ConocoPhillips Wilmington Plant is located at 1660 West Anaheim Street, Wilmington, CA 90744. The Ultra Low Sulfur Diesel Project is located at the Los Angeles Wilmington Plant.

Description of Nature, Purpose, and Beneficiaries of Project:
The ConocoPhillips ULSD project was developed to comply with the federal, state and SCAQMD regulations that limit the sulfur content of diesel fuels. The project includes the following activities: 1) modifications to Hydrotreater Unit 90; 2) replacement of an existing charge heater with a functionally identical replacement heater; 3) installation of a Selective Catalytic Reduction Unit to control NOx emissions from the replacement heater, with aqueous ammonia supplied from an existing aqueous ammonia storage tank; 4) demolition of an existing cooling tower and replacement with a new cooling tower of the same capacity; 5) minor modifications to the mid barrel handling and shipping system including a new jet shipping pump, two new pumps for handling jet and diesel blendstocks, and one new sample pump and associated piping to create separate facilities for handling jet and diesel fuel; 6) minor modifications to the hydrogen distribution system including new hydrogen distribution piping; 7) and modifications to one storage tank to allow a change of service (i.e., contents). In response to the court's decision on the 2004 Final Negative Declaration and Addendum, an EIR is required for the ConocoPhillips ULSD Project to address air quality impacts only from the proposed project.

Lead Agency:	**Division:**
South Coast Air Quality Management District	Planning, Rule Development and Area Sources

Initial Study and all Supporting Documentation are Available at:

SCAQMD Headquarters 21865 Copley Drive Diamond Bar, CA 91765	Or by Calling: (909) 396-2039

The Initial Study is also available by accessing:
http://aqmd.gov/ceqa/nonaqmd.html

The Notice of Preparation is provided through the following:

☑ Los Angeles Times (March 28, 2012)	☑ Daily Breeze (March 28, 2012)	☑ SCAQMD Website
☑ SCAQMD Public Information Center	☑ Interested Parties	☑ SCAQMD Mailing List

Review Period:
March 28, 2012 through April 26, 2012

CEQA Contact Person:	**Phone Number:**	**E-Mail Address**
Jeff Inabinet	(909) 396-2453	jinabinet@aqmd.gov

APPENDIX B

AIR EMISSION CALCULATIONS

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Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Operational Emissions Summary

Source	Estimated Emissions (lbs/day)					
	CO	VOC	NOx	SOx	PM10	PM2.5
Pre-Project						
Stationary Sources						
Fugitives						
Pumps	0.00	4.41	0.00	0.00	0.00	0.00
Compressors	0.00	2.82	0.00	0.00	0.00	0.00
Valves	0.00	64.49	0.00	0.00	0.00	0.00
Flanges	0.00	12.44	0.00	0.00	0.00	0.00
Process Drains	0.00	10.74	0.00	0.00	0.00	0.00
Heater B-201	22.64	4.53	30.50	2.50	4.85	4.85
Total Pre-Project Emissions	**22.64**	**99.42**	**30.50**	**2.50**	**4.85**	**4.85**
Post-Project						
Stationary Sources						
Fugitives						
Pumps	0.00	4.41	0.00	0.00	0.00	0.00
Compressors	0.00	2.82	0.00	0.00	0.00	0.00
Valves	0.00	66.16	0.00	0.00	0.00	0.00
Flanges	0.00	15.09	0.00	0.00	0.00	0.00
Process Drains	0.00	11.62	0.00	0.00	0.00	0.00
Heater B-401	6.04	5.44	4.96	4.19	5.83	5.83
Tank 331		0.20				
Hydrogen Production	2.28	2.28	3.50	0.10	2.73	2.73
Construction						
30-Year Amortized GHG						
Off-site Sources						
Delivery Trucks	11.55	1.57	14.80	0.12	0.26	0.26
Electricity Production	2.29	0.11	13.17	1.37	0.46	0.46
Total Post-Project Emissions	**22.15**	**109.70**	**36.43**	**5.79**	**9.28**	**9.28**
Net Emissions Increases	**-0.48**	**10.28**	**5.93**	**3.29**	**4.43**	**4.43**

Net Emissions Increases = Post-Project Emissions - Pre-Project Emissions

Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Unit 90 Fugitive Emissions

Component/ Control		Service(1)	EF(2) lb/yr/ source	Pre-Project(3)			Post-Project(4)			Change		
				Count	lb/yr	lb/day	Count	lb/yr	lb/day	Count	lb/yr	lb/day
Pumps	Sealless	LL	0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
	Mechanical seal	LL	104	7	728.0	2.0	7	728.0	2.0	0	0.0	0.0
	Mechanical seal	HL	80	11	880.0	2.4	11	880.0	2.4	0	0.0	0.0
Compressors		G/V	514	2	1028.0	2.8	2	1028.0	2.8	0	0.0	0.0
Valves	Bellows sealed	G/V/LL	0	17	0.0	0.0	243	0.0	0.0	226	0.0	0.0
	Approved I&M prog.(< 500 ppm)	G/V	23	712	16376.0	44.9	746	17158.0	47.0	34	782.0	2.1
	Approved I&M prog.(< 500 ppm)	LL	19	377	7163.0	19.6	368	6992.0	19.2	-9	-171.0	-0.5
PSVs	Closed vent system	G/V/LL	0	18	0.0	0.0	17	0.0	0.0	-1	0.0	0.0
Flanges		G/V/LL	1.5	1426	2139.0	5.9	1584	2376.0	6.5	158	237.0	0.6
Connections		G/V/LL	1.5	1488	2232.0	6.1	1923	2884.5	7.9	435	652.5	1.8
Others		G/V/LL	1.5	113	169.5	0.5	164	246.0	0.7	51	76.5	0.2
Process Drains			80	49	3920.0	10.7	53	4240.0	11.6	4	320.0	0.9
Total						**94.9**			**100.1**			**5.2**

(1) G = gas, V = vapor, LL = light liquid, HL = heavy liquid

(2) Emission Factors from the Jay Chen Memo, BACT/LAER for Valves as VOC Fugitive Sources, April 2, 1999.

(3) Based on actual component counts prior to the Project.

(4) Based on as-built survey following completion of the Project..

Approach: The Project resulted in changes to the number of components in the unit, which would potentially increase fugitive VOC emissions. Fugitive emissions components are required to be monitored under Rule 1173 and accurate component counts are available. Potential increases in emissions would be those emissions associated with the increase in the number of a particular type of component. Project Impact = Post-Project - Pre-Project.

Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Heater Emissions Change

Heater B-201(1)

	CO	VOC	NOx	SOx	PM10	PM2.5
Emissions (lbs/day)	22.6	4.5	30.5	2.5	4.9	4.9
Emissions (tonnes/yr)						

Heater B-401(2)

	CO	VOC	NOx	SOx	PM10	PM2.5
Emission Factor (lb/mmscf)		7			7.5	7.5
Emission Factor (lb/hr)	0.25		0.21			
Emission Factor (lb/mmBtu)				0.0051		
Emissions (lbs/day)	6.04	5.4	4.96	4.19	5.83	5.83
Emissions (tonnes/yr)						

	CO	VOC	NOx	SOx	PM10	PM2.5
Total Emissions Change (lbs/day)	-16.60	0.91	-25.54	1.69	0.98	0.98

(1) Heater B-201 emissions are peak emissions during 2002 and 2003.

(2) Heater B-401 emissions based on maximum duty of 34 mmBtu/hr using permit-limitted emission factors or SCAQMD default factors, as appropriate.

Approach: Heater B-201 was removed and replaced with Heater B-401, which has the same firing rate, 34 mmBtu/hr, as B-201. During 2002 and 2003, B-201 did not operate at the maximum rated capacity on a daily basis. Therefore, the emissions for the peak operating day were used to evaluate the increase in emissions associated with the ULSD Project.

Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Hydrogen Production

Hydrogen Production Demand from Proposed Project

	Production (mmscf/yr)
Pre-Project	3,686.50
Post-Project	4,197.50
Incremental Change	511.00

Emissions Associated with Hydrogen Production

	CO	VOC	NOx	SOx	PM10	PM2.5(1)
Emission Factor (lb/mmscf) (2)	1.63	1.63	2.5	0.07	1.95	1.95
Emissions (lbs/day)	2.28	2.28	3.50	0.10	2.73	2.73

(1) PM2.5 emissions are assumed to be equivalent to PM10 emissions.

(2) City of Carson, EIR for the Air Products Hydrogen Facility and Specialty Gas Facility (SCH# 97071078), June 15, 1998.

Approach: The hydrogen demand for Units 89 and 90 combined was compared from 2002-2003 and 2006-2008. The increase was attributed to U90 solely to ensure the worst-case demand was attributed to the ULSD project.

Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Electricity Production

Electricity Demand

	Power (hp)	Power (MWh)
Pre-Project	640	0.5
Post-Project	1675	1.2

Electricity Generation Emissions

	CO	VOC	NOx	SOx	PM10	PM2.5 (2)
Pre-Project Emission Factor (lbs/MW-hr) (1)	0.2	0.01	1.15	0.12	0.04	0.04
Post-Project Emission Factor (lbs/MW-hr) (1)	0.2	0.01	1.15	0.12	0.04	0.04
Pre-Project Emissions (lbs/day)	2.3	0.1	13.2	1.4	0.5	0.5
Post-Project Emissions (lbs/day)	6.0	0.3	34.5	3.6	1.2	1.2
Net Emissions (lbs/day)	**3.7**	**0.2**	**21.3**	**2.2**	**0.7**	**0.7**

(1) Source: SCAQMD CEQA Air Quality Handbook, Table A9-11-B (SCAQMD, 1993)

(2) PM2.5 emissions assumed to be equivalent to PM10 emissions.

Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Vehicle Emissions

On Road Mobile Emission Factors from California ARB EMFAC2002 Scenario Year 2004 (Model Years A11965 to 2004)

Vehicle Type	CO Emissions Factor (lb/mile)	VOC Emission Factor (lb/mile)	NOx Emissions Factor (lb/mile)	SOx Emissions Factor (lb/mile)	PM10 Emissions Factor (lb/mile)	PM2.5 Emissions Factor (lb/mile)(1)
Workers Commuting	0.016559	0.001771	0.0018	0.00001	0.000079	0.000079
Light Duty Trucks	0.016559	0.001771	0.0018	0.00001	0.000079	0.000079
Bus	0.02309	0.003148	0.029607	0.000243	0.000519	0.000519
Heavy Diesel Trucks	0.02309	0.003148	0.029607	0.000243	0.000519	0.000519

	Parameters			Peak Day Emissions, lbs/day					
Source	Number of Vehicles	Total Number of Trips	Distance Traveled	CO	VOC	NOx	SOx	PM10	PM2.5
Workers Commuting	0	0	16.2	0.00	0.00	0.00	0.00	0.00	0.00
On-site Cars	0	0	10	0.00	0.00	0.00	0.00	0.00	0.00
Light Duty Trucks	0	0	16.2	0.00	0.00	0.00	0.00	0.00	0.00
Buses	0	0	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Daily Delivery Trucks(2)	5	10	50	11.55	1.57	14.80	0.12	0.26	0.26
Heavy Diesel Trucks	0	0	4	0.00	0.00	0.00	0.00	0.00	0.00
Total Vehicle Emisions				11.55	1.57	14.80	0.12	0.26	0.26

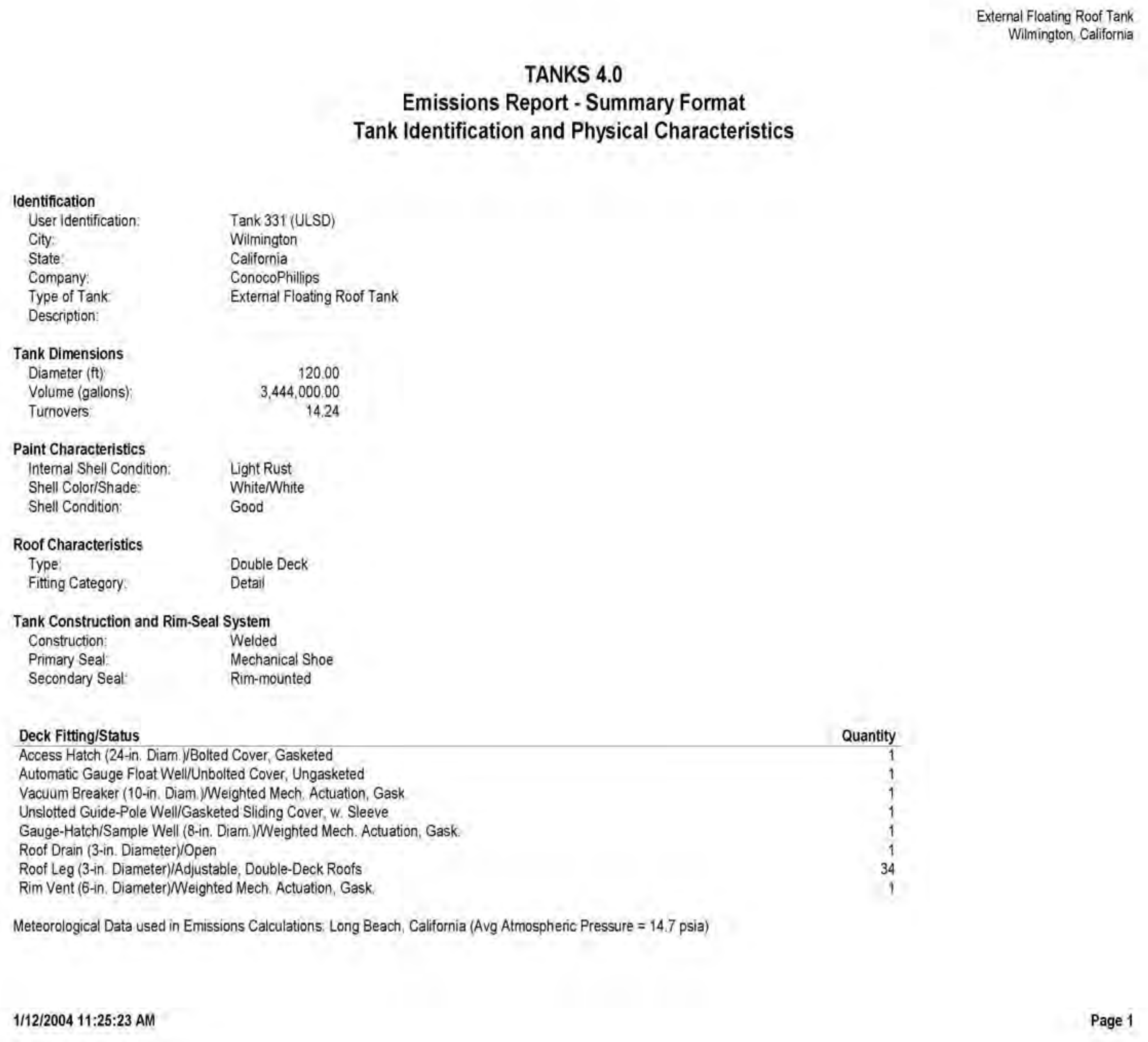
(1) PM2.5 emissions assumed to be equivalent to PM10 emissions.

(2) Based on 1 ammonia delivery and catalyst change out requiring 4 trucks per day for 14 days (5 total trucks on the peak day).

Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

Tank Emissions



External Floating Roof Tank
Wilmington, California

TANKS 4.0
Emissions Report - Summary Format
Tank Identification and Physical Characteristics

Identification

User Identification:	Tank 331 (ULSD)
City:	Wilmington
State:	California
Company:	ConocoPhillips
Type of Tank:	External Floating Roof Tank
Description:	

Tank Dimensions

Diameter (ft):	120.00
Volume (gallons):	3,444,000.00
Turnovers:	14.24

Paint Characteristics

Internal Shell Condition:	Light Rust
Shell Color/Shade:	White/White
Shell Condition:	Good

Roof Characteristics

Type:	Double Deck
Fitting Category:	Detail

Tank Construction and Rim-Seal System

Construction:	Welded
Primary Seal:	Mechanical Shoe
Secondary Seal:	Rim-mounted

Deck Fitting/Status	Quantity
Access Hatch (24-in. Diam.)/Bolted Cover, Gasketed	1
Automatic Gauge Float Well/Unbolted Cover, Ungasketed	1
Vacuum Breaker (10-in. Diam.)/Weighted Mech. Actuation, Gask.	1
Unslotted Guide-Pole Well/Gasketed Sliding Cover, w. Sleeve	1
Gauge-Hatch/Sample Well (8-in. Diam.)/Weighted Mech. Actuation, Gask.	1
Roof Drain (3-in. Diameter)/Open	1
Roof Leg (3-in. Diameter)/Adjustable, Double-Deck Roofs	34
Rim Vent (6-in. Diameter)/Weighted Mech. Actuation, Gask.	1

Meteorological Data used in Emissions Calculations: Long Beach, California (Avg Atmospheric Pressure = 14.7 psia)

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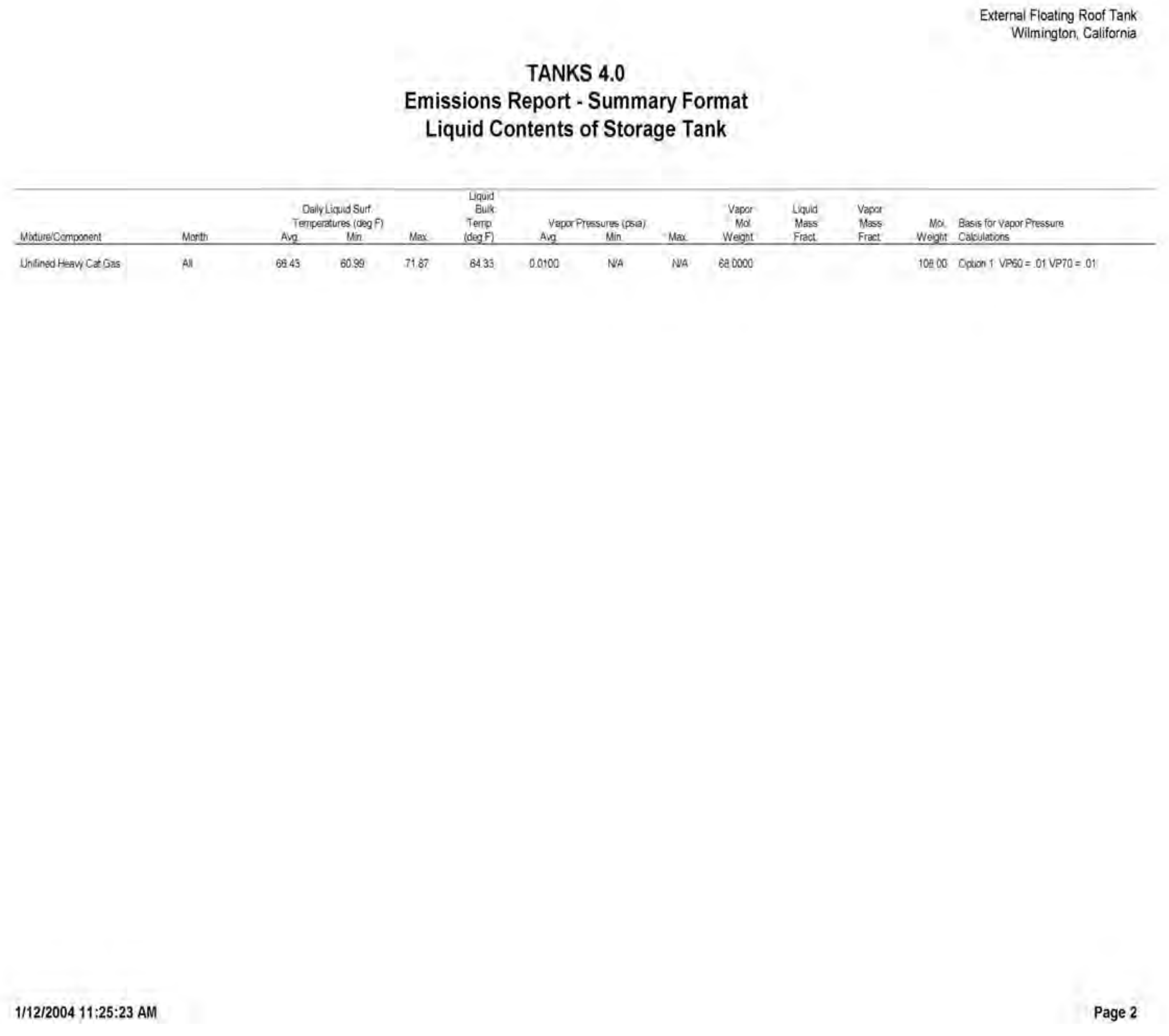
Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project



External Floating Roof Tank
Wilmington, California

TANKS 4.0
Emissions Report - Summary Format
Liquid Contents of Storage Tank

Mixture/Component	Month	Daily Liquid Surf. Temperatures (deg F) Avg.	Min.	Max.	Liquid Bulk Temp (deg F)	Vapor Pressures (psia) Avg.	Min.	Max.	Vapor Mol. Weight	Liquid Mass Fract.	Vapor Mass Fract.	Mol. Weight	Basis for Vapor Pressure Calculations
Unfined Heavy Cat Gas	All	68.43	60.99	71.87	64.33	0.0100	N/A	N/A	68.0000			108.00	Option 1: VP60 = .01 VP70 = .01

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Appendix B

Phillips 66
Ultra Low Sulfur Diesel Project

External Floating Roof Tank
Wilmington, California

TANKS 4.0
Emissions Report - Summary Format
Individual Tank Emission Totals

Annual Emissions Report

	Losses(lbs)				
Components	Rim Seal Loss	Withdrawal Loss	Deck Fitting Loss	Deck Seam Loss	Total Emissions
Unifined Heavy Cat Gas	4.36	77.10	1.84	0.00	83.31

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APPENDIX C

HEALTH RISK ASSESSMENT

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Phillips 66 Los Angeles Refinery
Wilmington Plant
Health Risk Analysis
Ultra Low Sulfur Diesel Project

January 11, 2013

Prepared for: Phillips 66 Los Angeles Refinery – Wilmington Plant
Prepared by: Environmental Audit, Inc.
1000 Ortega Way, Suite A
Placentia, CA 92780
714-632-8521

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FACILITY INFORMATION

The Phillips 66 Los Angeles Refinery – Wilmington Plant (Refinery) is located at 1660 W. Anaheim Street, Wilmington, California (see Figure 1). The Refinery processes crude oil into marketable products including gasoline, diesel fuel, jet fuel, and other products. The Refinery is bordered by a residential area, a roofing materials plant, and a portion of the Harbor 110 Freeway to the east; the Ken Malloy Harbor Regional Park, Harbor College, Harbor Park Municipal Golf Course, and a small residential area to the north; Gaffey Street including a firing range, vacant fields, recreational fields, and a U.S. Navy fuel storage facility to the west; and, a warehouse facility to the south. The closest resident is adjacent to the eastern Refinery property boundary. The South Coast Air Quality Management District (SCAQMD) identification number for the facility is 171107.

INTRODUCTION

Following legal challenge, the California Supreme Court concluded that there were certain deficiencies in previously prepared CEQA documents for the Phillips 66 ULSD Project and required the SCAQMD to prepare an EIR to analyze the air quality impacts of the Project. As a result, a Draft Environmental Impact Report (EIR) is now being prepared for the ULSD Project as required by the California Supreme Court to correct deficiencies identified in the Court's decision. However, the Refinery modifications proposed as part of the ULSD Project have been completed and Phillips 66 has been producing ULSD at its Los Angeles Refinery since 2006, as required by federal, state, and SCAQMD ULSD regulations.

As part of the CEQA process, Environmental Audit Inc. (EAI) has performed a health risk analysis for the ULSD Project. EAI has calculated emissions to evaluate the maximum potential impacts of toxic air contaminants (TACs) associated with the improvements from the ULSD Project. The physical modifications in Unit 90, as a result of the Project, included replacing Heater B-201 with Heater B-401 and an increase in the number of fugitive components (i.e., valves, flange, pumps, etc.) in Unit 90. Therefore, to determine the project health risk has been determined by comparing the health risks associated with Heater B-201 before the project with the health risks associated with Heater B-401 and the incremental increase in fugitive emissions in Unit 90 as a result of the ULSD Project.

Based on information provided by Phillips 66, the USLD Project has been modeled as the net difference between the previously existing Unit 90 Heater B-201 (U90B201) and replacement Heater B-401 (U90B401) and associated fugitives (U90FUG). The previously existing U90B201 was modeled as a point source (See Figure 2). The replacement U90B401 and U90FUG were modeled as a point source and a volume source, respectively (See Figure 3). The incremental health risk for the ULSD Project is the net difference between the pre-project and post-project health risk.

TACs in the emissions from the sources are included in the SCAQMD Rule 1401 – New Source Review for Toxic Air Contaminants. The health risks were evaluated using the SCAQMD *Risk*

Assessment Procedures for Rules 1401 and 212 Version 7.0 (July 2005). The analysis for cancer and non-cancer risks is presented below. The sources are expected to emit 26 chemicals which are chemicals listed in Attachment I of the SCAQMD Rule 1401 Guidelines – 12 are considered carcinogens, 22 are considered to have adverse chronic health effects, and 11 are considered to have adverse acute health effects (See Attachment B).

EMISSION ESTIMATES

The emissions estimates of TACs from the heaters are calculated using emission factors from a source test. Fugitive emissions are based on the refinery specific speciation of Unit 90. The emission factors used for emission sources are from the *2012 ConocoPhillips Company Los Angeles Refinery - Wilmington Plant AB 2588 Revision F 2006-2007* (ConocoPhillips, 2012) and *the 2001 Tosco Los Angeles Refinery Wilmington Plant AB2588 HRA* (Tosco, 2001). The calculated emissions are presented in Attachment A.

HEALTH RISK ASSESSMENT

The California Air Resources Board (CARB) Hotspots Analysis Reporting Program (HARP) model is the most appropriate model for determining the air quality impact from ULSD Project. The HARP model (CARB, 2005) combines the dispersion model with a risk calculation model based on the Air Toxics Hot Spots Program Risk Assessment Guidelines (OEHHA, 2003). The dispersion portion of the model provides estimates of source-specific annual and hourly maximum ambient groundlevel concentrations. The risk calculator in the HARP model estimates the cancer risk, chronic index, and acute index values. The HARP model incorporates US EPA Industrial Source Complex as the dispersion model, however, AERMOD is now the preferred dispersion model, and therefore, this analysis utilizes HARP On-Ramp to import groundlevel concentrations from AERMOD into HARP. The model default values were modified to conform to the SCAQMD Supplement Guidelines for Preparing Risk Assessment for the Air Toxics “Hot Spots” Information and Assessment Act (AB2588) (SCAQMD, 2005).

The pre-project analysis is modeled as a single point source (U90B201). The post-project analysis is modeled as a point source (U90B401) and a volume source (U90FUG). The source parameters are listed in Attachment C. The locations of the sources were identified based on data provided by Phillips 66 and the Torrance USGS Quadrangles (see attached Figure 2 and 3).

The receptors used in the model include a fenceline receptor grid and a fine receptor grid. The Refinery is located on a hillside; therefore, terrain variations were included for the receptor networks. The fenceline receptor grid (maximal spacing every 100 meters(m)) were used to determine the maximum concentrations at the property line of the Refinery. A fine receptor grid (100 m x 100 m spacing) was used to identify the maximum impact locations. The pre-project and post-project analyses used identical receptor grids. Figures 2 and 3 shows all modeled receptors.

All maximum impact locations are verified as credible locations for receptors (i.e., streets, railroad tracks, and waterways are not considered valid receptor locations). The locations of the maximum impacts are then verified for the type of receptor and are reported below. Selected tables from the

HARP model are included in Attachment D. The applicable output results from the HARP model are in Attachment E.

PRE-PROJECT RISK ANALYSIS

Cancer Risk Analysis

Under the pre-project or baseline case, the maximum cancer risk from Unit 90 Heater B-201 for an exposed individual resident (MEIR) is located approximately 260 east of the Refinery (No. 861, UTM Coordinates 381700, 3737600, See Figure 2). The cancer risk is 7.35 x 10^{-8} or 0.07 cancer cases in one million at the MEIR. Hexavalent chromium contributes approximately 75.5 percent of the calculated cancer risk at the MEIR. The inhalation pathway accounts for 84.4 percent of the cancer risk. Detailed cancer risk contributions by pathway and pollutants are presented in Attachment D.

The maximum exposed incremental cancer risk at an occupational exposure (MEIW) is located approximately 100 meters east of the Refinery (No. 788, UTM Coordinates 382500, 3737400, See Figure 2). The incremental cancer risk is 1.89 x 10^{-8} or 0.02 cancer cases in one million at the MEIW. Hexavalent chromium contributes approximately 67.7 percent of the calculated cancer risk at the MEIW. The inhalation pathway accounts for 75.7 percent of the cancer risk. Detailed cancer risk contributions by pathway and pollutants are presented in Attachment D.

Non-Cancer Risk Analysis

Under the pre-project or baseline case, the maximum chronic hazard index (MCHI) total for Unit 90 Heater B-201 for the respiratory system is 0.0028. The MCHI is located approximately 100 meters east of the Refinery (No. 788, UTM Coordinates 382500, 3737400, See Figure 2). Arsenic contributes approximately 97.2 percent of the calculated MCHI. Detailed contribution by pollutant to the chronic hazard index for the maximum receptor location is presented in Attachment D.

The maximum acute hazard index (MAHI) total for the central nervous system is 0.0001. The MAHI is located on the eastern boundary of the Refinery (No. 778, UTM Coordinates 381500, 3737400, See Figure 2). Arsenic contributes approximately 90.3 percent of the calculated MAHI. Detailed contribution by pollutant to the acute hazard index for the maximum receptor location is presented in Attachment D.

POST-PROJECT RISK ANALYSIS

Cancer Risk Analysis

Under the post-project case, the maximum cancer risk from Unit 90 Heater B-401 and associated fugitives for the MEIR is located approximately 260 meters east of the Refinery (No. 861, UTM Coordinates 381700, 3737600, See Figure 3). The cancer risk is 1.50 x 10^{-7} or 0.15 cancer cases in one million at the MEIR. Hexavalent chromium contributes approximately 48.1 percent of the calculated cancer risk at the MEIR. The inhalation pathway accounts for 59.1 percent of the cancer risk. Detailed cancer risk contributions by pathway and pollutants are presented in Attachment D.

The MEIW is located approximately 100 meters east of the Refinery (No. 788, UTM Coordinates 382500, 3737400, See Figure 3). The incremental cancer risk is 2.81 x 10^{-8} or 0.03 cancer cases in one million at the MEIW. Hexavalent chromium contributes approximately 58.7 percent of the calculated cancer risk at the MEIW. The inhalation pathway accounts for approximately 68.0 percent of the cancer risk. Detailed cancer risk contributions by pathway and pollutants are presented in Attachment D.

Non-Cancer Risk Analysis

Under the post-project case, the maximum chronic hazard index (MCHI) total for Unit 90 Heater B-401 and associated fugitives for the respiratory system is 0.0037. The MCHI is located approximately 100 meters east of the Refinery (No. 788, UTM Coordinates 382500, 3737400, See Figure 3). Arsenic contributes approximately 96.4 percent of the calculated MCHI. Detailed contribution by pollutant to the chronic hazard index for the maximum receptor location is presented in Attachment D.

The maximum acute hazard index (MAHI) total for the central nervous system is 0.0001. The MAHI is located at the northwestern boundary of the Refinery (No. 1933, UTM Coordinates 380641, 3738324, See Figure 3). Arsenic contributes approximately 90.3 percent of the calculated MAHI. Detailed contribution by pollutant to the acute hazard index for the maximum receptor location is presented in Attachment D.

INCREMENTAL RISK ANALYSIS

As shown in Table D-1 in Attachment D, the incremental cancer risk of the ULSD Project is 7.65 x 10^{-8} (0.15-0.07) or 0.08 per million at the MEIR and 9.20 x 10^{-9} (0.03-0.02) or 0.01 per million at the MEIW. Table D-1 in Attachment D also shows the incremental MCHI is 0.0008. The acute risk for the replacement heater is at a different location from the previous heater, therefore, the acute risk for U90 B-201 cannot be subtracted from the new acute risk value. The acute risk value for the ULSD project is 0.0001. The health risks for the TACs emitted from the ULSD Project are below the significance threshold of ten cancer cases per one million for cancer risk and chronic and acute hazard indices are below the 1.0 non-cancer risk significance thresholds.

CONCLUSIONS

The health risks for the TACs emitted from the USLD Project are below the significance threshold of ten cancer cases in one million for cancer risk and chronic and acute hazard indices are below the 1.0 non-cancer risk significance threshold established under CEQA. Therefore, cancer risk and hazard index thresholds for the ULSD Project are not expected to be exceeded at any receptor location.

REFERENCES

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FIGURES

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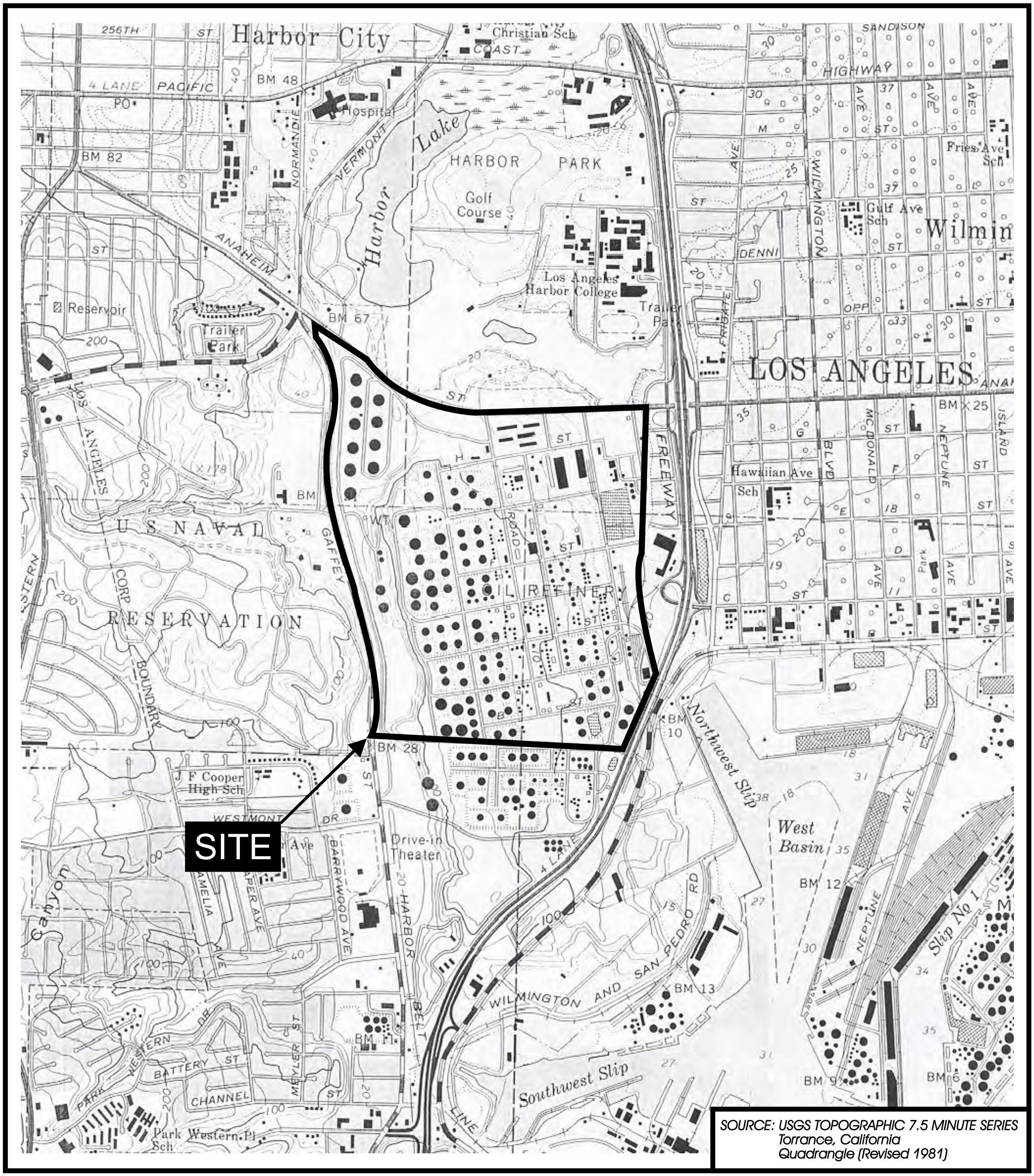

SOURCE: USGS TOPOGRAPHIC 7.5 MINUTE SERIES
Torrance, California
Quadrangle (Revised 1981)

Environmental Audit, Inc.

FIGURE 1
SITE LOCATION MAP
Phillips 66 Los Angeles Refinery
Wilmington Plant

Project No. 2696

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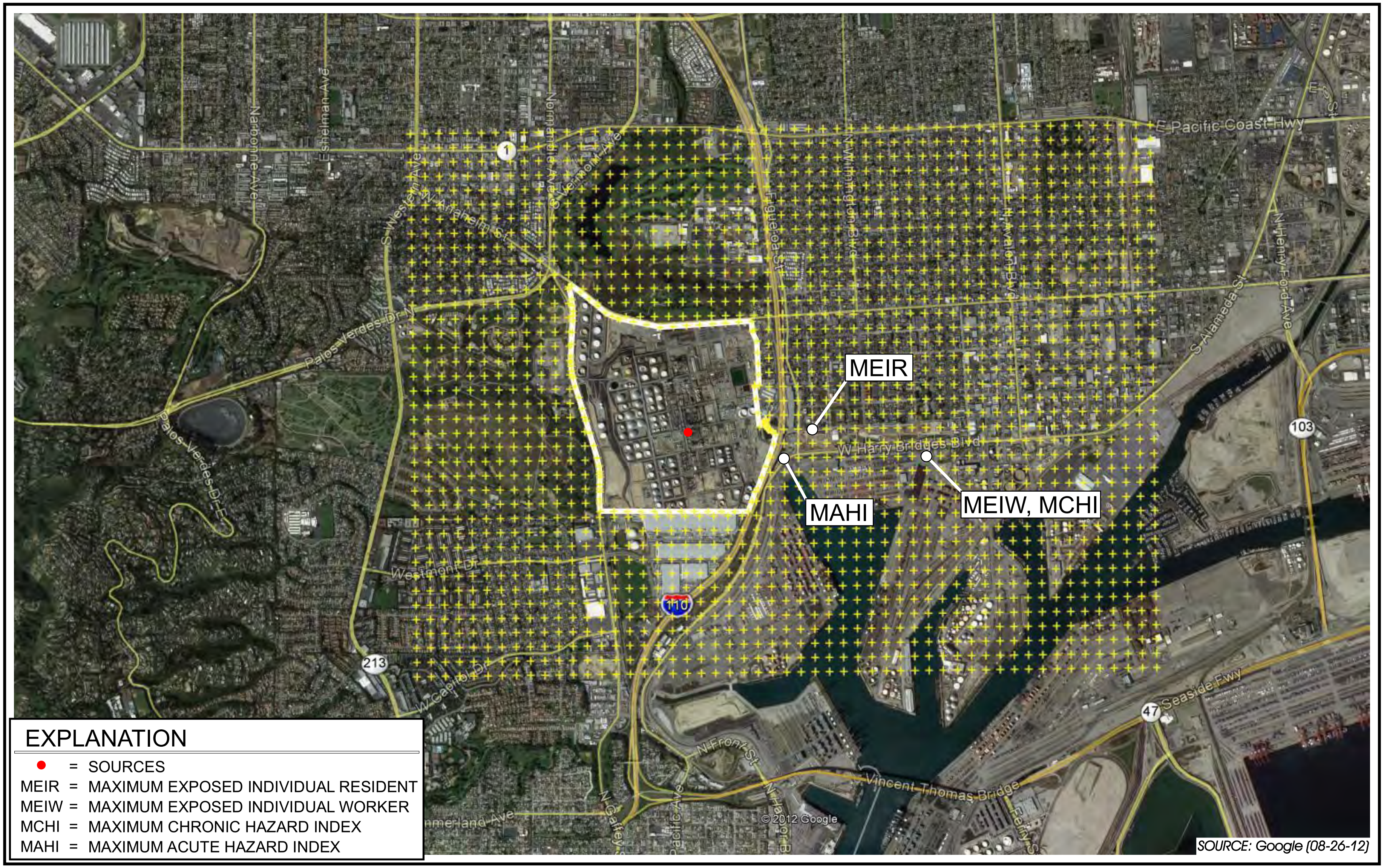

SOURCE: Google (08-26-12)

EXPLANATION

● = SOURCES
MEIR = MAXIMUM EXPOSED INDIVIDUAL RESIDENT
MEIW = MAXIMUM EXPOSED INDIVIDUAL WORKER
MCHI = MAXIMUM CHRONIC HAZARD INDEX
MAHI = MAXIMUM ACUTE HAZARD INDEX

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FIGURE 2
PRE-PROJECT - MAX IMPACT LOCATION MAP
Phillips 66 Los Angeles Refinery
Wilmington Plant

Project No. 2696
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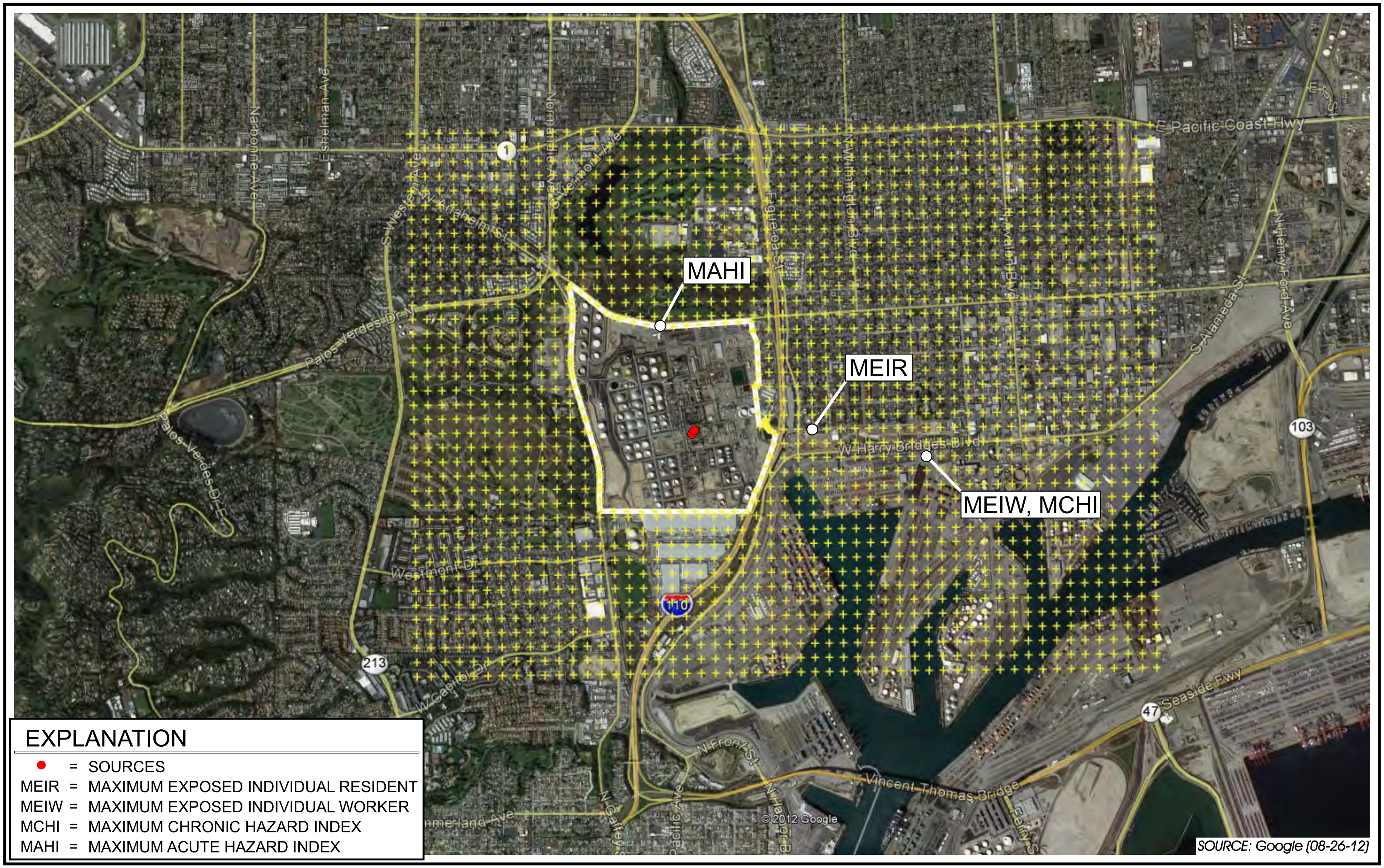

EXPLANATION

● = SOURCES
MEIR = MAXIMUM EXPOSED INDIVIDUAL RESIDENT
MEIW = MAXIMUM EXPOSED INDIVIDUAL WORKER
MCHI = MAXIMUM CHRONIC HAZARD INDEX
MAHI = MAXIMUM ACUTE HAZARD INDEX

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FIGURE 3
POST-PROJECT - MAX IMPACT LOCATION MAP
Phillips 66 Los Angeles Refinery
Wilmington Plant

Project No. 2696
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ATTACHMENT A

Emission Calculations

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Attachment A
Phillips 66 - Wilmington Plant
ULSD Project
Table A-1
Pre-Project Heater 201 Emissions

Process Equipment Description:	U90 B-201 Htr
Fuel Type:	Refinery Fuel
Process Units:	MMCF

Control Equipment:	Low NOx Burner
Control Type:	HLNX
Estimation Method:	Source Testing
Yearly Emis. Est. Equation:	F_y x EF
Max Hourly Emis. Est. Equation:	F_m x EF

Parameter Symbols/Names	**Values**	
F_y = Total Yearly Amount of Fuel Burned	188.35	MMCF/yr
F_m = Maximum Hourly Amount of Fuel Burned	0.02	MMCF/hr
EF = Source Test Emission Factor	(see below)	lbs/MMCF
Process Operation Schedule	24	hours/day
	7	days/week
	52	weeks/year
Refinery Fuel Gas HHV	1316	btu/scf
Firing Rate	679.1	mmbtu/day

Emittent Species Name (1)	Emittent ID (CAS Number)	Rule 1401	Emission Factor (2) (lbs/MMCF)	Annual Avg Emissions (lbs/yr)	Hourly Max Emissions (lbs/hr)
Acenaphthene	83329		4.74E-06	8.93E-04	1.02E-07
Acenaphthylene	208968		3.00E-06	5.65E-04	6.45E-08
Acetaldehyde	75070	Y	1.00E-02	1.89E+00	2.15E-04
Anthracene	120127		5.10E-06	9.61E-04	1.10E-07
Antimony	7440360		1.53E-03	2.88E-01	3.29E-05
Arsenic	7440382	Y	1.00E-03	1.89E-01	2.16E-05
Barium	7440393		ND	ND	ND
Benz (a) Anthracene	56553	Y	ND	ND	ND
Benzene	71432	Y	1.32E-02	2.49E+00	2.85E-04
Benzo (a) Pyrene	50328	Y	ND	ND	ND
Benzo (b) Fluoranthene	205992	Y	ND	ND	ND
Benzo (g,h,i) perylene	191242	Y	ND	ND	ND
Benzo (k) Fluoranthene	207089	Y	ND	ND	ND
Beryllium	7440417	Y	2.69E-04	5.06E-02	5.77E-06
Cadmium	7440439	Y	6.59E-04	1.24E-01	1.42E-05
Chromium (Hexavalent)	18540299	Y	4.29E-04	8.08E-02	9.22E-06
Chromium (Total)	7440473		5.37E-04	1.01E-01	1.15E-05
Chrysene	218019	Y	ND	ND	ND
Copper	7440508	Y	ND	ND	ND
Dibenz (a, h) Anthracene	53703	Y	ND	ND	ND
Fluoranthene	206440		5.79E-06	1.09E-03	1.24E-07
Fluorene	86737		2.63E-05	4.94E-03	5.64E-07
Formaldehyde	50000	Y	6.11E-05	1.15E-02	1.31E-06
Hydrogen Sulfide	7783064	Y	1.44E-02	2.72E+00	3.11E-04
Indeno (1, 2, 3-cd) Pyrene	193395	Y	5.60E-07	1.05E-04	1.20E-08
Lead	7439921	Y	ND	ND	ND
Manganese	7439965	Y	4.40E-03	8.28E-01	9.45E-05
Mercury	7439976	Y	1.01E-04	1.89E-02	2.16E-06
Naphthalene	91203	Y	3.26E-04	6.13E-02	7.00E-06
Nickel	7440020	Y	ND	ND	ND
PAHs	1150	Y	4.02E-04	7.57E-02	8.64E-06
Phenanthrene	85018		2.03E-05	3.81E-03	4.35E-07
Phenol	108952	Y	7.77E-04	1.46E-01	1.67E-05
Phosphorous	7723140		4.49E-03	8.45E-01	9.64E-05
Pyrene	129000		1.18E-05	2.22E-03	2.53E-07
Selenium	7782492	Y	2.69E-03	5.06E-01	5.77E-05
Silver	7440224	Y	5.37E-04	1.01E-01	1.15E-05
Thallium	7440280		1.88E-03	3.53E-01	4.03E-05
Toluene	108883	Y	1.58E-02	2.97E+00	3.39E-04
Zinc	7440666		1.34E-02	2.52E+00	2.88E-04

(1) PAHs present the total of Acenaphthene, Acenaphthylene, Anthracene, Benz(a)Anthracene, Benzo(a)Pyrene, Benzo(b)Fluoranthene, Benzo(g,h,i)Perylene, Benzo(k)Fluoranthene, Chrysene, Dibenzo(a,b)Anthracene, Fluoroanthene, Fluorene, Indeno(1,2,3-cd)Pyrene, Naphthalene, Phenanthrene, and Pyrene.

(2) Emission factors provided by Unocal were derived from a source test conducted on process heater unit 100 (heater equipped with low NOx burner) on December 15-22, 1992 with the exception to the factors for Benzene, Hydrogen Sulfide, Phenol, and Toluene, where the emission factors were derived from WSPA, Low NOx process heater burning refinery gas, tested on June 2, 1992, pg.30.

ND = Non-detect for all three test runs.

Attachment A
Phillips 66 - Wilmington Plant
ULSD Project
Table A-2
Post-Project Heater 401 Emissions

Process Equipment Description:	U90 B-401 Htr
Fuel Type:	Refinery Fuel
Process Units:	MMCF

Control Equipment:	Low NOx Burner & SCR
Control Type:	HLNX & SCR
Estimation Method:	Source Testing
Yearly Emis. Est. Equation:	F_y x EF
Max Hourly Emis. Est. Equation:	F_m x EF

Parameter Symbols/Names	**Values**	
F_y = Total Yearly Amount of Fuel Burned	226.32	MMCF/yr
F_m = Maximum Hourly Amount of Fuel Burned	0.03	MMCF/hr
EF = Source Test Emission Factor	(see below)	lbs/MMCF
Process Operation Schedule	24	hours/day
	7	days/week
	52	weeks/year
Refinery Fuel Gas HHV	1316	btu/scf
Firing Rate	34	mmbtu/hr

Emittent Species Name (1)	Emittent ID (CAS Number)	Rule 1401	Emission Factor (2) (lbs/MMCF)	Annual Avg Emissions (lbs/yr)	Hourly Max Emissions (lbs/hr)
Acenaphthene	83329		5.06E-06	1.14E-03	1.31E-07
Acenaphthylene	208968		3.20E-06	7.24E-04	8.27E-08
Acetaldehyde	75070	Y	1.07E-02	2.42E+00	2.76E-04
Ammonia (lb/hr)	7664417	Y	1.07E-01	9.38E+02	1.07E-01
Anthracene	120127		5.44E-06	1.23E-03	1.41E-07
Antimony	7440360		1.63E-03	3.69E-01	4.22E-05
Arsenic	7440382	Y	1.07E-03	2.42E-01	2.77E-05
Barium	7440393		ND	ND	ND
Benz (a) Anthracene	56553	Y	ND	ND	ND
Benzene	71432	Y	1.41E-02	3.20E+00	3.65E-04
Benzo (a) Pyrene	50328	Y	ND	ND	ND
Benzo (b) Fluoranthene	205992	Y	ND	ND	ND
Benzo (g,h,i) perylene	191242	Y	ND	ND	ND
Benzo (k) Fluoranthene	207089	Y	ND	ND	ND
Beryllium	7440417	Y	2.86E-04	6.48E-02	7.40E-06
Cadmium	7440439	Y	7.02E-04	1.59E-01	1.81E-05
Chromium (Hexavalent)	18540299	Y	4.58E-04	1.04E-01	1.18E-05
Chromium (Total)	7440473		5.73E-04	1.30E-01	1.48E-05
Chrysene	218019	Y	ND	ND	ND
Copper	7440508	Y	ND	ND	ND
Dibenz (a, h) Anthracene	53703	Y	ND	ND	ND
Fluoranthene	206440		6.18E-06	1.40E-03	1.60E-07
Fluorene	86737		2.80E-05	6.34E-03	7.23E-07
Formaldehyde	50000	Y	6.51E-05	1.47E-02	1.68E-06
Hydrogen Sulfide	7783064	Y	1.54E-02	3.49E+00	3.98E-04
Indeno (1, 2, 3-cd) Pyrene	193395	Y	5.97E-07	1.35E-04	1.54E-08
Lead	7439921	Y	ND	ND	ND
Manganese	7439965	Y	4.69E-03	1.06E+00	1.21E-04
Mercury	7439976	Y	1.07E-04	2.43E-02	2.77E-06
Naphthalene	91203	Y	3.47E-04	7.86E-02	8.97E-06
Nickel	7440020	Y	ND	ND	ND
PAHs	1150	Y	4.29E-04	9.70E-02	1.11E-05
Phenanthrene	85018		2.16E-05	4.89E-03	5.58E-07
Phenol	108952	Y	8.29E-04	1.88E-01	2.14E-05
Phosphorous	7723140		4.78E-03	1.08E+00	1.24E-04
Pyrene	129000		1.25E-05	2.84E-03	3.24E-07
Selenium	7782492	Y	2.86E-03	6.48E-01	7.40E-05
Silver	7440224	Y	5.73E-04	1.30E-01	1.48E-05
Thallium	7440280		2.00E-03	4.53E-01	5.17E-05
Toluene	108883	Y	1.68E-02	3.80E+00	4.34E-04
Zinc	7440666		1.43E-02	3.23E+00	3.69E-04

(1) PAHs present the total of Acenaphthene, Acenaphthylene, Anthracene, Benz(a)Anthracene, Benzo(a)Pyrene, Benzo(b)Fluoranthene, Benzo(g,h,i)Perylene, Benzo(k)Fluoranthene, Chrysene, Dibenzo(a,b)Anthracene, Fluoroanthene, Fluorene, Indeno(1,2,3-cd)Pyrene, Naphthalene, Phenanthrene, and Pyrene.

(2) Emission factors provided by Unocal were derived from a source test conducted on process heater unit 100 (heater equipped with low NOx burner) on December 15-22, 1992 with the exception to the factors for Benzene, Hydrogen Sulfide, Phenol, and Toluene, where the emission factors were derived from WSPA, Low NOx process heater burning refinery gas, tested on June 2, 1992, pg.30.
Ammonia emissions were based on the permitted limit of 5 ppmv with flue gas rate of 1258 lb-mole/hr.

ND = Non-detect for all three test runs.

Attachment A
Phillips 66 - Wilmington Plant
ULSD Project
Table A-3
Post-Project Incremental Fugitive Emissions

Emittent Species Name	Emittent ID (CAS Number)	Rule 1401	Emission Factor (1) (lb/lb VOC)	Annual Avg Emissions (lbs/yr)	Daily Avg Emissions (lbs/day)	Hourly Max Emissions (lbs/hr)
Total VOC	NA	NA	NA	1898.00	5.20	0.22
1,2,4-Trimethylbenzene	95636		2.21E-03	4.19E+00	1.15E-02	1.31E-06
1,3-Butadiene	106990	Y	1.17E-04	2.23E-01	6.10E-04	6.96E-08
2,2,4-Trimethylpentane	540841		6.46E-04	1.23E+00	3.36E-03	3.84E-07
Benzene	71432	Y	1.59E-04	3.02E-01	8.28E-04	9.45E-08
Chrysene	218019	Y	3.52E-05	6.68E-02	1.83E-04	2.09E-08
Cumene	98828		2.37E-04	4.50E-01	1.23E-03	1.41E-07
Cyclohexane	110827		3.97E-04	7.54E-01	2.06E-03	2.36E-07
Ethylbenzene	100414	Y	5.05E-04	9.59E-01	2.63E-03	3.00E-07
Ethylene	74851	Y	1.17E-04	2.23E-01	6.10E-04	6.96E-08
Hexane	110543	Y	2.11E-03	4.01E+00	1.10E-02	1.25E-06
Hydrogen Sulfide	7783064	Y	7.81E-06	1.48E-02	4.06E-05	4.64E-09
Indeno[1,2,3-cd]pyrene	193395	Y	1.76E-04	3.34E-01	9.15E-04	1.04E-07
m-Cresol	108394	Y	3.52E-05	6.68E-02	1.83E-04	2.09E-08
m-Xylene	108383	Y	7.70E-04	1.46E+00	4.01E-03	4.57E-07
Naphthalene	91203	Y	1.70E-03	3.22E+00	8.83E-03	1.01E-06
o-Cresol	95487	Y	3.52E-05	6.68E-02	1.83E-04	2.09E-08
o-Xylene	95476	Y	7.39E-04	1.40E+00	3.84E-03	4.39E-07
p-Cresol	106445	Y	3.52E-05	6.68E-02	1.83E-04	2.09E-08
Phenol	108952	Y	3.52E-05	6.68E-02	1.83E-04	2.09E-08
Propylene	115071	Y	1.17E-04	2.23E-01	6.10E-04	6.96E-08
p-Xylene	106423	Y	7.70E-04	1.46E+00	4.01E-03	4.57E-07
Styrene	100425	Y	1.32E-04	2.50E-01	6.86E-04	7.83E-08
Toluene	108883	Y	6.38E-04	1.21E+00	3.32E-03	3.79E-07
Xylenes, mixed	1210	Y	2.28E-03	4.33E+00	1.19E-02	1.35E-06

(1) Speciation from 2001 Tosco AB2588 HRA for Unit 90.

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ATTACHMENT B

Health Risk Tables

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Attachment B
Phillips 66 - Wilmington Plant
ULSD Project
Health Data

CHEMICAL	CAS NO.	CancerPF (Inhalation) (mg/kg-d)$^{-1}$	CancerPF (Oral) (mg/kg-d)$^{-1}$	ChronicREL (Inhalation) (μg/m^3)	ChronicREL (Oral) (mg/kg-d)	AcuteREL (Inhalation) (μg/m^3)
1,3-Butadiene	106990	0.6	*	20	*	*
Acetaldehyde	75070	1.00E-02	*	140	*	470
Arsenic	1016	12	1.5	0.015	0.0000035	0.2
Benzene	71432	1.00E-01	*	60	*	1300
Beryllium	7440417	8.4	*	0.007	0.002	*
Cadmium	7440439	15	*	0.02	0.0005	*
Chrysene	218019	0.039	0.12	*	*	*
Chromium (VI)	18540299	5.10E+02	*	0.2	0.02	*
Cresols	1319773	*	*	600	*	*
Ethyl Benzene	100414	0.0087	*	2000	*	*
Formaldehyde	50000	0.021	*	9.00E+00	*	55
Hydrogen Sulfide	7783064	*	*	1.00E+01	*	42
Hexane	110543	*	*	7000	*	*
Indeno[1,2,3-cd]pyrene	193395	3.90E-01	1.20E+00	*	*	*
Manganese	7439965	*	*	9.00E-02	*	*
Mercury	7439976	*	*	3.00E-02	0.00016	0.6
Naphthalene	91203	0.12	*	9	*	*
Ammonia	7664417	*	*	200	*	3200
PAHs	1150	*	*	*	*	*
Phenol	108952	*	*	200	*	5800
Propylene	115071	*	*	3000	*	*
Selenium	7782492	*	*	2.00E+01	*	*
Silver	7440224	*	*	*	*	*
Styrene	100425	*	*	900	*	21000
Toluene	108883	*	*	300	*	37000
Xylenes	1330207	*	*	700	*	22000

PF = Potency Factor
REL = Reference Exposure Limit
Source: SCAQMD, Risk Assessment Proceedures for Rules 1401 and 212,
Attachment L, Tables for Applications Deemed Complete on or after July 1, 2005.

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ATTACHMENT C

Source Parameters

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Attachment C
Phillips 66 - Wilmington Plant
ULSD Project
Source Parameters

Source Name	UTME (m)	UTMN (m)	Length (m)	Width (m)	Height (m)	Diameter (m)	Velocity (m/s)	Temp (F)
U90B201	380844	3737597			45.73	1.43	1.092	785
U90B401	380870	3737598			45.73	1.43	1.092	785
U90FUG	380560	3737580	70	70	1.83			

M:\MC\2696 Conoco - ULSD\HRA\2696 ULSD HRA Tables.xls:Source Parameters

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ATTACHMENT D

Detailed Risk Tables

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Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-1
HRA Risk Summary

Scenario	MEIR	MEIW	MCHI	MAHI
Pre-Project	7.35E-08	1.89E-08	2.82E-03	1.24E-04
Post-Project	1.50E-07	2.81E-08	3.66E-03	1.45E-04
Incremental Risk	**7.65E-08**	**9.20E-09**	**8.40E-04**	**1.45E-04**

Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-2
Pre-Project Maxium Exposed Individual Resident

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
Acetaldehyde	2.54E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.54E-11
Arsenic	3.05E-09	7.31E-09	3.56E-09	0.00E+00	0.00E+00	0.00E+00	6.54E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-08	1.46E-08
Benzene	3.35E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.35E-10
Beryllium	5.72E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.72E-10
Cadmium	2.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-09
Chromium(VI)	5.55E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.55E-08
Formaldehyde	3.25E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.25E-13
Hydrogen Sulfide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Indeno[1,2,3-cd]pyrene	4.95E-14	6.58E-13	9.86E-14	0.00E+00	0.00E+00	0.00E+00	8.35E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E-12	1.64E-12
Manganese	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Naphthalene	9.90E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.90E-12
PAHs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phenol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Selenium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Silver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Toluene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUM	6.20E-08	7.31E-09	3.56E-09	0.00E+00	0.00E+00	0.00E+00	6.54E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-08	7.35E-08

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
Acetaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Arsenic	4.1%	9.9%	4.8%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.6%	19.9%
Benzene	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Beryllium	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
Cadmium	3.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.4%
Chromium(VI)	75.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	75.5%
Formaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydrogen Sulfide	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indeno[1,2,3-cd]pyrene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Manganese	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mercury	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Naphthalene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PAHs	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Phenol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Selenium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silver	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toluene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SUM	84.4%	9.9%	4.8%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.6%	100.0%

Oral is the combined risk of all non-inhalation pathways.

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Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-3
Pre-Project Maxium Exposed Individual Worker

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
Acetaldehyde	5.87E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.87E-12
Arsenic	7.04E-10	3.24E-09	1.37E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.61E-09	5.32E-09
Benzene	7.73E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.73E-11
Beryllium	1.32E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-10
Cadmium	5.78E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.78E-10
Chromium(VI)	1.28E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-08
Formaldehyde	7.50E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.50E-14
Hydrogen Sulfide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Indeno[1,2,3-cd]pyrene	1.27E-14	2.92E-13	3.79E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-13	3.43E-13
Manganese	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Naphthalene	2.28E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-12
PAHs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phenol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Selenium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Silver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Toluene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUM	1.43E-08	3.24E-09	1.37E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.61E-09	1.89E-08

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
Acetaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Arsenic	3.7%	17.1%	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.4%	28.1%
Benzene	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Beryllium	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
Cadmium	3.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.1%
Chromium(VI)	67.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	67.7%
Formaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydrogen Sulfide	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indeno[1,2,3-cd]pyrene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Manganese	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mercury	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Naphthalene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PAHs	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Phenol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Selenium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silver	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toluene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SUM	75.7%	17.1%	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.4%	100.0%

Oral is the combined risk of all non-inhalation pathways.

Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-4
Pre-Project Maxium Chronic Hazard Index

CHEM	CV	CNS	BONE	DEVEL	ENDO	EYE	GILV	IMMUN	KIDN	REPRO	RESP	SKIN	BLOOD	MAX	CNS
Acetaldehyde	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.34E-08	0.00E+00	0.00E+00	7.34E-08	**0.0%**
Arsenic	2.74E-03	**2.74E-03**	0.00E+00	2.74E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.74E-03	2.74E-03	0.00E+00	2.74E-03	**97.2%**
Benzene	0.00E+00	**2.26E-07**	0.00E+00	2.26E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.26E-07	2.26E-07	**0.0%**
Beryllium	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.53E-07	3.93E-05	0.00E+00	0.00E+00	3.93E-05	0.00E+00	0.00E+00	3.93E-05	**0.0%**
Cadmium	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.03E-05	0.00E+00	3.37E-05	0.00E+00	0.00E+00	5.03E-05	**0.0%**
Chromium(VI)	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-06	0.00E+00	1.04E-07	2.20E-06	**0.0%**
Formaldehyde	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.94E-09	0.00E+00	0.00E+00	6.94E-09	**0.0%**
Hydrogen Sulfide	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E-06	0.00E+00	0.00E+00	1.48E-06	**0.0%**
Manganese	0.00E+00	**5.00E-05**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-05	**1.8%**
Mercury	0.00E+00	**2.28E-05**	0.00E+00	2.28E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-05	**0.8%**
Naphthalene	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-08	0.00E+00	0.00E+00	3.70E-08	**0.0%**
PAHs	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.0%**
Phenol	3.97E-09	**3.97E-09**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.97E-09	0.00E+00	3.97E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.97E-09	**0.0%**
Selenium	1.37E-07	**1.37E-07**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.37E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.37E-07	**0.0%**
Toluene	0.00E+00	**5.38E-08**	0.00E+00	5.38E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.38E-08	0.00E+00	0.00E+00	5.38E-08	**0.0%**
SUM	2.74E-03	**2.82E-03**	0.00E+00	2.77E-03	0.00E+00	0.00E+00	7.94E-07	3.93E-05	7.31E-05	0.00E+00	2.82E-03	2.74E-03	3.29E-07	2.82E-03	**100.0%**

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Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-5
Pre-Project Maxium Acute Hazard Index

CHEM	CV	CNS	BONE	DEVEL	ENDO	EYE	GILV	IMMUN	KIDN	REPRO	RESP	SKIN	BLOOD	MAX	CNS
Acetaldehyde	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	4.75E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E-07	0.00E+00	0.00E+00	4.75E-07	**0.0%**
Arsenic	1.12E-04	**1.12E-04**	0.00E+00	1.12E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-04	**90.3%**
Benzene	0.00E+00	**0.00E+00**	0.00E+00	2.28E-07	0.00E+00	0.00E+00	0.00E+00	2.28E-07	0.00E+00	2.28E-07	0.00E+00	0.00E+00	2.28E-07	2.28E-07	**0.0%**
Formaldehyde	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	2.48E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.48E-08	**0.0%**
Hydrogen Sulfide	0.00E+00	**7.70E-06**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-06	**6.2%**
Mercury	0.00E+00	**3.74E-06**	0.00E+00	3.74E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.74E-06	**3.0%**
Phenol	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	2.99E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.99E-09	0.00E+00	0.00E+00	2.99E-09	**0.0%**
Toluene	0.00E+00	**9.52E-09**	0.00E+00	9.52E-09	0.00E+00	9.52E-09	0.00E+00	0.00E+00	0.00E+00	9.52E-09	9.52E-09	0.00E+00	0.00E+00	9.52E-09	**0.0%**
SUM	1.12E-04	**1.24E-04**	0.00E+00	1.16E-04	0.00E+00	5.13E-07	0.00E+00	2.28E-07	0.00E+00	2.37E-07	4.88E-07	0.00E+00	2.28E-07	1.24E-04	**100.0%**

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Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-6
Post-Project Maxium Exposed Individual Resident

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
1,3-Butadiene	1.62E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-09
Acetaldehyde	3.29E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-11
Arsenic	3.95E-09	9.44E-09	4.60E-09	0.00E+00	0.00E+00	0.00E+00	8.44E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-08	1.88E-08
Benzene	7.99E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.99E-10
Beryllium	7.39E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.39E-10
Cadmium	3.24E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.24E-09
Chrysene	2.82E-11	3.75E-10	5.62E-11	0.00E+00	0.00E+00	0.00E+00	4.76E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.08E-10	9.36E-10
Chromium(VI)	7.21E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.21E-08
Cresols	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ethyl Benzene	1.01E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-10
Formaldehyde	4.19E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.19E-13
Hydrogen Sulfide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hexane	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Indeno[1,2,3-cd]pyrene	1.41E-09	1.88E-08	2.81E-09	0.00E+00	0.00E+00	0.00E+00	2.38E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.54E-08	4.68E-08
Manganese	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Naphthalene	4.68E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.68E-09
Ammonia	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAHs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phenol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Propylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Selenium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Silver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Styrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Toluene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xylenes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUM	8.86E-08	2.86E-08	7.46E-09	0.00E+00	0.00E+00	0.00E+00	2.51E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.12E-08	1.50E-07

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
1,3-Butadiene	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%
Acetaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Arsenic	2.6%	6.3%	3.1%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	9.9%	12.5%
Benzene	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Beryllium	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Cadmium	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%
Chrysene	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.6%
Chromium(VI)	48.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	48.1%
Cresols	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ethyl Benzene	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Formaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydrogen Sulfide	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hexane	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indeno[1,2,3-cd]pyrene	0.9%	12.5%	1.9%	0.0%	0.0%	0.0%	15.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	30.3%	31.2%
Manganese	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mercury	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Naphthalene	3.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.1%
Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PAHs	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Phenol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Propylene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Selenium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silver	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Styrene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toluene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Xylenes	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SUM	59.1%	19.1%	5.0%	0.0%	0.0%	0.0%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	40.8%	100.0%

Oral is the combined risk of all non-inhalation pathways.

M:\MC\2696 Conoco - ULSD\HRA\2696 ULSD HRA Tables.xls:PostMEIR

Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-7
Post-Project Maxium Exposed Individual Worker

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
1,3-Butadiene	1.21E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.21E-10
Acetaldehyde	7.55E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.55E-12
Arsenic	9.06E-10	4.17E-09	1.76E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.93E-09	6.84E-09
Benzene	1.27E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-10
Beryllium	1.70E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-10
Cadmium	7.44E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-10
Chrysene	2.35E-12	5.39E-11	7.00E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.09E-11	6.32E-11
Chromium(VI)	1.65E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E-08
Cresols	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ethyl Benzene	7.52E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.52E-12
Formaldehyde	9.63E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.63E-14
Hydrogen Sulfide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hexane	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Indeno[1,2,3-cd]pyrene	1.17E-10	2.70E-09	3.50E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-09	3.16E-09
Manganese	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Naphthalene	3.51E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.51E-10
Ammonia	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAHs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phenol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Propylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Selenium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Silver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Styrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Toluene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xylenes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUM	1.91E-08	6.92E-09	2.12E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.04E-09	2.81E-08

CHEM	INHAL	DERM	SOIL	MOTHER	FISH	WATER	VEG	DAIRY	BEEF	CHICK	PIG	EGG	MEAT	ORAL	TOTAL
1,3-Butadiene	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Acetaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Arsenic	3.2%	14.8%	6.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	21.1%	24.3%
Benzene	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Beryllium	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Cadmium	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%
Chrysene	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%
Chromium(VI)	58.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	58.7%
Cresols	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ethyl Benzene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Formaldehyde	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydrogen Sulfide	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hexane	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indeno[1,2,3-cd]pyrene	0.4%	9.6%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.9%	11.2%
Manganese	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mercury	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Naphthalene	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PAHs	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Phenol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Propylene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Selenium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silver	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Styrene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toluene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Xylenes	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SUM	68.0%	24.6%	7.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	32.2%	100.0%

Oral is the combined risk of all non-inhalation pathways.

Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-8
Post-Project Maxium Chronic Hazard Index

CHEM	CV	CNS	BONE	DEVEL	ENDO	EYE	GILV	IMMUN	KIDN	REPRO	RESP	SKIN	BLOOD	MAX	RESP
1,3-Butadiene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.76E-07	**0.00E+00**	0.00E+00	0.00E+00	1.76E-07	**0.0%**
Acetaldehyde	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**9.44E-08**	0.00E+00	0.00E+00	9.44E-08	**0.0%**
Arsenic	3.53E-03	3.53E-03	0.00E+00	3.53E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**3.53E-03**	3.53E-03	0.00E+00	3.53E-03	**96.4%**
Benzene	0.00E+00	3.71E-07	0.00E+00	3.71E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	3.71E-07	3.71E-07	**0.0%**
Beryllium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-07	5.05E-05	0.00E+00	0.00E+00	**5.05E-05**	0.00E+00	0.00E+00	5.05E-05	**1.4%**
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.48E-05	0.00E+00	**4.34E-05**	0.00E+00	0.00E+00	6.48E-05	**1.2%**
Chromium(VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**2.84E-06**	0.00E+00	1.34E-07	2.84E-06	**0.1%**
Cresols	0.00E+00	5.26E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	5.26E-09	**0.0%**
Ethyl Benzene	0.00E+00	0.00E+00	0.00E+00	7.56E-09	7.56E-09	0.00E+00	7.56E-09	0.00E+00	7.56E-09	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	7.56E-09	**0.0%**
Formaldehyde	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**8.92E-09**	0.00E+00	0.00E+00	8.92E-09	**0.0%**
Hydrogen Sulfide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**1.93E-06**	0.00E+00	0.00E+00	1.93E-06	**0.1%**
Hexane	0.00E+00	9.03E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	9.03E-09	**0.0%**
Manganese	0.00E+00	6.43E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	6.43E-05	**0.0%**
Mercury	0.00E+00	2.94E-05	0.00E+00	2.94E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.94E-05	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	2.94E-05	**0.0%**
Naphthalene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**5.69E-06**	0.00E+00	0.00E+00	5.69E-06	**0.2%**
Ammonia	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**2.56E-05**	0.00E+00	0.00E+00	2.56E-05	**0.7%**
Phenol	1.04E-08	1.04E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E-08	0.00E+00	1.04E-08	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	1.04E-08	**0.0%**
Propylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**1.17E-09**	0.00E+00	0.00E+00	1.17E-09	**0.0%**
Selenium	1.77E-07	1.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-07	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	1.77E-07	**0.0%**
Styrene	0.00E+00	4.38E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	4.38E-09	**0.0%**
Toluene	0.00E+00	1.33E-07	0.00E+00	1.33E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**1.33E-07**	0.00E+00	0.00E+00	1.33E-07	**0.0%**
Xylenes	0.00E+00	9.75E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**9.75E-08**	0.00E+00	0.00E+00	9.75E-08	**0.0%**
SUM	3.53E-03	3.62E-03	0.00E+00	3.56E-03	7.56E-09	0.00E+00	1.03E-06	5.05E-05	9.43E-05	1.76E-07	**3.66E-03**	3.53E-03	5.05E-07	3.66E-03	**100.0%**

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Attachment D
Phillips 66 - Wilmington Plant
ULSD Project
Table D-9
Post-Project Maxium Acute Hazard Index

CHEM	CV	CNS	BONE	DEVEL	ENDO	EYE	GILV	IMMUN	KIDN	REPRO	RESP	SKIN	BLOOD	MAX	CNS
Acetaldehyde	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	5.56E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.56E-07	0.00E+00	0.00E+00	5.56E-07	**0.0%**
Arsenic	1.31E-04	**1.31E-04**	0.00E+00	1.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E-04	**90.3%**
Benzene	0.00E+00	**0.00E+00**	0.00E+00	2.66E-07	0.00E+00	0.00E+00	0.00E+00	2.66E-07	0.00E+00	2.66E-07	0.00E+00	0.00E+00	2.66E-07	2.66E-07	**0.0%**
Formaldehyde	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	2.89E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.89E-08	**0.0%**
Hydrogen Sulfide	0.00E+00	**8.97E-06**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.97E-06	**6.2%**
Mercury	0.00E+00	**4.37E-06**	0.00E+00	4.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.37E-06	**3.0%**
Ammonia	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	3.17E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-05	0.00E+00	0.00E+00	3.17E-05	**0.0%**
Phenol	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	3.51E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.51E-09	0.00E+00	0.00E+00	3.51E-09	**0.0%**
Styrene	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	1.23E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-11	0.00E+00	0.00E+00	1.23E-11	**0.0%**
Toluene	0.00E+00	**1.11E-08**	0.00E+00	1.11E-08	0.00E+00	1.11E-08	0.00E+00	0.00E+00	0.00E+00	1.11E-08	1.11E-08	0.00E+00	0.00E+00	1.11E-08	**0.0%**
Xylenes	0.00E+00	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00	2.03E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.03E-10	0.00E+00	0.00E+00	2.03E-10	**0.0%**
SUM	1.31E-04	**1.45E-04**	0.00E+00	1.36E-04	0.00E+00	3.23E-05	0.00E+00	2.66E-07	0.00E+00	2.77E-07	3.22E-05	0.00E+00	2.66E-07	1.45E-04	**100.0%**

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ATTACHMENT E

Electronic Files

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This file: C:\HARP\PROJECTS\2696CP\2696B201\2696 B201 MEIR.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:35:57 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B201.EMS
   Site parameters file: C:\HARP\PROJECTS\resident pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Exposure duration: 70 year (adult resident)
Analysis method:   Derived  (Adjusted) Method
Health effect:     Cancer Risk
Receptor(s):       861
Sources(s):        All
Chemicals(s):      All

SITE PARAMETERS

DEPOSITION

   Deposition rate (m/s)            0.02

DRINKING WATER

*** Pathway disabled ***

FISH

*** Pathway disabled ***

PASTURE

*** Pathway disabled ***

HOME GROWN PRODUCE

   HUMAN INGESTION
   Fraction of ingested leafy vegetable
     from home grown source          0.052
   Fraction of ingested exposed vegetable
     from home grown source          0.052
   Fraction of ingested protected vegetable
     from home grown source          0.052
   Fraction of ingested root vegetable
```

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MEIR.txt  1/4/2013, 5:36:04PM

     from home grown source          0.052

PIGS, CHICKENS AND EGGS

*** Pathway disabled ***

DERMAL ABSORPTION

*** Pathway enabled ***

SOIL INGESTION

*** Pathway enabled ***

MOTHER'S MILK

*** Pathway enabled ***



CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                                                  BACKGROUND (ug/m^3)
0001  75070      Acetaldehyde    Acetaldehyde                                                                                    0.000E+00
0002  7440382    Arsenic         Arsenic                                                                                         0.000E+00
0003  71432      Benzene         Benzene                                                                                         0.000E+00
0004  7440417    Beryllium       Beryllium                                                                                       0.000E+00
0005  7440439    Cadmium         Cadmium                                                                                         0.000E+00
0006  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                                                              0.000E+00
0007  50000      Formaldehyde    Formaldehyde                                                                                    0.000E+00
0008  7783064    H2S             Hydrogen sulfide                                                                                0.000E+00
0009  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                                                          0.000E+00
0010  7439965    Manganese       Manganese                                                                                       0.000E+00
0011  7439976    Mercury         Mercury                                                                                         0.000E+00
0012  91203      Naphthalene     Naphthalene                                                                                     0.000E+00
0013  1150       PAHs-w/         PAHs, total, with individ. components also reported                                             0.000E+00
0014  108952     Phenol          Phenol                                                                                          0.000E+00
0015  7782492    Selenium        Selenium                                                                                        0.000E+00
0016  7440224    Silver          Silver                                                                                          0.000E+00
0017  108883     Toluene         Toluene                                                                                         0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)     ChronicREL(Inh)    ChronicREL(Oral)   AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1       ug/m^3             mg/kg-d            ug/m^3

0001  75070      Acetaldehyde    1.00E-02           *                  1.40E+02           *                  4.70E+02
0002  7440382    Arsenic         1.20E+01           1.50E+00           1.50E-02           3.50E-06           2.00E-01
0003  71432      Benzene         1.00E-01           *                  6.00E+01           *                  1.30E+03
0004  7440417    Beryllium       8.40E+00           *                  7.00E-03           2.00E-03           *
0005  7440439    Cadmium         1.50E+01           *                  2.00E-02           5.00E-04           *
0006  18540299   Cr(VI)          5.10E+02           *                  2.00E-01           2.00E-02           *
0007  50000      Formaldehyde    2.10E-02           *                  9.00E+00           *                  5.50E+01
0008  7783064    H2S             *                  *                  1.00E+01           *                  4.20E+01
0009  193395     In[1,2,3-cd]pyr 3.90E-01           1.20E+00           *                  *                  *
0010  7439965    Manganese       *                  *                  9.00E-02           *                  *
0011  7439976    Mercury         *                  *                  3.00E-02           1.60E-04           6.00E-01
0012  91203      Naphthalene     1.20E-01           *                  9.00E+00           *                  *

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MEIR.txt  1/4/2013, 5:36:04PM

0013  1150       PAHs-w/         *                  *                  *                  *                  *
0014  108952     Phenol          *                  *                  2.00E+02           *                  5.80E+03
0015  7782492    Selenium        *                  *                  2.00E+01           *                  *
0016  7440224    Silver          *                  *                  *                  *                  *
0017  108883     Toluene         *                  *                  3.00E+02           *                  3.70E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B201  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
75070           Acetaldehyde                   1               0        1.89E+00        2.15E-04
7440382         Arsenic                        1               0        1.89E-01        2.16E-05
71432           Benzene                        1               0        2.49E+00        2.85E-04
7440417         Beryllium                      1               0        5.06E-02        5.77E-06
7440439         Cadmium                        1               0        1.24E-01        1.42E-05
18540299        Cr(VI)                         1               0        8.08E-02        9.22E-06
50000           Formaldehyde                   1               0        1.15E-02        1.31E-06
7783064         H2S                            1               0        2.72E+00        3.11E-04
193395          In[1,2,3-cd]pyr                1               0        1.05E-04        1.20E-08
7439965         Manganese                      1               0        8.28E-01        9.45E-05
7439976         Mercury                        1               0        1.89E-02        2.16E-06
91203           Naphthalene                    1               0        6.13E-02        7.00E-06
1150            PAHs-w/                        1               0        7.57E-02        8.64E-06
108952          Phenol                         1               0        1.46E-01        1.67E-05
7782492         Selenium                       1               0        5.06E-01        5.77E-05
7440224         Silver                         1               0        1.01E-01        1.15E-05
108883          Toluene                        1               0        2.97E+00        3.39E-04

CANCER RISK REPORT

DOMINANT PATHWAYS, Receptor 861
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG    DAIRY     BEEF    CHICK      PIG      EGG
0001         A        -        -        -        -        -        -        -        -        -        -        -
0002         A      YES        -        -        -        -        -        -        -        -        -        -
0003         A        -        -        -        -        -        -        -        -        -        -        -
0004         A        -        -        -        -        -        -        -        -        -        -        -
0005         A        -        -        -        -        -        -        -        -        -        -        -
0006         A        -        -        -        -        -        -        -        -        -        -        -
0007         A        -        -        -        -        -        -        -        -        -        -        -
0008         -        -        -        -        -        -        -        -        -        -        -        -
0009         -      YES        -        -        -        -      YES        -        -        -        -        -
0010         -        -        -        -        -        -        -        -        -        -        -        -
0011         -        -        -        -        -        -        -        -        -        -        -        -
0012         A        -        -        -        -        -        -        -        -        -        -        -
0013         -        -        -        -        -        -        -        -        -        -        -        -
0014         -        -        -        -        -        -        -        -        -        -        -        -
0015         -        -        -        -        -        -        -        -        -        -        -        -
0016         -        -        -        -        -        -        -        -        -        -        -        -
0017         -        -        -        -        -        -        -        -        -        -        -        -

DERIVED CANCER RISK, RECEPTOR 861
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG    DAIRY     BEEF    CHICK      PIG      EGG     MEAT     ORAL    TOTAL   UTME
0001  2.54E-11 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.54E-11
0002  3.05E-09 7.31E-09 3.56E-09 0.00E+00 0.00E+00 0.00E+00 6.54E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.15E-08 1.46E-08

                                                                                                                                             Page: 3
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MEIR.txt  1/4/2013, 5:36:04PM

0003  3.35E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.35E-10
0004  5.72E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.72E-10
0005  2.50E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.50E-09
0006  5.55E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.55E-08
0007  3.25E-13 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.25E-13
0008  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0009  4.95E-14 6.58E-13 9.86E-14 0.00E+00 0.00E+00 0.00E+00 8.35E-13 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.59E-12 1.64E-12
0010  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0011  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0012  9.90E-12 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.90E-12
0013  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0014  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0015  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0016  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0017  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
SUM   6.20E-08 7.31E-09 3.56E-09 0.00E+00 0.00E+00 0.00E+00 6.54E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.15E-08 7.35E-08 381700 373
```

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MEIW.txt  1/4/2013, 5:37:20PM

This file: C:\HARP\PROJECTS\2696CP\2696B201\2696 B201 MEIW.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:37:14 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B201.EMS
   Site parameters file: C:\HARP\PROJECTS\worker pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Exposure duration: Standard work schedule (49 wks/yr, 5 days/wk, 8 hrs/day, 40 yrs)
Analysis method:   Point estimate
Health effect:     Cancer Risk
Receptor(s):       788
Sources(s):        All
Chemicals(s):      All

SITE PARAMETERS

DEPOSITION

   Deposition rate (m/s)             0.02

DRINKING WATER

*** Pathway disabled ***

FISH

*** Pathway disabled ***

PASTURE

*** Pathway disabled ***

HOME GROWN PRODUCE

*** Pathway disabled ***

PIGS, CHICKENS AND EGGS

*** Pathway disabled ***

DERMAL ABSORPTION

                                                                                                                                              Page: 1
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MEIW.txt  1/4/2013, 5:37:20PM

*** Pathway enabled ***

SOIL INGESTION

*** Pathway enabled ***

MOTHER'S MILK

*** Pathway disabled ***



CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS       ABBREVIATION    POLLUTANT NAME                                                      BACKGROUND (ug/m^3)
0001  75070     Acetaldehyde    Acetaldehyde                                                        0.000E+00
0002  7440382   Arsenic         Arsenic                                                             0.000E+00
0003  71432     Benzene         Benzene                                                             0.000E+00
0004  7440417   Beryllium       Beryllium                                                           0.000E+00
0005  7440439   Cadmium         Cadmium                                                             0.000E+00
0006  18540299  Cr(VI)          Chromium, hexavalent (& compounds)                                  0.000E+00
0007  50000     Formaldehyde    Formaldehyde                                                        0.000E+00
0008  7783064   H2S             Hydrogen sulfide                                                    0.000E+00
0009  193395    In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                              0.000E+00
0010  7439965   Manganese       Manganese                                                           0.000E+00
0011  7439976   Mercury         Mercury                                                             0.000E+00
0012  91203     Naphthalene     Naphthalene                                                         0.000E+00
0013  1150      PAHs-w/         PAHs, total, with individ. components also reported                 0.000E+00
0014  108952    Phenol          Phenol                                                              0.000E+00
0015  7782492   Selenium        Selenium                                                            0.000E+00
0016  7440224   Silver          Silver                                                              0.000E+00
0017  108883    Toluene         Toluene                                                             0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS       ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)     ChronicREL(Inh)    ChronicREL(Oral)   AcuteREL
                                (mg/kg-d)^-1       (mg/kg-d)^-1       ug/m^3             mg/kg-d            ug/m^3

0001  75070     Acetaldehyde    1.00E-02           *                  1.40E+02           *                  4.70E+02
0002  7440382   Arsenic         1.20E+01           1.50E+00           1.50E-02           3.50E-06           2.00E-01
0003  71432     Benzene         1.00E-01           *                  6.00E+01           *                  1.30E+03
0004  7440417   Beryllium       8.40E+00           *                  7.00E-03           2.00E-03           *
0005  7440439   Cadmium         1.50E+01           *                  2.00E-02           5.00E-04           *
0006  18540299  Cr(VI)          5.10E+02           *                  2.00E-01           2.00E-02           *
0007  50000     Formaldehyde    2.10E-02           *                  9.00E+00           *                  5.50E+01
0008  7783064   H2S             *                  *                  1.00E+01           *                  4.20E+01
0009  193395    In[1,2,3-cd]pyr 3.90E-01           1.20E+00           *                  *                  *
0010  7439965   Manganese       *                  *                  9.00E-02           *                  *
0011  7439976   Mercury         *                  *                  3.00E-02           1.60E-04           6.00E-01
0012  91203     Naphthalene     1.20E-01           *                  9.00E+00           *                  *
0013  1150      PAHs-w/         *                  *                  *                  *                  *
0014  108952    Phenol          *                  *                  2.00E+02           *                  5.80E+03
0015  7782492   Selenium        *                  *                  2.00E+01           *                  *
0016  7440224   Silver          *                  *                  *                  *                  *
0017  108883    Toluene         *                  *                  3.00E+02           *                  3.70E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.EMS
CHEMICALS ADDED OR DELETED: none

                                                                                                                   Page: 2
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MEIW.txt  1/4/2013, 5:37:20PM

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B201  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
75070           Acetaldehyde                   1               0        1.89E+00        2.15E-04
7440382         Arsenic                        1               0        1.89E-01        2.16E-05
71432           Benzene                        1               0        2.49E+00        2.85E-04
7440417         Beryllium                      1               0        5.06E-02        5.77E-06
7440439         Cadmium                        1               0        1.24E-01        1.42E-05
18540299        Cr(VI)                         1               0        8.08E-02        9.22E-06
50000           Formaldehyde                   1               0        1.15E-02        1.31E-06
7783064         H2S                            1               0        2.72E+00        3.11E-04
193395          In[1,2,3-cd]pyr                1               0        1.05E-04        1.20E-08
7439965         Manganese                      1               0        8.28E-01        9.45E-05
7439976         Mercury                        1               0        1.89E-02        2.16E-06
91203           Naphthalene                    1               0        6.13E-02        7.00E-06
1150            PAHs-w/                        1               0        7.57E-02        8.64E-06
108952          Phenol                         1               0        1.46E-01        1.67E-05
7782492         Selenium                       1               0        5.06E-01        5.77E-05
7440224         Silver                         1               0        1.01E-01        1.15E-05
108883          Toluene                        1               0        2.97E+00        3.39E-04

CANCER RISK REPORT

AVERAGE CANCER RISK, RECEPTOR 788
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG    DAIRY     BEEF    CHICK      PIG      EGG     MEAT     ORAL    TOTAL   UTME
0001  5.87E-12 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.87E-12
0002  7.04E-10 3.24E-09 1.37E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.61E-09 5.32E-09
0003  7.73E-11 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.73E-11
0004  1.32E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.32E-10
0005  5.78E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.78E-10
0006  1.28E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.28E-08
0007  7.50E-14 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.50E-14
0008  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0009  1.27E-14 2.92E-13 3.79E-14 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.30E-13 3.43E-13
0010  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0011  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0012  2.28E-12 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.28E-12
0013  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0014  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0015  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0016  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0017  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
SUM   1.43E-08 3.24E-09 1.37E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.61E-09 1.89E-08 382500 373
```

```
This file: C:\HARP\PROJECTS\2696CP\2696B201\2696 B201 MCHI.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:36:19 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B201.EMS
   Site parameters file: C:\HARP\PROJECTS\resident pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Exposure duration: resident
Analysis method:   Derived (OEHHA) Method
Health effect:     Chronic HI
Receptor(s):       788
Sources(s):        All
Chemicals(s):      All

SITE PARAMETERS

DEPOSITION

   Deposition rate (m/s)             0.02

DRINKING WATER

*** Pathway disabled ***

FISH

*** Pathway disabled ***

PASTURE

*** Pathway disabled ***

HOME GROWN PRODUCE

   HUMAN INGESTION
   Fraction of ingested leafy vegetable
     from home grown source          0.052
   Fraction of ingested exposed vegetable
     from home grown source          0.052
   Fraction of ingested protected vegetable
     from home grown source          0.052
   Fraction of ingested root vegetable
```

```
File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MCHI.txt  1/4/2013, 5:36:26PM

     from home grown source          0.052

PIGS, CHICKENS AND EGGS

*** Pathway disabled ***

DERMAL ABSORPTION

*** Pathway enabled ***

SOIL INGESTION

*** Pathway enabled ***

MOTHER'S MILK

*** Pathway enabled ***



CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                        BACKGROUND (ug/m^3)
0001  75070      Acetaldehyde    Acetaldehyde                                                          0.000E+00
0002  7440382    Arsenic         Arsenic                                                               0.000E+00
0003  71432      Benzene         Benzene                                                               0.000E+00
0004  7440417    Beryllium       Beryllium                                                             0.000E+00
0005  7440439    Cadmium         Cadmium                                                               0.000E+00
0006  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                                    0.000E+00
0007  50000      Formaldehyde    Formaldehyde                                                          0.000E+00
0008  7783064    H2S             Hydrogen sulfide                                                      0.000E+00
0009  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                                0.000E+00
0010  7439965    Manganese       Manganese                                                             0.000E+00
0011  7439976    Mercury         Mercury                                                               0.000E+00
0012  91203      Naphthalene     Naphthalene                                                           0.000E+00
0013  1150       PAHs-w/         PAHs, total, with individ. components also reported                   0.000E+00
0014  108952     Phenol          Phenol                                                                0.000E+00
0015  7782492    Selenium        Selenium                                                              0.000E+00
0016  7440224    Silver          Silver                                                                0.000E+00
0017  108883     Toluene         Toluene                                                               0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)      ChronicREL(Inh)     ChronicREL(Oral)    AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1        ug/m^3              mg/kg-d             ug/m^3

0001  75070      Acetaldehyde    1.00E-02           *                   1.40E+02            *                   4.70E+02
0002  7440382    Arsenic         1.20E+01           1.50E+00            1.50E-02            3.50E-06            2.00E-01
0003  71432      Benzene         1.00E-01           *                   6.00E+01            *                   1.30E+03
0004  7440417    Beryllium       8.40E+00           *                   7.00E-03            2.00E-03            *
0005  7440439    Cadmium         1.50E+01           *                   2.00E-02            5.00E-04            *
0006  18540299   Cr(VI)          5.10E+02           *                   2.00E-01            2.00E-02            *
0007  50000      Formaldehyde    2.10E-02           *                   9.00E+00            *                   5.50E+01
0008  7783064    H2S             *                  *                   1.00E+01            *                   4.20E+01
0009  193395     In[1,2,3-cd]pyr 3.90E-01           1.20E+00            *                   *                   *
0010  7439965    Manganese       *                  *                   9.00E-02            *                   *
0011  7439976    Mercury         *                  *                   3.00E-02            1.60E-04            6.00E-01
0012  91203      Naphthalene     1.20E-01           *                   9.00E+00            *                   *
```

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MCHI.txt  1/4/2013, 5:36:26PM

0013  1150       PAHs-w/         *                  *                  *                  *                  *
0014  108952     Phenol          *                  *                  2.00E+02           *                  5.80E+03
0015  7782492    Selenium        *                  *                  2.00E+01           *                  *
0016  7440224    Silver          *                  *                  *                  *                  *
0017  108883     Toluene         *                  *                  3.00E+02           *                  3.70E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B201  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                 MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
75070           Acetaldehyde                    1               0        1.89E+00        2.15E-04
7440382         Arsenic                         1               0        1.89E-01        2.16E-05
71432           Benzene                         1               0        2.49E+00        2.85E-04
7440417         Beryllium                       1               0        5.06E-02        5.77E-06
7440439         Cadmium                         1               0        1.24E-01        1.42E-05
18540299        Cr(VI)                          1               0        8.08E-02        9.22E-06
50000           Formaldehyde                    1               0        1.15E-02        1.31E-06
7783064         H2S                             1               0        2.72E+00        3.11E-04
193395          In[1,2,3-cd]pyr                 1               0        1.05E-04        1.20E-08
7439965         Manganese                       1               0        8.28E-01        9.45E-05
7439976         Mercury                         1               0        1.89E-02        2.16E-06
91203           Naphthalene                     1               0        6.13E-02        7.00E-06
1150            PAHs-w/                         1               0        7.57E-02        8.64E-06
108952          Phenol                          1               0        1.46E-01        1.67E-05
7782492         Selenium                        1               0        5.06E-01        5.77E-05
7440224         Silver                          1               0        1.01E-01        1.15E-05
108883          Toluene                         1               0        2.97E+00        3.39E-04

CHRONIC HI REPORT

DOMINANT PATHWAYS, Receptor 788
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG    DAIRY     BEEF    CHICK      PIG      EGG
0001       YES        -        -        -        -        -        -        -        -        -        -        -
0002       YES      YES      YES        -        -        -        -        -        -        -        -        -
0003       YES        -        -        -        -        -        -        -        -        -        -        -
0004       YES        -      YES        -        -        -      YES        -        -        -        -        -
0005       YES        -      YES        -        -        -      YES        -        -        -        -        -
0006       YES        -      YES        -        -        -      YES        -        -        -        -        -
0007       YES        -        -        -        -        -        -        -        -        -        -        -
0008       YES        -        -        -        -        -        -        -        -        -        -        -
0009       YES      YES        -        -        -        -      YES        -        -        -        -        -
0010       YES        -        -        -        -        -        -        -        -        -        -        -
0011       YES      YES        -        -        -        -      YES        -        -        -        -        -
0012       YES        -        -        -        -        -        -        -        -        -        -        -
0013         -        -        -        -        -        -        -        -        -        -        -        -
0014       YES        -        -        -        -        -        -        -        -        -        -        -
0015       YES        -        -        -        -        -        -        -        -        -        -        -
0016       YES        -        -        -        -        -        -        -        -        -        -        -
0017       YES        -        -        -        -        -        -        -        -        -        -        -

DERIVED CHRONIC HI, RECEPTOR 788
CHEM        CV      CNS     BONE    DEVEL     ENDO      EYE     GILV    IMMUN     KIDN    REPRO     RESP     SKIN    BLOOD      MAX   UTME    UTMN
0001  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.34E-08 0.00E+00 0.00E+00 7.34E-08
0002  2.74E-03 2.74E-03 0.00E+00 2.74E-03 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.74E-03 2.74E-03 0.00E+00 2.74E-03

                                                                                                                              Page: 3
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MCHI.txt  1/4/2013, 5:36:26PM

0003  0.00E+00 2.26E-07 0.00E+00 2.26E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.26E-07 2.26E-07
0004  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 6.53E-07 3.93E-05 0.00E+00 0.00E+00 3.93E-05 0.00E+00 0.00E+00 3.93E-05
0005  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.03E-05 0.00E+00 3.37E-05 0.00E+00 0.00E+00 5.03E-05
0006  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.20E-06 0.00E+00 1.04E-07 2.20E-06
0007  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 6.94E-09 0.00E+00 0.00E+00 6.94E-09
0008  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.48E-06 0.00E+00 0.00E+00 1.48E-06
0009  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0010  0.00E+00 5.00E-05 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.00E-05
0011  0.00E+00 2.28E-05 0.00E+00 2.28E-05 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.28E-05 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.28E-05
0012  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.70E-08 0.00E+00 0.00E+00 3.70E-08
0013  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0014  3.97E-09 3.97E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.97E-09 0.00E+00 3.97E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.97E-09
0015  1.37E-07 1.37E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.37E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.37E-07
0016  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0017  0.00E+00 5.38E-08 0.00E+00 5.38E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.38E-08 0.00E+00 0.00E+00 5.38E-08
SUM   2.74E-03 2.82E-03 0.00E+00 2.77E-03 0.00E+00 0.00E+00 7.94E-07 3.93E-05 7.31E-05 0.00E+00 2.82E-03 2.74E-03 3.29E-07 2.82E-03 382500 3737400
```

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MAHI.txt  1/4/2013, 5:35:40PM

This file: C:\HARP\PROJECTS\2696CP\2696B201\2696 B201 MAHI.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:35:34 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B201.EMS
   Site parameters file: C:\HARP\PROJECTS\resident pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Analysis method:   Point Estimate
Health effect:     Acute HI Simple (Concurrent Max.)
Receptor(s):       778
Sources(s):        All
Chemicals(s):      All

CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                            BACKGROUND (ug/m^3)
0001  75070      Acetaldehyde    Acetaldehyde                                                              0.000E+00
0002  7440382    Arsenic         Arsenic                                                                   0.000E+00
0003  71432      Benzene         Benzene                                                                   0.000E+00
0004  7440417    Beryllium       Beryllium                                                                 0.000E+00
0005  7440439    Cadmium         Cadmium                                                                   0.000E+00
0006  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                                        0.000E+00
0007  50000      Formaldehyde    Formaldehyde                                                              0.000E+00
0008  7783064    H2S             Hydrogen sulfide                                                          0.000E+00
0009  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                                    0.000E+00
0010  7439965    Manganese       Manganese                                                                 0.000E+00
0011  7439976    Mercury         Mercury                                                                   0.000E+00
0012  91203      Naphthalene     Naphthalene                                                               0.000E+00
0013  1150       PAHs-w/         PAHs, total, with individ. components also reported                       0.000E+00
0014  108952     Phenol          Phenol                                                                    0.000E+00
0015  7782492    Selenium        Selenium                                                                  0.000E+00
0016  7440224    Silver          Silver                                                                    0.000E+00
0017  108883     Toluene         Toluene                                                                   0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)      ChronicREL(Inh)     ChronicREL(Oral)    AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1        ug/m^3              mg/kg-d             ug/m^3

0001  75070      Acetaldehyde    1.00E-02           *                   1.40E+02            *                   4.70E+02
0002  7440382    Arsenic         1.20E+01           1.50E+00            1.50E-02            3.50E-06            2.00E-01
0003  71432      Benzene         1.00E-01           *                   6.00E+01            *                   1.30E+03
0004  7440417    Beryllium       8.40E+00           *                   7.00E-03            2.00E-03            *
0005  7440439    Cadmium         1.50E+01           *                   2.00E-02            5.00E-04            *

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B201 MAHI.txt  1/4/2013, 5:35:40PM

0006  18540299   Cr(VI)          5.10E+02           *                   2.00E-01            2.00E-02            *
0007  50000      Formaldehyde    2.10E-02           *                   9.00E+00            *                   5.50E+01
0008  7783064    H2S             *                  *                   1.00E+01            *                   4.20E+01
0009  193395     In[1,2,3-cd]pyr 3.90E-01           1.20E+00            *                   *                   *
0010  7439965    Manganese       *                  *                   9.00E-02            *                   *
0011  7439976    Mercury         *                  *                   3.00E-02            1.60E-04            6.00E-01
0012  91203      Naphthalene     1.20E-01           *                   9.00E+00            *                   *
0013  1150       PAHs-w/         *                  *                   *                   *                   *
0014  108952     Phenol          *                  *                   2.00E+02            *                   5.80E+03
0015  7782492    Selenium        *                  *                   2.00E+01            *                   *
0016  7440224    Silver          *                  *                   *                   *                   *
0017  108883     Toluene         *                  *                   3.00E+02            *                   3.70E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B201\2696B201.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B201  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
75070           Acetaldehyde                   1               0        1.89E+00        2.15E-04
7440382         Arsenic                        1               0        1.89E-01        2.16E-05
71432           Benzene                        1               0        2.49E+00        2.85E-04
7440417         Beryllium                      1               0        5.06E-02        5.77E-06
7440439         Cadmium                        1               0        1.24E-01        1.42E-05
18540299        Cr(VI)                         1               0        8.08E-02        9.22E-06
50000           Formaldehyde                   1               0        1.15E-02        1.31E-06
7783064         H2S                            1               0        2.72E+00        3.11E-04
193395          In[1,2,3-cd]pyr                1               0        1.05E-04        1.20E-08
7439965         Manganese                      1               0        8.28E-01        9.45E-05
7439976         Mercury                        1               0        1.89E-02        2.16E-06
91203           Naphthalene                    1               0        6.13E-02        7.00E-06
1150            PAHs-w/                        1               0        7.57E-02        8.64E-06
108952          Phenol                         1               0        1.46E-01        1.67E-05
7782492         Selenium                       1               0        5.06E-01        5.77E-05
7440224         Silver                         1               0        1.01E-01        1.15E-05
108883          Toluene                        1               0        2.97E+00        3.39E-04

ACUTE HI REPORT

ACUTE HI, RECEPTOR 778
CHEM        CV      CNS     BONE    DEVEL     ENDO      EYE     GILV    IMMUN     KIDN    REPRO     RESP     SKIN    BLOOD      MAX    UTME     UTMN
0001  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.75E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.75E-07 0.00E+00 0.00E+00 4.75E-07
0002  1.12E-04 1.12E-04 0.00E+00 1.12E-04 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.12E-04
0003  0.00E+00 0.00E+00 0.00E+00 2.28E-07 0.00E+00 0.00E+00 0.00E+00 2.28E-07 0.00E+00 2.28E-07 0.00E+00 0.00E+00 2.28E-07 2.28E-07
0004  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0005  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0006  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0007  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.48E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.48E-08
0008  0.00E+00 7.70E-06 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.70E-06
0009  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0010  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0011  0.00E+00 3.74E-06 0.00E+00 3.74E-06 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.74E-06
0012  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0013  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0014  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.99E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.99E-09 0.00E+00 0.00E+00 2.99E-09
0015  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
```

```
0016  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0017  0.00E+00 9.52E-09 0.00E+00 9.52E-09 0.00E+00 9.52E-09 0.00E+00 0.00E+00 0.00E+00 9.52E-09 9.52E-09 0.00E+00 0.00E+00 9.52E-09
SUM   1.12E-04 1.24E-04 0.00E+00 1.16E-04 0.00E+00 5.13E-07 0.00E+00 2.28E-07 0.00E+00 2.37E-07 4.88E-07 0.00E+00 2.28E-07 1.24E-04 381500 3737400
```

```
This file: C:\HARP\PROJECTS\2696CP\2696B401\2696 B401 MEIR.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:47:23 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B401.EMS
   Site parameters file: C:\HARP\PROJECTS\resident pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Exposure duration: 70 year (adult resident)
Analysis method:   Derived  (Adjusted) Method
Health effect:     Cancer Risk
Receptor(s):       861
Sources(s):        All
Chemicals(s):      All

SITE PARAMETERS

DEPOSITION

   Deposition rate (m/s)            0.02

DRINKING WATER

*** Pathway disabled ***

FISH

*** Pathway disabled ***

PASTURE

*** Pathway disabled ***

HOME GROWN PRODUCE

   HUMAN INGESTION
   Fraction of ingested leafy vegetable
     from home grown source          0.052
   Fraction of ingested exposed vegetable
     from home grown source          0.052
   Fraction of ingested protected vegetable
     from home grown source          0.052
   Fraction of ingested root vegetable
```

```
File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MEIR.txt  1/4/2013, 5:47:25PM

     from home grown source          0.052

PIGS, CHICKENS AND EGGS

*** Pathway disabled ***

DERMAL ABSORPTION

*** Pathway enabled ***

SOIL INGESTION

*** Pathway enabled ***

MOTHER'S MILK

*** Pathway enabled ***



CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                         BACKGROUND (ug/m^3)
0001  106990     1,3-Butadiene   1,3-Butadiene                                                          0.000E+00
0002  75070      Acetaldehyde    Acetaldehyde                                                           0.000E+00
0003  1016       As cmpd(inorg)  Arsenic compounds (inorganic)                                          0.000E+00
0004  71432      Benzene         Benzene                                                                0.000E+00
0005  7440417    Beryllium       Beryllium                                                              0.000E+00
0006  7440439    Cadmium         Cadmium                                                                0.000E+00
0007  218019     Chrysene        Chrysene                                                               0.000E+00
0008  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                                     0.000E+00
0009  1319773    Cresols         Cresols (mixtures of) {Cresylic acid}                                  0.000E+00
0010  100414     Ethyl Benzene   Ethyl benzene                                                          0.000E+00
0011  50000      Formaldehyde    Formaldehyde                                                           0.000E+00
0012  7783064    H2S             Hydrogen sulfide                                                       0.000E+00
0013  110543     Hexane          Hexane                                                                 0.000E+00
0014  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                                 0.000E+00
0015  7439965    Manganese       Manganese                                                              0.000E+00
0016  7439976    Mercury         Mercury                                                                0.000E+00
0017  91203      Naphthalene     Naphthalene                                                            0.000E+00
0018  7664417    NH3             Ammonia                                                                0.000E+00
0019  1150       PAHs-w/         PAHs, total, with individ. components also reported                    0.000E+00
0020  108952     Phenol          Phenol                                                                 0.000E+00
0021  115071     Propylene       Propylene                                                              0.000E+00
0022  7782492    Selenium        Selenium                                                               0.000E+00
0023  7440224    Silver          Silver                                                                 0.000E+00
0024  100425     Styrene         Styrene                                                                0.000E+00
0025  108883     Toluene         Toluene                                                                0.000E+00
0026  1330207    Xylenes         Xylenes (mixed)                                                        0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)      ChronicREL(Inh)     ChronicREL(Oral)    AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1        ug/m^3              mg/kg-d             ug/m^3

0001  106990     1,3-Butadiene   6.00E-01           *                   2.00E+01            *                   *
0002  75070      Acetaldehyde    1.00E-02           *                   1.40E+02            *                   4.70E+02
0003  1016       As cmpd(inorg)  1.20E+01           1.50E+00            1.50E-02            3.50E-06            2.00E-01

                                                                                                                                        Page: 2
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MEIR.txt  1/4/2013, 5:47:25PM

0004  71432      Benzene         1.00E-01           *                   6.00E+01            *                   1.30E+03
0005  7440417    Beryllium       8.40E+00           *                   7.00E-03            2.00E-03            *
0006  7440439    Cadmium         1.50E+01           *                   2.00E-02            5.00E-04            *
0007  218019     Chrysene        3.90E-02           1.20E-01            *                   *                   *
0008  18540299   Cr(VI)          5.10E+02           *                   2.00E-01            2.00E-02            *
0009  1319773    Cresols         *                  *                   6.00E+02            *                   *
0010  100414     Ethyl Benzene   8.70E-03           *                   2.00E+03            *                   *
0011  50000      Formaldehyde    2.10E-02           *                   9.00E+00            *                   5.50E+01
0012  7783064    H2S             *                  *                   1.00E+01            *                   4.20E+01
0013  110543     Hexane          *                  *                   7.00E+03            *                   *
0014  193395     In[1,2,3-cd]pyr 3.90E-01           1.20E+00            *                   *                   *
0015  7439965    Manganese       *                  *                   9.00E-02            *                   *
0016  7439976    Mercury         *                  *                   3.00E-02            1.60E-04            6.00E-01
0017  91203      Naphthalene     1.20E-01           *                   9.00E+00            *                   *
0018  7664417    NH3             *                  *                   2.00E+02            *                   3.20E+03
0019  1150       PAHs-w/         *                  *                   *                   *                   *
0020  108952     Phenol          *                  *                   2.00E+02            *                   5.80E+03
0021  115071     Propylene       *                  *                   3.00E+03            *                   *
0022  7782492    Selenium        *                  *                   2.00E+01            *                   *
0023  7440224    Silver          *                  *                   *                   *                   *
0024  100425     Styrene         *                  *                   9.00E+02            *                   2.10E+04
0025  108883     Toluene         *                  *                   3.00E+02            *                   3.70E+04
0026  1330207    Xylenes         *                  *                   7.00E+02            *                   2.20E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B401  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0        0.00E+00        0.00E+00
75070           Acetaldehyde                   1               0        2.42E+00        2.76E-04
1016            As cmpd(inorg)                 1               0        2.42E-01        2.77E-05
71432           Benzene                        1               0        3.20E+00        3.65E-04
7440417         Beryllium                      1               0        6.48E-02        7.40E-06
7440439         Cadmium                        1               0        1.59E-01        1.81E-05
218019          Chrysene                       1               0        0.00E+00        0.00E+00
18540299        Cr(VI)                         1               0        1.04E-01        1.18E-05
1319773         Cresols                        1               0        0.00E+00        0.00E+00
100414          Ethyl Benzene                  1               0        0.00E+00        0.00E+00
50000           Formaldehyde                   1               0        1.47E-02        1.68E-06
7783064         H2S                            1               0        3.49E+00        3.98E-04
110543          Hexane                         1               0        0.00E+00        0.00E+00
193395          In[1,2,3-cd]pyr                1               0        1.35E-04        1.54E-08
7439965         Manganese                      1               0        1.06E+00        1.21E-04
7439976         Mercury                        1               0        2.43E-02        2.77E-06
91203           Naphthalene                    1               0        7.86E-02        8.97E-06
7664417         NH3                            1               0        9.38E+02        1.07E-01
1150            PAHs-w/                        1               0        9.70E-02        1.11E-05
108952          Phenol                         1               0        1.88E-01        2.14E-05
115071          Propylene                      1               0        0.00E+00        0.00E+00
7782492         Selenium                       1               0        6.48E-01        7.40E-05
7440224         Silver                         1               0        1.30E-01        1.48E-05
100425          Styrene                        1               0        0.00E+00        0.00E+00
108883          Toluene                        1               0        3.80E+00        4.34E-04
1330207         Xylenes                        1               0        0.00E+00        0.00E+00
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MEIR.txt  1/4/2013, 5:47:25PM

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=2   NAME=U90FUG  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0       2.23E-01        6.96E-08
75070           Acetaldehyde                   1               0       0.00E+00        0.00E+00
1016            As cmpd(inorg)                 1               0       0.00E+00        0.00E+00
71432           Benzene                        1               0       3.02E-01        9.45E-08
7440417         Beryllium                      1               0       0.00E+00        0.00E+00
7440439         Cadmium                        1               0       0.00E+00        0.00E+00
218019          Chrysene                       1               0       6.68E-02        2.09E-08
18540299        Cr(VI)                         1               0       0.00E+00        0.00E+00
1319773         Cresols                        1               0       2.00E-01        6.26E-08
100414          Ethyl Benzene                  1               0       9.59E-01        3.00E-07
50000           Formaldehyde                   1               0       0.00E+00        0.00E+00
7783064         H2S                            1               0       1.48E-02        4.64E-09
110543          Hexane                         1               0       4.01E+00        1.25E-06
193395          In[1,2,3-cd]pyr                1               0       3.34E-01        1.04E-07
7439965         Manganese                      1               0       0.00E+00        0.00E+00
7439976         Mercury                        1               0       0.00E+00        0.00E+00
91203           Naphthalene                    1               0       3.22E+00        1.01E-06
7664417         NH3                            1               0       0.00E+00        0.00E+00
1150            PAHs-w/                        1               0       0.00E+00        0.00E+00
108952          Phenol                         1               0       6.68E-02        2.09E-08
115071          Propylene                      1               0       2.23E-01        6.96E-08
7782492         Selenium                       1               0       0.00E+00        0.00E+00
7440224         Silver                         1               0       0.00E+00        0.00E+00
100425          Styrene                        1               0       2.50E-01        7.83E-08
108883          Toluene                        1               0       1.21E+00        3.79E-07
1330207         Xylenes                        1               0       4.33E+00        1.35E-06

CANCER RISK REPORT

DOMINANT PATHWAYS, Receptor 861
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG     DAIRY     BEEF    CHICK      PIG      EGG
0001         A        -        -        -        -        -        -        -        -        -        -        -
0002         A        -        -        -        -        -        -        -        -        -        -        -
0003         A      YES        -        -        -        -        -        -        -        -        -        -
0004         A        -        -        -        -        -        -        -        -        -        -        -
0005         A        -        -        -        -        -        -        -        -        -        -        -
0006         A        -        -        -        -        -        -        -        -        -        -        -
0007         -      YES        -        -        -        -      YES        -        -        -        -        -
0008         A        -        -        -        -        -        -        -        -        -        -        -
0009         -        -        -        -        -        -        -        -        -        -        -        -
0010         A        -        -        -        -        -        -        -        -        -        -        -
0011         A        -        -        -        -        -        -        -        -        -        -        -
0012         -        -        -        -        -        -        -        -        -        -        -        -
0013         -        -        -        -        -        -        -        -        -        -        -        -
0014         -      YES        -        -        -        -      YES        -        -        -        -        -
0015         -        -        -        -        -        -        -        -        -        -        -        -
0016         -        -        -        -        -        -        -        -        -        -        -        -
0017         A        -        -        -        -        -        -        -        -        -        -        -
0018         -        -        -        -        -        -        -        -        -        -        -        -
0019         -        -        -        -        -        -        -        -        -        -        -        -
0020         -        -        -        -        -        -        -        -        -        -        -        -
0021         -        -        -        -        -        -        -        -        -        -        -        -

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0022          -         -         -         -         -         -         -         -         -         -         -         -
0023          -         -         -         -         -         -         -         -         -         -         -         -
0024          -         -         -         -         -         -         -         -         -         -         -         -
0025          -         -         -         -         -         -         -         -         -         -         -         -
0026          -         -         -         -         -         -         -         -         -         -         -         -

DERIVED CANCER RISK, RECEPTOR 861
CHEM      INHAL      DERM      SOIL    MOTHER      FISH     WATER       VEG     DAIRY      BEEF     CHICK       PIG       EGG      MEAT      ORAL     TOTAL   UTME
0001  1.62E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.62E-09
0002  3.29E-11 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.29E-11
0003  3.95E-09 9.44E-09 4.60E-09 0.00E+00 0.00E+00 0.00E+00 8.44E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.49E-08 1.88E-08
0004  7.99E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.99E-10
0005  7.39E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.39E-10
0006  3.24E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.24E-09
0007  2.82E-11 3.75E-10 5.62E-11 0.00E+00 0.00E+00 0.00E+00 4.76E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.08E-10 9.36E-10
0008  7.21E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.21E-08
0009  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0010  1.01E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.01E-10
0011  4.19E-13 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.19E-13
0012  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0013  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0014  1.41E-09 1.88E-08 2.81E-09 0.00E+00 0.00E+00 0.00E+00 2.38E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.54E-08 4.68E-08
0015  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0016  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0017  4.68E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.68E-09
0018  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0019  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0020  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0021  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0022  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0023  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0024  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0025  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0026  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
SUM   8.86E-08 2.86E-08 7.46E-09 0.00E+00 0.00E+00 0.00E+00 2.51E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 6.12E-08 1.50E-07 381700 373
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This file: C:\HARP\PROJECTS\2696CP\2696B401\2696 B401 MEIW.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:48:30 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B401.EMS
   Site parameters file: C:\HARP\PROJECTS\worker pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Exposure duration: Standard work schedule (49 wks/yr, 5 days/wk, 8 hrs/day, 40 yrs)
Analysis method:   Point estimate
Health effect:     Cancer Risk
Receptor(s):       788
Sources(s):        All
Chemicals(s):      All

SITE PARAMETERS

DEPOSITION

   Deposition rate (m/s)             0.02

DRINKING WATER

*** Pathway disabled ***

FISH

*** Pathway disabled ***

PASTURE

*** Pathway disabled ***

HOME GROWN PRODUCE

*** Pathway disabled ***

PIGS, CHICKENS AND EGGS

*** Pathway disabled ***

DERMAL ABSORPTION
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MEIW.txt  1/4/2013, 5:48:31PM

*** Pathway enabled ***

SOIL INGESTION

*** Pathway enabled ***

MOTHER'S MILK

*** Pathway disabled ***



CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                  BACKGROUND (ug/m^3)
0001  106990     1,3-Butadiene   1,3-Butadiene                                                   0.000E+00
0002  75070      Acetaldehyde    Acetaldehyde                                                    0.000E+00
0003  1016       As cmpd(inorg)  Arsenic compounds (inorganic)                                   0.000E+00
0004  71432      Benzene         Benzene                                                         0.000E+00
0005  7440417    Beryllium       Beryllium                                                       0.000E+00
0006  7440439    Cadmium         Cadmium                                                         0.000E+00
0007  218019     Chrysene        Chrysene                                                        0.000E+00
0008  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                              0.000E+00
0009  1319773    Cresols         Cresols (mixtures of) {Cresylic acid}                           0.000E+00
0010  100414     Ethyl Benzene   Ethyl benzene                                                   0.000E+00
0011  50000      Formaldehyde    Formaldehyde                                                    0.000E+00
0012  7783064    H2S             Hydrogen sulfide                                                0.000E+00
0013  110543     Hexane          Hexane                                                          0.000E+00
0014  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                          0.000E+00
0015  7439965    Manganese       Manganese                                                       0.000E+00
0016  7439976    Mercury         Mercury                                                         0.000E+00
0017  91203      Naphthalene     Naphthalene                                                     0.000E+00
0018  7664417    NH3             Ammonia                                                         0.000E+00
0019  1150       PAHs-w/         PAHs, total, with individ. components also reported             0.000E+00
0020  108952     Phenol          Phenol                                                          0.000E+00
0021  115071     Propylene       Propylene                                                       0.000E+00
0022  7782492    Selenium        Selenium                                                        0.000E+00
0023  7440224    Silver          Silver                                                          0.000E+00
0024  100425     Styrene         Styrene                                                         0.000E+00
0025  108883     Toluene         Toluene                                                         0.000E+00
0026  1330207    Xylenes         Xylenes (mixed)                                                 0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)      ChronicREL(Inh)     ChronicREL(Oral)    AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1        ug/m^3              mg/kg-d             ug/m^3

0001  106990     1,3-Butadiene   6.00E-01           *                   2.00E+01            *                   *
0002  75070      Acetaldehyde    1.00E-02           *                   1.40E+02            *                   4.70E+02
0003  1016       As cmpd(inorg)  1.20E+01           1.50E+00            1.50E-02            3.50E-06            2.00E-01
0004  71432      Benzene         1.00E-01           *                   6.00E+01            *                   1.30E+03
0005  7440417    Beryllium       8.40E+00           *                   7.00E-03            2.00E-03            *
0006  7440439    Cadmium         1.50E+01           *                   2.00E-02            5.00E-04            *
0007  218019     Chrysene        3.90E-02           1.20E-01            *                   *                   *
0008  18540299   Cr(VI)          5.10E+02           *                   2.00E-01            2.00E-02            *
0009  1319773    Cresols         *                  *                   6.00E+02            *                   *
0010  100414     Ethyl Benzene   8.70E-03           *                   2.00E+03            *                   *
0011  50000      Formaldehyde    2.10E-02           *                   9.00E+00            *                   5.50E+01

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MEIW.txt  1/4/2013, 5:48:31PM

0012  7783064    H2S             *                  *                   1.00E+01           *                   4.20E+01
0013  110543     Hexane          *                  *                   7.00E+03           *                   *
0014  193395     In[1,2,3-cd]pyr 3.90E-01           1.20E+00            *                  *                   *
0015  7439965    Manganese       *                  *                   9.00E-02           *                   *
0016  7439976    Mercury         *                  *                   3.00E-02           1.60E-04            6.00E-01
0017  91203      Naphthalene     1.20E-01           *                   9.00E+00           *                   *
0018  7664417    NH3             *                  *                   2.00E+02           *                   3.20E+03
0019  1150       PAHs-w/         *                  *                   *                  *                   *
0020  108952     Phenol          *                  *                   2.00E+02           *                   5.80E+03
0021  115071     Propylene       *                  *                   3.00E+03           *                   *
0022  7782492    Selenium        *                  *                   2.00E+01           *                   *
0023  7440224    Silver          *                  *                   *                  *                   *
0024  100425     Styrene         *                  *                   9.00E+02           *                   2.10E+04
0025  108883     Toluene         *                  *                   3.00E+02           *                   3.70E+04
0026  1330207    Xylenes         *                  *                   7.00E+02           *                   2.20E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B401  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0        0.00E+00        0.00E+00
75070           Acetaldehyde                   1               0        2.42E+00        2.76E-04
1016            As cmpd(inorg)                 1               0        2.42E-01        2.77E-05
71432           Benzene                        1               0        3.20E+00        3.65E-04
7440417         Beryllium                      1               0        6.48E-02        7.40E-06
7440439         Cadmium                        1               0        1.59E-01        1.81E-05
218019          Chrysene                       1               0        0.00E+00        0.00E+00
18540299        Cr(VI)                         1               0        1.04E-01        1.18E-05
1319773         Cresols                        1               0        0.00E+00        0.00E+00
100414          Ethyl Benzene                  1               0        0.00E+00        0.00E+00
50000           Formaldehyde                   1               0        1.47E-02        1.68E-06
7783064         H2S                            1               0        3.49E+00        3.98E-04
110543          Hexane                         1               0        0.00E+00        0.00E+00
193395          In[1,2,3-cd]pyr                1               0        1.35E-04        1.54E-08
7439965         Manganese                      1               0        1.06E+00        1.21E-04
7439976         Mercury                        1               0        2.43E-02        2.77E-06
91203           Naphthalene                    1               0        7.86E-02        8.97E-06
7664417         NH3                            1               0        9.38E+02        1.07E-01
1150            PAHs-w/                        1               0        9.70E-02        1.11E-05
108952          Phenol                         1               0        1.88E-01        2.14E-05
115071          Propylene                      1               0        0.00E+00        0.00E+00
7782492         Selenium                       1               0        6.48E-01        7.40E-05
7440224         Silver                         1               0        1.30E-01        1.48E-05
100425          Styrene                        1               0        0.00E+00        0.00E+00
108883          Toluene                        1               0        3.80E+00        4.34E-04
1330207         Xylenes                        1               0        0.00E+00        0.00E+00

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=2   NAME=U90FUG  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0        2.23E-01        6.96E-08
75070           Acetaldehyde                   1               0        0.00E+00        0.00E+00
1016            As cmpd(inorg)                 1               0        0.00E+00        0.00E+00
71432           Benzene                        1               0        3.02E-01        9.45E-08

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MEIW.txt  1/4/2013, 5:48:31PM

7440417         Beryllium                      1               0        0.00E+00        0.00E+00
7440439         Cadmium                        1               0        0.00E+00        0.00E+00
218019          Chrysene                       1               0        6.68E-02        2.09E-08
18540299        Cr(VI)                         1               0        0.00E+00        0.00E+00
1319773         Cresols                        1               0        2.00E-01        6.26E-08
100414          Ethyl Benzene                  1               0        9.59E-01        3.00E-07
50000           Formaldehyde                   1               0        0.00E+00        0.00E+00
7783064         H2S                            1               0        1.48E-02        4.64E-09
110543          Hexane                         1               0        4.01E+00        1.25E-06
193395          In[1,2,3-cd]pyr                1               0        3.34E-01        1.04E-07
7439965         Manganese                      1               0        0.00E+00        0.00E+00
7439976         Mercury                        1               0        0.00E+00        0.00E+00
91203           Naphthalene                    1               0        3.22E+00        1.01E-06
7664417         NH3                            1               0        0.00E+00        0.00E+00
1150            PAHs-w/                        1               0        0.00E+00        0.00E+00
108952          Phenol                         1               0        6.68E-02        2.09E-08
115071          Propylene                      1               0        2.23E-01        6.96E-08
7782492         Selenium                       1               0        0.00E+00        0.00E+00
7440224         Silver                         1               0        0.00E+00        0.00E+00
100425          Styrene                        1               0        2.50E-01        7.83E-08
108883          Toluene                        1               0        1.21E+00        3.79E-07
1330207         Xylenes                        1               0        4.33E+00        1.35E-06

CANCER RISK REPORT

AVERAGE CANCER RISK, RECEPTOR 788
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG    DAIRY     BEEF    CHICK      PIG      EGG     MEAT     ORAL    TOTAL   UTME
0001  1.21E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.21E-10
0002  7.55E-12 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.55E-12
0003  9.06E-10 4.17E-09 1.76E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.93E-09 6.84E-09
0004  1.27E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.27E-10
0005  1.70E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.70E-10
0006  7.44E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.44E-10
0007  2.35E-12 5.39E-11 7.00E-12 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 6.09E-11 6.32E-11
0008  1.65E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.65E-08
0009  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0010  7.52E-12 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.52E-12
0011  9.63E-14 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.63E-14
0012  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0013  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0014  1.17E-10 2.70E-09 3.50E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.05E-09 3.16E-09
0015  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0016  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0017  3.51E-10 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.51E-10
0018  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0019  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0020  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0021  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0022  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0023  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0024  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0025  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0026  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
SUM   1.91E-08 6.92E-09 2.12E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.04E-09 2.81E-08 382500 373

                                                                                                                                     Page: 4
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This file: C:\HARP\PROJECTS\2696CP\2696B401\2696 B401 MCHI.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:47:36 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B401.EMS
   Site parameters file: C:\HARP\PROJECTS\resident pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Exposure duration: resident
Analysis method:   Derived (OEHHA) Method
Health effect:     Chronic HI
Receptor(s):       788
Sources(s):        All
Chemicals(s):      All

SITE PARAMETERS

DEPOSITION

   Deposition rate (m/s)             0.02

DRINKING WATER

*** Pathway disabled ***

FISH

*** Pathway disabled ***

PASTURE

*** Pathway disabled ***

HOME GROWN PRODUCE

   HUMAN INGESTION
   Fraction of ingested leafy vegetable
     from home grown source          0.052
   Fraction of ingested exposed vegetable
     from home grown source          0.052
   Fraction of ingested protected vegetable
     from home grown source          0.052
   Fraction of ingested root vegetable
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     from home grown source          0.052

PIGS, CHICKENS AND EGGS

*** Pathway disabled ***

DERMAL ABSORPTION

*** Pathway enabled ***

SOIL INGESTION

*** Pathway enabled ***

MOTHER'S MILK

*** Pathway enabled ***


CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                                    BACKGROUND (ug/m^3)
0001  106990     1,3-Butadiene   1,3-Butadiene                                                                     0.000E+00
0002  75070      Acetaldehyde    Acetaldehyde                                                                      0.000E+00
0003  1016       As cmpd(inorg)  Arsenic compounds (inorganic)                                                     0.000E+00
0004  71432      Benzene         Benzene                                                                           0.000E+00
0005  7440417    Beryllium       Beryllium                                                                         0.000E+00
0006  7440439    Cadmium         Cadmium                                                                           0.000E+00
0007  218019     Chrysene        Chrysene                                                                          0.000E+00
0008  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                                                0.000E+00
0009  1319773    Cresols         Cresols (mixtures of) {Cresylic acid}                                             0.000E+00
0010  100414     Ethyl Benzene   Ethyl benzene                                                                     0.000E+00
0011  50000      Formaldehyde    Formaldehyde                                                                      0.000E+00
0012  7783064    H2S             Hydrogen sulfide                                                                  0.000E+00
0013  110543     Hexane          Hexane                                                                            0.000E+00
0014  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                                            0.000E+00
0015  7439965    Manganese       Manganese                                                                         0.000E+00
0016  7439976    Mercury         Mercury                                                                           0.000E+00
0017  91203      Naphthalene     Naphthalene                                                                       0.000E+00
0018  7664417    NH3             Ammonia                                                                           0.000E+00
0019  1150       PAHs-w/         PAHs, total, with individ. components also reported                               0.000E+00
0020  108952     Phenol          Phenol                                                                            0.000E+00
0021  115071     Propylene       Propylene                                                                         0.000E+00
0022  7782492    Selenium        Selenium                                                                          0.000E+00
0023  7440224    Silver          Silver                                                                            0.000E+00
0024  100425     Styrene         Styrene                                                                           0.000E+00
0025  108883     Toluene         Toluene                                                                           0.000E+00
0026  1330207    Xylenes         Xylenes (mixed)                                                                   0.000E+00

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)      ChronicREL(Inh)     ChronicREL(Oral)    AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1        ug/m^3              mg/kg-d             ug/m^3

0001  106990     1,3-Butadiene   6.00E-01           *                   2.00E+01            *                   *
0002  75070      Acetaldehyde    1.00E-02           *                   1.40E+02            *                   4.70E+02
0003  1016       As cmpd(inorg)  1.20E+01           1.50E+00            1.50E-02            3.50E-06            2.00E-01
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MCHI.txt  1/4/2013, 5:47:38PM

0004  71432      Benzene         1.00E-01          *                   6.00E+01           *                  1.30E+03
0005  7440417    Beryllium       8.40E+00          *                   7.00E-03           2.00E-03           *
0006  7440439    Cadmium         1.50E+01          *                   2.00E-02           5.00E-04           *
0007  218019     Chrysene        3.90E-02          1.20E-01            *                  *                  *
0008  18540299   Cr(VI)          5.10E+02          *                   2.00E-01           2.00E-02           *
0009  1319773    Cresols         *                 *                   6.00E+02           *                  *
0010  100414     Ethyl Benzene   8.70E-03          *                   2.00E+03           *                  *
0011  50000      Formaldehyde    2.10E-02          *                   9.00E+00           *                  5.50E+01
0012  7783064    H2S             *                 *                   1.00E+01           *                  4.20E+01
0013  110543     Hexane          *                 *                   7.00E+03           *                  *
0014  193395     In[1,2,3-cd]pyr 3.90E-01          1.20E+00            *                  *                  *
0015  7439965    Manganese       *                 *                   9.00E-02           *                  *
0016  7439976    Mercury         *                 *                   3.00E-02           1.60E-04           6.00E-01
0017  91203      Naphthalene     1.20E-01          *                   9.00E+00           *                  *
0018  7664417    NH3             *                 *                   2.00E+02           *                  3.20E+03
0019  1150       PAHs-w/         *                 *                   *                  *                  *
0020  108952     Phenol          *                 *                   2.00E+02           *                  5.80E+03
0021  115071     Propylene       *                 *                   3.00E+03           *                  *
0022  7782492    Selenium        *                 *                   2.00E+01           *                  *
0023  7440224    Silver          *                 *                   *                  *                  *
0024  100425     Styrene         *                 *                   9.00E+02           *                  2.10E+04
0025  108883     Toluene         *                 *                   3.00E+02           *                  3.70E+04
0026  1330207    Xylenes         *                 *                   7.00E+02           *                  2.20E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B401  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0        0.00E+00        0.00E+00
75070           Acetaldehyde                   1               0        2.42E+00        2.76E-04
1016            As cmpd(inorg)                 1               0        2.42E-01        2.77E-05
71432           Benzene                        1               0        3.20E+00        3.65E-04
7440417         Beryllium                      1               0        6.48E-02        7.40E-06
7440439         Cadmium                        1               0        1.59E-01        1.81E-05
218019          Chrysene                       1               0        0.00E+00        0.00E+00
18540299        Cr(VI)                         1               0        1.04E-01        1.18E-05
1319773         Cresols                        1               0        0.00E+00        0.00E+00
100414          Ethyl Benzene                  1               0        0.00E+00        0.00E+00
50000           Formaldehyde                   1               0        1.47E-02        1.68E-06
7783064         H2S                            1               0        3.49E+00        3.98E-04
110543          Hexane                         1               0        0.00E+00        0.00E+00
193395          In[1,2,3-cd]pyr                1               0        1.35E-04        1.54E-08
7439965         Manganese                      1               0        1.06E+00        1.21E-04
7439976         Mercury                        1               0        2.43E-02        2.77E-06
91203           Naphthalene                    1               0        7.86E-02        8.97E-06
7664417         NH3                            1               0        9.38E+02        1.07E-01
1150            PAHs-w/                        1               0        9.70E-02        1.11E-05
108952          Phenol                         1               0        1.88E-01        2.14E-05
115071          Propylene                      1               0        0.00E+00        0.00E+00
7782492         Selenium                       1               0        6.48E-01        7.40E-05
7440224         Silver                         1               0        1.30E-01        1.48E-05
100425          Styrene                        1               0        0.00E+00        0.00E+00
108883          Toluene                        1               0        3.80E+00        4.34E-04
1330207         Xylenes                        1               0        0.00E+00        0.00E+00

                                                                                                                          Page: 3
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MCHI.txt  1/4/2013, 5:47:38PM

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=2   NAME=U90FUG  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0       2.23E-01        6.96E-08
75070           Acetaldehyde                   1               0       0.00E+00        0.00E+00
1016            As cmpd(inorg)                 1               0       0.00E+00        0.00E+00
71432           Benzene                        1               0       3.02E-01        9.45E-08
7440417         Beryllium                      1               0       0.00E+00        0.00E+00
7440439         Cadmium                        1               0       0.00E+00        0.00E+00
218019          Chrysene                       1               0       6.68E-02        2.09E-08
18540299        Cr(VI)                         1               0       0.00E+00        0.00E+00
1319773         Cresols                        1               0       2.00E-01        6.26E-08
100414          Ethyl Benzene                  1               0       9.59E-01        3.00E-07
50000           Formaldehyde                   1               0       0.00E+00        0.00E+00
7783064         H2S                            1               0       1.48E-02        4.64E-09
110543          Hexane                         1               0       4.01E+00        1.25E-06
193395          In[1,2,3-cd]pyr                1               0       3.34E-01        1.04E-07
7439965         Manganese                      1               0       0.00E+00        0.00E+00
7439976         Mercury                        1               0       0.00E+00        0.00E+00
91203           Naphthalene                    1               0       3.22E+00        1.01E-06
7664417         NH3                            1               0       0.00E+00        0.00E+00
1150            PAHs-w/                        1               0       0.00E+00        0.00E+00
108952          Phenol                         1               0       6.68E-02        2.09E-08
115071          Propylene                      1               0       2.23E-01        6.96E-08
7782492         Selenium                       1               0       0.00E+00        0.00E+00
7440224         Silver                         1               0       0.00E+00        0.00E+00
100425          Styrene                        1               0       2.50E-01        7.83E-08
108883          Toluene                        1               0       1.21E+00        3.79E-07
1330207         Xylenes                        1               0       4.33E+00        1.35E-06

CHRONIC HI REPORT

DOMINANT PATHWAYS, Receptor 788
CHEM     INHAL     DERM     SOIL   MOTHER     FISH    WATER      VEG     DAIRY     BEEF    CHICK      PIG      EGG
0001       YES        -        -        -        -        -        -        -        -        -        -        -
0002       YES        -        -        -        -        -        -        -        -        -        -        -
0003       YES      YES      YES        -        -        -        -        -        -        -        -        -
0004       YES        -        -        -        -        -        -        -        -        -        -        -
0005       YES        -      YES        -        -        -      YES        -        -        -        -        -
0006       YES        -      YES        -        -        -      YES        -        -        -        -        -
0007       YES      YES        -        -        -        -      YES        -        -        -        -        -
0008       YES        -      YES        -        -        -      YES        -        -        -        -        -
0009       YES        -        -        -        -        -        -        -        -        -        -        -
0010       YES        -        -        -        -        -        -        -        -        -        -        -
0011       YES        -        -        -        -        -        -        -        -        -        -        -
0012       YES        -        -        -        -        -        -        -        -        -        -        -
0013       YES        -        -        -        -        -        -        -        -        -        -        -
0014       YES      YES        -        -        -        -      YES        -        -        -        -        -
0015       YES        -        -        -        -        -        -        -        -        -        -        -
0016       YES      YES        -        -        -        -      YES        -        -        -        -        -
0017       YES        -        -        -        -        -        -        -        -        -        -        -
0018       YES        -        -        -        -        -        -        -        -        -        -        -
0019         -        -        -        -        -        -        -        -        -        -        -        -
0020       YES        -        -        -        -        -        -        -        -        -        -        -
0021       YES        -        -        -        -        -        -        -        -        -        -        -

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0022       YES        -        -        -        -        -        -        -        -        -        -        -
0023       YES        -        -        -        -        -        -        -        -        -        -        -
0024       YES        -        -        -        -        -        -        -        -        -        -        -
0025       YES        -        -        -        -        -        -        -        -        -        -        -
0026       YES        -        -        -        -        -        -        -        -        -        -        -

DERIVED CHRONIC HI, RECEPTOR 788
CHEM         CV      CNS     BONE    DEVEL     ENDO      EYE     GILV    IMMUN     KIDN    REPRO     RESP     SKIN    BLOOD      MAX   UTME    UTMN
0001  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.76E-07 0.00E+00 0.00E+00 0.00E+00 1.76E-07
0002  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.44E-08 0.00E+00 0.00E+00 9.44E-08
0003  3.53E-03 3.53E-03 0.00E+00 3.53E-03 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.53E-03 3.53E-03 0.00E+00 3.53E-03
0004  0.00E+00 3.71E-07 0.00E+00 3.71E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.71E-07 3.71E-07
0005  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 8.40E-07 5.05E-05 0.00E+00 0.00E+00 5.05E-05 0.00E+00 0.00E+00 5.05E-05
0006  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 6.48E-05 0.00E+00 4.34E-05 0.00E+00 0.00E+00 6.48E-05
0007  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0008  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.84E-06 0.00E+00 1.34E-07 2.84E-06
0009  0.00E+00 5.26E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.26E-09
0010  0.00E+00 0.00E+00 0.00E+00 7.56E-09 7.56E-09 0.00E+00 7.56E-09 0.00E+00 7.56E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 7.56E-09
0011  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 8.92E-09 0.00E+00 0.00E+00 8.92E-09
0012  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.93E-06 0.00E+00 0.00E+00 1.93E-06
0013  0.00E+00 9.03E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.03E-09
0014  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0015  0.00E+00 6.43E-05 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 6.43E-05
0016  0.00E+00 2.94E-05 0.00E+00 2.94E-05 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.94E-05 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.94E-05
0017  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.69E-06 0.00E+00 0.00E+00 5.69E-06
0018  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.56E-05 0.00E+00 0.00E+00 2.56E-05
0019  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0020  1.04E-08 1.04E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.04E-08 0.00E+00 1.04E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.04E-08
0021  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.17E-09 0.00E+00 0.00E+00 1.17E-09
0022  1.77E-07 1.77E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.77E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.77E-07
0023  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0024  0.00E+00 4.38E-09 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 4.38E-09
0025  0.00E+00 1.33E-07 0.00E+00 1.33E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.33E-07 0.00E+00 0.00E+00 1.33E-07
0026  0.00E+00 9.75E-08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.75E-08 0.00E+00 0.00E+00 9.75E-08
SUM   3.53E-03 3.62E-03 0.00E+00 3.56E-03 7.56E-09 0.00E+00 1.03E-06 5.05E-05 9.43E-05 1.76E-07 3.66E-03 3.53E-03 5.05E-07 3.66E-03 382500 3737400
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MAHI.txt  1/4/2013, 5:47:01PM

This file: C:\HARP\PROJECTS\2696CP\2696B401\2696 B401 MAHI.txt

Created by HARP Version 1.4f  Build 23.11.01
Uses ISC Version 99155
Uses BPIP (Dated: 04112)
Creation date: 1/4/2013 5:46:59 PM


EXCEPTION REPORT
   (there have been no changes or exceptions)

INPUT FILES:
   Source-Receptor file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.SRC
   Averaging period adjustment factors file: not applicable
   Emission rates file: 2696B401.EMS
   Site parameters file: C:\HARP\PROJECTS\resident pathway.sit

Coordinate system: UTM NAD83

Screening mode is OFF

Analysis method:   Point Estimate
Health effect:     Acute HI Simple (Concurrent Max.)
Receptor(s):       1933
Sources(s):        All
Chemicals(s):      All

CHEMICAL CROSS-REFERENCE TABLE AND BACKGROUND CONCENTRATIONS
CHEM  CAS        ABBREVIATION    POLLUTANT NAME                                                                    BACKGROUND (ug/m^3)
0001  106990     1,3-Butadiene   1,3-Butadiene                                                                     0.000E+00
0002  75070      Acetaldehyde    Acetaldehyde                                                                      0.000E+00
0003  1016       As cmpd(inorg)  Arsenic compounds (inorganic)                                                     0.000E+00
0004  71432      Benzene         Benzene                                                                           0.000E+00
0005  7440417    Beryllium       Beryllium                                                                         0.000E+00
0006  7440439    Cadmium         Cadmium                                                                           0.000E+00
0007  218019     Chrysene        Chrysene                                                                          0.000E+00
0008  18540299   Cr(VI)          Chromium, hexavalent (& compounds)                                                0.000E+00
0009  1319773    Cresols         Cresols (mixtures of) {Cresylic acid}                                             0.000E+00
0010  100414     Ethyl Benzene   Ethyl benzene                                                                     0.000E+00
0011  50000      Formaldehyde    Formaldehyde                                                                      0.000E+00
0012  7783064    H2S             Hydrogen sulfide                                                                  0.000E+00
0013  110543     Hexane          Hexane                                                                            0.000E+00
0014  193395     In[1,2,3-cd]pyr Indeno[1,2,3-cd]pyrene                                                            0.000E+00
0015  7439965    Manganese       Manganese                                                                         0.000E+00
0016  7439976    Mercury         Mercury                                                                           0.000E+00
0017  91203      Naphthalene     Naphthalene                                                                       0.000E+00
0018  7664417    NH3             Ammonia                                                                           0.000E+00
0019  1150       PAHs-w/         PAHs, total, with individ. components also reported                               0.000E+00
0020  108952     Phenol          Phenol                                                                            0.000E+00
0021  115071     Propylene       Propylene                                                                         0.000E+00
0022  7782492    Selenium        Selenium                                                                          0.000E+00
0023  7440224    Silver          Silver                                                                            0.000E+00
0024  100425     Styrene         Styrene                                                                           0.000E+00
0025  108883     Toluene         Toluene                                                                           0.000E+00
0026  1330207    Xylenes         Xylenes (mixed)                                                                   0.000E+00

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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MAHI.txt  1/4/2013, 5:47:01PM

CHEMICAL HEALTH VALUES
CHEM  CAS        ABBREVIATION    CancerPF(Inh)      CancerPF(Oral)      ChronicREL(Inh)     ChronicREL(Oral)    AcuteREL
                                 (mg/kg-d)^-1       (mg/kg-d)^-1        ug/m^3              mg/kg-d             ug/m^3

0001  106990     1,3-Butadiene   6.00E-01           *                   2.00E+01            *                   *
0002  75070      Acetaldehyde    1.00E-02           *                   1.40E+02            *                   4.70E+02
0003  1016       As cmpd(inorg)  1.20E+01           1.50E+00            1.50E-02            3.50E-06            2.00E-01
0004  71432      Benzene         1.00E-01           *                   6.00E+01            *                   1.30E+03
0005  7440417    Beryllium       8.40E+00           *                   7.00E-03            2.00E-03            *
0006  7440439    Cadmium         1.50E+01           *                   2.00E-02            5.00E-04            *
0007  218019     Chrysene        3.90E-02           1.20E-01            *                   *                   *
0008  18540299   Cr(VI)          5.10E+02           *                   2.00E-01            2.00E-02            *
0009  1319773    Cresols         *                  *                   6.00E+02            *                   *
0010  100414     Ethyl Benzene   8.70E-03           *                   2.00E+03            *                   *
0011  50000      Formaldehyde    2.10E-02           *                   9.00E+00            *                   5.50E+01
0012  7783064    H2S             *                  *                   1.00E+01            *                   4.20E+01
0013  110543     Hexane          *                  *                   7.00E+03            *                   *
0014  193395     In[1,2,3-cd]pyr 3.90E-01           1.20E+00            *                   *                   *
0015  7439965    Manganese       *                  *                   9.00E-02            *                   *
0016  7439976    Mercury         *                  *                   3.00E-02            1.60E-04            6.00E-01
0017  91203      Naphthalene     1.20E-01           *                   9.00E+00            *                   *
0018  7664417    NH3             *                  *                   2.00E+02            *                   3.20E+03
0019  1150       PAHs-w/         *                  *                   *                   *                   *
0020  108952     Phenol          *                  *                   2.00E+02            *                   5.80E+03
0021  115071     Propylene       *                  *                   3.00E+03            *                   *
0022  7782492    Selenium        *                  *                   2.00E+01            *                   *
0023  7440224    Silver          *                  *                   *                   *                   *
0024  100425     Styrene         *                  *                   9.00E+02            *                   2.10E+04
0025  108883     Toluene         *                  *                   3.00E+02            *                   3.70E+04
0026  1330207    Xylenes         *                  *                   7.00E+02            *                   2.20E+04

EMISSIONS DATA SOURCE: Emission rates loaded from file: C:\HARP\PROJECTS\2696CP\2696B401\2696B401.EMS
CHEMICALS ADDED OR DELETED: none

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=1   NAME=U90B401  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                  1               0        0.00E+00        0.00E+00
75070           Acetaldehyde                   1               0        2.42E+00        2.76E-04
1016            As cmpd(inorg)                 1               0        2.42E-01        2.77E-05
71432           Benzene                        1               0        3.20E+00        3.65E-04
7440417         Beryllium                      1               0        6.48E-02        7.40E-06
7440439         Cadmium                        1               0        1.59E-01        1.81E-05
218019          Chrysene                       1               0        0.00E+00        0.00E+00
18540299        Cr(VI)                         1               0        1.04E-01        1.18E-05
1319773         Cresols                        1               0        0.00E+00        0.00E+00
100414          Ethyl Benzene                  1               0        0.00E+00        0.00E+00
50000           Formaldehyde                   1               0        1.47E-02        1.68E-06
7783064         H2S                            1               0        3.49E+00        3.98E-04
110543          Hexane                         1               0        0.00E+00        0.00E+00
193395          In[1,2,3-cd]pyr                1               0        1.35E-04        1.54E-08
7439965         Manganese                      1               0        1.06E+00        1.21E-04
7439976         Mercury                        1               0        2.43E-02        2.77E-06
91203           Naphthalene                    1               0        7.86E-02        8.97E-06
7664417         NH3                            1               0        9.38E+02        1.07E-01
1150            PAHs-w/                        1               0        9.70E-02        1.11E-05
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File: M:\MC\2696 Conoco - ULSD\HRA\Risk Files\2696 B401 MAHI.txt  1/4/2013, 5:47:01PM

108952          Phenol                       1              0        1.88E-01        2.14E-05
115071          Propylene                    1              0        0.00E+00        0.00E+00
7782492         Selenium                     1              0        6.48E-01        7.40E-05
7440224         Silver                       1              0        1.30E-01        1.48E-05
100425          Styrene                      1              0        0.00E+00        0.00E+00
108883          Toluene                      1              0        3.80E+00        4.34E-04
1330207         Xylenes                      1              0        0.00E+00        0.00E+00

EMISSIONS FOR FACILITY FAC=1   DEV=*   PRO=*   STK=2   NAME=U90FUG  EMS (lbs/yr)
SOURCE MULTIPLIER=1
CAS             ABBREV                MULTIPLIER     BG (ug/m^3)   AVRG (lbs/yr)    MAX (lbs/hr)
106990          1,3-Butadiene                1              0        2.23E-01        6.96E-08
75070           Acetaldehyde                 1              0        0.00E+00        0.00E+00
1016            As cmpd(inorg)               1              0        0.00E+00        0.00E+00
71432           Benzene                      1              0        3.02E-01        9.45E-08
7440417         Beryllium                    1              0        0.00E+00        0.00E+00
7440439         Cadmium                      1              0        0.00E+00        0.00E+00
218019          Chrysene                     1              0        6.68E-02        2.09E-08
18540299        Cr(VI)                       1              0        0.00E+00        0.00E+00
1319773         Cresols                      1              0        2.00E-01        6.26E-08
100414          Ethyl Benzene                1              0        9.59E-01        3.00E-07
50000           Formaldehyde                 1              0        0.00E+00        0.00E+00
7783064         H2S                          1              0        1.48E-02        4.64E-09
110543          Hexane                       1              0        4.01E+00        1.25E-06
193395          In[1,2,3-cd]pyr              1              0        3.34E-01        1.04E-07
7439965         Manganese                    1              0        0.00E+00        0.00E+00
7439976         Mercury                      1              0        0.00E+00        0.00E+00
91203           Naphthalene                  1              0        3.22E+00        1.01E-06
7664417         NH3                          1              0        0.00E+00        0.00E+00
1150            PAHs-w/                      1              0        0.00E+00        0.00E+00
108952          Phenol                       1              0        6.68E-02        2.09E-08
115071          Propylene                    1              0        2.23E-01        6.96E-08
7782492         Selenium                     1              0        0.00E+00        0.00E+00
7440224         Silver                       1              0        0.00E+00        0.00E+00
100425          Styrene                      1              0        2.50E-01        7.83E-08
108883          Toluene                      1              0        1.21E+00        3.79E-07
1330207         Xylenes                      1              0        4.33E+00        1.35E-06

ACUTE HI REPORT

ACUTE HI, RECEPTOR 1933
CHEM        CV      CNS     BONE    DEVEL     ENDO      EYE     GILV    IMMUN     KIDN    REPRO     RESP     SKIN    BLOOD      MAX   UTME    UTMN
0001  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0002  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.56E-07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.56E-07 0.00E+00 0.00E+00 5.56E-07
0003  1.31E-04 1.31E-04 0.00E+00 1.31E-04 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 1.31E-04
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SUM   1.31E-04 1.45E-04 0.00E+00 1.36E-04 0.00E+00 3.23E-05 0.00E+00 2.66E-07 0.00E+00 2.77E-07 3.22E-05 0.00E+00 2.66E-07 1.45E-04 380641 3738324
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ORIGINAL ARTICLE

Air pollution affects lung cancer survival

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ABSTRACT

Rationale Exposure to ambient air pollutants has been associated with increased lung cancer incidence and mortality, but due to the high case fatality rate, little is known about the impacts of air pollution exposures on survival after diagnosis. This study aimed to determine whether ambient air pollutant exposures are associated with the survival of patients with lung cancer.
Methods Participants were 352 053 patients with newly diagnosed lung cancer during 1988–2009 in California, ascertained by the California Cancer Registry. Average residential ambient air pollutant concentrations were estimated for each participant's follow-up period. Cox proportional hazards models were used to estimate HRs relating air pollutant exposures to all-cause mortality overall and stratified by stage (localised only, regional and distant site) and histology (squamous cell carcinoma, adenocarcinoma, small cell carcinoma, large cell carcinoma and others) at diagnosis, adjusting for potential individual and area-level confounders.
Results Adjusting for histology and other potential confounders, the HRs associated with 1 SD increases in NO$_2$, O$_3$, PM$_{10}$, PM$_{2.5}$ for patients with localised stage at diagnosis were 1.30 (95% CI 1.28 to 1.32), 1.04 (95% CI 1.02 to 1.05), 1.26 (95% CI 1.25 to 1.28) and 1.38 (95% CI 1.35 to 1.41), respectively. Adjusted HRs were smaller in later stages and varied by histological type within stage ($p<0.01$, except O$_3$). The largest associations were for patients with early-stage non-small cell cancers, particularly adenocarcinomas.
Conclusions These epidemiological findings support the hypothesis that air pollution exposures after lung cancer diagnosis shorten survival. Future studies should evaluate the impacts of exposure reduction.

Key messages

What is the key question?

- Does exposure to ambient air pollution after diagnosis of lung cancer affect survival?

What is the bottom line?

- Patients with lung cancer, with higher average ambient NO$_2$, PM$_{2.5}$ and PM$_{10}$ exposures since diagnosis, had shorter survival, with the largest differences in survival for patients with early-stage non-small cell cancers (particularly adenocarcinomas).

Why read on?

- This is the first study to link individual-level estimates of air pollution exposures after lung cancer diagnosis to survival, and the study population was the population-based sample of 352 053 patients with newly diagnosed lung cancer during 1988–2009 in California, as ascertained by the California Cancer Registry.

INTRODUCTION

Lung cancer has been the most common cancer for decades. Worldwide, lung cancer causes nearly one in five cancer deaths, about 1.59 million deaths annually (http://globocan.iarc.fr). This heavy burden is largely a result of a high prevalence of cigarette smoking, the leading cause of lung cancer; advanced stage at diagnosis; and poor survival, especially among those with advanced stage disease.[1 2] Accordingly, interventions have focused on the reduction of tobacco use, early-stage diagnosis and improved treatment. Although progress has been made in each area, lung cancer survival remains stubbornly poor, suggesting that novel approaches are needed.[3–6] A promising approach is identifying and intervening on modifiable determinants of survival; however, little research attention has been directed to determinants beyond smoking. One modifiable determinant of emerging interest is ambient air pollution,[7] which was recently classified as carcinogenic by the International Agency for Research on Cancer (IARC).[8]

A growing body of evidence indicates that ambient air pollutants are associated with lung cancer incidence and mortality.[9–12] However, relatively little is known about air pollution effects on survival after any cancer diagnosis.[13 14] We reasoned that if ambient air pollution is a carcinogen affecting lung cancer development, then inhaled pollutants may also drive tumour progression through the same mechanistic pathways to shorten survival after diagnosis. If ambient air pollution increases both the incidence of lung cancer and shortens survival after diagnosis, then it could have a larger contribution to lung cancer mortality than previously understood.

To determine whether ambient air pollutants are associated with survival in patients with lung cancer, we conducted a population-based cohort study of 352 053 California residents with lung cancer newly diagnosed in 1988–2009. We estimated average residential exposures to nitrogen dioxide, ozone and particulate matter air pollutants from diagnosis to end of follow-up and related these exposures to all-cause mortality and lung cancer-specific mortality by stage and tumour histology at diagnosis.

Linked

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METHODS

Lung cancer cases and individual-level data

Our study population included lung cancer cases (ICD-O-3 site code C34) diagnosed in 1988–2009 and registered by the California Cancer Registry (CCR), the statewide population-based cancer surveillance system (http://www.ccrcal.org). The CCR has collected information on all newly diagnosed cancers (except non-melanoma skin cancer) in California since 1988 and has received the highest level of data quality certification from the North American Association of Central Cancer Registries.[15] The CCR gathers individual-level data on demographics (age, sex, marital status, race/ethnicity), date of diagnosis, tumour characteristics at diagnosis (stage, anatomical site, histology), treatment occurring <6 months after diagnosis and patients' vital status (date of death or date last known alive). The CCR routinely updates patients' vital status by linking to the electronic death certificate master file from the California Department of Public Health, recording the underlying cause of death for deceased patients, as defined by the Department of Health Services. After excluding patients with diagnoses of in situ cancer (N=305) and non-carcinoma histology (N=20 964), there were 352 053 cases remaining for analysis with complete information on follow-up, date of birth, date of diagnosis and race/ethnicity. We created standard histology groupings[16] using ICD-O-3 morphology codes for carcinoma (8010–8576): squamous cell carcinoma (8050–8078, 8083–8084), adenocarcinoma (8140, 8211, 8230–8231, 8250–8260, 8323, 8480–8490, 8550–8551, 8570–8574, 8576), small cell carcinoma (8041–8045, 8246), large cell—includes giant cell, clear cell and large cell undifferentiated—carcinoma (8010–8012, 8014–8031, 8035, 8310) and other carcinomas (remaining codes).

No patient contact was conducted for this analysis; so, individual patient-informed consent was not required. The CCR operates under the annual review of the State of California Committee for the Protection of Human Subjects (ie, Institutional Review Board), which provided approval for this analysis.

Geocoding

We geocoded residential addresses at the date of diagnosis using the Texas A&M geocoding service (geoservices.tamu.edu). Details of the process, used by cancer registries throughout the USA, are provided elsewhere.[17] Briefly, address records were geocoded to the centroid of the smallest resolvable area based on the address completeness, ranging from tax assessor parcels to state centroid when no address information was available (in <0.1% of cases). In previous work, this method substantially improved spatial resolution.[18]

Area-level covariates

Area-level covariates were assigned to each patient using the geocodes. Rural–urban commuting area (RUCA) codes, based on data from the 2000 decennial census, classify census tracts into ordinal ranks (1–10, from metropolitan to rural) based on the size and direction of primary commuting flows, using measures of population density, urbanisation and daily commuting (http://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes.aspx).

Education index was defined as the average years of schooling in the patient's census tract based on a weighted sum of the distribution of years of schooling.[19] Socioeconomic status, at the patient's census block group, was calculated using validated area-level measures from multiple census years.[20]

Air pollution exposure assignments

California air pollutant data were obtained from the US Environmental Protection Agency's (EPA) Air Quality System (AQS) database.[21] Data were available for nitrogen dioxide (NO_2, ppb), ozone (O_3, ppb), particulate matter with diameter <10 µm (PM_{10}, µg/m^3) and 2.5 µm ($PM_{2.5}$, µg/m^3). Hourly measurements were summarised as 24-hour averages for NO_2, PM_{10} and $PM_{2.5}$ and average 8 hour daily maximum for O_3. Monthly average concentrations were spatially interpolated to residence locations from up to four closest air quality monitoring stations within a 50 km radius using the well-established method of inverse distance weighting,[22 23] with the decay parameter equal to the inverse of the square of the distance of the residence from each monitoring site. Interpolation performance is summarised in online supplementary eTable 1. We excluded exposure assignments when the nearest monitor was located >25 km away or a geocode match was unavailable. Residential ambient air pollution exposure assignments were calculated as the average of the patient-level interpolated monthly concentrations from the date of diagnosis to the date of last follow-up or death. $PM_{2.5}$ exposure assignments were only available for patients diagnosed in 1998 and later, because routine monitoring did not start until 1998. Our primary goal was to evaluate associations with large-scale regional variation in ambient pollutants; so, to account for potential confounding by local traffic, we calculated and adjusted for the distance from residential address to primary interstate highways and primary US and state highways.

Outcome

Survival time was calculated from the date of newly diagnosed lung cancer to the date of death from any cause (all-cause mortality). For sensitivity analysis, we assessed time to death from an underlying cause of lung cancer (ICD-9 code 1629 for 1988–1998 deaths and ICD-10 code C349 deaths after 1998). The last day of follow-up was 31 December 2011.

Statistical analysis

Descriptive statistics were calculated for survival, air pollution exposures and other covariates. Median survival and 5-year survival rates were calculated after stratifying patients by the stage at diagnosis and categorised air pollution exposures (cut-offs: 25th and 75th percentiles, and average of the two). Cox proportional hazards models were used to model time to all-cause mortality, allowing for right censoring due to loss to follow-up (or study end) or, in the case of time to lung cancer mortality, censoring due to death from another underlying cause. Preliminary analyses determined that the following potential confounding variables were predictors of mortality; so, all models adjusted for age, sex, race/ethnicity (non-Hispanic white, Hispanic, non-Hispanic black, other/unknown), marital status (single, married, formerly married, unknown), education index (quartiles), socioeconomic status (quintiles), dichotomised rural–urban community area (metropolitan core (1), non-metropolitan core (>1)), categorised distance to primary interstate highway (<300 m, 300–1500 m, >1500 m, missing), categorised distance to primary US and state highways (<300 m, 300–1500 m, >1500 m, missing), categorised year of diagnosis (1988–1992, 1993–1997, 1998–2002, 2003–2009), calendar month of diagnosis and initial treatment (surgery, radiation and/or chemotherapy vs none).

Single pollutant models were used to estimate HRs associated with a 1 SD increase in continuous air pollution exposure, after

Table 1 Demographic, tumour and treatment characteristics of patients with lung cancer in California by stage of diagnosis, 1988–2009

Characteristics (mean±SD or %)	Localised only (n=59 609)	Regional (n=73 513)	Distant site(s) (n=186 496)	Unknown* (n=32 435)	Total (n=352 053)
Age (years)	69.9±10.5	68.8±10.5	68.7±11.3	72.5±10.7	69.3±11.0
% Male	49.8	54.7	56.1	54.8	54.6
Race/ethnicity, %					
Non-Hispanic white	81.0	78.7	75.0	79.2	77.2
Hispanic	6.5	7.1	8.8	7.4	7.9
Non-Hispanic black	6.2	7.2	7.9	6.9	7.4
Other/unknown	6.2	7.0	8.3	6.5	7.5
Marital status, %					
Single	9.4	9.6	11.9	9.6	10.8
Married	56.2	57.1	53.7	47.9	54.3
Formerly married	32.5	31.5	32.1	37.6	32.6
Unknown	1.8	1.8	2.3	4.9	2.4
Education index†, %					
Low	22.3	23.6	25.6	29.6	25.0
Low–medium	24.5	25.0	24.8	27.4	25.0
Medium–high	25.4	25.4	24.9	24.2	25.0
High	27.9	26.1	24.7	18.8	25.0
Rural–urban commuting area (RUCA), %					
Non-metropolitan core	13.8	14.1	13.8	18.7	14.3
Metropolitan core	86.2	85.9	86.2	81.3	85.7
Unknown	<0.1	<0.1	<0.1	<0.1	<0.1
Socioeconomic status (SES), %					
Lowest	14.0	15.0	16.6	18.8	16.1
Lower-middle	20.3	20.7	20.9	23.6	21.0
Middle	21.6	22.1	22.0	22.2	22.0
Higher-middle	21.8	21.3	20.8	19.8	21.0
Highest	21.1	19.6	18.2	15.2	18.7
Unknown	1.3	1.3	1.4	0.5	1.3
Year of diagnosis, %					
1988–1992	22.2	22.4	19.8	38.8	22.5
1993–1997	23.1	22.3	21.6	29.0	22.7
1998–2002	23.0	22.9	23.9	18.7	23.0
2003–2009‡	31.7	32.4	34.7	13.6	31.8
Histology at diagnosis, %					
Squamous cell	26.1	27.2	15.2	22.3	20.2
Adenocarcinoma	45.0	35.4	35.4	23.1	35.9
Small cell	5.7	13.2	18.1	13.8	14.6
Large cell	12.1	14.3	20.8	35.7	19.3
Other	11.2	9.9	10.5	5.2	10.0
Treatment types					
Surgery, %					
No	32.5	59.6	94.6	92.8	76.6
Yes	67.4	40.3	5.2	4.5	23.0
Unknown	0.1	0.1	0.2	2.7	0.4
Radiation, %					
No	81.3	52.1	56.7	72.8	61.4
Yes	18.7	47.9	43.3	26.8	38.6
Unknown	<0.1	<0.1	<0.1	0.5	0.1
Chemotherapy, %					
No	87.0	59.2	55.1	76.2	63.3
Yes	11.3	38.0	41.2	19.8	33.5
Unknown	1.6	2.8	3.7	4.0	3.2
Geocode match quality, %					
Street address match	91.5	91.5	91.5	89.1	91.3
Area-level match	8.5	8.5	8.5	10.8	8.7
Other or missing	<0.1	<0.1	<0.1	<0.1	<0.1
Median survival time (years)	3.6	1.3	0.4	0.7	0.7
Median survival time (years), by histology at diagnosis					
Squamous cell	2.6	1.1	0.4	0.7	0.8

Continued

Table 1 Continued

Characteristics (mean±SD or %)	Localised only (n=59 609)	Regional (n=73 513)	Distant site(s) (n=186 496)	Unknown* (n=32 435)	Total (n=352 053)
Adenocarcinoma	5.1	1.9	0.4	0.8	0.9
Small cell	1.5	1.0	0.4	0.8	0.6
Large cell	1.6	0.8	0.2	0.6	0.4
Other	6.1	1.3	0.4	1.0	0.8

*Insufficient evidence available to assign a stage (eg, patient dies before workup is complete, patient refuses diagnostic procedure or limited workup is performed due to patient's age or simultaneous contraindicating condition).
†Categorised by quartiles.
‡Most recent year of diagnosis category includes 7 years, while the other categories each include 5 years.

adjusting for the aforementioned covariates. Initial models also adjusted for stage and histology at diagnosis. We then evaluated evidence for modification of air pollution associations by stage and then by histology. Final single pollutant models were fit separately for each stage and histology. Sensitivity analyses were performed by further stratifying stage-specific models (adjusted for histology) by sex, race/ethnicity, year of diagnosis, metropolitan core group and large urban areas (Los Angeles County, Bay Area Counties and San Diego County).

Analyses were performed using SAS V.9.4 (SAS Institute). Select graphical displays were created using R V.3.1.3 (R Development Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, 2012). Hypothesis tests were two-sided, with a 0.05 type I error rate.

RESULTS

Characteristics of the study participants are presented in table 1. Patients were on average 69.3 years old at diagnosis, predominantly non-Hispanic white (77.2%), and most of them lived in a metropolitan core (85.7%). More than half of lung cancers were diagnosed at an advanced stage (53.0% distant site). During the study period, there were 324 266 deaths (92.1% of 352 053 patients). Of these deaths, 78.3% were assigned an underlying cause of lung cancer. Median survival times for localised, regional and distant site diagnoses were 3.6, 1.3 and 0.4 years, respectively. For patients with localised stage at diagnosis, median survival was shortest for patients with small and large cell carcinomas (1.5 and 1.6 years, respectively) and longest for patients with adenocarcinoma (5.1 years). The number of patients with 'unknown' stage at diagnosis decreased from 12 573 in 1988–1992 (5-year period) to 4399 in 2003–2009 (7-year period), likely due to changes in technology, medical practice and/or coding practices. The highest quality geocode match (street address) was obtained for 91.1% of patients.

Average air pollution exposure assignments (average from diagnosis to end of follow-up for each patient ≤25 km from a monitor) across patients were 21.9 ppb for NO_2, 40.2 ppb for O_3, 31.8 μg/m^3 for PM_{10} and 13.7 μg/m^3 for $PM_{2.5}$ (table 2). As expected, PM_{10}, $PM_{2.5}$ and NO_2 were more highly correlated (Pearson's R=0.70–0.76) than O_3 and PM_{10} (R=0.36), O_3 and NO_2 (R=−0.01) or O_3 and $PM_{2.5}$ (R=−0.02). Over the study period, there were long-term downward trends in NO_2, PM_{10} and $PM_{2.5}$ in California (see online supplementary eFigure 1 and eTable 2). Only 8.7% of patients lived <300 m from a primary interstate highway, while 45.4% lived >1500 m (see online supplementary eTable 3).

We observed a pattern of shorter median survival and lower 5-year survival for patients with local or regional stage at diagnosis who had higher categorised NO_2, PM_{10} or $PM_{2.5}$ exposures (table 3). For example, median survival for patients with local stage at diagnosis was 2.4 years for those with high $PM_{2.5}$ exposure (≥16 μg/m^3) and 5.7 years for those with low $PM_{2.5}$ exposure (<10 μg/m^3). Survival for patients with distant stage at diagnosis was poor and showed little variation with air pollution exposure.

After adjusting for important determinants of survival and potential confounders (including stage and histology), the HRs for all-cause mortality associated with a 1 SD increase in each pollutant were 1.13 (95% CI 1.12 to 1.13) for NO_2, 1.02 (95% CI 1.02 to 1.03) for O_3, 1.11 (95% CI 1.11 to 1.12) for PM_{10} and 1.16 (95% CI 1.16 to 1.17) for $PM_{2.5}$ (see online supplementary eTable 4). As shown in table 4, these associations varied by stage at diagnosis (all interaction p<0.01) and were of similar magnitude whether considering all-cause mortality or

Table 2 Air pollution exposure assignments based on residence at diagnosis, by stage at diagnosis

Air pollution exposures (mean±SD or %)	Localised only (n=59 609)	Regional (n=73 513)	Distant site(s) (n=186 496)	Unknown (n=32 435)	Total (n=352 053)
NO_2 (ppb)	20.6±9.3	21.4±9.7	22.0±10.4	24.5±11.3	21.9±10.2
% available*	87.6	86.8	87.3	83.0	86.8
O_3 (ppb)	40.3±9.7	40.3±10.8	40.0±12.8	41.2±12.8	40.2±11.9
% available*	93.6	93.2	93.3	89.9	93.0
PM_{10} (μg/m^3)	30.5±10.7	31.4±11.6	31.9±12.4	35.0±13.5	31.8±12.1
% available*	91.7	91.3	91.4	88.6	91.2
$PM_{2.5}$ (μg/m^3)†	13.0±4.5	13.4±4.9	13.9±5.6	14.6±5.7	13.7±5.3
% available*	86.5	84.3	82.6	76.8	83.3

*Percentage of patients with exposure assignment available (requires a monitor for that pollutant ≤25 km from residential address and non-missing geocode).
†$PM_{2.5}$ data are reported only for the subset of patients whose cancer was diagnosed in 1998 or later.
$PM_{2.5}$, particulate matter with diameter <2.5 μm; PM_{10}, particulate matter with diameter <10 μm.

Table 3 Median survival and 5-year survival rate, by stage at diagnosis and air pollution exposure

Categorised air pollution exposure	Median survival (years)			Five-year survival rate (%)*		
	Localised	Regional	Distant	Localised	Regional	Distant
NO_2 (ppb)						
<14	5.4	1.6	0.3	50	24	4
14–20.5	4.2	1.4	0.4	45	21	4
20.5–27	3.2	1.2	0.4	38	17	3
≥27	2.2	1.0	0.3	30	12	2
O_3 (ppb)						
<32	2.8	1.0	0.3	36	16	2
32–39.5	3.8	1.4	0.5	42	19	3
39.5–47	4.9	1.6	0.5	49	23	4
≥47	2.7	1.1	0.3	35	15	2
PM_{10} (μg/m^3)						
<23	4.7	1.5	0.3	47	23	4
23–30.5	4.4	1.4	0.4	45	20	4
30.5–38	3.7	1.3	0.4	43	19	3
≥38	2.1	1.0	0.3	27	11	2
$PM_{2.5}$ (μg/m^3)†						
<10	5.7	1.9	0.3	51	27	4
10–13	5.0	1.9	0.5	48	25	5
13–16	4.5	1.5	0.5	46	23	4
≥16	2.4	1.2	0.3	31	14	2

*SEs of all 5-year survival rates are <1%, with calculations based on >5800 patients per group.
†$PM_{2.5}$ results are only for the subset of patients whose cancer was diagnosed in 1998 or later.
$PM_{2.5}$, particulate matter with diameter <2.5 μm; PM_{10}, particulate matter with diameter <10 μm.

lung cancer-specific mortality. For each pollutant, adjusted HRs were larger for patients diagnosed at early stages. After stratifying by stage, we found additional variation in the associations by histology (all interaction p<0.01, except O_3). After stratifying by stage and histology, exposure to NO_2, PM_{10} and $PM_{2.5}$ remained strongly associated with all-cause mortality, with the largest magnitude-adjusted HR for local stage (figure 1). The adjusted HRs for NO_2, PM_{10} and $PM_{2.5}$ were generally smaller for patients with small cell carcinoma and larger for patients with adenocarcinoma (eg, local stage HR for PM_{10}: 1.16 (95% CI 1.11 to 1.21) vs 1.30 (95% CI 1.28 to 1.33), respectively). O_3 was not statistically significantly associated with all-cause mortality for patients with small and large cell cancer, but was modestly associated for patients with squamous cell carcinoma and adenocarcinoma (local stage adjusted HR of 1.04 (95% CI 1.02 to 1.07) and 1.03 (95% CI 1.01 to 1.05), respectively). Dose–response associations were evaluated in adjusted Cox models with categorised air pollution exposures, stratified by stage (data not shown). Results were qualitatively similar to the unadjusted associations in table 3.

In sensitivity analyses, no substantial heterogeneity in stage-specific adjusted HR was found by sex, race/ethnicity or distance to air quality monitors (see online supplementary eTables 5a, b). There was modest heterogeneity by year of diagnosis, particularly for NO_2 and PM_{10}, but the patterns of larger HR for patients diagnosed at earlier stages remained consistent. Patients with local stage at diagnosis living in a metropolitan core had slightly higher HR for PM_{10} and $PM_{2.5}$ than those living in non-metropolitan core areas (eg, $PM_{2.5}$ HR of 1.40 vs 1.25), a pattern that was also observed in the subsets of patients diagnosed in Los Angeles County, the San Francisco Bay area or San Diego County. These findings merit further study.

DISCUSSION

While ambient air pollutants have been associated with lung cancer incidence and mortality,[7 9–11] their impacts on survival after diagnosis have yet to be fully assessed.[14] In a population-based study of 352 053 patients with newly diagnosed lung cancer in California, we observed reduced survival associated with higher average NO_2, $PM_{2.5}$ and PM_{10} exposure over the follow-up period after diagnosis. HRs associated with these pollutants were largest for early-stage cancers and varied by histology, with the largest HR in early-stage non-small cell cancers, particularly adenocarcinoma.

A growing number of large cohort studies have found evidence for associations between air pollution exposures and lung cancer mortality using either incident lung cancer or death from lung cancer.[9–12] Meta-analysis estimates of the relative risk of lung cancer incidence/death (not stratified by stage) were slightly smaller than those observed in our study (1.04 (95% CI 1.01 to 1.08) for a 10 ppb increase in NO_2,[11] 1.08 (95% CI 1.00 to 1.17) for a 10 μg/m[3] increase in PM_{10}[10] and 1.04 (95% CI 1.02 to 1.07) for a 5 μg/m^3 increase in $PM_{2.5}$) and showed some evidence for heterogeneity by histology.[10] For the two most common histologies, relative risks associated with a 5 μg/m^3 increase in $PM_{2.5}$ were 1.18 (95% CI 1.03 to 1.35) for adenocarcinoma and 1.05 (95% CI 0.85 to 1.31) for squamous cell carcinoma.[10]

Few studies have attempted to disentangle determinants of lung cancer incidence from determinants of lung cancer survival due to the high case fatality rate.[10 24] To our knowledge, only one study has related air pollution exposures to survival in patients diagnosed with lung cancer.[14] Xu *et al*[14] studied white patients with respiratory cancer in Honolulu and Los Angeles between 1992–2008 and found adjusted HR slightly larger than that we observed for all-cause mortality (1.48 (95% CI 1.44 to 1.52) for a 10 μg/m^3 increase in PM_{10}; 1.57 (95% CI 1.53 to 1.61) for a 5 μg/m^3 increase in $PM_{2.5}$; 1.04 (95% CI 1.03 to 1.06) for a 10 ppb change in O_3) and slightly larger PM associations when restricting the analysis to Los Angeles cases only. Key differences include that we interpolated ambient exposures to residence locations (rather than using county-level exposures) and that we considered only lung cancer cases stratified by stage and histology. Xu *et al* considered all respiratory cancer cases and adjusted for primary cancer site and stage. By fully conditioning on disease type and severity at diagnosis, we more effectively target inference about air pollution exposure associations with survival after diagnosis by limiting carryover effects from differences at diagnosis potentially caused by earlier air pollution exposures.

Our observed associations were clinically significant (≤38% increased risk of death depending on stage and pollutant), suggesting that reductions in exposure have the potential to improve lung cancer survival. As expected, we observed a substantially larger association with survival in local compared with distant stage at diagnosis. As lung cancer screening becomes widely implemented, a shift to diagnosis at earlier stages is likely to occur. This is the stage at which air pollutants appear to have the most impact on survival. To maximise the effectiveness of lung cancer screening, interventions targeting modifiable determinants of survival for early-stage diagnoses are needed. Our findings suggest that future work should investigate the impact of interventions to reduce air pollution exposures (eg, avoidance, relocation, home filtration systems) on lung cancer survival.

Table 4 Adjusted* HRs (95% CI) for all-cause and lung cancer mortality associated with 1 SD increase in air pollutant exposure,† stratified by stage at diagnosis

Air pollutant	Stage at diagnosis	Sample size	All-cause mortality HR (95% CI)	Lung cancer mortality HR (95% CI)
NO_2	Localised only	52 223	1.30 (1.28 to 1.32)	1.31 (1.29 to 1.33)
	Regional	63 777	1.18 (1.17 to 1.20)	1.18 (1.16 to 1.19)
	Distant site(s)	162 816	1.07 (1.07 to 1.08)‡	1.07 (1.06 to 1.08)
	Overall§	305 721	1.13 (1.12 to 1.13)‡	1.12 (1.11 to 1.12)‡
O_3	Localised only	55 823	1.04 (1.02 to 1.05)	1.05 (1.04 to 1.07)
	Regional	68 504	1.03 (1.02 to 1.04)	1.03 (1.02 to 1.05)
	Distant site(s)	174 022	1.01 (1.01 to 1.02)‡	1.02 (1.01 to 1.02)‡
	Overall§	327 513	1.02 (1.02 to 1.03)‡	1.03 (1.02 to 1.03)‡
PM_{10}	Localised only	54 671	1.26 (1.25 to 1.28)	1.27 (1.25 to 1.29)
	Regional	67 108	1.16 (1.15 to 1.17)	1.15 (1.14 to 1.17)
	Distant site(s)	170 415	1.07 (1.06 to 1.07)‡	1.07 (1.06 to 1.07)‡
	Overall§	320 940	1.11 (1.11 to 1.12)‡	1.11 (1.10 to 1.11)‡
$PM_{2.5}$¶	Localised only	28 212	1.38 (1.35 to 1.41)	1.39 (1.36 to 1.43)
	Regional	34 223	1.26 (1.24 to 1.28)	1.24 (1.22 to 1.27)
	Distant site(s)	90 243	1.10 (1.09 to 1.11)‡	1.10 (1.09 to 1.11)
	Overall§	160 707	1.16 (1.16 to 1.17)‡	1.15 (1.14 to 1.16)‡

*Adjusted for age, sex, race/ethnicity, marital status, education index, socioeconomic status, rural–urban commuting area, distance to primary interstate highway, distance to primary US and state highways, histology at diagnosis, month of diagnosis, year of diagnosis and initial treatment.
†SD values: 10.2 ppb for NO_2, 11.9 ppb for O_3, 12.1 $\mu g/m^3$ for PM_{10} and 5.3 $\mu g/m^3$ for $PM_{2.5}$.
‡Estimate and CI bounds appear identical due to rounding.
§Overall analyses do not stratify by stage, but adjust for stage and include patients with unknown stage.
¶$PM_{2.5}$ results are only for the subset of patients whose cancer was diagnosed in 1998 or later.
$PM_{2.5}$, particulate matter with diameter <2.5 μm; PM_{10}, particulate matter with diameter <10 μm.

The pathophysiological mechanism underlying the relationship between NO_2, $PM_{2.5}$ and PM_{10} and lung cancer survival is uncertain. Ambient air pollution has been classified as a carcinogen and therefore may affect cancer progression after diagnosis via the same well-described pathways including oxidative stress, DNA damage, cell proliferation or epigenetic modifications. We observed some of the largest air pollution HRs for adenocarcinoma, the only common histological subtype of lung cancer that develops in a significant number of non-smokers.[25 26] More generally, air pollution may reduce survival in the susceptible subpopulation of patients with cancer, for example, by impairing respiratory function.

Strengths of our study include the population-based, large sample size drawn from all cases diagnosed in California, minimising selection bias and avoiding the survivorship bias in standard cohort studies. Using standardised methods, the CCR collects detailed clinical data and individual-level information on important determinants of survival (histology, stage, age and year of diagnosis; first course of treatment, sex, race/ethnicity and marital status). Our study focused on California, which has one of the most extensive and longest running air quality monitoring networks in the USA.

Several limitations of our study should be considered. The CCR collects information only on first course treatments, but residual confounding by subsequent treatments is unlikely since treatment is determined primarily by stage at diagnosis, and we stratify by stage. Follow-up in the CCR is passive, but nearly complete (>95%) for cancers with short survival. Individualised residential ambient air pollution exposure assignments offer a refinement over area-level exposure assignments (eg, reducing spatial exposure misclassification, which can attenuate associations),[10 27 28] but are subject to standard limitations, including inability to account for individual behaviour (eg, patients with cancer may spend even more time indoors than the general population), changes of residence or potentially long periods of time at medical facilities located in an area with different air pollution levels. We focused on air pollution exposures with large-scale regional variability using spatial interpolation of air quality monitoring data, which does not capture the effects of traffic-related pollution (TRP) that varies over a finer spatial scale. We accounted for potential confounding by a crude measure of local traffic (distance to highways). Future investigation of the effects of TRP on lung cancer survival requires the development of high spatially resolved TRP exposure metrics (eg, using land-use regression or line-source dispersion models) to directly evaluate TRP associations. The air pollution monitoring network is less dense in rural areas; so, exclusion of patients living >25 km from a monitor differentially excludes patients in rural areas. Long-term downward trends in NO_2, PM_{10} and $PM_{2.5}$ in California during the study period have been recognised previously.[29] The lack of consistent long-term temporal trend for O_3 likely reduced the variability in O_3 exposure across participants. Note that because survival is relatively short in patients with lung cancer, we expected short-term (seasonal) variability to dominate long-term variability during each patient's follow-up period. We adjusted for month of diagnosis in our models to account for potential confounding by short-term temporal factors. Results were robust to sensitivity analyses stratifying by categorised year of diagnosis, suggesting that long-term trends did not induce spurious associations (particularly of concern for early-stage diagnosis adenocarcinoma cases with longer median survival). Finally, we lacked individual-level data on important potential confounders/effect modifiers and risk factors (eg, smoking, diet, alcohol use, education, access to care, obesity, previous lung disease and occupational exposures). These omitted factors could have spuriously induced the observed associations only if they were strongly associated with the spatiotemporal distribution of ambient air pollution exposures, which seems unlikely. Previous studies have suggested that non-smokers may be at greater risk for air pollution-related lung cancer incidence/mortality than current smokers.[10] While smoking is an important risk factor, previous data suggest that, at diagnosis, only 39% of patients with lung cancer are current smokers (drops to 14% at 5 months after diagnosis).[30]

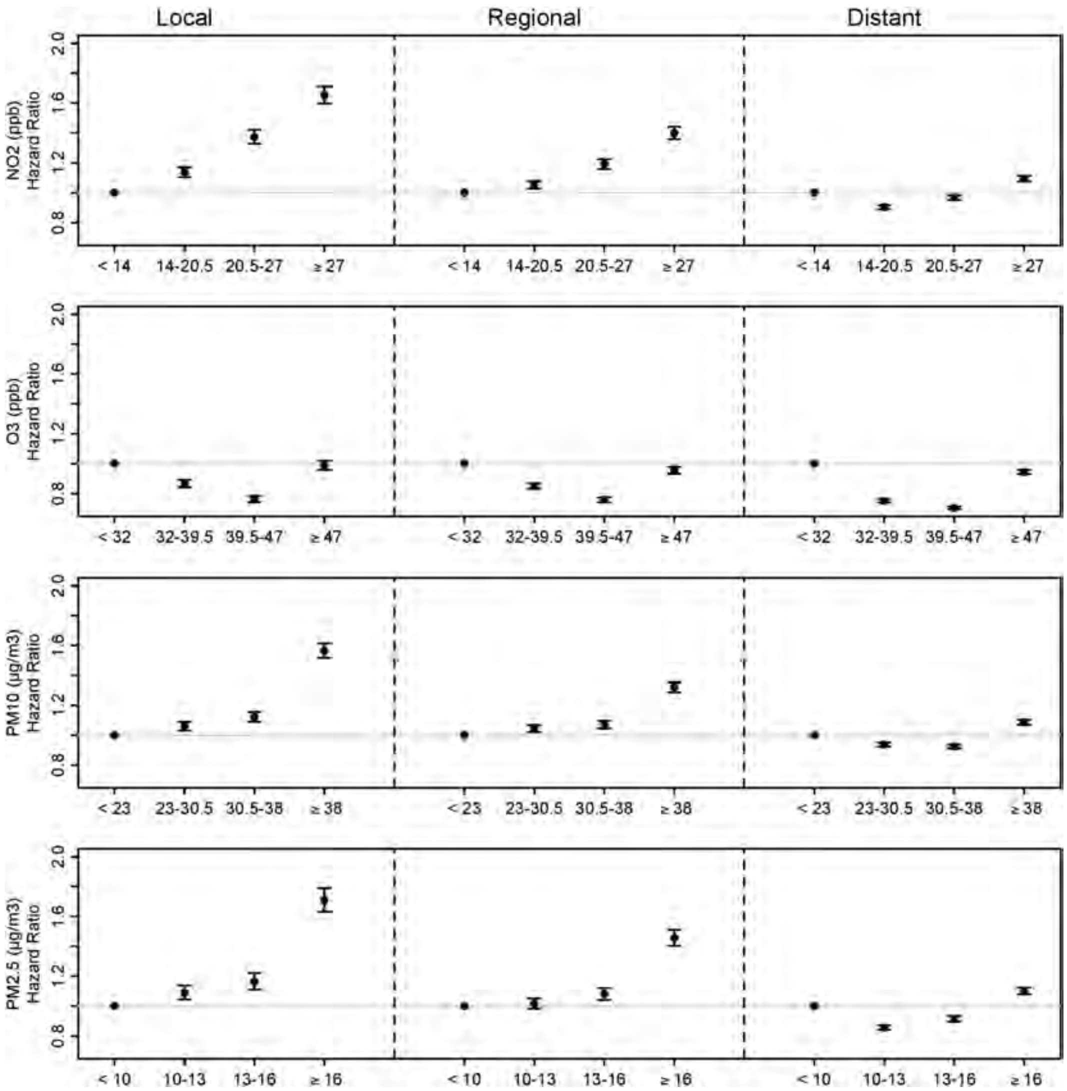

Figure 1 Adjusted[a] HRs and 95% CIs for all-cause mortality associated with 1 SD increase in air pollutant exposure,[bc] stratified by stage and histology at diagnosis. [a]Adjusted for age, sex, race/ethnicity, marital status, education index, socioeconomic status, rural–urban commuting area, distance to primary interstate highway, distance to primary US and state highways, month of diagnosis, year of diagnosis and initial treatment. [b]SD values: 10.2 ppb for NO_2, 11.9 ppb for O_3, 12.1 μg/m^3 for PM_{10} (particulate matter with diameter <10 μm) and 5.3 μg/m^3 for $PM_{2.5}$ (particulate matter with diameter <2.5 μm). [c]$PM_{2.5}$ results are only for the subset of patients whose cancer was diagnosed in 1998 or later.

In summary, we found evidence for associations between all-cause and lung cancer-specific mortalities and NO_2, $PM_{2.5}$ and PM_{10}, robust to a number of sensitivity analyses. Future studies should evaluate the impacts of ambient air pollution exposure reduction, since controlling patients' exposures could offer a novel approach to improve lung cancer outcomes, especially among patients diagnosed at early stages.

Contributors Study concept, design and obtained funding: MC and FDG; acquisition, analysis or interpretation of data and critical revision of the manuscript for important intellectual content: all authors; drafting of the manuscript: SPE, MC, FDG and Y-HS; statistical analysis: Y-HS and HD; administrative, technical or material support: MC, LL and FWL; study supervision: MC, FDG and SPE.

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Competing interests None declared.

Ethics approval State of California Committee for the Protection of Human Subjects.

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THORAX

Air pollution affects lung cancer survival

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AGU FALL MEETING
San Francisco | 12–16 December 2016

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Associated Entries

Abstract

A13N-01 Monitoring of Emissions From a Refinery Tank Farm Using a Combination of Optical Remote Sensing Techniques

Laki Tisopulos

Monday, 12 December 2016
13:40 - 13:56
Moscone West - 3006

Abstract

A13N-02 Quantification of Gas Emissions from Refinieries, Gas Stations, Oil Wells and Agriculture using Optical Solar Occultation Flux and Tracer Correlation Methods

Johan Mellqvist

Monday, 12 December 2016
13:56 - 14:09
Moscone West - 3006

Abstract

A13N-03 Application of optical remote sensing techniques to quantify emissions from urban oil wells, storage tanks, and other small stationary sources

Olga Pikelnaya

Monday, 12 December 2016
14:09 - 14:22
Moscone West - 3006

Abstract

A13N-04 Methods and Results from Measurements of the Emissions of Gaseous and Particulate Pollutants from Individual Ships in the Port Areas of Los Angeles and Long Beach

Jörg Beecken

Monday, 12 December 2016
14:22 - 14:35
Moscone West - 3006

AGU FALL MEETING
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A13N-02: Quantification of Gas Emissions from Refinieries, Gas Stations, Oil Wells and Agriculture using Optical Solar Occultation Flux and Tracer Correlation Methods

Monday, 12 December 2016
13:56 - 14:09
Moscone West - 3006

Industrial volatile organic compound (VOC) emissions may contribute significantly to ozone formation. In order to investigate how much small sources contribute to the VOC concentrations in the Los Angeles metropolitan area a comprehensive emission study has been carried out on behalf of the South Coast Air Quality Management District (SCAQMD). VOC emissions from major sources such as refineries, oil wells, petrol stations oil depots and oil platforms were measured during September and October 2015 using several unique optical methods, including the Solar Occultation Flux method (SOF) and tracer correlation technique based on extractive FTIR and DOAS combined with an open path multi reflection cell. In addition, measurements of ammonia emissions from farming in Chino were demonstrated. The measurements in this study were quality assured by carrying out a controlled source gas release study and side by side measurements with several other techniques. The results from the field campaign show that the emissions from the above mentioned sources are largely underestimated in inventories with potential impact on the air quality in the Los Angeles metropolitan area. The results show that oil and gas production is a very significant VOC emission source. In this presentation the techniques will be discussed together with the main results from the campaign including the quality assurance work.

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Increased Risk of Paroxysmal Atrial Fibrillation Episodes Associated with Acute Increases in Ambient Air Pollution

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Objectives: We reported previously that 24-hr moving average ambient air pollution concentrations were positively associated with ventricular arrhythmias detected by implantable cardioverter defibrillators (ICDs). ICDs also detect paroxysmal atrial fibrillation episodes (PAF) that result in rapid ventricular rates. In this same cohort of ICD patients, we assessed the association between ambient air pollution and episodes of PAF.

Design: We performed a case–crossover study.

Participants: Patients who lived in the Boston, Massachusetts, metropolitan area and who had ICDs implanted between June 1995 and December 1999 ($n = 203$) were followed until July 2002.

Evaluations/Measurements: We used conditional logistic regression to explore the association between community air pollution and 91 electrophysiologist-confirmed episodes of PAF among 29 subjects.

Results: We found a statistically significant positive association between episodes of PAF and increased ozone concentration (22 ppb) in the hour before the arrhythmia (odds ratio = 2.08; 95% confidence interval = 1.22, 3.54; $p = 0.001$). The risk estimate for a longer (24-hr) moving average was smaller, thus suggesting an immediate effect. Positive but not statistically significant risks were associated with fine particles, nitrogen dioxide, and black carbon.

Conclusions: Increased ambient O_3 pollution was associated with increased risk of episodes of rapid ventricular response due to PAF, thereby suggesting that community air pollution may be a precipitant of these events.

Key words: air pollution, arrhythmias, fibrillation, epidemiology, case–crossover, ozone. *Environ Health Perspect* 114:120–123 (2006). doi:10.1289/ehp.8371 available via *http://dx.doi.org/* [Online 20 September 2005]

In previous studies, we reported statistically significant associations between ambient air pollution and cardiac arrhythmias in patients with implantable cardioverter defibrillator (ICD) devices (Dockery et al. 2005a, 2005b; Peters et al. 2000b; Rich et al. 2005). A pilot study of 100 patients in Boston, Massachusetts, found significantly increased risk of ICD discharges associated with nitrogen dioxide and black carbon among patients with repeated events (Peters et al. 2000b). In a larger study of approximately 200 Boston-area ICD patients, we found a nonstatistically significant increased risk of ventricular arrhythmias (confirmed by an electrophysiologist) associated with 2-day mean NO_2, particulate matter < 2.5 μm in aerodynamic diameter ($PM_{2.5}$), black carbon, carbon monoxide, ozone, and sulfur dioxide (Dockery et al. 2005a, 2005b). In a case–crossover analysis of these data, which allowed us to match the time of onset of these arrhythmias with ambient air pollution concentrations, we found stronger, statistically significant associations of ventricular arrhythmias with mean $PM_{2.5}$ and O_3 in the 24 hr before the arrhythmia (Rich et al. 2005).

Although ICDs are designed to detect and treat life-threatening ventricular arrhythmias, supraventricular arrhythmias may also be detected. Many of these supraventricular arrhythmias may be atrial fibrillation, which is the most common sustained arrhythmia in clinical practice (Go et al. 2001) and a risk factor for stroke (Prystowsky et al. 1996) and premature mortality (Kanel et al. 1983). We used a case–crossover design to examine the association of ICD-detected paroxysmal atrial fibrillation and hourly measurements of community air pollution concentrations.

Materials and Methods

Study population. Two hundred three patients who had a third-generation Guidant ICD (Cardiac Pacemakers, Inc., Minneapolis, MN) implanted at the Tufts–New England Medical Center between 1 June 1995 and 31 December 1999, were followed until their last clinic visit before 15 July 2002. Patients who lived within 40 km (25 mi) of the air pollution monitoring station at the Harvard School of Public Health were included for analysis. The Guidant ICDs record intracardiac electrograms and were the most common ICD implanted at Tufts–New England Medical Center during the study period. Each patient's first 14 days after implantation and any events that occurred during inpatient hospital visits were excluded. Further description of this population has been published previously (Dockery et al. 2005a, 2005b).

Outcome and clinical data. For each ICD-recorded episode of tachyarrhythmia, the date, time, beat-to-beat intervals, and intracardiac electrogram before, during, and after episodes were recovered from the ICD. In a small number of cases in which the patient experienced a large number of ICD-detected episodes since the previous clinic visit, early electrograms in the ICD memory, but none of the other episode-specific data, may have been overwritten. ICD settings including ventricular tachycardia rate cutoffs (i.e., detection rates) were also abstracted from the ICD records. Ventricular tachycardia rate cutoffs were set by the treating electrophysiologist based on the clinical features of the patients.

All of the ICD-detected episodes were reviewed and characterized by an electrophysiologist (M.S.L) blinded to air pollution levels. Details of this arrhythmia classification have been published previously (Dockery et al. 2005b). Briefly, patients who presented with atrial fibrillation at all clinic follow-ups were classified as in permanent atrial fibrillation, and they were excluded from this analysis. Episodes of paroxysmal atrial fibrillation (PAF) were defined by a ventricular rate between 120 and 200 beats per minute, irregularity of the beat-to-beat intervals, no change in QRS morphology (except for a small number of cases with no ventricular electrogram), and lack of conversion following ventricular therapies

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(except when therapy was not applied). If a dual-chamber device had been implanted and an atrial electrogram was available, the atrial electrogram was also used to characterize ICD-recorded episodes. This analysis was restricted to PAF episodes that occurred at least 60 min after the previous event. Residence ZIP code, date of birth, race/ethnicity, clinic visit dates, and medications prescribed (beta-blockers, digoxin, and other antiarrhythmics) were abstracted from patients' records.

The Harvard School of Public Health Human Subjects Committee and the Tufts–New England Medical Center Institutional Review Board approved this record review study.

Air pollution. The air pollution measurements have been described previously (Dockery et al. 2005a, 2005b; Rich et al. 2005). Briefly, ambient concentrations of O_3, NO_2, SO_2, and CO were measured hourly by the Massachusetts Department of Environmental Protection at four to six sites in the Boston metropolitan area during the entire follow-up period. We calculated the hourly average air pollution concentration across all available monitoring stations, accounting for differences in the annual mean and daily standardized deviations of each monitor (Schwartz 2000). $PM_{2.5}$ was measured hourly in South Boston (~ 5 km east of the Harvard School of Public Health) from 1 April 1995 to 20 January 1998, and at the Harvard School of Public Health from 16 March 1999 to 31 July 2002. Black carbon was measured hourly in South Boston from 1 April 1995 to 29 March 1997, and at the Harvard School of Public Health from 15 October 1999 to 31 July 2002.

Acute effect of pollutants. We analyzed the association of ambient air pollution concentrations and episodes of PAF using a case–crossover design (Maclure 1991). These methods have been used previously to study triggers of acute cardiovascular events (Albert et al. 2000; D'Ippoliti et al. 2003; Hallqvist et al. 2000; Mittleman et al. 1995; Peters et al. 2000a; Rich et al. 2005). In this design, each subject contributes information as a case during the event periods and as a matched control during nonevent times. Because cases and their matched controls are derived from the same person and a conditional analysis is conducted, non-time-varying potential confounders such as underlying medical condition and long-term smoking history are controlled by design. Variables that may be related to both air pollution and the occurrence of PAF that fluctuate over time (e.g., meteorologic conditions) are possible confounders.

We defined case periods by the detection time of each confirmed episode of PAF, rounded to the nearest hour. We matched control periods on weekday and hour of the day within the same calendar month (Lumley and Levy 2000). We calculated average pollution concentrations and weather conditions during the hour and during the 24 hours before the case and control time periods for this analysis.

Conditional logistic regression models, including the mean pollutant concentration in the hour of the arrhythmia (lag hour 0) and natural splines [3 degrees of freedom (df)] for the mean temperature, dew point, and barometric pressure in the 24 hr before the arrhythmia, were run separately for each pollutant ($PM_{2.5}$, black carbon, NO_2, CO, SO_2 and O_3). Different individuals may have different cardiac responses to pollution, based on their clinical history and genetic characteristics. Therefore, we included a frailty term (Therneau and Grambsch 2000) for each subject (akin to a random intercept) in all the above models. Odds ratios (ORs), 95% confidence intervals (CIs), and *p*-values for statistical significance testing are presented for an interquartile range increase in each pollutant. We considered associations with longer exposures before the PAF episode using the mean of the pollutant in the previous 24 hr (lag hours 0–23).

To assess the sensitivity of our results to the influence of outliers, we reran analyses, trimming the highest 5% and lowest 5% of air pollution concentrations. For O_3, which has a strong seasonal pattern, we examined whether the association between PAF and O_3 concentration was limited to the 6 months with the highest mean ambient temperature (May–October) by adding an O_3/warm month interaction term to the conditional logistic regression model. We assessed the linearity of the PAF and O_3 association by replacing the linear air pollution term with a penalized spline (3 df) in the conditional logistic regression model. We plotted the covariate adjusted log OR for the risk of PAF in the spline and linear models versus 1-hr O_3 concentration.

We used SAS (version 9.1; SAS Institute Inc., Cary, NC) software to construct all datasets and to calculate descriptive statistics. We used S-Plus 6.2 (Insightful Inc., Seattle, WA) software for all modeling.

Results

There were 203 ICD patients enrolled in the study who lived within 40 km of the Harvard School of Public Health with a mean (± SD) follow-up time of 3.1 ± 1.8 years (maximum = 7.0 years). Ninety-five patients had a total of 1,574 recorded ICD events, 933 of which were separated by > 1 hr. Ninety-one (9.8 %) of these events, among 29 subjects, were confirmed episodes of PAF. Because $PM_{2.5}$ and black carbon were not measured during the entire study period, analyses of $PM_{2.5}$ included at most 52 episodes of PAF from 22 subjects, and analyses of black carbon included at most 46 episodes of PAF from 18 subjects.

The 29 subjects with PAF episodes were primarily male (79%) and white (79%), and they ranged in age from 45 to 78 years (mean, 65 years). At their first clinic follow-up visit, 69% of subjects were listed as being prescribed beta-blockers, 57% digoxin, and 24% other antiarrhythmics (i.e., amiodarone, quinidine, sotalol, or mexilitine). Two subjects (7%) were not prescribed any of these medications. The most common diagnoses at implantation were coronary artery disease (76%) and idiopathic cardiomyopathy (22%). Before ICD implantation, 55% of subjects had left ventricular ejection fractions < 35%. Subjects' ICDs were programmed with ventricular tachycardia detection rates (i.e., ventricular rate threshold above which the electrogram and date/time for a tachyarrhythmia would be recorded) that had a 10th to 90th percentile range of 140 to 200 beats/min (median = 175).

Of the 29 subjects who experienced at least one episode of PAF, 15 (52%) experienced > 1 event, while 2 (7%) experienced ≥ 10. Twenty (69%) also experienced a ventricular arrhythmia during follow-up. Episodes of PAF were more frequent in the late morning (0900–1100 hr), with a smaller evening peak (1800–2000 hr).

The distributions of air pollution concentrations and meteorologic characteristics in Boston during the study period, averaged hourly and daily, are summarized in Table 1. The highest average $PM_{2.5}$ and black carbon concentrations were observed early in the morning (0600–0800 hr), highest NO_2 in the early morning (0600–0800 hr) and early evening (1600–2100 hr), and highest O_3 at midday (1200–1400 hr). Further detail has been provided previously (Dockery et al. 2005b).

We found a statistically significant increased risk of PAF associated with mean O_3 concentration in the concurrent hour (lag hour 0; Table 2). The estimated relative odds for the 24-hr moving average concentration was positive (OR > 1), but not statistically significant. We did not find statistically significant associations with any other pollutant in the concurrent hour, but associations were positive for $PM_{2.5}$ and NO_2. Risk estimates for 24-hr average $PM_{2.5}$, NO_2, and black carbon were positive, but none was statistically significant. Risk estimates for 24-hr average CO and SO_2 were protective (OR < 1), but neither was statistically significant (Table 2).

For O_3 in the concurrent hour, there was little change in risk of PAF when we excluded the top 5% and bottom 5% of concentrations (OR = 2.15, 95% CI = 1.04–4.44, $p = 0.04$). The association between PAF and O_3 in the concurrent hour in the cold months (OR = 2.21; 95% CI = 0.98–4.98; $p = 0.06$) was comparable to that in the warm months (OR = 1.98; 95% CI = 1.05–3.73; $p = 0.04$), with no significant interaction ($p = 0.84$).

Figure 1 shows the covariate adjusted log OR for the risk of PAF versus 1-hr O_3 concentration modeled using first a linear term and then a penalized spline (3 df). We found no evidence of a deviation from linearity (nonlinear term, $p = 0.63$).

Discussion

In a study designed to assess the association of ambient air pollution with ventricular arrhythmias among ICD patients, 91 of the ICD-detected episodes were identified by electrophysiologist review as PAF. Although these episodes of PAF were likely an underrepresentation of all those PAF episodes experienced by these patients, they provided a unique opportunity to assess associations between air pollution and episodes of PAF. We found a statistically significant 2-fold increase in risk of PAF episodes associated with each 22-ppb increase in mean ambient O_3 concentration in the concurrent hour. We found no evidence that this association was nonlinear.

An earlier study reported a 10.5% increase in supraventricular ectopy (~ 3.5 beats/hr increase in supraventricular ectopy compared to the population mean rate of supraventricular ectopy) associated with each 7-µg/m^3 increase in ambient PM_{10} (particulate matter < 10 µm in aerodynamic diameter) concentration in a panel of chronic obstructive pulmonary disease patients (Brauer et al. 2001). They reported smaller increases in supraventricular ectopy associated with outdoor and personal $PM_{2.5}$ and sulfates.

Table 1. Boston air pollution profile, August 1995 to June 2002.

Parameter	No. of hours or days	Percentile			Maximum
		25th	50th	75th	
$PM_{2.5}$ (µg/m^3)[a]					
Hourly	48,592	5.6	9.2	15.0	84.1
Daily	2079	6.7	9.8	14.5	53.2
Black carbon (µg/m^3)[b]					
Hourly	36,789	0.44	0.77	1.35	23.93
Daily	1555	0.58	0.94	1.41	7.32
NO_2 (ppb)					
Hourly	60,555	15.8	21.7	29.0	78.8
Daily	2526	18.1	22.4	27.3	61.8
SO_2 (ppb)					
Hourly	60,620	2.6	4.3	7.5	71.6
Daily	2526	3.2	4.8	7.3	31.4
CO (ppm)					
Hourly	60,091	0.46	0.73	1.04	5.83
Daily	2526	0.52	0.78	1.03	2.48
O_3 (ppb)					
Hourly	60,210	11.3	22.2	33.0	119.5
Daily	2524	15.2	22.6	30.9	77.5
Temperature (°C)					
Hourly	60,449	3	11	18	36
Daily	2526	4	11	18	32
Dew point (°C)					
Hourly	60,356	–3	6	13	25
Daily	2526	–2	5	13	23
Barometric pressure (mmHg)					
Hourly	60,379	758	762	766	784
Daily	2525	758	762	766	781

Air pollution was measured hourly; total possible hours = 60,624; total possible days = 2,526.
[a]Concentrations missing from 21 January 1998 to 15 March 1999. [b]Concentrations missing from 30 March 1997 to 15 October 1999.

Table 2. ORs for PAF associated with an interquartile range increase in the mean of pollutant lag hours.

Mean of pollutant	Interquartile range	Lags	No. of subjects	No. of PAF episodes	OR (95% CI)	*p*-Value
$PM_{2.5}$ (µg/m^3)	9.4	0	22	52	1.41 (0.82–2.42)	0.22
	7.8	0–23	22	47	1.13 (0.63–2.03)	0.68
Black carbon (µg/m^3)	0.91	0	18	46	0.81 (0.42–1.56)	0.53
	0.83	0–23	18	46	1.46 (0.67–3.17)	0.34
NO_2 (ppb)	13.2	0	28	90	1.21 (0.80–1.83)	0.37
	9.2	0–23	27	89	1.18 (0.79–1.76)	0.43
CO (ppm)	0.58	0	28	90	0.87 (0.56–1.37)	0.55
	0.51	0–23	28	90	0.71 (0.39–1.28)	0.25
SO_2 (ppb)	4.9	0	28	90	1.02 (0.81–1.28)	0.87
	4.1	0–23	28	90	0.99 (0.71–1.39)	0.97
O_3 (ppb)	21.7	0	28	90	2.08 (1.22–3.54)	0.007
	15.8	0–23	28	89	1.60 (0.89–2.89)	0.12

Our findings identify ambient air pollution as a potential precipitant of supraventricular arrhythmias. Atrial fibrillation is the most common supraventricular arrhythmia. At least 2.3 million adults in the United States have some form of atrial fibrillation (Go et al. 2001), and this number is likely an underestimate because many people with this condition are asymptomatic (Chugh et al. 2001). The incidence of atrial fibrillation doubles with each decade of adult life (Falk 2001). Although atrial fibrillation is not usually considered a lethal rhythm, it is associated with premature mortality and increased risk for hospitalization and stroke (Wolf et al. 1998; Benjamin et al. 1998). If not on antithrombotic therapy, people with atrial fibrillation have a 5-fold increased risk of stroke (Ryder and Benjamin 1999). Therefore, even a modest risk of atrial fibrillation associated with acute exposure to elevated ambient air pollution in the general population would have a substantial attributable risk.

In prior analyses in this cohort of ICD patients, we found significantly increased risk of ventricular arrhythmias associated with mean $PM_{2.5}$ and O_3 concentrations in the 24 hr before the episode (Rich et al. 2005), and marginally significant increased risk ($p < 0.10$) associated with mean black carbon and NO_2 concentrations over the previous 2 days (Dockery et al. 2005a, 2005b). The findings of positive associations between episodes of PAF and O_3 concentration (1-hr) is consistent with these observations, although the timing (1 hr vs. 24 hr or 1 day) suggests a more rapid response to air pollution with PAF.

O_3 is an acute lung irritant that has been associated with acute myocardial infarction (Ruidavets et al. 2005), decreased lung function, exacerbation of asthma or other respiratory conditions, increased hospitalizations, and premature mortality (Thurston and Ito 1999). O_3 is a highly reactive oxidant formed

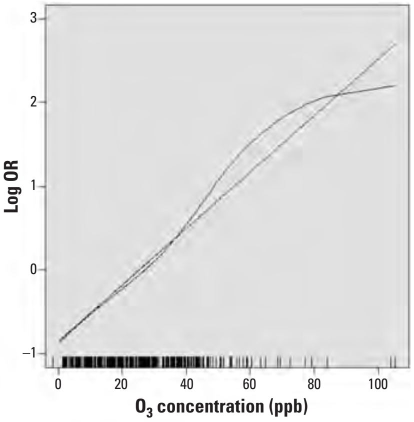

Figure 1. Log OR of PAF by 1-hr O_3 concentration modeled as a linear term and using a penalized spline with 3 df. Vertical lines on abscissa indicate the O_3 concentrations of observed events.

by photochemical reactions in the atmosphere. O_3 concentrations are highest on warm sunny days, and highest during the afternoon hours. However, we found a statistically significant association with O_3 after adjustment for temperature, and we found no evidence that the O_3 associations were restricted to the six warmest months.

We also found positive associations with $PM_{2.5}$, NO_2, and black carbon, but the CIs were wide and the risk estimates were not statistically significant. The number of PAF episodes with matching O_3 and NO_2 concentrations was small ($n = 90$), and they were even smaller for $PM_{2.5}$ ($n = 52$) and black carbon ($n = 46$), which resulted in reduced power to detect any associations. Thus, this small number of confirmed PAF episodes dictates caution in our interpretation of specific associations. Although we have highlighted the association with O_3 in the concurrent hour, it would be premature to attribute the increased risk of PAF to O_3 alone. We suggest that community air pollution may be associated with the incidence of PAF. Confirmation of this association and examination of associations with specific pollutants requires a larger number of confirmed PAF episodes.

A problem in studying incidence of PAF is the definition of time of onset of new episodes. Although the ICD device provides a detection time for each episode of PAF, this is the time that the ventricular rate (responding to the atrial stimulus) exceeded the patient's specific programmed criteria for a tachyarrhythmia. The PAF episode may have started earlier than the time recorded by the ICD. This situation would lead to mismatching of air pollution concentrations to case and control time periods. However, this exposure misclassification would be nondifferential with respect to case/control status. Therefore, it would have resulted in a bias toward the null, underestimates of risk, and wide CIs.

Episodes of PAF also may have been misclassified. However, any outcome misclassification, if present, was likely independent of air pollution levels and nondifferential. This misclassification would have produced wider CIs, a bias toward the null, and underestimates of risk.

Our analysis was limited to a subset of all PAF episodes that these subjects experienced. PAF episodes with ventricular response rates that remained below the ICD's preset detection criteria for the duration of the arrhythmia would not have been recorded. These underdetected episodes likely represented a substantial fraction of the PAF episodes experienced by these patients. However, we used the case–crossover method, where each person serves as his or her own control, and event times are contrasted with matched control times. Such misclassification would have resulted in a loss of power, but no bias in our risk estimates. Whether our finding of an association between transient ambient air pollution concentrations and PAF is limited to this particular subset of PAF episodes, however, is unknown. New studies using devices programmed to detect a wider range of PAF episodes with more precise data on the timing of arrhythmia initiation are required to confirm and quantify this association further.

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A 10-year time-series analysis of respiratory and cardiovascular morbidity in Nicosia, Cyprus: the effect of short-term changes in air pollution and dust storms

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Abstract

Background -: To date, a substantial body of research has shown adverse health effects of short-term changes in levels of air pollution. Such associations have not been investigated in smaller size cities in the Eastern Mediterranean. A particular feature in the region is dust blown from the Sahara a few times a year resulting in extreme PM_{10} concentrations. It is not entirely clear whether such natural phenomena pose the same risks.

Methods -: The effect of changes in daily levels of particulate matter (PM_{10}) and ozone (O_3) on hospitalization for all, cardiovascular and respiratory causes in the two hospitals in Nicosia during 1 January 1995 and 30 December 2004 was investigated using generalized additive Poisson models after controlling for long- and short-term patterns as well as for the effect of weather. Meteorological records were reviewed to identify dust-storm days and analyses were repeated to quantify their effect on cardio-respiratory morbidity.

Results -: For every 10 μg/m^3 increase in daily average PM_{10} concentrations, there was a 0.9% (95%CI: 0.6%, 1.2%) increase in all-cause and 1.2% (95%CI: -0.0%, 2.4%) increase in cardiovascular admissions. With respect to respiratory causes, an effect was observed only in the warm months. No lagged effects with levels of PM_{10} were observed. In contrast, positive associations with levels of ozone were only observed the two days prior to admission. These appeared stronger for cardiovascular causes and independent of the effect of PM. All-cause and cardiovascular admissions were 4.8% (95%CI: 0.7%, 9.0%) and 10.4% (95%CI: -4.7%, 27.9%) higher on dust storm days respectively. In both cases the magnitude of effect was comparable to that seen on the quartile of non-storm days with the highest levels of PM_{10}.

Conclusion -: We observed an increased risk of hospitalization at elevated levels of particulate matter and ozone generally consistent with the magnitude seen across several European cities. We also observed an increased risk of hospitalization on dust storm days, particularly for cardiovascular causes. While inference from these associations is limited due to the small number of dust storm days in the study period, it would appear imperative to issue health warnings for these natural events, particularly directed towards vulnerable population groups.

Background

In the last 20 years, evidence on adverse health effects – both increased hospitalization and mortality – of elevated ambient levels of air pollutants has been accumulating [1,2], more so recently with the use of meta-analyses of single-city time-series analyses [3,4] or multi-city studies [5,6]. With the major exception of the APHEA project, a multi-centre European study with a common protocol [7] in as many as 15 and 29 European cites in its phases I and II respectively [8-10], the majority of evidence comes from US cities e.g. the National Morbidity, Mortality and Air Pollution Study (NMMAPS) [11,12]. While large cities in the Eastern Mediterranean, such as Athens, Tel Aviv and Istanbul were considered in APHEA, associations have not been investigated in smaller size cities where socio-economic factors (such as driving patterns, time spent outdoors and access to health care) as well as climatic conditions might vary considerably. A particular feature of the Eastern Mediterranean is episodes of re-suspended wind blown dust from desert regions, raising particle concentrations a few times a year considerably above European guidelines [13]. It is not entirely clear whether high levels of particulate matter from such natural phenomena pose the same risks on cardiovascular and respiratory health as particles from anthropogenic sources. With PM_{10} concentrations comparable to the high levels seen in other much larger Southern European cities as well as frequently affected by dust storms, the capital of Cyprus, Nicosia (population approximately 270,000) offers an opportunity to address this issue. Using a time-series approach, this study investigates associations between daily levels of (a) particulate matter with aerodynamic diameter < 10 μm (PM_{10}) on non-storm and dust storm days separately as well as (b) ozone (O_3) on counts of hospital admissions for all, respiratory and cardiovascular causes during the 10-year period 1995–2004.

Methods

Data and data sources

Based on ICD code of diagnosis for inpatient admission, all cardiovascular (ICD10 codes I00–I52) and respiratory (ICD10 codes J00–J99) admissions between 1 January 1995 to 30 December 2004 (i.e. a total of 3,652 days) were obtained from the two public hospitals in Nicosia (i.e. Nicosia General and Makarios Hospital) with information on gender, age, date of admission and discharge as well as whether inpatient was resident in the district of Nicosia. The daily volume of all-cause admissions in the same period was obtained from the Cyprus Statistical Services, aggregated in 8 age- and sex-strata – males and females, aged 4 or less, 5–14, 15–64 and 65 or older. Hourly measurements of PM_{10} and O_3 were available from two ambient air quality monitoring stations: (a) a local traffic-representative station located centrally at the Nicosia General Hospital and (b) a station reflecting background levels in the rural location of Ayia Marina, approximately 40 km from Nicosia. Continuous monitoring of coarse particles was performed with TEOM (Tapered Element Oscilling Micro-balance) instruments. Data from the rural station were available only from 1997 for ozone and 1999 for PM_{10}, reducing the study period to 8 and 6 years respectively. Thus, the main analyses presented here were based on a single exposure series as recorded at the traffic-representative station. Completeness of the main data series of air pollutants was generally satisfactory and concurred with previous practice, including the protocol used in APHEA. Commonly, missing values are replaced using a weighted average of values from other monitoring stations on that day. With only one other station, located rurally and thus not necessarily representative of exposure in the capital, imputation of missing values was not considered not least because availability of data did not cover the full period of investigation and would replace only a small fraction of the missing values. The background station was mainly used to aid in the identification of dust-storm days, since due to its rural location it is not affected by local traffic pollution. Nevertheless, the effect on the observed estimates of using the background station to define exposure was considered in sensitivity analyses. Daily averages of air and dew point temperature, relative humidity, wind speed, precipitation and barometric pressure based on hourly measurements of Thermohygrographs (i.e. instantaneous values) were obtained from the Cyprus Meteorological Services.

Identification of dust-storm days

Dust storm events affect Cyprus at least a few days a year resulting in extreme PM concentrations, which sometimes may persist for a few consecutive days. To construct a calendar of such events, an iterative approach was used whereby starting with a pool of days (N = 773) with at least 1 hourly measurement of PM_{10} higher than 150 μg/m^3 recorded at Nicosia Central or higher than 100 μg/m^3 at the rural station (in both cases, 2 standard deviations (SD) away from the mean of hourly values on the logarithmic scale), paper-form meteorological records from the main International Airport at Larnaca (50 km from Nicosia) were reviewed to identify those days when a meteorological observer (as part of their hour-by-hour coding of weather and visibility conditions) noted poor visibility due to "dust in suspension" at any part of a given day, which did not refer to hazy conditions or dust from local sources i.e. a result of re-suspension. Candidate days were then cross-checked against a number of data-based criteria to assess the extent to which levels of PM_{10} on those days where indeed uncharacteristic, including (i) daily average levels of PM_{10} higher than 2 SDs away from the mean as recorded at the rural station, not as prone to traffic pollution and/or (ii) levels of PM_{10} higher than 2 SDs away from the mean in the centre of Nicosia after excluding hours of pick traffic and/or (iii) days identified as outliers (2 SDs away from the predicted value) using a predictive model of levels of PM_{10} based on levels the previous day and adjusting for weather variables including temperature, barometric pressure, precipitation and wind speed. The data-based criteria were not used to identify dust-storm days *per se* but to correct the original calendar which was based only on meteorological observations (i.e. either confirm, invalidate or propose additional days) with the main aim of categorizing days into *confirmed* events, where the criteria were in agreement with the meteorological observation and *suspected* events, where all criteria suggest an event that might have been overlooked or coded otherwise by the observer. Possible markers of dust storm events used in the past, such as low carbon monoxide levels [14], reduced visibility range [15], or based on investigation of aerosol optical depth [16,17], were not electronically available. Finally, in accordance to previous practice [16,18-20], backwards wind trajectories for up to 4 days ending in Cyprus (35°N, 33°E) on the day and about the time the meteorological observation was made were used to track the possible source of each identified event in the Sahara or Arabian peninsula using the National Oceanic and Atmospheric Administration (NOAA) HYSPLIT model.

Statistical analyses

Only days with at least 12 hourly measurements were used to calculate daily averages of air pollutants (PM_{10} and O_3) as well as daily 8-hour maximum moving average for O_3. The effect of changes in levels of air pollutants on the number of daily admissions was investigated in Poisson regression models (a) as linear terms, expressed as percentage increase in mean number of daily admissions per 10 μg/m³ or 10 ppb increase in levels of PM_{10} and O_3 respectively, (b) across quartiles of increasing levels of PM_{10} (after including and excluding dust storm days) and O_3 to assess non-linearity of effects and (c) to include a categorical variable for dust storm days and restrict the estimation of a linear effect to non-storm days only (i.e. Dust Storm Day (= 0 or 1) + PM_{10} daily average × [1-Dust Storm Day]). The magnitude of effect on these days was then compared to the effects seen across quartiles of all non-storm days with increasing levels of PM_{10}. In accordance to previous practice, to ensure that extreme values of PM_{10} (in this case, most likely to be a result of air blown dust) would not influence the estimation of linear effects, the main analyses excluded days with average PM_{10} concentrations greater than 150 μg/m³ (25 days). Furthermore, to assess the extent to which associations persist at lower ambient levels of air pollution, analyses were repeated restricted to days with daily averages of PM_{10} less than 100 μg/m³ or 75 μg/m³ (the European standard at the time). Finally, to assess and correct for overdispersion, or extra-Poisson variation in the data, models were repeated using negative Binomial models (i.e. an overdispersed Poisson distribution). Model fit was assessed by inspection of the overdispersion parameter, the model deviance as well as patterns and magnitude of the residuals.

Generalized Additive Models (GAM) with natural splines were used to remove long-term seasonality (starting with the practical choice of 40 degrees of freedom to capture 4 seasons over the 10 year period) and penalized cubic splines to control for possible non-linear effects of the meteorological variables on the outcome (with a maximum of 5 degrees of freedom). In order to control for short-term patterns of admissions, day of the week was included in the models as a categorical variable. Before including the air pollution variables in the model, a base model was constructed to remove seasonality i.e. long-term trend and weekly patterns. Minimising the absolute value of the sum of the partial autocorrelation function was used to assess the appropriateness of the degree of smoothing. To avoid oversmoothing and, thus, eliminating patterns due to the exposure under study, windows below 2 months were generally not considered [21]. The weather variables as well as the appropriate lags for these to include in the models were then chosen by minimizing the Unbiased Risk Estimator (UBRE) and/or the Akaike's Information Criterion (AIC). All models were checked for remaining autocorrelation by examining plots of the partial autocorrelation function and, if necessary, sensitivity of the inferences was assessed in autoregressive Poisson models. The final model controlled for long- and short-term trend, temperature on the same day as well as the two previous days (lags 1 and 2) and relative humidity on the same day. Wind speed, precipitation and barometric pressure were not considered as confounders of the association between air pollutants and hospitalization. The effect of ozone was assessed before and after controlling for the effect of PM_{10}.

Same-day and lagged exposure (up to 2 previous days) were considered. Due to lack of statistical power, distributed lag models were not considered [22]. Similarly, due to the small number of daily cause-specific admissions, analyses were only stratified by gender (all ages combined) or age (i.e. younger/older than 15 years of age). Models were repeated to include interaction terms between levels of pollutants and season to investigate evidence for effect modification either (a) during cold and warm months indexed by monthly average temperature levels or (b) on days when average daily temperature was higher or lower than 20 or 30°. Finally, where possible (i.e. cause-specific investigation), all analyses were repeated to exclude non-Nicosia residents since these may represent transfers from other hospitals and, as such, can dilute any effect since day of admission may not accurately reflect day of exposure. Data manipulation was performed in STATA SE 9.0. Analyses were performed using the MGCV package in the R software (R 2.2.0).

Results

Admissions in Nicosia hospitals nearly doubled in the 10-year period. There has been a 3-fold increase in cardiovascular admissions rising from an average of 1 in the early years to 4 towards the end, averaging at 3 daily. For respiratory causes, admissions averaged approximately 4 daily in much of the 10 years. Table 1 shows summary statistics of the daily number of all-cause and cause-specific admissions. Numbers are also shown before and after restricting to Nicosia residents. Combining all age/sex groups ensured that there would be at least 1 cause-specific admission in at least 85% of days. The low number of daily events meant that it was not uncommon for as many as 75% of days with no admissions if age- and sex-groups would be considered separately. As about 25% and 14% of those admitted for cardiovascular and respiratory cause respectively were non-Nicosia residents, the figures reduce to an average of 2.2 and 3.5 admissions daily.

Table 1 also shows the distribution of daily 24-hour average concentrations of PM_{10} and daily maximum 8-hour moving average of O_3 as measured at either station as well as daily averages of the meteorological factors considered in the models. In addition to 354 (9.7%) and 387 (10.6%) days for which no PM_{10} and O_3 were recorded at the central station respectively, an additional 81 (2.2%) and 57 (1.6%) days were excluded from the analyses as only fewer than 12 hourly measurements were available. Similarly, for the background station, around 15% of days were excluded. Daily mean levels of PM_{10} in Nicosia Central ranged from 5.0 to 1370.6 μg/m^3 (interquartile range: 40.0–64.1) with, as expected, slightly higher concentrations during the colder months. In the rural station, levels of PM_{10} ranged from 6.3 to 952.4 μg/m^3 (interquartile range: 17.0–36.3) and, in contrast to the pattern observed in the central station, appeared lower during the cold sea-

Table 1: Summary statistics for daily number of admissions, levels of air pollutants and meteorological factors in the 10-year period 1 Jan 1995–30 Dec 2004 (n = 3652 days).

A. Daily number of hospital admissions for all, cardiovascular and respiratory causes									
		Total number (% Nicosia residents)[1]	Mean	SD	Min	25%	Median	75%	Max
All causes		178 091	48.8	20.1	4	31	50	63	111
Cardiovascular[2]		10 896 (75%)	3.0 (2.2)	2.4 (1.9)	0 (0)	1 (1)	3 (2)	4 (3)	22 (11)
Respiratory[2]		14 827 (86%)	4.1 (3.5)	3.7 (3.1)	0 (0)	1 (1)	3 (2)	6 (5)	20 (18)
B. Levels of air pollutants, shown separately for cold and warm months[3]									
		Number of Days (% of total days)[4]	Mean	SD	Min	5%	Median	95%	Max
Nicosia Central									
PM_{10} 24-hour average (μg/m^3)	Cold	1553 (85.7%)	57.6	52.5	5.0	20.0	50.8	103.0	1370.6
	Warm	1664 (90.4%)	53.4	30.7	18.4	32.0	50.5	77.6	933.5
O_3 8-hour MA max (ppb)	Cold	1514 (83.6%)	28.7	12.6	3.7	9.9	27.5	50.2	63.6
	Warm	1692 (92.0%)	44.4	10.3	7.8	24.4	46.1	58.8	71.1
Ayia Marina[5]									
PM_{10} 24-hour average (μg/m^3)	Cold	918 (84.5%)	25.9	28.0	6.3	9.3	19.0	62.3	553.2
	Warm	903 (81.8%)	35.7	40.5	8.1	16.0	30.9	58.9	952.4
O_3 8-hour MA max (ppb)	Cold	1155 (80.1%)	45.7	6.8	30.2	35.1	44.6	58.4	71.0
	Warm	1247 (84.7%)	54.9	8.2	28.9	40.6	55.2	68.1	78.7
C. Meteorological factors									
Temperature	Cold	1812 (100%)	12.9	3.6	1.9	7.4	12.5	19.1	27.2
	Warm	1840 (100%)	25.8	3.9	11.8	19.0	26.3	31.4	35.5
Rel. Humidity		3591 (98.3%)	65.0	14.0	16.6	38.5	66.2	85.8	96.5
Dew Point		3591 (98.3%)	11.3	5.5	-7.6	2.4	10.8	20.4	24.2

Notes: [1] In the case of cause-specific admissions, information on residence was available allowing the analyses to be restricted to those resident in the Nicosia district; the same was not possible for all-cause admissions as only aggregated data were available. In parentheses, the proportion of Nicosia residents among total number of admissions. [2] Summary statistics when restricting numbers to Nicosia residents are shown in parentheses. [3] Cold months include Jan, Feb, Mar Apr, Nov and Dec, based on monthly average temperatures, while warm months include all the rest. [4] About 10% of the 3652 days in the 10-year study period were excluded as no data were available as well as an additional 2% of days for which only less than 12 hourly measurements were recorded. [5] PM_{10} and O_3 data from the station of Ayia Marina were available only from 1999 and 1997 onwards reducing the study period to 6 and 8 years respectively.

son since winter levels are mainly influenced by local sources. With the exception of extreme values thought to be the result of dust storms, levels of air pollutants in Nicosia were comparable to those seen in many southern European cities and exceeded the European standard of 75 μg/m^3 (at the time) between 11–57 days a year. The maximum 8-hour moving average for ozone ranged between 3.7 and 71.1 ppb (interquartile range: 26.0–48.0) in Nicosia and 28.9 and 78.7 ppb (interquartile range: 43.2–57.0) in Ayia Marina.

Table 2 presents the percentage increase in all, cardiovascular and respiratory admissions per 10 μg/m^3 increase in PM_{10} and 10 ppb increase in O_3 concentrations in Nicosia Central as estimated in single-pollutant models. For a 10 μg/m^3 increase in same-day levels of PM_{10}, there was a 0.85% (95%CI: 0.55%, 1.15%) increase in all-cause admissions. At 1.18% (95%CI: -0.01%, 2.37%) increase for every 10 μg/m^3 in PM_{10}, a stronger association, and only just short of statistical significance, was observed with admissions for cardiovascular causes. As expected, wider confidence intervals were observed after adjusting for overdispersion. However, at 0.83% (95%CI: 0.38%, 1.28%) increase in all-cause admissions and 1.19% (95%CI: -0.10%, 2.49%) in cardiovascular admissions per 10 μg/m^3 increase in PM_{10}, the magnitude of effects and, thus, inferences remain largely unaffected. Surprisingly, no overall association between levels of PM_{10} and respiratory admissions was observed. Furthermore, observed associations did not appear to be simply driven by days with the highest levels of PM_{10}; similar, if not stronger, associations were observed when analyses were restricted to days with PM_{10} concentrations less than 100 μg/m^3(N = 3133) and 75 μg/m^3 (N = 2801) – not shown in detail. Generally, no positive associations were observed with levels of PM_{10} the 2 previous days. In contrast, only effects of lagged exposure to ozone were observed. Effects appeared much stronger for cardiovascular causes, with a 2.91% (95%CI: 0.12%, 5.77%) increase for a 10 ppb increase in levels of ozone the previous day (lag 1). With the exception of a possible association in women, no overall association was observed with respiratory admissions. While it does not necessarily describe the exposure experience of the population in Nicosia, some similar associations and patterns were observed in sensitivity analyses where exposure was defined in terms of the

Table 2: Percentage increase (and 95% CI) in admissions after adjusting for long- and short-term patterns as well as the effect of weather per 10 μg/m^3 increase in PM_{10} and 10 ppb increase in O_3 concentrations in Nicosia Central.

A. Per 10 μg/m^3 increase in daily 24-hour average PM_{10} [4]

	All admissions[2] Lag 0[5]	Cardiovascular[3] Lag 0[5]	Respiratory Lag 0[5]	Cardiovascular + Respiratory Lag 0[5]
All age/sex groups	0.85 (0.55,1.15)	1.18 (-0.01,2.37)	0.10 (-0.91,1.11)	0.56 (-0.21,1.34)
Nicosia residents[1]		0.73 (-0.62,2.09)	0.25 (-0.84,1.36)	0.38 (-0.47,1.23)
Males	0.96 (0.54,1.39)	1.27 (-0.15,2.72)	-0.06 (-1.37,1.26)	0.63 (-0.34,1.62)
Females	0.74 (0.31,1.18)	0.99 (-1.11,3.14)	0.39 (-1.21,2.02)	0.59 (-0.68,1.87)
Aged <15	0.47 (-0.13,1.08)		-0.35 (-1.77,1.08)	
Aged >15	0.98 (0.63,1.33)		0.59 (-0.87,2.07)	

B. Per 10 ppb increase in daily maximum 8-hour moving average O_3

	All admissions[2] Lag 2[5]	Cardiovascular[3] Lag 1[5]	Respiratory Lag 2[5]	Cardiovascular + Respiratory Lag 2[5]
All age/sex groups	0.51 (-0.16,1.18)	2.91 (0.12,5.77)	0.44 (-1.85,2.78)	0.70 (-1.05,2.49)
Nicosia residents[1]		2.48 (-0.72,5.78)	0.73 (-1.75,3.27)	0.81 (-1.13,2.80)
Males	0.58 (-0.35,1.52)	2.70 (-0.63,6.13)	-1.76 (-4.63,1.19)	-0.00 (-2.17,2.22)
Females	0.45 (-0.50,1.41)	3.46 (-1.53,8.70)	3.89 (0.12,7.80)	1.93 (-1.03,4.97)
Aged <15	1.58 (0.25,2.92)		2.27 (-0.95,5.60)	
Aged >15	0.15 (-0.62,0.92)		-1.65 (-4.89,1.70)	

Notes: [1] After restricting the analyses to Nicosia residents. [2] Only aggregate numbers of all-cause admissions were available, thus it was not possible to restrict numbers to Nicosia residents. [3] Only includes people of adult age (15+) due to the rarity of cardiovascular events in those aged less than 15. [4] Restricted to days with daily average < 150 μg/m^3. [5] Only the lag (lag 0 = same day or lag 1, 2 = previous two days) with the strongest positive association is shown.

rural station for the reduced period for which data were available. For example, a comparable 0.81% (95%CI: 0.36%, 1.27%) increase in all-cause admissions was estimated per 10 μg/m^3 increase in same-day levels of PM_{10} as recorded in the background station. In contrast, only weak non-significant associations were observed with cause-specific admissions. Furthermore, while generally statistically non-significant, a similar pattern of lagged effects of levels of ozone at the rural station was also observed.

Figure 1 presents the percentage increase in admissions per 10 ppb increase in O_3 up to two days previously before (represented with *solid* squares) and after adjusting for same-day levels of PM_{10}(represented with *empty* squares). Associations with levels of ozone appeared independent of the effect of particles as adjustments either had no effect or only strengthened the observed associations. While associations with PM_{10} slightly attenuated in co-pollutant models, the conclusions were generally unchanged. Effects of ozone levels on cardiovascular admissions picked at lag 1 while for respiratory admissions were only apparent at lag 2 and appeared restricted to women and, possibly, the younger age-group. While it is true that multiple testing across sub-groups and at different lags might produce some statistically significant results, the observed patterns of a lagged effect appear consistent (even though non-significant) across causes and groups.

While no overall association with respiratory admissions was observed, there appeared to be some pronounced differences in effect estimates by season. Table 3 shows the percentage increase in respiratory admissions (along with p-values for effect modification) across cold and warm months. While there was no effect during the colder months, an increase of 1.80% (95%CI: -0.22%, 3.85%) on admissions per 10 μg/m^3 increase in PM_{10} was observed during the warm season. While slight short of statistical significance, there was some suggestion of effect modification by season (p-value < 0.10). The effect, if any, seemed to be restricted to people of adult age (p-value for effect modification = 0.02) and appeared much stronger in women (p-value = 0.05). In contrast, no differential effects by season were observed in the case of all-cause and cardiovascular admissions. Figure 2 presents the estimated percentage increase in all and cause-specific admissions by (a) cold and warm months, as indexed by average monthly temperature and (b) cold and warm days as indexed by mean daily temperature lower or higher than 20 or 30°. While certainly not as pronounced (or statistically significant), the pattern of differential effects on respiratory admissions was replicated when models considered cold and warm days as indexed by the average daily temperature (instead of months). In this case, some stronger (albeit not statistically significant) effects of PM_{10} on the warmest of days (temperature > 30°) were also observed on cardiovascular admissions. Any inference, however, was constrained by the wide confidence intervals around these estimates due to the small number of days with mean daily temperature higher than 30° (N = 233). As expected, an effect of ozone on respiratory admissions also appeared somewhat stronger during the warm season. The opposite, however, was observed in the case of cardiovascular admissions, with some possibly stronger effects of ozone during the colder months.

A total of 63 candidate dust storm days were identified in the period under investigation (Table 4). Amongst these, a total of 45 days with uncharacteristically high levels of PM_{10} at both stations were confirmed by meteorological records. An additional 11 days identified by the Meteorological Services as dust-storm events showed relatively usual levels of PM_{10}. With maximum hourly levels of PM_{10} in the background station only ranging between 22.63 and 66.6 across these days, these possibly describe events of a milder intensity. Finally, 7 days were identified that, while recorded as "Haze" by the Meteorological Services, these were nonetheless days when extreme values of PM_{10} were recorded at both stations. Since these were (a) either consecutive days (such as an event on 4–6 April 2000) or (b) they were days on either side of confirmed dust storms (such as 7 February 1996), they most likely depict "true" events overlooked by the meteorological observer. Hourly PM_{10} concentrations at either station during the "suspected" event of 4–6 April 2000 are shown in Figure 3. Both levels and patterns of PM_{10} during the three-day period appeared similar to those observed during the confirmed dust-storm event of 3–6 April 2003. Figure 4 shows 4-day backwards trajectories ending in Cyprus on the day/time of the four suspected dust storm events identifying the Sahara desert or the Arabian Peninsula as a likely source. Similar southerly (mainly in the spring) or easterly (mainly in the autumn) wind trajectories, generally consistent with previously described transport patterns [23], were observed on all other days.

Figure 5 plots the percentage increase in hospital admissions observed on (i) all 63 days as well as (ii) across the 56 days of confirmed events irrespective of levels of PM10 i.e. including storms of milder intensity and (iii) restricted to the 45 days of confirmed events with the highest levels of PM10. On the 63 dust-storm days, admissions were 4.8% (95%CI: 0.7%, 9.0%), 10.4% (95%CI: -4.7%, 27.9%) and 3.1% (95%CI: -10.2%, 18.3%) higher for all, cardiovascular and respiratory admissions respectively. While the observed effect achieved statistical significance only in the case of all-cause admissions, this is likely to be a result of the small number of daily events in the case of cause-specific admissions. The overall effect of dust storms on the risk of hospitalisation appeared similar in men and women, 5.7% (95%CI: 0.1%, 11.6%) and 4.0%

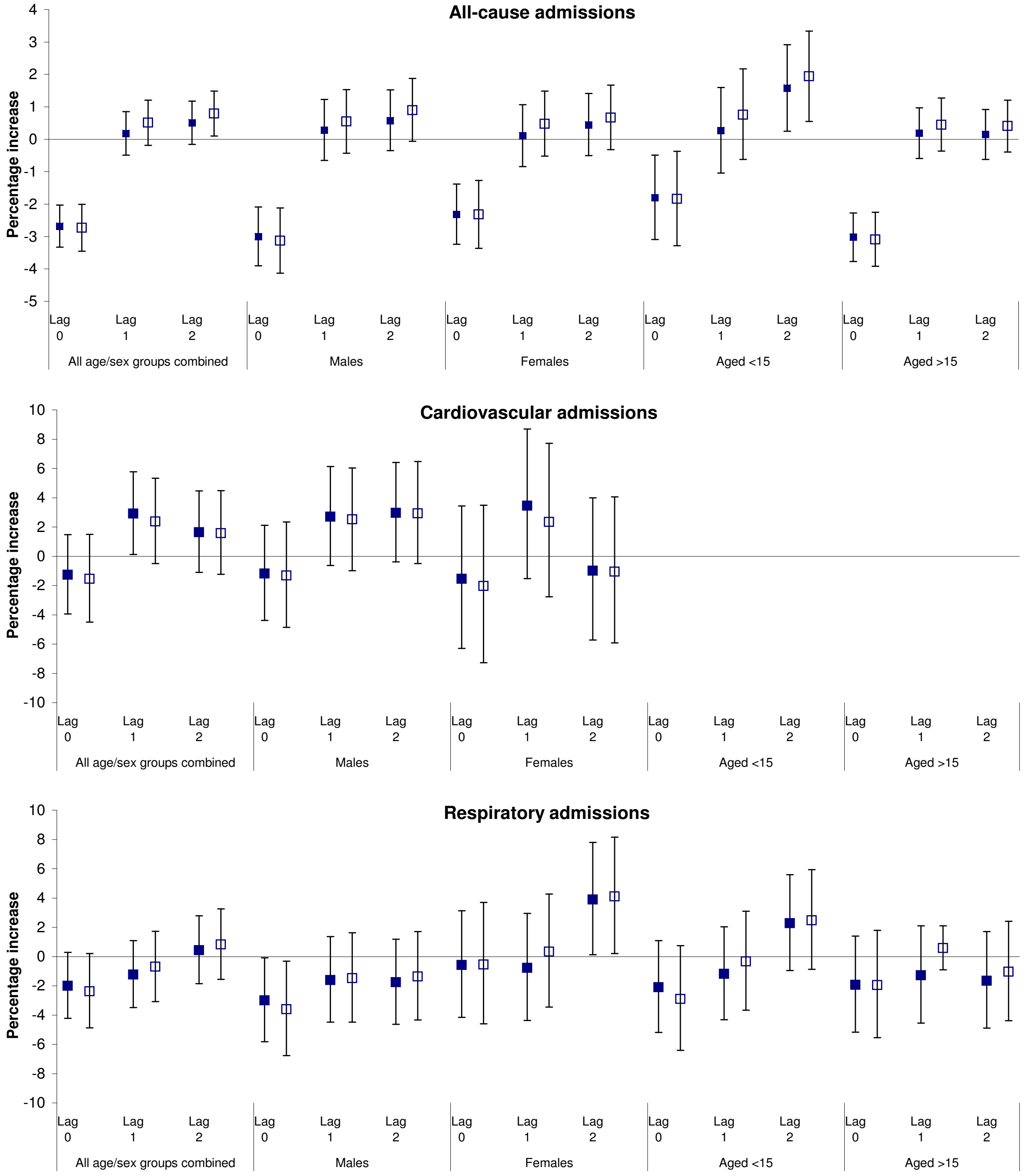

Figure 1

The effect of short-term changes in ozone concentrations on hospital admissions. Percentage increase (and 95% CI) in all, cardiovascular and respiratory admissions per 10 ppb increase in the daily maximum 8-hour moving average levels of O_3 in Nicosia Central the same (lag 0) and two previous days (lags 1 and 2) before (*solid squares*) and after (*empty squares*) controlling for levels of PM_{10} as estimated in models adjusting for long- and short-term patterns as well as the effect of weather.

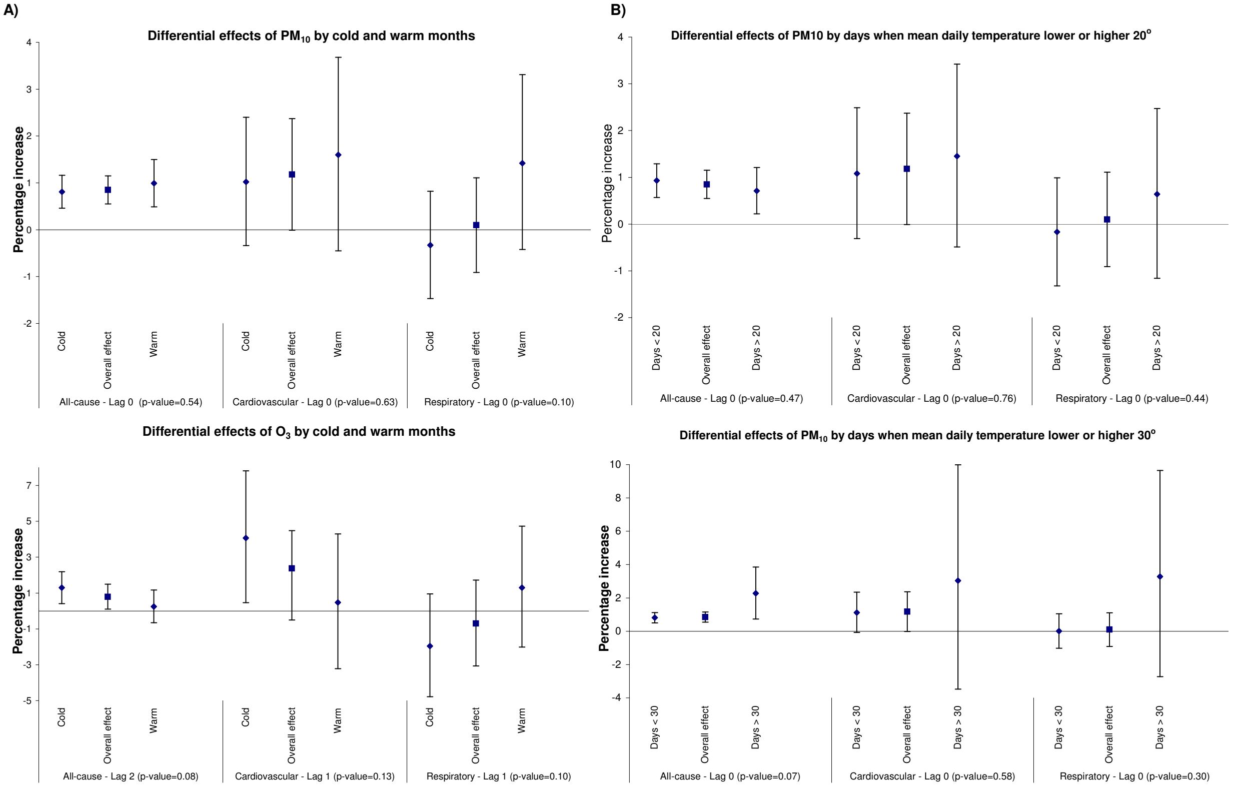

Figure 2
Seasonal effects of short-term changes in concentrations of air pollutants on hospital admissions. Percentage increase (and 95% CI) in all-cause, cardiovascular and respiratory admissions per 10 μg/m^{3}increase in PM_{10} or 10 ppb increase in O_3 (after adjusting for levels of PM_{10}) by A) cold and warm months as indexed by monthly average temperature and B) cold and warm days as indexed by mean daily temperature lower or higher than 20 or 30° (shown only for PM).

(95%CI: -1.8%, 10.1%) respectively, or in those younger/ older than 15 years of age, 5.6% (95%CI: -2.4%, 14.2%) and 4.7% (95%CI: -0.0%, 9.6%) respectively. Restricting the analyses to the 56 or 45 confirmed dust-storm days did not affect the conclusions; if anything, the effect on cardiovascular admissions appeared stronger.

For comparison purposes, figure 5 also presents the percentage increase in admissions across quartiles of non-storm days with increasing levels of PM_{10} after adjustments for seasonality and the confounding effect of weather. Stepwise increases were observed for all and cardiovascular causes, with 5.4% (95%CI: 3.6%, 7.2%) and

Table 3: Differential effects of a 10 μg/m^3 increase in PM_{10} on respiratory admissions during the cold and warm season after adjusting for long- and short-term patterns as well as the effect of weather.

	Percentage increase (and 95% CI) per 10 μg/m^3 increase in PM_{10} [1]		
	Cold months[2]	Warm months[3]	P-value for effect modification
All age/sex groups	-0.33 (-1.47,0.82)	1.42 (-0.42,3.31)	0.102
Nicosia Residents[4]	-0.22 (-1.45,1.02)	1.80 (-0.22,3.85)	0.083
Males	-0.16 (-1.76,1.46)	1.10 (-1.47,3.74)	0.397
Females	-0.26 (-2.18,1.70)	3.27 (-0.00,6.65)	0.059
Aged <15	-0.31 (-2.02,1.42)	-0.59 (-3.53,2.45)	0.872
Aged 15+	0.02 (-1.76,1.83)	3.89 (1.05,6.80)	0.018

Notes: [1] Restricted to days where daily mean PM_{10} < 150 μg/m^3.[2] [3] Cold months include Jan, Feb, Mar Apr, Nov and Dec based on monthly average temperature; warm months include all the rest. [4] After restricting the analyses to Nicosia residents.

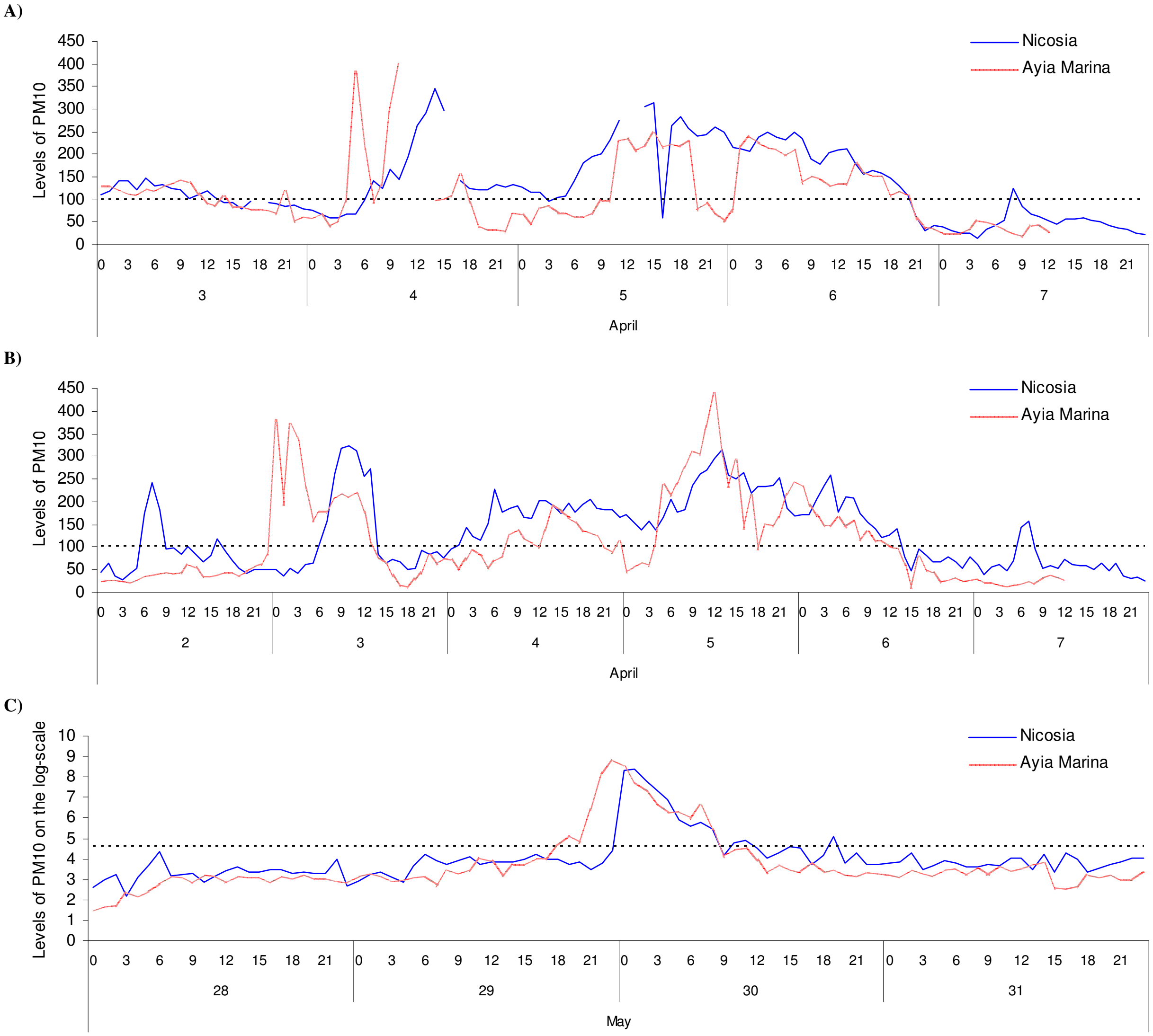

Figure 3
Typical levels of PM_{10} concentrations during a dust storm. Hourly levels of PM_{10} concentrations as recorded at Nicosia Central and Ayia Marina stations during A) a *suspected* dust storm, not confirmed by Meteorological Services records, between 4–6 April 2000, B) a dust storm confirmed by Meteorological Services records between 3–6 April 2003 and C) a confirmed dust storm with the highest recorded levels of PM_{10} (log-scale) between 29–30 May 2003.

7.1% (95%CI 0.1%, 14.6%) increased admissions respectively in the quartile of days with the highest levels of PM_{10} (>64 μg/m^3) compared to the quartile of days with the lowest levels (PM_{10} < 40 μg/m^3); in both cases, p-value for linear trend < 0.01. This was not the case with respiratory admissions, where the risk of admissions rose by 2.4% (95%CI: -3.0%, 8.2%), 4.2% (95%CI: -1.5%, 10.2%) and 2.8% (95%CI: -2.8%, 8.8%) across quartiles, at least partly explaining the lack of an overall linear association. In all cases, however, the magnitude of effects on dust-storm days appeared at least comparable to the effects seen on non-storm days with the highest PM levels.

Discussion

Main findings

Short-term changes in PM_{10} increase the risk of same-day hospitalization for all-cause and cardiovascular causes in Nicosia hospitals. An effect on respiratory health was

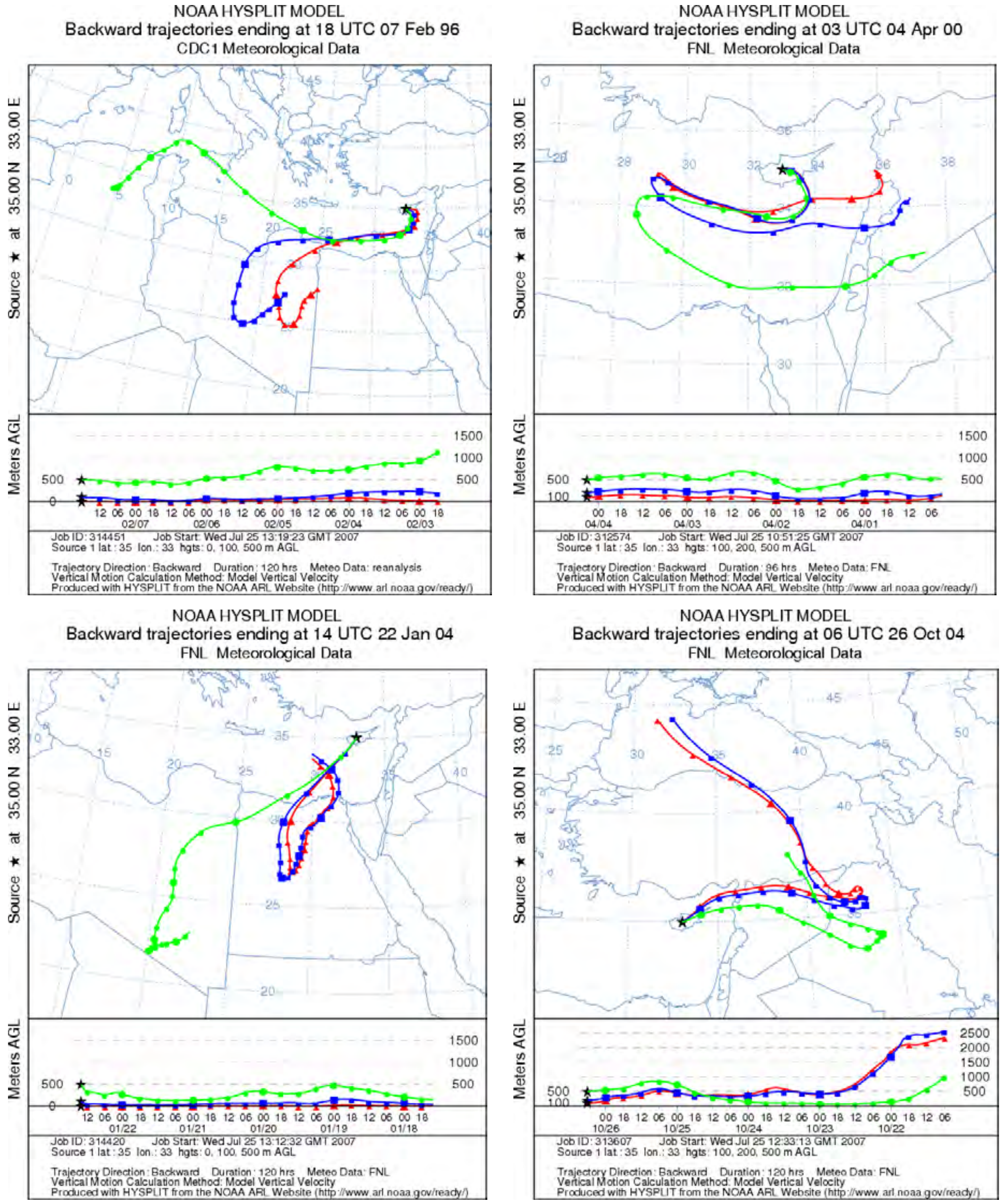

Figure 4

Identification of the likely source of dust storm events. Backwards wind trajectories ending in Nicosia on the day and about the time of the first elevated PM_{10} concentrations of the four suspected dust storm events.

Table 4: Calendar of confirmed and suspected dust-storm events as identified by either a meteorology observer at Larnaca airport and/or uncharacteristic levels of PM_{10}.

Year	Dates	Number of days	Max number of consecutive days
1995	9 Apr*	1	1
1996	7 Feb#, 8 Feb, 9 Feb	3	3
1997	22 Apr*, 8 Dec	2	1
1998	16 Mar, 27 Mar, 28 Mar, 5 Jul	4	2
1999	17 Feb*, 19 Mar, 30 Mar, 7 May	4	1
2000	4 Apr#, 5 Apr#, 6 Apr#, 13 Apr, 18 Apr, 19 Apr, 18 Nov, 30 Dec*	8	3
2001	27 Feb*, 28 Feb*, 1 Mar, 18 Apr, 19 Apr, 22 Apr, 1 May, 13 May	8	3
2002	31 Mar*, 5 Apr, 6 Apr, 15 Apr, 1 Oct*, 19 Oct, 20 Oct, 10 Nov	8	2
2003	13 Jan, 2 Feb, 18 Feb*, 2 Mar*, 18 Mar, 19 Mar, 3 Apr, 4 Apr, 5 Apr, 6 Apr, 17 Apr*, 24 Apr, 29 May, 30 May, 11 Sept, 17 Sept	16	4
2004	16 Jan, 22 Jan#, 5 Mar, 27 Mar, 7 May, 10 May, 26 Oct#, 27 Oct#	9	2
Total		**63**	**4**

Notes: * Days which were identified as dust storms by the Meteorological services but for which levels of PM_{10} were not uncharacteristically high at either station, n = 11, possibly indicating dust storms of milder intensity # Days which were not identified as dust storms by the Meteorological Services but PM_{10} were uncharacteristically high at both stations, n = 7.

observed only during the warm season. In contrast to the effects seen with same-day levels of PM_{10}, only lagged effects were observed with levels of ozone. These associations appeared independent of the effect of levels of PM_{10} and, perhaps, stronger for cardiovascular causes. More interestingly, there was also evidence to suggest that risk of hospitalization was higher on dust storm days. While a statistically significant association was observed only for overall admissions, in all cases, effects were at least comparable in magnitude to those seen on non-storm days with the highest levels of PM_{10}, particularly for cardiovascular causes.

Limitations

Several studies have shown that the effect of air pollution on hospitalization is stronger for certain cardio-respiratory conditions [24] and among certain sub-groups of the population, such as children, the elderly or people with a recent history [25-28]. The small number of daily events in a city the size of Nicosia provides limited statistical power to permit a finer age-, sex, or cause-specific analysis. This is, in fact, portrayed in the often low precision of the estimates and, thus, wide confidence intervals. Furthermore, multiple testing across sub-groups or different lags might produce some spurious associations. For this reason, the sub-group analyses were *a priori* restricted to gender (only)- and age (only)-specific comparisons and lagged exposure for up to 2 days. Due to lack of statistical power in a small sample, distributed lag models were not considered. Models investigating effect modification and non-linear effects across quartiles are only complimentary to the main analysis, nevertheless necessary, in the first case to highlight important differences by season and, in the case of the latter, to provide a basis of comparison (and a similar unit of measurement) between dust storm and non-storm days. The observed patterns appear not only internally consistent but, as a result of the long period of investigation (i.e. 10-years), the magnitude of estimates in a small city the size of Nicosia seem to be in agreement with those observed in large studies elsewhere.

As with all hospital data, there might be to some extent misclassification of the cause of admission, particularly in people with both respiratory and cardiovascular pathologies. However, it is unlikely that such misclassification is temporally related to levels of air pollutants and, thus, can only bias our estimates towards the null. With only one air quality station in Nicosia in operation for the full 10-year period of investigation, the analyses presented here are based on a single exposure series. Thus, replacing missing values in about 10% of days (and an additional 2–3% days purposefully excluded due to availability of less than 12 hourly measurements) was not possible. Nevertheless, the data series is generally longer than in similar time-series studies. Furthermore, similar patterns were observed when analyses were repeated for the reduced period for which data were available from the background station. Finally, identification of dust-storm days was mainly based on visibility observations and coding practices of a meteorological observer. Subjective in nature as it may be, a series of data-based criteria were used to validate the observations. It is likely that some dust storms, especially those of milder intensity, might have been missed out. However, it is unlikely that days with high levels of PM solely due to traffic sources were considered as dust-storm days. At any rate, the observed effect persisted

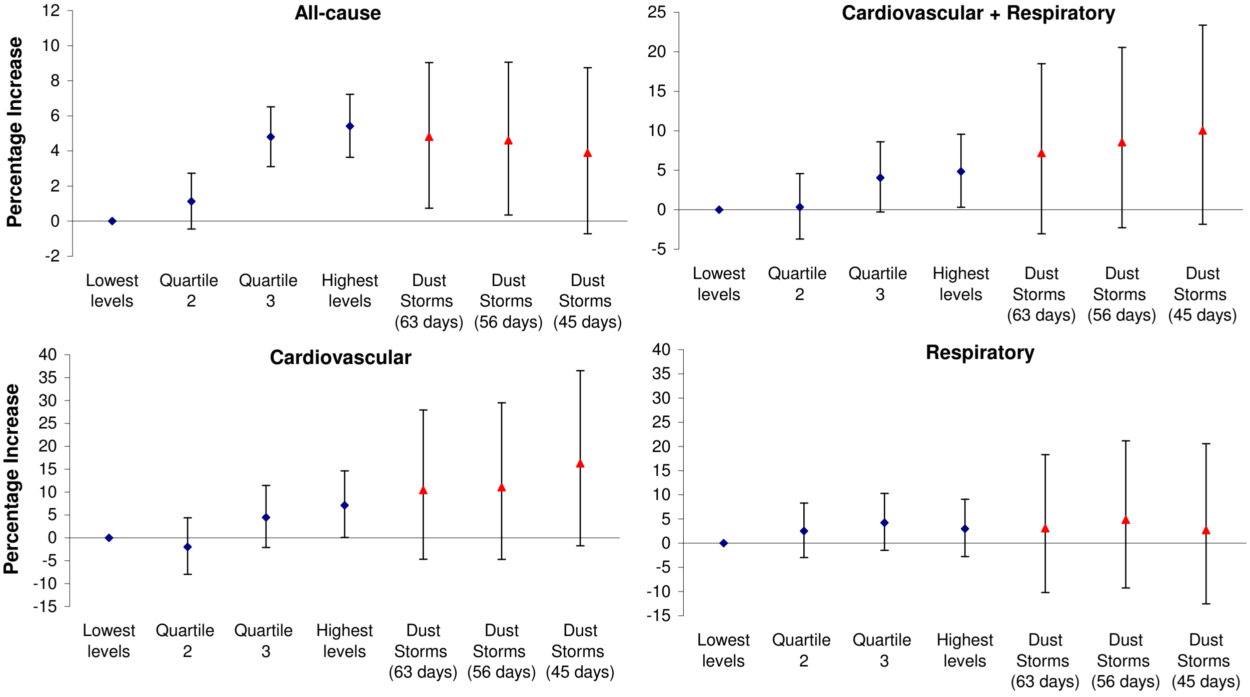

Figure 5
Hospital admissions on dust storm days as compared to non-storm days. Percentage increase (and 95% CI) in all, cardiovascular and respiratory admissions across quartiles of days with increasing levels of particulate matter (PM_{10}), compared to the quarter of days with the lowest levels, after adjusting for seasonality and the confounding effect of weather. Shown separately, the estimated percentage increase in admissions on dust-storm days (n = 63 all candidate days, 56 confirmed dates irrespective of levels of PM and 45 confirmed dates with the highest levels of PM). Note: scales are not comparable across graphs.

when restricting inferences to the group of days for which meteorological observations and measurements at the three sites were in agreement.

The effect of short-term changes in air pollutants on hospitalisation

Even though at limited power due to the small number of daily events in a city the size of Nicosia, the long period of investigation has allowed for some positive (and statistically significant) associations between levels of particulate matter and risk of hospitalization to be observed. Estimates seem consistent with the size of effects seen across several European cities, particularly for cardiovascular causes (i.e. 0.4%–1.4% per 10 $\mu g/m^3$ increase in PM) [29,30]. Surprisingly, other than the warm season, no overall effect was observed with respiratory admissions. While several studies have shown associations between levels of PM and respiratory mortality [6,10], there have been some inconsistent results in the case of hospital admissions [31], with some studies only showing associations in certain sub-groups [32] or for certain respiratory causes, such as COPD and asthma [33]. Furthermore, admissions during the colder months are mainly driven by viral respiratory infections. Even though models adjusted for the observed seasonal pattern with higher respiratory admissions in the colder season, it is possible that not explicitly controlling for these causes (due to lack of data) has masked a possible effect in the colder months, particularly in children (aged less than 15). It is also important to note that, in the case of respiratory admissions, a striking weakly pattern was observed with a large dip in admissions on Tuesdays (2 daily admissions on average) on either side of high volume on Mondays and Wednesdays (9 daily admissions). With the exception of the elderly (aged 65+), similar patterns were observed in all age and sex groups. While it was not clear whether this was due to reduced bed availability, there was some indication that people admitted on Monday were more likely to be discharged before Wednesday (42.5%) while those admitted on Wednesday were more likely to be kept until the following Monday (as many as 37% and only 13% for any longer). The extent to which this atypical weekly pattern has produced a discrepancy between actual need and admission and, thus, contributed to the lack of any strong association with overall respiratory admissions is not known.

No positive effects were observed with levels of PM_{10} the 2 previous days. While lagged or cumulative effects have commonly been observed between levels of PM and mortality in several studies [34], it is not uncommon for the strongest associations to be observed with same-day levels in the case of hospital admissions [12,35]. Perhaps, even more so in the case of Cypriot cities where, with no referral system, direct access to specialist health care may be considerably easier than in larger European or US cities. A number of person-based studies have now used average levels of air pollutants the 24 hours preceding an event (rather than same calendar day which would include hours after as well as before the event) and, at least amongst susceptible populations, have shown effects in as little as 6 hours prior to an arrhythmia and even 2 hours prior to a myocardial infarction [36-39].

In contrast to the same-day association with levels of PM, only effects of lagged exposure to ozone were observed. Negative associations with same-day levels of ozone have previously been observed in several of the 23 APHEA cities, an effect which persisted even in the summer period in at least 4 of the cities, namely Rome, Paris, Tel Aviv and Valencia [40]. While explanations for this are not clear, it is thought to be a product of the relationship between ozone (a secondary pollutant produced by photochemical reactions) and traffic-related primary pollutants such as nitrogen oxides (NO) and volatile organic compounds (VOC) which can reduce ozone concentrations at least at the local scale. Thus, high ozone concentrations in stations located in central parts of cities, such as in this case, may reflect low levels of local traffic pollutants or good dispersion conditions, which can lead to negative associations with health indicators, at least in the short-run, whereas it is common for stronger associations with ozone to be subsequently observed at lagged intervals. A similar pattern of negative same-day associations, albeit much weaker, was observed with levels of ozone as recorded at the rural station, not influenced by local pollution. Finally, while, there have generally been some inconsistent findings for the association between cardiovascular morbidity and levels of ozone, with some reporting positive [41], no or even negative associations [42], effects of a similar magnitude have been previously reported between levels of ozone two days before admission for cardiovascular causes in London [43]. In general, neither the fact that stronger associations with lagged rather than concurrent exposure nor that stronger effects for cardiovascular than respiratory admissions were observed seem inconsistent with previous findings [43-45].

Effect modification by season

Seasonal differential effects of changes in levels of air pollution on the risk of hospitalization have been previously reported, particularly with respects to stronger effects of PM on respiratory health during the warm season such as those observed here [32,43,46]. Other studies, however, have found little evidence of differential effects by season [47,48]. It is uncertain whether such differential effects carry biological plausibility, i.e. a synergistic effect of air pollution and temperature amplifying people's response to lower levels of air pollutants than normally, or it simply, reflects an increased proportion of time spent outdoors, and thus higher exposure, on warm days [49]. In APHEA, for instance, the stronger effects of PM_{10} on total mortality observed in the warmer than colder cities persisted when latitude was used instead of actual temperature, thus, it was proposed that ambient measurements in warmer places may represent the average population exposure more accurately than in colder places where people do not spend as much time outdoors [21]. Here, other than some weak evidence of strongest effects on cardiorespiratory morbidity on the warmest days (>30°), generally, more pronounced differential effects were observed across cold-warm months rather than across cold-warm days (based on daily mean temperature).

In the light of evidence of ozone effects on mortality restricted to the warm season across 23 APHEA cities, the stronger association between cardiovascular admissions and ozone during the colder season observed here appears surprising [40]. However, some similar patterns have been observed elsewhere, particularly amongst the elderly [50]; possible explanations for this pattern are unclear and it might simply be a chance finding. Nonetheless, in a recent cross-sectional study in Korea, it was reported that measures of blood pressure, a risk factor for cardiovascular disease, were significantly associated with PM_{10} levels only in the warm season while the reverse was true for O_3, with associations only during the cold season [51].

The effect of dust storms

Long-range transport of Saharan dust across the Mediterranean into southern Europe [52,53], and less frequently as far north as the British Isles [54], is well established. Consistent with a recent examination of these events [23], our analysis also suggests that there has been a rise in their frequency, at least half of which seem to occur during the spring months and can last for as many as four consecutive days. Unlike the mineral and chemical composition as well as transport patterns of Saharan dust, the possible health effects of these natural events have not been extensively studied. There is some modest evidence from Taiwan and Korea of adverse effects of wind-blown dust from the Mongolia/China desert on both cardiovascular and respiratory health, some times lasting for up 3 days after the event [55-57]; reported associations were, however, not always statistically significant.

In contrast, a study of 17 episodes with a high concentration of coarse (crustal-derived) but not fine particles during a six-year period in Spokane, Washington, revealed no evidence of an increased risk of death on dust days [14]. Similarly, an investigation into an unusual event of transported dust over the Atlantic to Greater Vancouver, Canada, has shown no effect on hospital admissions [58]. Some studies have, in fact, reported strengthening of the observed health effects when windblown dust days were excluded from the analyses [59] or reduced health effects on windy days [60], in both cases suggestive that crustal-derived particles are more benign that those from anthropogenic processes. In our analyses, we have not observed an attenuation of effects by including dust-storm days. On the contrary, we found evidence of increased admissions on dust-storm days of similar magnitude to the effects seen on non-storm days with the highest concentrations. Of course, the possibility of air-borne dust containing particles of anthropogenic sources can not be excluded since mega-cities, such as Cairo, are commonly on the path of these events. Alternatively, some support for the adverse effects of particles due to natural sources observed here comes from a recent study of the biological content in dust transferred to Haifa, Israel during similar events in 2004–2005 that revealed both an increase in the concentration of airborne microorganisms and a change in the usual content of fungal population in PM samples, both which are thought to affect human health [19]. Similar findings have been reported from aeromicrobiological analyses of samples on the Turkish coastal town of Erdemli [61].

Conclusion

We observed an increased risk of hospitalization at elevated levels of particulate matter and ozone generally consistent with the magnitude seen across several European cities. Interestingly, we also observed an increased risk of hospitalization on dust storm days, particularly for cardiovascular causes. While inference from these associations is limited due to the small number of dust storm days in the study period, these effects did not appear to be an artifact of including days of high traffic pollution. While these represent non-preventable events, with a magnitude of effects at least comparable to those on days with the highest levels of PM_{10} from traffic sources, such events may merit special health warnings directed to the most vulnerable population groups.

List of abbreviations

$\mu g/m^3$: Micrograms per cubic metre; AIC: Akaike information criterion; APHEA: The Air Pollution and Health: a European Approach Project; CI: Confidence Interval; ICD: International Classification of Diseases; HYSPLIT: Hybrid Single-Particle Lagrangian Integrated Trajectory; GAM: Generalized Additive Models; NMMAPS: The National Morbidity, Mortality and Air Pollution Study; NOAA: National Oceanic and Atmospheric Administration; O_3: Ozone; PM_{10}: Particulate matter with aerodynamic diameter less than 10 microns; ppb: parts per billion; SD: Standard deviation; TEOM: Tapered Element Oscilling Micro-balance; UBRE: Unbiased Risk Estimator.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

PY, PD and PK conceived and secured funding for the study from the Cyprus Ministry of Health. PY, NM and OK collected the data. NM compiled the data and performed the statistical analyses. PK, JS and DD provided guidance and statistical advice. All authors assisted in the interpretation of results. NM wrote the first draft of this paper. All authors contributed towards the final version. All authors read and approved the final manuscript.

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