South Coast AQMD

Proposed Amended Rule 1135

Emissions of Oxides of Nitrogen from Electric Power Generating Systems

Working Group Meeting #3

June 13, 2018

Agenda

- Summary of Working Group Meeting #2
- Continue BARCT analysis
  - Technology assessment
  - Establishing BARCT emission limits
  - Cost-effectiveness
- Initial Rule concepts

Previous Working Group Meeting

- Updated status of individual stakeholder meetings
- Presented 2016 emissions data by equipment category
- Discussed initial BARCT analysis
  - Identified emission levels of existing units
  - Assessed rules in other districts
- Provided initial rule concepts for Applicability and Emission Limits

BARCT Analysis

BARCT Analysis Approach

1. *Identify Emission Levels for Existing Units* ✓
2. *Assess Rules in Other Air Districts Regulating Same Equipment* ✓
3. Technology Assessment
4. Establishing the BARCT Emission Limit and Other Considerations
5. Cost-Effectiveness

Technology Assessment

Overview of Technology Assessment

Assessment of SCAQMD Regulatory Requirements

Assessment of Emission Limits for Existing Units

Other Regulatory Requirements

Assessment of Pollution Control Technologies

Assessment of Pollution Control Technologies

- Assessed technological feasibility of NOx controls for
  - Gas turbines
  - Utility boilers
  - Non-emergency internal combustion engines
- Sources researched for assessment
  - Scientific literature
  - Vendor information
  - Strategies utilized in practice

NOx Control Technologies for Gas Turbines

Combustion Controls	Post-Combustion Controls
Dry Low-NOx Combustors*	Selective Catalytic Reduction*
Steam/Water Injection*	Catalytic Absorption Systems
Catalytic Combustion	

* Primary control approaches

NOx Control Technologies for Utility Boilers

Combustion Controls	Post-Combustion Controls
Low-NOx Burners*	Selective Catalytic Reduction*
Flue Gas Recirculation	Selective Non-Catalytic Reduction
Overfire Air	
Staged Fuel Combustion	
Burners Out of Service	

* Primary control approaches

NOx Control Technologies for Internal Combustion Engines

Combustion Controls	Post-Combustion Controls
Air-Fuel Ratio	Selective Catalytic Reduction*
Turbocharged/Aftercooled	Selective Non-Catalytic Reduction
Fuel Injection or Spark Timing	Non-Selective Catalytic Reduction
Exhaust Gas Recirculation	Non-Thermal Plasma
Pre-Stratified Charge	

* Primary control approach

Summary of Primary NOx Control Technologies

Control Technique	Equipment Type
Selective Catalytic Reduction	Gas turbines, utility boilers, and internal combustion engines (diesel)
Dry Low-NOx Combustors	Gas turbines
Steam/Water Injection	Gas turbines
Low-NOx Burners	Utility boilers

- Control techniques may be combined to increase overall NOx reduction achieved

Selective Catalytic Reduction (Turbines, Boilers, and Engines)

- Primary post-combustion NOx control technology[1]
  - Used in turbines, boilers, internal combustion engines (including heavy duty trucks), and other NOx generating equipment
  - One of the most effective NOx abatement techniques
- Ammonia is injected into the exhaust gas, which passes through the catalyst reactor, resulting in the reduction of NH_3 and NOx to N_2 and H_2O
  - Can reduce NOx to 95% or more
    - Turbines: 2 ppm
    - Utility boilers: 5 ppm
    - Internal combustion engines (diesel): 0.5 g/bhp-hr

[1] https://www.epa.gov/sites/production/files/2017-12/documents/scrcostmanualchapter7thedition_2016revisions2017.pdf

Selective Catalytic Reduction *(continued)*

- Disadvantages
  - Requires on-site storage of ammonia, a hazardous chemical
    - Pure anhydrous ammonia is extremely toxic and no new permits issued
    - Aqueous ammonia is somewhat safer; higher storage and shipping costs
    - Urea is safer to store; higher capital costs
  - Has the potential for ammonia slip, where unreacted ammonia is emitted
  - Limited by its range of optimum operating temperature conditions (e.g., 400 to 800˚F for conventional SCR)
  - Catalyst susceptible to "poisoning" if flue gas contains contaminants (e.g., particulates, sulfur compounds, reagent salts, etc.)
  - Facilities may be space constrained to add more catalyst modules

Dry Low-NOx Combustors (Turbines)

- Prior to combustion, gaseous fuel and compressed air are pre-mixed, minimizing localized hot spots that produce elevated combustion temperatures and therefore, less NOx is formed
  - Control NOx to 9 ppm
- Disadvantages
  - Requires that the combustor becomes an intrinsic part of the turbine design
  - Not available as a retrofit technology; must be designed for each turbine application

Water or Steam Injection (Turbines)

- Injection of water or steam into the flame area, lowering the flame temperature and reducing NOx formation
  - NOx is reduced by at least 60%
  - Controls NOx to <u>25 ppm</u>
- Addition of water or steam increases mass flow through the turbine and creates a small amount of additional power
- Disadvantages
  - Water needs to be demineralized, which adds cost and complexity
  - Increases CO emissions

Low-NOx Burners (Boilers)

- Controls fuel and air mixing at the burner reducing the peak flame temperature and therefore, less NOx is formed
  - Control NOx levels to 30 ppm (Ultra-Low-NOx Burners to 7 ppm)
- Disadvantages
  - Retrofits to an existing boiler may require complex engineering and design

Summary of Primary NOx Control Technologies

Control Technique	Equipment Type	NOx Levels (ppm)
Selective Catalytic Reduction	Turbines	2
	Utility Boilers	5
	Internal combustion engines (diesel)	0.5 g/bhp-hr
Dry Low-NOx Combustors	Turbines	9
Steam/Water Injection	Turbines	25
Low-NOx Burners	Utility Boilers	7

Summary of Combined NOx Control Technologies

Equipment Type	Combined Control Technologies	NOx Levels (ppm)
Gas Turbines	SCR/Water Injection	2
	SCR/Dry Low-NOx Combustor	2
Utility Boilers	SCR/LNB	5

BARCT Analysis Approach

Identify Emission Levels for Existing Units ✓

Assess Rules in Other Air Districts Regulating Same Equipment ✓

Technology Assessment ✓

Establishing the BARCT Emission Limit and Other Considerations

Cost-Effectiveness

Establishing the BARCT Limit

Establishing the BARCT Limit

- Recommended BARCT limits are established using information gathered from:
  - Existing units
  - Other regulatory requirements
  - BACT requirements
  - Technology assessment

Simple Cycle Natural Gas Turbines

	Existing Units	Other Regulatory Requirements	Technology Assessment	BARCT Recommendation
Retrofit	9.0 ppm	5-25 ppm*	2.5 ppm	2.5 ppm
New Install	2.5 ppm	2.5-25 ppm*	2.5 ppm	2.5 ppm

* Limit dependent on capacity

Combined Cycle Natural Gas Turbines

	Existing Units	Other Regulatory Requirements	Technology Assessment	BARCT Recommendation
Retrofit		5-25 ppm*	2.0 ppm	2.0 ppm
New Install	2.0 ppm	2.0-25 ppm*	2.0 ppm	2.0 ppm

* Limit dependent on capacity

Utility Boilers

	Existing Units	Other Regulatory Requirements	Technology Assessment	BARCT Recommendation
Retrofit	5.0 ppm	6.0 ppm	5.0 ppm	5.0 ppm
New Install	5.0 ppm	5.0 - 6.0 ppm	5.0 ppm	5.0 ppm

Non-Emergency Internal Combustion Engines

	Existing Units	Other Regulatory Requirements	Technology Assessment	BARCT Recommendation
Retrofit	82 ppm	56 - 140 ppm		0.5 g/bhp-hr*
New Install	51 ppm	0.5 g/bhp-hr*	0.5 g/bhp-hr*	0.5 g/bhp-hr*

* 0.5 g/bhp-hr is approximately 45 ppm (assuming 40% efficiency)

Summary of BARCT Recommendations

- Limits may be met by retrofit or replacement

Equipment Type	NOx Limit
Simple Cycle Turbine	2.5 ppm
Combined Cycle Turbine	2.0 ppm
Utility Boiler	5.0 ppm
Non-Emergency Internal Combustion Engine (diesel)	0.5 g/bhp-hr

BARCT Analysis Approach

1. *Identify Emission Levels for Existing Units* ✓
2. *Assess Rules in Other Air Districts Regulating Same Equipment* ✓
3. *Technology Assessment* ✓
4. *Establishing the BARCT Emission Limit and Other Considerations* ✓
5. Cost-Effectiveness

Cost-Effectiveness

Cost-Effectiveness

- Threshold is \$50,000/ton NOx reduced
- Calculated using Discounted Cash Flow Method
  - Cost Effectiveness = Present Value / Emissions Reduction Over Equipment Life
  - Present Value = Capital Cost + (Annual Operating Costs * Present Value Formula)
  - Present Value Formula = $(1 - 1/(1 + r)^n)/ r)$
    - $r = (i - f)/(1 + f)$
    - i = nominal interest rate
    - f = inflation rate

NOx Limits Evaluated for Cost-Effectiveness

Equipment Type	NOx (ppm)
Simple Cycle Turbine	2.5
Combined Cycle Turbine	2.0
Utility Boiler	5.0
Non-Emergency Internal Combustion Engine (diesel)	45*

* 0.5 g/bhp-hr is approximately 45 ppm (assuming 40% efficiency)

Estimated Emissions Inventory and Reductions

- Baseline Emissions
  - Determined by using reported fuel consumption and permit emission limit
- PAR 1135 Emissions
  - Determined by using reported fuel consumption and proposed emission limit
- Emission Reductions = Baseline Emissions - PAR 1135 Emissions

Cost Estimates for Gas Turbines and Utility Boilers

- Retrofit costs determined using U.S. EPA's Air Pollution Control Cost Estimation Spreadsheet for Selective Catalytic Reduction[1]
  - Methodology based on U.S. EPA Clean Air Markets Division Integrated Planning Model
  - Size and costs of SCR based on size, fuel burned, NOx removal efficiency, reagent consumption rate, and catalyst costs
  - Capital costs annualized over 25 years at 4% interest rate
  - Annual MW output based on 2016 annual reported emissions
  - Values reported in 2015 dollars
- Stakeholders are welcome to provide staff with their own costs and cost effectiveness calculations

[1] https://www.epa.gov/sites/production/files/2017-12/documents/scrcostmanualchapter7thedition_2016revisions2017.pdf

Simple Cycle Natural Gas Turbines

- 30 of 75 simple cycle natural gas turbines have permitted NOx limits greater than proposed NOx limit of 2.5 ppm
  - Evaluated cost-effectiveness at the proposed NOx limit
    - 1 unit permitted at 3.5 ppm NOx
    - 25 units permitted at 5 ppm NOx
      - Presenting lowest use and highest use units
    - 2 units permitted at 9 ppm NOx
      - Evaluated only 1 unit, second unit currently not in commission
    - 2 units permitted at 24 ppm NOx

Emissions and Cost-Effectiveness for Simple Cycle Natural Gas Turbines

Input (MM Btu/hr)	Output (MW)	Annual NOx Emissions (tons)	Estimated MWh/yr	%Capacity	NOx Permit Limit (ppm)	Capital Cost (millions)	Operating Cost (millions)	Emission Reductions (tons)	Cost-Effectiveness
69.12	6	0.06	120	0.23	24	1.6	0.12	0.041	$3,435,688
69.12	6	0.13	240	0.46	24	1.6	0.12	0.082	$1,718,448
298	31	0.09	270	0.10	9	4.7	0.34	0.08	$5,119,056
448	47	8.91	40,000	9.6	5	6.1	0.47	4.46	$103,862
450	45	1.24	4,000	0.99	5	6.2	0.44	0.90	$588,226
457	48	0.49	1,500	0.36	3.5	7.9	0.74	0.03	$26,566,828

Cost-Effectiveness for Simple Cycle Natural Gas Turbines

- Cost-effectiveness evaluated for each permit limit
- At current use levels, cost-effectiveness exceeds $50,000 per ton
- Current average use levels for simple cycle turbines above BARCT limit are approximately 1% of MWH capacity
  - Highest unit is < 10% MWH capacity
- Considering low use exemptions based on cost-effectiveness capacity thresholds

Combined Cycle Gas Turbine

- 9 of 28 combined cycle natural gas turbines have permitted NOx limits greater than proposed NOx limit of 2.0 ppm
  - Evaluated cost-effectiveness at the proposed NOx limit
    - 3 units permitted at 2.5 ppm NOx
    - 2 units permitted at 7 ppm NOx
    - 1 units permitted at 7.6 ppm NOx
    - 3 units permitted at 9 ppm NOx

Emissions and Cost-Effectiveness for Combined Cycle Natural Gas Turbines

Input (MM Btu/hr)	Output (MW)	Annual NOx Emissions (tons)	Estimated MWh/yr	%Capacity	NOx Permit Limit	Capital Cost (Millions)	Operating Cost (millions)	Emission Reductions (tons)	Cost-Effectiveness
258.6	32	1.1	32,000	11%	2.5	$4.8	$0.3	0.2	$2,086,891
1805	290*	32.8	900,000	35%	2.5	$20.1	$1.6	6.8	$274,577
1805	290*	35.3	1,000,000	39%	2.5	$20.1	$1.6	7.5	$250,777
1088	182	12.1	60,000	4%	7	$14.8	$1.1	7.8	$169,744
1088	182	8.9	40,000	3%	7	$14.8	$1.1	5.2	$253,696
442	48	4.3	35,000	8%	7.6	$6.2	$0.5	3.2	$97,935
350	30	0.8	6,000	2%	9	$4.6	$0.3	0.6	$669,774
350	60	0.5	4,000	1%	9	$7.2	$0.5	0.4	$1,579,869
350	60	0.5	4,000	1%	9	$7.2	$0.5	0.4	$1,579,869

* Includes associated duct burner

Cost-Effectiveness for Combined Cycle Natural Gas Turbines

- Cost-effectiveness evaluated for each permit limit
- At current use levels, cost-effectiveness exceeds $50,000 per ton
- For 2.5 ppm combined cycle turbines, Cost-effectiveness threshold never reached, even when use is at 100%
- Current average use levels for combined cycle turbines above BARCT limit are approximately 3% of MWH capacity
  - Highest unit is < 10% MWH capacity
- Considering exemption for combined cycle turbines permitted at 2.5 ppm
- Considering low use exemptions based on cost-effectiveness capacity thresholds

Utility Boilers

- 17 of the 24 utility boilers are scheduled for repowering due to once-through-cooling (OTC) policy by 2029 at the latest
- 7 utility boilers remaining
  - 2 units meet the proposed NOx limit of 5 ppm
  - Evaluated cost-effectiveness for the remaining 5 units at the proposed NOx limit of 5 ppm
    - Current permit limits (ppm): 7, 7, 28, 40, and 82

Emissions and Cost-Effectiveness for Utility Boilers

Input (MM Btu/hr)	Output (MW)	Annual NOx Emissions (tons)	Estimated MWh/yr	%Capacity	NOx Permit Limit (ppm)	Capital Cost (millions)	Operating Cost (millions)	Emission Reductions (tons)	Cost-Effectiveness
2900	320	1.0	34,000	1.2%	7	$21	$1.6	1.0	$1,873,220
2900	320	1.2	39,000	1.4%	7	$21	$1.6	1.2	$1,561,668
527	44	12	23,000	6.0%	38	$5.9	$0.45	12	$45,991
260	20	3.3	6,200	3.5%	40	$3.5	$0.26	3.3	$94,424
492	44	8.8	7,600	2.0%	82	$5.9	$0.45	8.8	$59,804

Cost-Effectiveness for Utility Boilers

- Cost-effectiveness evaluated for each permit limit
- Calculated a capacity threshold for $50,000 cost-effectiveness

NOx Permit Limit (ppm)	Average Capacity (%)	Average Cost-Effectiveness ($/ton reduced)	Capacity Threshold for Cost-Effectiveness (%)
7	1.3	$1.7 million	40
38	6.0	$45,991	5
40	3.5	$94,424	6
82	1.97	$59,804	2.01

Summary of Cost-Effectiveness for Utility Boilers

- 2 of the units have cost-effectiveness < $50,000 per ton reduced at current use
  - 7 ppm utility boilers
    - Cost-effectiveness threshold reached when use is greater than 40%
  - 38 ppm utility boiler
    - Cost-effectiveness threshold reached when use is greater than 5%
  - 40 ppm utility boiler
    - Cost-effectiveness threshold reached when use is greater than 6%
  - 82 ppm utility boiler
    - Cost-effectiveness threshold reached when use is greater than 2%
- Considering low use exemptions based on cost-effectiveness capacity thresholds

Cost Estimates for Non-Emergency Internal Combustion Engines (Diesel)

- Replacement cost for a 2800 kW (4,000 BHP) EPA Tier 4 certified engine (meets 0.5 g/bhp-hr NOx) is approximately $3.9 million
  - Engine replacement and exhaust after treatment: $2.1 million
  - Generator set refurbishment and testing: $0.3 million
  - Removal and transportation: $0.5 million
  - Infrastructure: $1 million
  - Operating costs: Assumed to be unchanged

Emissions and Cost-Effectiveness for Non-Emergency Internal Combustion Engines (Diesel)

- Evaluated cost-effectiveness for all 6 engines at the proposed NOx limit of 45 ppm (0.5 g/bhp-hr is approximately 45 ppm, assuming 40% efficiency)

Size (BHP)	Annual NOx Emissions (tons)	NOx Permit Limit (ppm)	Capital Cost (million)	Emission Reductions (tons)	Cost Effectiveness ($/ton NOx)
1575	16	140	$3.9	9.9	$14,826
1950	5.3	103	$3.9	2.7	$52,034
2150	8.2	97	$3.9	3.9	$35,414
1500	12	97	$3.9	5.6	$24,768
2200	22	82	$3.9	8.4	$15,520
3900	5.9	51	$3.9	0.7	$224,221

Summary of Cost-Effectiveness for Non-Emergency Internal Combustion Engines (Diesel)

- Proposed NOx limit of 0.5 g/bhp-hr is cost-effective for 5 of the 6 units
  - Average (excluding 51 ppm unit): $22,757/ton NOx

Rule Concepts

Emission Limits

Equipment Type	Proposed Limit
Non-Emergency Internal Combustion Engines (Diesel)	0.5 g/bhp-hr
Boilers	5.0 ppm
Simple Cycle	2.5 ppm
Combined Cycle	2.0 ppm

- Limits averaged over one hour
- Effective date still under consideration
- Considering exemption for units with permitted limits near BARCT limits
- Considering low use exemptions based on cost-effectiveness capacity thresholds
- Considering replacement requirement for equipment older than 25 to 35 years

Monitoring and Testing

- Monitoring is critical to ensure equipment is operating properly
- Retain continuous emission monitoring and Relative Accuracy Test Audit (RATA) requirements
  - Update Continuous Emission Monitoring Systems (CEMS) Requirements Document for Utility Boilers
  - Remove monitoring requirements for data no longer necessary to determine compliance including volumetric flow, heat input rate, and net MWH produced
  - Add monitoring requirements for ammonia

Data Acquisition

- Retain data acquisition system requirements
  - NOx emission rate (ppm)
  - O2 concentration (ppm)
  - Ammonia (ppm)

Recordkeeping and Reporting

- Current requirements
  - Compliance plan
  - Monthly reporting
  - RECLAIM requirements
- Proposed Requirements
  - Require records maintained and made available upon request for five years

Tentative Schedule

July 2018	Next Working Group Meeting
Summer 2018	Public Workshop
Fall 2018	Stationary Source Committee
Fall 2018	Set Hearing
Fall 2018	Public Hearing

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