APPENDIX C

COST EFFECTIVENESS ANALYSIS FOR PROPOSED AMENDMENTS TO RULE 4306 AND RULE 4320

November 25, 2020

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APPENDIX C
COST EFFECTIVENESS ANALYSIS

I. INTRODUCTION

The California Health and Safety Code 40920.6(a) requires the San Joaquin Valley Unified Air Pollution Control District to conduct both an "absolute" cost effectiveness analysis and an incremental cost effectiveness analysis of available emission control options prior to adopting each Best Available Retrofit Control Technology (BARCT) rule. The purpose of conducting a cost effectiveness analysis is to evaluate the economic reasonableness of the pollution control measure or rule. The analysis also serves as a guideline in developing the control requirements of a rule.

II. SUMMARY AND CONCLUSION

A. Absolute Cost Effectiveness Analysis

Absolute cost effectiveness examines the cost of reaching the proposed emission limits using the current emissions as a baseline. Cost effectiveness is calculated as the added annual cost (in $/year) of a control technology or technique, divided by the emission reduction achieved (in tons reduced/year). The annual costs include annualized capital equipment costs and engineering design costs plus the annual labor and maintenance costs. Higher cost numbers are typically for smaller, low-use units since the annual costs result in relatively lower emission reductions. The analysis shows that the cost effectiveness values improve for larger units, units with a higher operating capacity factor, and more restrictive NOx limits relative to the current limits.

The detailed analyses showing the costs for installed capital equipment, electricity, fuel, and operations and maintenance costs are shown in Tables C-2 to C-40. Results are summarized in Table C-1, below. Rule 4306 establishes NOx limits that units must achieve to operate in the District and are based on technologic and economic feasibility. The Rule 4320 Advanced Emission Reduction Option (AERO) limits are meant to be the most stringent technologically feasible options but may not be economically feasible for all units to achieve. The controls required to reach the final NOx emission levels are either Selective Catalytic Reduction (SRC) or Ultra-Low NOx Burners (ULNB). As summarized in Table 1, cost for these controls can be very high and implementation may not be possible due to space limitations that would prevent installation of the control equipment. As discussed in the Staff Report, an option for operators to pay a lower-cost emission fee is included in the rule to mitigate the economic feasibility of the proposed limits.

Table C-1 Cost Effectiveness Summary

Compliance Scenario	Average Cost Effectiveness ($/ton)	Absolute Cost Effectiveness Range ($/ton)
RULE 4306		
ULNB (15 ppmv to 7 ppmv)	$54,700	$49,800 to $62,900
Tuning (9 ppmv to 7 ppmv)	$72,700 to 84,000	$57,600 to $100,700
ULNB (15 ppmv to 9 ppmv)	$72,600	$66,100 to $83,500
Tuning (12 ppmv to 9 ppmv)	$65,600	$55,700 to $82,400
ULNB (12 ppmv to 9 ppmv)	$106,500	$93,900 to $128,300
SCR (9 ppmv to 5 ppmv)	$22,000 to $52,000	$2,100 to $70,100
SCR (7 ppmv to 5 ppmv)	$44,100 to $104,000	$4,200 to $140,200
Oil Field Steam Generator (15 ppmv to 9 ppmv)	$43,100 to $106,000	$43,100 to $118,500
Refinery Boilers (25 ppmv to 9 ppmv)	$27,600	$27,300 to $28,000
Refinery Heaters (30 ppmv to 15 ppmv)	$13,000	$12,000 to $15,200
RULE 4320		
SCR (9 ppmv to 2.5 ppmv)	$13,400 to $66,100	$1,300 to $145,900
SCR (7 ppmv to 2.5 ppmv)	$19,300 to $94,900	$1,800 to $209,600
Oil Field Steam Generator (7 ppmv to 5 ppmv)	$50,600	$50,600
Existing SCR Modification (5 ppmv to 2.5 ppmv)	$13,200 to $14,900	$10,000 to $17,400

Note: The Average Value is the average for the range of units with a spread indicating the different fuel usages that were analyzed. The Absolute Value is the lowest and highest values calculated under that compliance scenario and typically represent the cost for a large, high-use unit and a small, low-use unit. All values were rounded to two significant digits due to uncertainty in the data and variations between units.

B. Incremental Cost Effectiveness

Incremental cost effectiveness (ICE) indicates the additional cost for further controlling a unit from the proposed limit to the lowest possible level. Costs are evaluated similar to absolute costs but are only calculated for the controls and reductions beyond what is required to comply with the rule. ICE does not reveal the emission reduction potential of the control options, but examines the more stringent options which were not considered to be cost effective. Due to the increased costs and marginal emission reductions, the ICE calculations are typically much higher cost effectiveness than the absolute cost effectiveness values are not directly comparable.

The incremental cost effectiveness analysis result would be similar to those shown in Tables C-2 through C-40. For the ICE analysis, the emission reduction is the difference between the current rule NOx limits to proposed NOx limits. Those tables show that the cost-effectiveness for the smaller units.

III. SOURCES OF COST DATA

District staff used cost information provided by control equipment manufacturers and vendors, and from stakeholders to conduct a cost effectiveness analysis of the proposed NOx limits in Proposed Rules 4306 and 4320. Specifically the data used in the analysis came from the following sources:

1. R.F. MacDonald Company
2. Nationwide Boiler
3. Esys The Energy Controls Company
4. PCL Industrial Services, Inc
5. Aera Energy LLC.
6. Zeeco, Inc.
7. Honeywell International Inc. (Callidus Technologies)
8. Kern Oil & Refining Co.
9. Western States Petroleum Association
10. Bakersfield Renewable Fuels, LLC

Cost information submitted to the District was used to create the range of costs located in Tables C-1 through C-40.

IV. COST EFFECTIVENESS ANALYSIS PROCEDURE

A. Cost Effectiveness Analysis Procedure

To illustrate the cost effectiveness of complying with the proposed limits, District staff's analysis provides varying cost effectiveness values depending on the size of the unit and the annual capacity factor that the unit is operated. The actual compliance costs and cost effectiveness values would depend on several factors such as the type of unit, site-specific operating conditions, and the appropriate emission limits the unit has to meet.

B. Absolute Cost Effectiveness (ACE) Calculation Method

The absolute cost effectiveness of a control technology is calculated as follows:

1. Determine an equivalent annual equipment cost using a capital recovery factor based on an assumed interest rate of 10 percent and equipment life of 10 years. The annualized capital equipment cost is calculated by multiplying the installed capital equipment cost by the capital recovery factor of 0.163.
2. Determine the annual electricity, fuel, and operation and maintenance costs of a control technology.
3. Calculate the annual cost by adding the costs calculated in Step 1 and Step 2.
4. Calculate the emission reduction in tons/year.
5. Calculate the absolute cost effectiveness by dividing the cost in Step 3 by the emissions reduction in Step 4.

C. Incremental Cost Effectiveness (ICE) Calculation Method

The incremental cost effectiveness of a control technology is calculated as follows:

1. Identify the complying control options appropriate to the existing equipment.
2. Estimate the annual average cost of each control option by using Steps 1 to 3 of the ACE calculation method.
3. Calculate the potential emission reduction for each control option. The potential emission reductions (PE) are the difference between the current emissions and the potential emissions using the new control technology.

D. Cost Calculation Details

For Rule 4306, District staff analyzed the absolute cost effectiveness based on installing and operating an ultra low NOx (ULNB) burner system, tuning of the unit, or installing a selective catalytic reduction (SCR) system. The absolute cost effectiveness analysis was conducted for several sizes of units operating at 75% capacity factor for boilers and heaters. 80% capacity factor was used for oil field steam generators.

E. Cost Effectiveness Tables

Rule 4306 Category A.1 (>5 MMBtu/hr and ≤20 MMBtu/hr Fire Tube Boilers)

<u>Category A.1a</u>
Retrofit Technology Needed to Achieve Proposed Rule Limit of 7 ppmv by **2023**:

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

Table C-2

ULN Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
15 ppmv to 7 ppmv Cost Effectiveness

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
20	$85,500	$13,937	$4,016	$13,758	$31,710	0.64	$49,757
15	$68,400	$11,149	$3,346	$10,318	$24,814	0.48	$51,915
10	$51,300	$8,362	$2,008	$6,879	$17,248	0.32	$54,131
>5	$34,200	$5,575	$1,004	$3,439	$10,018	0.16	$62,878
					Average Cost Effectiveness		$54,670

Category A.1b

Retrofit Technology Needed to Achieve Proposed Rule Limit of 7 ppmv by **2029**:

- Tuning existing burner, Combustion Controls Upgrade, and FGR fan Upgrade

Based on meetings with manufacturers and vendors, the majority of units permitted at 9 ppmv can comply with the 7 ppmv NOx limit by tuning the existing burner, upgrading combustion controls, and upgrading the FGR fan. However, some units may be required to retrofit their units with ultra low NOx burners. The longer compliance schedule for these units will allow for technological advances and for operators to explore more cost effective options to comply with the proposed Rule 4306 or Rule 4320 NOx limits.

Table C-3

Tuning Existing Burner Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 7 ppmv Cost Effectiveness

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
20	$28,500	$4,646	$1,004	$3,439	$9,089	0.16	$57,641
15	$24,700	$4,026	$837	$2,580	$7,442	0.12	$62,931
10	$20,900	$3,407	$502	$1,720	$5,628	0.08	$71,389
>5	$17,100	$2,787	$251	$860	$3,898	0.04	$98,887
					Average Cost Effectiveness		$72,712

Rule 4306 Categories A.2-A.5 (>5 MMBtu/hr and ≤20 MMBtu/hr)

Category A.2-A.5a
Retrofit Technology Needed to Achieve Proposed Rule Limit of 9 ppmv by **2023**:

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, FGR fan Upgrade

Table C-4

ULN Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor 15 ppmv to 9 ppmv Cost Effectiveness							
Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
20	$85,500	$13,937	$4,016	$13,758	$31,710	0.48	$66,115
15	$68,400	$11,149	$3,346	$10,318	$24,814	0.36	$68,983
10	$51,300	$8,362	$2,008	$6,879	$17,248	0.24	$71,927
>5	$34,200	$5,575	$1,004	$3,439	$10,018	0.12	$83,550
					Average Cost Effectiveness		$72,644

Category A.2-A.5b
Retrofit Technology Needed to Achieve Proposed Rule Limit of 9 ppmv by **2029**:

- Tuning existing burner, Combustion Controls Upgrade, and FGR fan Upgrade
- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

Based on meetings with manufacturers and vendors, some units permitted at 12 ppm can comply with the 9 ppm NOx limit by tuning the existing burner, upgrading combustion controls, and upgrading the FGR fan. Other units may be required to retrofit their units with ultra low NOx burners. The longer compliance schedule for these units will allow for technological advances and for operators to explore more cost effective options to comply with the proposed Rule 4306 or Rule 4320 NOx limits.

Table C-5

Tuning Existing Burner Cost Effectiveness Calculation for Units at 75% Capacity Factor
12 ppmv to 9 ppmv Cost Effectiveness

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
20	$28,500	$4,646	$2,008	$6,879	$13,532	0.24	$55,667
15	$24,700	$4,026	$1,673	$5,159	$10,858	0.18	$59,557
10	$20,900	$3,407	$1,004	$3,439	$7,850	0.12	$64,585
>5	$17,100	$2,787	$502	$1,720	$5,009	0.06	$82,421
					Average Cost Effectiveness		$65,558

Table C-6

ULN Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
12 ppmv to 9 ppmv Cost Effectiveness

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
20	$85,500	$13,937	$2,008	$6,879	$22,823	0.24	$93,887
15	$68,400	$11,149	$1,673	$5,159	$17,981	0.18	$98,627
10	$51,300	$8,362	$1,004	$3,439	$12,805	0.12	$105,353
>5	$34,200	$5,575	$502	$1,720	$7,796	0.06	$128,286
					Average Cost Effectiveness		$106,538

Rule 4306 Category B.1 and B.2 (>20 MMBtu/hr and ≤75 MMBtu/hr)

<u>Category B.1 and B.2</u>
Retrofit Technology Needed to Achieve Proposed Rule Limit of 7 ppmv by **2023**:

- Tuning existing burner, Combustion Controls Upgrade, and FGR fan Upgrade

Based on meetings with manufacturers and vendors, the majority of units permitted at 9 ppm can comply with the 7 ppm NOx limit by tuning the existing burner, upgrading combustion controls, and upgrading the FGR fan.

Table C-7

Tuning Existing Burner Cost Effectiveness Calculation for Units at 75% Capacity Factor 9 ppmv to 7 ppmv Cost Effectiveness							
Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$95,190	$15,516	$13,385	$17,197	$46,098	0.59	$77,961
70	$91,720	$14,950	$13,385	$16,051	$44,386	0.55	$80,427
65	$88,248	$14,384	$10,039	$14,904	$39,327	0.51	$76,742
60	$84,776	$13,818	$10,039	$13,758	$37,615	0.47	$79,517
55	$81,304	$13,253	$10,039	$12,611	$35,903	0.43	$82,797
50	$77,832	$12,687	$8,366	$11,465	$32,517	0.39	$82,489
45	$74,360	$12,121	$6,693	$10,318	$29,131	0.35	$82,111
40	$70,888	$11,555	$5,019	$9,172	$25,746	0.32	$81,640
35	$67,416	$10,989	$4,016	$8,025	$23,030	0.28	$83,459
30	$63,944	$10,423	$3,346	$6,879	$20,648	0.24	$87,299
25	$60,472	$9,857	$2,677	$5,732	$18,266	0.20	$92,675
>20	$57,000	$9,291	$2,008	$4,586	$15,885	0.16	$100,740
					Average Cost Effectiveness		$83,988

Rule 4306 Category B.3 (>75 MMBtu/hr)

Category B.3a
Retrofit Technology Needed to Achieve Proposed Rule Limit of 5 ppmv by **2023**:

- SCR with anhydrous ammonia reagent system
- SCR with urea or aqueous ammonia reagent system with reagent vaporizer

Boilers and process heaters with a heat input greater than 75 MMBtu/hr require SCR retrofit to comply with the proposed 5 ppm NOx limit. SCR systems require a reducing agent to reduce NOx emissions. Anhydrous ammonia is the least expensive reagent, but can be hazardous. Aqueous ammonia and urea are safer reagents, but are more expensive because they are less efficient.

Table C-8

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$689,000	$112,307	-$33,463	-$91,717	$7,260	$12,221	$6,608	3.15	$2,095
150	$689,000	$112,307	-$33,463	-$68,788	$5,445	$12,221	$27,722	2.37	$11,721
125	$689,000	$112,307	-$33,463	-$57,323	$4,537	$12,221	$38,279	1.97	$19,421
100	$627,000	$102,201	-$33,463	-$45,859	$3,630	$11,110	$37,619	1.58	$23,858
95	$627,000	$102,201	-$33,463	-$43,566	$3,448	$11,110	$39,731	1.50	$26,523
90	$627,000	$102,201	-$33,463	-$41,273	$3,267	$11,110	$41,842	1.42	$29,485
85	$570,000	$92,910	-$33,463	-$38,980	$3,085	$10,100	$33,653	1.34	$25,109
80	$570,000	$92,910	-$33,463	-$36,687	$2,904	$10,100	$35,764	1.26	$28,352
>75	$570,000	$92,910	-$33,463	-$34,394	$2,722	$10,100	$37,876	1.18	$32,027
							Average Cost Effectiveness		$22,066

Table C-9

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$8,515	$12,221	$45,027	3.61	$12,461
150	$917,000	$149,471	-$33,463	-$68,788	$6,386	$12,221	$65,827	2.71	$24,289
125	$917,000	$149,471	-$33,463	-$57,323	$5,322	$12,221	$76,228	2.26	$33,752
100	$855,000	$139,365	-$33,463	-$45,859	$4,257	$11,110	$75,411	1.81	$41,738
95	$855,000	$139,365	-$33,463	-$43,566	$4,044	$11,110	$77,491	1.72	$45,147
90	$855,000	$139,365	-$33,463	-$41,273	$3,832	$11,110	$79,571	1.63	$48,934
85	$798,000	$130,074	-$33,463	-$38,980	$3,619	$10,100	$71,350	1.54	$46,460
80	$798,000	$130,074	-$33,463	-$36,687	$3,406	$10,100	$73,430	1.45	$50,803
>75	$798,000	$130,074	-$33,463	-$34,394	$3,193	$10,100	$75,510	1.36	$55,725
							Average Cost Effectiveness		$39,923

Table C-10

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$28,185	$12,221	$64,697	3.15	$20,515
150	$917,000	$149,471	-$33,463	-$68,788	$21,139	$12,221	$80,580	2.37	$34,069
125	$917,000	$149,471	-$33,463	-$57,323	$17,616	$12,221	$88,522	1.97	$44,912
100	$855,000	$139,365	-$33,463	-$45,859	$14,093	$11,110	$85,246	1.58	$54,063
95	$855,000	$139,365	-$33,463	-$43,566	$13,388	$11,110	$86,834	1.50	$57,968
90	$855,000	$139,365	-$33,463	-$41,273	$12,683	$11,110	$88,423	1.42	$62,308
85	$798,000	$130,074	-$33,463	-$38,980	$11,979	$10,100	$79,710	1.34	$59,473
80	$798,000	$130,074	-$33,463	-$36,687	$11,274	$10,100	$81,298	1.26	$64,449
>75	$798,000	$130,074	-$33,463	-$34,394	$10,569	$10,100	$82,887	1.18	$70,089
							Average Cost Effectiveness		$51,983

<u>Category B.3b</u>
Retrofit Technology Needed to Achieve Proposed Rule Limit of 5 ppmv by **2029**:

- SCR with anhydrous ammonia reagent system
- SCR with urea or aqueous ammonia reagent system with reagent vaporizer

District staff determined that it was less cost effective for units permitted at 7 ppm or less to retrofit to meet the proposed 4306 NOx limit of 5 ppm than for units permitted at higher limits. The longer compliance schedule for these units will allow for technological advances and for operators to explore more cost effective options to comply with the proposed Rule 4306 or Rule 4320 NOx limits.

Table C-11

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor

7 ppmv to 5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$689,000	$112,307	-$33,463	-$91,717	$7,260	$12,221	$6,608	1.58	$4,191
150	$689,000	$112,307	-$33,463	-$68,788	$5,445	$12,221	$27,722	1.18	$23,442
125	$689,000	$112,307	-$33,463	-$57,323	$4,537	$12,221	$38,279	0.99	$38,842
100	$627,000	$102,201	-$33,463	-$45,859	$3,630	$11,110	$37,619	0.79	$47,716
95	$627,000	$102,201	-$33,463	-$43,566	$3,448	$11,110	$39,731	0.75	$53,047
90	$627,000	$102,201	-$33,463	-$41,273	$3,267	$11,110	$41,842	0.71	$58,969
85	$570,000	$92,910	-$33,463	-$38,980	$3,085	$10,100	$33,653	0.67	$50,217
80	$570,000	$92,910	-$33,463	-$36,687	$2,904	$10,100	$35,764	0.63	$56,704
>75	$570,000	$92,910	-$33,463	-$34,394	$2,722	$10,100	$37,876	0.59	$64,055
							Average Cost Effectiveness		$44,131

Table C-12

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor

7 ppmv to 5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$8,278	$12,221	$44,790	1.58	$28,406
150	$917,000	$149,471	-$33,463	-$68,788	$6,209	$12,221	$65,650	1.18	$55,513
125	$917,000	$149,471	-$33,463	-$57,323	$5,174	$12,221	$76,080	0.99	$77,199
100	$855,000	$139,365	-$33,463	-$45,859	$4,139	$11,110	$75,293	0.79	$95,501
95	$855,000	$139,365	-$33,463	-$43,566	$3,932	$11,110	$77,379	0.75	$103,312
90	$855,000	$139,365	-$33,463	-$41,273	$3,725	$11,110	$79,465	0.71	$111,991
85	$798,000	$130,074	-$33,463	-$38,980	$3,518	$10,100	$71,250	0.67	$106,320
80	$798,000	$130,074	-$33,463	-$36,687	$3,311	$10,100	$73,336	0.63	$116,273
>75	$798,000	$130,074	-$33,463	-$34,394	$3,104	$10,100	$75,422	0.59	$127,552
							Average Cost Effectiveness		$91,341

Table C-13

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
7 ppmv to 5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$28,185	$12,221	$64,697	1.58	$41,031
150	$917,000	$149,471	-$33,463	-$68,788	$21,139	$12,221	$80,580	1.18	$68,138
125	$917,000	$149,471	-$33,463	-$57,323	$17,616	$12,221	$88,522	0.99	$89,824
100	$855,000	$139,365	-$33,463	-$45,859	$14,093	$11,110	$85,246	0.79	$108,126
95	$855,000	$139,365	-$33,463	-$43,566	$13,388	$11,110	$86,834	0.75	$115,937
90	$855,000	$139,365	-$33,463	-$41,273	$12,683	$11,110	$88,423	0.71	$124,616
85	$798,000	$130,074	-$33,463	-$38,980	$11,979	$10,100	$79,710	0.67	$118,945
80	$798,000	$130,074	-$33,463	-$36,687	$11,274	$10,100	$81,298	0.63	$128,898
>75	$798,000	$130,074	-$33,463	-$34,394	$10,569	$10,100	$82,887	0.59	$140,177
							Average Cost Effectiveness		$103,966

Rule 4306 Category C.1 (>5 MMBtu/hr and ≤20 MMBtu/hr Oil Field Steam Generators)

Retrofit Technology Needed to Achieve Proposed Rule Limit of 9 ppmv:

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

Table C-14

ULN Retrofit Cost Effectiveness Calculation for Units at 80% Capacity Factor
15 ppmv to 9 ppmv Cost Effectiveness

Size MMBtu/hr	Avg Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
20	$339,750	$55,379	$5,230	-	$60,609	0.51	$118,473
18	$275,198	$44,857	$2,615	-	$47,472	0.46	$103,105
15	$210,645	$34,335	$2,615	-	$36,950	0.38	$96,302
					Average Cost Effectiveness		$105,960

Rule 4306 Category C.2 (>20 MMBtu/hr and ≤75 MMBtu/hr Oil Field Steam Generators)

Retrofit Technology Needed to Achieve Proposed Rule Limit of 9 ppmv:

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

Approximately 90% of the oilfield steam generators in this size range have a heat input of 62.5 MMBtu/hr. As this is the most common size unit, the cost effectiveness analysis focused on units with a heat input of 62.5 MMBtu/hr. These units are generally older and higher emitting than larger oilfield steam generators. Units in this category will be required to retrofit to meet the proposed 9 ppm NOx limit.

Table C-15

ULN Retrofit Cost Effectiveness Calculation for Units at 80% Capacity Factor **15 ppmv to 9 ppmv Cost Effectiveness**							
Size MMBtu/hr	Avg Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
62.5	$342,581	$55,841	$13,075	-	$68,915	1.60	$43,107
					Average Cost Effectiveness		

Rule 4306 Category C.3 (>75 MMBtu/hr Oil Field Steam Generators)

98% of the oilfield steam generators in this size range have a heat input of 85 MMBtu/hr. These units are generally newer and have better control technology than smaller oilfield steam generators. All permitted units in this category already meet proposed Rule 4306 NOx limit of 7 ppmv.

Rule 4306 Category C.4 (>20 MMBtu/hr and ≤75 MMBtu/hr Oil Field Steam Generators fired on <50% PUC natural gas)

The District is proposing to maintain the Rule 4306 NOx limit of 15 ppmv for units fired on less than 50% PUC quality gas. This is because the impurities in waste gas can increase NOx emissions and ultra low NOx burners are designed to be operated on PUC quality gas. All permitted units in this category already meet proposed Rule 4306 limit of 15 ppmv.

Rule 4306 Category D.1 (>5 MMBtu/hr and ≤40 MMBtu/hr Boilers at Refineries)

The District is proposing to maintain the Rule 4306 NOx limit of 30 ppmv for smaller boilers at refineries. This is because many of these units are fired on non-PUC quality gas, the impurities in waste gas can increase NOx emissions, and ultra low NOx burners are designed to be operated on PUC quality gas. All permitted units in this category already meet proposed Rule 4306 limit of 30 ppmv. However, the units will be subject to a 5 ppmv NOx limit when the unit is replaced. The cost effectiveness analysis below is for the incremental cost of installing an SCR system on the replacement unit.

Retrofit Technology Needed to Achieve Proposed Rule Limit of 5 ppmv upon replacement:

- SCR with anhydrous ammonia reagent system
- SCR with urea or aqueous ammonia reagent system

Table C-16

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
30 ppmv to 5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
30	$407,290	$66,388	-	-	$2,681	$5,509	$74,578	2.99	$24,975
25	$390,320	$63,622	-	-	$2,234	$5,280	$71,136	2.49	$28,587
							Average Cost Effectiveness		$26,781

Table C-17

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
30 ppmv to 5 ppmv Cost Effectiveness – *32.5%* Urea *Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
30	$705,970	$115,073	-	-	$3,087	$5,509	$123,669	2.99	$41,415
25	$689,000	$112,307	-	-	$2,572	$5,280	$120,159	2.49	$48,288
							Average Cost Effectiveness		$44,852

Table C-18

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
30 ppmv to 5 ppmv Cost Effectiveness – *19.5% Aqueous Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
30	$705,970	$115,073	-	-	$10,634	$5,509	$131,216	2.99	$43,943
25	$689,000	$112,307	-	-	$8,861	$5,280	$126,448	2.49	$50,815
							Average Cost Effectiveness		$47,379

Rule 4306 Category D.2 (>40 MMBtu/hr and ≤110 MMBtu/hr Boilers at Refineries)

Retrofit/Replacement Technology Needed to Achieve Proposed Rule Limit of 9 ppmv by **2023**:

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

The District is proposing a Rule 4306 NOx limit of 9 ppmv for boilers at refineries with a heat input greater than 40 MMBtu/hr and less than or equal to 110 MMBtu/hr. This NOx limit is lower for process heaters. Based on conversations with operators, vendors, and manufacturers, boilers in this size range are capable of meeting lower NOx limits than process heaters. The cost effectiveness analysis below is based on units retrofitting from a 25 ppmv NOx limit, because all units in this size range are currently permitted at 25 ppmv, to a 9 ppmv limit.

Table C-19

ULN Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
25 ppmv to 9 ppmv Cost Effectiveness

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
100	$438,900	$71,541	$33,463	$68,788	$173,791	6.37	$27,270
95	$418,950	$68,289	$33,463	$65,349	$167,100	6.05	$27,600
90	$399,000	$65,037	$33,463	$61,909	$160,409	5.74	$27,967
					Average Cost Effectiveness		$27,613

Retrofit Technology Needed to Achieve Proposed Rule Limit of 5 ppmv <u>upon replacement</u>:

- SCR with anhydrous ammonia reagent system
- SCR with urea or aqueous ammonia reagent system

Units in this size range will be subject to a 5 ppmv NOx limit when the unit is replaced. The cost effectiveness analysis below is for the incremental cost of installing an SCR system on the replacement unit.

Table C-20

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
25 ppmv to 5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
100	$821,370	$133,883	-	-	$8,935	$11,110	$153,929	7.95	$19,363
95	$821,370	$133,883	-	-	$8,488	$11,110	$153,482	7.55	$20,323
90	$821,370	$133,883	-	-	$8,042	$11,110	$153,035	7.15	$21,389
							Average Cost Effectiveness		$20,358

Table C-21

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
30 ppmv to 5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
100	$1,120,050	$182,568	-	-	$10,289	$11,110	$203,967	7.95	$25,657
95	$1,120,050	$182,568	-	-	$9,774	$11,110	$203,452	7.55	$26,939
90	$1,120,050	$182,568	-	-	$9,260	$11,110	$202,938	7.15	$28,364
							Average Cost Effectiveness		$26,987

Table C-22

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
30 ppmv to 5 ppmv Cost Effectiveness – *19.5% Aqueous Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
100	$1,120,050	$182,568	-	-	$35,445	$11,110	$229,123	7.95	$28,822
95	$1,120,050	$182,568	-	-	$33,673	$11,110	$227,351	7.55	$30,104
90	$1,120,050	$182,568	-	-	$31,901	$11,110	$225,579	7.15	$31,529
							Average Cost Effectiveness		$30,151

Rule 4306 Category D.3 (>110 MMBtu/hr Boilers at Refineries)

The District is proposing to maintain the Rule 4306 NOx limit of 5 ppmv for boilers with a heat input greater than 110 MMBtu/hr. There is only one boiler in this size range operating in the District. This unit has a SCR system and meets the proposed Rule 4306 limit of 5 ppmv.

Rule 4306 Category D.4 (>5 MMBtu/hr and ≤40 MMBtu/hr Process Heaters at Refineries)

The District is proposing to maintain the Rule 4306 NOx limit of 30 ppmv for smaller process heaters at refineries. This is because many of these units are fired on non-PUC quality gas, the impurities in waste gas can increase NOx emissions, and ultra low NOx burners are designed to be operated on PUC quality gas. All permitted units in this category already meet proposed Rule 4306 limit of 30 ppmv. However, the units will be subject to a 9 ppmv NOx limit when the unit is replaced. The cost effectiveness analysis below is for the incremental cost of installing ultra low NOx burners, combustion controls, and FGR on the replacement unit.

Retrofit Technology Needed to Achieve Proposed Rule Limit of 9 ppmv upon replacement.

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

Table C-23

ULN Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
30 ppmv to 9 ppmv Cost Effectiveness

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
40	144,960	23,585	7,355	-	30,940	3.29	9,404
35	124,009	20,176	7,355	-	27,531	2.87	9,593
30	103,058	16,768	7,355	-	24,123	2.47	9,766
25	93,431	15,201	7,355	-	22,556	2.06	10,950
20	72,480	11,792	7,355	-	19,147	1.64	11,675
15	62,854	10,226	7,355	-	17,581	1.23	14,293
10	41,903	6,818	7,355	-	14,173	0.83	11,764
>5	20,951	3,409	7,355	-	10,764	0.41	26,254
					Average Cost Effectiveness		12,962

Rule 4306 Category D.5 (>40 MMBtu/hr and ≤110 MMBtu/hr Process Heaters at Refineries)

Retrofit Technology Needed to Achieve Proposed Rule Limit of 15 ppmv by **2023**:

- New Ultra Low NOx (ULN) burner, Combustion Controls Upgrade, and FGR fan Upgrade

The District is proposing a Rule 4306 NOx limit of 15 ppmv for process heaters at refineries with a heat input greater than 40 MMBtu/hr and less than or equal to 110 MMBtu/hr. This NOx limit is higher for process heaters than for similarly sized boilers. Based on conversations with operators, vendors, and manufacturers, process heaters in this size range are not capable of meeting as low of NOx limits as boilers. The cost effectiveness analysis below is based on units retrofitting from a 30 ppmv NOx limit because the majority of units in this size range are currently permitted at 30 ppmv.

Table C-24

ULN Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor 30 ppmv to 15 ppmv Cost Effectiveness							
Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
110	404,303	65,780	12,257	-	78,037	6.50	12,006
100	362,400	58,962	12,257	-	71,219	5.91	12,051
80	289,920	47,170	12,257	-	59,427	4.73	12,564
60	217,440	35,377	12,257	-	47,634	3.55	13,418
40	144,960	23,585	12,257	-	35,842	2.36	15,187
					Average Cost Effectiveness		13,045

Rule 4306 Category D.6 (>110 MMBtu/hr Process Heaters at Refineries)

The District is proposing to maintain the Rule 4306 NOx limit of 5 ppmv for process heaters with a heat input greater than 110 MMBtu/hr. There is only one unit in this size range operating in the District. This unit has a SCR system and meets the proposed Rule 4306 limit of 5 ppmv.

Rule 4306 Category E (Low Use Boilers – 9-30 Billion Btu/yr)

The District is proposing to maintain the Rule 4306 NOx limit of 30 ppmv units with fuel use less than 30 billion Btu/year. This category is necessary for low use and emergency units. District staff determined that it was not cost effective to require units with low fuel usage to retrofit to meet lower NOx limits. All permitted units in this category already meet proposed Rule 4306 limit of 30 ppmv.

Rule 4320 Cost Effectiveness Discussion

Cost effectiveness for Rule 4320 depend on the current level of controls, unit size, fuel usage and NOx emission limits. For larger, high operating capacity units, SCR costs may be as low as $1,000 per ton due to the cost savings from decreased fuel and electricity usage. SCR costs for smaller units, with lower total emissions, can be as high as $210,000 per ton. Below are some examples of cost effectiveness analyses for units retrofitting to meet proposed Rule 4320 NOx limits.

Rule 4320 Categories B.1 and B.2 (>20 MMBtu/hr and ≤75 MMBtu/hr)

Retrofit Technology Needed to Achieve Proposed Rule Limit of 2.5 ppmv:

- SCR with anhydrous ammonia reagent system

- SCR with urea or aqueous ammonia reagent system with reagent vaporizer

Boilers and process heaters with a heat input greater than 20 MMBtu/hr and less than or equal to 75 MMBtu require SCR retrofit to comply with the proposed 2.5 ppm NOx limit. SCR systems require a reducing agent to reduce NOx emissions. Anhydrous ammonia is the least expensive reagent, but can be hazardous. Aqueous ammonia and urea are safer reagents, but are more expensive because they are less efficient. Complying with a 2.5 ppmv NOx limit requires an additional layer of catalyst and more reagent than SCR systems designed to meet a higher NOx limit.

Table C-25

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
7 ppmv to 2.5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$427,500	$69,683	-$33,463	-$34,394	$2,722	$7,575	$12,123	1.36	$8,947
70	$414,550	$67,572	-$33,463	-$32,101	$2,541	$7,346	$11,894	1.26	$9,405
65	$401,595	$65,460	-$33,463	-$29,808	$2,359	$7,116	$11,664	1.17	$9,932
60	$388,640	$63,348	-$33,463	-$27,515	$2,178	$6,886	$11,435	1.08	$10,548
55	$375,685	$61,237	-$33,463	-$25,222	$1,996	$6,657	$11,205	0.99	$11,276
50	$362,730	$59,125	-$16,731	-$22,929	$1,815	$6,427	$27,707	0.90	$30,670
45	$349,775	$57,013	-$16,731	-$20,636	$1,633	$6,198	$27,477	0.81	$33,795
40	$336,820	$54,902	-$16,731	-$18,343	$1,452	$5,968	$27,247	0.72	$37,702
35	$323,865	$52,790	-$10,039	-$16,051	$1,270	$5,739	$33,710	0.63	$53,308
30	$310,910	$50,678	-$6,693	-$13,758	$1,089	$5,509	$36,826	0.54	$67,942
25	$297,955	$48,567	-$6,693	-$11,465	$907	$5,280	$36,596	0.45	$81,022
>20	$285,000	$46,455	-$6,693	-$9,172	$726	$5,050	$36,367	0.36	$100,641
							Average Cost Effectiveness		$37,932

Table C-26

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor 9 ppmv to 2.5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*									
Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$427,500	$69,683	-$33,463	-$34,394	$2,722	$7,575	$12,123	1.95	$6,229
70	$414,550	$67,572	-$33,463	-$32,101	$2,541	$7,346	$11,894	1.82	$6,548
65	$401,595	$65,460	-$33,463	-$29,808	$2,359	$7,116	$11,664	1.69	$6,915
60	$388,640	$63,348	-$33,463	-$27,515	$2,178	$6,886	$11,435	1.56	$7,344
55	$375,685	$61,237	-$33,463	-$25,222	$1,996	$6,657	$11,205	1.43	$7,850
50	$362,730	$59,125	-$16,731	-$22,929	$1,815	$6,427	$27,707	1.30	$21,353
45	$349,775	$57,013	-$16,731	-$20,636	$1,633	$6,198	$27,477	1.17	$23,528
40	$336,820	$54,902	-$16,731	-$18,343	$1,452	$5,968	$27,247	1.04	$26,248
35	$323,865	$52,790	-$10,039	-$16,051	$1,270	$5,739	$33,710	0.91	$37,113
30	$310,910	$50,678	-$6,693	-$13,758	$1,089	$5,509	$36,826	0.78	$47,301
25	$297,955	$48,567	-$6,693	-$11,465	$907	$5,280	$36,596	0.65	$56,407
>20	$285,000	$46,455	-$6,693	-$9,172	$726	$5,050	$36,367	0.52	$70,067
							Average Cost Effectiveness		$26,409

Table C-27

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor 7 ppmv to 2.5 ppmv Cost Effectiveness – *32.5% Urea Reagent*									
Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$655,000	$106,765	-$33,463	-$34,394	$3,193	$7,575	$49,676	1.36	$36,660
70	$642,090	$104,661	-$33,463	-$32,101	$2,980	$7,346	$49,422	1.26	$39,078
65	$629,181	$102,557	-$33,463	-$29,808	$2,767	$7,116	$49,169	1.17	$41,868
60	$616,272	$100,452	-$33,463	-$27,515	$2,554	$6,886	$48,915	1.08	$45,123
55	$603,363	$98,348	-$33,463	-$25,222	$2,342	$6,657	$48,661	0.99	$48,969
50	$590,454	$96,244	-$16,731	-$22,929	$2,129	$6,427	$65,139	0.90	$72,107
45	$577,545	$94,140	-$16,731	-$20,636	$1,916	$6,198	$64,886	0.81	$79,806
40	$564,636	$92,036	-$16,731	-$18,343	$1,703	$5,968	$64,632	0.72	$89,431
35	$551,727	$89,932	-$10,039	-$16,051	$1,490	$5,739	$71,071	0.63	$112,389
30	$538,818	$87,827	-$6,693	-$13,758	$1,277	$5,509	$74,163	0.54	$136,827
25	$525,909	$85,723	-$6,693	-$11,465	$1,064	$5,280	$73,910	0.45	$163,630
>20	$513,000	$83,619	-$6,693	-$9,172	$851	$5,050	$73,656	0.36	$203,836
							Average Cost Effectiveness		$89,144

Table C-28

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 2.5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$655,000	$106,765	-$33,463	-$34,394	$3,193	$7,575	$49,676	1.95	$25,523
70	$642,090	$104,661	-$33,463	-$32,101	$2,980	$7,346	$49,422	1.82	$27,206
65	$629,181	$102,557	-$33,463	-$29,808	$2,767	$7,116	$49,169	1.69	$29,148
60	$616,272	$100,452	-$33,463	-$27,515	$2,554	$6,886	$48,915	1.56	$31,414
55	$603,363	$98,348	-$33,463	-$25,222	$2,342	$6,657	$48,661	1.43	$34,093
50	$590,454	$96,244	-$16,731	-$22,929	$2,129	$6,427	$65,139	1.30	$50,201
45	$577,545	$94,140	-$16,731	-$20,636	$1,916	$6,198	$64,886	1.17	$55,561
40	$564,636	$92,036	-$16,731	-$18,343	$1,703	$5,968	$64,632	1.04	$62,262
35	$551,727	$89,932	-$10,039	-$16,051	$1,490	$5,739	$71,071	0.91	$78,246
30	$538,818	$87,827	-$6,693	-$13,758	$1,277	$5,509	$74,163	0.78	$95,259
25	$525,909	$85,723	-$6,693	-$11,465	$1,064	$5,280	$73,910	0.65	$113,920
>20	$513,000	$83,619	-$6,693	-$9,172	$851	$5,050	$73,656	0.52	$141,911
							Average Cost Effectiveness		$62,062

Table C-29

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
7 ppmv to 2.5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$655,000	$106,765	-$33,463	-$34,394	$11,050	$7,575	$57,533	1.36	$42,458
70	$642,090	$104,661	-$33,463	-$32,101	$10,313	$7,346	$56,756	1.26	$44,876
65	$629,181	$102,557	-$33,463	-$29,808	$9,577	$7,116	$55,978	1.17	$47,666
60	$616,272	$100,452	-$33,463	-$27,515	$8,840	$6,886	$55,201	1.08	$50,921
55	$603,363	$98,348	-$33,463	-$25,222	$8,103	$6,657	$54,423	0.99	$54,768
50	$590,454	$96,244	-$16,731	-$22,929	$7,367	$6,427	$70,377	0.90	$77,905
45	$577,545	$94,140	-$16,731	-$20,636	$6,630	$6,198	$69,600	0.81	$85,605
40	$564,636	$92,036	-$16,731	-$18,343	$5,893	$5,968	$68,822	0.72	$95,229
35	$551,727	$89,932	-$10,039	-$16,051	$5,157	$5,739	$74,737	0.63	$118,188
30	$538,818	$87,827	-$6,693	-$13,758	$4,420	$5,509	$77,306	0.54	$142,625
25	$525,909	$85,723	-$6,693	-$11,465	$3,683	$5,280	$76,529	0.45	$169,429
>20	$513,000	$83,619	-$6,693	-$9,172	$2,947	$5,050	$75,751	0.36	$209,634
							Average Cost Effectiveness		$94,942

Table C-30

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 2.5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
75	$655,000	$106,765	-$33,463	-$34,394	$11,050	$7,575	$57,533	1.95	$29,559
70	$642,090	$104,661	-$33,463	-$32,101	$10,313	$7,346	$56,756	1.82	$31,243
65	$629,181	$102,557	-$33,463	-$29,808	$9,577	$7,116	$55,978	1.69	$33,185
60	$616,272	$100,452	-$33,463	-$27,515	$8,840	$6,886	$55,201	1.56	$35,451
55	$603,363	$98,348	-$33,463	-$25,222	$8,103	$6,657	$54,423	1.43	$38,129
50	$590,454	$96,244	-$16,731	-$22,929	$7,367	$6,427	$70,377	1.30	$54,237
45	$577,545	$94,140	-$16,731	-$20,636	$6,630	$6,198	$69,600	1.17	$59,598
40	$564,636	$92,036	-$16,731	-$18,343	$5,893	$5,968	$68,822	1.04	$66,299
35	$551,727	$89,932	-$10,039	-$16,051	$5,157	$5,739	$74,737	0.91	$82,283
30	$538,818	$87,827	-$6,693	-$13,758	$4,420	$5,509	$77,306	0.78	$99,296
25	$525,909	$85,723	-$6,693	-$11,465	$3,683	$5,280	$76,529	0.65	$117,957
>20	$513,000	$83,619	-$6,693	-$9,172	$2,947	$5,050	$75,751	0.52	$145,948
							Average Cost Effectiveness		$66,099

Rule 4320 Category B.3 (>75 MMBtu/hr Boilers)

<u>Category B.3a</u>
Retrofit Technology Needed to Achieve Proposed Rule Limit of 2.5 ppmv by **2023**:

- SCR with anhydrous ammonia reagent system
- SCR with urea or aqueous ammonia reagent system and reagent vaporizer

Boilers and process heaters with a heat input greater than 75 MMBtu/hr require SCR retrofit to comply with the proposed 2.5 ppmv NOx limit. SCR systems require a reducing agent to reduce NOx emissions. Anhydrous ammonia is the least expensive reagent, but can be hazardous. Aqueous ammonia and urea are safer reagents, but are more expensive because they are less efficient. Complying with a 2.5 ppmv NOx limit requires an additional layer of catalyst and more reagent than SCR systems designed to meet a higher NOx limit.

Table C-31

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
7 ppmv to 2.5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$689,000	$112,307	-$33,463	-$91,717	$7,260	$12,221	$6,608	3.61	$1,829
150	$689,000	$112,307	-$33,463	-$68,788	$5,445	$12,221	$27,722	2.71	$10,229
125	$689,000	$112,307	-$33,463	-$57,323	$4,537	$12,221	$38,279	2.26	$16,949
100	$627,000	$102,201	-$33,463	-$45,859	$3,630	$11,110	$37,619	1.81	$20,822
95	$627,000	$102,201	-$33,463	-$43,566	$3,448	$11,110	$39,731	1.72	$23,148
90	$627,000	$102,201	-$33,463	-$41,273	$3,267	$11,110	$41,842	1.63	$25,732
85	$570,000	$92,910	-$33,463	-$38,980	$3,085	$10,100	$33,653	1.54	$21,913
80	$570,000	$92,910	-$33,463	-$36,687	$2,904	$10,100	$35,764	1.45	$24,743
>75	$570,000	$92,910	-$33,463	-$34,394	$2,722	$10,100	$37,876	1.36	$27,951
							Average Cost Effectiveness		$19,257

Table C-32

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 2.5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$689,000	$112,307	-$33,463	-$91,717	$7,260	$12,221	$6,608	5.19	$1,273
150	$689,000	$112,307	-$33,463	-$68,788	$5,445	$12,221	$27,722	3.89	$7,122
125	$689,000	$112,307	-$33,463	-$57,323	$4,537	$12,221	$38,279	3.24	$11,800
100	$627,000	$102,201	-$33,463	-$45,859	$3,630	$11,110	$37,619	2.60	$14,496
95	$627,000	$102,201	-$33,463	-$43,566	$3,448	$11,110	$39,731	2.47	$16,115
90	$627,000	$102,201	-$33,463	-$41,273	$3,267	$11,110	$41,842	2.34	$17,915
85	$570,000	$92,910	-$33,463	-$38,980	$3,085	$10,100	$33,653	2.21	$15,256
80	$570,000	$92,910	-$33,463	-$36,687	$2,904	$10,100	$35,764	2.08	$17,226
>75	$570,000	$92,910	-$33,463	-$34,394	$2,722	$10,100	$37,876	1.95	$19,460
							Average Cost Effectiveness		$13,407

Table C-33

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
7 ppmv to 2.5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$8,515	$12,221	$45,027	3.61	$12,461
150	$917,000	$149,471	-$33,463	-$68,788	$6,386	$12,221	$65,827	2.71	$24,289
125	$917,000	$149,471	-$33,463	-$57,323	$5,322	$12,221	$76,228	2.26	$33,752
100	$855,000	$139,365	-$33,463	-$45,859	$4,257	$11,110	$75,411	1.81	$41,738
95	$855,000	$139,365	-$33,463	-$43,566	$4,044	$11,110	$77,491	1.72	$45,147
90	$855,000	$139,365	-$33,463	-$41,273	$3,832	$11,110	$79,571	1.63	$48,934
85	$798,000	$130,074	-$33,463	-$38,980	$3,619	$10,100	$71,350	1.54	$46,460
80	$798,000	$130,074	-$33,463	-$36,687	$3,406	$10,100	$73,430	1.45	$50,803
>75	$798,000	$130,074	-$33,463	-$34,394	$3,193	$10,100	$75,510	1.36	$55,725
							Average Cost Effectiveness		$39,923

Table C-34

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 2.5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$8,515	$12,221	$45,027	5.19	$8,675
150	$917,000	$149,471	-$33,463	-$68,788	$6,386	$12,221	$65,827	3.89	$16,910
125	$917,000	$149,471	-$33,463	-$57,323	$5,322	$12,221	$76,228	3.24	$23,498
100	$855,000	$139,365	-$33,463	-$45,859	$4,257	$11,110	$75,411	2.60	$29,058
95	$855,000	$139,365	-$33,463	-$43,566	$4,044	$11,110	$77,491	2.47	$31,431
90	$855,000	$139,365	-$33,463	-$41,273	$3,832	$11,110	$79,571	2.34	$34,068
85	$798,000	$130,074	-$33,463	-$38,980	$3,619	$10,100	$71,350	2.21	$32,345
80	$798,000	$130,074	-$33,463	-$36,687	$3,406	$10,100	$73,430	2.08	$35,369
>75	$798,000	$130,074	-$33,463	-$34,394	$3,193	$10,100	$75,510	1.95	$38,796
							Average Cost Effectiveness		$27,794

Table C-35

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
7 ppmv to 2.5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$29,466	$12,221	$65,978	3.61	$18,259
150	$917,000	$149,471	-$33,463	-$68,788	$22,100	$12,221	$81,541	2.71	$30,088
125	$917,000	$149,471	-$33,463	-$57,323	$18,417	$12,221	$89,322	2.26	$39,551
100	$855,000	$139,365	-$33,463	-$45,859	$14,733	$11,110	$85,887	1.81	$47,537
95	$855,000	$139,365	-$33,463	-$43,566	$13,997	$11,110	$87,443	1.72	$50,945
90	$855,000	$139,365	-$33,463	-$41,273	$13,260	$11,110	$88,999	1.63	$54,733
85	$798,000	$130,074	-$33,463	-$38,980	$12,523	$10,100	$80,255	1.54	$52,258
80	$798,000	$130,074	-$33,463	-$36,687	$11,787	$10,100	$81,811	1.45	$56,601
>75	$798,000	$130,074	-$33,463	-$34,394	$11,050	$10,100	$83,367	1.36	$61,523
							Average Cost Effectiveness		$45,722

Table C-36

SCR Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
9 ppmv to 2.5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$917,000	$149,471	-$33,463	-$91,717	$29,466	$12,221	$65,978	5.19	$12,712
150	$917,000	$149,471	-$33,463	-$68,788	$22,100	$12,221	$81,541	3.89	$20,947
125	$917,000	$149,471	-$33,463	-$57,323	$18,417	$12,221	$89,322	3.24	$27,535
100	$855,000	$139,365	-$33,463	-$45,859	$14,733	$11,110	$85,887	2.60	$33,095
95	$855,000	$139,365	-$33,463	-$43,566	$13,997	$11,110	$87,443	2.47	$35,468
90	$855,000	$139,365	-$33,463	-$41,273	$13,260	$11,110	$88,999	2.34	$38,105
85	$798,000	$130,074	-$33,463	-$38,980	$12,523	$10,100	$80,255	2.21	$36,382
80	$798,000	$130,074	-$33,463	-$36,687	$11,787	$10,100	$81,811	2.08	$39,406
>75	$798,000	$130,074	-$33,463	-$34,394	$11,050	$10,100	$83,367	1.95	$42,832
							Average Cost Effectiveness		$31,831

Rule 4320 Category C.3 (>75 MMBtu/hr Oil Field Steam Generators)

Retrofit Technology Needed to Achieve Proposed Rule Limit of 5 ppmv:

- New Ultra Low NOx (ULN) burner and Combustion Controls Upgrade

The proposed Rule 4320 NOx limit for oilfield steam generators with a heat input greater than 75 MMBtu/hr is 5 ppmv. These units are generally newer and have better control technology than smaller oilfield steam generators. All permitted units in this category already meet proposed Rule 4306 NOx limit of 7 ppmv, The cost analysis below is based on ULN burner retrofit.

Table C-37

ULN Retrofit Cost Effectiveness Calculation for Units at 80% Capacity Factor
7 ppmv to 5 ppmv Cost Effectiveness

Size MMBtu/hr	Avg Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental O&M $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
85	$141,563	$23,075	$13,075	-	$36,149	0.71	$50,572
					Average Cost Effectiveness		

Rule 4320 Category D.3 and D.6 (>110 MMBtu/hr Petroleum Refinery Boilers and Heaters)

Retrofit Technology Needed to Achieve Proposed Rule Limit of 2.5 ppmv:

- Extra layer of catalyst, additional reagent, and tuning

The cost effectiveness analysis below is for the incremental retrofit costs for units with existing SCR systems to go from 5 ppmv to 2.5 ppmv. This is achieved by installing an extra layer of catalyst, using more reagent, and tuning the unit. If existing SCR housing cannot accept an additional layer of catalyst the units would require a new SCR housing which would increase costs

Table C-38

Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
5 ppmv to 2.5 ppmv Cost Effectiveness – *Anhydrous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
250	$114,000	$18,582	$0	$0	$209	$6,722	$25,513	2.55	$10,021
200	$105,855	$17,254	$0	$0	$168	$6,111	$23,532	2.04	$11,554
150	$97,712	$15,927	$0	$0	$126	$6,111	$22,163	1.53	$14,509
125	$93,641	$15,263	$0	$0	$105	$6,111	$21,479	1.27	$16,873
							Average Cost Effectiveness		$13,239

Table C-39

Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
5 ppmv to 2.5 ppmv Cost Effectiveness – *32.5% Urea Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$105,855	$17,254	$0	$0	$237	$6,111	$23,601	2.04	$11,588
150	$97,712	$15,927	$0	$0	$177	$6,111	$22,215	1.53	$14,543
125	$93,641	$15,263	$0	$0	$148	$6,111	$21,522	1.27	$16,907
							Average Cost Effectiveness		$14,346

Table C-40

Retrofit Cost Effectiveness Calculation for Units at 75% Capacity Factor
5 ppmv to 2.5 ppmv Cost Effectiveness – *19.5% Aqueous Ammonia Reagent*

Size MMBtu/hr	Total Capital Cost $	Annualized Capital Cost	Incremental Electricity $/yr	Incremental Fuel $/yr	Reagent Cost $/yr	Catalyst Replacement $/yr	Annualized Cost $/yr	NOx reduced tons/yr	CE $/ton NOx
200	$105,855	$17,254	$0	$0	$1,281	$6,111	$24,646	2.04	$12,101
150	$97,712	$15,927	$0	$0	$961	$6,111	$22,998	1.53	$15,056
125	$93,641	$15,263	$0	$0	$801	$6,111	$22,175	1.27	$17,420
							Average Cost Effectiveness		$14,859

Direct PM2.5 Control Technology

Currently, there are a several produced gas fired steam generators operating in crude oil production facilities that are required by their permits to operate SOx scrubbers and ESPs (to reduce SOx emissions and visible emissions to burning high sulfur produced gas).

As illustrated below, electrostatic precipitator (ESP) and wet scrubber PM control technology are not a cost-effective option for this source category. The cost of the ESP technology does not include costs of retrofitting equipment and/or the facility or compliance monitoring costs, which would drive the cost-effectiveness up even more. In addition, the annualized costs provided by EPA for the wet scrubber system are in 2002 dollars, which means the value above would be even greater if it were adjusted to 2018 dollars.

PM Potential Emissions Reductions for an ESP and Scrubber

For the purposes of these calculations, the following assumptions were made:

1. For simplicity, the analysis will evaluate the cost-effectiveness of these technologies for total PM reductions from liquid fuel fired units.
2. The PM control efficiency of an ESP is 99%.
3. The PM control efficiency of a scrubber is 99%.

Potential Emissions Reductions$_{ESP}$ = (Total PM Emissions) x (Control Efficiency)
Potential Emissions Reduction$_{ESP}$ = 0.02 tons/year X 0.99
Potential Emissions Reduction$_{ESP}$ = 0.0198 tons/ year (tpy)

Potential Emissions Reductions $_{scrubber}$ = (Total PM Emissions) x (Control Efficiency)
Potential Emissions Reduction $_{scrubber}$ = 0.02 tons/year X 0.99
Potential Emissions Reduction $_{scrubber}$ = 0.0198 tons/ year (tpy)

Annualized Cost of an ESP and Wet Scrubber

The capital cost for the installation of an ESP for a 1-5 MMBtu/hr boiler ranges from \$90,000 - \$100,000 and the annual maintenance cost is \$1,000-\$2,000.[1] For the wet scrubber system, EPA estimated the annualized cost at \$5,300-\$102,000 per sm^3/sec at an average air flow rate of 0.7- 47 sm^3/sec.[2] The following assumptions in the cost-effectiveness calculations:

1. The capital cost of an ESP for a 5 MMBtu/hr boiler is assumed to be \$100,000.
2. The annual maintenance cost of an ESP for a 5 MMBtu/hr boiler is assumed to be \$2,000.
3. The annualized cost of a wet scrubber system is assumed to be the median of the range above (\$53,650 per sm^3/sec).
4. The average air flow rate for a wet scrubber system is assumed to be the median of the range above (23.85 sm^3/sec).
5. The total capital and maintenance cost of an ESP will be calculated by multiplying the cost of 1 unit by the total number of units.
6. The total annualized cost of a wet scrubber will be calculated by multiplying the annualized cost of 1 unit by the total number of units.
7. Lifetime of the ESP is 10 years at 10% interest. To account for this, the annualized capital cost will be calculated by multiplying the total capital cost by the capital recovery factor of 0.1627 and adding the annual maintenance costs.

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[1] Catherine Roberts. (March 2009) *Information on Air Pollution Control Technology for Woody Biomass Boilers.* Environmental Protection Agency Office of Air Quality Planning and Standards and Northeast States for Coordinated Air Use Management.
[2] (2002). *Air Pollution Control Technology Fact Sheet: Spray-Chamber/Spray-Tower Wet Scrubber.* Environmental Protection Agency.

Annual $Cost_{ESP}$ = (Total Capital Cost) x (0.1627) + (Annual Maintenance Cost x 62)
Annual $Cost_{ESP}$ = ($100,000 x 62) x (0.1627) + ($2,000 x 62)
Annual $Cost_{ESP}$ = $1,132,740/year

Annual $Cost_{scrubber}$ = (Annualized Cost of 1 unit) x (Number of Units) x (Average Flow Rate)
Annual $Cost_{scrubber}$ = ($53,650/ sm^3/sec) x (62) x (23.85 sm^3/sec)
Annual $Cost_{scrubber}$ = $79,332,255 year

<u>Cost-effectiveness of an ESP and Wet Scrubber</u>

Cost-effectiveness = Annual Cost / Annual Emissions Reductions

$Cost\text{-}effectiveness_{ESP}$ = ($1,132,740/year) / (0.0198 tons/ year)
$Cost\text{-}effectiveness_{ESP}$ = $57,209,091/ton of PM

$Cost\text{-}effectiveness_{scrubber}$ = ($79,332,255/year) / (0.0198 tons/ year)
$Cost\text{-}effectiveness_{scrubber}$ = $4,006,679,545/ton of PM