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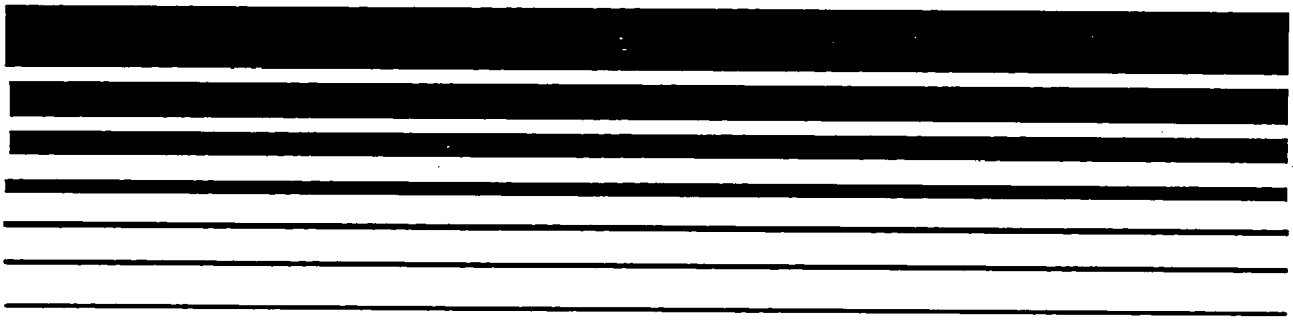
Model Boiler Cost Analysis for Controlling Sulfur Dioxide (SO_2) Emissions from Small Steam Generating Units



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EPA-450/3-89-14

MODEL BOILER COST ANALYSIS FOR CONTROLLING SULFUR DIOXIDE (SO_2) EMISSIONS FROM SMALL STEAM GENERATING UNITS

Emission Standards Division

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, N.C. 27711

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1.0 INTRODUCTION

This report presents estimates of the costs and cost effectiveness associated with controlling sulfur dioxide (SO_2) emissions from small coal- and oil-fired steam generating units (i.e., boilers). The report was prepared as part of the project to develop new source performance standards (NSPS) for small boilers under Section 111 of the Clean Air Act. Small boilers are defined as industrial-commercial-institutional boilers having heat input capacities of 29 MW (100 million Btu/hour) or less. The regulatory baseline and alternative control levels used in this cost analysis are discussed in the report entitled, "Overview of the Regulatory Baseline, Technical Basis, and Alternative Control Levels for Sulfur Dioxide (SO_2) Emission Standards for Small Steam Generating Units".[1]

2.0 SUMMARY

Capital, operation and maintenance (O&M), and annualized costs were estimated for model boiler/SO_2 control systems firing coal and oil in EPA Region V. The SO_2 control techniques examined for coal-fired boilers were the use of low sulfur coal, flue gas desulfurization (FGD) systems, and fluidized bed combustion (FBC) units. For oil-fired boilers, the use of medium sulfur oil, very low sulfur oil, and FGD systems were examined.

Annualized costs for the model coal-fired boilers at the regulatory baseline range from $599,000/yr at the 2.9 MW (10 million Btu/hour) boiler size and 0.26 capacity factor to $3,661,000/yr at the 29 MW (100 million Btu/hour) boiler size and 0.55 capacity factor. The increase in annualized costs over the regulatory baseline for Alternative Control Level 1 (i.e., firing low sulfur coal) ranges from 4 to 7 percent. Alternative Control Level 2 (i.e., 90 percent SO_2 reduction) increases annualized costs by 22 to 56 percent over the regulatory baseline.

The incremental cost effectiveness of emission control associated with Alternative Control Level 1 over the regulatory baseline ranges from $536/Mg ($486/ton) at the 29 MW (100 million Btu/hour) boiler size and 0.55 capacity factor to $2,120/Mg ($1,920/ton) at the 2.9 MW (10 million Btu/hour) size and 0.26 capacity factor. The incremental cost effectiveness of emission control associated with Alternative Control Level 2 over Alternative Control Level 1 ranges from $3,060/Mg ($2,830/ton) to $33,300/Mg ($30,200/ton) over the same range in boiler size and capacity factor.

Annualized costs for model oil-fired boilers at the regulatory baseline range from $330,000/yr at the 2.9 MW (10 million Btu/hour) size and 0.26 capacity factor to $2,623,000/yr at the 29 MW (100 million Btu/hour) size and 0.55 capacity factor. Compared to the regulatory baseline, Alternative Control Level 1 (i.e., firing medium sulfur oil) increases annualized costs by 2 to 4 percent; Alternative Control Level 2 (i.e., firing very low sulfur oil) increases annualized costs by 8 to 21 percent; and Alternative Control Level 3 (90 percent SO_2 reduction) raises annualized costs by 29 to 96 percent.

The incremental cost effectiveness of emission control associated with Alternative Control Level 1 over the regulatory baseline averages about $339/Mg ($308/ton) for all boiler sizes and capacity factors. The incremental cost effectiveness of emission control associated with Alternative Control Level 2 over Alternative Control Level 1 averages about $1,560/Mg ($1,420/ton) for all boiler sizes and capacity factors. This is because the only cost differences between these alternative control levels are fuel cost differences. Since these costs vary in proportion to SO_2 emission differences, incremental cost effectiveness does not change with boiler size or capacity factor.

The incremental cost effectiveness of emission control associated with Alternative Control Level 3 over Alternative Control Level 2 increases with decreasing boiler size and capacity factor from $12,300/Mg ($11,200/ton) to $393,000/Mg ($357,000/ton). This reflects the economies of scale associated with FGD systems.

3.0 MODEL BOILER COSTING METHODOLOGY

This model boiler cost analysis estimates capital, O&M, and annualized costs using the methodology discussed in References 2 and 3. The selection of model boiler types and sizes used in this analysis is discussed in Reference 4. All costs are presented in June 1985 dollars. Capital and O&M costs were updated from other time bases using the Chemical Engineering (CE) plant cost and Bureau of Labor Statistics (BLS) producer price indices, respectively. The total cost for each model system includes the costs of the boiler, fuel, and add-on SO_2 control equipment, where applicable.

The SO_2 alternative control levels used in this analysis are summarized in Table 1. As discussed in Reference 1, a regulatory baseline of 1,550 ng/J (3.6 lb/million Btu) is selected for coal-fired boilers for purposes of analysis. This emission level is represented by the firing of type F-bituminous coal. This coal has a maximum expected SO_2 emission rate of 1,550 ng/J (3.6 lb/million Btu) and a long-term average SO_2 emission rate of 1,230 ng/J (2.86 lb/million Btu). Alternative Control Level 1 for coal is an emission level of 520 ng/J (1.2 lb/million Btu). In the analysis, this emission level is met by firing low sulfur, type-B bituminous coal. Alternative Control Level 2 for coal is a requirement of 90 percent SO_2 reduction on a continuous basis. This level can be achieved using either FGD or FBC systems. Various coal types were examined to determine the lowest cost option for FGD or FBC application. Type F-bituminous coal results in the lowest annualized costs for a 90 percent SO_2 reduction requirement.

As discussed in Reference 1, a regulatory baseline of 1,290 ng/J (3.0 lb/million Btu) is selected for oil-fired boilers for purposes of analysis. Alternative Control Level 1 for oil is an emission level of 690 ng/J (1.6 lb/million Btu). In the analysis, this emission level is achieved by the firing of medium sulfur oil. Alternative Control Level 2 for oil is an emission level of 210 ng/J (0.50 lb/million Btu), which is met by firing very low sulfur oil. Although either very low sulfur residual oil or distillate oil can be used to meet Alternative Control Level 2, only distillate oil is considered to be universally available in this sulfur

content range. The sulfur content of distillate oils can range up to 210 ng SO_2/J (0.50 lb SO_2/million Btu), but the average distillate oil contains about 130 ng SO_2/J (0.30 lb SO_2/million Btu). As a result, the typical distillate oil selected for this analysis produces SO_2 emissions of 130 ng/J (0.30 lb/million Btu). Ninety percent SO_2 reduction is required under Alternative Control Level 3 and is met by use of FGD systems. High sulfur oil was chosen for use with an FGD system to meet Alternative Control Level 3 because it results in the lowest annualized costs for the FGD option.

The costs associated with Alternative Control Level 2 for coal-fired boilers and Alternative Control Level 3 for oil-fired boilers are based on costs for sodium and dual alkali FGD systems. Although not specifically included, costs for wet lime/limestone FGD, lime spray drying, and FBC are in the same general range as those for sodium and dual alkali FGD. Therefore, the costs presented for these alternative control levels are representative of systems that are capable of achieving 90 percent SO_2 reduction on a continuous basis.

The fuel prices used in this analysis are presented in Table 2. These are projected prices for fuel delivered in EPA Region V, levelized over a 15-year period from 1992 to 2007. Region V fuel prices were used for illustrative purposes. Similar cost results would be expected using fuel prices for other EPA regions.

For the various alternative control levels, costs were estimated for appropriate methods to ensure compliance. For the reduced sulfur oil alternatives, shipment fuel sampling and analysis are required. Both the specified procedure and the associated costs for this compliance option are discussed in Reference 6. The low sulfur coal alternative would require continuous monitoring of some type, either daily fuel sampling and analysis of the coal fired or installation of an outlet SO_2 continuous emission monitor (CEM). Daily fuel sampling and analysis result in lower continuous monitoring costs. For the 90 percent SO_2 reduction alternatives, continuous monitoring is required. Costs for daily fuel sampling and analysis at the inlet and an SO_2 CEM at the outlet are used in this analysis.[7] (An inlet SO_2 CEM could be used instead of fuel sampling and analysis for FGD applications, but this would result in higher costs.)

4.0 MODEL BOILER COST ANALYSIS RESULTS

4.1 COAL

Tables 3 and 4 present the costs of model coal-fired boilers operating at capacity factors of 0.26 and 0.55, respectively. Annualized costs for model boilers at the regulatory baseline range from $599,000/yr at the 2.9 MW (10 million Btu/hour) boiler size and 0.26 capacity factor to $3,661,000/yr at the 29 MW (100 million Btu/hour) boiler size and 0.55 capacity factor. The increase in annualized costs over the regulatory baseline for Alternative Control Level 1 ranges from 4 to 7 percent. Requiring 90 percent reduction under Alternative Control Level 2 increases annualized costs by 22 to 56 percent over the regulatory baseline.

Tables 5 and 6 present the results of the analysis for the model coal-fired boilers at capacity factors of 0.26 and 0.55, respectively. The incremental cost effectiveness of emission control associated with Alternative Control Level 1 (i.e., firing low sulfur coal) over the regulatory baseline ranges from $536/Mg ($486/ton) at the 29 MW (100 million Btu/hour) boiler size and 0.55 capacity factor to $2,120/Mg ($1,920/ton) at the 2.9 MW (10 million Btu/hour) boiler size and 0.26 capacity factor. The incremental cost effectiveness of emission control associated with Alternative Control Level 2 over Alternative Control Level 1 ranges from $3,060/Mg ($2,830/ton) at the 29 MW (100 million Btu/hour) boiler size and 0.55 capacity factor to $33,300/Mg ($30,200/ton) at the 2.9 MW (10 million Btu/hour) size and 0.26 capacity factor.

The incremental cost effectiveness of emission control associated with Alternative Control Level 1 decreases with increasing boiler size and capacity factor. This is due to the fact that daily fuel sampling and analysis are required for compliance under Alternative Control Level 1 but not under the regulatory baseline. While the annualized costs associated with the daily fuel sampling and analysis remain constant as boiler size and capacity factor increase, the SO_2 emission reductions under Alternative Control Level 1 increase. Other costs associated with SO_2 control (e.g.,

fuel costs) increase in proportion to boiler size and capacity factor. As a result, the incremental cost effectiveness of emission control decreases as boiler size and capacity factor increase.

A similar trend occurs when comparing Alternative Control Level 2 to Alternative Control Level 1. In this case, an outlet SO_2 CEM is required for compliance under Alternative Control Level 2 in addition to fuel sampling and analysis. While the annualized costs for the CEM remain constant as boiler size and capacity factor increase, SO_2 emission reductions increase. In addition, due to economies of scale, the annualized costs of FGD systems (on a heat input capacity basis) decrease as boiler size increases. Thus, the incremental cost effectiveness of emission control between Alternative Control Level 2 and Alternative Control Level 1 decreases as boiler size increases.

4.2 OIL

Tables 7 and 8 present the costs of oil-fired model boilers operating at capacity factors of 0.26 and 0.55, respectively. Annualized costs for boilers at the regulatory baseline range from $330,000/yr at the 2.9 MW (10 million Btu/hour) size and 0.26 capacity factor to $2,623,000/yr at the 29 MW (100 million Btu/hour) size and 0.55 capacity factor. Compared to the regulatory baseline, Alternative Control Level 1 increases annualized costs by 2 to 4 percent; Alternative Control Level 2 increases annualized costs by 8 to 21 percent; and Alternative Control Level 3 increases annualized costs by 29 to 96 percent.

Tables 9 and 10 present the results of the analysis for oil-fired boilers operating at 0.26 and 0.55 capacity factors, respectively. The incremental cost effectiveness of emission control associated with Alternative Control Level 1 over the regulatory baseline remains essentially constant for all boiler sizes and capacity factors, averaging about $339/Mg ($308/ton). This is because the difference in annualized costs between Alternative Control Level 1 and the regulatory baseline is due primarily to the price difference between high and medium sulfur oil. Since both SO_2

emission rates and fuel prices are specified on a heat input basis, varying boiler size or capacity factor has little impact on incremental cost effectiveness.

The incremental cost effectiveness of emission control associated with Alternative Control Level 2 over Alternative Control Level 1 also does not vary with boiler size or capacity factor. The annualized cost differences between the two alternative control levels are again due primarily to the price difference between medium sulfur and very low sulfur oil. As discussed above, when both SO_2 emission rates and fuel prices are specified on a heat input basis, varying boiler size or capacity factor has little impact on incremental cost effectiveness. Thus, the incremental cost effectiveness of emission control between Alternative Control Level 2 and Alternative Control Level 1 remains essentially constant at an average $1,560/Mg ($1,420/ton) for all boiler sizes and capacity factors.

The incremental cost effectiveness of emission control associated with Alternative Control Level 3 over Alternative Control Level 2 increases from $12,300/Mg ($11,200/ton) at the 29 MW (100 million Btu/hour) boiler size and 0.55 capacity factor to $393,000/Mg ($357,000/ton) at the 2.9 MW (10 million Btu/hour) size and 0.26 capacity factor. This increase in incremental cost effectiveness with decreasing boiler size and capacity factor is due to the Alternative Control Level 3 continuous compliance requirement and FGD economies of scale, as discussed for coal-fired boilers in Section 4.1.

5.0 REFERENCES

1. Overview of the Regulatory Baseline, Technical Basis, and Alternative Control Levels for Sulfur Dioxide (SO_2) Emission Standards for Small Steam Generating Units. U. S. Environmental Protection Agency, Research Triangle Park, NC. EPA Publication No. EPA-450/3-89-12. May 1989.

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4. U. S. Environmental Protection Agency. Small Steam Generating Unit Characteristics and Emission Control Techniques. Research Triangle Park, NC. March 31, 1989.

5. Letter from Hogan, T., Energy and Environmental Analysis, Inc., to Link, T. E., EPA/EAB. June 5, 1987. Annualized Industrial Fuel Prices.

6. Memorandum from Copland, R., EPA/SDB, to Waddell, T., Radian Corporation. March 27, 1989. Cost of Oil Shipment (Lot) Sampling/Analysis Alternative for Small Boilers.

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TABLE 1. SO_2 ALTERNATIVE CONTROL LEVELS

	SO_2 Emission Standard	Basis
Coal		
Regulatory baseline	1,550 ng/J (3.6 lb/million Btu)	Medium sulfur coal[a]
Alternative Control Level 1	520 ng/J (1.2 lb/million Btu)	Low sulfur coal[b]
Alternative Control Level 2	90% SO_2 reduction	FGD or FBC[c]
Oil		
Regulatory baseline	1,290 ng/J (3.0 lb/million Btu)	High sulfur oil
Alternative Control Level 1	690 ng/J (1.6 lb/million Btu)	Medium sulfur oil
Alternative Control Level 2	210 ng/J (0.5 lb/million Btu)	Very low sulfur oil
Alternative Control Level 3	90% SO_2 reduction	FGD

[a]Type F-bituminous

[b]Type B-bituminous

[c]FGD = Flue gas desulfurization

FBC = Fluidized Bed Combustion

SOURCE: Reference 1.

TABLE 2. PROJECTED FUEL PRICES FOR EPA REGION V

	$/GJ ($/million Btu)[a]
Coal:	
Low sulfur bituminous	2.73 (2.88)
Medium sulfur bituminous	2.38 (2.51)
Oil:	
High sulfur residual	3.51 (3.70)
Medium sulfur residual	3.70 (3.90)
Distillate	4.61 (4.86)
Natural Gas:[b]	4.49 (4.73)

[a]Levelized prices in June 1985 dollars.

[b]Industrial non-carriage market price. Used during FGD malfunction.

SOURCE: Reference 5.

TABLE 3. Model Boiler Cost Analysis for Sulfur Dioxide Control Alternatives for Coal-fired Boilers in Region V at 0.26 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	Coal type,	Actual SO_2 emission rate, ng/J (lb/MMBtu)		Annual SO_2 emissions, Mg/yr (tons/yr)		Capital costs, $1,000	O & M costs, $1,000/yr			Annualized cost, $1,000/yr
							Fuel	Nonfuel	Total	
2.9 MW (10 MMBtu/hr)										
Baseline	F-BIT	1,230	(2.86)	30	(33)	1,555	57	285	342	599
Level 1/LSC	B-BIT	465	(1.08)	11	(12)	1,580	66	311	377	638
Level 2/PR	F-BIT	93	(0.22)	2.2	(2.5)	2,399	57	479	536	935
7.3 MW (25 MMBtu/hr)										
Baseline	F-BIT	1,230	(2.86)	74	(81)	2,797	143	391	534	998
Level 1/LSC	B-BIT	465	(1.08)	28	(31)	2,823	164	418	582	1,050
Level 2/PR	F-BIT	93	(0.22)	5.6	(6.2)	3,833	143	605	748	1,391
14.6 MW (50 MMBtu/hr)										
Baseline	F-BIT	1,230	(2.86)	150	(160)	4,967	286	592	878	1,703
Level 1/LSC	B-BIT	465	(1.08)	56	(61)	4,994	328	619	947	1,776
Level 2/PR	F-BIT	93	(0.22)	11	(12)	6,366	286	837	1,123	2,159
22.0 MW (75 MMBtu/hr)										
Baseline	F-BIT	1,230	(2.86)	220	(240)	7,136	429	663	1,092	2,280
Level 1/LSC	B-BIT	465	(1.08)	84	(92)	7,165	492	689	1,181	2,374
Level 2/PR	F-BIT	93	(0.22)	17	(18)	8,761	429	936	1,365	2,793
29.3 MW (100 MMBtu/hr)										
Baseline	F-BIT	1,230	(2.86)	300	(330)	9,158	572	742	1,314	2,840
Level 1/LSC	B-BIT	465	(1.08)	109	(120)	9,189	656	768	1,424	2,955
Level 2/PR	F-BIT	93	(0.22)	22	(25)	10,991	572	1,042	1,614	3,482

[a] All costs are in June 1985 dollars.

[b] LSC = Low sulfur coal
PR = Percent reduction system (Flue gas desulfurization or fluidized bed combustion)

[c] No compliance costs are included with the baseline option.

[d] Alternative Control Level 1 includes the compliance costs associated with fuel sampling/analysis.

[e] Alternative Control Level 2 includes the costs associated with daily fuel sampling/analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 4. Model Boiler Cost Analysis for Sulfur Dioxide Control Alternatives for Coal-fired Boilers in Region V at 0.55 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	Coal type,	Actual SO_2 emission rate, ng/J (lb/MMBtu)	Annual S_2 emissions, Mg/yr (tons/yr)	Capital costs, $1,000	O & M costs, $1,000/yr			Annualized cost, $1,000/yr
					Fuel	Nonfuel	Total	
2.9 MW (10 MMBtu/hr)								
Baseline	F-BIT	1,230 (2.86)	63 (69)	1,574	121	355	476	735
Level 1/LSC	B-BIT	465 (1.08)	24 (26)	1,599	139	382	521	784
Level 2/PR	F-BIT	93 (0.22)	4.7 (5.2)	2,424	121	581	702	1,107
7.3 MW (25 MMBtu/hr)								
Baseline	F-BIT	1,230 (2.86)	150 (170)	2,830	302	492	794	1,261
Level 1/LSC	B-BIT	465 (1.08)	59 (65)	2,858	347	518	865	1,337
Level 2/PR	F-BIT	93 (0.22)	12 (13)	3,877	302	751	1,053	1,712
14.6 MW (50 MMBtu/hr)								
Baseline	F-BIT	1,230 (2.86)	310 (340)	5,020	605	729	1,334	2,165
Level 1/LSC	B-BIT	465 (1.08)	120 (130)	5,051	694	755	1,449	2,285
Level 2/PR	F-BIT	93 (0.22)	24 (26)	6,435	605	1,045	1,650	2,753
22.0 MW (75 MMBtu/hr)								
Baseline	F-BIT	1,230 (2.86)	470 (520)	7,207	907	818	1,725	2,920
Level 1/LSC	B-BIT	465 (1.08)	180 (200)	7,241	1,041	843	1,884	3,085
Level 2/PR	F-BIT	93 (0.22)	36 (39)	8,853	907	1,185	2,092	3,618
29.3 MW (100 MMBtu/hr)								
Baseline	F-BIT	1,230 (2.86)	630 (690)	9,247	1,209	917	2,126	3,661
Level 1/LSC	B-BIT	465 (1.08)	240 (260)	9,285	1,388	941	2,329	3,870
Level 2/PR	F-BIT	93 (0.22)	45 (50)	11,106	1,209	1,333	2,542	4,465

[a] All costs are in June 1985 dollars.

[b] LSC = Low sulfur coal
PR = Percent reduction system (Flue gas desulfurization or fluidized bed combustion)

[c] No compliance costs are included with the baseline option.

[d] Alternative Control Level 1 includes the compliance costs associated with fuel sampling/analysis.

[e] Alternative Control Level 2 includes the costs associated with daily fuel sampling/analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 5. Cost Effectiveness Results of Sulfur Dioxide Control Alternatives for Coal-fired Boilers in Region V at 0.26 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	Coal type,	Actual SO_2 emission rate, ng/J (lb/MMBtu)	Annual emission Mg/yr (ton/yr)		Annualized cost, $1000/yr	Incremental cost effectiveness, $/Mg ($/ton)	
2.9 MW (10 MMBtu/hr)							
Baseline	F-BIT	1,230 (2.86)	30	(33)	599	-	-
Level 1/LSC	B-BIT	465 (1.08)	11	(12)	638	2,120	(1,920)
Level 2/PR	F-BIT	93 (0.22)	2.2	(2.5)	935	33,300	(30,200)
7.3 MW (25 MMBtu/hr)							
Baseline	F-BIT	1,230 (2.86)	74	(81)	998	-	-
Level 1/LSC	B-BIT	465 (1.08)	28	(31)	1,050	1,130	(1,030)
Level 2/PR	F-BIT	93 (0.22)	5.6	(6.2)	1,391	15,300	(13,900)
14.6 MW (50 MMBtu/hr)							
Baseline	F-BIT	1,230 (2.86)	150	(160)	1,703	-	-
Level 1/LSC	B-BIT	465 (1.08)	56	(61)	1,776	775	(741)
Level 2/PR	F-BIT	93 (0.22)	11	(12)	2,159	8,580	(7,780)
22.0 MW (75 MMBtu/hr)							
Baseline	F-BIT	1,230 (2.86)	220	(240)	2,280	-	-
Level 1/LSC	B-BIT	465 (1.08)	84	(92)	2,374	690	(636)
Level 2/PR	F-BIT	93 (0.22)	17	(18)	2,793	6,260	(5,680)
29.3 MW (100 MMBtu/hr)							
Baseline	F-BIT	1,230 (2.86)	300	(330)	2,840	-	-
Level 1/LSC	B-BIT	465 (1.08)	109	(120)	2,955	602	(548)
Level 2/PR	F-BIT	93 (0.22)	22	(25)	3,482	6,090	(5,530)

[a] All costs are in June 1985 dollars.

[b] LSC = Low sulfur coal
PR = Percent reduction system (Flue gas desulfurization or fluidized bed combustion).

[c] No compliance costs are included with the baseline option.

[d] Alternative Control Level 1 includes the compliance costs associated with fuel sampling/analysis.

[e] Alternative Control Level 2 includes the costs associated with daily fuel sampling analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 6. Cost Effectiveness Results of Sulfur Dioxide Control Alternatives for Coal-fired Boilers in Region V at 0.55 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	Coal type,	Actual SO_2 emission rate, ng/J (lb/MMBtu)	Annual emission Mg/yr (ton/yr)	Annualized cost, $1000/yr	Incremental cost effectiveness, $/Mg ($/ton)
2.9 MW (10 MMBtu/hr)					
Baseline	F-BIT	1,230 (2.86)	63 (69)	735	- -
Level 1/LSC	B-BIT	465 (1.08)	24 (26)	784	1,260 (1,140)
Level 2/PR	F-BIT	93 (0.22)	4.7 (5.2)	1,107	17,100 (15,500)
7.3 MW (25 MMBtu/hr)					
Baseline	F-BIT	1,230 (2.86)	150 (170)	1,261	- -
Level 1/LSC	B-BIT	465 (1.08)	59 (65)	1,337	835 (724)
Level 2/PR	F-BIT	93 (0.22)	12 (13)	1,712	7,950 (7,210)
14.6 MW (50 MMBtu/hr)					
Baseline	F-BIT	1,230 (2.86)	310 (340)	2,165	- -
Level 1/LSC	B-BIT	465 (1.08)	120 (130)	2,285	632 (571)
Level 2/PR	F-BIT	93 (0.22)	24 (26)	2,753	4,850 (4,500)
22.0 MW (75 MMBtu/hr)					
Baseline	F-BIT	1,230 (2.86)	470 (520)	2,920	- -
Level 1/LSC	B-BIT	465 (1.08)	180 (200)	3,085	569 (516)
Level 2/PR	F-BIT	93 (0.22)	36 (39)	3,618	3,690 (3,310)
29.3 MW (100 MMBtu/hr)					
Baseline	F-BIT	1,230 (2.86)	630 (690)	3,661	- -
Level 1/LSC	B-BIT	465 (1.08)	240 (260)	3,870	536 (486)
Level 2/PR	F-BIT	93 (0.22)	45 (50)	4,465	3,060 (2,830)

[a] All costs are in June 1985 dollars.

[b] LSC = Low sulfur coal
PR = Percent reduction system (Flue gas desulfurization or fluidized bed combustion).

[c] No compliance costs are included with the baseline option.

[d] Alternative Control Level 1 includes the compliance costs associated with fuel sampling/analysis.

[e] Alternative Control Level 2 includes the costs associated with daily fuel sampling analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 7. Model Boiler Cost Analysis for Sulfur Dioxide Control Alternatives for Oil-fired Boilers in Region V at 0.26 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	SO_2 emission rate, ng/J (lb/MMBtu)	Annual SO_2 emissions, Mg/yr (tons/yr)	Capital costs, $1,000	O & M costs, $1,000/yr			Annualized cost, $1,000/yr
				Fuel	Nonfuel	Total	
2.9 MW (10 MMBtu/hr)							
Baseline	1,290 (3.00)	31 (34)	445	84	174	258	330
Level 1/MSRO	688 (1.60)	17 (18)	445	89	175	264	336
Level 2/DISTO	129 (0.30)	3.1 (3.4)	434	111	174	285	355
Level 3/PR	98 (0.23)	2.4 (2.6)	1,172	84	374	458	648
7.3 MW (25 MMBtu/hr)							
Baseline	1,290 (3.00)	77 (85)	733	211	230	441	561
Level 1/MSRO	688 (1.60)	41 (46)	734	222	232	454	573
Level 2/DISTO	129 (0.30)	7.7 (8.5)	717	277	230	507	624
Level 3/PR	98 (0.23)	5.9 (6.5)	1,682	211	455	666	942
14.6 MW (50 MMBtu/hr)							
Baseline	1,290 (3.00)	155 (171)	1,481	421	274	695	939
Level 1/MSRO	688 (1.60)	83 (91)	1,483	444	275	719	963
Level 2/DISTO	129 (0.30)	15 (17)	1,463	553	274	827	1,068
Level 3/PR	98 (0.23)	12 (13)	2,699	421	536	957	1,406
22.0 MW (75 MMBtu/hr)							
Baseline	1,290 (3.00)	232 (256)	1,900	632	318	950	1,264
Level 1/MSRO	688 (1.60)	124 (137)	1,903	666	319	985	1,299
Level 2/DISTO	129 (0.30)	23 (26)	1,883	830	318	1,148	1,458
Level 3/PR	98 (0.23)	18 (19)	3,341	632	615	1,247	1,805
29.3 MW (100 MMBtu/hr)							
Baseline	1,290 (3.00)	310 (342)	2,277	843	361	1,204	1,579
Level 1/MSRO	688 (1.60)	165 (182)	2,281	888	362	1,250	1,626
Level 2/DISTO	129 (0.30)	31 (34)	2,262	1,107	361	1,468	1,839
Level 3/PR	98 (0.23)	24 (26)	3,921	843	691	1,534	2,186

[a] All costs are in June 1985 dollars.

[b] MSRO = Medium sulfur residual oil
DISTO = Distillate oil
PR = 90% SO2 removal (based on flue gas desulfurization)

[c] The compliance costs for Alternative Control Level 1 are the costs associated with shipment fuel sampling/analysis.

[d] No compliance costs associated with distillate oil combustion to meet Alternative Control Level 2.

[e] The compliance costs for Alternative Control Level 3 are the costs associated with daily fuel sampling/analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 8. Model Boiler Cost Analysis for Sulfur Dioxide Control Alternatives for Oil-fired Boilers in Region V at 0.55 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	SO_2 emission rate, ng/J	(lb/MMBtu)	Annual SO_2 emissions, Mg/yr	(tons/yr)	Capital costs, $1,000	O & M costs, $1,000/yr			Annualized cost, $1,000/yr
						Fuel	Nonfuel	Total	
2.9 MW (10 MMBtu/hr)									
Baseline	1,290	(3.00)	66	(72)	461	178	220	398	471
Level 1/MSRO	688	(1.60)	35	(39)	462	188	220	408	482
Level 2/DISTO	129	(0.30)	6.6	(7.2)	453	234	219	453	526
Level 3/PR	98	(0.23)	5.0	(5.5)	1,194	178	452	630	824
7.3 MW (25 MMBtu/hr)									
Baseline	1,290	(3.00)	164	(181)	764	446	291	737	860
Level 1/MSRO	688	(1.60)	87	(96)	766	470	292	762	885
Level 2/DISTO	129	(0.30)	16	(18)	754	585	292	877	997
Level 3/PR	98	(0.23)	12	(14)	1,723	446	565	1,011	1,295
14.6 MW (50 MMBtu/hr)									
Baseline	1,290	(3.00)	328	(361)	1,535	891	346	1,237	1,487
Level 1/MSRO	688	(1.60)	175	(193)	1,539	940	346	1,286	1,537
Level 2/DISTO	129	(0.30)	33	(36)	1,529	1,171	346	1,517	1,764
Level 3/PR	98	(0.23)	25	(27)	2,769	891	682	1,573	2,036
22.0 MW (75 MMBtu/hr)									
Baseline	1,290	(3.00)	492	(542)	1,976	1,337	401	1,738	2,059
Level 1/MSRO	688	(1.60)	262	(289)	1,982	1,409	402	1,811	2,133
Level 2/DISTO	129	(0.30)	49	(54)	1,977	1,756	401	2,157	2,476
Level 3/PR	98	(0.23)	37	(41)	3,440	1,337	797	2,134	2,712
29.3 MW (100 MMBtu/hr)									
Baseline	1,290	(3.00)	656	(723)	2,374	1,783	455	2,238	2,623
Level 1/MSRO	688	(1.60)	350	(385)	2,382	1,879	456	2,335	2,722
Level 2/DISTO	129	(0.30)	66	(72)	2,384	2,342	455	2,797	3,181
Level 3/PR	98	(0.23)	50	(55)	4,046	1,783	910	2,693	3,375

[a]All costs are in June 1985 dollars.

[b]MSRO = Medium sulfur residual oil
DISTO = Distillate oil
PR = 90% SO_2 removal (based on flue gas desulfurization)

[c]The compliance costs for Alternative Control Level 1 are the costs associated with shipment fuel sampling/analysis.

[d]No compliance costs associated with distillate oil combustion to meet Alternative Control Level 2.

[e]The compliance costs for Alternative Control Level 3 are the costs associated with daily fuel sampling/analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 9. Cost Effectiveness Results of Sulfur Dioxide Control Alternatives for Oil-fired Boilers in Region V at 0.26 Capacity Factor[a]

Boiler Size/Control[b,c,d,e]	SO_2 emission rate, ng/J (lb/MMBtu)	Annual emissions, Mg/yr (ton/yr)	Annualized cost, $1000/yr	Incremental cost effectiveness, $/Mg ($/ton)
2.9 MW (10 MMBtu/hr)				
Baseline	1,290 (3.00)	31 (34)	330	- -
Level 1/MSRO	688 (1.60)	17 (18)	336	415 (376)
Level 2/DISTO	129 (0.30)	3.1 (3.4)	355	1,410 (1,280)
Level 3/PR	98 (0.23)	2.4 (2.6)	648	393,000 (357,000)
7.3 MW (25 MMBtu/hr)				
Baseline	1,290 (3.00)	77 (85)	561	- -
Level 1/MSRO	688 (1.60)	41 (46)	573	332 (301)
Level 2/DISTO	129 (0.30)	7.7 (8.5)	624	1,520 (1,380)
Level 3/PR	98 (0.23)	5.9 (6.5)	942	171,000 (155,000)
14.6 MW (50 MMBtu/hr)				
Baseline	1,290 (3.00)	155 (171)	939	- -
Level 1/MSRO	688 (1.60)	83 (91)	963	332 (301)
Level 2/DISTO	129 (0.30)	15 (17)	1,068	1,560 (1,420)
Level 3/PR	98 (0.23)	12 (13)	1,406	90,700 (82,300)
22.0 MW (75 MMBtu/hr)				
Baseline	1,290 (3.00)	232 (256)	1,264	- -
Level 1/MSRO	688 (1.60)	124 (137)	1,299	323 (293)
Level 2/DISTO	129 (0.30)	23 (26)	1,458	1,580 (1,430)
Level 3/PR	98 (0.23)	18 (19)	1,805	62,100 (56,300)
29.3 MW (100 MMBtu/hr)				
Baseline	1,290 (3.00)	310 (342)	1,579	- -
Level 1/MSRO	688 (1.60)	165 (182)	1,626	325 (295)
Level 2/DISTO	129 (0.30)	31 (34)	1,839	1,590 (1,440)
Level 3/PR	98 (0.23)	24 (26)	2,186	46,600 (42,300)

[a]All costs are in June 1985 dollars.

[b]MSRO = Medium sulfur residual oil
DISTO = Distillate oil
PR = 90% SO_2 removal (based on flue gas desulfurization)

[c]The compliance costs for Alternative Control Level 1 are the costs associated with shipment fuel sampling/analysis.

[d]No compliance costs associated with distillate oil combustion to meet Alternative Control Level 2.

[e]The compliance costs for Alternative Control Level 3 are the costs associated with daily fuel sampling/analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

TABLE 10. Cost Effectiveness Results of Sulfur Dioxide Control Alternatives for Oil-fired Boilers in Region V at 0.55 Capacity Factor[a]

Boiler Size/ Control[b,c,d,e]	SO_2 emission rate, ng/J	SO_2 emission rate, (lb/MMBtu)	Annual emissions, Mg/yr	Annual emissions, (ton/yr)	Annualized cost, $1000/yr	Incremental cost effectiveness, $/Mg	Incremental cost effectiveness, ($/ton)
2.9 MW (10 MMBtu/hr)							
Baseline	1,290	(3.00)	66	(72)	471	-	-
Level 1/MSRO	688	(1.60)	35	(39)	482	360	(330)
Level 2/DISTO	129	(0.30)	6.6	(7.2)	526	1,550	(1,400)
Level 3/PR	98	(0.23)	5.0	(5.5)	824	189,000	(172,000)
7.3 MW (25 MMBtu/hr)							
Baseline	1,290	(3.00)	164	(181)	860	-	-
Level 1/MSRO	688	(1.60)	87	(96)	885	327	(297)
Level 2/DISTO	129	(0.30)	16	(18)	997	1,580	(1,430)
Level 3/PR	98	(0.23)	12	(14)	1,295	75,600	(68,600)
14.6 MW (50 MMBtu/hr)							
Baseline	1,290	(3.00)	328	(361)	1,487	-	-
Level 1/MSRO	688	(1.60)	175	(193)	1,537	327	(297)
Level 2/DISTO	129	(0.30)	33	(36)	1,764	1,600	(1,450)
Level 3/PR	98	(0.23)	25	(27)	2,036	34,500	(31,300)
22.0 MW (75 MMBtu/hr)							
Baseline	1,290	(3.00)	492	(542)	2,059	-	-
Level 1/MSRO	688	(1.60)	262	(289)	2,133	322	(293)
Level 2/DISTO	129	(0.30)	49	(54)	2,476	1,610	(1,460)
Level 3/PR	98	(0.23)	37	(41)	2,712	20,000	(18,100)
29.3 MW (100 MMBtu/hr)							
Baseline	1,290	(3.00)	656	(723)	2,623	-	-
Level 1/MSRO	688	(1.60)	350	(385)	2,722	324	(294)
Level 2/DISTO	129	(0.30)	66	(72)	3,181	1,620	(1,470)
Level 3/PR	98	(0.23)	50	(55)	3,375	12,300	(11,200)

[a] All costs are in June 1985 dollars.

[b] MSRO = Medium sulfur residual oil.
DISTO = Distillate oil.
PR = 90% SO_2 removal (based on flue gas desulfurization)

[c] The compliance costs for Alternative Control Level 1 are the costs associated with shipment fuel sampling/analysis.

[d] No compliance costs associated with distillate oil combustion to meet Alternative Control Level 2.

[e] The compliance costs for Alternative Control Level 3 are the costs associated with daily fuel sampling/analysis at the FGD inlet and continuous emission monitoring at the FGD outlet.

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This report presents estimates of the cost and cost effectiveness associated with controlling sulfur dioxide (SO_2) emissions from small coal-and oil-fired industrial-commercial-institutional steam generating units (small boilers). The report was prepared during development of proposed new source performance standards (NSPS) for small boilers (boilers with heat input capacities of 100 million Btu/hour or less).

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