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**ULTRAFINE CALCIUM AEROSOL:
GENERATION AND USE AS A SORBENT
FOR SULFUR IN COAL COMBUSTION**

Final Report for the Period
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DEPARTMENT OF DEVELOPMENT
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November 1991

MASTER

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**Ultrafine Calcium Aerosol: Generation and Use
as a Sorbent for Sulfur in Coal Combustion**

PART II

**Economic Feasibility Study of
Dry-Injection of Novel Powders
for Flue Gas Desulfurization**

by

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8/24/91

INTRODUCTION

The goal of this study is to determine the cost effectiveness of using calcium-hydroxide powder sorbent in a commercial power plant flue gas desulfurization (FGD) application. The cost analysis methodology found herein is a direct application of the one found in the January 1986 report, "Economic Evaluation of Dry-Injection Flue Gas Desulfurization Technology" by the Electric Power Research Institute (EPRI). The EPRI study addresses the economic issue of installing a dry-injection FGD system on a 1000 MW (2-500 MW units) power plant using sodium-rich powder sorbents derived from nahcolite and trona ores. In this report's treatment, the calcium-based derivatives of hydrated limestone are compared directly to nahcolite and trona for both low and high sulfur coals. This type of evaluation is allowable due to the similar material handling properties of 1/4 inch hydrated limestone in comparison to those properties for nahcolite and trona. Thus, this report repeats the EPRI cost analysis for a slightly modified limestone-based FGD design. Note that the calculation methodology is not discussed in this report as it has already been outlined in the EPRI study. Instead, Appendices A and B contain copies of the calculation spreadsheets based on the EPRI method for the hydrated limestone system. Comments have been inserted throughout the calculations to explain assumption or design considerations that differ from those of the original EPRI treatment. In order to establish a basis for comparison, the EPRI calculations were re-applied for nahcolite and trona using a spreadsheet similar to the hydrated limestone analysis. These last calculations have not been included in the original text of this report but they are provided on the accompanying diskette for reference purposes.

This report compliments the experimental study in part I of this report in which

two different sorbents were used: aluminum isopropoxide (organometallic), and calcium hydroxide. Due to the unique design requirements and the high costs associated with the use of the organometallic, an economic study is not justified at this time. The following study considers the use of hydrated lime.

SYSTEM OVERVIEW

The simplified schematic for a single boiler, modified FGD system as suggested by the EPRI study is shown in Figures 1 and 2. Note that the primary difference between limestone systems and the nahcolite/trona system is the injection point for the reagent: the limestone is injected before combustion in the make-up air inlet stream while the trona/nahcolite injection point is directly after combustion near the air preheater section. It may be necessary to move the limestone injection point before the boiler due to the high temperature requirements of the calcium-hydroxide desulfurization reaction. The cost associated with relocating the injection ductwork is assumed to be negligible in this report. Note that a similar injection scenario is suggested in the original EPRI study for injection of regular, non-hydrated limestone. The primary difference between this treatment of limestone and the one of the EPRI study is that hydrated limestone must be stored in covered, dry silos much like the trona and nahcolite whereas the untreated limestone may be piled in much less expensive outdoor shelters. This is another reason that the EPRI study method may be considered directly applicable to the economic FGD analysis of hydrated limestone.

In regards to the original EPRI treatment, this treatment differs in that each boiler is assumed to be serviced by two 50-percent capacity pulverizer systems. This slight design modification nearly doubles the capital costs of Area 20 (the pulverizer

Note: flow surfaces 1-9 are not referenced in this report.

These design schematics are a slightly modified editions of the one found in the original EPRI treatment. [See reference (1), Sect.3, pg.2 for original schematic]

Figure 1: Hydrated limestone FGD Process Flow Diagram for Reagent Handling, SO₂, and Particulate Removal Systems

These design schematics are a slightly modified editions of the one found in the original EPRI treatment. [See reference (1), Sect.3, pg.2 for original schematic]

Figure 2: Nahcolite/Trona FGD Process Flow Diagram for Reagent Handling, SO₂, and Particulate Removal Systems

area) over the single, full-capacity design used in the original EPRI study. This liberal choice of double redundancy was taken because it is thought to be a more realistic assumption when individual maintenance and downtime of the pulverizers is considered. Also, this type of pulverization system can easily handle the extra tonnage of reagent needed for flue gas desulfurization if reagent purity (percent active Ca or Na) drops slightly below the design specifications for any given reagent. For example, if small amounts of dolomitic limestone were mixed with the high-calcium limestone used in this report. The change in the total system costs for this type of reagent substitution is thought to be small for two reasons: the differential labor, power, and waste handling costs would be small compared to the other costs of the system; and the baghouse specification (28-32 compartments per house) should be able to handle the extra spent reagent tonnage without incurring additional cost. The only major change to the economics would be the additional cost incurred in purchasing larger amounts of bulk reagent; thus, if the drop in amount of available calcium (or sodium) in a given reagent is small (less than 15%), the total operation costs will not change significantly.

In order to completely understand the EPRI system, the reader is referred directly to the original EPRI study as listed in the reference section of this report. The detailed outline of the system mechanics is beyond the scope of this analysis so it is assumed that the reader has the report or they are familiar with its content. Requests for copies of the EPRI report should be directed to Research Report Center (RCC), P.O. Box 50490, Palo Alto, CA 94303, (415) 965-4081. The remainder of this report is dedicated to a discussion of the economic results and conclusions of the analysis.

DISCUSSION OF RESULTS

The results as shown in Figures 3-9 represent the respective economic performances of hydrated limestone versus nahcolite and trona ores as each reactant was used to size a 70-percent efficient FGD system. In all cases, a 1000 MW power plant output was assumed as generated by two 500 MW boiler units. Each boiler was assumed to have its own FGD and fabric filter systems while a common reagent handling area was shared by all boiler lines. Based on the combustion properties of the coal and the quantity of sulfur in the flue gases, the amount of reagent needed to reach the desired desulfurization efficiency and overall levelized costs of the FGD system were determined. In order to demonstrate the sensitivity of the evaluation to the coal's sulfur content and flue gas flowrate, calculations were performed on each reagent using both low and high sulfur coal combustion data. In order to more clearly show the distribution of costs, the EPRI example is again followed by charting FGD and fabric filter particulate control system costs separately. A discussion of the economic findings of this analysis is given below.

Base Case O&M Costs.

Figures 3 and 4 show the base O&M reagent cost performances for low and high sulfur coals respectively. Note that the units of cost are given in dollars per kilowatt of plant generating capacity (\$/kW) in 1982 dollars. These numbers give an indication of the expected fixed and variable costs incurred for the system during the first year of operation. In this case, fixed costs represent the annual manpower and

First year \$/kW - December 1982

FGD Base Case O&M Cost

First year \$/kW - December 1982

Fabric Filter Base Case O&M Cost

Figure 3: Base Case O&M Cost For Low Sulfur Coal

First year \$/kW - December 1982

FGD Base Case O&M Cost

First year \$/kW - December 1982

Fabric Filter Base Case O&M Cost

Figure 4: Base Case O&M Cost For High Sulfur Coal

maintenance material costs of operation while variable costs make up the remainder of the bar graph items, i.e. waste handling, reagent, bag filter, and power costs. Note that the variable costs for FGD are different than those associated with the fabric filters. Example calculations for the hydrated limestone may be found at the end of this report under the heading, '5.4 OPERATING AND MAINTENANCE CALCULATIONS.'

FGD. In general, the most significant feature of Figures 3 and 4 is that the calculated total FGD O&M costs for the hydrated limestone system are less than one-third of those for the nahcolite and trona based systems. This can primarily be attributed to the fact that limestone typically has a much larger amount of available reactant (active calcium) than either of the sodium-based ores. For example, the hydrated limestone used in this analysis has 49.9-percent available calcium while nahcolite and trona yield respectively only 19.3 and 26.25-percent available sodium. Given the reaction chemistry (stoichiometry and NSR for 70% efficiency), the calculations conclusively show that much larger amounts of nahcolite and trona are needed to reach the desired SO₂ removal efficiency. Also, since the average bulk price of the limestone is significantly less than that for nahcolite and trona, this also contributes to the apparent cost differences. (See TABLE 1, Bulk Reagent Price Data) Clearly, chemical availability (percent active component) and bulk reagent costs play highly sensitive roles in these economic calculations. In regard to FGD O&M costs, the figures indicate that hydrated limestone yields the best economic value.

Fabric filters. The lower portions of Figures 3 and 4 show that these associated fabric filter costs are not affected by the choice of reagent using the EPRI economic method. This is because these costs are functions of the flue gas flow rate and, to a lesser extent, the amount of ash generated by the coal combustion. Examination of the calculation spreadsheets show that both of these last properties are strongly

dependent on the type of coal being utilized.

Base Case Capital Costs

The bar charts as shown in Figures 5 and 6 show the associated capital cost distributions for each reagent given low and high sulfur coals respectively. Example capital cost calculations for hydrated limestone may be found in the Appendices under the heading, '5.3 CAPITAL COST CALCULATIONS.'

FGD. Figures 5 and 6 show the capital cost for FGD to be dominated by one item: process capital. Process capital is the largest expense here because it represents the equipment costs (purchase and installation) required for each system to handle specific amounts of raw material and pulverized reagent. Since these costs are governed by the amount of reagent necessary to reach 70-percent desulfurization efficiency, again we see that the favorable chemical attributes of hydrated limestone result in much lower cost than either nahcolite or trona. Within the actual process capital calculations, as shown in Appendices A and B, it can be seen that the largest share of process capital costs are associated with the reagent receiving and pulverization (Areas 10 and 20).

In regards to the other FGD capital costs, only two, preproduction costs and inventory capital, are not taken to be directly proportional to the process capital expense. For example, engineering and home office fees are taken to be 12.5-percent of the process capital cost. Thus, when the process capital cost grows, these linked items also grow in a proportional manner. The remaining item of preproduction cost is taken to be a weak function of FGD O&M costs and total plant investment, TPI.

Figure 5: Base Case Capital Cost for Low Sulfur Coal

Figure 6: Base Case Capital Cost for High Sulfur Coal

Inventory capital is taken to be the 'as received' price of two months worth of reagent. Again, the reader is referred to the original EPRI study for details on these calculations.

Fabric filters. As in the case of O&M costs, the distribution of capital cost associated with the fabric filters is not sensitive to the type of reagent being utilized. These costs depend only on the amount of ash being generated and the flow rate of the combustion flue gases. However, it is worth noting that the total fabric filter capital costs are, in general, significantly greater than those associated with FGD. We also note that in the original EPRI analysis, these same items are much less expensive and approximately equal in magnitude. The primary reason for this difference is that the coals used in this analysis have much higher sulfur and ash contents than the coal used in the EPRI study. For example, the Wyoming low sulfur coal used in the EPRI treatment has just 0.48-percent sulfur and 6.4-percent ash content! The coals used in this analysis were not chosen for their unique ability to minimize the costs but because they represent typical coals whose usage might benefit from their integration with a dry-injection FGD system. Therefore, the academic analysis presented here may be viewed as practical from both the engineering and economic standpoints.

Distribution of Levelized Costs

The bar chart Figures 7 and 8 show the associated levelized cost distribution for each reagent given low and high sulfur coals. Note that the units of levelized cost are given in mills per kilowatt-hour (Mill/kWH) over the 30 year period from 1983 to 2012. These figures are more informative than those of the previous discussions in

FGD Distribution of Levelized Cost

Fabric Filter Distribution of Levelized Cost

Figure 7: Base Case Levelized Cost for Low Sulfur Coal

30 Year Levelized Cost MIII/KWH - (1983-2012)

FGD Distribution of Levelized Cost

30 Year Levelized Cost MIII/KWH - (1983-2012)

Fabric Filter Distribution of Levelized Cost

Figure 8: Base Case Levelized Cost for High Sulfur Coal

that the levelized basis is applied to both O&M costs (fixed and variable) and the start-up process capital costs simultaneously. In fact, the levelized costs give an indication of the total cost (in 1983 dollars) over 30 years as distributed on an averaged annual basis. This explains why the levelization of the once incurred capital costs contribute much less than annually incurred fixed and variable costs. For further information on the method or levelization factors, consult the economic premise as listed in the original EPRI report.

FGD. The upper bar graphs given in Figures 7 and 8 confirm the trends established in the previous discussions: the economic FGD performance of hydrated limestone is superior to that of either nahcolite or trona. Once again, this economic superiority is achieved due to the hydrated limestone's reasonable pricing and excellent availability of calcium. Notice that the levelized FGD cost of using the hydrated limestone is less than one-third of those similar costs for the other reagents. This result is to be expected since the total levelized costs are dominated by the previously discussed O&M costs. (See Figures 3 and 4, FGD Base Case O&M Cost Distributions)

Fiber filter. The lower portions of Figures 7 and 8 show the expected result that the fabric filter costs are not influenced by the choice of reagent. These costs depend only on the combustion flue gas rate and coal ash content .

Sensitivity to Reagent Price

Figure 9 shows the results of a sensitivity analysis that demonstrate the dependence of the total (FGD+Fabric Filter) levelized costs as affected by the

Levelized Cost Sensitivity to Reagent Price

Levelized Cost Sensitivity to Reagent Price

Figure 9: Levelized Total Cost Sensitivity to Reagent Price

'as received' reagent price. This analysis was performed using the calculation spreadsheets by varying the reagent bulk price as shown below:

	Avg. reagent price used in base-case calculations (\$/ton)	Sensitivity study reagent price range (\$/ton)
hydrated limestone	60.00	45.00 - 90.00
nahcolite	100.00	50.00 - 150.00
trona	75.00	37.50 - 112.50

TABLE 1: Bulk Reagent Price Data

The results in Figure 9 show that hydrated limestone is the least sensitive to reagent price variation. Table 2 below quantifies the sensitivities (slopes in this case) as shown in Figure 9.

	Sensitivity, (MILLS/kWH)/(\$/ton)	
	<u>1.5% sulfur coal</u>	<u>3.5% sulfur coal</u>
hydrated limestone	0.0409	0.0730
nahcolite	0.0994	0.174
trona	0.117	0.204

TABLE 2: Levelized Total Cost Sensitivity to Reagent Price

Sensitivity to NSR

In this report, a sensitivity analysis of levelized cost with respect to varying NSR, normalized stoichiometric ratio, has not been performed. The NSR represents the experimentally determined molar ratio of active component (Ca or Na) to sulfur required to reach a specific level of desulfurization - 70-percent desulfurization in the case of this study. It has been assumed that the NSR values used in the calculations provide an accurate representation of the actual desulfurization reaction; so therefore, a lengthy analysis of this type is thought not to be justified. However, this does not imply that the NSR is not important! In fact, the NSR value is one of the most critical considerations in the entire analysis. Within the calculations, it is used as a multiplying factor to determine the amount of reagent needed to reach the needed 70-percent removal efficiency and any large error in this value can add or subtract millions to the economic analysis. Thus, the NSR value is not to be trivialized.

In the future, as more accurate NSR data becomes available, the calculation spreadsheets supplied with this report can be easily modified to yield a more representative economic analysis. Until then, the results presented herein provide an adequate model based on the EPRI method and available data set.

Sensitivity to Coal Sulfur Content

The data as presented in Table 3 below represent the primary effects of changing the coal's sulfur content on the FGD only levelized costs. Note that the EPRI method accounts for the costs associated with the FGD separately from those of the

fabric filters (particulate handling), so it is possible to segregate the effects of sulfur content in the levelized cost analysis, i.e., FGD costs change with sulfur content and fabric filter costs change largely with flue gas flowrate and coal ash content. The combustion properties for each coal may be found on the first pages of Appendices A and B.

	FGD Levelized Cost (MILLS/kWH)		$\Delta\%$ change in	$\Delta\%$ change in
	<u>low sulfur coal</u>	<u>high sulfur coal</u>	<u>sulfur</u>	<u>levelized cost</u>
hyd. limestone	4.01	6.53	133.0	62.84
nahcolite	13.23	21.22	133.0	60.39
trona	12.15	20.35	133.0	67.48

TABLE 3: FGD Levelized Cost Sensitivity to Coal Sulfur Content

As expected, the results as given in Table 3 shows that increases in percent sulfur significantly affect the levelized costs associated with the FGD system. Note that this report does not discuss the fabric filter levelized cost sensitivity due to flue gas rate and coal ash content. These expenses are small compared to the those associated with the varying sulfur content.

CONCLUSIONS

An economic evaluation of the feasibility of using hydrated limestone versus nahcolite and trona ores for dry-injection FGD has been presented using combustion data for both low and high sulfur coal. An economic analysis based on the original EPRI method has been generated and formulations put into spreadsheet form for greater accuracy in calculation. It is concluded from these economic calculations and their subsequent evaluation that the FGD performance of hydrated limestone is economically superior to both nahcolite and trona ores. It is suggested that in the future, efforts be taken to further refine the sorbent NSR database so that a more precise economic evaluation may be performed. Until then, the data and results provided in this report may be assumed to be accurate representations of hydrated limestone's economic worth as an FGD sorbant.

REFERENCES

"Economic Evaluation of Dry-Injection Flue Gas Desulfurization Technology", EPRI CS4373 (Jan. 1986)

"Coal Conservation Systems Technical Data Book", HCP/T2286-01/4, Section IA.50.1, p. 10a (March 1982)

APPENDIX A

Hydrated Limestone FGD Spreadsheet Calculations (w/ low sulfur coal combustion data)

Single plant size and coal energy analysis:

Coal source:	Pennsylvania, Butler County, Upper Freemont		<man.input>
Single plant output:	500	MW	<man.input>
Single plant heat rate:	9,000	BTU/Kwh	<man.input>
Coal heating value:	9,000	BTU/lb	<man.input>
Coal consumption rate:	250	tons/hr	<man.input>
Gas rate (boiler inlet):	1,216,000	scfm	<man.input>
Gas rate (preheater outlet):	1,811,840	scfm	<autocalc>
Target SO2 removal:	70	percent	<man.input>

Ultimate coal analysis: (wt%, dry basis)

C (carbon):	69.20	<man.input>
H (hydrogen):	4.46	<man.input>
S (sulfur):	1.50	<man.input>
N2 (nitrogen):	1.30	<man.input>
O2 (oxygen):	7.74	<man.input>
Ash:	15.80	<man.input>
Total:	100.00	<autocalc>

Flue gas composition: (mole%, wet basis)

CO2 (Carbon dioxide):	14.20	<man.input>
O2 (oxygen):	3.30	<man.input>
N2 (nitrogen):	74.60	<man.input>
H2O (water):	7.80	<man.input>
SO2 (sulfur dioxide):	0.1150	<man.input>
Total:	100.0	<autocalc>

Reference:

Coal Conservation Systems Technical Data Book,
HCP/T2286-01/4, Section IA.50.1, p.10a. (March 1982)

Comments:

- 1.) The flue gas characteristics are given based on 20% excess air rate.
- 2.) The moisture content of the analysis is 2.6% by weight
- 3.) Feed air is at 80 °F and 60% relative humidity for this analysis.
- 4.) Complete combustion of the coal is assumed.
- 5.) Air preheater outlet conditions are assumed to be 277°F and 16 psia

Analysis of reactant:

Powder sorbant: calcium hydroxide as hydrated lime <man.input>

Reactant near analysis: (wt%)

Calcium hydroxide: 92.4 <man.input>

Bulk remainder: 7.6 <man.input>

Total: 100 <autocalc>

Percent available Ca in pure reagent: 54.1 <man.input>

Percent available calcium in study, %Ca.: 49.9884 <autocalc>

Delivered cost of reactant (\$/ton): 60 <man.input>

Important values for a multiple boiler plant. (assume all boilers same capacity):

Number of boilers: 2 <man.input>

Single boiler capacity: 500 MW <autocalc>

Total power output: 1,000 MW <autocalc>

Sum total coal required: 500 tons/hr <autocalc>

Sum total hot flue gas rate: 3,623,680 scfm <autocalc>

5.2 REAGENT AND WASTE QUALITY CALCULATIONS (per boiler)

5.2.1 Step 1: Plant heat method to determine lb-Sulfur per hour (S).

%S F.G.: 100 % S assumed to gases <man.input>

$$S = (M_{\text{coal}})(\%S)(\%S \text{ F.G.})(0.2)$$

S = 7,500 lb-S/hr <autocalc>

5.2.2 Step 2: Calculation of stoichiometric amount of reagent for pure reaction.

$$M1 = (0.06263)(S)/(\%Ca)$$

M1 = 9.40 tons/hr <autocalc>

5.2.3 Step 3: Calculation to determine sorbant injection rate for 70% removal.

From experimental data at the reaction temperature of 750 °C, this efficiency is achieved for the specified NSR value as given below.

NSR70% = 0.92 (ratio) <man.input>

$$Mr = (M1)(NSR70\%)$$

Mr = 8.64 tons/hr <autocalc>

5.2.4 Step 4: Calculation to determine tons per hour of spent sorbant.

Since the sorbant being used is nearly 100% pure (and dry), it is concluded that the amount of spent sorbant is approximately proportional to the ratio of solids out to solids in. This is of course only valid if all the sorbant is assumed to react. This is on an absolute molar mass basis.

$$R_{\text{solids}} = \{(\text{mol solids out}) * M[\text{solids out}]\} / \{(\text{mol solids in}) * M[\text{solids in}]\}$$

Rsolids = 1.621 (ratio) <man.input>

$$M_{\text{spent}} = (Mr)(R_{\text{solids}})$$

Mspent = 14.01 tons/hr <autocalc>

5.2.5 Step 5: Calculation to determine tons per hour of fly ash.

$$M_{\text{ash}} = (0.01)(M_{\text{coal}})(\%ash)(\%fly \text{ ash}) / (100 - \%carbon \text{ in ash})$$

Mash = 36.09 tons/hr <autocalc>

5.2.6 Step 6: Calculation to determine the total waste production rate.

$$M_{\text{waste}} = M_{\text{spent}} + M_{\text{ash}}$$

Mwaste = 50.10 tons/hr <autocalc>

5.3 CAPITAL COST CALCULATIONS

5.3.1.1 Reagent Unloading and Storage Installed Capital Cost (C10).

Using EPRI Fig. 5-3 based on the total sorbant flow rate, TSFR=(Mr)(no. boilers):

$$C10 = \$4,000,000 \quad \text{<man.input>}$$

5.3.1.2 Pulverizer Area Installed Capital Costs (C20).

Using EPRI Fig. 5-4 based on TPH=Mr/2 (redundancy=2) per pulverizer system:

$$$(TPH \text{ on Fig. 5-4}) = \$1,700,000 \quad \text{<man.input>}$$

$$C20 = $(\text{Redundancy})(\text{No. Boilers})$$

$$C20 = \$6,800,000 \quad \text{<autocalc>}$$

Note: the material handling properties were assumed to lie somewhere between those listed for Trona and Nahcolate. Also, a double redundancy factor was used for this calculation. (i.e. 2-50% system)

5.3.1.3 SO₂ Removal Capital Costs (C30).

Using EPRI Fig. 5-5 based on the sorbant flow rate per boiler, Mr:

$$$(Mr \text{ on Fig. 5-5}) = \$140,000 \quad \text{<man.input>}$$

$$C30 = $(\text{No. Boilers})$$

$$C30 = \$280,000 \quad \text{<autocalc>}$$

5.3.1.4 Differential Capital Costs (C40).

Using EPRI Fig. 5-6 based on Mash and Mwash rates per boiler:

$$ASC(\text{Mwash Fig. 5-6, curve C}): \$4,300,000 \quad \text{<man.input>}$$

$$ASCa(\text{Mash Fig. 5-6, curve C}): \$3,600,000 \quad \text{<man.input>}$$

$$IDFC = (0.098)(acfm)(\text{No. Boilers})$$

$$IDFC = \$355,121 \quad \text{<autocalc>}$$

$$AHDC = (ASC-ASCa)(\text{No. Boilers})$$

$$AHDC = \$1,400,000 \quad \text{<autocalc>}$$

$$C40 = AHDC+IDFC$$

$$C40 = \$1,755,121 \quad \text{<autocalc>}$$

CAPITAL COST CALCULATIONS: (continued)

where: ASCt = Ash system cost for total waste
ASCa = Ash system cost for ash only
IDFC = Installed Differential Fan Cost
AHDC = Ash Handling Differential Cost

General Support Capital Costs (C50).

C50 = \$50,000 (all cases) <man.input>

Baghouse Capital Costs. (C60).

Using EPRI Fig. 5-7 based on flue gas flow rate per boiler:

\$(Mr on Fig. 5-7) = \$26,000,000 <man.input>

C60 = \$(No. Boilers with baghouses)

C60 = \$52,000,000 <autocalc>

5.3.1.7 Total Process Capital Costs (A).

A = C10+C20+C30+C40+C50+C60

A = \$64,885,121 <autocalc>

TOTAL PROCESS CAPITAL SUMMARY TABLE

<autocalc>

	<u>FGD</u>	<u>Fabric Filter</u>
Area 10:	C10 = \$4,000,000	\$0
Area 20:	C20 = \$6,800,000	\$0
Area 30:	C30 = \$280,000	\$0
Area 40:	C40 = \$1,755,121	\$0
Area 50:	C50 = \$50,000	\$0
Area 60:	C60 = <u>\$0</u>	<u>\$52,000,000</u>
TOTAL PROCESS CAPITAL (A):	\$12,885,121	\$52,000,000

CAPITAL COST CALCULATIONS: (continued)

5.3.2 Total Plant Cost (TPC) and 5.3.3.1 Total Plant Investment (TPI) Summary

TPC/TPI SUMMARY TABLE <autocalc>

		<u>FDG</u>	<u>Fabric Filter</u>
(A) Total Process Capital		\$12,885,121	\$52,000,000
(B) General Facilities (10% of A)		\$1,288,512	\$5,200,000
(C) Engineering & Home Office Fees (12.5% of A)		\$1,610,640	\$6,500,000
(D) Project contingency			
Area 10:	= (C10)(0.25)	\$1,000,000	\$0
Area 20:	= (C20)(0.25)	\$1,700,000	\$0
Area 30:	= (C30)(0.30)	\$84,000	\$0
Area 40:	= (C40)(0.20)	\$351,024	\$0
Area 50:	= (C50)(0.25)	\$12,500	\$0
Area 60:	= (C60)(0.07)	\$0	\$3,640,000
TOTAL=	\$6,787,524	\$3,147,524	\$3,640,000
(E) Process contingency			
Area 10:	= (C10)(0.075)	\$300,000	\$0
Area 20:	= (C20)(0.30)	\$2,040,000	\$0
Area 30:	= (C30)(0.40)	\$112,000	\$0
Area 40:	= (C40)(0.05)	\$87,756	\$0
Area 50:	= (C50)(0.10)	\$5,000	\$0
Area 60:	= (C60)(0.00) (NOTE 1)	\$0	\$0
TOTAL=	\$2,544,756	\$2,544,756	\$0
(F) Sales Tax (NOTE 2)		\$0	\$0
TOTAL PLANT COSTS (TPC)		\$21,476,553	\$67,340,000
AFDC (3.7% of TPC)		\$794,632	\$2,491,580
TOTAL=	\$3,286,212		
TOTAL PLANT INVESTMENT (TPI)		\$22,271,185	\$69,831,580
TOTAL=	\$92,102,765		

NOTE 1 - Area 60 fabric filter optionally included or stand alone

NOTE 2 - Factored into installed capital cost for this EPRI study method

CAPITAL COST CALCULATIONS: (continued)

5.3.3.2 Other Capital Items.

- Royalties (G) assumed zero for this EPRI study method.
- Preproduction costs (H) is calculated from the first year fixed (FOM) and variable (VOM) operating costs and TPI in this EPRI study method.

$$\begin{array}{lll}\text{FGD:} & H = (1/12)(FOM+VOM)+2\%(TPI_{fgd}) & \\ & H = \$1,127,158 & \text{<autocalc>}\end{array}$$

$$\begin{array}{lll}\text{Fabric Filters:} & H = (1/12)(FOM+VOM)+2\%(TPI_{ff}) & \\ & H = \$1,955,658 & \text{<autocalc>}\end{array}$$

- Inventory capital (I) is two months of reagent costs

$$\begin{array}{lll}\text{FGD:} & I = (1/6)(8760 \text{ hr/yr})(Mr)(\text{No. boilers})(\$/\text{ton of reagent}) & \\ & I = \$1,514,594 & \text{<autocalc>}\end{array}$$

- Land cost (K) is treated as an operating cost in this EPRI study method.
It is included in the waste handling and is not treated separately.

5.4 OPERATING AND MAINTENANCE COST CALCULATIONS

5.4.1.1 Annual Operating Labor (L).

$$\begin{array}{lll}\text{FGD:} & L = (OJ)(ALR)(8760 \text{ hr/yr}) & \\ & L = \$240,462 & \text{<autocalc>}\end{array}$$

where: OJ = operators on duty per shift, default=0.75(No. Boilers)
= 0.5 FOR REAG. HANDLING + 0.5(No. boilers) FOR FGD
ALR = average labor rate, default=\$18.30/man-hr

$$\begin{array}{lll}\text{Fabric Filters:} & L = (OJ)(ALR)(8760 \text{ hr/yr}) & \\ & L = \$224,431 & \text{<autocalc>}\end{array}$$

where: OJ = operators on duty per shift, default=0.70(No. Boilers)
ALR = average labor rate, default=\$18.30/man-hr

5.4.1.2 Annual Operating Maintenance and Support Costs

$$\begin{array}{lll}\text{FGD:} & \text{Maintenance labor (M)} = (0.02)(A) & \\ & M = \$257,702 & \text{<autocalc>}\end{array}$$

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

Maintenance materials (N) = (0.03)(A)

N = \$386,554

<autocalc>

Administrative and Support Labor (P) = (0.3)(L+M)

P = \$149,449

<autocalc>

Fabric Filters:

Maintenance labor (M) = (0.02)(A)

M = \$1,040,000

<autocalc>

Maintenance materials (N) = (0.03)(A)

N = \$1,560,000

<autocalc>

Administrative and Support Labor (P) = (0.3)(L+M)

P = \$379,329

<autocalc>

5.4.1.3 Annual Total Fixed Cost (FOM).

FGD:

FOM = L+M+N+P

FOM = \$1,034,167

<autocalc>

Fabric Filters:

FOM = L+M+N+P

FOM = \$3,203,761

<autocalc>

5.4.2.1 Annual Reagent Costs (RC).

RC = (Mr)(URC)(NCF)(No. Boilers)(8760 hr/yr)

RC = \$5,906,918

<autocalc>

where: URC = Unit reagent cost (\$/ton)

NCF = Normal Capacity Factor (0.65 used for this EPRI study method)

5.4.2.2 Annual Power Cost (PC).

The FGD power used in the EPRI study method is dominated by the requirements of the following areas: 10, 20 and 40.

Area 10 annual FGD power usage (PU10).

Using EPRI Fig. 5-8 based on the total sorbant flow rate, TSFR=(Mr)(No. Boilers):

PU10 = kW(TSFR on Fig. 5-8)

PU10 = 100 kW

<man.input>

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

Area 20 annual FGD power usage (PU20).

Using EPRI Fig. 5-9 based on $TPH = Mr/2$ (redundancy=2) per pulverizer system:

kW(TPH on Fig. 5-9) = 200 kW <man.input>

PU20 = kW(TPH on Fig. 5-9)(Redundancy)(No. Boilers)

PU20 = 800 kW <autocalc>

Area 40 annual FGD power usage (PU40).

Using EPRI Fig. 5-10 based on air scfm/ boiler & 1.5" W.G. drop/fan:

kW(scfm on Fig. 5-10) = 360 kW <man.input>

PU40 = kW(scfm on Fig. 5-10)(No. Boilers)

PU40 = 720 kW <autocalc>

Annual FGD net approximate power cost (PCfgd).

$PCfgd = [(PU10+PU20+PU40)(UPC)(HCF)(8670 \text{ hr/yr})]/1000$

PCfgd = \$505,634 <autocalc>

where: UPC = unit power cost (mills/kWh), 45 used for EPRI study method

HCF = high capacity factor, 0.80 used for EPRI study method

The fabric filter area power used in the EPRI study method is dominated by the requirements of area 60.

Area 60 annual FGD power usage (PU60).

Using EPRI Fig. 5-10 based on scfm air/ boiler & 7.5" W.G. across filters:

kW(scfm on Fig. 5-10) = 1,800 kW <man.input>

PU60 = kW(scfm on Fig. 5-10)(No. Boilers)

PU60 = 3,600 kW <autocalc>

Annual fabric filter net approximate power cost (PCff).

$PCff = [(PU60)(UPC)(HCF)(8670 \text{ hr/yr})]/1000$

PCff = \$1,123,632 <autocalc>

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

where: UPC = Unit power cost (mills/kWh), 45 used for EPRI study method

HCF = High capacity factor, 0.80 used for EPRI study method

5.4.2.3 Annual Waste Disposal Costs.

Annual total waste disposal cost for ash and spent sorbant (WCt):

$$WCt = (M_{\text{waste}})(HDC)(NCF)(8760 \text{ hr/yr})(\text{No. Boilers})$$

$$WCt = \$2,624,731 \quad \text{<autocalc>}$$

where: HDC = High disposal cost (\$/ton), \$4.60 for EPRI study method

NCF = Normal capacity factor, 0.65 used for EPRI study method

Annual total waste disposal cost for ash only (WCa).

$$WCa = (M_{\text{ash}})(LDC)(NCF)(8760 \text{ hr/yr})(\text{No. Boilers})$$

$$WCa = \$1,890,639 \quad \text{<autocalc>}$$

where: LDC = Low disposal cost (\$/ton), \$4.60 for EPRI study method

NCF = Normal capacity factor, 0.65 used for EPRI study method

Annual additional cost for waste disposal (WCn)

$$WCn = WCt - WCa$$

$$WCn = \$734,092 \quad \text{<autocalc>}$$

5.4.2.4 Annual Bag Replacement Cost (BRC)

$$BRC = [(acfm)(BRR)(UBRC)(\text{No. Boilers})] / [(A/C)(CA)]$$

$$BRC = \$490,284 \quad \text{<autocalc>}$$

where: BRR = Bag replacement rate, default to 0.33

UBRC = Unit bag replacement costs, default to \$82/bag

A/C = Air to cloth ratio, (ACFM/ft²), default to 2.0

CA = Cloth area, (ft²/bag), default to 100

5.4.2.5 Annual Total Variable Operating Costs (VOM).

FGD:

VOM

Reagent (RC): \$5,906,918

Power (PCfgd): \$505,634

Waste (WCn): \$734,092

Total: \$7,146,645

<autocalc>

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

Fabric Filters:

VOM

Power (PCff): \$1,123,632

Waste (WCa): \$1,890,639

Bags (BRC): \$490,284

Total: \$3,504,555

<autocalc>

5.5 FIRST-YEAR \$/KW CALCULATION

Required Project Capital Table

	FDG	Fabric Filter
	<u>\$/kW</u>	<u>\$/kW</u>
(A) Process Capital	12.89	52.00
(B) General Facilities	1.29	5.20
(C) Engineering and Home Office Fees	1.61	6.50
(D) Project Contingency	3.15	3.64
(E) Process Contingency	<u>2.54</u>	<u>0.00</u>
TPC	21.48	67.34
AFDC	<u>0.79</u>	<u>2.49</u>
TPI	22.27	69.83
(H) Preproduction Costs	1.13	1.96
(I) Inventory Capital	<u>1.51</u>	<u>0.00</u>
TOTAL CAPITAL REQUIREMENT (TCR)	24.91	71.79

5.6 LEVELIZED COST CALCULATION

FGD Levelized Cost Table <autocalc>

		Levelization	Conversion	FDG
	(\$/kW)	factor	factor	Mills/kW
(A) Process Capital	12.89	0.153	0.176	0.35
(B) General Facilities	1.29	0.153	0.176	0.03
(C) Engr. and Home Office Fees	1.61	0.153	0.176	0.04
(D) Project Contingency	3.15	0.153	0.176	0.08
(E) Process Contingency	<u>2.54</u>	0.153	0.176	<u>0.07</u>
TPC	21.48			0.58
AFDC	<u>0.79</u>	0.153	0.176	<u>0.02</u>
TPI	22.27			0.60
(H) Preproduction Costs	1.13	0.153	0.176	0.03
(I) Inventory Capital	<u>1.51</u>	0.153	0.176	0.04
TCR	24.91			→ 0.67
Fixed Costs	1.03	2.310	0.176	→ 0.42
Variable Costs				
Reagent	5.91	2.310	0.176	2.40
Power	0.51	2.440	0.176	0.22
Waste	<u>0.73</u>	2.310	0.176	<u>0.30</u>
Total	7.15			→ <u>2.92</u>
TOTAL FGD LEVELIZED COST				4.01

5.6 LEVELIZED COST CALCULATION (continued)

Fabric Filter Levelized Cost Table

<autocalc>

	(\$/kW)	Levelization factor	Conversion factor	Fabric Filter Mills/kW
(A) Process Capital	52.00	0.153	0.176	1.40
(B) General Facilities	5.20	0.153	0.176	0.14
(C) Engr. and Home Office Fees	6.50	0.153	0.176	0.18
(D) Project Contingency	3.64	0.153	0.176	0.10
(E) Process Contingency	0.00	0.153	0.176	0.00
TPC	67.34			1.81
AFDC	2.49	0.153	0.176	0.07
TPI	69.83			1.88
(H) Preproduction Costs	1.96	0.153	0.176	0.05
(I) Inventory Capital	0.00	0.153	0.176	0.00
TCR	71.79			→ 1.93
Fixed Costs	3.20	2.310	0.176	→ 1.30
Variable Costs				
Power	1.12	2.440	0.176	0.48
Waste	1.89	2.310	0.176	0.77
Bags	0.49	2.310	0.176	0.20
Total	3.50			→ 1.45
TOTAL FILTER LEVEL. COST				4.69

APPENDIX B

Hydrated Limestone FGD Spreadsheet Calculations (w/ high sulfur coal combustion data)

Single plant size and coal energy analysis:

Coal source:	Ohio, Harrison County, Pittsburgh No. 8.	<man.input>
Single plant output:	500 MW	<man.input>
Single plant heat rate:	9,000 BTU/Kwh	<man.input>
Coal heating value:	12,000 BTU/lb	<man.input>
Coal consumption rate:	187.5 tons/hr	<man.input>
Gas rate (boiler inlet):	951,000 scfm	<man.input>
Gas rate (preheater outlet):	1,416,990 scfm	<autocalc>
Target SO2 removal:	70 percent	<man.input>

Ultimate coal analysis: (wt%, dry basis)

C (carbon):	71.30	<man.input>
H (hydrogen):	5.03	<man.input>
S (sulfur):	3.50	<man.input>
N2 (nitrogen):	1.34	<man.input>
O2 (oxygen):	9.23	<man.input>
Ash:	9.60	<man.input>
Total:	100.00	<autocalc>

Flue gas composition: (mole%, wet basis)

CO2 (Carbon dioxide):	14.00	<man.input>
O2 (oxygen):	3.30	<man.input>
N2 (nitrogen):	74.80	<man.input>
H2O (water):	7.60	<man.input>
SO2 (sulfur dioxide):	0.258	<man.input>
Total:	100.0	<autocalc>

Reference:

Coal Conservation Systems Technical Data Book,
HCP/T2286-01/4, Section IA.50.1, p.10a. (March 1982)

Comments:

- 1.) The flue gas characteristics are given based on 20% excess air rate.
- 2.) The moisture content of the analysis is 2.8% t / weight
- 3.) Feed air is at 80 °F and 60% relative humidity for this analysis.
- 4.) Complete combustion of the coal is assumed.
- 5.) Air preheater outlet conditions are assumed to be 277°F and 16 psia

Analysis of reactant: _____

Powder sorbant: calcium hydroxide as hydrated lime

<man.input>

Reactant near analysis: (wt%)

Calcium hydroxide: 92.4

<man.input>

Bulk remainder: 7.6

<man.input>

Total: 100

<autocalc>

Percent available Ca in pure reagent: 54.1

<man.input>

Percent available calcium in study, %Ca.: 49.9884

<autocalc>

Delivered cost of reactant (\$/ton): 60

<man.input>

Important values for a multiple boiler plant. (assume all boilers same capacity):

Number of boilers: 2

<man.input>

Single boiler capacity: 500 MW

<autocalc>

Total power output: 1,000 MW

<autocalc>

Sum total coal required: 375 tons/hr

<autocalc>

Sum total hot flue gas rate: 2,833,980 scfm

<autocalc>

5.2 REAGENT AND WASTE QUALITY CALCULATIONS (per boiler)

5.2.1 Step 1: Plant heat method to determine lb-Sulfur per hour (S).

%S F.G.: 100 % S assumed to gases <man.input>

$$S = (M_{\text{coal}})(\%S)(\%S \text{ F.G.})(0.2)$$

S = 13,125 lb-S/hr <autocalc>

5.2.2 Step 2: Calculation of stoichiometric amount of reagent for pure reaction.

$$M1 = (0.06263)(S)/(\%Ca)$$

M1 = 16.44 tons/hr <autocalc>

5.2.3 Step 3: Calculation to determine sorbant injection rate for 70% removal.

From experimental data at the reaction temperature of 750 °C, this efficiency is achieved for the specified NSR value as given below.

NSR70% = 0.92 (ratio) <man.input>

$$Mr = (M1)(NSR70\%)$$

Mr = 15.13 tons/hr <autocalc>

5.2.4 Step 4: Calculation to determine tons per hour of spent sorbant.

Since the sorbant being used is nearly 100% pure (and dry), it is concluded that the amount of spent sorbant is approximately proportional to the ratio of solids out to solids in. This is of course only valid if all the sorbant is assumed to react. This is on an absolute molar mass basis.

$$R_{\text{solids}} = \{(\text{mol solids out}) \cdot M[\text{solids out}]\} / \{(\text{mol solids in}) \cdot M[\text{solids in}]\}$$

Rsolids = 1.621 (ratio) <man.input>

$$M_{\text{spent}} = (Mr)(R_{\text{solids}})$$

Mspent = 24.52 tons/hr <autocalc>

5.2.5 Step 5: Calculation to determine tons per hour of fly ash.

$$M_{\text{ash}} = (0.01)(M_{\text{coal}})(\%ash)(\%fly \text{ ash}) / (100 - \%carbon \text{ in ash})$$

Mash = 16.45 tons/hr <autocalc>

5.2.6 Step 6: Calculation to determine the total waste production rate.

$$M_{\text{waste}} = M_{\text{spent}} + M_{\text{ash}}$$

Mwaste = 40.97 tons/hr <autocalc>

5.3 CAPITAL COST CALCULATIONS

5.3.1.1 Reagent Unloading and Storage Installed Capital Cost (C10).

Using EPRI Fig. 5-3 based on the total sorbant flow rate, TSFR=(Mr)(no. boilers):

$$C10 = \$6,000,000 \quad \text{<man.input>}$$

5.3.1.2 Pulverizer Area Installed Capital Costs (C20).

Using EPRI Fig. 5-4 based on TPH=Mr/2 (redundancy=2) per pulverizer system:

$$$(TPH \text{ on Fig. 5-4}) = \$2,300,000 \quad \text{<man.input>}$$

$$C20 = $(\text{Redundancy})(\text{No. Boilers})$$

$$C20 = \$9,200,000 \quad \text{<autocalc>}$$

Note: the material handling properties were assumed to lie somewhere between those listed for Trona and Nahcolate. Also, a double redundancy factor was used for this calculation. (i.e. 2-50% system)

5.3.1.3 SO₂ Removal Capital Costs (C30).

Using EPRI Fig. 5-5 based on the sorbant flow rate per boiler, Mr:

$$$(Mr \text{ on Fig. 5-5}) = \$170,000 \quad \text{<man.input>}$$

$$C30 = $(\text{No. Boilers})$$

$$C30 = \$340,000 \quad \text{<autocalc>}$$

5.3.1.4 Differential Capital Costs (C40).

Using EPRI Fig. 5-6 based on Mash and M_{waste} rates per boiler:

$$ASCt(\text{Mwaste Fig. 5-6, curve C}): \$3,900,000 \quad \text{<man.input>}$$

$$ASCa(\text{Mash Fig. 5-6, curve C}): \$2,600,000 \quad \text{<man.input>}$$

$$IDFC = (0.098)(acfm)(\text{No. Boilers})$$

$$IDFC = \$277,730 \quad \text{<autocalc>}$$

$$AHDC = (ASCt-ASCa)(\text{No. Boilers})$$

$$AHDC = \$2,600,000 \quad \text{<autocalc>}$$

$$C40 = AHDC+IDFC$$

$$C40 = \$2,877,730 \quad \text{<autocalc>}$$

CAPITAL COST CALCULATIONS: (continued)

where: ASCt = Ash system cost for total waste
ASCa = Ash system cost for ash only
IDFC = Installed Differential Fan Cost
AHDC = Ash Handling Differential Cost

General Support Capital Costs (C50).

C50 = \$50,000 (all cases) <man.input>

Baghouse Capital Costs. (C60).

Using EPRI Fig. 5-7 based on flue gas flow rate per boiler:

\$(Mr on Fig. 5-7) = \$21,500,000 <man.input>

C60 = \$(/No. Boilers with baghouses)

C60 = \$43,000,000 <autocalc>

5.3.1.7 Total Process Capital Costs (A).

A = C10+C20+C30+C40+C50+C60

A = \$61,467,730 <autocalc>

TOTAL PROCESS CAPITAL SUMMARY TABLE

<autocalc>

	<u>FGD</u>	<u>Fabric Filter</u>
Area 10:	C10 = \$6,000,000	\$0
Area 20:	C20 = \$9,200,000	\$0
Area 30:	C30 = \$340,000	\$0
Area 40:	C40 = \$2,877,730	\$0
Area 50:	C50 = \$50,000	\$0
Area 60:	C60 = \$0	<u>\$43,000,000</u>
TOTAL PROCESS CAPITAL (A):	\$18,467,730	\$43,000,000

CAPITAL COST CALCULATIONS: (continued)

5.3.2 Total Plant Cost (TPC) and 5.3.3.1 Total Plant Investment (TPI) Summary

TPC/TPI SUMMARY TABLE <autocalc>

		<u>FDG</u>	<u>Fabric Filter</u>
(A) Total Process Capital		\$18,467,730	\$43,000,000
(B) General Facilities (10% of A)		\$1,846,773	\$4,300,000
(C) Engineering & Home Office Fees (12.5% of A)		\$2,308,466	\$5,375,000
(D) Project contingency			
Area 10:	= (C10)(0.25)	\$1,500,000	\$0
Area 20:	= (C20)(0.25)	\$2,300,000	\$0
Area 30:	= (C30)(0.30)	\$102,000	\$0
Area 40:	= (C40)(0.20)	\$575,546	\$0
Area 50:	= (C50)(0.25)	\$12,500	\$0
Area 60:	= (C60)(0.07)	\$0	\$3,010,000
TOTAL=	\$7,500,046	\$4,490,046	\$3,010,000
(E) Process contingency			
Area 10:	= (C10)(0.075)	\$450,000	\$0
Area 20:	= (C20)(0.30)	\$2,760,000	\$0
Area 30:	= (C30)(0.40)	\$136,000	\$0
Area 40:	= (C40)(0.05)	\$143,887	\$0
Area 50:	= (C50)(0.10)	\$5,000	\$0
Area 60:	= (C60)(0.00) (NOTE 1)	\$0	\$0
TOTAL=	\$3,494,887	\$3,494,887	\$0
(F) Sales Tax (NOTE 2)		\$0	\$0
TOTAL PLANT COSTS (TPC)		\$30,607,902	\$55,685,000
AFDC (3.7% of TPC)		\$1,132,492	\$2,060,345
TOTAL=	\$3,192,837		
TOTAL PLANT INVESTMENT (TPI)		\$31,740,394	\$57,745,345
TOTAL=	\$89,485,739		

NOTE 1 - Area 60 fabric filter optionally included or stand alone

NOTE 2 - Factored into installed capital cost for this EPRI study method

CAPITAL COST CALCULATIONS: (continued)

5.3.3.2 Other Capital Items.

- Royalties (G) assumed zero for this EPRI study method.
- Preproduction costs (H) is calculated from the first year fixed (FOM) and variable (VOM) operating costs and TPI in this EPRI study method.

$$\begin{array}{lll}\text{FGD:} & H = (1/12)(FOM+VOM)+2\%(TPI_{fgd}) & \\ & H = \$1,770,402 & \text{<autocalc>}\end{array}$$

$$\begin{array}{lll}\text{Fabric Filters:} & H = (1/12)(FOM+VOM)+2\%(TPI_{ff}) & \\ & H = \$1,556,464 & \text{<autocalc>}\end{array}$$

- Inventory capital (I) is two months of reagent costs

$$\begin{array}{lll}\text{FGD:} & I = (1/6)(8760 \text{ hr/yr})(Mr)(\text{No. boilers})(\$/\text{ton of reagent}) & \\ & I = \$2,650,540 & \text{<autocalc>}\end{array}$$

- Land cost (K) is treated as an operating cost in this EPRI study method.
It is included in the waste handling and is not treated separately.

5.4 OPERATING AND MAINTENANCE COST CALCULATIONS

5.4.1.1 Annual Operating Labor (L).

$$\begin{array}{lll}\text{FGD:} & L = (OJ)(ALR)(8760 \text{ hr/yr}) & \\ & L = \$240,462 & \text{<autocalc>}\end{array}$$

where: OJ = operators on duty per shift, default=0.75(No. Boilers)
= 0.5 FOR REAG. HANDLING + 0.5(No. boilers) FOR FGD
ALR = average labor rate, default=\$18.30/man-hr

$$\begin{array}{lll}\text{Fabric Filters:} & L = (OJ)(ALR)(8760 \text{ hr/yr}) & \\ & L = \$224,431 & \text{<autocalc>}\end{array}$$

where: OJ = operators on duty per shift, default=0.70(No. Boilers)
ALR = average labor rate, default=\$18.30/man-hr

5.4.1.2 Annual Operating Maintenance and Support Costs

$$\begin{array}{lll}\text{FGD:} & \text{Maintenance labor (M)} = (0.02)(A) & \\ & M = \$369,355 & \text{<autocalc>}\end{array}$$

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

$$\text{Maintenance materials (N)} = (0.03)(A)$$

$$N = \$554,032$$

<autocalc>

$$\text{Administrative and Support Labor (P)} = (0.3)(L+M)$$

$$P = \$182,945$$

<autocalc>

Fabric Filters:

$$\text{Maintenance labor (M)} = (0.02)(A)$$

$$M = \$860,000$$

<autocalc>

$$\text{Maintenance materials (N)} = (0.03)(A)$$

$$N = \$1,290,000$$

<autocalc>

$$\text{Administrative and Support Labor (P)} = (0.3)(L+M)$$

$$P = \$325,329$$

<autocalc>

5.4.1.3 Annual Total Fixed Cost (FOM).

FGD:

$$\text{FOM} = L+M+N+P$$

$$\text{FOM} = \$1,346,793$$

<autocalc>

Fabric Filters:

$$\text{FOM} = L+M+N+P$$

$$\text{FOM} = \$2,699,761$$

<autocalc>

5.4.2.1 Annual Reagent Costs (RC).

$$\text{RC} = (\text{Mr})(\text{URC})(\text{NCF})(\text{No. Boilers})(8760 \text{ hr/yr})$$

$$\text{RC} = \$10,337,107$$

<autocalc>

where: URC = Unit reagent cost (\$/ton)

NCF = Normal Capacity Factor (0.65 used for this EPRI study method)

5.4.2.2 Annual Power Cost (PC).

The FGD power used in the EPRI study method is dominated by the requirements of the following areas: 10, 20 and 40.

Area 10 annual FGD power usage (PU10).

Using EPRI Fig. 5-8 based on the total sorbant flow rate, TSFR=(Mr)(No. Boilers):

$$\text{PU10} = \text{kW}(\text{TSFR on Fig. 5-8})$$

$$\text{PU10} = 170 \text{ kW}$$

<man.input>

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

Area 20 annual FGD power usage (PU20).

Using EPRI Fig. 5-9 based on TPH=Mr/2 (redundancy=2) per pulverizer system:

$$\text{kW(TPH on Fig. 5-9)} = 350 \quad \text{kW} \quad \text{<man.input>}$$

$$\text{PU20} = \text{Kw(TPH on Fig. 5-9)}(\text{Redundancy})(\text{No. Boilers})$$

$$\text{PU20} = 1,400 \quad \text{kW} \quad \text{<autocalc>}$$

Area 40 annual FGD power usage (PU40).

Using EPRI Fig. 5-10 based on air scfm/ boiler & 1.5" W.G. drop/fan:

$$\text{kW(scfm on Fig. 5-10)} = 270 \quad \text{kW} \quad \text{<man.input>}$$

$$\text{PU40} = \text{kW(scfm on Fig. 5-10)}(\text{No. Boilers})$$

$$\text{PU40} = 540 \quad \text{kW} \quad \text{<autocalc>}$$

Annual FGD net approximate power cost (PCfgd).

$$\text{PCfgd} = [(\text{PU10} + \text{PU20} + \text{PU40})(\text{UPC})(\text{HCF})(8670 \text{ hr/yr})]/1000$$

$$\text{PCfgd} = \$658,573 \quad \text{<autocalc>}$$

where: UPC = unit power cost (mills/kWh), 45 used for EPRI study method

HCF = high capacity factor, 0.80 used for EPRI study method

The fabric filter area power used in the EPRI study method is dominated by the requirements of area 60.

Area 60 annual FGD power usage (PU60).

Using EPRI Fig. 5-10 based on scfm air/ boiler & 7.5" W.G. across filters:

$$\text{kW(scfm on Fig. 5-10)} = 1,400 \quad \text{kW} \quad \text{<man.input>}$$

$$\text{PU60} = \text{kW(scfm on Fig. 5-10)}(\text{No. Boilers})$$

$$\text{PU60} = 2,800 \quad \text{kW} \quad \text{<autocalc>}$$

Annual fabric filter net approximate power cost (PCff).

$$\text{PCff} = [(\text{PU60})(\text{UPC})(\text{HCF})(8670 \text{ hr/yr})]/1000$$

$$\text{PCff} = \$873,936 \quad \text{<autocalc>}$$

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

where: UPC = Unit power cost (mills/kWh), 45 used for EPRI study method
HCF = High capacity factor, 0.80 used for EPRI study method

5.4.2.3 Annual Waste Disposal Costs.

Annual total waste disposal cost for ash and spent sorbant (WCt):

$$\begin{aligned} WCt &= (M_{\text{waste}})(HDC)(NCF)(8760 \text{ hr/yr})(\text{No. Boilers}) \\ WCt &= \$2,146,218 \end{aligned} \quad \text{<autocalc>}$$

where: HDC = High disposal cost (\$/ton), \$4.60 for EPRI study method
NCF = Normal capacity factor, 0.65 used for EPRI study method

Annual total waste disposal cost for ash only (WCa).

$$\begin{aligned} WCa &= (M_{\text{ash}})(LDC)(NCF)(8760 \text{ hr/yr})(\text{No. Boilers}) \\ WCa &= \$861,557 \end{aligned} \quad \text{<autocalc>}$$

where: LDC = Low disposal cost (\$/ton), \$4.60 for EPRI study method
NCF = Normal capacity factor, 0.65 used for EPRI study method

Annual additional cost for waste disposal (WCn)

$$\begin{aligned} WCn &= WCt - WCa \\ WCn &= \$1,284,661 \end{aligned} \quad \text{<autocalc>}$$

5.4.2.4 Annual Bag Replacement Cost (BRC)

$$\begin{aligned} BRC &= [(acfm)(BRR)(UBRC)(\text{No. Boilers})]/[(A/C)(CA)] \\ BRC &= \$383,437 \end{aligned} \quad \text{<autocalc>}$$

where: BRR = Bag replacement rate, default to 0.33
UBRC = Unit bag replacement costs, default to \$82/bag
A/C = Air to cloth ratio, (ACFM/ft²), default to 2.0
CA = Cloth area, (ft²/bag), default to 100

5.4.2.5 Annual Total Variable Operating Costs (VOM).

<u>FGD:</u>	<u>VOM</u>	
Reagent (RC):	\$10,337,107	
Power (PCfgd):	\$658,573	
Waste (WCn):	<u>\$1,284,661</u>	
Total:	\$12,280,342	<autocalc>

OPERATING AND MAINTENANCE COST CALCULATIONS (continued)

Fabric Filters:

	<u>VOM</u>
Power (PCff):	\$873,936
Waste (WCa):	\$861,557
<u>Bags (BRC):</u>	<u>\$383,437</u>
Total:	\$2,118,931

<autocalc>

5.5 FIRST-YEAR \$/KW CALCULATION

Required Project Capital Table

	FDG	Fabric Filter
	<u>\$/KW</u>	<u>\$/KW</u>
(A) Process Capital	18.47	43.00
(B) General Facilities	1.85	4.30
(C) Engineering and Home Office Fees	2.31	5.38
(D) Project Contingency	4.49	3.01
(E) Process Contingency	<u>3.49</u>	<u>0.00</u>
TPC	30.61	55.69
AFDC	<u>1.13</u>	<u>2.06</u>
TPI	31.74	57.75
(H) Preproduction Costs	1.77	1.56
(I) Inventory Capital	<u>2.65</u>	<u>0.00</u>
TOTAL CAPITAL REQUIREMENT (TCR)	36.16	59.30

5.6 LEVELIZED COST CALCULATION

FGD Levelized Cost Table <autocalc>

		Levelization	Conversion	FDG
	(\$/kW)	factor	factor	Mills/kW
(A) Process Capital	18.47	0.153	0.176	0.50
(B) General Facilities	1.85	0.153	0.176	0.05
(C) Engr. and Home Office Fees	2.31	0.153	0.176	0.06
(D) Project Contingency	4.49	0.153	0.176	0.12
(E) Process Contingency	<u>3.49</u>	0.153	0.176	<u>0.09</u>
TPC	30.61			0.82
AFDC	<u>1.13</u>	0.153	0.176	<u>0.03</u>
TPI	31.74			0.85
(H) Preproduction Costs	1.77	0.153	0.176	0.05
(I) Inventory Capital	<u>2.65</u>	0.153	0.176	0.07
TCR	36.16			→ 0.97
Fixed Costs	1.35	2.310	0.176	→ 0.55
Variable Costs				
Reagent	10.34	2.310	0.176	4.20
Power	0.66	2.440	0.176	0.28
Waste	<u>1.28</u>	2.310	0.176	<u>0.52</u>
Total	12.28			→ <u>5.01</u>
TOTAL FGD LEVELIZED COST				6.53

5.6 LEVELIZED COST CALCULATION (continued)

Fabric Filter Levelized Cost Table

<autocalc>

	(\$/kW)	Levelization factor	Conversion factor	Fabric Filter Mills/kW
(A) Process Capital	43.00	0.153	0.176	1.16
(B) General Facilities	4.30	0.153	0.176	0.12
(C) Engr. and Home Office Fees	5.38	0.153	0.176	0.14
(D) Project Contingency	3.01	0.153	0.176	0.08
(E) Process Contingency	<u>0.00</u>	0.153	0.176	<u>0.00</u>
TPC	55.69			1.50
AFDC	<u>2.06</u>	0.153	0.176	<u>0.06</u>
TPI	57.75			1.55
(H) Preproduction Costs	1.56	0.153	0.176	0.04
(I) Inventory Capital	<u>0.00</u>	0.153	0.176	0.00
TCR	59.30			→ 1.60
Fixed Costs	2.70	2.310	0.176	→ 1.10
Variable Costs				
Power	0.87	2.440	0.176	0.38
Waste	0.86	2.310	0.176	0.35
Bags	<u>0.38</u>	2.310	0.176	<u>0.16</u>
Total	2.12			→ <u>0.88</u>
TOTAL FILTER LEVEL. COST				3.58

**DATE
FILMED**

9 / 23 / 93

END