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**Coal-Fired Boiler Costs for
Industrial Applications**

Shelby C. Kurzius
Richard W. Barnes

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COAL-FIRED BOILER COSTS FOR INDUSTRIAL APPLICATIONS*

Shelby C. Kurzius**
Richard W. Barnes

ORNL/CON--67

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Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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** Consultant to Oak Ridge National Laboratory, employed by Lockheed Missiles & Space Company, Inc., Oak Ridge Engineering Center, Oak Ridge, Tennessee 37830.

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ABSTRACT

Several of the current sources of information provide data on coal-fired steam boiler costs. As published, these data give widely varying and possibly inconsistent conclusions. This study was undertaken to determine the extent to which the differences in the various sets of published data bases could be resolved and, if possible, to arrive at more reliable cost correlations to be used in Oak Ridge Energy Demand Models. Our principal finding is that it is indeed possible to restate the costs within each data base on a more consistent basis. When this is done, reasonable engineering correlations of all the cost data versus steam plant capacity can be made over the 10,000 to 500,000 lb/hr range.

1. INTRODUCTION AND SUMMARY

The Energy Division of Oak Ridge National Laboratory is assisting the Energy Information Administration in the development of computer-based mathematical models which simulate the industrial demand for energy in the U.S. This model is to be discretized over each of the ten Federal regions. Thus, energy demand and costs in each region are to be forecast versus projected industrial output. A key feature of this developing model which requires improvement is the capital and O&M cost factor for grass roots coal-fired industrial boilers and their associated pollution control system.

Several of the best current sources of information on these costs (Refs. 1 through 7) provide valuable data basis. These data bases, however, give widely varying and possibly inconsistent results. This task was undertaken to determine the extent to which the differences in the various data bases could be resolved and, if possible, to arrive at more reliable cost correlations to be used in the mathematical models.

Our principal finding is that it is indeed possible to restate the costs within each data base on a more consistent basis. When this is done, reasonable ($\pm 20\%$) engineering correlations of all the cost data versus steam plant capacity can be made over the 10,000 to 500,000 lb/hr range. The correlations developed herein and the departure of the individual cost data points therefrom provide good cost and variance inputs to the mathematical models.

2. TECHNICAL APPROACH

Review of Refs. 1 through 7 reveals that in-house differences in cost estimating methodology appreciably impacts the data in each of the data bases. To overcome this while still retaining the benefits of the separate cost estimates the following procedures were followed.

A. Capital Costs

Direct Costs. Where detailed breakdowns are available in the data bases direct costs were allocated to the following categories:

1. land and permits
2. yard and site work
3. boiler house and electrical
4. boiler plant equipment
5. boiler water systems (feedwater and condensor)
6. coal handling and storage
7. ash and spent stone handling and disposal
8. particulate control system
9. flue gas desulfurization system

The original data base inputs were all accepted except where they are obviously estimated on an inconsistent basis, or utilize the same data but not an equivalent basis. Where the original data for a particular direct category were revised - or where they were completely missing and an estimate has been made - this is indicated by enclosing the entry in brackets in the tables of results discussed in the next section of this report.

Much inconsistency was accounted for by land and permits cost estimates, or the lack thereof. To cope with this, United Engineers' estimate (Ref. 2) of \$300,000* at 250,000 lb/hr and ICF's estimate (Ref. 1) were combined and all of the other costs in this category - except where estimates were actually prepared - were scaled according to:

$$\text{Land and Permits Costs} = \$300,000 \left(\frac{\text{capacity}}{250,000} \right)^{0.5}$$

No set aside was allocated to fuel stockpile costs, because this is a startup fuel cost. Capacity has units of lb/hr.

Indirect Costs. Standardization was achieved by allocating 20% of total direct costs for contingency and capital costs, which is good practice consistent with industry usage. Similarly, 15% of total direct costs were allocated for engineering and design costs.

B. O&M Costs

Annual operating and materials costs have been reformulated on a consistent basis in terms of fixed and variable costs comparing the following elements:

Fixed O&M Costs

1. Staff Costs. These are generally the largest component of steam plant O&M costs. ICF's staff cost estimates (Ref. 1), largely based on United Engineers' study (Ref. 3), have been accepted, except that particulate control system staff costs have been incorporated into the steam plant staff costs. Thus, for pulverized coal fired boilers:

$$\begin{array}{l} \text{Steam Plant Annual} \\ \text{Staff Costs} \end{array} = (20 \text{ men} \times \$21,500/\text{men yr}) (\text{capacity}/250,000)^{0.7}$$

*All cost figures cited prior to the Conclusions and Recommendations section of this report refer to the time frame of the reference data bases, i.e., generally to 1977 dollars.

FGD System Annual
Staff Costs = 31% of steam plant staff costs

Particulate System
Staff Costs = 4% of steam plant staff costs

Stoker coal-fired staff costs are estimated (Ref. 1) at 5% less than those for pulverized coal-fired systems. Fluidized bed combustor staff costs were scaled from the estimates of Ref. 3, using the same 0.7 exponent. Capacity has units of lb/hr.

2. Fixed Maintenance Materials Costs. Based on the surprisingly consistent data presented in Refs. 1 through 4 these costs were estimated annually at $0.6 \pm 0.3\%$ of the total capital costs for the steam plants, FGD systems and the fluidized bed combustors.

3. General and Administrative Costs. These annual costs were estimated at 20% of staff costs. The results generally are in fair agreement with estimates based on 10% of the sum of variable (at 100% capacity utilization) and fixed O&M costs, a fairly common but more rational procedure for estimating these staff-related costs.

Variable O&M Costs. These are given for 100% capacity utilization and are directly scaleable to actual or projected capacity utilization factors.

1. Variable Maintenance Materials Costs. Again, from the inputs furnished in Refs. 1 through 4, these costs were synthesized and standardized by using the following estimated percentages of total capital costs:

Estimated Annual Variable Maintenance Costs

Steam Plant	$0.5 \pm 0.2\%$ of total capital costs
FGD System	1.1% of total capital costs
FBC Plant	0.7% of total capital costs

2. Waste Disposal Costs. ICF's and Exxon's estimates (Refs. 1 and 4) of \$8 per ton, which includes \$6 per ton for landfill costs, were employed for dry ash and FGD dewatered ash sludge disposal. Water associated with ash in mixed ash/sludge (which is dewatered to 40 wt. % H_2O in FGD operations) is however charged to FGD O&M costs, since dry ash would be disposed of otherwise.

FBC operations produce a mix of spent stone and ash which is very suitable for such applications as road fill, construction site fill, railroad track bed fill, etc. A net off site credit for FBC waste seems entirely feasible in future operations. To reflect this conservatively no landfill charge is used for FBC waste disposal which is costed simply at \$2 per ton for trucking.

Limestone requirements were calculated for the various coals by using an input Ca/S atomic ratio of 4/3 for FGD operation and 10/3 for FBC operation, corresponding to calcium utilization efficiencies of 75% and 30%, respectively. This is consistent with the estimates in Refs. 1 through 5.

3. Supplies and Utilities Costs. Cost data reviewed in Refs. 1 and 2 were relied on in the form of the following algorithms:

Annual Supplies and Utilities Costs, per Unit Capacity

Stoker-fired Conventional Steam Plant	(\$0.25/lb/hr)	$\left(\frac{250,000}{\text{Capacity}}\right)^{0.1}$
Pulverized-fired Steam Plant	(\$0.33/lb/hr)	$\left(\frac{250,000}{\text{Capacity}}\right)^{0.1}$
FBC Operations, ex Limestone	(\$0.22/lb/hr)	$\left(\frac{250,000}{\text{Capacity}}\right)^{0.1}$
Baghouse (or ESP*) Operations	11% of total Baghouse (or ESP*) capital costs	

Limestone costs are a major component of FGD (and FBC) O&M costs. ICF (Ref. 1) employed at \$15 per ton cost for limestone; Exxon (Ref. 4) used \$12 per ton, and United Engineers (Ref. 3) used \$7.40 per ton. The current Huntsville, Alabama bulk cost for crushed stone within a 25 mile radius is \$6.25 per ton. Clearly, much variation exists in this cost element. Standardization of limestone costs was done in this study by using a median cost of \$10 per ton throughout.

FGD system annual supplies and utilities costs reviewed in Ref. 1 were reformulated to the following algorithms, which implicitly assume that these costs vary directly with the amount of sulfur in the coal consumed:

$$\text{FGD System Utilities Costs per unit capacity} = (\$0.31/\text{lb/hr}/\%S) (12,000/\text{HHV})$$

$$\text{FGD System Supplies Costs per unit capacity} = (\$0.25/\text{lb/hr}/\%S) (12,000/\text{HHV})$$

* Assumption

In the above expression lb/hr refers to steam capacity. HHV (higher heating value in Btu/lb) and %S (sulfur), refer to feed coal properties. It is useful to note that the \$0.25/lb/hr/%S cost figure in the second algorithm pertains to a limestone cost of \$10 per ton. With limestone at \$15 per ton, this cost is \$0.35/lb/hr/%S.

3. RESULTS

A standard work sheet for the estimation of coal-fired industrial burner capital and O&M costs has been prepared as part of this study. Tables 1 through 6 summarize the inputs from the data bases reviewed in the format of these work sheets. Where gaps in the data bases were discovered, or where it was necessary for consistency within the sets of data to reformulate a cost input according to the methodology discussed in the previous section, the particular tabular input involved has been entered between parenthesis. Otherwise, the entries are as given in the original reference.

Grass roots unit capital costs resulting from this standardization of the data bases are plotted as a function of steam capacity in Figs. 1, 2, and 3. Figure 1 presents results for the limited data base relating to packaged coal-fired boiler costs (all stoker-fired). Figure 2 presents results for stoker-fired field erected units, together with the surprisingly well-correlated results for FGD system capital costs. Figure 3 similarly presents for pulverized coal-fired units (all field-erected) along with results relating to the limited data base for fluidized bed combustors. Similarly, fixed and variable unit O&M cost results for all cases are presented in Figs. 4 and 5. As is evident,

Table 1. Coal-fired boiler costs for industrial applications: case studies by ICF, June 1978 (Ref. 1)

Coal consumption (@100% capacity, T/hr)	25,110	50,210	100,420	95,910	143,850	191,750
Steam Capacity (000lb/hr)	50	100	200	200	300	400
psig/°F	650/750°	650/750°	650/750°	650/750°	650/750°	650/750°
ΔH, Btu/lb	1168.5	1168.5	1168.5	1168.5	1168.5	1168.5
Coal ¹						
HHV, Btu/lb	12,000	12,000	12,000	12,000	12,000	12,000
% S	2.5	2.5	2.5	2.5	2.5	2.5
% Ash	14.0	14.0	14.0	14.0	14.0	14.0
Boiler						
Construction	Field	Field	Field	Field	Field	Field
Coal feed	Stoker	Stoker	Stoker	Stoker	Stoker	Stoker
Efficiency	85%	85%	85%	89%	89%	89%
<u>Capital Costs Summary (1977-\$/thousands)</u> (Reformulated for consistency)						
Direct						
Land & permits	126	(190)	(268)	(268)	(329)	(379)
Yard & site work	300	380	495	495	580	655
Boiler house & electrical	405	660	1,070	1,090	1,450	1,770
Boiler plant equipment	1,110	2,070	3,600	4,000	5,535	6,965
Boiler water systems						
Coal handling & storage	215	400	750	750	1,080	1,400
Ash handling & disposal	240	365	550	550	700	835
Emission Controls						
Particulate system (baghouse)	200	370	685	685	900	1,280
FGD system	910	1,580	2,755	2,755	3,815	4,800
TOTAL DIRECT COSTS	3,506	6,015	10,173	10,593	14,479	18,084
Indirect						
Contingency & capital (@20%)	701	1,203	2,035	2,119	2,896	3,617
Engineering & design (@15%)	526	902	1,526	1,589	2,172	2,713
TOTAL PLANT COSTS	4,733	8,120	13,734	14,301	19,547	24,414
Unit capacity cost, (\$/lb/hr)	94.66	81.20	68.67	71.50	65.16	61.04
Unit capacity cost (less FGD)	70.09	59.87	50.07	52.91	47.99	44.84
<u>Annual Operating & Materials Costs @100% Capacity Utilization (1977-\$/thousands)</u> (Without FGD/FGD only - where breakdown is available)						
Staff	145/45	235/75	383/121	403/120	535/159	654/196
Materials, fixed maintenance	(21/7)	(36/13)	(60/22)	(63/22)	(86/31)	(108/39)
Materials, variable maintenance	(18/14)	(30/24)	(50/41)	(53/41)	(72/57)	(90/71)
Waste disposal	28/63	56/126	112/253	107/242	161/363	214/484
Supplies & utilities	451/(70)	82/(140)	153/(280)	169/(280)	244/(420)	316/(560)
General & administrative	(29/9)	(47/15)	(77/24)	(81/24)	(107/32)	(131/39)
TOTAL O&M COSTS	286/208	486/393	835/741	876/729	1,205/1,062	1,513/1,380
UNIT CAPACITY O&M COST (\$/yr/lb/hr) (@100% CUF)	5.72/4.16	4.86/3.93	4.18/3.70	4.38/3.64	4.02/3.54	3.78/3.47

¹Northern Appalachian (also Central Appalachian, Rockies, Midwest and Western).

Table 2. Coal-fired boiler costs for industrial applications: case studies by EXXON, January 1977 (Ref. 4)
(FBC vs conventional systems)

Coal consumption (@100% capacity, T/hr)	76,635	58,920	76,635	58,920	
Steam	No Fed Conventional	Conventional with FGD	Fluidized bed combustor	Fluidized bed combustor	
Capacity (000lb/hr)	100	100	1200	100	
psig/°F	650/750°				
ΔH, Btu/lb	1168.5				
Coal	Compliance	High S	Compliance	High S	
HHV, Btu/lb	8,150	10,500	8,150	10,600	
% S	0.4	3.6	0.4	3.6	
% Ash	5.8	8.0	5.8	8.0	
Boiler					
Construction	Field	Field	Package	Package	
Coal feed	Stoker	Stoker	(FBC)	(FBC)	
Efficiency	82%	82%	82%	82%	
<u>Capital Costs Summary (1975-\$/thousands)</u> (Reformulated for consistency)					
					<u>Original Exxon cost allowance</u>
Direct					
Land & permits	(190)	(190)	(190)	(190)	None
Yard & site work ²	(380)	(380)	(380)	(380)	None
Boiler house & electrical ²	(660)	(660)	(660)	(660)	None
Boiler plant equipment	2,600	2,600	2,690	2,690	As shown + backup
Boiler water systems ³	(450)	(450)	(450)	(450)	None (in O&M)
Coal handling & storage ²	(400)	(400)	(400)	(400)	1,500 (too high)
Stone & ash handling & disposal	0 + 400	300 + 400	100 + 400	300 + 400	As shown
Emission Controls					
Particulate system (ESP)	450	(450) ⁴	450	450	As shown
FGD system	No FGD	1,700	-	-	As shown
TOTAL DIRECT COSTS	5,530	7,530	5,720	5,920	
Indirect					
Contingency & capital (@20%)	1,106	1,506	1,144	1,184	
Engineering & design (@15%) ⁵					
TOTAL PLANT COSTS	6,636	9,036	6,864	7,104	
Unit capacity cost, (\$/lb/hr)	66.36	90.36	68.64	71.04	
Unit capacity cost (less FGD)	No FGD	66.36	(FBC)	(FBC)	
<u>Annual Operating & Materials Costs @100% Capacity Utilization (1975-\$/thousands)</u> (Without FGD/FGD only - where breakdown is available)					
Staff	(235)	(310)	(275)	(275)	
Materials, fixed maintenance	(40)	(45)	(41)	(43)	
Materials, variable maintenance	(33)	(53)	(48)	(50)	
Waste disposal	(36)	(212)	(36) ⁶	(58)	
Supplies & utilities	(86)	(314)	(84)	(305)	
General & administrative	(47)	(62)	(55)	(55)	
TOTAL O&M COSTS	477	966	539	786	
UNIT CAPACITY O&M COST (\$/yr/lb/hr) (@100% CUF)	4.77	9.66	5.33	7.86	

¹Exxon performed case studies for 125 psig sat'd steam but recommended boiler cost multipliers of 4.075 (FBC) & 4.13 (conventional) to convert to 650/750°. These multipliers have been used for following text.

²Figures shown are from ICF study.

³E&A:410, Burns & Roe:490.

⁴Exxon studies showed none.

⁵Included by Exxon in contingency & capital figures.

⁶Assumed no lower than conventional case.

Table 3. Coal-fired boiler costs for industrial applications: case studies by United Engineers, Inc., June 1977 (Refs. 2 & 3)

Coal consumption (@100% capacity, T/hr)	140,240	130,780	122,800 ¹
Steam	Conventional	Conventional	Fluidized bed combustor
Capacity (000lb/hr)	250	250	250
psig/°F	650/750°	650/750°	650/750°
ΔH, Btu/lb	1168.5	1168.5	1168.5
Coal			
HHV, Btu/lb	11,000	11,000	13,000
% S	0.61	3.61	2.3
% Ash	16.07	16.07	7.0
Boiler			
Construction	Field	Field	Package
Coal feed	Stoker	Pulverized	--
Efficiency	83%	89%	80.2%

Capital Costs Summary (1977-\$/thousands)
(Reformulated for consistency)

Direct			
Land & permits	300	300	
Yard & site work	600	610	
Boiler house & electrical	1,190	1,160	No
Boiler plant equipment ²	4,115	5,105	
Boiler water systems ²	205	205	Breakdown
Coal handling & storage	1,680	1,660	
Stone & ash handling & disposal	~ 100 ³	(~ 100) ³	
Emission Controls			
Particulate system (ESP)	~ 300 ³	(~ 300) ³	
FGD system	No FGD	No FGD	
TOTAL DIRECT COSTS	8,490	9,440	10,500
Indirect			
Contingency & capital (@20%)	1,698	1,888	2,100
Engineering & design (@15%)	1,274	1,416	1,575
TOTAL PLANT COSTS	11,462	12,744	14,175
Unit capacity cost, (\$/lb/hr)	45.85	50.98	56.70
Unit capacity cost (less FGD)	No FGD	No FGD	(FBC)

Annual Operating & Materials Costs @100% Capacity Utilization (1977-\$/thousands)
(Without FGD/FGD only - where breakdown is available)

Staff	235	452	500
Materials, fixed maintenance	(69)	(76)	(85)
Materials, variable maintenance	(57)	(64)	(99)
Waste disposal	(180)	(168)	(82)
Supplies & utilities	(107)	(107)	(294) ⁴ + 75
General & administrative	(86)	(90)	(100)
TOTAL O&M COSTS	929	957	1,235
UNIT CAPACITY O&M COST (\$/yr/lb/hr)			
(@100% CUF)	3.72	3.83	4.94

¹This includes: Ash 8,596 T/yr; Feed Limestone 29,447 T/yr; CaSO₄ 12,011 T/yr (Ca/S = 3.33).

²These totals are combined in the original.

³Based on overall total of \$400,000 for emission controls plus solids handling and disposal.

⁴Limestone.

Table 4. Coal-fired boiler costs for industrial applications: case studies by EEA, Inc., late 1978 (Ref. 5)

Coal consumption (@100% capacity, T/hr)	5,478.8	18,262	63,920	118,710
Steam				
Capacity (MMBtu/hr)	11.8	40.7	128.8	239.3
psig/°F	150/356°	250/406°	700/700°	700/700°
ΔH, Btu/lb	1015.5	1021.6	1163.9	1168.9
Coal				
HHV, Btu/lb	12,000	12,000	12,000	12,000
% S	Compliance	3.0	3.0	3.0
% Ash	11.5	11.5	11.5	11.5
Boiler				
Construction	Package	Package	Field	Field
Coal feed	Stoker	Stoker	Stoker	Pulverized
Efficiency	80%	83.3%	85.7%	85.7%

Capital Costs Summary (1977-\$/thousands)
(Reformulated for consistency)

Direct				
Land & permits	(65)	(120)	(215)	(294)
Yard & site work	28	82	313	476
Boiler house & electrical ¹	47	204	813	1,438
Boiler plant equipment	168	565	2,083	3,288
Boiler water systems ²	32	107	481	722
Coal handling & storage	188	292	355	583
Ash handling & disposal	121	174	254	323
Emission Controls				
Particulate system (ESP)	No ESP	369	633	751
FGD system	No FGD	762	1,949	2,891
TOTAL DIRECT COSTS	649	2,675	7,096	10,766
Indirect				
Contingency & capital (@20%)	130	535	1,419	2,153
Engineering & design (@15%)	97	401	1,064	1,615
TOTAL PLANT COSTS	876	3,611	9,569	14,534
Unit capacity cost, (\$/lb/hr)	No FGD/ESP	88.57	74.26	60.73
Unit capacity cost (less FGD)	74.11	63.34	53.84	44.42

Annual Operating & Materials Costs @100% Capacity Utilization (1977-\$/thousands)
(Without FGD/FGD only - where breakdown is available)

Staff	(50)	(120)/(37)	(268)/(83)	(434)/(134)
Materials, fixed maintenance	(5)	(15)/(6)	(42)/(15)	(64)/(23)
Materials, variable maintenance	(4)	(13)/(11)	(35)/(35)	(53)/(43)
Waste disposal	(5)	(17)/(50)	(59)/(174)	(109)/(325)
Supplies & utilities	(4)	(70)/(68)	(128)/(216)	(172)/(402)
General & administrative	(10)	(24)/(7)	(54)/(17)	(87)/(27)
TOTAL O&M COSTS	78.6	260/180	580/541	919/955
UNIT CAPACITY O&M COST (\$/yr/lb/hr)				
(@100% CUF)	6.65	6.38/4.42 ³	4.55/4.20	3.84/3.99

¹This is on basis of half of EEA's estimate of "offsite utilities" + powerhouse at \$4/lb/hr.

²This is figured at \$2.50 to \$3.00/lb/hr.

³ESP = 54.

Table 5. Coal-fired boiler costs for industrial applications: case studies by Burns & Roe, Inc (as reported by RPA, Inc., December 1977, Ref. 6)

Coal consumption (@100% capacity, T/hr)	-	-	-	-	-
Steam					
Capacity (000lb/hr)	100	200	300	400	600
psig/°F	600/750°	600/750°	600/750°	600/750°	900/825°
ΔH, Btu/lb	1170.6	1170.6	1170.6	1170.6	
Coal					
HHV, Btu/lb	?	?	?	?	?
% S					
% Ash					
Boiler					
Construction	Field	Field	Field	Field	Field
Coal feed	Stoker	Stoker	Pulverized	Pulverized	Pulverized
Efficiency	?	?	?	?	?
<u>Capital Costs Summary (1977-\$/thousands)</u> <u>(Reformulated for consistency)</u>					
Direct					
Land & permits	150	232	311	366	
Yard & site work	130	143	159	174	
Boiler house & electrical	332	394	459	668	
Boiler plant equipment	1,617	4,173	6,830	9,109	
Boiler water systems	448	838	1,040	1,284	
Coal handling & storage	207	376	532	682	
Ash handling & disposal	38	73	108	143	
Emission Controls					
Particulate system (ESP)	149	298	447	596	
FGD system	No FGD	No FGD	No FGD	No FGD	
TOTAL DIRECT COSTS	3,109	6,527	9,886	13,022	17,717
Indirect					
Contingency & capital (20%)	622	1,305	1,977	2,605	
Engineering & design (15%)	466	979	1,483	1,954	
TOTAL PLANT COSTS	4,197	8,811	13,346	17,581	23,918
Unit capacity cost, (\$/lb/hr)	No FGD	No FGD	No FGD	No FGD	No FGD
Unit capacity cost (less FGD)	41.97	44.06	44.49	43.95	39.86
<u>Annual Operating & Materials Costs @100% Capacity Utilization (1977-\$/thousands)</u> <u>(Without FGD/FGD only - where breakdown is available)</u>					
Staff					
Materials, fixed maintenance					
Materials, variable maintenance					
Waste disposal					
Supplies & utilities					
General & administrative					
TOTAL O&M COSTS	No O&M	No O&M	No O&M	No O&M	
UNIT CAPACITY O&M COST (\$/yr/lb/hr)					
(@100% CUF)					

Table 6. Coal-fired boiler costs for industrial applications: case studies by ORNL; ICES Report, May 1977 (Ref. 7)

Coal consumption (@100% capacity, T/hr)				
Steam				See note
Capacity (000lb/hr)	10	25	50	
psig/°F (estimated)	250/406°	250/406°	250/406°	
ΔH, Btu/lb	1021.6	1021.6	1021.6	
Coal				
HHV, Btu/lb				
% S				
% Ash				
Boiler				
Construction	Package	Package	Package	
Coal feed	Stoker	Stoker	Stoker	
Efficiency	?	?	?	
<u>Capital Costs Summary (1977-\$/thousands)</u>				
<u>(Reformulated for consistency)</u>				
Direct				
Land & permits				
Yard & site work				
Boiler house & electrical				
Boiler plant equipment	190	318	470	
Boiler water systems				
Coal handling & storage				
Ash handling & disposal				
Emission Controls				
Particulate system				
FGD system				
TOTAL DIRECT COSTS				
Indirect				
Contingency & capital (@20%)				
Engineering & design (@15%)				
TOTAL PLANT COSTS				
Unit capacity cost, (\$/lb/hr)				
Unit capacity cost (less FGD)				
<u>Annual Operating & Materials Costs @100% Capacity Utilization (1977-\$/thousands)</u>				
<u>(Without FGD/FGD only - where breakdown is available)</u>				
Staff				
Materials, fixed maintenance				
Materials, variable maintenance				
Waste disposal				
Supplies & utilities				
General & administrative				
TOTAL O&M COSTS				
UNIT CAPACITY O&M COST (\$/yr/lb/hr)				
(@100% CUP)				

NOTE: These figures are per Power Law Scaling to the .56, power).

ORNL-DWG-81-20510

Figure 1. Packaged Coal-Fired Boiler Costs (Stoker Fed)

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Figure 2. Stoker-Fired, Field-Erected Coal-Fired Boiler Costs and Flue Gas Desulfurization Costs

ORNL-DWG-81-20512

Figure 3. Costs for Pulverized Coal-Fired, Field-Erected Boilers and for Fluidized Bed Combustors

Figure 4. Variable Operating and Maintenance Costs for Coal-Fired Boilers

Figure 5. Fixed Operating and Maintenance Costs for Coal-Fired Boilers

reasonable engineering correlation of all the cost data can be made as a function of plant capacity.

Table 7 recapitulates the total, standardized fixed and variable components of the annual O&M costs derived from the individual data bases, along with the algorithm requisite to converting the unit O&M costs based on 100% capacity utilization to the corresponding quantities based on actually utilized (or projected) capacities. Since the latter are often on the order of 50% (Ref. 1), this is quite an important factor.

Finally, based on the foregoing results for the 100,000 and 250,000 lb/hr case studies, the statistical profile of coal-fired boiler costs shown in Table 8 was constructed. In Table 8, normalized estimated capital cost components and their standard deviations, along with corresponding O&M cost components for the statistical steam plant and FGD system are presented. These in turn served as the basis for the normalized variance estimates of all capital O&M costs, and the primary factors impacting them are presented in Table 9. As is evident from the results shown in Table 9, all of the legitimate variance estimates fall in the range $\pm$ (15 to 20%), with a mean of $\pm$ 17%.

4. CONCLUSIONS AND RECOMMENDATIONS

This study has shown that it is useful to restate the costs within each industrial coal-fired boiler cost data base on a more consistent set-to-set basis. When this is done, reasonable engineering correlations of all the cost data versus steam plant capacity can be made over the 10,000 to 500,000 lb/hr range, with variances on the order of $\pm$ 17%.

Table 7. Breakdown of O&M costs into fixed and variable unit costs

100% capacity utilization: '77 \$/yr/lb/hr					
Source	Capacity (lb/hr)	Total steam plant, ex FGD		FGD system	
		Fixed	Variable	Fixed	Variable
ICF	50,000	3.90(Baghouse)	1.82 ¹	1.22	2.94 ²
	100,000	3.18	1.68 ¹	1.03	2.90 ²
	200,000				
	(stoker)	2.60	1.58 ¹	.83	2.87
	200,000				
	(PCF)	2.73	1.64 ¹	.83	2.81 ²
	300,000	2.43	1.59 ¹	.74	2.80 ²
	400,000	2.23	1.55 ¹	.68	2.79 ²
Exxon	100,000	3.22 (ESP)	1.55 ³	.95	4.24 ⁴
	FBC				
	(compliance coal)			3.71	1.68 ⁵
FBC	100,000			3.73	4.13 ⁶
United Engineers	250,000				
	(stoker)	2.34	1.38 ⁷	(No FGD)	
	250,000				
	(PCF)	2.47	1.36 ⁷	(No FGD)	
FBC	250,000			2.74	2.20 ⁸
EEA	11,800(Pkg)	5.52(No ESP)	1.13(No ESP)	(No FGD)	
	40,800(Pkg)	3.91 (ESP)	2.46 ⁹	1.24	3.17 ¹⁰
	128,900	2.82	1.72 ⁹	.90	3.30 ¹⁰
	239,300	2.44	1.40 ⁹	.77	3.22 ¹⁰

¹All ICF Steam Plant variable costs are based on coal at 12,000 Btu/lb and 14.0% ash.

²All ICF FGD variable costs are based on coal at 12,000 Btu/lb and 2.5% S.

³Exxon Steam Plant variable cost is based on coal at 10,600 Btu/lb and 8.0% ash.

⁴This variable cost is based on coal at 10,600 Btu/lb and 3.6% S.

⁵Based on coal at 8,150 Btu/lb and 0.4% S.

⁶Based on coal at 10,600 Btu/lb and 3.6% S.

⁷All United Engineers Steam Plant variable costs are for 11,000 Btu/lb and 16.1% ash.

⁸This variable cost is based on coal at 13,000 Btu/lb and 2.3% S.

⁹The ESP charges (\$1.32 @ 11% of installed ESP capital expense per year) appears too high for this size plant. The variable costs are based on compliance coal at 12,000 Btu/lb and 11.5% ash.

¹⁰The variable costs for the FGD system are based on coal at 12,000 Btu/lb and 3.0% S.

NOTE: The total unit O&M costs per lb/hr of actually utilized capacity

$$= \frac{\text{Fixed unit O\&M cost @100\%CUF} + \text{Variable unit O\&M costs @100\%CUF}^*}{\text{Actual CUF}}$$

*This component is not a function of CUF.

Table 8. Statistical profile of coal-fired boiler costs
(Based on 100,000 and 250,000 lb/hr case studies)

A. Normalized estimated capital cost components and standard variations

Steam plant:

Land and permits	0.038	±.04
Yard and site work	0.058	±.020
Boiler house and electrical	0.130	±.039
Boiler plant equipment and water systems	0.573	±.106
Coal handling and storage	0.088	±.038
Waste handling and storage	0.043	±.029
Particulate controls	<u>0.070</u>	±.031

Total 1.000

FGD system 0.410 ±.099

B. Normalized estimated O&M cost components

	<u>Steam plant</u>	<u>FGD system</u>
Staff	0.50	0.20
Fixed maintenance materials	0.07	0.03
Variable maintenance materials	0.06	0.06
Waste disposal	0.11	0.32
Supplies and utilities	0.16	0.35
General and administration	<u>0.10</u>	<u>0.04</u>
Total	1.00	1.00

Table 9. Variances in normalized costs

Item	Source	Capital Costs		O&M Costs	
		Steam plant	FGD system	Steam plant	FGD system
DOE regional adj.	ICF report	±0.11	±0.11	±0.11	±0.11
Coal variance ¹	ICF report	±0.039	±0.069	±0.012	±0.014 (low sulfur) ±0.058 (high sulfur)
Boiler efficiency var.	Variances within groupings via effect on firing rate requirement	±0.02	±0.02	±0.02	±0.02
Steam variance ²	Burns & Roe (High pressure steam)	±0.02	±0.02	±0.02	±0.02
Plant components normalized cost variances ³					
Land & permits @±100% uncertainty		± .04	-	-	-
Yard & site work		± .02	-	-	-
Boiler house & electrical		± .04	-	-	-
Boiler plant equipment		± .11	-	-	-
Boiler water systems		± .04	-	-	-
Coal handling & storage		± .03	-	-	-
Ash handling & disposal of wastes		± .03	-	-	-
Particulate controls		-	± .10	-	-
FGD controls		-	-	-	-

Statistical normalized capital costs variance.		±0.18	±0.17	-	-
= $\sqrt{\Sigma \text{variance}^2}$					

O&M normalized costs variances ³ at 100% capacity utilization:					
Staff	Est @15% Uncertainty ⁴			±.075	±.03
Materials, fixed maintenance	Est @18% Uncertainty ⁵			±.013	±.005
Materials, variable maintenance	Est @18% "			±.011	±.011
Waste disposal	Est @25% "			±.028	±.08
Supplier & utility	Est @20% "			±.032	±.07
General & admin.	Est @15% "			±.015	±.006

Statistical normalized O&M costs variance ($\sqrt{\Sigma \text{variance}^2}$).				±0.145	±.168

¹HHV, %S, %Ash...quality.²After correction to firing rate requirement.³From variation @ 100 & 250 KPPH estimates from case studies.⁴Based on estimated staff fluctuation.⁵Based on capital cost variances.

Using a 20% inflation factor to update the predominantly 1977 cost data to August 1979, these correlations are as follows:

<u>Grass Roots Unit Capital Costs, \$/lb/hr</u>	
Stoker-fired, packaged coal-fired boilers, ex FGD system	$\$81.00 (\text{capacity}/25,000)^{-0.13}$ (10,000 $\leq$ capacity $\leq$ 60,000 lb/hr)
Stoker-fired, field-erected coal-fired boilers, ex FGD system	$\$71.00 (\text{capacity}/100,000)^{-0.28}$ (50,000 $\leq$ capacity $\leq$ 300,000 lb/hr)
FGD systems, all type boilers	$\$25.50 (\text{capacity}/100,000)^{-0.21}$
Pulverized coal-fired boilers, ex FGD system	$\$57.50 (\text{capacity}/300,000)^{-0.27}$ (175,000 $\leq$ capacity $\leq$ 700,000 lb/hr)
Fluidized bed combustion coal-fired boilers	$\$64.00 (\text{capacity}/300,000)^{-0.2}$ (100,000 $\leq$ capacity $\leq$ 300,000 lb/hr)

No crossover, or break, points were observed in the capital cost data in the ranges considered.

Finally, the annual unit capacity O&M costs relations converted to August 1979 dollars are:

<u>Fixed Unit Capacity O&M Costs, \$/yr/lb/hr</u>	
Stoker-fired steam plant ex FGD	$\$3.75 (\text{capacity}/100,000)^{-0.29}$
Pulverized coal-fired steam plant, ex FGD	$\$4.00 (\text{capacity}/100,000)^{-0.29}$
Fluidized bed combustion	$\$4.40 (\text{capacity}/100,000)^{-0.29}$
FGD system	$\$1.20 (\text{capacity}/100,000)^{-0.28}$

Variable Unit Capacity O&M Costs, \$/yr/lb/hr

Stoker-fired steam plant, ex FGD (and fluidized bed combustion using compliance coal)	\$2.00 (capacity/100,000) ^{-0.15}
Pulverized coal-fired steam plant, ex FGD	\$2.25 (capacity/100,000) ^{-0.15}
FGD system (and fluidized bed combustion of high sulfur coal)	\$3.30 (% S/2.5) (12,000/HHV)

In the latter correlation %S and HHV refer to the feed coal, with dimensions of Btu/lb for HHV.

REFERENCES

1. Anon., *"Economic Considerations in Industrial Boiler Fuel Choice,"* Final Report submitted to the Congressional Budget Office, ICF, Inc., Washington, D.C., June 1978.
2. Anon., *"Estimates of Costs of Conventional Coal Fired Steam Production Plants,"* prepared for Union Carbide Corporation, Nuclear Division, United Engineers and Constructors Inc., June 1977.
3. Anon., *"Estimates of Costs of a Fluidized Bed Steam Generating Plant,"* prepared for Union Carbide Corporation, Nuclear Division, United Engineers and Constructors Inc., July 1977.
4. Farmer, M. H., E. M. Magee, and F. M. Spooner, *"Application of Fluidized-Bed Technology to Industrial Boilers,"* prepared for U.S. Federal Energy Administration, U.S. Energy Research and Development Administration and U.S. Environmental Protection Agency, Exxon Research and Engineering Co., Lenden, N.J., January 1977.
5. Anon., *"Industrial Fuel Choice Analysis Model, Appendix H, Boiler Capital and O&M Cost Data,"* EEA Inc., Arlington, VA, January 8, 1979.
6. Anon., *"The Potential for Cogeneration Development in Six Major Industries by 1985,"* RA-77-1018, Resource Plannings Associates, Inc., December 1977. (The cost inputs cited were prepared for RPA by Burns and Roe Corp., Paramus, N.J.).
7. Farshan, E., *"Central Heating-Package Boilers,"* prepared for Argonne National Laboratory, ANL/CES/TE 77-6, Oak Ridge National Laboratory, Oak Ridge, TN, May 1977.

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