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Tennessee Valley Authority
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Energy Demonstrations
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Muscle Shoals Al 35660

EDT-105

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-80-022
February 1980

Economics of Disposal of Lime/Limestone Scrubbing Wastes: Surface Mine Disposal and Dravo Landfill Processes

Interagency Energy/Environment R&D Program Report

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Economics of Disposal of Lime/Limestone Scrubbing Wastes:
Surface Mine Disposal and Dravo Landfill Processes

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EPA Interagency Agreement No. D8-E721-BI
Program Element No. INE624A

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

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ABSTRACT

Economic evaluations were made of flyash and limestone scrubbing waste disposal in a surface mine and in a landfill after treatment with a Dravo Lime Company chemical additive. For the base-case (new 500-MW midwestern plant burning 3.5% sulfur, 16% ash, 10,500 Btu/lb coal), capital investment for the mine disposal process is 16.0 $/kW and annual revenue requirements are 0.98 mill/kWh, compared with 20.0 $/kW and 1.44 mills/kWh for the Dravo landfill process, excluding dry flyash collection costs of 19.2 $/kW and 0.56 mill/kWh. A moderate cost reduction is obtained for mine disposal, compared with landfill disposal of the same waste, by elimination of disposal land requirements and reduction of earthmoving equipment requirements. Purchase and handling of the chemical additive for the Dravo landfill process account for most of the cost differences between the two processes. Power plant size, coal sulfur and ash contents, and distance to the disposal site have major effects on costs for both processes. Modular cost breakdowns show purchase and handling of fixatives, thickening, ESP units, and disposal labor to be major cost elements.

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ABBREVIATIONS AND GENERAL CONVERSION FACTORS

ABBREVIATIONS

Btu	British thermal unit
cc	cubic centimeter
ESP	electrostatic precipitator
°F	degrees Fahrenheit
FGC	flue gas cleaning
FGD	flue gas desulfurization
ft	feet
ft/sec	feet per second
g	gram
gal	gallon
gpm	gallons per minute
hp	horsepower
hr	hour
in.	inch
k	thousand
kW	kilowatt
kWh	kilowatthour
lb	pound
M	million
MW	megawatt
NSPS	new source performance standards
sec	second

CONVERSION FACTORS

To convert from English units	To	Multiply by
acres	hectares	0.405
British thermal units	kilocalories	0.252
degrees Fahrenheit -32	degrees Celsius	0.555
feet	meters	0.3048
square feet	square meters	0.093
cubic feet	cubic meters	0.0283
gallons	liters	3.785
inches H_2O head	bars	0.0025
miles	meters	1609
pounds	kilograms	0.454
pounds per square inch	bars	0.069
pounds per cubic foot	grams per cubic centimeter	0.016
short tons[a]	metric tons	0.907

a. All tons are expressed in short tons in this report.

ECONOMICS OF DISPOSAL OF LIME-LIMESTONE SCRUBBING WASTES: SURFACE MINE DISPOSAL AND DRAVO LANDFILL PROCESSES

EXECUTIVE SUMMARY

INTRODUCTION

Large volumes of flyash and flue gas desulfurization (FGD) wastes are produced by flue gas cleaning (FGC) processes. Disposal of these wastes is an important concern for operators of coal-fired power stations. Increased use of coal for electricity generation, increased use of waste-producing FGD processes, and more stringent environmental regulations for waste disposal are expected to complicate this concern in the coming years. The Waste and Water Program sponsored by the U.S. Environmental Protection Agency (EPA) deals with the numerous aspects of power plant waste control and water pollution control. As part of this program the Tennessee Valley Authority (TVA) has conducted several economic evaluations of FGC waste disposal processes. This phase of the study consists of economic evaluations of disposal in a surface mine and landfill disposal of waste from a Dravo Lime Company fixation process. In addition, costs for the base-case conditions of six processes evaluated previously are included for comparison.

BACKGROUND

Lime and limestone scrubbing FGD processes produce a waste slurry of 10% to 15% solids consisting of calcium sulfites and sulfates, unreacted absorbent, and flyash. Under the conditions used in this study the slurry typically has a high sulfite to sulfate ratio, appreciable unreacted limestone and limestone impurities, and trace amounts of flyash. The high-sulfite sludge can be mechanically dewatered to about 50% to 60% solids and without further treatment is a poorly handling semisolid of doubtful stability in landfill disposal.

Flyash, a simultaneously generated large volume waste, may be disposed of separately or with the FGD waste. As a dry material it may also be blended with the dewatered FGD waste to obtain additional dewatering and increased stability, although flyash blending alone does not produce a solid waste of satisfactory stability under all power plant conditions.

FGD waste can be disposed of by direct ponding, by ponding after dewatering to various degrees, or by dewatering and treatment with additives to produce a solid waste for landfill disposal. Additives such as flyash or purchased chemicals, or both, may be used to improve handling and postdisposal characteristics. Several commercial fixation processes are available in which additives such as lime, portland cement, or proprietary materials are used, often in conjunction with flyash, to produce hydraulic-cement reactions in the waste ingredients. The Dravo process uses Calcilox,® a processed blast-furnace slag, as the fixative.

Surface coal mines are an attractive possibility for FGC waste disposal because of their geographic distribution and the large volume of excavation they represent. The use of the mine eliminates the need for additional large areas of land for disposal and site maintenance can be combined with or replaced by the extensive reclamation procedures now practiced in surface mining.

Surface mining is extensively practiced in the Appalachian regions, the Interior basins of the central Mississippi Valley, and in the Rocky Mountains and Great Plains. Surface mines in the Appalachians are typically smaller than those of other regions and often disadvantageous in form and topographical location for use as waste disposal sites. Area mining, in which a large area is progessively mined by successive cuts, is more widely practiced in the Interior basins and the West. Many western mines are very large, producing several million tons of coal per year. Their ratio of overburden removed to coal removed (stripping ratio) is also relatively low, leaving more volume for potential waste disposal. Although no geographic area is precluded from mine disposal, western mines appear generally more adaptable to mine disposal.

Some surface mines are used for ash disposal. Two western area-type surface mines are used for disposal of dewatered FGD waste disposal. One of these, the Baukol Noonan, Inc., Mine near Center, North Dakota, is used as a model for the mine disposal process evaluated in this study. About 4 million tons per year of lignite in a main seam about 11 feet thick is recovered from beneath 50 to 150 feet of overburden. The FGC waste is dumped from trucks on the pit floor or between spoil banks before reclamation.

DESIGN AND ECONOMIC PREMISES

The premises used in this study are the same as those used for the previous TVA studies of FGC waste disposal economics. A midwestern power plant operating under regulated-utility economics and burning a typical eastern bituminous coal is used as the basis for the evaluations. Case variations, in which one design premise is varied to evaluate its economic effects, are included. The plant is assumed to meet 1971 new source performance standards (NSPS) of 0.10 lb/MBtu flyash emission and 1.2 lb/MBtu SO_2 emission.

Design Premises

The base case is a new 500-MW power plant with a 9000 Btu/kWh heat rate. A 30-year declining-load operating schedule of 127,500 hours and a 7,000-hour first-year operating schedule are used. Case variations consist of 200- and 1500-MW new power plants, existing power plants with 25, 20, and 15 years remaining life, and a constant-load 7,000 hr/yr (210,000 hours total) operating schedule. A 9200 Btu/kWh heat rate is used for the 200-MW and existing 500-MW power plants.

The base-case fuel is a 3.5% sulfur, 16% ash coal with a 10,500 Btu/lb high heating value. Case variations for fuel consist of coals with 2% and 5% sulfur and 12% and 20% ash. The flue gas composition is based on an air rate of 133% of stoichiometric requirements and emission of 80% of the ash in the coal as flyash and 95% of the sulfur in the coal as sulfur oxides.

The scrubber waste is based on a 15% total solids effluent sludge produced by a limestone system operating at a $CaCO_3$ to sulfur removed stoichiometric molar ratio of 1.5, using 95% $CaCO_3$ limestone. The sulfur species in the sludge is assumed to be 85% $CaSO_3 \cdot 1/2H_2O$ and 15% $CaSO_4 \cdot 2H_2O$. The remaining solids are unreacted limestone and limestone impurities. Waste treatment consists of dewatering the scrubber effluent and blending the dewatered sludge with dry flyash (and Calcilox for the Dravo landfill process). The waste is trucked to the disposal site.

For the base case the disposal site is located 1 mile from the power plant. Case variations of 5 and 10 miles are also included. For the mine disposal process, the waste is dumped between spoil banks. For the Dravo landfill process an area landfill with a 30-foot waste depth is used. Land costs are based on requirements for the life of the power plant.

Economic Premises

Capital investment using mid-1979 costs and first-year annual revenue requirements using mid-1980 costs are calculated based on a 60:40 debt to equity ratio, 10% interest on bonds, and a 14% return to stockholders. Process costs consist of all waste processing and disposal costs downstream from the scrubber effluent waste line and the electrostatic precipitator (ESP) ash collection hoppers. ESP costs are included as a separate entity.

Capital costs consist of direct costs for process equipment and its installation, all ancilliary equipment, and other supportive installations; indirect construction costs; contingencies; land; and working capital. Annual revenue requirements (based on 7000 hours of operation) consist of raw materials costs; direct costs for labor and supervision, maintenance, utilities, and disposal operations; and indirect costs for capital charges and overheads.

PROCESS DESCRIPTIONS

Mine Disposal

The 15% solids scrubber effluent is thickened to 35% solids in a thickener. The thickener underflow is filtered on rotary vacuum filters to 60% solids and conveyed to a pug mill mixer. Flyash, pneumatically conveyed from the ESP units to storage silos, is also fed to the mixer using a weigh feeder. The blended waste, containing 74% solids in the base case, is conveyed to an adjacent concrete storage area. The waste is loaded into dump trucks with a front loader and hauled to the mine over mine haul roads. The waste is dumped between spoil banks. A crawler dozer is used to maintain access to the dumping area and manage the waste. The waste is covered during normal reclamation operations. It is assumed that no additional mining or reclamation costs are incurred by the mine operator and that no fees are paid by the power plant.

Dravo Landfill Process

The same thickening and filtration operations are performed on the FGD sludge as described for the mine disposal process. The dewatered waste is blended in the mixer with flyash. In addition, Calcilox is added to the mixer at a rate of 7% of the solids in the FGD sludge. The Calcilox is received by rail and pneumatically unloaded into 30-day-capacity storage silos. From the silos it is conveyed to a weigh feeder that meters it to the mixer. The blended waste, containing 75% solids, is conveyed by belt conveyors to a roofed concrete-floored storage area. The waste is loaded and transported in the same manner as the mine disposal process waste.

At the landfill site successive blocks are stripped of topsoil and the waste is deposited to a depth of 30 feet. The waste is covered daily with 1 foot of subsoil and given a final 3-foot topsoil cover. A scraper, crawler dozer, roller, and watering truck are used to maintain the site.

Waste Produced

The waste is assumed to have a bulk density of 97 lb/ft^3 and the physical characteristics of a loose soil. The waste quantities and compositions are shown in Table S-1. The yearly quantities and disposal-area requirements are shown in Table S-2.

RESULTS

The capital investment and annual revenue requirements for the base cases are shown in Tables S-3 and S-4. These results and other results in the text do not include ESP capital investment of $9,614,000 (19.2 $/kW) and annual revenue requirements of $1,975,000 (0.56 mill/kWh), which may be added for comparison with other FGD processes. ESP costs are included as a separate entity to allow comparison with previously

TABLE S-1. WASTE PRODUCED

	Scrubber sludge - lb/hr		Flyash - lb/hr	Calcilox - lb/hr[a]	Total - mine disposal		Total - Dravo landfill	
	Solids	Water			Lb/hr	% solids	Lb/hr	% solids
Base case	61,400	41,000	54,400	4,300	156,800	74	161,100	75
Variations from base case								
200 MW	25,100	16,700	22,300	1,800	64,100	74	65,900	75
1500 MW	184,300	122,800	163,200	12,900	470,300	74	483,200	75
25 years remaining life	62,800	41,900	55,600	4,400	160,300	74	164,700	75
20 years remaining life	62,800	41,900	55,600	4,400	160,300	74	164,700	75
15 years remaining life	62,800	41,900	55,600	4,400	160,300	74	164,700	75
2% sulfur in coal	27,100	18,100	53,400	1,900	98,600	82	100,500	82
5% sulfur in coal	95,700	63,800	54,900	6,700	214,400	70	221,100	71
12% ash in coal	57,200	38,100	38,500	4,000	133,800	72	137,800	72
20% ash in coal	66,100	44,100	72,300	4,600	182,500	76	187,800	76
5 miles to disposal	61,400	41,000	54,400	4,300	156,800	74	161,100	75
10 miles to disposal	61,400	41,000	54,400	4,300	156,800	74	161,100	75
200 MW, constant load	25,100	16,700	22,300	1,800	64,100	74	65,900	75
500 MW, constant load	61,400	41,000	54,400	4,300	156,800	74	161,100	75
1500 MW, constant load	184,300	122,800	163,200	12,900	470,300	74	483,200	75

a. Dravo process only; 7% Calcilox, based on scrubber solids.

TABLE S-2. ANNUAL AND LIFETIME WASTE QUANTITIES AND DISPOSAL AREA REQUIREMENTS

	Mine disposal			Dravo landfill		
	Tons/first year	Acres/first year (5 ft depth)	Acres/lifetime (5 ft depth)	Tons/first year	Acres/first year (30 ft depth)	Acres/lifetime (30 ft depth)
Base case	548,800	52	947	563,900	8.9	162
Case variations						
200 MW	224,400	21	386	230,700	3.6	66
1500 MW	1,646,100	156	2,838	1,691,200	26.7	486
25 years remaining life[a]	561,100	53	702	576,500	9.1	120
20 years remaining life[b]	561,100	53	436	576,500	9.1	75
15 years remaining life[c]	561,100	53	247	576,500	9.1	42
2% sulfur in coal	345,100	33	595	351,800	5.6	101
5% sulfur in coal	750,400	71	1,293	773,900	12.2	222
12% ash in coal	468,300	44	807	482,300	7.6	139
20% ash in coal	638,800	61	1,102	654,900	10.3	188
5 miles to disposal	548,800	52	947	563,900	8.9	162
10 miles to disposal	548,800	52	947	563,900	8.9	162
7,000 hr/yr constant schedule[d]						
200 MW	224,400	21	636	230,700	3.6	109
500 MW	548,800	52	1,560	563,900	8.9	267
1500 MW	1,646,100	156	4,674	1,691,200	26.7	800

Basis: 97 lb/ft^3 bulk density, wet waste, no in-place compaction. First year based on 7,000 hours of operation. Lifetime operation 127,500 hours except as noted. a. 92,500 lifetime hours. b. 57,500 lifetime hours. c. 32,500 lifetime hours. d. 210,000 lifetime hours.

TABLE S-3. BASE-CASE CAPITAL INVESTMENT

	Capital investment, k$	
	Mine disposal	Dravo landfill
Process equipment	1,985	2,161
Piping and insulation	139	151
Foundation and structural	242	264
Excavation and site preparation	53	58
Electrical	345	367
Instrumentation	56	60
Buildings	504	654
Total	3,324	3,715
Services and miscellaneous	50	56
Total	3,374	3,771
Mobile equipment	559	790
Total direct investment	3,933	4,561
Engineering design and supervision	322	426
Architect and engineering contractor	81	107
Construction expense	686	752
Contractor fees	272	301
Total	5,294	6,147
Contingency	1,059	1,229
Total fixed investment	6,353	7,376
Allowance for startup and modifications	579	659
Interest during construction	762	885
Total depreciable investment	7,694	8,920
Land	14	581
Working capital	288	523
Total capital investment	7,996	10,004
$/kW	16.0	20.0

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash (and Calcilox in Dravo landfill process), and trucked 1 mile to disposal; mid-1979 cost basis.

TABLE S-4. BASE-CASE ANNUAL REVENUE REQUIREMENTS

	Annual revenue requirements, k$	
	Mine disposal	Dravo landfill
Direct Costs		
Delivered raw materials		
Calcilox		966
Total raw material costs		966
Conversion costs		
Operating labor and supervision		
Plant	438	438
Disposal equipment	596	745
Plant maintenance - 4% of direct investment	157	182
Landfill operation		
Landfill preparation		15
Truck fuel and maintenance	33	34
Earthmoving equipment fuel and maintenance	66	9
Electricity	108	108
Analyses	17	17
Total conversion costs	1,383	1,629
Total direct costs	1,383	2,595
Indirect Costs		
Capital charges		
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment	602	698
Average cost of capital and taxes at 8.6% of total capital investment	688	860
Overhead		
Plant, 50% of conversion costs less electricity	653	760
Administrative, 10% of total labor and supervision	103	118
Total indirect costs	2,047	2,437
Total annual revenue requirements	3,430	5,032
Equivalent unit revenue requirements		
Mills/kWh	0.98	1.44
$/ton waste	6.3	8.9
$/ton solids	8.5	11.9

Basis: One-year, 7,000-hour operation of system described in capital investment summary; mid-1980 cost basis.

evaluated processes, some of which utilized wet-scrubbing flyash removal. Capital investment is $7,996,000 (16.0 $/kW) for the mine disposal process and $10,004,000 (20.0 $/kW) for the Dravo landfill process. Higher direct costs for process equipment and higher mobile equipment and land costs in the Dravo landfill process account for most of the differences in costs. Annual revenue requirements are $3,430,200 (0.98 mill/kWh) for the mine disposal process and $5,032,400 (1.44 mills/kWh) for the Dravo landfill process. The differences are due to the cost of Calcilox, higher disposal labor costs, and higher indirect costs based on capital investment for the Dravo landfill process. The cost of Calcilox, which accounts for 37% of the Dravo landfill process direct costs, accounts for 60% of the annual revenue requirement cost difference between the processes. Labor and supervision, particularly disposal labor and supervision, is the dominant direct cost element in both processes, accounting for 75% of the mine disposal process direct costs and 46% of the Dravo landfill direct costs.

Case Variations

Capital investment and annual revenue requirements summaries for the case variations are shown in Tables S-5 and S-6. Power plant size variation has the largest effect on costs for both processes. For 200-, 500-, and 1500-MW power plants, the capital investments are 29.6, 16.0, and 10.9 $/kW for the mine disposal process and 35.9, 20.0, and 13.8 $/kW for the Dravo landfill process. For the same 200-, 500-, and 1500-MW power plants, annual revenue requirements are 1.79, 0.98, and 0.60 mills/kWh for the mine disposal process and 2.43, 1.44, and 0.98 mills/kWh for the Dravo landfill process. Economy of scale in equipment and in labor and supervision is responsible for the variations in cost. The rate of increase in costs with power plant size is greater for the Dravo landfill process because of its raw material and disposal-area land costs, which increase linearly with size.

Reductions in remaining lives to 25, 20, and 15 years increase the mine disposal process costs slightly because of the higher heat rate for existing plants and the accelerated depreciation schedule. These same effects in the Dravo landfill process are counteracted by decreasing disposal-area land costs, resulting in a slight decrease in the capital investment with age. Annual revenue requirements for the Dravo landfill process increase slightly with age because of the accelerated depreciation schedule.

The sulfur content of the coal has an appreciable effect on the cost of both processes. For coal sulfur contents of 2.0%, 3.5%, and 5.0%, capital investment is 14.1, 16.0, and 18.3 $/kW for the mine disposal process and 17.2, 20.0, and 23.8 $/kW for the Dravo landfill process. For the same coal sulfur contents, annual revenue requirements are 0.84, 0.98, and 1.14 mills/kWh for the mine disposal process and 1.12, 1.44, and 1.90 mills/kWh for the Dravo landfill process. Raw material, disposal labor and supervision, and mobile equipment costs are most affected. The Dravo landfill process annual revenue requirements

TABLE S-5. CAPITAL INVESTMENT SUMMARIES

MINE DISPOSAL AND DRAVO LANDFILL PROCESSES

Condition	Mine disposal k$	Mine disposal $/kW	Mine disposal $/ton[a]	Dravo landfill k$	Dravo landfill $/kW	Dravo landfill $/ton[a]
Base case	7,996	16.0	0.80	10,004	20.0	0.97
Variations from base case						
200 MW	5,917	29.6	1.46	7,180	35.9	1.71
1500 MW	16,306	10.9	0.55	20,632	13.8	0.67
25 years remaining life	8,067	16.2	1.09	9,960	19.9	1.31
20 years remaining life	8,067	16.2	1.75	9,793	19.6	2.07
15 years remaining life	8,067	16.2	3.10	9,677	19.4	3.62
2% sulfur in coal	7,056	14.1	1.12	8,586	17.2	1.34
5% sulfur in coal	9,161	18.3	0.67	11,923	23.9	0.85
12% ash in coal	7,422	14.8	0.87	9,302	18.6	1.06
20% ash in coal	8,589	17.2	0.74	10,749	21.5	0.90
5 miles to disposal	8,554	17.1	0.86	10,573	21.2	1.03
10 miles to disposal	8,846	17.7	0.88	10,843	21.7	1.06
200 MW, constant load	5,917	29.6	0.88	7,330	36.7	1.74
500 MW, constant load	7,996	16.0	0.80	10,392	20.8	1.01
1500 MW, constant load	16,308	10.9	0.33	21,783	14.5	0.71

a. Based on total dry solids, as disposed of, during the life of the power plant.

TABLE S-6. ANNUAL REVENUE REQUIREMENTS SUMMARIES

MINE DISPOSAL AND DRAVO LANDFILL PROCESSES

Condition	Mine disposal k$	Mine disposal Mills/kWh	Mine disposal $/ton waste[a]	Mine disposal $/ton solids	Dravo landfill k$	Dravo landfill Mills/kWh	Dravo landfill $/ton waste[a]	Dravo landfill $/ton solids
Base case	3,430	0.98	6.25	8.45	5,032	1.44	8.90	11.90
Variations from base case								
200 MW	2,508	1.79	11.18	15.10	3,397	2.43	14.72	19.63
1500 MW	6,336	0.60	3.85	5.20	10,322	0.98	6.10	8.14
25 years remaining life	3,523	1.01	6.28	8.49	5,149	1.47	8.93	11.91
20 years remaining life	3,562	1.02	6.35	8.58	5,179	1.48	8.98	11.98
15 years remaining life	3,679	1.05	6.56	8.86	5,304	1.52	9.20	12.27
2% sulfur in coal	2,938	0.84	8.51	10.38	3,910	1.12	11.11	13.55
5% sulfur in coal	3,974	1.14	5.30	7.46	6,666	1.90	8.61	12.13
12% ash in coal	3,294	0.94	7.03	9.77	4,799	1.37	9.95	13.82
20% ash in coal	3,604	1.03	5.64	7.42	5,297	1.51	8.09	10.64
5 miles to disposal	4,128	1.18	7.52	10.17	5,735	1.64	10.17	13.56
10 miles to disposal	4,545	1.30	8.28	11.19	6,185	1.77	10.97	14.62
200 MW, constant load	2,508	1.79	11.18	15.10	3,410	2.44	14.78	19.71
500 MW, constant load	3,430	0.98	6.25	8.45	5,066	1.45	8.98	11.98
1500 MW, constant load	6,336	0.60	3.85	5.20	10,421	0.99	6.16	8.22

a. Wet waste, as disposed of, based on 7,000 hours of operation.

increase more rapidly with increase in coal sulfur content than those of the mine disposal process because of the raw material costs for Calcilox.

Coal ash content has a moderate effect on costs, similar to but less than the effect of coal sulfur content. For coal ash contents of 12%, 16%, and 20% capital investment is 14.8, 16.0, and 17.2 $/kW for the mine disposal process and 18.6, 20.0, and 21.5 $/kW for the Dravo landfill process. Annual revenue requirements are 0.94, 0.98, and 1.03 mills/kWh for the mine disposal process and 1.37, 1.44, and 1.51 mills/kWh for the Dravo landfill process.

Distances to the disposal site of 5 and 10 miles instead of the base-case 1-mile distance produce slight increases in capital investment because of increased truck requirements. The annual revenue requirements for the 1-, 5-, and 10-mile distances are 0.98, 1.18, and 1.30 mills/kWh for the mine disposal process and 1.44, 1.64, and 1.77 mills/kWh for the Dravo landfill process. The increases are largely due to increased trucking labor and operating costs.

Modular Cost Comparisons

Base-case cost breakdowns by processing area were made for the two processes evaluated in this study and the six processes previously evaluated. Schematic flow diagrams are shown in Figure S-1. Two of the six processes are ponding processes--untreated ponding and a Dravo fixation process in which the sludge is thickened and mixed with lime and Calcilox before ponding. Two are landfill fixation processes in which the sludge is thickened, filtered, and blended with fixatives. The IUCS process fixative is lime. The Chemfix process fixatives are portland cement and sodium silicate. In the IUCS process the waste is processed at the power plant and trucked to the landfill. In the Chemfix process the thickened sludge is pumped to the landfill where it is filtered, fixed, and distributed on the landfill with scrapers. One process consists of a sludge - flyash blending process in which the sludge is thickened, filtered, blended with dry flyash, and trucked to a landfill. The remaining process uses an air-oxidation scrubber modification to produce a high-sulfate (gypsum) sludge that is thickened, filtered, and trucked to a landfill without further treatment. In all processes not using dry flyash, the flyash is removed in the scrubber. Flyash is included on the FGD sludge, and the equipment is sized accordingly, for processes not requiring dry flyash because of the design premises in use at the time of the earlier studies. For comparison purposes the additional costs of ESP units and scrubber effluent air-oxidation modifications are included as additional costs. The modular cost breakdowns are shown in Table S-7.

In those cases in which flyash is collected separately the cost of ESP units constitutes about one-half of the capital investments. In annual revenue requirements separate flyash collection accounts for about one-third of the total for these three processes. In comparison, simultaneous flyash removal results in relatively modest increases in thickening and filtration costs. Separate collection of flyash is,

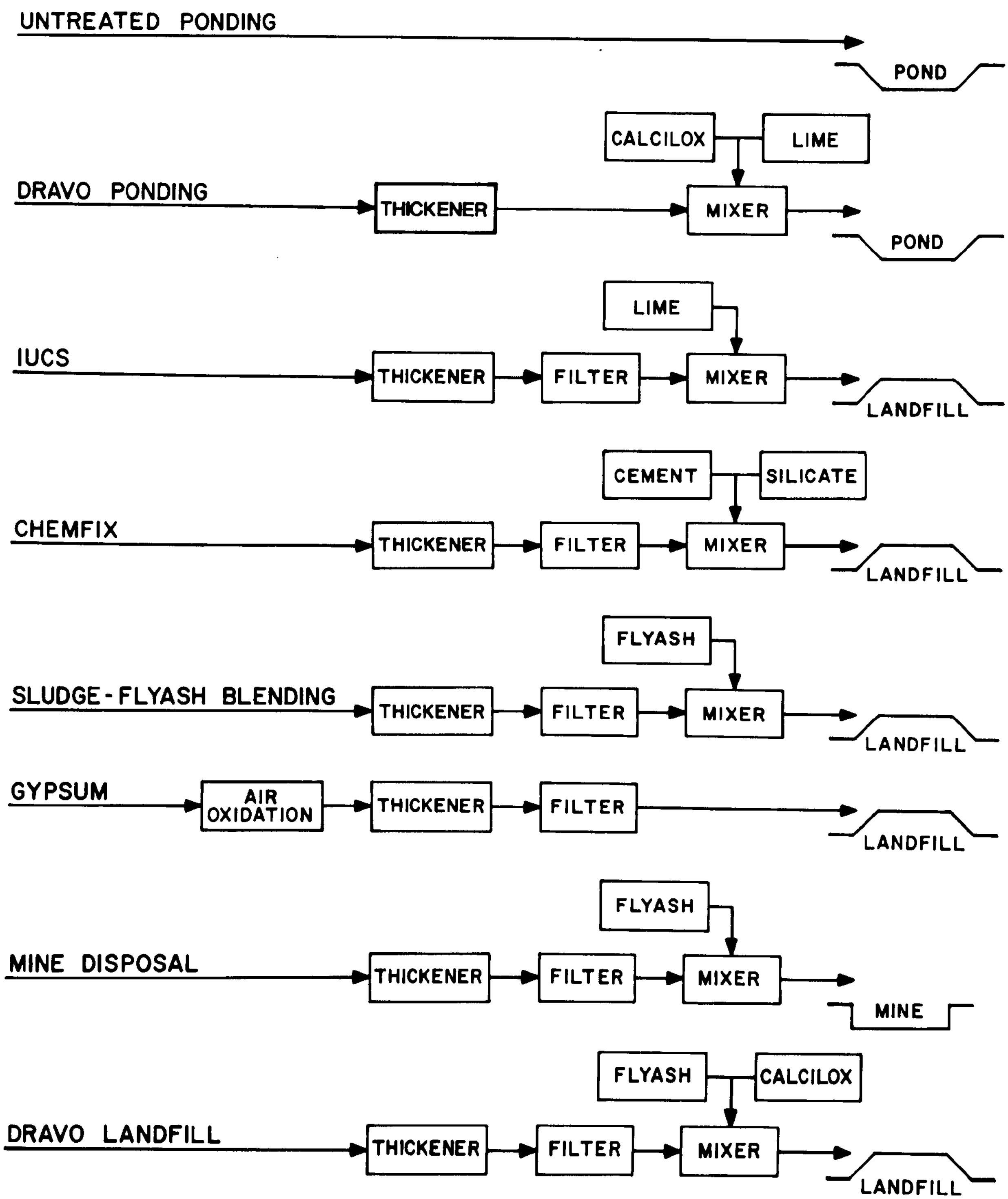


Figure S-1. Process flow diagrams.

TABLE S-7. MODULAR COSTS BY PROCESSING AREA FOR EIGHT DISPOSAL PROCESSES

	Capital investment by processing area, $/kW							
	Other	Raw materials	Thickening	Filtration	Mixing	Storage	Disposal	Total
Ponding					1.4		33.0	34.4
Dravo ponding		9.0	8.4		0.5		30.3	48.2
IUCS		4.2	8.5	4.1	1.1		3.5	21.4
Chemfix		7.4	8.7	4.2	1.5		5.3	27.1
Sludge - fly ash blending	19.2[a]	4.4	6.3	2.5	0.9		3.1	36.4
Gypsum	4.6[b]		5.2	3.0			2.6	15.4
Mine disposal	19.2[a]	4.4	6.2	2.5	0.9		2.0	35.3
Dravo landfill	19.2[a]	6.2	6.0	2.2	0.8	1.1	3.8	39.4
	Annual revenue requirements by processing area, mills/kWh							
Ponding					0.14		0.80	0.94
Dravo ponding		0.91	0.24		0.03		0.74	1.91
IUCS		0.44	0.29	0.18	0.06		0.54	1.51
Chemfix		0.94	0.28	0.17	0.05		0.56	2.00
Sludge - fly ash blending	0.56[c]	0.22	0.24	0.11	0.05		0.45	1.64
Gypsum	0.29[d]		0.29	0.16			0.44	1.18
Mine disposal	0.56[c]	0.22	0.25	0.11	0.05		0.36	1.54
Dravo landfill	0.56[c]	0.57	0.22	0.10	0.05	0.03	0.47	2.00

Basis: 500-MW power plant, 127,500-hour life, 7,000 hr/yr revenue requirement basis; 3.5% sulfur, 16% ash coal; fly ash removal in scrubber where cost is not shown. Limestone scrubber, 1.5 stoichiometry, 15% solids waste to disposal system.

a. $9,614,000 ESP cost for separate fly ash collection.
b. $2,303,000 air-oxidation modifications.
c. $1,975,000 ESP operating costs.
d. $1,005.000 air-oxidation operating costs.

of course, possible with all of the processes evaluated and would require similar costs for all processes. In comparison of landfill processes with separate flyash collection, cost differences would largely be reduced to cost differences in the raw material portion of the cost breakdown.

For processes using purchased fixatives raw materials are an important element of both capital investment and annual revenue requirements. Flyash handling is also a relatively expensive element. The advantage of a single fixative is illustrated by comparison of raw material costs for the Dravo ponding and Chemfix processes, which use two additives, with the IUCS process which uses one. The IUCS process has raw material capital investment and annual revenue requirements about one-half those of the others.

Thickening is the largest capital investment cost element, excluding ESP costs, for all of the nonponding processes and is also a large cost element in annual revenue requirements. The gypsum process has a major advantage over the other processes in thickening capital investment but little in thickening annual revenue requirements.

Filtration is also a large cost element, though considerably less so than thickening. Filtration costs for the gypsum process are lower than the other simultaneous flyash-FGD waste filtration processes because of the superior filtration characteristics of the high-sulfate sludge. Mixing costs are a minor part of both capital investment and annual revenue requirements.

Transportation and disposal-site costs illustrate fundamental differences between ponding and solid waste disposal methods. Capital investment for pond construction is an order of magnitude greater than the capital investment for trucks and landfill site operations. Capital investment for transport lines is also an important element. For the Chemfix process, in which the thickened sludge is pumped to the disposal site for further treatment, the cost of transport lines is not offset by the minor savings in mobile equipment. Among the landfill and mine disposal processes, transportation and disposal-site costs are a relatively minor element of total capital investment. As a percentage of total capital investment disposal land costs for all the processes (excluding mine disposal which has none) are similar, ranging from 8% for untreated ponding to 5% for the Chemfix process.

Annual revenue requirements for ponding process transportation and disposal-site operations are also higher than the same costs for landfill and mine disposal processes, although the differences are less pronounced than the capital investment differences. About two-thirds of the annual revenue requirement direct costs for ponding consist of pond operations. Transportation of the waste is a relatively minor cost element. In contrast, about four-fifths of the direct costs for transportation and disposal-site operations in the landfill and mine disposal processes are for loading and hauling.

Process Comparisons

In overall comparison of the processes evaluated, the most important capital investment cost elements are separate flyash collection, raw material handling, thickening, and pond waste disposal. Untreated ponding, with almost all of the capital investment in transportation and pond costs, has a relatively high capital investment. Dravo ponding which combines high raw material costs for two additives, thickening costs, and ponding costs has the highest capital investment. Among landfill fixation processes the Dravo landfill process has the highest capital investment, almost half of which is ESP costs for separate flyash collection.

Sludge - flyash blending and mine disposal differ only slightly in capital investment. The reduction in mobile equipment and land requirements effected by use of the mine as a disposal site accounts for the difference in capital costs between the two processes.

The difference in capital investments between the IUCS and Chemfix processes is largely in raw material handling costs as a result of the additional fixative. However, additional costs for transportation of the waste also occur because the waste is processed at the disposal site. A similar effect in raw material costs between one- and two-fixative processes is seen in the two-fixative Dravo ponding process.

The considerably lower capital investment of the gypsum process is a result of the low cost of the necessary scrubber modifications, improved thickening and filtration characteristics, and a reduction in transportation and landfill costs.

Large cost elements in annual revenue requirements are separate flyash collection, raw material purchase and handling, and disposal. Untreated ponding has the lowest annual revenue requirements, almost all of them for disposal. The Dravo landfill process (with costs for both separate flyash collection and a fixative) and the Chemfix process (with costs for two fixatives and higher transportation costs) both have high annual revenue requirements. Dravo ponding, with two fixatives, but no ESP and filtration costs, has slightly lower annual revenue requirements. The IUCS process, with one fixative, and no ESP costs, has the lowest annual revenue requirements of the fixation processes. If dry flyash were used in the IUCS process, however, it would be similar in cost to the other fixation processes.

The small difference in annual revenue requirements between the sludge - flyash blending and mine disposal processes is a result of reduced landfill costs and lower indirect costs based on capital investment.

The gypsum process annual revenue requirements are second only to ponding. The low cost is a result of relatively modest additional costs for air oxidation, the absence of raw material and mixing costs, and lower transportation and landfill costs than other landfill processes.

CONCLUSIONS

Mine disposal is approximately one-fifth lower in capital investment and one-third lower in annual revenue requirements than the Dravo landfill process. The cost differences are largely a result of additional costs for purchase and handling of Calcilox.® Reduced disposal costs for the mine disposal process are minor.

Cost reductions directly associated with mine disposal are a result of reductions in land and mobile equipment requirements and reduced disposal labor and mobile equipment operating costs. The costs associated with the use of a fixative lie largely in purchase of Calcilox and installation of equipment for handling it. Waste processing and disposal costs are not greatly affected by the use of the fixative. ESP costs are a large part of the total FGC costs for both processes.

Other large capital investment cost elements for both processes are raw materials handling (which includes flyash) and thickening. Labor and supervision costs, particularly for disposal operations, are the largest direct cost element in annual revenue requirements. Disposal-site operations, consisting of fuel, maintenance, and land preparation are minor costs. Utility costs are also minor.

Power plant size has the largest effect on costs of the case variations studied, largely because of economy of scale, particularly in process equipment, and lower labor and supervision costs, relative to plant size, at the larger power plant sizes. The effect of power plant size on the Dravo landfill process annual revenue requirements is less pronounced because it has raw materials and disposal land costs linearly related to waste quantities.

Coal sulfur content produces large differences in the capital investments and annual revenue requirements for both processes. The variations are greater for the Dravo landfill process because of the effects of disposal-area land requirements and raw material requirements, which are not factors in the mine disposal process. Coal ash content also had an important effect on capital investment and annual revenue requirements, although less than coal sulfur content in the ranges evaluated.

The increased distance to the disposal site produces a moderate increase in capital investment and a large increase in annual revenue requirements for both processes. The results indicate that hauling distance is an important consideration. Mine disposal is an economically favorable disposal option in comparison to on-site disposal only for the more favorable circumstances of mine location. For the five-mile distance to the disposal site the increase in trucking costs eliminate the cost savings associated with mine disposal instead of on-site landfill.

Breakdown of costs into modular processing areas for the eight processes evaluated in this series of studies illustrates the effect of various process functions. ESP costs, for processes in which flyash is collected separately, are a large part of both capital investment and annual revenue requirements. Excluding ESP costs, raw material purchase and handling, thickening capital investment, and pond capital investment are high-cost areas.

Raw material costs are also an important part of annual revenue requirements when purchased fixatives are used. The use of more than one fixative compounds the costs in these areas because they are almost completely additive. Flyash handling, although larger in volume, is not greatly higher in cost than purchased fixative handling.

Thickening is a large cost element. Filtration is less costly and mixing is a minor cost.

Capital investment for transport lines and pond construction is an order of magnitude greater than mobile equipment and landfill-site capital investment.

In comparison of the seven processes for high-sulfite waste, ponding is shown to be a low-cost disposal option, if practical, if there is no treatment of the sludge. Treatment and fixation before ponding add the high-cost processing areas without materially reducing pond costs. Landfill processes, excluding ESP costs, are lower in capital investment than ponding processes. This advantage is reduced when purchased fixatives are used, particularly if two are used. Landfill annual revenue requirements are only competitive with ponding if no purchased fixatives are used.

The gypsum process results illustrate the large decrease in capital costs attainable by improvement in stoichiometry and the dewatering characteristics of the waste. Annual revenue requirements for the gypsum process are intermediate between untreated ponding or landfill without purchased fixatives and the landfill processes with purchased fixatives.

RECOMMENDATIONS

The results indicate that certain cost-sensitive areas, such as thickening and filtration, can be studied as modules applicable to several processes. Such comparisons would more clearly illustrate cost similarities and differences among processes.

Transportation whether by truck or pipeline is also an important cost factor, many elements of which are independent of particular processes. Transportation alternatives should particularly be investigated in greater variety and with emphasis on energy requirement costs. Landfill preparation and operation should be investigated with emphasis on definition of additional costs for site investigations, pollution control, monitoring, and reclamation costs associated with existing and pending legislation. Legislation, such as the Resources Conservation Recovery Act, should be continually kept in perspective. In addition, the rapidly increasing body of information on waste chemical and physical characteristics and disposal data from evolving technologies should be incorporated into future studies. Processes, such as the gypsum process, that have not been commercially demonstrated could change significantly in cost as information on them develops.

ECONOMICS OF DISPOSAL OF LIME-LIMESTONE SCRUBBING WASTES:

SURFACE MINE DISPOSAL AND DRAVO LANDFILL PROCESSES

INTRODUCTION

An important part of the operation of a modern coal-fired power plant is the disposal of flue gas cleaning (FGC) wastes. These wastes include large quantities of flyash (produced by particulate matter removal) and sulfur-salt sludge (produced by the majority of present flue gas desulfurization--FGD--processes). Disposal of these wastes presents problems because of the volume of material and the environmental effects their transportation and disposal may create. The increased use of coal for electricity generation projected for the next 20 years (Hayes, 1979, and Griffith, 1979, summarize a number of these projections) can be expected to intensify these problems.

Numerous regenerable FGD processes are in various stages of development and application; numerous studies of useful applications for FGC products are also in progress. The prospect for the foreseeable future, however, is an increasing production of waste from emission control processes which must be disposed of (Santhanam and others, 1979). Laseke and Devitt (1979) list 16,000 MW of utility FGD systems in operation and an additional 46,000 MW under construction or planned, most of which are waste-producing processes. It is predicted that 25% of coal-fired facilities will be equipped with FGD systems by 1986. Leo and Rossoff (1978a) projected production of FGD wastes to 1998 for a number of control strategies and emission limits. Their projections for waste-disposal land requirements in 1998 range to an extreme of 350 square miles nationally for exclusive use of limestone-scrubbing FGD.

Environmental concerns about FGC waste disposal center on chemical and physical characteristics of the wastes which affect pollution of ground and surface waters and physical characteristics which affect reclamation and subsequent use. Failure of impoundments, fugitive dusts and gases, and visual affects of large waste sites are other concerns which impinge on waste disposal considerations. The influence of environmental legislation, particularly the Resource Conservation and Recovery Act (RCRA) of 1976, has not been fully assessed. Some disposal methods may be precluded or circumscribed, either generally or on an individual basis (Duvel and others, 1979).

During the past several years EPA has sponsored the Waste and Water Program which is concerned with the numerous aspects of power plant waste control and water pollution control. The program deals in part with the technology and economics of FGC waste disposal. TVA has conducted two previous studies under this program on the economics of several alternative FGD waste disposal methods (Barrier and others, 1978, 1979). This study continues these studies with economic evaluations of disposal of FGC waste in a surface mine and landfill disposal of FGC waste chemically treated in a Dravo Lime Company fixation process.

Disposal of FGC waste in mines is an obviously attractive disposal method. Large disposal-site land requirements are eliminated. In most cases extensive reclamation is required following mining operations, which can replace or be combined with similar operations required for FGC waste disposal sites. In some cases the FGC waste might serve a useful function in subsidence control or in control of mine runoff acidity. Lunt and others (1977) made an extensive assessment of FGC waste disposal in mines, finding both underground and surface mine disposal technically feasible though subject to numerous site-specific factors. A few power plants dispose of flyash in surface mines (Kelley, 1979). In early 1979 there were two commercial utility applications of FGD waste disposal in mines, both in Western area-type strip mines. Texas Utilities Company uses mine disposal at their Martin Lake power station. The FGD sludge is dewatered, blended with dry flyash, and transported to the nearby mine by rail cars. At the Minnkota Power Cooperative Milton R. Young Power Station near Center, North Dakota, FGC waste is trucked to the nearby Baukol Noonan, Inc., mine serving the power plant. The sludge is the product of a wet-scrubbing system using flyash from the plant electrostatic precipitator (ESP) units and lime as the absorbents. The disposal operation is being evaluated by EPA through a grant to the University of North Dakota (Manz and Gullicks, 1979) for field measurements and a contract with Arthur D. Little for overall assessment of the operation. The mine disposal evaluation in this study is modeled in part on this operation.

This study deals primarily with FGD waste disposal costs. These costs are therefore treated as an entity, separate from other control procedures which may be necessary in the power plant operation. Flyash removal is treated as a separate cost. Other waste collection and disposal procedures which may be necessary, such as bottom ash and waste water disposal, are not included. With the increasing comprehensiveness of pollution control regulations, however, an integrated system incorporating all aspects of waste disposal may prove economically advantageous.

BACKGROUND

FLUE GAS CLEANING WASTE

The waste product in most lime and limestone scrubbing processes consists of a 10% to 15% solids slurry of calcium sulfur salts, unreacted absorbent, and flyash. The calcium salts consist primarily of calcium sulfite hemihydrate ($CaSO_3 \cdot 1/2H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$), either of which can be the dominant species, depending on the flue gas and scrubbing conditions. The ratio of sulfite to sulfate is a primary factor in determining sludge characteristics affecting both dewatering and postdisposal behavior. The properties of FGD sludges related to sulfite to sulfate ratio have been summarized by Leo and Rossoff (1976, 1978b), and Santhanam and others (1979). Limestone scrubbing wastes also contain appreciable quantities of unreacted limestone and limestone impurities. Flyash is present in trace to major quantities depending on upstream removal efficiencies.

Under the conditions in this study, using a typical eastern bituminous coal and scrubbing with limestone slurry to meet the 1.2 lb SO_2/MBtu new source performance standards (NSPS), the scrubber effluent typically has a high sulfite to sulfate ratio. The slurry can be dewatered to about 60% solids, in which condition it is a poorly handling material of uncertain stability. Different fuel and scrubbing conditions or forced-air oxidation can produce a high-gypsum sludge with improved dewatering and stability characteristics. Disposal of gypsum from forced-air oxidation was evaluated in a previous phase of these studies (Barrier and others, 1979).

The collection and disposal of flyash is closely bound, if not integral, to considerations of FGD waste disposal. As a simultaneously generated large volume of waste, codisposal with FGD waste may offer economic and practical benefits. In addition, flyash can aid in dewatering and stabilization of the FGD waste. Flyash is, however, enriched in the many trace and minor elements in coal and can contribute to contaminants in leachate from the waste. The characteristics of flyash, both as a separate material and as a component of FGC waste, have been extensively reported. Leo and Rossoff (1978b) and Coltharp and others (1979) provide recent summaries of pertinent studies. The behavior of heavy metals associated with flyash-soil environments has been reported by Theis and others (1977).

Several alternatives are available for disposal of FGD wastes from wet-scrubbing processes. It can be pumped directly to a disposal pond which serves as a settling basin for partial water recovery. It can be dewatered to various degrees by intermediate ponding or by mechanical methods before being ponded or impounded. In addition, flyash or chemical additives, or both, can be added to improve handling or post-disposal properties. All of these methods have been or are used. The present trend is toward increased dewatering and stabilization (Santhanam and others, 1979).

Stabilization using additives is attractive because it can reduce uncertainties of both short- and long-term behavior of FGD wastes. Treatments which reduce permeability, decrease liquefaction tendencies, or improve compressive strength reduce concerns about seepage and runoff contamination, structural failure, and land reuse. In addition, handling properties can be improved, allowing a wider selection of transportation and emplacement methods.

Stabilization by addition of non-FGC additives, some in conjunction with flyash, has been widely investigated. Fling and others (1978) have described field tests in progress at the EPA-TVA Shawnee test facility. Leo and Rossoff (1976, 1978b) summarize these and other investigations. A number of companies offer or have offered fixation processes, most of them proprietary. Duvel and others (1978) have summarized these processes. The Dravo Lime Company and IU Conversion Systems (IUCS) presently operate commercial facilities. Other utilities operate nonproprietary fixation processes. Leo and Rossoff (1978b) report 15 power plants operating or committed to chemical treatment of FGD waste by 1979.

Most chemical treatment, or fixation, processes employ additives which produce a series of hydraulic reactions between lime, silica, and alumina similar to those that occur in the setting of hydraulic cement. Flyash is often used to provide the silica and alumina. Lime is often used as an additive to supplement low-calcium flyashes. Fixation processes can be designed to compensate for the numerous site-specific conditions associated with FGC wastes and to produce a product adapted to specific disposal requirements. This degree of flexibility is not as great in sludge - flyash blending processes, since the composition is fixed by the amount and composition of FGC wastes being produced. In some cases flyash alone is not sufficient to produce a solid waste of acceptable handling and postdisposal properties.

DRAVO PROCESS

The Dravo process is based on a patented fixation process of the Dravo Lime Company. The Dravo process uses a proprietary material called Calcilox® derived from blast-furnace slag. Calcilox, which is sometimes compared to portland cement, has a similar composition, though higher in alumina. Its reactions in water are similar to those of a hydraulic cement. When Calcilox is added to wet FGD sludge these reactions, and reactions into which the gypsum in the sludge also enters, produce a sludge of increased strength and reduced permeability. The curing period is dependent on the amount of Calcilox used, the solids content of the waste, and chemical and physical conditions such as pH and temperature. Lime is sometimes used to accelerate the reactions.

The Dravo process can be used in three variations. In the full impoundment method the Calcilox is mixed with thickened sludge and pumped to a pond for final disposal. This method is used in a commercial operation at the Pennsylvania Power Company's Bruce Mansfield Station. Alternately, the treated sludge can be pumped to a pond for curing, after which it is excavated and disposed of as landfill material. This interim ponding method was used at the Duquesne Light Company's Phillips Power Station. Both of these methods were included in a previous TVA economic evaluation of sludge disposal methods (Barrier and others, 1978).

The third method consists of mechanical dewatering of the FGD sludge to the extent that it can be handled as a solid and disposed of directly as landfill. The Calcilox is added either during dewatering or after dewatering in a separate mixing step. The latter method is used in this study.

DISPOSAL IN COAL SURFACE MINES

With the exception of stone quarrying, surface mining of coal is the most geographically diffuse of U.S. mining operations. Figure 1 shows the general distribution of coal surface mining in the United States. In 1975 coal surface mining was conducted in 24 states (Westerstrom and Harris, 1977). Not shown is a large area of northern California and eastern Oregon and Washington where scattered operations have been or are conducted (Westerstrom, 1976). With the exception of the Pennsylvania anthracite regions these areas represent bituminous, subbituminous, and lignite mining operations that can be divided into three regional groupings: the Appalachian region, the Interior basins, and the Rocky Mountains and Great Plains. Each region is characterized by conditions of terrain, geology, and climate which differentiate it to some degree from the other regions. Mining methods are adapted to these conditions and consequently follow regional patterns. Chironis (1978) summarizes modern surface mining techniques on a regional basis. Environmental regulations have led to considerable modification of surface mining techniques in recent years. The additional effect of regulations stemming from the Surface Mining Control and Reclamation Act of 1977 is likely to lead to additional changes in techniques and mining patterns (Todd, 1979). The use of surface mines as FGC waste disposal sites is influenced both by the regional patterns of mining techniques and by the environmental regulations that affect these operations.

In the Appalachians (excluding the eastern Pennsylvania anthracite regions) variations of contour stripping and box cut mining are widely used surface-mining methods designed to cope with rugged terrain. The coal outcrop is followed along a hillside, mining into the slope as far as overburden removal is economically feasible. Additional coal may

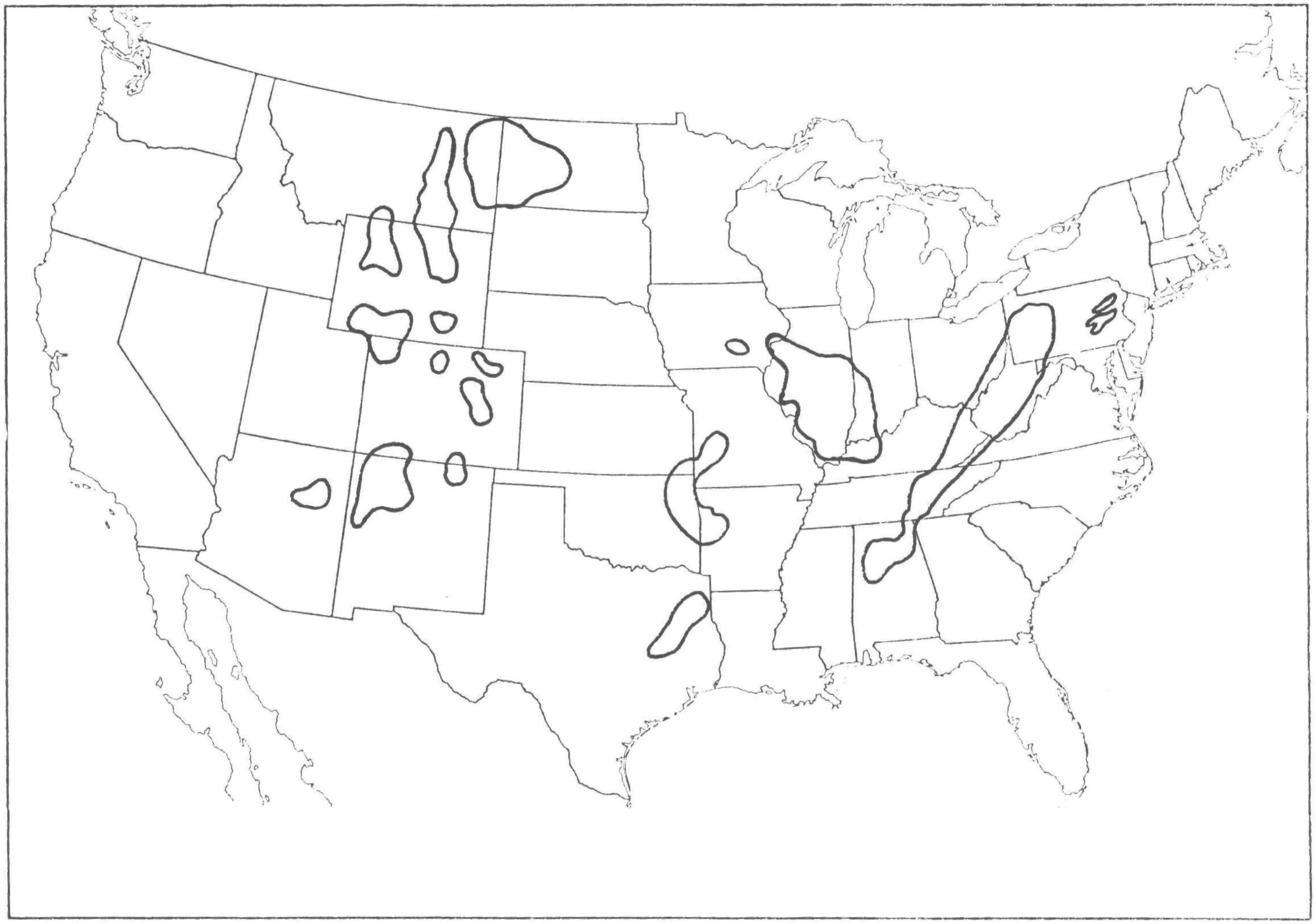


Figure 1. Approximate areas of coal surface mining in the United States.

(derived from Chironis, 1978, Averitt, 1975) be removed by augering or other mining methods. In the past the spoil was dumped downslope and the mined area was left as a sinuous hillside bench with a highwall on the upslope side.

Environmental regulations controlling downslope spoil casting and requiring restoration of original contours have led to modifications of these methods (Coal Age, 1978). Reclamation methods using haulback techniques or block cutting are widely used. Haulback consists of continual transportation of spoil to the previously mined area where it is emplaced to restore original contours. Block cutting involves mining of blocks in successions designed to allow spoil from each block to be placed in the previously mined block.

Hilltop or mountaintop removal, in which the coal is mined completely across a hilltop, is also used in the Appalachian regions. Area mining is used in locations where the terrain is suitable.

Considerable attention is placed on spoil control in most of these mining operations. Segregation of topsoil and toxic materials is often necessary. Drainage and seepage are also important concerns. Topographical control of runoff, structured fills, catchment areas, and reduction of unreclaimed area are important in reducing potential water pollution problems.

Considered as potential disposal sites Appalachian surface mines suffer several disadvantages less pronounced in surface mines of other regions. The mines are smaller and often located in remote and rugged terrain. They may also be poorly sited topographically to be used as a disposal site for wastes with a potential for water pollution. Mining operation modifications designed to meet environmental regulations also complicate the use of the mines for disposal. The unreclaimed area is reduced and pit congestion is increased, making coordination of a major waste disposal operation with the mining operation more difficult. Although not precluding waste disposal, these conditions may make it less generally applicable in the Appalachian region than elsewhere.

Area-type surface-mining methods can be used where relatively flat-lying beds and low relief permit mining over a large continuous area. Area mining is most used in the Interior basins and particularly in the Great Plains and Rocky Mountain Regions. In the Western United States, area mines producing several million tons per year, and eventually to mine coal from thousands of acres, are not uncommon. Jackson (1978) describes a number of these mines. Area mining begins with an initial longitudinal cut of convenient width to accommodate the equipment used. A subsequent cut is made along the highwall of this pit and the spoil is dumped into the first cut. Mining continues in this manner over the area to be mined, with the spoil from each cut being dumped into the preceeding cut. The dumped spoil forms long rows and conical piles which may fill the mined-out pit or only partially cover the floor, depending on the ratio of overburden to coal removed (stripping ratio) and the increase in volume of the spoil over the undisturbed overburden volume (swell ratio). Reclamation follows as closely as practical behind the mining operation to minimize potential pollution and erosion problems. This generally consists of leveling and contouring of the spoil, replacement of topsoil, and revegetation.

Area surface mines appear to be best suited to FGC waste disposal. They are generally larger size and the volume of production provides a potentially greater volume for disposal. In larger mines the scale of waste disposal operations is less likely to approach the scale of mining operations, reducing the effect of mutual interference and the necessity of close coordination. The shape of the mined area and the generally less-rugged terrain may reduce difficulties of seepage control and monitoring. In addition reclamation is usually to restore a rolling terrain in which concerns of slope stability are less extensive than in steeply sloping areas. In area mines of extensive size, waste placement so that it does not interfere with future mining of unrecovered coal is also more feasible. In mining operations such as contour stripping waste disposal could be objectionable on the grounds that unrecovered coal could be contaminated or its recovery hindered.

Area surface mines, of course, have as wide a geographical distribution as surface mines in general. Smaller area mines are not uncommon in Ohio, Pennsylvania, and Alabama. Large area mines are common in the Interior basins, though Illinois and western Kentucky, the major producers, produced almost as much coal by underground mining as by surface mining of all types in 1975 (Westerstrom, 1977). In contrast, the West and Southwest are predominately area-type surface-mining regions. Only in Utah (which has no surface mines) and Iowa did underground production exceed surface production in 1975 (Westerstrom, 1977).

A large, area mine with a relatively low stripping ratio is used as the basis for the mine disposal process in this study. A conceptual model of such a mine is shown in Figure 2. Such a mine is represented by the Baukol-Noonan, Inc., Center Mine near Center, North Dakota, that supplies lignite to the adjacent Minnkota Power Cooperative, Inc., Milton R. Young Power Station. The main lignite seam is about 11 feet thick and is overlain by 50 to 150 feet of poorly consolidated to unconsolidated clays and underlain by a similar clay. Production capacity is over 4 million tons per year. In 1978 these mining operations extended over three sections of rolling grassland. Overburden was being stripped by dragline from the highwall side and dumped in irregular rows in the previous cut. The lignite was removed by a shovel on the pit floor and hauled to the power plant in off-road trucks. The exposed pit floor remaining was generally about 200 feet wide. Roads were bulldozed between the spoil pile rows. Reclamation proceeded at a sufficient distance behind stripping to leave an area more than sufficient for waste disposal.

Figure 2. Area surface mine.

DESIGN AND ECONOMIC PREMISES

The premises used in this evaluation are the same as those used in the two previous TVA evaluations of FGC waste disposal (Barrier and others, 1978, 1979). The design premises specify the location, design, and operation of the power plant. The economic premises specify the economic conditions under which the plant is built and operated and the methodology of cost calculations. The premises specify a midwestern power plant burning an eastern coal and operating under regulated-utility economics. Case variations in which one condition is varied to evaluate the economic effects of changes in certain conditions are also included.

DESIGN PREMISES

The utility plant design and operation is based on Federal Energy Regulatory Commission (FERC) historical data and TVA experience. The conditions used are representative of a typical modern boiler for which FGD systems would be most likely considered. A midwestern location typical of Illinois, Indiana, and Kentucky is used. The design for both processes is assumed to be proven in commercial operation. No provisions are made for additional spares or special sizing to compensate for unknown design and operating factors.

Emission Standards

NSPS established by EPA in 1971 (Chaput, 1976, summarizes these regulations) are used in this study. These specify a maximum emission of 0.10 lb/MBtu for particulate matter and 1.2 lb/MBtu for SO_2. The flyash and scrubber efficiencies required for the coal ash and sulfur contents evaluated are:

% in coal		Removal efficiency - % in flue gas	
Sulfur	Ash	Sulfur	Flyash
2.0	16	63	99.5
3.5	16	79	99.5
5.0	16	85	99.5
3.5	12	79	99.3
3.5	20	79	99.6

Detailed cost estimates in this study include both particulate removal by ESP and all waste-related costs beginning with the FGD scrubber effluent. Costs for a limestone scrubber without waste processing and disposal facilities, calculated using the same premise conditions, are included as a total sum.

Fuel

The coal compositions are composites of several hundred samples representing major U.S. coal production areas. Sulfur contents of 2.0%, 3.5%, and 5.0% dry basis and ash contents of 12%, 16%, and 20% wet basis are used. The coal has a heating value of 10,500 Btu/lb, as fired. The as-fired compositions and flow rates for the 500-MW unit size are shown in Table 1.

TABLE 1. COAL COMPOSITIONS AND BASE-CASE FLOW RATES

	2.0% sulfur		3.5% sulfur		5.0% sulfur	
Component	Wt %	Lb/hr	Wt %	Lb/hr	Wt %	Lb/hr
C	58.03	248,700	57.56	246,800	56.89	244,000
H_2	4.17	17,900	4.14	17,700	4.09	17,500
N_2	1.30	5,600	1.29	5,500	1.27	5,400
O_2	7.81	33,500	7.00	30,000	6.40	27,400
S	1.80	7,700	3.12	13,400	4.46	19,100
Cl	0.15	600	0.15	600	0.15	600
Ash	16.00	68,600	16.00	68,600	16.00	68,600
H_2O	10.74	46,000	10.74	46,000	10.74	46,000
Total	100.00	428,600	100.00	428,600	100.00	428,600

Power Plant

A single, balanced-draft, horizontal, frontal-fired boiler design is used. For the base case a 500-MW net output unit is used as representative of units now being constructed or planned (Kidder, Peabody & Co., 1978). Case variations of 200-MW and 1500-MW (composed of three 500-MW units) are used to represent the size ranges most commonly encountered in current utility construction.

Power Plant Operation

A power plant operating life of 30 years with a declining number of operating hours per year is used. The operating schedule is shown below:

Operating year	Capacity factor, %	Operating hours per year
1-10	80	7,000
11-15	57	5,000
16-20	40	3,000
21-30	17	1,500
Total		127,500
Average	48.5	4,250

The same schedule is used for existing plants; existing units 5, 10, and 15 years old have remaining operating lives of 92,500, 57,500, and 32,500 total hours. Case variations representing a 30-year life with a constant 7000 hours per year operating schedule are also evaluated. A heat rate of 9000 Btu/kWh is used for new 500-MW units. A heat rate of 9200 Btu/kWh is used for existing 500-MW units and new 200-MW units.

Flue Gas Composition

Flue gas composition is the result of fuel, boiler design, and a variety of operating conditions. The compositions used in this study were calculated for the boiler and coals described above. A total air rate of 133% of stoichiometric requirements was used. This consists of 20% excess air to the boiler and 13% inleakage. These values represent TVA experience with this type of boiler design. It is assumed that 80% of the ash in the coal and 95% of the sulfur in the coal are emitted in the flue gas. It is also assumed that 99% of the sulfur emitted is SO_2 and the remainder is SO_3. The flue gas compositions used for new 500-MW units are shown in Table 2.

TABLE 2. FLUE GAS COMPOSITIONS, NEW 500-MW UNITS

Flue gas component	2.0% sulfur, lb/hr	3.5% sulfur, lb/hr	5.0% sulfur, lb/hr
N_2	3,439,000	3,450,000	3,443,000
O_2	257,400	258,200	257,800
CO_2	911,600	904,200	894,700
SO_2	14,500	25,130	35,920
SO_3	183	317	454
NO	3,002	3,009	3,000
HCl	661	661	661
H_2O	265,400	264,500	262,400
Flyash	54,880	54,880	54,880

Scrubber Design

The scrubber system is a wet limestone slurry system. The design is generic, based on TVA operating experience, general industry information, and information from process equipment vendors. Four parallel trains are used for the 500-MW units and two parallel trains are used for the 200-MW units. A single mobile-bed scrubber with a presaturator and mist eliminator is used in each train.

Scrubber stoichiometry is 1.5 moles of $CaCO_3$ per mole of SO_x removed. The limestone is assumed to be 95% $CaCO_3$ and 5% inert minerals which are discarded in the waste. The scrubber slurry is assumed to contain 15% total solids, consisting of sulfur salts, unreacted limestone, and inert material from the limestone. The sulfur salts are assumed to be 85% calcium sulfite hemihydrate ($CaSO_3 \cdot 1/2H_2O$) and 15% calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$).

Waste Treatment and Disposal

The sludge from the scrubbers is dewatered with conventional thickeners and vacuum filtration to a solids content of 60%. Recovered water is returned to the scrubber system. The sludge and dry flyash (and Calcilox® in the Dravo landfill process) are mechanically blended to form a waste of 70% to 82% solids. This material is assumed sufficiently dewatered to be handled on conveyors and loading equipment as a soillike material. The bulk density is assumed to be 1.56 g/cc (97 lb/ft^3).

Front loaders and rear-dump on-road trucks are used for loading and transporting the waste. Conventional earthmoving equipment is provided for the disposal site.

The landfill site is assumed to be level and suitable for typical landfill use. The size of the landfill is based on the lifetime volume of waste produced and a fill depth of 30 feet.

Case Variations

Case variations, consisting of a change in one design premise while holding the others at the base-case conditions, are included to determine the sensitivity of the process economics to operating condition variations. The case variations used in this study are shown below.

Premise condition	Base case	Case variations: Mine disposal	Case variations: Dravo landfill
Both processes			
Power plant size, MW	500	200, 1,500	200, 1,500
Remaining life, years	30	25, 20, 15	25, 20, 15
Lifetime operating hours	127,500	210,000	210,000
Sulfur in coal, %	3.5	2, 5	2, 5
Ash in coal, %	16	12, 20	12, 20
Miles to disposal site	1	5, 10	5, 10

ECONOMIC PREMISES

The economic premises are based on regulated utility economics. They are designed to provide a breakdown of capital investment costs for construction of the system and first-year annual revenue requirements for its operation. The capital structure is assumed to be 60% debt and 40% equity. Interest on bonds is 10% and the return to stockholders is 14%. The premise criteria define cost indexes; equipment installation, land, and other construction costs; capital charges and interest; and operating costs. Capital costs are obtained from engineering, processing, and equipment manufacturing firms, and TVA cost data. Procedures are developed from publications dealing with costs and estimating such as Peters and Timmerhaus (1968) and Popper (1970). Revenue requirement direct costs are based on current labor and supervisory rates, current material and utility costs, and industry practices.

The premises represent projects in which design begins in mid-1977 and construction is completed in mid-1980, followed by a mid-1980 startup. Capital costs are assumed 50% expended in mid-1979. Capital costs are projected to mid-1979 and revenue requirements are projected to mid-1980. Scaling to other time periods can use mid-1979 as the basis for capital costs and mid-1980 as the basis for revenue requirements.

Capital Costs

Capital costs are categorized as direct investment, indirect investment, contingency, other capital charges, land costs, and working capital. Total fixed investment consists of the sum of direct and indirect capital costs and a contingency based on direct and indirect investment. Total depreciable investment consists of total fixed investment plus the other capital charges. Investment costs are projected from historical *Chemical Engineering* annual cost indexes (1974-1976) as shown in Table 3. The costs are based on construction of a proven design and an orderly construction program without delays or overruns caused by equipment, material, or labor shortages.

TABLE 3. COST INDEXES AND PROJECTIONS

Year	1974	1975	1976	1977[a]	1978[a]	1979[a]	1980[a]	1981[a]
Plant	165.4	182.4	197.9	214.7	232.9	251.5	271.6	293.3
Material[b]	171.2	194.7	210.3	227.1	245.3	264.9	286.1	309.0
Labor[c]	163.3	168.6	183.8	200.3	218.3	237.9	259.3	282.6

a. Projections.
b. Same as index in *Chemical Engineering* for "equipment, machinery, supports."
c. Same as index in *Chemical Engineering* for "construction labor."

Mobile equipment is assigned a 6-year life, based on industry practice. Replacement is covered by an increased interim replacement allowance in revenue requirements.

Direct Investment--

Direct capital costs consist of all costs, excluding land, for materials and labor to install the complete waste disposal system. Included are site preparation, excavation, buildings, storage facilities, landscaping, paving, fencing, and 6600 feet of paved road. Process equipment includes all major equipment and all equipment ancillary to the major equipment, such as piping, instrumentation, electrical equipment, and vehicles. Services, utilities, and miscellaneous costs involved in construction are 1.5% of the direct investment.

Indirect Investment--

Indirect investment costs consist of various contractor charges and fees and construction expenses. The following cost divisions and determinations are used.

Engineering design and supervision--This cost is calculated as a function of the complexity of the system as determined by the number of major equipment items, excluding mobile equipment. The empirical formula used is:

Engineering design and supervision = (8900)(1.294)(number of major equipment pieces)

Architect and engineering contractor expense--This expense is calculated as 25% of the engineering design and supervision costs for major equipment items.

Construction expense--This expense includes temporary facilities, utilities, and equipment used during construction. The expense is calculated as an empirical function of direct investment:

$$\text{Construction expense} = 0.25\,(\text{direct investment excluding landfill equipment in M\$})^{0.83}$$

Contractor fees--Direct investment is also used to determine contractor fees:

$$\text{Contractor fees} = 0.096\,(\text{total direct investment in M\$})^{0.76}$$

Contingency--

Contingency is 20% of the sum of direct investment and indirect investment.

Other Capital Charges--

Other capital charges consist of an allowance for startup and modifications and interest during construction. The allowance for startup and modifications is 10% of the total fixed investment excluding mobile equipment. Interest during construction is 12% of the total fixed investment. It is based on the simple interest which would be accumulated at 10% per year under the premise construction and expenditure schedule.

Land--

Total land requirements, including the waste disposal area, are assumed to be purchased at the beginning of the project. A land cost of $3500 per acre is used.

Working Capital--

Working capital consists of money invested in raw materials and supplies, products in process, and finished products; cash retained for operating expenses; accounts receivable; accounts payable; and taxes payable. Working capital is assumed to be equivalent to the sum of 3 weeks of raw material costs, 7 weeks of direct costs, and 7 weeks of overhead costs.

Annual Revenue Requirements

Annual revenue requirements are based on a 7000 hr/yr operating schedule using the same operational profile and remaining life assumptions that were used for the power plant design premises. Costs are projected to 1980 dollars to represent a mid-1980 startup. The revenue requirements are divided into direct costs for raw materials and conversion and indirect costs for capital charges and overheads.

Direct Costs--

Projected direct costs for raw materials, labor, and electricity are shown in Table 4. Operating labor and supervision is based on the quantity, size, and complexity of the major process equipment. Labor for analyses is based on the number of chemical analyses and physical tests needed for process control. Electrical requirements are determined from the operating horsepower of electrical equipment. The rates are based on purchase from an independent source with full capital recovery provided and are adjusted for the quantity used.

TABLE 4. PROJECTED 1980 UNIT COSTS

FOR RAW MATERIALS, LABOR, AND UTILITIES

			$/unit
Calcilox			64.00/ton
Labor			
Operating labor			12.50/man-hr
Analyses			17.00/man-hr
Mobile equipment			17.00/man-hr
	200 MW	500 MW	1500 MW
Utilities			
Electricity, kWh	0.031	0.029	0.027

Fuel and maintenance costs for mobile equipment are based on information from companies operating similar disposal and transportation systems. A cost of $0.16 per ton of waste is used for earthmoving equipment for the Dravo landfill process. A cost of $0.12 per ton of waste is used for mine disposal because only a bulldozer is required. Truck rates for the different distances are:

Distance traveled, miles	$/ton of waste
1	0.06
5	0.20
10	0.39

Landfill operation costs for the Dravo landfill process are assigned a value of $1700 per acre of landfill required. These costs are allocated by acreage actually used--filled to 30 feet and covered with soil--during the period costed.

Other maintenance costs are based on the direct investment costs. They are adjusted for the size and complexity of the system and are assumed to be constant over the life of the plant, the increase in costs balanced by the decline in operating hours. Maintenance costs of 4% of the direct investment are used for all conditions.

Indirect Costs--

Indirect costs consist of capital charges and overheads. A summary of capital charges, based on regulated utility economics, is shown in Table 5. Straight-line depreciation is used, based on the remaining life of the power plant when the FGC system is installed. The allowance for interim replacement is increased to 2.1% to 2.5%, depending on the age of the power plant, from the usual average of about 0.35% because of the unknown life span of FGC systems and the short life (6-year) of the mobile equipment. The insurance and property tax allowance is 2.0% of the total depreciable capital investment. Cost of capital is based on the assumed capital structure. Plant overhead is assumed to be 50% of the total conversion cost less the cost of utilities. Administrative overhead is assumed to be 10% of the total labor and supervision cost.

TABLE 5. ANNUAL CAPITAL CHARGES FOR POWER INDUSTRY FINANCING

	Percentage of total depreciable capital investment			
Years remaining life	30	25	20	15
Depreciation - straight line (based on years remaining life of power unit)	3.3	4.0	5.0	6.7
Interim replacements (equipment having less than 30-year life)	2.5	2.4	2.3	2.1
Insurance and property taxes	2.0	2.0	2.0	2.0
Total rate applied to original investment	7.8	8.8	9.3	10.8

	Percentage of unrecovered capital investment
Cost of capital (capital structure assumed to be 60% debt and 40% equity)	
Bonds at 10% interest	6.0
Equity[a] at 14% return to stockholder	5.6
Income taxes (Federal and State)	5.6
Total rate applied to depreciation base	17.2[b]

a. Contains retained earnings and dividends.

b. Applied on an average basis. The total annual percentage of original fixed investment for new plants would be 7.8% + 1/2 (17.2%) = 16.4%.

SYSTEMS ESTIMATED

The generic designs used in this study were developed from material balances, flowsheets, and layout diagrams using the design premises as specifications. Major equipment design and costs were obtained from equipment vendors, engineering firms, and internal TVA information. Other equipment such as piping, electrical equipment, instrumentation, and structures is based on standard engineering design methods and industry practice.

The evaluations are limited to the dewatering and disposal requirements of the processes. Both processes begin with the equipment which receives the 15% solids slurry from the limestone scrubber and the dry flyash from the ESP units. For purposes of comparison with complete FGC processes, costs of the ESP units and a limestone scrubber without waste disposal facilities are included as a single sum.

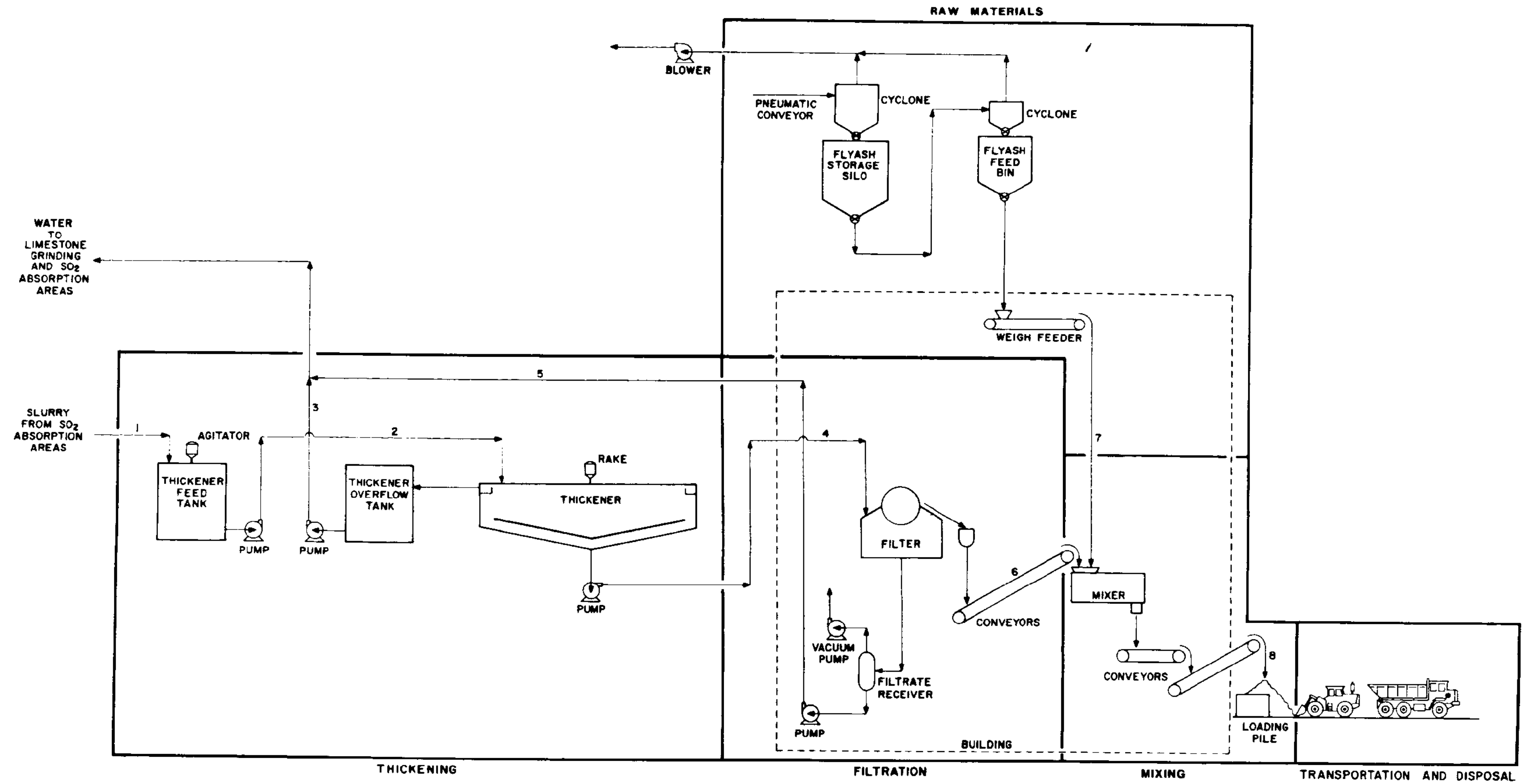
MINE DISPOSAL

This process consists of a conventional thickener and vacuum filter dewatering system for the FGD slurry, followed by blending of the FGD sludge with dry flyash. The blended waste is loaded, trucked to the mine, and emplaced using standard solids-handling equipment. The base-case flow diagram and material balance is shown in Figure 3. The equipment layout is shown in Figure 4.

The 15% solids slurry from the scrubber purge streams is pumped to an agitated thickener feed tank with a 45-minute capacity. The slurry is pumped to the 160-foot-diameter thickener where it settles to form a 35% solids underflow. Thickener overflow is returned to the scrubber feed preparation area. Thickener underflow is filtered on rotary vacuum filters to form a 60% solids cake. Filtrate is returned to the scrubber feed preparation area. The filter cake is conveyed to a pug mill mixer where it is mixed with a metered quantity of dry flyash to form a 74% solids waste. The waste is conveyed to a concrete pad storage area.

Flyash collected in the ESP unit collectors is pneumatically conveyed to two steel storage silos with a combined capacity of 60 hours. The flyash is fed by gravity to a feed bin supplying a belt weigh feeder which meters it to the mixer.

The waste is loaded in rear-dumping on-road trucks for transportation to the mine. A wheeled front-end loader is used to manage the storage pile and load the trucks.



STREAM NO	1	2	3	4	5	6	7	8
DESCRIPTION	SLURRY TO FEED TANK	SLURRY TO THICKENER	RECYCLE WATER TO ABSORBER	UNDERFLOW TO FILTER	RECYCLE H_2O FROM FILTER	FILTER CAKE TO MIXER	FLYASH TO MIXER	MATERIAL TO DISPOSAL
LB / HR	409,480	409,480	233,989	175,491	73,121	102,370	54,407	156,777
GPM	745	745	468	277	146	131		
SP. GR	1.10	1.10	1.00	1.27	1.00	1.56	2.00	1.60
UNDISSOLVED SOLIDS, %	15	15	0	35	0	60		74

Figure 3. Mine disposal base-case flow diagram and material balance.

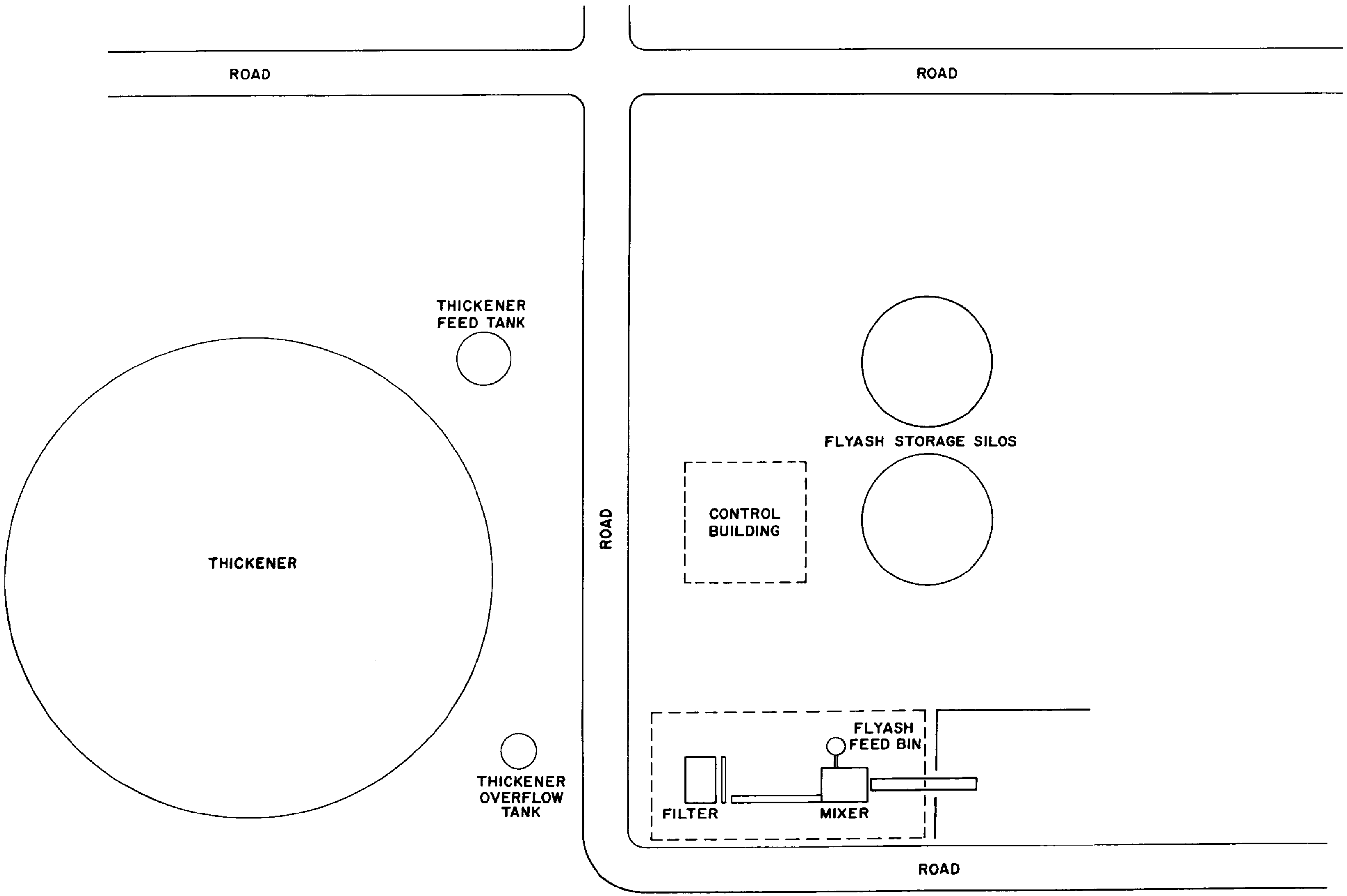


Figure 4. Mine disposal base-case equipment layout.

For the base case the mine is assumed to be located one mile from the power plant. The waste is assumed to be dumped between the spoil pile rows. A crawler dozer is provided to maintain access roads and for control of the waste as required. It is assumed the waste will not be piled to depths greater than that obtained in dumping from the trucks to insure deep burial and minimize ground movement resulting from differential settling between localized beds of waste in the spoil. It is also assumed that reclamation is unaffected by the presence of the waste and that leveling of the spoil will cover the waste with the upper portions of the spoil piles. Similar assumptions would apply for the alternates of dumping the waste in mined portions of the working cut (leaving room for movement of mining equipment) or from roads constructed across the spoil piles. These methods are considered more likely to affect mining operations and are thus less generally applicable in a conceptual model.

No costs other than those associated with transportation of the waste and maintenance of the disposal area are assigned to the disposal operation. Other costs would depend on site-specific factors such as lease relationships, the relationship between the mine operator and the power plant, the operator's valuation of possible effects on his operation, and actual effects created by conditions at a specific mine.

Major Equipment

The base-case major equipment list is shown in Table 6. The equipment list is divided into major processing areas representing the modular division of cost by area. For purposes of comparison with other processes flyash handling is included in the raw materials handling area because it is similar in handling characteristics and process effects to a purchased raw material. The waste storage area is a concrete pad with concrete retaining walls and is not equipped with process equipment.

Other Equipment

Other equipment consists of all ancillary equipment such as structures, piping, electrical equipment, and mobile equipment necessary for the process.

Piping--

Stainless steel is used for slurry lines under 3 inches in diameter. Rubber-lined carbon steel is used for slurry lines 3 inches and larger in diameter. Carbon steel is used for all process and utility water lines.

Foundation and Structural--

Foundations and supporting structures are based on the size and weight of the equipment and necessary supporting structure.

Electrical--

Electrical equipment consists of feeder lines from the power plant transformer yard, transformers and motor control centers, lines to

TABLE 6. MINE DISPOSAL

BASE-CASE EQUIPMENT LIST

Area 1--Raw Materials Handling

	Item	No.	Description
1.	Pneumatic conveyor system, flyash	1	Complete system with blower, cyclone receiver, receiver filter, 200 hp motor, 28 tons/hr
2.	Storage silo, flyash	2	82,000 ft^3, 1,600 tons, field erected, 41 ft dia, 62 ft high, carbon steel with top, 60° cone bottom
3.	Feeder, discharge	2	Rotary airlock type, 28,000 lb/hr, 9 in. dia x 9 in. long, carbon steel
4.	Vibrator, fly-ash storage silo	16	Electromechanical, rotary vibrators, 1 hp motor
5.	Feed bin, flyash	1	11,000 ft^3, 19 ft dia, 38 ft high, with top, 60° cone bottom, carbon steel
6.	Feeder, bin discharge	1	Rotary airlock type, 9 in. dia, 9 in. long, carbon steel
7.	Vibrator, feed bin	8	Electromechanical, rotary vibrators, 1 hp motor
8.	Weigh feeder, flyash	1	5 ft long, 24 in. belt, 2 hp motor, carbon steel, 27 tons/hr

Area 2--Thickening

	Item	No.	Description
1.	Tank, thickener feed	1	34,000 gal, field erected, 18 ft dia, 18 ft high, open top, carbon steel, rubber lined with four 18 in. x 18 ft baffles, offset 3-1/2 in. from wall
2.	Agitator, thickener feed	1	25 hp, 72 in. dia blade, rubber coated

(continued)

TABLE 6 (continued)

Item	No.	Description
3. Pump, thickener feed	2	745 gpm, 75 ft head, rubber lined, 40 hp motor
4. Thickener	1	160 ft dia, 10 ft high, rubber lined concrete basin with rake and motor (1 spare motor)
5. Tank, thickener overflow	1	8,000 gal, 12 ft dia, 10 ft high, carbon steel, rubber lined with flat bottom
6. Pump, thickener overflow recycle	2	468 gpm, 75 ft head, rubber lined, 20 hp motor
7. Pump, thickener underflow to filter	2	277 gpm, 75 ft head, rubber lined, 15 hp motor
8. Sump pump, thickener tunnel	1	5 gpm, 10 ft head, carbon steel, 1/4 hp motor

Area 3--Filtration

Item	No.	Description
1. Filter, rotary drum	2	500 ft^2 surface area, 12 ft dia, 14 ft long drum, stainless steel (wetted parts), vacuum and filtrate pumps included
2. Pump, filtrate recycle	2	146 gpm, 75 ft head, rubber lined, 15 hp motor
3. Conveyor, horizontal belt	1	52 tons/hr, 16 ft long, 24 in. belt, 100 ft/min, 3/4 hp
4. Conveyor, sloping belt	1	52 tons/hr, 30 ft long, 24 in. belt, 100 ft/min, 1 hp

(continued)

TABLE 6 (continued)

Area 4--Mixing		
1. Mixer, pug mill	2	78 tons/hr, 75 hp motor each, carbon steel
2. Conveyor, sloping belt	1	79 tons/hr, 30 ft long, 25 ft rise, 24 in. belt, 100 ft/min, 5 hp

Area 5--Storage

No process equipment.

Area 6--Disposal

Item	No.	Description
1. Wheel loader	1	Front-end wheel loader with 4.5 yd^3 bucket
2. Disposal truck	3	35 ton capacity, 13 yd^3, rear dump
3. Dozer	1	Crawler dozer, 300 hp

individual equipment items, and miscellaneous items required for the electrical system. Line and equipment sizes are based on the connected horsepower.

Instrumentation--

Instrumentation consists of all required sensors and control equipment, graphic boards, annunciators, piping and wiring systems, and panels.

Excavation and Site Preparation--

All excavation, grading, and installation of subbases required for installation of foundations and roadways are included. The estimates are based on the volume of material removed or emplaced.

Buildings--

A 1600 ft^2 12-foot-high control room building is provided for all cases. A 3800 ft^2 40-foot-high process building is used for the 200- and 500-MW plant sizes. A 7500 ft^2 40-foot-high building is used for the 1500-MW plant size.

Roadways--

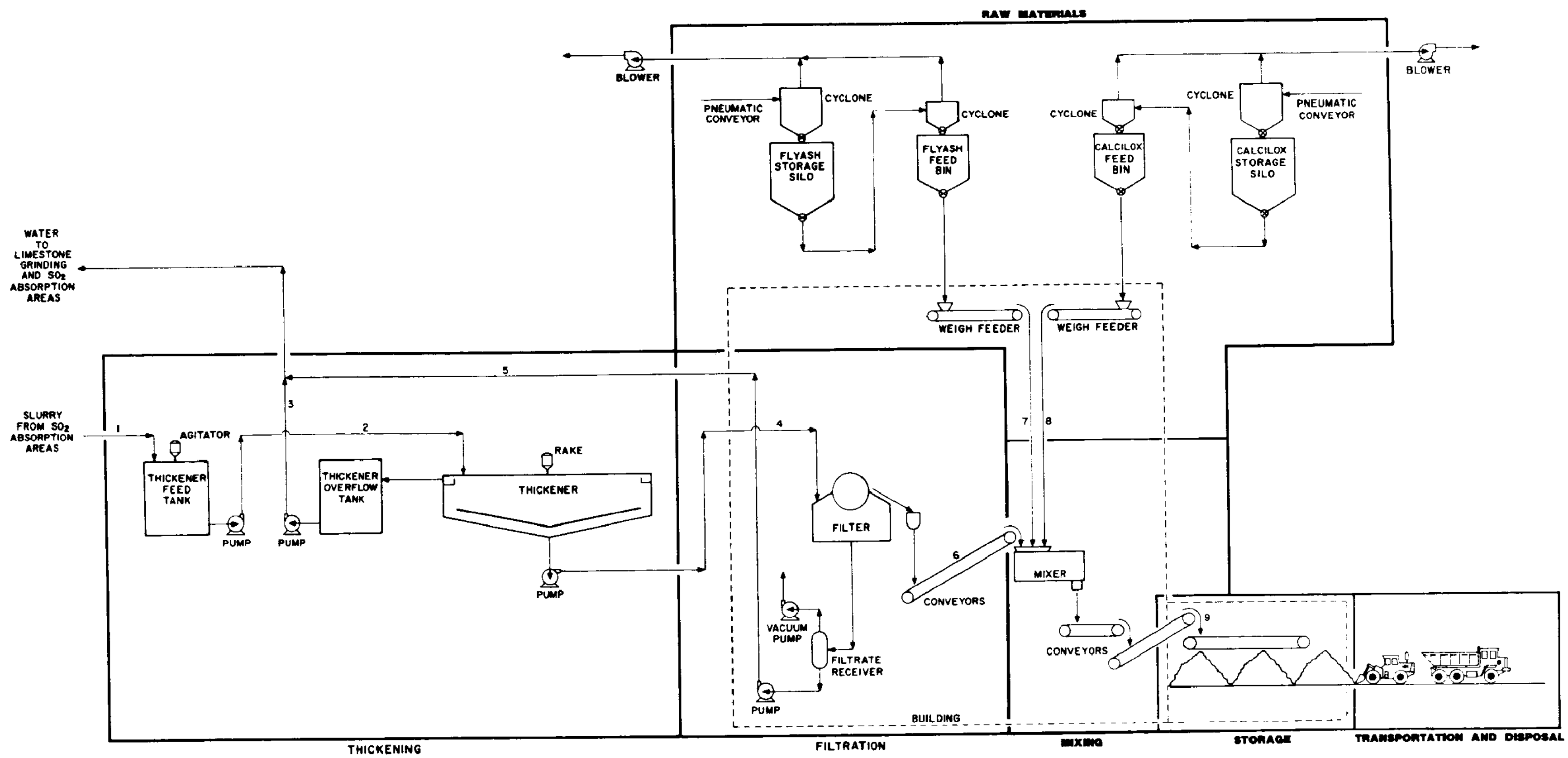
The equivalent of 6600 feet of bituminous-surfaced road is included for all cases. This includes access roads, parking areas, and access roadways for waste haulage.

DRAVO LANDFILL PROCESS

The mechanical dewatering and dry blending variation of the process is used in this evaluation. For purposes of comparison the basic sludge - flyash blending process is used to produce dewatered sludge. Additional equipment for handling and blending of the Calcilox with the dewatered sludge, along with the dry flyash, is included. The dry flyash provides additional increase in solids content, insuring a short curing time and a readily handling material. At the suggestion of Dravo a covered 72-hour storage area was also included in the process. The base-case flow diagram and material balance is shown in Figure 5. The equipment layout is shown in Figure 6.

The FGD sludge dewatering system used is identical to the dewatering system used for the mine disposal process. The 15% solids slurry from the FGD system is dewatered to 35% solids in a thickener and filtered to 60% solids in a rotary vacuum filter. Thickener overflow and the filtrate are returned to the scrubber feed preparation area. The filter cake is transferred to a pug mill mixer by belt conveyor.

A pneumatic conveyor system is used to transport the flyash from the ESP collectors to two steel storage silos with a total storage capacity of 60 hours. Flyash flows by gravity from the storage silos into the weigh feeder feed bin from which it is metered to the mixer in a belt weigh feeder.



STREAM NO	1	2	3	4	5	6	7	8	9
DESCRIPTION	SLURRY TO FEED TANK	SLURRY TO THICKENER	RECYCLE WATER TO ABSORBER	UNDERFLOW TO FILTER	RECYCLE H_2O FROM FILTER	FILTER CAKE TO MIXER	FLYASH TO MIXER	CALCILOX TO MIXER	BLENDED PRODUCT TO STOCKPILE
LB / HR	409,480	409,480	233,989	175,491	73,121	102,370	54,407	4,300	161,077
GPM	745	745	468	277	146	131			
SP. GR.	1.10	1.10	1.00	1.27	1.00	1.56	2.00	1.36	1.60
UNDISSOLVED SOLIDS, %	15	15	0	35	0	60	100	100	74.6

Figure 5. Dravo landfill process base-case flow diagram and material balance.

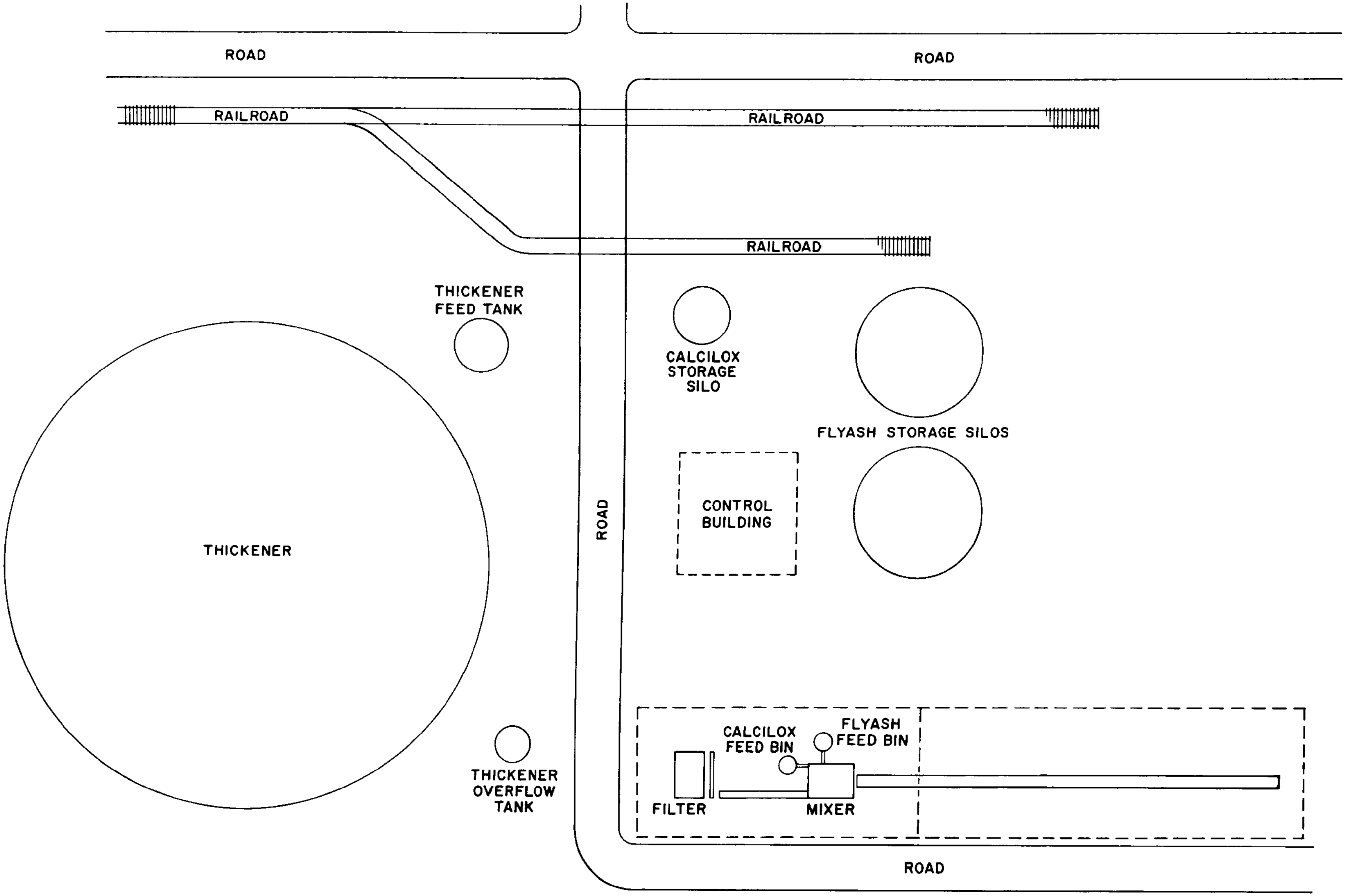


Figure 6. Dravo landfill process base-case equipment layout.

Calcilox is received by rail hopper car and unloaded into a steel storage silo. The Calcilox is pneumatically conveyed to a feed bin and metered to the mixer in a belt weigh feeder.

The blended waste from the mixer is transported by belt conveyor to a roofed 72-hour storage area. A horizontal belt conveyor with a traveling tripper distributes the waste along the 150-foot length of the storage area.

A wheeled front-end loader is used to maintain the storage area and load the on-road, rear-dump trucks which transport the waste to the landfill.

The landfill is located one mile from the power plant. An area-type fill is used in which blocks are successively cleared of topsoil, filled to a 30-foot depth, and covered with soil. Equipment and provisions are included for grading, soil covering, and site maintenance to control runoff and erosion.

Major Equipment

The base-case major equipment list is shown in Table 7. The equipment is divided into major process areas in a manner analogous to the modular division of the mine disposal process. In this process a covered waste area with a 3-day storage capacity is also provided.

Other Equipment

Other equipment such as piping, foundations and structures, and electrical equipment is determined as discussed for the mine disposal process. In addition to this equipment the storage area building and equipment and a railway spur are included for this process. The spur is assumed to connect to an existing spur adjacent to the FGD site.

WASTE QUANTITIES

The waste produced is calculated from the premise conditions of sulfur oxides and flyash emitted and the amount removed to meet NSPS. The scrubber sludge composition includes unreacted limestone and limestone impurities based on the premise stoichiometry and limestone with 5% insoluble impurities. No flyash is included in the scrubber sludge. The total quantity of waste is based on scrubber sludge dewatered to 60% solids, completely dry flyash, and--for the Dravo landfill process--addition of Calcilox equal to 7% of the weight of the scrubber sludge solids. The waste quantities produced by the processes evaluated in this study are shown in Table 8.

Many bulk density data on sludge - flyash mixtures are based on measurements of core samples from impoundments and laboratory tests of blends from scrubber systems. Leo and Rossoff (1978b) summarize results of 92 lb/ft^3 (1.48 g/cc) to 111 lb/ft^3 (1.78 g/cc) for vacuum-filtered

TABLE 7. DRAVO LANDFILL

BASE-CASE EQUIPMENT LIST

Area 1--Raw Materials Handling

	Item	No.	Description
1.	Pneumatic conveying system, flyash	1	Complete system with blower, cyclone receiver, receiver filter, 200 hp motor, 28 tons/hr
2.	Storage silo, flyash	2	82,000 ft^3, 1,600 tons, field erected, 41 ft dia, 62 ft high, carbon steel with top, 60^o cone bottom
3.	Feeder, discharge	2	Rotary airlock type, 28,000 lb/hr, 9 in. dia x 9 in. long, carbon steel
4.	Vibrator, flyash storage	16	Electromechanical, rotary vibrators, 1 hp motor
5.	Feed bin, flyash	1	11,000 ft^3, 19 ft dia, 38 ft high, with top, 60^o cone bottom, carbon steel
6.	Feeder, bin discharge	1	Rotary airlock type, 9 in. dia, 9 in. long, carbon steel
7.	Vibrator, feed bin	8	Electromechanical, rotary vibrators, 1 hp motor
8.	Weigh feeder, flyash	1	5 ft long, 24 in. belt, 2 hp motor, carbon steel, 28 tons/hr
9.	Pneumatic conveying system, Calcilox	1	Complete system with blower, cyclone receiver, receiver filter, 50 hp motor, 3 tons/hr
10.	Storage silo, Calcilox	1	13,000 ft^3, 550 tons, field erected, 19 ft dia, 29 ft high, carbon steel with top, 60^o cone bottom
11.	Feeder, discharge	1	Rotary airlock type, 4,300 lb/hr, 9 in. dia x 9 in. long, carbon steel
12.	Vibrator, Calcilox storage silo	8	Electromechanical, rotary vibrators, 1 hp motor
13.	Feed bin, Calcilox	1	860 ft^3, 9 ft dia x 18 ft high, with top, 60^o cone bottom, carbon steel

(continued)

TABLE 7 (continued)

Item	No.	Description
14. Feeder, discharge	1	Rotary airlock type, 4,300 lb/hr, 9 in. dia x 9 in. long, carbon steel
15. Vibrator, feed bin	4	Electromechanical, rotary vibrators, 1 hp motor
16. Weigh feeder, Calcilox	1	5 ft long, 12 in. belt, 1/3 hp motor, carbon steel, 3 tons/hr

Area 2--Thickening

Item	No.	Description
1. Tank, thickener feed	1	34,000 gal, field erected, 18 ft dia, 18 ft high, open top, carbon steel, rubber lined with four 18 in. x 18 ft baffles, offset 3-1/2 in. from wall
2. Agitator, thickener feed	1	25 hp, 72 in. dia blade, rubber coated
3. Pump, thickener feed	2	745 gpm, 75 ft head, rubber lined, 40 hp motor
4. Thickener	1	160 ft dia, 10 ft high, rubber lined concrete basin with rake and motor (1 spare motor)
5. Tank, thickener overflow	1	8,000 gal, 12 ft dia, 10 ft high, carbon steel, rubber lined with flat bottom
6. Pump, thickener overflow recycle	2	468 gpm, 75 ft head, rubber lined, 20 hp motor
7. Pump, thickener underflow to filter	2	277 gpm, 75 ft head, rubber lined, 15 hp motor
8. Sump pump, thickener tunnel	1	5 gpm, 10 ft head, carbon steel, 1/4 hp motor

(continued)

TABLE 7 (continued)

Area 3--Filtration

	Item	No.	Description
1.	Filter, rotary drum	2	500 ft^2 surface area, 12 ft dia, 14 ft long drum, stainless steel (wetted parts), vacuum and filtrate pumps included
2.	Pump, filtrate recycle	2	146 gpm, 75 ft head, rubber lined, 15 hp motor
3.	Conveyor, horizontal belt	1	52 tons/hr, 16 ft long, 24 in. belt, 100 ft/min, 3/4 hp
4.	Conveyor, sloping belt	1	52 tons/hr, 30 ft long, 24 in. belt, 100 ft/min, 1 hp

Area 4--Mixing

	Item	No.	Description
1.	Mixer, pug mill	2	81 tons/hr, 75 hp motor, carbon steel
2.	Conveyor, sloping belt	1	81 tons/hr, 30 ft long, 25 ft rise, 24 in. belt, 100 ft/min, 5 hp

Area 5--Storage

	Item	No.	Description
1.	Storage shed	1	Concrete pad with roof only, 150 ft long, 50 ft wide, 40 ft high
2.	Conveyor, horizontal belt with traveling tripper	1	81 tons/hr, 150 ft long, 30 in. belt, 100 ft/min, 5 hp

(continued)

TABLE 7 (continued)

Area 6--Disposal

	Item	No.	Description
1.	Wheel loader	1	Front-end wheel loader with 4.5 yd^3 bucket
2.	Disposal trucks	3	35 ton capacity, 13 yd^3, rear dump
3.	Dozer	1	Crawler dozer, 300 hp
4.	Scraper grader	1	11 yd^3, 150 hp
5.	Roller	1	4 x 4 sheeps foot, towed
6.	Water tank truck	1	6,000 gal
7.	Pickup truck	1	

TABLE 8. WASTE PRODUCED

	Scrubber sludge - lb/hr		Flyash - lb/hr	Calcilox - lb/hr[a]	Total - mine disposal		Total - Dravo landfill	
	Solids	Water			Lb/hr	% solids	Lb/hr	% solids
Base case	61,400	41,000	54,400	4,300	156,800	74	161,100	75
Variations from base case								
200 MW	25,100	16,700	22,300	1,800	64,100	74	65,900	75
1500 MW	184,300	122,800	163,200	12,900	470,300	74	483,200	75
25 years remaining life	62,800	41,900	55,600	4,400	160,300	74	164,700	75
20 years remaining life	62,800	41,900	55,600	4,400	160,300	74	164,700	75
15 years remaining life	62,800	41,900	55,600	4,400	160,300	74	164,700	75
2% sulfur in coal	27,100	18,100	53,400	1,900	98,600	82	100,500	82
5% sulfur in coal	95,700	63,800	54,900	6,700	214,400	70	221,100	71
12% ash in coal	57,200	38,100	38,500	4,000	133,800	72	137,800	72
20% ash in coal	66,100	44,100	72,300	4,600	182,500	76	187,800	76
5 miles to disposal	61,400	41,000	54,400	4,300	156,800	74	161,100	75
10 miles to disposal	61,400	41,000	54,400	4,300	156,800	74	161,100	75
200 MW, constant load	25,100	16,700	22,300	1,800	64,100	74	65,900	75
500 MW, constant load	61,400	41,000	54,400	4,300	156,800	74	161,100	75
1500 MW, constant load	184,300	122,800	163,200	12,900	470,300	74	483,200	75

a. Dravo process only; 7% Calcilox, based on scrubber solids.

limestone scrubber sludges of 53% to 80% solids and unspecified flyash content. Hagerty and others (1977) evaluated samples of actual scrubber sludge and sludge - flyash blends. They obtained dry bulk densities of about 75 to 100 lb/ft^3 (100 to 120 lb/ft^3 wet bulk density) at optimum moisture contents of about 15% to 30% using the standard Proctor test. Coltharp and others (1979) evaluated a variety of sludge - flyash mixtures using sludges of different sulfite contents and flyash from different coal types. They obtained dry bulk density results of 52 to 94 lb/ft^3 at optimum moisture contents of 16% to 35%, with one exception of 65%. High sulfite sludge - flyash blends of 50% each had dry bulk densities of 70 to 89 lb/ft^3 (92 to 111 lb/ft^3 wet bulk density) at optimum moisture contents of 25% to 35%.

The data illustrate, as the investigators themselves have emphasized, the wide variations in bulk densities of FGD sludges, flyashes, and sludge - flyash blends. The many variations of sludge type, flyash type and content, and moisture content, as well as sampling and testing methods, make extension of these data to other compositions difficult. Site-specific factors will necessarily be important factors in determining waste volumes for particular FGD waste disposal systems.

This study assumes a single waste wet bulk density of 97 lb/ft^3 (1.55 g/cc) for both processes. This represents a dry bulk density of 77 lb/ft^3 for the base-case mine disposal process and 78 lb/ft^3 for the base-case Dravo landfill process. The relationships of wet (γm) and dry (γd) bulk densities and moisture content (ω) are based on the ASTM Method 698-70 relationship:

$$\gamma d = [\gamma m/(\omega + 100)] \times 100$$

The waste quantities produced by the processes in this study are shown in Table 9. No in-place compaction is assumed. Acreage requirements are based on a 30-foot depth for the landfill process, in which earthmoving equipment is used to pile and grade the fill, and a 5-foot depth for the mine-disposal process, in which the waste is simply dumped between the spoil rows.

TABLE 9. ANNUAL AND LIFETIME WASTE QUANTITIES AND DISPOSAL AREA REQUIREMENTS

	Mine disposal			Dravo landfill		
	Tons/first year	Acres/first year (5 ft depth)	Acres/lifetime (5 ft depth)	Tons/first year	Acres/first year (30 ft depth)	Acres/lifetime (30 ft depth)
Base case	548,800	52	947	563,900	8.9	162
Case variations						
200 MW	224,400	21	386	230,700	3.6	66
1500 MW	1,646,100	156	2,838	1,691,200	26.7	486
25 years remaining life[a]	561,100	53	702	576,500	9.1	120
20 years remaining life[b]	561,100	53	436	576,500	9.1	75
15 years remaining life[c]	561,100	53	247	576,500	9.1	42
2% sulfur in coal	345,100	33	595	351,800	5.6	101
5% sulfur in coal	750,400	71	1,293	773,900	12.2	222
12% ash in coal	468,300	44	807	482,300	7.6	139
20% ash in coal	638,800	61	1,102	654,900	10.3	188
5 miles to disposal	548,800	52	947	563,900	8.9	162
10 miles to disposal	548,800	52	947	563,900	8.9	162
7,000 hr/yr constant schedule[d]						
200 MW	224,400	21	636	230,700	3.6	109
500 MW	548,800	52	1,560	563,900	8.9	267
1500 MW	1,646,100	156	4,674	1,691,200	26.7	800

Basis: 97 lb/ft^3 bulk density, wet waste, no in-place compaction. First year based on 7,000 hours of operation. Lifetime operation 127,500 hours except as noted. a. 92,500 lifetime hours. b. 57,500 lifetime hours. c. 32,500 lifetime hours. d. 210,000 lifetime hours.

RESULTS

Capital investment and annual revenue requirements for the base case and each case variation are shown in Appendix A. Table 10 shows a summary of capital investments for the mine disposal and Dravo landfill processes. Table 11 shows a summary of annual revenue requirements for both processes.

The estimates reported in Appendix A and in the text are for waste processing costs; they do not include either scrubber costs or ESP costs. For comparison with complete FGC systems the following costs for a limestone scrubber system without waste disposal facilities and for ESP units can be combined with the disposal costs:

	Capital investment	Annual revenue requirements
Scrubber	$36,368,000	$11,842,000
ESP system	9,614,000	1,975,000

The scrubber and ESP costs are based on a 500-MW power plant, using the same design and economic premises that were used for the waste disposal process evaluations.

In addition, the base cases of the two processes evaluated in this study and the six processes previously evaluated (Barrier and others, 1978, 1979) are included in modular form.

BASE CASE

Capital investment for the base-case mine disposal process is $7,996,000 (16.0 $/kW). Direct investment for process requirements is 42% of the total capital investment. Mobile equipment--consisting of loaders, trucks, and a dozer--is 7% of the total. Land cost is insignificant. Including ESP costs of $9,614,000 the total capital investment is $17,610,000 (35.2 $/kW).

Capital investment for the base-case Dravo landfill process is $10,004,000 (20.0 $/kW). Direct investment for process requirements is 37% of the total capital investment. Mobile equipment is 8% of the total and land is 6% of the total. Including ESP costs the total capital investment is $19,618,000 (39.2 $/kW).

Annual revenue requirements for the mine disposal process are $3,430,200 (0.98 mill/kWh). Direct costs, consisting entirely of con-

TABLE 10. CAPITAL INVESTMENT SUMMARIES

MINE DISPOSAL AND DRAVO LANDFILL PROCESSES

Condition	Mine disposal			Dravo landfill		
	k$	$/kW	$/ton[a]	k$	$/kW	$/ton[a]
Base case	7,996	16.0	0.80	10,004	20.0	0.97
Variations from base case						
200 MW	5,917	29.6	1.46	7,180	35.9	1.71
1500 MW	16,306	10.9	0.55	20,632	13.8	0.67
25 years remaining life	8,067	16.2	1.09	9,960	19.9	1.31
20 years remaining life	8,067	16.2	1.75	9,793	19.6	2.07
15 years remaining life	8,067	16.2	3.10	9,677	19.4	3.62
2% sulfur in coal	7,056	14.1	1.12	8,586	17.2	1.34
5% sulfur in coal	9,161	18.3	0.67	11,923	23.9	0.85
12% ash in coal	7,422	14.8	0.87	9,302	18.6	1.06
20% ash in coal	8,589	17.2	0.74	10,749	21.5	0.90
5 miles to disposal	8,554	17.1	0.86	10,573	21.2	1.03
10 miles to disposal	8,846	17.7	0.88	10,843	21.7	1.06
200 MW, constant load	5,917	29.6	0.88	7,330	36.7	1.74
500 MW, constant load	7,996	16.0	0.80	10,392	20.8	1.01
1500 MW, constant load	16,308	10.9	0.33	21,783	14.5	0.71

a. Based on total dry solids, as disposed of, during the life of the power plant.

TABLE 11. ANNUAL REVENUE REQUIREMENTS SUMMARIES

MINE DISPOSAL AND DRAVO LANDFILL PROCESSES

Condition	Mine disposal				Dravo landfill			
	k$	Mills/ kWh	$/ton waste[a]	$/ton solids	k$	Mills/ kWh	$/ton waste[a]	$/ton solids
Base case	3,430	0.98	6.25	8.45	5,032	1.44	8.90	11.90
Variations from base case								
200 MW	2,508	1.79	11.18	15.10	3,397	2.43	14.72	19.63
1500 MW	6,336	0.60	3.85	5.20	10,322	0.98	6.10	8.14
25 years remaining life	3,523	1.01	6.28	8.49	5,149	1.47	8.93	11.91
20 years remaining life	3,562	1.02	6.35	8.58	5,179	1.48	8.98	11.98
15 years remaining life	3,679	1.05	6.56	8.86	5,304	1.52	9.20	12.27
2% sulfur in coal	2,938	0.84	8.51	10.38	3,910	1.12	11.11	13.55
5% sulfur in coal	3,974	1.14	5.30	7.46	6,666	1.90	8.61	12.13
12% ash in coal	3,294	0.94	7.03	9.77	4,799	1.37	9.95	13.82
20% ash in coal	3,604	1.03	5.64	7.42	5,297	1.51	8.09	10.64
5 miles to disposal	4,128	1.18	7.52	10.17	5,735	1.64	10.17	13.56
10 miles to disposal	4,545	1.30	8.28	11.19	6,185	1.77	10.97	14.62
200 MW, constant load	2,508	1.79	11.18	15.10	3,410	2.44	14.78	19.71
500 MW, constant load	3,430	0.98	6.25	8.45	5,066	1.45	8.98	11.98
1500 MW, constant load	6,336	0.60	3.85	5.20	10,421	0.99	6.16	8.22

a. Wet waste, as disposed of, based on 7,000 hours of operation.

version costs, account for 40% of the annual revenue requirements. The largest element of direct costs is disposal labor, followed by process labor. Maintenance, fuel, and utilities account for only 25% of direct costs. The remaining 60% of annual revenue requirements consists of indirect costs for capital charges and overheads based on capital investment and direct costs. Including annual revenue requirements of $1,975,000 for ESP operation, the annual revenue requirements for the mine disposal process are $5,405,200 (1.54 mills/kWh).

Annual revenue requirements for the base-case Dravo landfill process are $5,032,400 (1.44 mills/kWh). Direct costs for this process account for 52% of the total. The cost of Calcilox® is the largest direct cost element; it constitutes 37% of direct costs. Disposal labor and process labor are the other large direct cost elements, together accounting for 46% of direct costs. Again, maintenance, fuel, and utilities constitute a relatively minor portion of direct costs. Including ESP operation annual revenue requirements for the Dravo landfill process are $7,007,100 (2.00 mills/kWh).

Both processes are labor intensive. The major portion of labor costs is involved in handling and transporting the waste. Mine disposal, which requires fewer man-hours at the disposal site, has lower disposal labor costs ($595,700 compared to $744,600 for the Dravo landfill process). Labor requirements for loading and transportation, which are identical for both processes, account for the major portion of disposal labor costs, however. Consequently, the savings in disposal labor requirements by mine disposal are relatively minor. The greatest difference in costs between the two processes is the cost of raw material, which accounts for 60% of the difference in annual revenue requirements between the two processes.

In terms of waste quantities, the mine disposal process annual revenue requirements are 6.3 $/ton of wet waste, as disposed of at 74% solids, and 8.5 $/ton of dry solids. The Dravo landfill annual revenue requirements are 8.9 $/ton of 75% solids wet waste and 11.9 $/ton of dry solids. Including ESP costs the mine disposal costs are 9.9 $/ton of wet waste and 13.3 $/ton of dry solids. With ESP costs the Dravo landfill process costs are 12.4 $/ton of wet waste and 16.6 $/ton of dry solids.

CASE VARIATIONS

Case variations for both processes were calculated to evaluate the effect of different conditions on costs. A constant 7000 hr/yr operating profile, power plant size and age, coal sulfur and ash content, and distance to the disposal site were evaluated. The effects of case variations, as a percentage change from the base case in $/kW and mills/kWh, are shown in Table 12.

TABLE 12. EFFECT OF CASE VARIATIONS ON UNIT COSTS,

RELATIVE TO BASE-CASE COSTS

Case variation	Percent change from base case[a]			
	Mine disposal		Dravo landfill	
	Capital investment[b]	Annual revenue requirements[c]	Capital investment[b]	Annual revenue requirements[c]
200 MW	+85	+83	+80	+69
1500 MW	-32	-39	-31	-32
25 years remaining life	+ 1	+ 3	- 1	+ 2
20 years remaining life	+ 1	+ 4	- 2	+ 3
15 years remaining life	+ 1	+ 7	- 3	+ 6
2% sulfur in coal	-12	-14	-14	-22
5% sulfur in coal	+11	+16	+19	+32
12% ash in coal	- 8	- 4	- 7	- 5
20% ash in coal	+ 8	+ 5	+ 8	+ 5
5 miles to disposal	+ 7	+20	+ 8	+14
10 miles to disposal	+11	+33	+ 9	+23
200 MW, constant load	+85	+83	+84	+69
500 MW, constant load	0	0	+ 4	+ 1
1500 MW, constant load	-32	-39	-28	-31

a. Base case is 500-MW, new (30-year life), 3.5% sulfur, 16% ash, 1 mile to disposal.

b. Percent difference in $/kW.

c. Percent difference in mills/kWh.

Power Plant Size and Operating Schedule

Declining-Load Operating Schedule--

Power plant size variations of 200- and 1500-MW were evaluated using the same declining-load operating schedule used for the 500-MW base case. Capital investment for both processes at the three power plant sizes is shown in Table 13. Annual revenue requirements are shown in Table 14. The same data are summarized graphically in Figure 7.

The data illustrate the decline in unit disposal costs with increasing power plant capacity. Capital investment for the mine disposal process is 29.6 $/kW for the 200-MW power plant size. It decreases to 16.0 and 10.9 $/kW for the 500- and 1500-MW power plants. Similarly, capital investment for the Dravo landfill process is 35.9 $/kW for the 200-MW power plant and decreases to 20.0 and 13.8 $/kW for the 500- and 1500-MW power plants.

In terms of percentage increase in total capital investment from 200- to 500- to 1500-MW power plant sizes, using the 200-MW size as the basis, the capital investments increase 35% and 175% for the mine disposal process and 39% and 187% for the Dravo landfill process. On the same basis power output increases 150% and 650%.

A similar relationship occurs in annual revenue requirements. The mine disposal process annual revenue requirements are 1.79 mills/kWh for the 200-MW power plant, 0.98 mill/kWh for the 500-MW power plant, and 0.60 mill/kWh for the 1500-MW power plant. The Dravo landfill process annual revenue requirements are 2.43 mills/kWh for the 200-MW power plant, 1.44 mills/kWh for the 500-MW power plant, and 0.98 mill/kWh for the 1500-MW power plant.

In terms of percentage increase in total annual revenue requirements, again using the 200-MW size as a basis, the mine disposal process annual revenue requirements increase 37% and 153% and the Dravo landfill process annual revenue requirements increase 48% and 204% for power output increases of 150% and 650%.

The economy of scale realized in both capital investment and annual revenue requirements is largely the result of general economies in process equipment, mobile equipment, labor, and related indirect costs. The Dravo landfill process has a slightly larger percentage increase in capital investment with size because of disposal-area land requirements, which increase linearly with waste volume, and thus with power plant output. The considerably larger percentage increase in annual revenue requirements with power plant size for the Dravo landfill process is largely a result of the raw material costs, which also increase linearly with power plant size.

Mine disposal, regardless of the process used to produce the waste, has a minor advantage in economy of scale through elimination of disposal-area land requirements. This advantage would, of course, be diminished or eliminated by fees to the operator or leasors if the fees were related

TABLE 13. POWER PLANT SIZE VARIATION, DECLINING LOAD, CAPITAL INVESTMENT

	Mine disposal, k$			Dravo landfill, k$		
	200 MW	500 MW	1500 MW	200 MW	500 MW	1500 MW
Process equipment	1,211	1,985	4,152	1,320	2,161	4,498
Piping and insulation	117	139	214	126	151	234
Foundation and structural	122	242	1,264	132	264	1,389
Excavation and site preparation	40	53	85	44	58	95
Electrical	284	345	540	300	367	579
Instrumentation	52	56	80	56	60	87
Buildings	504	504	954	564	654	1,404
Total	2,330	3,324	7,289	2,542	3,715	8,286
Services and miscellaneous	35	50	109	38	56	124
Total	2,365	3,374	7,398	2,580	3,771	8,410
Mobile equipment	476	559	1,104	707	790	1,335
Total direct investment	2,841	3,933	8,502	3,287	4,561	9,745
Engineering design and supervision	288	322	438	392	426	438
Architect and engineering contractor	72	81	110	98	107	109
Construction expense	511	686	1,316	549	752	1,464
Contractor fees	212	272	488	237	301	542
Total	3,924	5,294	10,854	4,563	6,147	12,298
Contingency	785	1,059	2,171	913	1,229	2,460
Total fixed investment	4,709	6,353	13,025	5,476	7,376	14,758
Allowance for startup and modifications	423	579	1,192	477	659	1,342
Interest during construction	565	762	1,563	657	885	1,771
Total depreciable investment	5,697	7,694	15,780	6,610	8,920	17,871
Land	11	14	28	242	581	1,729
Working capital	209	288	498	328	523	1,032
Total capital investment	5,917	7,966	16,306	7,180	10,004	20,632
$/kW	29.6	16.0	10.9	35.9	20.0	13.8

Basis
New midwestern plant with 30-year, 127,500-hour lfe and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP flyash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with flyash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE 14. POWER PLANT SIZE VARIATIONS, DECLINING LOAD, ANNUAL REVENUE REQUIREMENTS

	Mine disposal, k$			Dravo landfill, k$		
	200 MW	500 MW	1500 MW	200 MW	500 MW	1500 MW
Direct Costs						
Delivered raw materials						
Calcilox				403	966	2,893
Total raw material costs				403	966	2,893
Conversion costs						
Operating labor and supervision						
Plant	329	438	548	329	438	548
Disposal equipment	447	596	1,042	596	745	1,191
Plant maintenance - 4% of direct investment	114	157	340	131	182	390
Landfill operation						
Landfill preparation				6	15	45
Truck fuel and maintenance	14	33	99	14	34	102
Earthmoving equipment fuel and maintenance	27	66	198	37	90	271
Electricity	55	77	162	72	108	224
Analyses	17	17	26	17	17	26
Total conversion costs	1,002	1,383	2,414	1,201	1,629	2,796
Total direct costs	1,002	1,383	2,414	1,605	2,595	5,688
Indirect Costs						
Capital charges						
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment	446	602	1,236	518	698	1,399
Average cost of capital and taxes at 8.6% of total capital investment	509	688	1,402	618	860	1,774
Overhead						
Plant, 50% of conversion costs less electricity	473	653	1,126	565	760	1,286
Administrative, 10% of total labor and supervision	78	103	159	92	118	174
Total indirect costs	1,506	2,047	3,923	1,792	2,437	4,634
Total annual revenue requirements	2,508	3,430	6,336	3,397	5,032	10,322
Equivalent unit revenue requirements						
Mills/kWh	1.79	0.98	0.60	2.43	1.44	0.98
$/ton waste	11.2	6.3	3.9	14.7	8.9	6.1
$/ton dry solids	15.1	8.5	5.2	19.6	11.9	8.1

Basis
One-year, 7,000-hour operation of systems described in capital investment summary; mid-1980 cost basis.

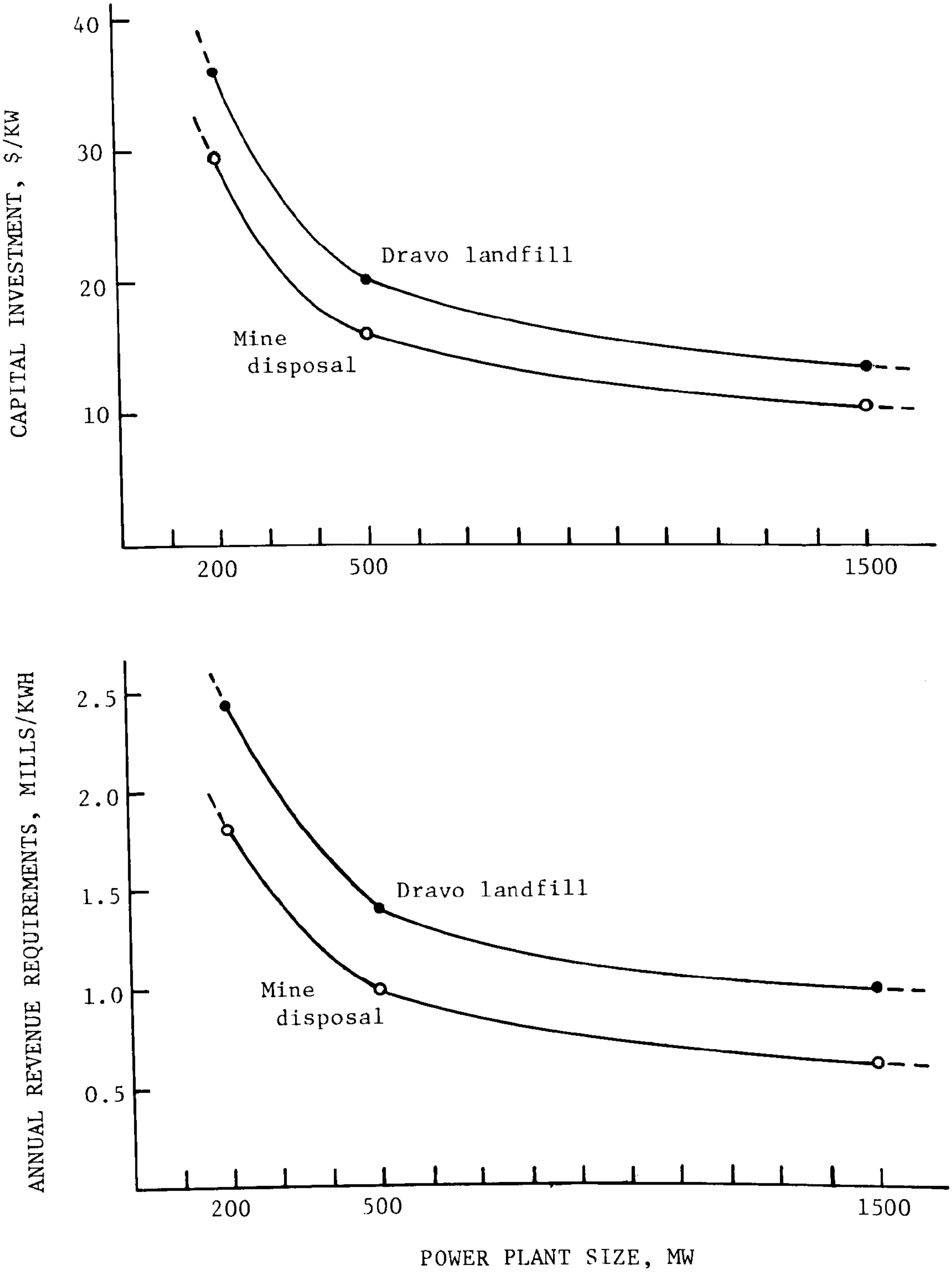


Figure 7. Effect of power plant size on disposal costs.

to waste volume. The mine disposal process evaluated in this study has a more significant advantage in economy of scale because it requires no purchased raw materials whose quantities are linearly related to waste volume.

Constant-Load Operating Schedule--

A constant-load operating schedule of 7,000 hr/yr for 30 years (210,000 lifetime operating hours, compared to 127,500 hours for the declining-load schedule) was evaluated for the three power plant sizes. The effect on both capital investment and first-year annual revenue requirements is negligible as shown in Table 15. The only capital investment cost element significantly affected is disposal-area land requirements. First-year annual revenue requirements are affected by increased indirect costs.

TABLE 15. CONSTANT LOAD VERSUS DECLINING LOAD

	Mine disposal, k$		Dravo landfill, k$	
	Capital investment	Annual revenue requirements[a]	Capital investment	Annual revenue requirements[a]
Constant Load[b]				
200 MW	5,917	2,508	7,330	3,410
500 MW	7,996	3,430	10,392	5,066
1500 MW	16,308	6,336	21,783	10,421
Declining Load[c]				
200 MW	5,917	2,508	7,180	3,397
500 MW	7,996	3,430	10,004	5,032
1500 MW	16,308	3,336	20,632	10,322

a. Based on 7,000 hr/yr operation.
b. 210,000 lifetime operating hours.
c. 127,500 lifetime operating hours.

Power Plant Remaining Life

In addition to the base-case new power plant with a 30-year remaining life, existing power plants with remaining lives of 25, 20, and 15 years were evaluated. These are shown below, compared to the base case, and graphically in Figure 8.

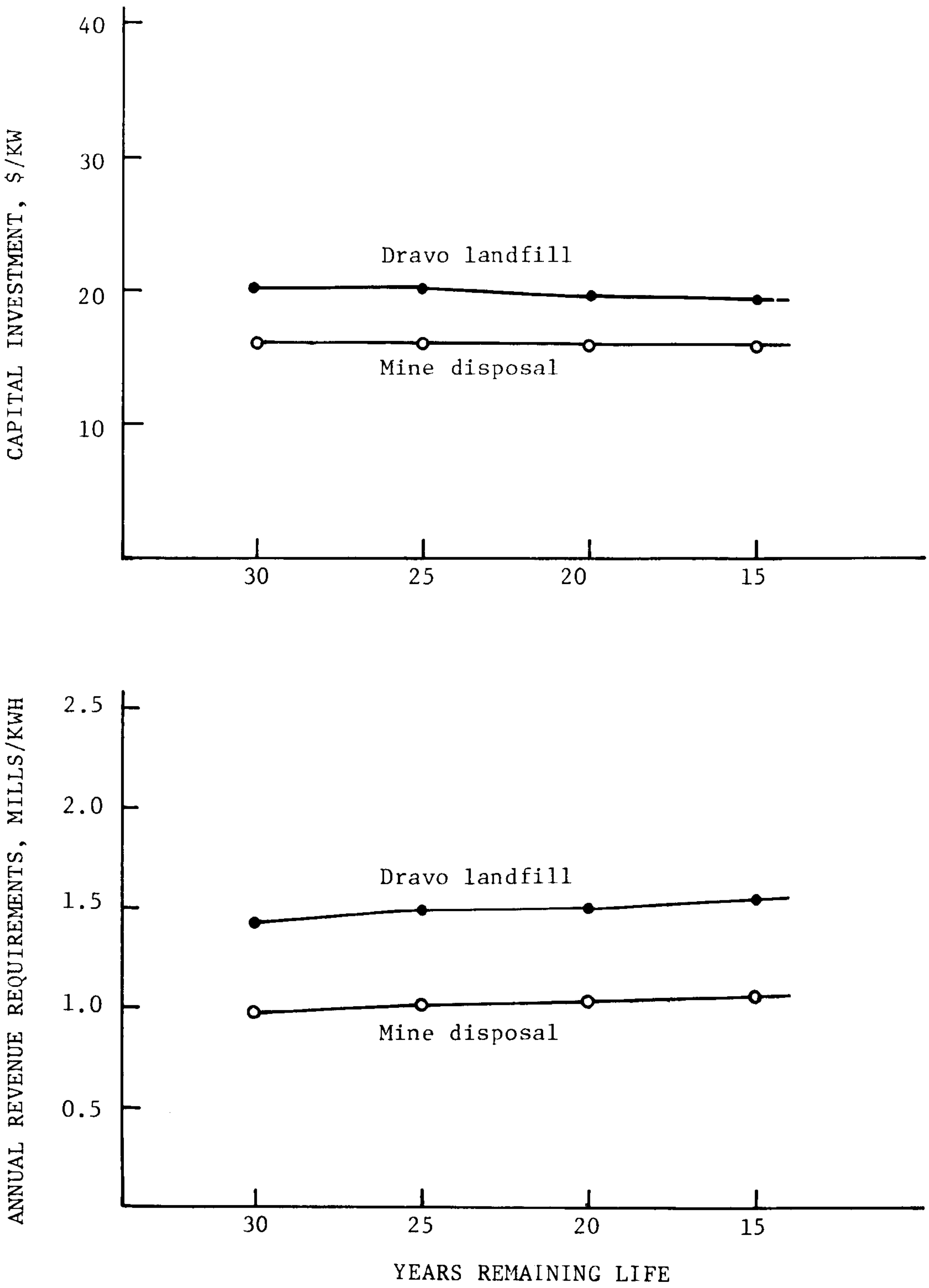


Figure 8. Effect of power plant remaining life on disposal costs.

	Remaining life, years			
	30	25	20	15
Mine disposal				
Capital investment, k$	7,996	8,067	8,067	8,067
Annual revenue requirement, k$	3,430	3,523	3,562	3,679
Dravo landfill				
Capital investment, k$	10,004	9,960	9,793	9,677
Annual revenue requirement, k$	5,032	5,149	5,179	5,304

Power plant age has little effect on either capital investment or annual revenue requirements. Capital investment is affected by increased process equipment costs resulting from the higher heat rate. In addition, the Dravo landfill process capital investment is reduced by the reduction in disposal-area land requirements. The result is an increase in capital investment for the mine disposal process of about 1% and a maximum decrease in capital investment of 3% for the Dravo landfill process.

Annual revenue requirements are increased a maximum of 7% for the mine disposal process and a maximum of 5% for the Dravo landfill process. The increases are a result of slight increases in raw material (for the Dravo landfill process) and conversion costs, but primarily they are a result of increased indirect costs. Capital charges, particularly depreciation, interim replacement and insurance, account for the major increase in annual revenue requirements.

Sulfur in Coal

Coal sulfur contents of 2.0% and 5.0% were evaluated in addition to the base-case 3.5% sulfur coal. Coal sulfur content has a considerable influence on both capital investment and annual revenue requirements because of its effect on process equipment size, raw material requirements, and disposal costs. The mine disposal process, with neither raw material nor disposal-area land requirements, is less economically sensitive to coal sulfur content.

Capital investment is primarily affected by process equipment and (for the Dravo landfill process) disposal area land requirements as shown below and in Figure 9. Mobile equipment costs are relatively insensitive to coal sulfur content because of the highly incremental nature of the equipment requirements.

Sulfur in coal, wt % dry	2.0		3.5		5.0	
	k$	$/kW	k$	$/kW	k$	$/kW
Mine disposal						
Process equipment	1,532	3.1	1,985	4.0	2,465	4.9
Mobile equipment	559	1.1	559	1.1	642	1.3
Total capital investment	7,056	14.1	7,996	16.0	9,161	18.3
Dravo landfill						
Process equipment	1,665	3.3	2,161	4.3	2,700	5.4
Mobile equipment	790	1.6	790	1.6	873	1.7
Land	364	0.7	581	1.2	795	1.6
Total capital investment	8,586	17.2	10,004	20.0	11,923	23.9

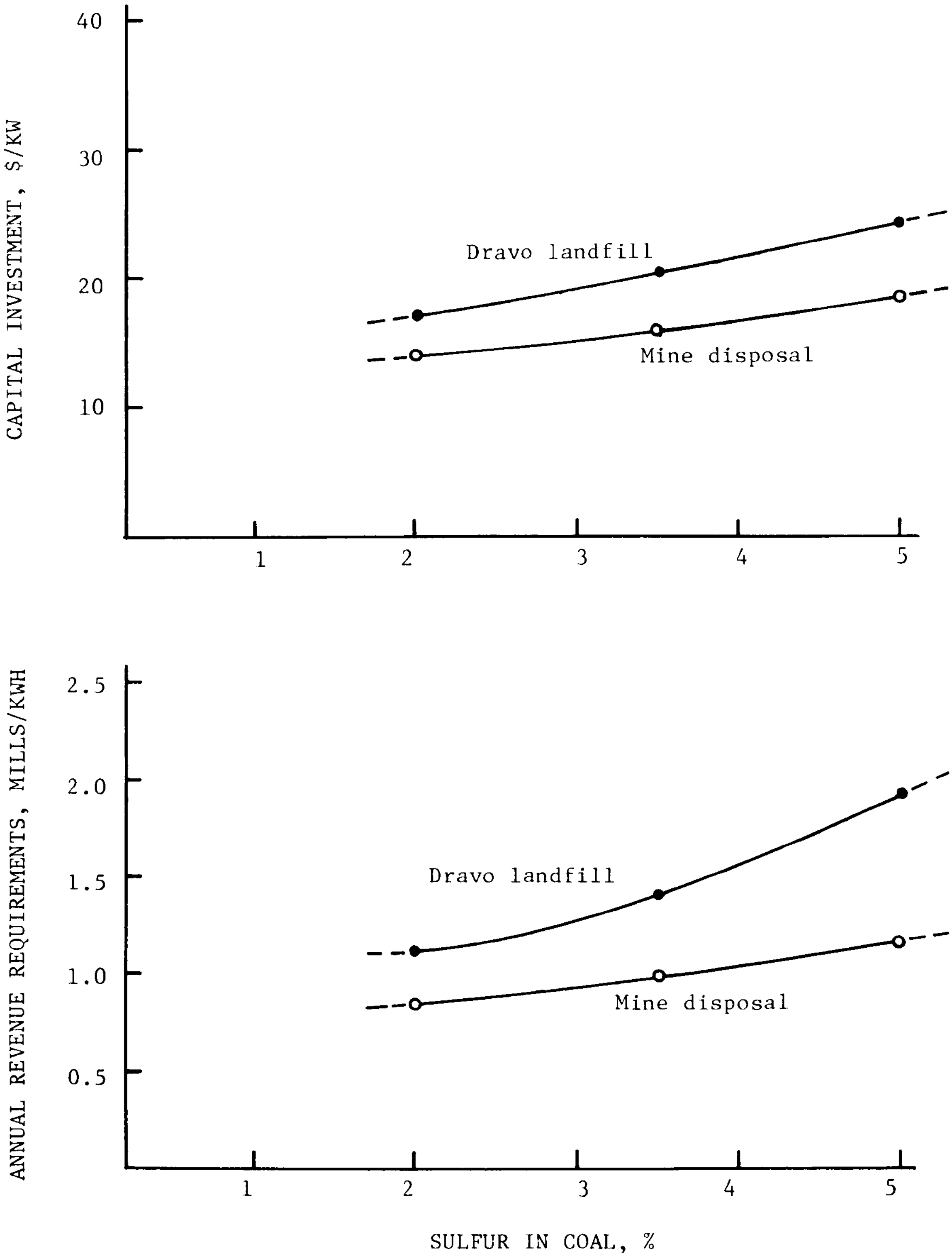


Figure 9. Effect of coal sulfur content on disposal costs.

The annual revenue requirement direct costs most affected by coal sulfur content are raw material, disposal labor and supervision, and mobile equipment operating costs. Of these, raw material cost for the Dravo landfill process has the largest effect on total costs. Disposal labor and supervision increases considerably with increasing coal sulfur content because of increased trucking requirements. Mobile equipment fuel and maintenance costs have large increases but do not constitute as large a part of annual revenue requirements. Process operating labor and supervision cost is not affected.

Sulfur in coal, wt % dry	2.0		3.5		5.0	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Mine disposal						
Disposal labor	447	0.13	596	0.17	745	0.21
Mobile equipment	62	0.02	99	0.03	135	0.04
Total annual revenue requirements	2,938	0.84	3,430	0.98	3,974	1.14
Dravo landfill						
Raw materials	429	0.12	966	0.28	1,504	0.43
Disposal labor	596	0.17	745	0.21	894	0.26
Mobile equipment	77	0.02	124	0.04	161	0.05
Total annual revenue requirements	3,910	1.12	5,032	1.44	6,666	1.90

Ash in Coal

Coal ash contents of 12% and 20% were evaluated in addition to the 16% ash base-case coal. Coal ash content has a moderate effect on capital investment and annual revenue requirements. As in the case of coal sulfur content the primary effect on capital investment direct costs is on process equipment, mobile equipment, and disposal-area land requirement costs. These are shown below and the totals are shown graphically in Figure 10.

Ash in coal, wt %	12		16		20	
	k$	$/kW	k$	$/kW	k$	$/kW
Mine disposal						
Process equipment	1,788	3.6	1,985	4.0	2,173	4.3
Mobile equipment	559	1.1	559	1.1	642	1.3
Total capital investment	7,422	14.8	7,996	16.0	8,589	17.2
Dravo landfill						
Process equipment	1,939	3.9	2,161	4.3	2,343	4.7
Mobile equipment	790	1.6	790	1.6	873	1.7
Land	497	1.0	581	1.2	676	1.4
Total capital investment	9,302	18.6	10,004	20.0	10,749	21.5

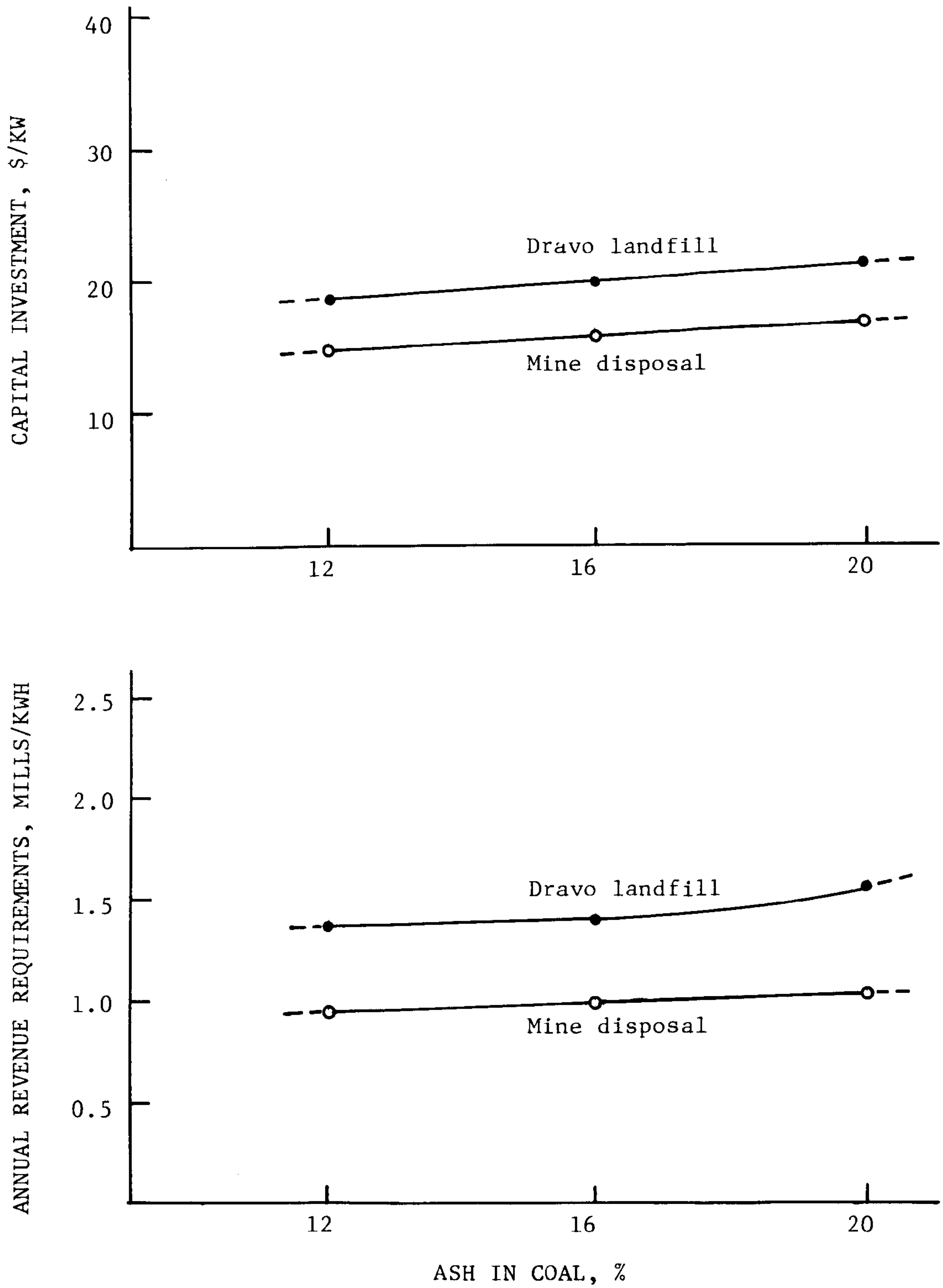


Figure 10. Effect of coal ash content on disposal costs.

Annual revenue requirements are affected by a modest increase in conversion costs (process maintenance, mobile equipment fuel and maintenance, and electricity). In addition, the Dravo landfill process has an increase in raw material costs because of the decreasing heat content of the coal as the ash content increases. More coal is burned, producing more FGD waste upon which the raw material consumption is based. There is no increase in labor and supervision costs.

Ash in coal, wt %	12		16		20	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Mine disposal						
Conversion	1,354	0.39	1,383	0.40	1,446	0.41
Total annual revenue requirements	3,294	0.94	3,430	0.98	3,604	1.03
Dravo landfill						
Raw materials	896	0.26	966	0.28	1,030	0.29
Conversion	1,591	0.45	1,629	0.47	1,696	0.48
Total annual revenue requirements	4,799	1.37	5,032	1.44	5,297	1.51

Distance to the Disposal Site

Distances of 5 and 10 miles to the disposal site were evaluated in addition to the base-case 1-mile distance. The only direct costs affected by distance are capital investment mobile equipment cost and annual revenue requirements disposal labor and supervision and truck fuel and maintenace.

Capital investment, shown below and in Figure 11, is little affected because of the minor portion composing mobile equipment costs.

Distance to disposal site	1 mile		5 miles		10 miles	
	k$	$/kW	k$	$/kW	k$	$/kW
Mine disposal						
Mobile equipment	559	1.1	890	1.8	1,055	2.1
Total capital investment	7,996	16.0	8,554	17.1	8,846	17.7
Dravo landfill						
Mobile equipment	790	1.6	1,121	2.2	1,286	2.6
Total capital investment	10,004	20.0	10,573	21.2	10,843	21.7

Annual revenue requirements, shown below and in Figure 11, are more affected. Mine disposal annual revenue requirements increase 20% for the 5-mile distance and 34% for the 10-mile distance, as compared to the base case. The Dravo landfill increases are 15% and 24% for the same distances. The increase is a result of greatly increased disposal labor for truck operation and truck fuel and maintenance costs.

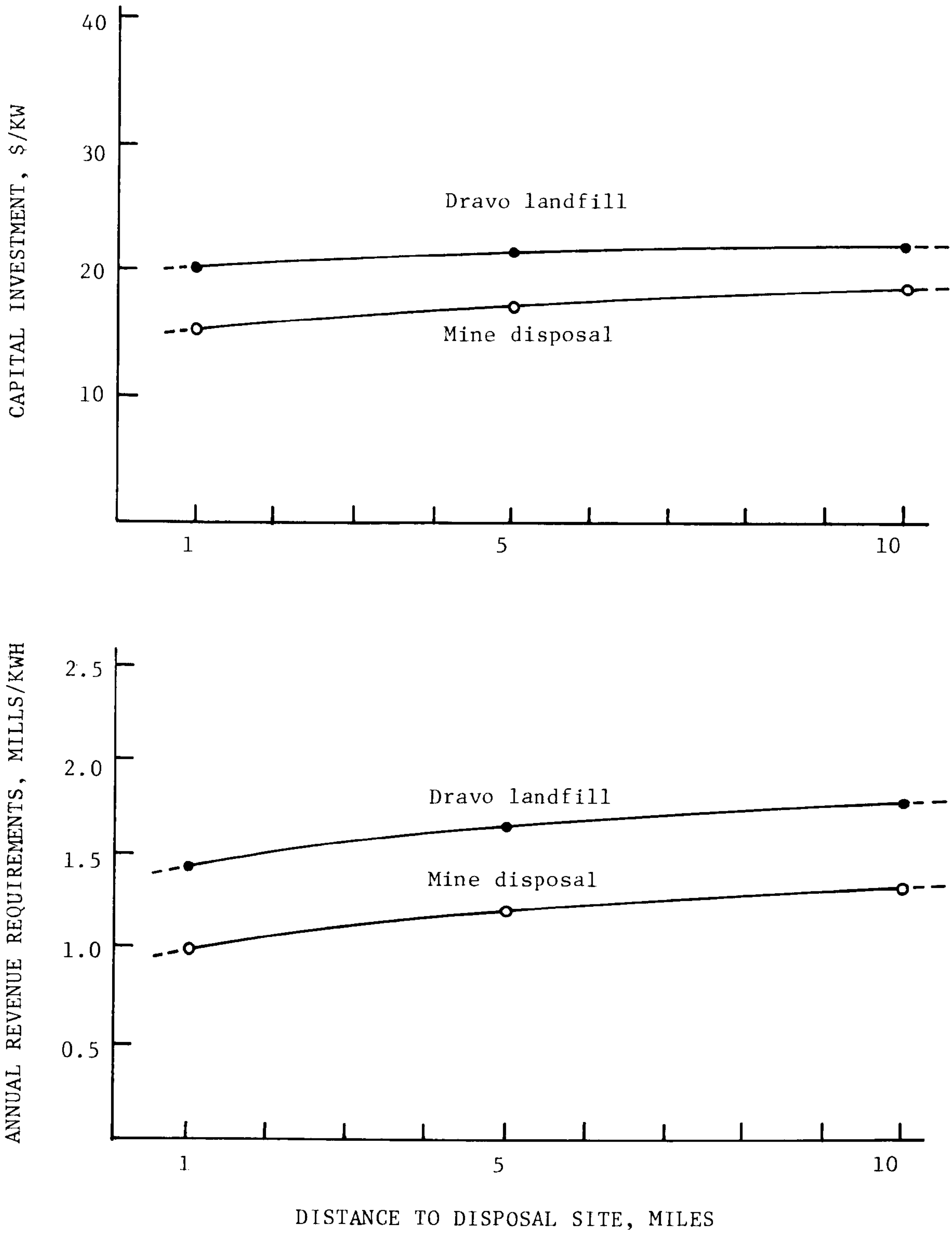


Figure 11. Effect of distance to disposal site on disposal costs.

Distance to disposal site	1 mile		5 miles		10 miles	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Mine disposal						
Disposal labor	596	0.17	894	0.26	1,042	0.30
Trucks	33	0.01	110	0.03	214	0.06
Total annual revenue requirements	3,430	0.98	4,128	1.18	4,545	1.30
Dravo landfill						
Disposal labor	745	0.21	1,042	0.30	1,191	0.34
Trucks	34	0.01	113	0.03	220	0.06
Total annual revenue requirements	5,032	1.44	5,735	1.64	6,185	1.77

MODULAR COST COMPARISONS

Cost breakdowns of the base cases by processing areas were made to facilitate identification of cost elements and comparison of different disposal processes. In addition to the mine disposal and Dravo landfill processes evaluated in this study, the six processes previously evaluated (Barrier and others, 1978, 1979) are also included in this comparison. Schematic flow diagrams are shown in Figure 12. Although evaluated over a 2-year period all of the processes are based on the same design and economic premises and the costs are projected to the same time period. All of the disposal costs are for both flyash and FGD waste. The flyash is either removed simultaneously with SO_2 in the scrubber or is collected separately and used in the FGD waste treatment process. Flyash is collected in the scrubber simultaneous with the sulfur oxides for processes not using dry flyash because of the design premises in use at the time of the earlier two studies. The six processes from the previous evaluations consist of two ponding processes and four landfill processes.

In the untreated ponding process (Tables 16 and 17) the 15% solids slurry from the absorbers, consisting of simultaneously collected flyash and sulfur salts, is collected in an agitated 63,000-gallon pond feed tank from which it is pumped to the pond. Excess water is pumped back into the FGD system. The material balance for the ponding process consists of 772,000 lb/hr of 15% solids feed to the pond, a return water rate of 540,000 lb/hr, and 232,000 lb/hr of 50% solids settled sludge at a specific gravity of 1.45.

The Dravo ponding process (Tables 18 and 19) is based on the Dravo Lime Company fixation process which uses Calcilox and lime as additives. In this variation the 15% solids slurry, consisting of simultaneously collected flyash and sulfur salts, is thickened to 35% solids and mixed with 7% Calcilox and 1% lime, both percentages based on total slurry solids. The treated sludge is then pumped to the pond where it is assumed to settle to a solids content of 50% and solidify over a period of about 20 days. The same pond design and recycle water system is used as is used for the untreated ponding process. In addition to the thickener and mix tank, the process includes equipment for unloading, storing, and metering the Calcilox and lime. The overall material balance consists of 772,000 lb/hr of sludge to the thickener; 331,000 lb/hr of sludge,

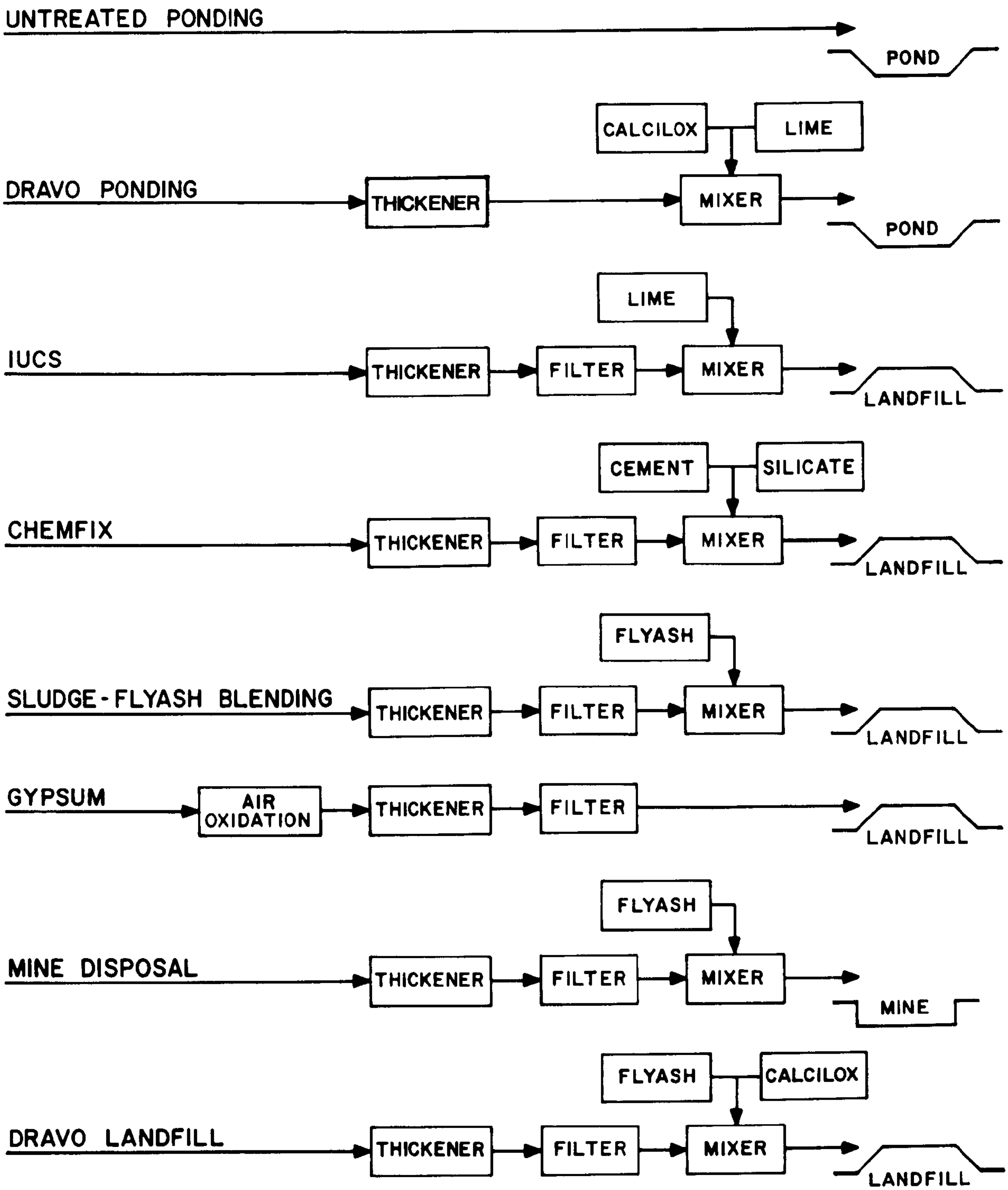


Figure 12. Process flow diagrams.

TABLE 16. MODULAR CAPITAL INVESTMENT - PONDING

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment				37		91	128
Piping and insulation				35		86	121
Transport lines						1,109	1,109
Foundation and structural				2		5	7
Site preparation				21		52	73
Electrical				115		280	395
Instrumentation				53			53
Process buildings							
Storage building							
Subtotal				263		1,623	1,886
Services and miscellaneous				3		25	28
Total				266		1,648	1,914
Pond construction						7,251	7,251
Mobile equipment							
Total direct investment				266		8,899	9,165
Engineering design and supervision				80		287	367
Architect and engineering				11		38	49
Construction expense				51		1,051	1,102
Contractor fees				31		486	517
Subtotal				439		10,761	11,200
Contingency				88		2,152	2,240
Total fixed investment				527		12,913	13,440
Allowance for startup				53		566	619
Interest during construction				63		1,550	1,613
Subtotal capital investment				643		15,029	15,672
Land				14		1,409	1,423
Working capital				60		56	116
Total capital investment				717		16,494	17,211
$/kW				1.4		33.0	34.4

Basis: Base-case conditions; 15% solids slurry from simultaneous flyash and SO_x removal in the scrubber pumped directly to the pond; pond water is recycled; 116,000 lb/hr solids in waste.

TABLE 17. MODULAR ANNUAL REVENUE REQUIREMENTS - PONDING

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials							
Conversion							
Operating manpower				170,800		48,200	219,000
Disposal manpower							
Process maintenance				54,900		21,700	76,600
Disposal operations							
Land preparation							
Trucks							
Earthmoving equipment							
Pond maintenance						217,500	217,500
Electricity				3,100		52,200	55,300
Analyses				8,500			8,500
Total conversion costs				237,300		339,600	576,900
Total direct costs				237,300		339,600	576,900
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance				40,600		899,700	940,300
Cost of capital and taxes				60,300		1,419,800	1,480,100
Overhead							
Plant				117,100		143,700	260,800
Administration				17,100		4,800	21,900
Total indirect costs				235,100		2,468,000	2,703,100
Total annual revenue requirements				472,400		2,807,600	3,280,000
Mills/kWh equivalent				0.14		0.80	0.94
$/ton wet sludge				0.2		1.0	1.2
$/ton dry sludge				1.2		6.9	8.1

TABLE 18. MODULAR CAPITAL INVESTMENT - DRAVO PONDING

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment	636	1,545		46		45	2,272
Piping and insulation	165	58		10		29	262
Transport lines						657	657
Foundation and structural	197	69		13		34	313
Site preparation	34	83		3		44	164
Electrical	614	214		39		107	974
Instrumentation	71	25		5		12	113
Process buildings	81	28		6			115
Storage building							
Subtotal	1,798	2,022		122		928	4,870
Services and miscellaneous	46	16		3		8	73
Total	1,844	2,038		125		936	4,943
Pond construction						7,410	7,410
Mobile equipment							
Total direct investment	1,844	2,038		125		8,346	12,353
Engineering design and supervision	339	180		11		291	821
Architect and engineering	67	35		2		58	162
Construction expense	434	479		29		685	1,627
Contractor fees	97	107		7		438	649
Subtotal	2,781	2,839		174		9,818	15,612
Contingency	556	568		35		1,963	3,122
Total fixed investment	3,337	3,407		209		11,781	18,734
Allowance for startup	334	340		21		437	1,132
Interest during construction	400	409		25		1,414	2,248
Subtotal capital investment	4,071	4,156		255		13,632	22,114
Land	5	10		1		1,434	1,450
Working capital	446	33		11		60	550
Total capital investment	4,522	4,199		267		15,126	24,114
$/kW	9.0	8.4		0.5		30.3	48.2

Basis: Base-case conditions; 35% solids thickened waste from simultaneous flyash and SO_x removal in the scrubber is treated with lime and Calcilox and pumped to the disposal pond; pond water is recycled; 125,000 lb/hr solids in waste.

TABLE 19. MODULAR ANNUAL REVENUE REQUIREMENTS - DRAVO PONDING

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials	1,840,400						1,840,400
Conversion							
Operating manpower	275,900	96,400		17,500		48,200	438,000
Disposal manpower							
Process maintenance	124,600	43,500		7,900		21,700	197,700
Disposal operations							
Land preparation							
Trucks							
Earthmoving equipment							
Pond maintenance						222,300	222,300
Electricity	49,800	18,600		11,000		24,300	103,700
Analyses	10,700	3,700		2,600			17,000
Total conversion costs	461,000	162,200		39,000		316,500	978,700
Total direct costs	2,301,400	162,200		39,000		316,500	2,819,100
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance	244,300	249,400		15,300		817,800	1,326,800
Cost of capital and taxes	388,900	361,100		23,000		1,300,800	2,073,800
Overhead							
Plant	205,600	71,800		14,000		146,100	437,500
Administration	27,600	9,600		1,800		4,800	43,800
Total indirect costs	866,400	691,900		54,100		2,269,500	3,881,900
Total annual revenue requirements	3,167,800	854,100		93,100		2,586,000	6,701,000
Mills/kWh equivalent	0.91	0.24		0.03		0.74	1.91
$/ton wet sludge	2.6	0.7		0.1		2.1	5.5
$/ton dry sludge	7.2	2.0		0.3		5.9	15.3

8,100 lb/hr of Calcilox, and 1,160 lb/hr of lime to the mix tank; 347,000 lb/hr of 36% solids sludge to the pond; and 97,000 lb/hr of recycle pond water.

The IU Conversion Systems, Inc. (IUCS) fixation process (Tables 20 and 21) produces a soillike material that is transported to the disposal site as a solid and disposed of in a landfill. The fixative is 4% lime, based on total slurry solids. The 15% solids slurry from the absorbers, consisting of simultaneously collected flyash and sulfur salts, is thickened to 35% solids, filtered to 60% solids on rotary drum filters, blended with the lime in blade-type mixers, and conveyed to a storage pile. The waste is then loaded into dump trucks with a front loader and hauled to the landfill site. The slurry feed rate is 772,000 lb/hr, the lime feed rate is 4,600 lb/hr, and 198,000 lb/hr of waste is produced.

The Chemfix process (Tables 22 and 23) differs from the other landfill processes in that the filtration and mixing facilities are situated at the disposal site. The 35% solids thickened sludge, consisting of simultaneously collected flyash and sulfur salts, is pumped to the disposal site. It is filtered to 60% solids and blended with 6.9% portland cement and 1.8% sodium silicate, based on total solids. The waste is then distributed in the landfill using scrapers. The slurry feed rate is 772,000 lb/hr, the cement and silicate feed rates are 8,000 and 2,100 lb/hr, and 203,000 lb/hr of waste is produced.

In the sludge - flyash blending process (Tables 24 and 25) the flyash is collected separately by an ESP, the absorber sludge is dewatered by thickening and filtration to 60% solids, and the two are blended in a blade-type mixer. The waste is then trucked to the landfill. The flyash from the ESP units is handled pneumatically and metered to the mixer using a weigh feeder in the same manner as the fixative additives. The slurry feed is 410,000 lb/hr, the flyash feed is 54,000 lb/hr, and 157,000 lb/hr of waste is produced.

In contrast to the other landfill processes, the gypsum process (Tables 26 and 27) uses the superior dewatering characteristics of high-sulfate sludges rather than additives to produce a landfill material. The scrubber slurry system is modified to provide for forced-air oxidation sufficient to produce a 15% solids slurry in which 95% of the sulfur is in the form of gypsum. The slurry, consisting of simultaneously collected flyash and sulfur salts, is thickened to 35% solids and filtered to 80% solids on rotary filters. The waste is then trucked to the landfill. The slurry feed rate is 756,000 lb/hr and 142,000 lb/hr of waste is produced.

The mine disposal process is shown in Tables 28 and 29 and the Dravo landfill process is shown in Tables 30 and 31.

Waste Quantities

Table 32 shows the amount of waste disposed of and the land requirements for the disposal area. Although the quantity of both flyash and

TABLE 20. MODULAR CAPITAL INVESTMENT - IUCS PROCESS

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment	383	1,556	510	102			2,551
Piping and insulation	55	54	49	18			176
Transport lines							
Foundation and structural	42	42	38	14			136
Site preparation	36	36	32	11			115
Electrical	198	198	179	64			639
Instrumentation	22	22	19	7			70
Process buildings	171	170	154	55			550
Storage building							
Subtotal	907	2,078	981	271			4,237
Services and miscellaneous	20	20	18	6			64
Total	927	2,098	999	277			4,301
Pond construction							
Mobile equipment						581	581
Total direct investment	927	2,098	999	277		581	4,882
Engineering design and supervision	95	181	91	25			392
Architect and engineering	24	45	23	6			98
Construction expense	181	409	195	54			839
Contractor fees	61	138	65	18		38	320
Subtotal	1,288	2,871	1,373	380		619	6,531
Contingency	258	573	275	76		124	1,306
Total fixed investment	1,546	3,444	1,648	456		743	7,837
Allowance for startup	155	344	165	46		16	726
Interest during construction	186	412	198	55		89	940
Subtotal capital investment	1,887	4,200	2,011	557		848	9,503
Land	5	5	4	2		660	676
Working capital	213	44	40	16		225	538
Total capital investment	2,105	4,249	2,055	575		1,733	10,717
$/kW	4.2	8.5	4.1	1.1		3.5	21.4

Basis: Base-case conditions; 60% solids thickened and filtered waste from simultaneous flyash and SO_x removal in the scrubber is mixed with lime and trucked to the disposal site; 120,000 lb/hr solids in waste.

TABLE 21. MODULAR ANNUAL REVENUE REQUIREMENTS - IUCS PROCESS

	Costs by area, $						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials	859,400						859,400
Conversion							
Operating manpower	135,800	135,800	122,600	43,800			438,000
Disposal manpower						893,500	893,500
Process maintenance	53,300	53,300	48,200	17,200			172,000
Disposal operations							
Land preparation						11,000	11,000
Trucks						41,600	41,600
Earthmoving equipment						110,900	110,900
Pond maintenance							
Electricity	47,100	24,600	18,200	17,100			107,000
Analyses	5,300	5,300	4,700	1,700			17,000
Total conversion costs	241,500	219,000	193,700	79,800		1,057,000	1,791,000
Total direct costs	1,100,900	219,000	193,700	79,800		1,057,000	2,650,400
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance	147,700	328,900	157,500	43,600		66,400	744,100
Cost of capital and taxes	181,000	365,400	176,700	49,500		149,100	921,700
Overhead							
Plant	97,200	97,200	87,700	31,400		528,500	842,000
Administration	13,600	13,600	12,300	4,400		89,300	133,200
Total indirect costs	439,500	805,100	434,200	128,900		833,300	2,641,000
Total annual revenue requirements	1,540,400	1,024,100	627,900	208,700		1,890,300	5,291,400
Mills/kWh equivalent	0.44	0.29	0.18	0.06		0.54	1.51
$/ton wet sludge	2.2	1.5	0.9	0.3		2.7	7.6
$/ton dry sludge	3.7	2.4	1.5	0.5		4.5	12.6

TABLE 22. MODULAR CAPITAL INVESTMENT - CHEMFIX PROCESS

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment	521	1,579	523	262			2,885
Piping and insulation	109	55	52	11			227
Transport lines						697	697
Foundation and structural	100	50	48	11			209
Site preparation	78	39	37	8			162
Electrical	409	205	196	43			853
Instrumentation	51	26	25	5			107
Process buildings	264	132	126	28			550
Storage building							
Subtotal	1,532	2,086	1,007	368		697	5,690
Services and miscellaneous	23	31	15	6		10	85
Total	1,555	2,117	1,022	374		707	5,775
Pond construction							
Mobile equipment						442	442
Total direct investment	1,555	2,117	1,022	374		1,149	6,217
Engineering design and supervision	156	186	97	33			472
Architect and engineering	39	47	24	8			118
Construction expense	354	422	220	76			1,072
Contractor fees	96	132	63	23		71	385
Subtotal	2,200	2,904	1,426	514		1,220	8,264
Contingency	440	581	285	103		244	1,653
Total fixed investment	2,640	3,485	1,711	617		1,464	9,917
Allowance for startup	265	350	171	62		100	948
Interest during construction	317	418	205	74		176	1,190
Subtotal capital investment	3,222	4,253	2,087	753		1,740	12,055
Land	5	5	3	1		679	693
Working capital	488	37	34	9		215	783
Total capital investment	3,715	4,295	2,124	763		2,634	13,531
$/kW	7.4	8.7	4.2	1.5		5.3	27.1

Basis: Base-case conditions; 60% solids waste from simultaneous flyash and SO_x removal in the scrubber is mixed with portland cement and sodium silicate and trucked to the disposal site; 125,800 lb/hr solids in waste.

TABLE 23. MODULAR ANNUAL REVENUE REQUIREMENTS - CHEMFIX PROCESS

	Costs by area, $						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials	2,177,000						2,177,000
Conversion							
Operating manpower	210,300	105,100	100,700	21,900			438,000
Disposal manpower						744,600	744,600
Process maintenance	90,400	51,600	45,700	10,700		32,600	231,000
Disposal operations							
Land preparation						11,000	11,000
Trucks							
Earthmoving equipment						213,200	213,200
Pond maintenance							
Electricity	33,100	19,600	15,000	11,000		24,300	103,000
Analyses	8,200	4,100	3,900	800			17,000
Total conversion costs	342,000	180,400	165,300	44,400		1,025,700	1,757,800
Total direct costs	2,519,000	180,400	165,300	44,400		1,025,700	3,934,800
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance	252,300	333,000	163,400	59,000		136,200	943,900
Cost of capital and taxes	319,500	369,400	182,700	65,600		226,500	1,163,700
Overhead							
Plant	154,500	80,400	75,200	16,700		500,600	827,400
Administration	21,000	10,500	10,100	2,200		74,500	118,300
Total indirect costs	747,300	793,300	431,400	143,500		937,800	3,053,300
Total annual revenue requirements	3,266,300	973,700	596,700	187,900		1,963,500	6,988,100
Mills/kWh equivalent	0.94	0.28	0.17	0.05		0.56	2.00
$/ton wet sludge	4.5	1.4	0.8	0.3		2.8	9.8
$/ton dry sludge	7.4	2.2	1.4	0.4		4.5	15.9

TABLE 24. MODULAR CAPITAL INVESTMENT - SLUDGE - FLYASH BLENDING

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment	495	1,101	333	56			1,985
Piping and insulation	53	47	24	15			139
Transport lines							
Foundation and structural	92	82	41	27			242
Site preparation	20	18	9	6			53
Electrical	159	59	79	48			345
Instrumentation	21	19	10	6			56
Process buildings	192	171	86	55			504
Storage building							
Subtotal	1,032	1,497	582	213			3,324
Services and miscellaneous	19	17	9	5			50
Total	1,051	1,514	591	218			3,374
Pond construction							
Mobile equipment						581	581
Total direct investment	1,051	1,514	591	218		581	3,955
Engineering design and supervision	104	150	59	21			334
Architect and engineering	26	38	14	5			83
Construction expense	214	308	120	44			686
Contractor fees	73	105	41	15		39	273
Subtotal	1,468	2,115	825	303		620	5,331
Contingency	293	423	165	61		124	1,066
Total fixed investment	1,761	2,538	990	364		744	6,397
Allowance for startup	176	254	99	36		17	582
Interest during construction	211	305	119	44		89	768
Subtotal capital investment	2,148	3,097	1,208	444		850	7,747
Land	5	5	2	2		522	536
Working capital	53	45	24	16		184	322
Total capital investment	2,206	3,147	1,234	462		1,556	8,605
$/kW	4.4	6.3	2.5	0.9		3.1	17.2

Basis: Base-case conditions; 60% solis thickened and filtered FGD waste is blended with dry flyash and trucked to the disposal site; 116,000 lb/hr solids in waste. ESP costs of $9,614,000 not shown.

TABLE 25. MODULAR ANNUAL REVENUE REQUIREMENTS - SLUDGE - FLYASH BLENDING

	Costs by area, $						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials							
Conversion							
Operating manpower	166,400	148,900	74,500	48,200			438,000
Disposal manpower						744,600	744,600
Process maintenance	60,100	53,800	26,900	17,400			158,200
Disposal operations							
Land preparation						8,700	8,700
Trucks						32,900	32,900
Earthmoving equipment						87,800	87,800
Pond maintenance							
Electricity	35,400	13,100	18,400	10,000			76,900
Analyses	6,400	5,800	2,900	1,900		______	17,000
Total conversion costs	268,300	221,600	122,700	77,500		874,000	1,564,100
Total direct costs	268,300	221,600	122,700	77,500		874,000	1,564,100
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance	168,200	242,400	94,600	34,800		66,600	606,600
Cost of capital and taxes	189,700	270,700	106,100	39,700		133,800	740,000
Overhead							
Plant	116,400	104,200	52,200	33,800		437,000	743,600
Administration	16,600	14,900	7,500	4,800		74,500	118,300
Total indirect costs	490,900	632,200	260,400	113,100		711,900	2,208,500
Total annual revenue requirements	759,200	853,800	383,100	190,600		1,585,900	3,772,600
Mills/kWh equivalent	0.22	0.24	0.11	0.05		0.45	1.08
$/ton wet sludge	1.4	1.6	0.7	0.3		2.9	6.9
$/ton dry sludge	1.9	2.1	0.9	0.5		3.9	9.3

Note: ESP annual revenue requirements of $1,975,000 not shown.

TABLE 26. MODULAR CAPITAL INVESTMENT - GYPSUM

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment		686	493				1,179
Piping and insulation		117	57				174
Transport lines							
Foundation and structural		17	8				25
Site preparation		28	14				42
Electrical		147	73				220
Instrumentation		35	17				52
Process buildings		117	57				174
Storage building							
Subtotal		1,147	719				1,866
Services and miscellaneous		18	9				27
Total		1,165	728				1,893
Pond construction							
Mobile equipment						498	498
Total direct investment		1,165	728			498	2,391
Engineering design and supervision		131	64				195
Architect and engineering		32	16				48
Construction expense		285	140				425
Contractor fees		90	57			39	186
Subtotal		1,703	1,005			537	3,245
Contingency		341	201			107	649
Total fixed investment		2,044	1,206			644	3,894
Allowance for startup		204	121			15	340
Interest during construction		245	145			77	467
Subtotal capital investment		2,493	1,472			736	4,701
Land		8	4			391	403
Working capital		81	42			184	307
Total capital investment		2,582	1,518			1,311	5,411
$/kW		5.2	3.0			2.6	10.8

Basis: Base-case conditions; waste from simultaneous removal of flyash and SO_x in the scrubber is oxidized to 95% sulfate by forced-air oxidation. Oxidized waste is thickened and filtered to 80% solids and trucked to the disposal site; 113,000 lb/hr solids in waste. Additional scrubber costs for air oxidation of $2,303,000 not shown.

TABLE 27. MODULAR ANNUAL REVENUE REQUIREMENTS - GYPSUM

	Costs by area, $						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials							
Conversion							
Operating manpower		293,500	144,500				438,000
Disposal manpower						744,600	744,600
Process maintenance		64,100	31,500				95,600
Disposal operations							
Land preparation						6,600	6,600
Trucks						29,800	29,800
Earthmoving equipment						79,400	79,400
Pond maintenance							
Electricity		20,300	29,000				49,300
Analyses		11,400	5,600				17,000
Total conversion costs		389,300	210,600			860,400	1,460,300
Total direct costs		389,300	210,600			860,400	1,460,300
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance		195,200	115,300			57,600	368,100
Cost of capital and taxes		222,100	130,500			112,700	465,300
Overhead							
Plant		184,500	90,800			430,200	705,500
Administration		29,400	14,400			74,500	118,300
Total indirect costs		631,200	351,000			675,000	1,657,200
Total annual revenue requirements		1,020,500	561,600			1,535,400	3,117,500
Mills/kWh equivalent		0.29	0.16			0.44	0.89
$/ton wet sludge		2.1	1.1			3.1	6.3
$/ton dry sludge		2.6	1.4			3.8	7.9

Note: Scrubber modifications for air oxidation annual revenue requirements of $1,005,000 not shown.

TABLE 28. MODULAR CAPITAL INVESTMENT - MINE DISPOSAL

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment	495	1,101	333	56			1,985
Piping and insulation	53	47	24	15			139
Transport lines							
Foundation and structural	92	82	41	27			242
Site preparation	20	18	9	6			53
Electrical	159	59	79	48			345
Instrumentation	21	19	10	6			56
Process buildings	192	171	86	55			504
Storage building							
Subtotal	1,032	1,497	582	213			3,324
Services and miscellaneous	19	17	9	5			50
Total	1,051	1,514	591	218			3,374
Pond construction							
Mobile equipment						559	559
Total direct investment	1,051	1,514	591	218		559	3,933
Engineering design and supervision	100	145	57	20			322
Architect and engineering	25	36	15	5			81
Construction expense	214	308	120	44			686
Contractor fees	72	105	41	15		39	272
Subtotal	1,462	2,108	824	302		598	5,294
Contingency	293	420	165	61		120	1,059
Total fixed investment	1,755	2,528	989	363		718	6,353
Allowance for startup	159	231	90	33		66	579
Interest during construction	210	303	119	44		86	762
Subtotal capital investment	2,124	3,062	1,198	440		870	7,694
Land	5	5	2	2			14
Working capital	54	46	24	16		148	288
Total capital investment	2,183	3,113	1,224	458		1,018	7,996
$/kW	4.4	6.2	2.5	0.9		2.0	16.0

Basis: Base-case conditions; 60% solids thickened and filtered waste from the FGD system is blended with dry flyash and trucked to a surface mine; 116,000 lb/hr solids in waste. ESP costs of $9,614,000 not shown.

TABLE 29. MODULAR ANNUAL REVENUE REQUIREMENTS - MINE DISPOSAL

	Costs by area, $						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials							
Conversion							
Operating manpower	166,400	148,900	74,500	48,200			438,000
Disposal manpower						595,700	595,700
Process maintenance	59,700	53,400	26,600	17,300			157,000
Disposal operations							
Land preparation							
Trucks						32,900	32,900
Earthmoving equipment						65,900	65,900
Pond maintenance							
Electricity	35,400	13,100	17,700	10,700			76,900
Analyses	6,400	5,800	2,900	1,900			17,000
Total conversion costs	267,900	221,200	121,700	78,100		694,500	1,383,400
Total direct costs	267,900	221,200	121,700	78,100		694,500	1,383,400
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance	166,300	239,700	93,800	34,500		68,100	602,400
Cost of capital and taxes	187,700	267,700	105,300	39,400		87,600	687,700
Overhead							
Plant	116,300	104,100	52,000	33,700		347,200	653,300
Administration	16,600	14,900	7,500	4,800		59,600	103,400
Total indirect costs	486,900	626,400	258,600	112,400		562,500	2,046,800
Total annual revenue requirements	754,800	847,600	380,300	190,500		1,257,000	3,430,200
Mills/kWh equivalent	0.22	0.24	0.11	0.05		0.36	0.98
$/ton wet sludge	1.3	1.5	0.7	0.3		2.2	6.0
$/ton dry sludge	1.8	2.0	0.9	0.5		3.0	8.2

Note: ESP annual revenue requirements of $1,975,000 not shown.

TABLE 30. MODULAR CAPITAL INVESTMENT - DRAVO LANDFILL

	Costs by area, k$						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Process equipment	588	1,093	330	56	94		2,161
Piping and insulation	75	40	20	12	4		151
Transport lines							
Foundation and structural	132	68	35	21	8		264
Site preparation	28	15	8	5	2		58
Electrical	184	95	47	30	11		367
Instrumentation	29	16	8	5	2		60
Process buildings	257	136	71	40			504
Storage building					150		150
Subtotal	1,293	1,463	519	169	271		3,715
Services and miscellaneous	20	21	8	3	4		56
Total	1,313	1,484	527	172	275		3,771
Pond construction							
Mobile equipment						790	790
Total direct investment	1,313	1,484	527	172	275	790	4,561
Engineering design and supervision	213	111	55	34	13		426
Architect and engineering	53	28	14	9	3		107
Construction expense	263	295	105	35	54		752
Contractor fees	87	98	35	12	18	51	301
Subtotal	1,929	2,016	736	262	363	841	6,147
Contingency	389	403	148	52	72	165	1,229
Total fixed investment	2,318	2,419	884	314	435	1,006	7,376
Allowance for startup	231	242	88	31	44	23	659
Interest during construction	278	291	106	37	52	121	885
Subtotal capital investment	2,827	2,952	1,078	382	531	1,150	8,920
Land	6	3	1	1	1	569	581
Working capital	251	36	20	12	4	180	503
Total capital investment	3,084	2,991	1,099	395	536	1,899	10,004
$/kW	6.2	6.0	2.2	0.8	1.1	3.8	20.0

Basis: Base-case conditions; 60% solids thickened and filtered waste from the FGD system is blended with dry flyash and Calcilox and trucked to the disposal site; 120,000 lb/hr solids in waste. ESP costs of $9,614,000 not shown.

TABLE 31. MODULAR ANNUAL REVENUE REQUIREMENTS - DRAVO LANDFILL

	Costs by area, $						
	Raw material	Thickening	Filtration	Mixing	Storage	Disposal	Total
Direct Costs							
Total raw materials	966,400						966,400
Conversion							
Operating manpower	219,000	113,900	56,900	35,000	13,200		438,000
Disposal manpower						744,600	744,600
Process maintenance	91,000	47,300	23,600	14,600	5,500		182,000
Disposal operations							
Land preparation						15,100	15,100
Trucks						33,800	33,800
Earthmoving equipment						90,200	90,200
Pond maintenance							
Electricity	55,000	16,300	22,700	11,800	2,100		107,900
Analyses	8,500	4,400	2,200	1,400	500		17,000
Total conversion costs	373,500	181,900	105,400	62,800	21,300	883,700	1,628,600
Total direct costs	1,339,900	181,900	105,400	62,800	21,300	883,700	2,595,000
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance	221,400	231,100	84,400	29,900	41,600	90,000	698,400
Cost of capital and taxes	265,200	257,200	94,500	34,000	46,100	163,300	860,300
Overhead							
Plant	159,300	82,800	41,400	25,500	9,600	441,800	760,400
Administration	21,900	11,400	5,700	3,500	1,300	74,500	118,300
Total indirect costs	667,800	582,500	226,000	92,900	98,600	769,600	2,437,400
Total annual revenue requirements	2,007,700	764,400	331,400	155,700	119,900	1,653,300	5,032,400
Mills/kWh equivalent	0.57	0.22	0.10	0.05	0.03	0.47	1.44
$/ton wet sludge	3.5	1.4	0.6	0.3	0.2	2.9	8.9
$/ton dry sludge	4.7	1.8	0.8	0.4	0.3	3.9	11.9

Note: ESP annual revenue requirements of $1,975,000 not shown.

sulfur is the same in all cases, the weights, and particularly the volumes, vary considerably. For the nongypsum processes, the largest contributor to the weight and volume differences is the amount of water in the waste, which varies from 50% to 25% of the total weight. Density differences (90 lb/ft^3 for the ponded waste and 97 lb/ft^3 for the landfill material) contribute less. The gypsum process has both the lowest weight and lowest volume of waste. The low weight is a result of the improved limestone utilization with the additional forced-air oxidation. At the stoichiometries used, the gypsum process uses 48,000 tons/yr less limestone, which appears in the other processes as unreacted absorbent. This more than compensates for the 38,000 tons/yr larger weight of sulfur salts (95% $CaSO_4 \cdot 2H_2O$ instead of 15%) in the gypsum process waste. The difference in waste volume is even more pronounced because of the higher bulk density and lower water content of the gypsum waste. At a density of 121 lb/ft^3 and 80% solids it occupies only 45% of the volume occupied by the settled untreated ponding waste and 72% of the volume of the landfilled blended sludge and flyash. The differences in volume between the gypsum waste and the fixed waste are more pronounced depending on the quantities of fixatives in the waste.

The differences in solid waste quantities are reflected in disposal costs although not to the same degree as they appear in weight and volume comparisons. This is largely a result of the incremental nature of the costs involved. Within broad ranges the same amount of earthmoving equipment and number of trucks are needed for a range of waste quantities. In general, the same quantity of earthmoving equipment is needed whether the waste is high sulfite or gypsum.

Base-Case Modular Cost Comparisons

The sludge - flyash blending process, the mine disposal process, and the Dravo landfill process require inclusion of ESP costs for comparison with the other processes. Using the same premise basis, ESP capital investment is \$9,614,000 (19.2 \$/kW) and annual revenue requirements are \$1,975,000 (0.56 mill/kWh). For similar comparisons air-oxidation scrubber modification costs are included in the gypsum process costs. Capital investment for air-oxidation modifications is \$2,303,000 (4.6 \$/kW) and annual revenue requirements are \$1,005,000 (0.29 mill/kWh).

In those cases in which flyash is collected separately the cost of ESP units and their operation is a major component of the waste disposal costs. The capital investment for separate flyash removal is about one-half of the sludge - flyash blending, mine disposal, and Dravo landfill processes capital investments. In annual revenue requirements separate flyash collection accounts for 28% to 36% of the total for these three processes. In comparison, simultaneous flyash removal results in relatively modest increases in thickening and filtration costs.

Separate collection of flyash is, of course, possible with all of the processes evaluated and would require similar costs for all processes. In comparison of landfill processes with separate flyash collection, cost differences would largely be reduced to cost differences in the raw material portion of the cost breakdown.

The raw material costs include the cost of purchased raw materials, their handling, and the handling of separately collected flyash. For the processes using purchased fixatives raw materials are an important element of both capital investment and annual revenue requirements. Flyash handling is also a relatively expensive element (4.5 $/kW in capital investment and 0.22 mill/kWh in annual revenue requirements). The advantage of a single fixative is illustrated by comparison of raw material costs for the Dravo ponding and Chemfix processes, which use two additives, with the IUCS process which uses one. The IUCS process has raw material capital investment and annual revenue requirements about one-half those of the others.

Thickening is the largest capital investment cost element, excluding ESP costs, for all of the nonponding processes. It is also a large cost element in annual revenue requirements. The gypsum process, with a more rapidly settling high-sulfate sludge, has a major advantage over the other processes in thickening capital investment but little in thickening annual revenue requirements.

Filtration is also a large cost element, though considerably less so than thickening. Both capital investment and annual revenue requirements for filtration are roughly one-half those for thickening. Filtration costs for the gypsum process are lower than the other simultaneous flyash-FGD waste filtration processes because of the superior filtration characteristics of the high-sulfate sludge. Filtration costs are lowest, however, for the processes in which only FGD waste is filtered. Mixing costs are a minor part of both capital investment and annual revenue requirements.

Transportation and disposal site costs illustrate fundamental differences between ponding and solid waste disposal methods. Capital investment for ponding transportation and disposal site costs is an order of magnitude greater than the capital investment for landfill transportation and disposal site operations. Pond construction accounts for 80% of the untreated ponding direct costs and 60% of the Dravo ponding process direct costs. Capital investment for transport lines is also an important element, accounting for 12% of the untreated ponding capital investment direct costs and 5% of the Dravo ponding capital investment direct costs. For the Chemfix process, in which the thickened sludge is pumped to the disposal site for further treatment, the cost of transport lines is not offset by the minor savings in mobile equipment. (Scrapers distribute the waste on the site and trucks are not used.) Mobile equipment capital investment is 0.9 $/kW for the Chemfix process, however, compared with 1.2 $/kW for the IUCS process. In addition, the Chemfix process requires an additional 1.4 $/kW for transport lines. Disposal land costs for both ponding processes are two to nearly four times greater than those for landfill processes. As a percentage of total capital investment, however, disposal land costs for all the processes (excluding mine disposal which has none) are similar, ranging from 8% for untreated ponding to 5% for the Chemfix process.

Among the landfill and mine disposal processes, transportation and disposal site costs are a relatively minor element of total capital investment. Direct capital investment consists of mobile equipment costs. Land cost is the only other major capital investment cost element. Both of these costs are a minor part of total capital investment in all the processes evaluated. Mine disposal, with reduced equipment and no disposal land requirements, has the lowest capital investment in this area. The gypsum process, with the smallest waste volume, has a lower transportation and disposal site capital investment than the other landfill processes.

Annual revenue requirements for ponding transportation and disposal site costs are also higher than those for landfill and mine disposal although the differences are less pronounced. About two-thirds of the annual revenue requirement direct costs for ponding transportation and disposal site operations consist of pond maintenance. Transportation of the waste is a relatively minor cost element. In contrast, about four-fifths of the annual revenue requirements direct cost for landfill and mine disposal transportation and disposal site operations is for labor and supervision, much of it for mobile equipment operation.

Capital Investment Comparisons

In overall comparison of the processes evaluated, the most important capital investment cost elements are separate flyash collection, raw material handling, thickening, and pond construction. Untreated ponding, with almost all of the capital investment in transportation and pond costs, has a capital investment of 34.4 $/kW. Dravo ponding, which combines high raw material costs for two additives, thickening costs, and pond costs, has the highest capital investment, 48.2 $/kW. Among landfill fixation processes the Dravo landfill process has the highest capital investment, 39.4 $/kW, almost half of which is ESP costs for separate flyash collection.

Sludge - flyash blending has a capital investment of 36.4 $/kW and mine disposal has a capital investment of 35.3 $/kW. Both costs include the 19.2 $/kW cost of ESP units for separate flyash removal. The reduction in mobile equipment and land requirements effected by use of the mine as a disposal site accounts for the difference in capital costs between the two processes.

The IUCS process, with one fixative, has a capital investment of 21.4 $/kW. The Chemfix process, with two fixatives, has a capital investment of 27.1 $/kW. The difference is largely in raw material handling costs as a result of the additional fixative. However, additional costs for transportation of the waste also occur because the waste is processed at the disposal site. A similar effect in raw material costs is seen in the two-fixative Dravo ponding process.

The gypsum process has a capital investment of 15.4 $/kW. The considerably lower capital investment is a result of a cost of only 4.6

$/kW for the necessary scrubber modifications, improved thickening and filtration characteristics, and a reduction in transportation and disposal site costs.

Annual Revenue Requirements Comparison

Large cost elements in annual revenue requirements are separate flyash collection, raw material purchase and handling, and disposal. Untreated ponding has the lowest annual revenue requirements, 0.94 mill/kWh, almost all of them for transportation and disposal site operations. The Dravo landfill process (with costs for both separate flyash collection and a fixative) and the Chemfix process (with costs for two fixatives and higher transportation costs) both have annual revenue requirements of 2.00 mills/kWh. Dravo ponding, with two fixatives and ponding costs, but no ESP and filtration costs, has annual revenue requirements of 1.91 mills/kWh. The IUCS process, with one fixative, has annual revenue requirements of 1.51 mills/kWh, the lowest of the fixation processes. If dry flyash were used in the IUCS process, however, it would be similar in cost to the other fixation processes.

The sludge - flyash blending and mine disposal processes have annual revenue requirements of 1.64 and 1.54 mills/kWh respectively. The largest cost element in both is ESP costs. The difference is a result of reduced disposal site costs and lower indirect costs based on capital investment.

The gypsum process annual revenue requirements are 1.18 mills/kWh, second only to ponding. The low cost is a result of relatively modest additional costs for air oxidation, the absence of raw material and mixing costs, and lower transportation and disposal site costs than other landfill processes.

CONCLUSIONS

In comparison with the Dravo landfill process, mine disposal is approximately one-fifth lower in capital investment and one-third lower in annual revenue requirements. The cost differences are largely a result of additional costs for purchase and handling of Calcilox.® Reduced disposal costs for the mine disposal process account for a small reduction in capital investment and annual revenue requirements.

Cost reductions directly associated with mine disposal are a result of reductions in land and mobile equipment requirements and reduced disposal labor and mobile equipment operating costs. The costs associated with the use of a fixative lie largely in purchase of Calcilox and installation of equipment for handling it. Because the quantity used is small relative to the wastes, processing and disposal costs are not greatly affected. ESP costs are a large part of the total FGC costs for both processes.

Other large capital investment cost elements for both processes are raw materials handling (which includes flyash) and thickening. Labor and supervision costs, particularly for disposal operations, are the largest direct cost element in annual revenue requirements. Disposal operations, consisting of fuel, maintenance, and land preparation for the Dravo landfill process, are minor costs. Utility costs are also minor.

CASE VARIATIONS

Power plant size has the largest effect on costs of the case variations studied. The differences are largely the result of economy of scale, particularly in process equipment. The largest effect in annual revenue requirement direct costs is a result of lower labor and supervision costs, relative to plant size, at the larger power plant sizes. The effect of power plant size on the Dravo landfill process annual revenue requirements is less pronounced because it has costs linearly related to waste quantities, particularly raw materials and disposal land, which the mine disposal process does not have.

Coal sulfur content produces large differences in the capital investments and annual revenue requirements for both processes. The variations are greater for the Dravo landfill process because of the effects of disposal-area land requirements and raw material requirements, which are not factors in the mine disposal process.

Coal ash content also had an important effect on capital investment and annual revenue requirements, although less than coal sulfur content in the ranges evaluated. The effect of ash content is essentially the same for both processes.

Distance to the disposal site is essentially a measure of the effects of variations in trucking costs on capital investment and annual revenue requirements. The increased distances produce a moderate increase in capital investment and a large increase in annual revenue requirements for both processes. The results indicate that hauling distance is an important consideration. Mine disposal is an economically favorable disposal option in comparison to on-site disposal only for the more favorable circumstances of mine location. For the five-mile distance to the disposal site the increase in trucking costs eliminate the cost savings associated with mine disposal instead of on-site landfill.

MODULAR COST COMPARISONS

Breakdown of costs into modular processing areas for the eight processes evaluated in this and the two previous studies illustrates the effect of various process functions. ESP costs, for processes in which flyash is collected separately, are a large part of both capital investment and annual revenue requirements. Excluding ESP costs, raw material purchase and handling, thickening capital investment, and pond capital investment are high-cost areas.

Raw material costs are also an important part of annual revenue requirements when purchased fixatives are used. The use of more than one fixative compounds the costs in these areas because they are almost completely additive. Flyash handling, although larger in volume, is not greatly higher in cost than purchased fixative handling, partially as a result of reduced storage facilities.

Thickening is a large element in capital investment and important in annual revenue requirements. Filtration is less costly in both. Mixing is a minor part of both capital investment and annual revenue requirements.

Capital investment for transport lines and pond construction is an order of magnitude greater than mobile equipment and landfill-site capital investment.

In comparison of the seven processes for high-sulfite waste, ponding is shown to be a low-cost disposal option, if practical, if there is no treatment of the sludge. Treatment and fixation before ponding add the high-cost processing areas without materially reducing pond costs. Landfill processes, excluding ESP costs, are lower in capital investment than ponding processes. This advantage is reduced when purchased fixatives are used, particularly if two are used. Landfill annual revenue requirements are only competitive with ponding if no purchased fixatives are used.

The gypsum process results illustrate the large decrease in capital costs attainable by improvement in the dewatering characteristics of the waste. The additional costs for air oxidation increase the annual revenue requirements about one-fourth. Annual revenue requirements for the gypsum process are thus intermediate between untreated ponding or landfill without fixation and the landfill fixation processes.

RECOMMENDATIONS

This study and the two previous studies summarized in the analysis of modular costs illustrate cost spectrums for a number of waste-disposal methods. The results suggest that certain cost-sensitive areas, such as thickening and filtration, may be studied from a functional viewpoint, as modular components applicable to several processes to more clearly delinate cost differences between processes. Transportation and disposal-area operations are also important cost factors, many elements of which are independent of particular processes. Transportation alternatives should particularly be investigated in greater variety and with emphasis on energy requirement costs. Landfill preparation and operation should be investigated with emphasis on definition of additional costs for site investigations, pollution control, and monitoring costs associated with existing and pending legislation. The effects of legislation such as the Resources Conservation and Recovery Act should always be kept in perspective.

In addition, the rapidly increasing information on waste chemical and physical characteristics and on evolving technologies such as the gypsum process should be incorporated into development of the conceptual designs upon which the economic evaluations are based. More accurate and detailed data on waste characteristics such as dewatering capabilities, bulk densities, and handling characteristics would greatly improve delineation of cost differences between disposal processes. Technological changes in evolving processes could radically alter their cost relationship to more defined processes.

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APPENDIX A

CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENT TABLES

TABLE A-1. MINE DISPOSAL

CAPITAL INVESTMENT

(Base case)

	Capital investment, k$	% of total
Process equipment	1,985	24.8
Piping and insulation	139	1.7
Foundation and structural	242	3.0
Excavation and site preparation	53	0.7
Electrical	345	4.3
Instrumentation	56	0.7
Buildings	504	6.3
Total	3,324	41.6
Services and miscellaneous	50	0.6
Total	3,374	42.2
Mobile equipment	559	7.0
Total direct investment	3,933	49.2
Engineering design and supervision	322	4.0
Architect and engineering contractor	81	1.0
Construction expense	686	8.6
Contractor fees	272	3.4
Total	5,294	66.2
Contingency	1,059	13.2
Total fixed investment	6,353	79.5
Allowance for startup and modifications	579	7.2
Interest during construction	762	9.5
Total depreciable investment	7,694	96.2
Land	14	0.2
Working capital	288	3.6
Total capital investment	7,996	
$/kW	16.0	

Basis

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-2. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(Base case)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,080 man-hr	12.50	438,000	12.8
Disposal equipment	35,080 man-hr	17.00	595,700	17.4
Plant maintenance - 4% of direct investment			157,000	4.6
Mine disposal operation				
Truck fuel and maintenance	548,800 tons	0.06	32,900	1.0
Earthmoving equipment fuel and maintenance	548,800 tons	0.12	65,900	1.9
Electricity	2,652,800 kWh	0.029	76,900	2.2
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,383,400	
Total direct costs			1,383,400	40.3
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			602,400	17.6
Average cost of capital and taxes at 8.60% of total capital investment			687,700	20.0
Overhead				
Plant, 50% of conversion costs less electricity			653,300	19.0
Administrative, 10% of total labor and supervision			103,400	3.0
Total indirect costs			2,046,800	59.7
Total annual revenue requirements			3,430,200	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	0.98	6.25		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-3. MINE DISPOSAL

CAPITAL INVESTMENT

(200 MW)

	Capital investment, k$	% of total
Process equipment	1,211	20.5
Piping and insulation	117	2.0
Foundation and structural	122	2.1
Excavation and site preparation	40	0.7
Electrical	284	4.8
Instrumentation	52	0.9
Buildings	504	8.5
Total	2,330	39.4
Services and miscellaneous	35	0.6
Total	2,365	40.0
Mobile equipment	476	8.0
Total direct investment	2,841	48.0
Engineering design and supervision	288	4.9
Architect and engineering contractor	72	1.2
Construction expense	511	8.6
Contractor fees	212	3.6
Total	3,924	66.3
Contingency	785	13.3
Total fixed investment	4,709	79.6
Allowance for startup and modifications	423	7.1
Interest during construction	565	9.5
Total depreciable investment	5,697	96.3
Land	11	0.2
Working capital	209	3.5
Total capital investment	5,917	
$/kW	29.6	

Basis
New 200-MW midwestern plant with 30-year, 127,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-4. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(200 MW)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50	328,500	13.1
Disposal equipment	26,280 man-hr	17.00	446,800	17.8
Plant maintenance - 4% of direct investment			114,000	4.5
Mine disposal operation				
Truck fuel and maintenance	224,400 tons	0.06	13,500	0.5
Earthmoving equipment fuel and maintenance	224,400 tons	0.12	26,900	1.1
Electricity	1,788,500 kWh	0.031	55,400	2.2
Analyses	1,000 hr	17.00	17,000	0.7
Total conversion costs			1,002,100	
Total direct costs			1,002,100	40.0
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			446,100	17.8
Average cost of capital and taxes at 8.6% of total capital investment			508,900	20.3
Overhead				
Plant, 50% of conversion costs less electricity			473,400	18.9
Administrative, 10% of total labor and supervision			77,500	3.1
Total indirect costs			1,505,900	60.0
Total annual revenue requirements			2,508,000	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.79	11.18

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-5. MINE DISPOSAL

CAPITAL INVESTMENT

(1500 MW)

	Capital investment, k$	% of total
Process equipment	4,152	25.5
Piping and insulation	214	1.3
Foundation and structural	1,264	7.8
Excavation and site preparation	85	0.5
Electrical	540	3.3
Instrumentation	80	0.5
Buildings	954	5.9
Total	7,289	44.7
Services and miscellaneous	109	0.7
Total	7,398	45.4
Mobile equipment	1,104	6.8
Total direct investment	8,502	52.1
Engineering design and supervision	438	2.7
Architect and engineering contractor	110	0.7
Construction expense	1,316	8.1
Contractor fees	488	3.0
Total	10,854	66.6
Contingency	2,171	13.3
Total fixed investment	13,025	79.9
Allowance for startup and modifications	1,192	7.3
Interest during construction	1,563	9.6
Total depreciable investment	15,780	96.8
Land	28	0.2
Working capital	498	3.0
Total capital investment	16,306	
$/kW	10.9	

Basis

New 1,500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-6. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(1500 MW)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50	547,500	8.6
Disposal equipment	61,320 man-hr	17.00	1,042,400	16.5
Plant maintenance - 4% of direct investment			340,000	5.4
Mine disposal operation				
Truck fuel and maintenance	1,646,100 tons	0.06	98,800	1.6
Earthmoving equipment fuel and maintenance	1,646,100 tons	0.12	197,500	3.1
Electricity	5,994,900 kWh	0.027	161,900	2.5
Analyses	1,500 hr	17.00	25,500	0.4
Total conversion costs			2,413,600	
Total direct costs			2,413,600	38.1
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			1,235,600	19.5
Average cost of capital and taxes at 8.6% of total capital investment			1,402,300	22.1
Overhead				
Plant, 50% of conversion costs less electricity			1,125,900	17.8
Administrative, 10% of total labor and supervision			159,000	2.5
Total indirect costs			3,922,800	61.9
Total annual revenue requirements			6,336,400	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	0.60	3.85		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-7. MINE DISPOSAL

CAPITAL INVESTMENT

(25 years remaining life)

	Capital investment, k$	% of total
Process equipment	2,026	25.1
Piping and insulation	140	1.7
Foundation and structural	239	3.0
Excavation and site preparation	53	0.7
Electrical	345	4.3
Instrumentation	56	0.7
Buildings	504	6.2
Total	3,363	41.7
Services and miscellaneous	50	0.6
Total	3,413	42.3
Mobile equipment	559	6.9
Total direct investment	3,972	49.2
Engineering design and supervision	322	4.0
Architect and engineering contractor	81	1.0
Construction expense	693	8.6
Contractor fees	274	3.4
Total	5,342	66.2
Contingency	1,068	13.2
Total fixed investment	6,410	79.5
Allowance for startup and modifications	585	7.3
Interest during construction	769	9.5
Total depreciable investment	7,764	96.2
Land	14	0.2
Working capital	289	3.6
Total capital investment	8,067	
$/kW	16.2	

Basis

Existing 500-MW midwestern plant with 25-year, 92,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-8. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(25 years remaining life)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	12.4
Disposal equipment	35,040 man-hr	17.00	595,700	16.9
Plant maintenance - 4% of direct investment			159,000	4.5
Mine disposal operation				
Truck fuel and maintenance	561,100 tons	0.06	33,700	1.0
Earthmoving equipment fuel and maintenance	561,100 tons	0.12	67,300	1.9
Electricity	2,652,000 kWh	0.029	76,900	2.2
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,387,600	
Total direct costs			1,387,600	39.4
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 8.80% of total depreciable investment			683,200	19.4
Average cost of capital and taxes at 8.6% of total capital investment			693,800	19.7
Overhead				
Plant, 50% of conversion costs less electricity			655,400	18.6
Administrative, 10% of total labor and supervision			103,400	2.9
Total indirect costs			2,135,800	60.6
Total annual revenue requirements			3,523,400	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.01	6.28		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-9. MINE DISPOSAL

CAPITAL INVESTMENT

(20 years remaining life)

	Capital investment, k$	% of total
Process equipment	2,026	25.1
Piping and insulation	140	1.7
Foundation and structural	239	3.0
Excavation and site preparation	53	0.7
Electrical	345	4.3
Instrumentation	56	0.7
Buildings	504	6.2
Total	3,363	41.7
Services and miscellaneous	50	0.6
Total	3,413	42.3
Mobile equipment	559	6.9
Total direct investment	3,972	49.2
Engineering design and supervision	322	4.0
Architect and engineering contractor	81	1.0
Construction expense	693	8.6
Contractor fees	274	3.4
Total	5,342	66.2
Contingency	1,068	13.2
Total fixed investment	6,410	79.5
Allowance for startup and modifications	585	7.3
Interest during construction	769	9.5
Total depreciable investment	7,764	96.2
Land	14	0.2
Working capital	289	3.6
Total capital investment	8,067	
$/kW	16.2	

Basis
Existing 500-MW midwestern plant with 15-year, 32,500-hr life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-10. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(20 years remaining life)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	12.3
Disposal equipment	35,040 man-hr	17.00	595,700	16.7
Plant maintenance - 4% of direct investment			159,000	4.5
Mine disposal operation				
Truck fuel and maintenance	561,100 tons	0.06	33,700	0.9
Earthmoving equipment fuel and maintenance	561,100 tons	0.12	67,300	1.9
Electricity	2,652,800 kWh	0.029	76,900	2.2
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,387,600	
Total direct costs			1,387,600	39.0
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 9.30% of total depreciable investment			722,100	20.3
Average cost of capital and taxes at 8.6% of total capital investment			693,800	19.5
Overhead				
Plant, 50% of conversion costs less electricity			655,400	18.4
Administrative, 10% of total labor and supervision			103,400	2.9
Total indirect costs			2,174,700	61.0
Total annual revenue requirements			3,562,300	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.02	6.35

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-11. MINE DISPOSAL

CAPITAL INVESTMENT

(15 years remaining life)

	Capital investment, k$	% of total
Process equipment	2,026	25.1
Piping and insulation	140	1.7
Foundation and structural	239	3.0
Excavation and site preparation	53	0.7
Electrical	345	4.3
Instrumentation	56	0.7
Buildings	504	6.2
Total	3,363	41.7
Services and miscellaneous	50	0.6
Total	3,413	42.3
Mobile equipment	559	6.9
Total direct investment	3,972	49.2
Engineering design and supervision	322	4.0
Architect and engineering contractor	81	1.0
Construction expense	693	8.6
Contractor fees	274	3.4
Total	5,342	66.2
Contingency	1,068	13.2
Total fixed investment	6,410	79.5
Allowance for startup and modifications	585	7.3
Interest during construction	769	9.5
Total depreciable investment	7,764	96.2
Land	14	0.2
Working capital	289	3.6
Total capital investment	8,067	
$/kW	16.2	

Basis

Existing 500-MW midwestern plant with 20-year, 57,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-12. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(15 years remaining life)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	11.9
Disposal equipment	35,040 man-hr	17.00	595,700	16.2
Plant maintenance - 4% of direct investment			159,000	4.3
Mine disposal operation				
Truck fuel and maintenance	561,100 tons	0.06	33,700	0.9
Earthmoving equipment fuel and maintenance	561,100 tons	0.12	67,300	1.8
Electricity	2,652,800 kWh	0.029	76,900	2.1
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,387,600	
Total direct costs			1,387,600	37.7
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 10.8% of total depreciable investment			838,500	22.8
Average cost of capital and taxes at 8.6% of total capital investment			693,800	18.9
Overhead				
Plant, 50% of conversion costs less electricity			655,400	17.8
Administrative, 10% of total labor and supervision			103,400	2.8
Total indirect costs			2,291,100	62.3
Total annual revenue requirements			3,678,700	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.05	6.56

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-13. MINE DISPOSAL

CAPITAL INVESTMENT

(2% sulfur in coal)

	Capital investment, k$	% of total
Process equipment	1,532	21.7
Piping and insulation	140	2.0
Foundation and structural	236	3.3
Excavation and site preparation	44	0.6
Electrical	325	4.6
Instrumentation	54	0.8
Buildings	504	7.1
Total	2,835	40.2
Services and miscellaneous	43	0.6
Total	2,878	40.8
Mobile equipment	559	7.9
Total direct investment	3,437	48.7
Engineering design and supervision	322	4.6
Architect and engineering contractor	81	1.1
Construction expense	601	8.5
Contractor fees	245	3.5
Total	4,686	66.4
Contingency	937	13.3
Total fixed investment	5,623	79.7
Allowance for startup and modifications	506	7.2
Interest during construction	675	9.6
Total depreciable investment	6,804	96.5
Land	10	0.1
Working capital	242	3.4
Total capital investment	7,056	
$/kW	14.1	

Basis

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 2.0% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-14. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(2% sulfur in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	14.9
Disposal equipment	26,280 man-hr	17.00	446,800	15.2
Plant maintenance - 4% of direct investment			137,000	4.7
Mine disposal operation				
Truck fuel and maintenance	345,100 tons	0.06	20,700	0.7
Earthmoving equipment fuel and maintenance	345,100 tons	0.12	41,400	1.4
Electricity	2,015,700 kWh	0.029	58,500	2.0
Analyses	1,000 hr	17.00	17,000	0.6
Total conversion costs			1,159,400	
Total direct costs			1,159,400	39.5
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			532,800	18.1
Average cost of capital and taxes at 8.6% of total capital investment			606,800	20.7
Overhead				
Plant, 50% of conversion costs less electricity			550,500	18.7
Administrative, 10% of total labor and supervision			88,500	3.0
Total indirect costs			1,778,600	60.5
Total annual revenue requirements			2,938,000	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	0.84	8.51

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-15. MINE DISPOSAL

CAPITAL INVESTMENT

(5% sulfur in coal)

	Capital investment, k$	% of total
Process equipment	2,465	26.9
Piping and insulation	151	1.6
Foundation and structural	248	2.7
Excavation and site preparation	62	0.7
Electrical	380	4.1
Instrumentation	63	0.7
Buildings	504	5.5
Total	3,873	42.3
Services and miscellaneous	58	0.6
Total	3,931	42.9
Mobile equipment	642	7.0
Total direct investment	4,573	49.9
Engineering design and supervision	322	3.5
Architect and engineering contractor	81	0.9
Construction expense	779	8.5
Contractor fees	305	3.3
Total	6,060	66.1
Contingency	1,212	13.2
Total fixed investment	7,272	79.4
Allowance for startup and modifications	663	7.2
Interest during construction	873	9.5
Total depreciable investment	8,808	96.1
Land	17	0.2
Working capital	336	3.7
Total capital investment	9,161	
$/kW	18.3	

Basis

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 5.0% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-16. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(5% sulfur in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	11.0
Disposal equipment	43,800 man-hr	17.00	744,600	18.7
Plant maintenance - 4% of direct investment			183,000	4.6
Mine disposal operation				
Truck fuel and maintenance	750,400 tons	0.06	45,000	1.1
Earthmoving equipment fuel and maintenance	750,400 tons	0.12	90,000	2.3
Electricity	3,519,600 kWh	0.029	102,100	2.6
Analyses	1,000 hr	17.00	17,000	0.4
Total conversion costs			1,619,700	
Total direct costs			1,619,700	40.7
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			689,700	17.4
Average cost of capital and taxes at 8.6% of total capital investment			787,800	19.8
Overhead				
Plant, 50% of conversion costs less electricity			758,800	19.1
Administrative, 10% of total labor and supervision			118,300	3.0
Total indirect costs			2,354,600	59.3
Total annual revenue requirements			3,974,300	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.14	5.30		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-17. MINE DISPOSAL

CAPITAL INVESTMENT

(12% ash in coal)

	Capital investment, k$	% of total
Process equipment	1,788	24.1
Piping and insulation	139	1.9
Foundation and structural	184	2.5
Excavation and site preparation	52	0.7
Electrical	306	4.1
Instrumentation	54	0.7
Buildings	504	6.8
Total	3,027	40.8
Services and miscellaneous	45	0.6
Total	3,072	41.4
Mobile equipment	559	7.5
Total direct investment	3,631	48.9
Engineering design and supervision	322	4.3
Architect and engineering contractor	81	1.1
Construction expense	635	8.6
Contractor fees	238	3.2
Total	4,907	66.1
Contingency	981	13.2
Total fixed investment	5,888	79.3
Allowance for startup and modifications	533	7.2
Interest during construction	707	9.5
Total depreciable investment	7,128	96.0
Land	12	0.2
Working capital	282	3.8
Total capital investment	7,422	
$/kW	14.8	

Basis

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 12% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-18. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(12% ash in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	13.3
Disposal equipment	35,040 man-hr	17.00	595,700	18.1
Plant maintenance - 4% of direct investment			145,000	4.4
Mine disposal operation				
Truck fuel and maintenance	468,300 tons	0.06	28,100	0.9
Earthmoving equipment fuel and maintenance	468,300 tons	0.12	56,200	1.7
Electricity	2,558,800 kWh	0.029	74,200	2.2
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,354,200	
Total direct costs			1,354,200	41.1
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			588,100	16.9
Average cost of capital and taxes at 8.6% of total capital investment			638,300	19.4
Overhead				
Plant, 50% of conversion costs less electricity			640,000	19.4
Administrative, 10% of total labor and supervision			103,400	3.1
Total indirect costs			1,939,800	58.9
Total annual revenue requirements			3,294,000	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	0.94	7.03		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-19. MINE DISPOSAL

CAPITAL INVESTMENT

(20% ash in coal)

	Capital investment, k$	% of total
Process equipment	2,173	25.3
Piping and insulation	140	1.6
Foundation and structural	311	3.6
Excavation and site preparation	55	0.6
Electrical	340	4.0
Instrumentation	56	0.6
Buildings	504	5.9
Total	3,579	41.7
Services and miscellaneous	54	0.6
Total	3,633	42.3
Mobile equipment	642	7.5
Total direct investment	4,275	49.8
Engineering design and supervision	322	3.7
Architect and engineering contractor	81	0.9
Construction expense	729	8.4
Contractor fees	290	3.4
Total	5,697	66.3
Contingency	1,139	13.3
Total fixed investment	6,836	79.6
Allowance for startup and modifications	619	7.2
Interest during construction	820	9.5
Total depreciable investment	8,275	96.3
Land	16	0.2
Working capital	298	3.5
Total capital investment	8,589	
$/kW	17.2	

Basis

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 20% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with flyash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-20. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(20% ash in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	12.2
Disposal equipment	35,040 man-hr	17.00	595,700	16.5
Plant maintenance - 4% of direct investment			171,000	4.7
Mine disposal operation				
Truck fuel and maintenance	638,800 tons	0.06	38,300	1.1
Earthmoving equipment fuel and maintenance	638,800 tons	0.12	76,700	2.1
Electricity	3,754,600 kWh	0.029	108,900	3.0
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,445,600	
Total direct costs			1,445,600	40.1
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			647,900	18.0
Average cost of capital and taxes at 8.6% of total capital investment			738,700	20.5
Overhead				
Plant, 50% of conversion costs less electricity			668,400	18.6
Administrative, 10% of total labor and supervision			103,400	2.9
Total indirect costs			2,158,400	59.9
Total annual revenue requirements			3,604,000	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.03	5.64		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-21. MINE DISPOSAL

CAPITAL INVESTMENT

(5 miles to disposal)

	Capital investment, k$	% of total
Process equipment	1,985	23.2
Piping and insulation	139	1.6
Foundation and structural	242	2.8
Excavation and site preparation	53	0.6
Electrical	345	4.0
Instrumentation	56	0.7
Buildings	504	5.9
Total	3,324	38.9
Services and miscellaneous	50	0.6
Total	3,374	39.4
Mobile equipment	890	10.4
Total direct investment	4,264	49.8
Engineering design and supervision	322	3.8
Architect and engineering contractor	81	0.9
Construction expense	686	8.0
Contractor fees	289	3.4
Total	5,642	66.0
Contingency	1,128	13.2
Total fixed investment	6,770	79.1
Allowance for startup and modifications	588	6.9
Interest during construction	812	9.5
Total depreciable investment	8,170	95.5
Land	14	0.2
Working capital	370	4.3
Total capital investment	8,554	
$/kW	17.1	

Basis
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 5 miles to surface mine; mid-1979 cost basis.

TABLE A-22. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(5 miles to disposal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	10.6
Disposal equipment	52,560 man-hr	17.00	893,500	21.6
Plant maintenance - 4% of direct investment			171,000	4.1
Mine disposal operation				
Truck fuel and maintenance	548,800 tons	0.20	109,800	2.7
Earthmoving equipment fuel and maintenance	548,800 tons	0.12	65,900	1.6
Electricity	2,652,800 kWh	0.029	76,900	1.9
Analyses	1,000 hr	17.00	17,000	0.4
Total conversion costs			1,772,100	
Total direct costs			1,772,100	42.9
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			639,700	15.5
Average cost of capital and taxes at 8.6% of total capital investment			735,600	17.8
Overhead				
Plant, 50% of conversion costs less electricity			847,600	20.5
Administrative, 10% of total labor and supervision			133,200	3.2
Total indirect costs			2,356,100	57.1
Total annual revenue requirements			4,128,200	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.18	7.52

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-23. MINE DISPOSAL

CAPITAL INVESTMENT

(10 miles to disposal)

	Capital investment, k$	% of total
Process equipment	1,985	22.4
Piping and insulation	139	1.6
Foundation and structural	242	2.7
Excavation and site preparation	53	0.6
Electrical	345	3.9
Instrumentation	56	0.6
Buildings	504	5.7
Total	3,324	37.5
Services and miscellaneous	50	0.6
Total	3,374	38.1
Mobile equipment	1,055	11.9
Total direct investment	4,429	50.0
Engineering design and supervision	322	3.6
Architect and engineering contractor	81	0.9
Construction expense	686	7.8
Contractor fees	297	3.4
Total	5,815	65.7
Contingency	1.163	13.2
Total fixed investment	6,978	78.9
Allowance for startup and modifications	592	6.7
Interest during construction	837	9.5
Total depreciable investment	8,407	95.1
Land	14	0.2
Working capital	425	4.7
Total capital investment	8,846	
$/kW	17.7	

Basis

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 10 miles to surface mine; mid-1979 cost basis.

TABLE A-24. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(10 miles to disposal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	9.6
Disposal equipment	61,320 man-hr	17.00	1,042,400	22.9
Plant maintenance - 4% of direct investment			177,000	3.9
Mine disposal operation				
Truck fuel and maintenance	548,800 tons	0.39	214,000	4.7
Earthmoving equipment fuel and maintenance	548,800 tons	0.12	65,900	1.5
Electricity	2,652,800 kWh	0.029	76,900	1.7
Analyses	1,000 hr	17.00	17,000	0.4
Total conversion costs			2,031,200	
Total direct costs			2,031,200	44.7
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			658,300	14.5
Average cost of capital and taxes at 8.6% of total capital investment			729,800	16.1
Overhead				
Plant, 50% of conversion costs less electricity			977,200	21.5
Administrative, 10% of total labor and supervision			148,000	3.3
Total indirect costs			2,513,300	55.3
Total annual revenue requirements			4,544,500	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.30	8.28

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-25. MINE DISPOSAL

CAPITAL INVESTMENT

(200-MW constant load)

	Capital investment, k$	% of total
Process equipment	1,211	20.5
Piping and insulation	117	2.0
Foundation and structural	122	2.0
Excavation and site preparation	40	0.7
Electrical	284	4.8
Instrumentation	52	0.9
Buildings	504	8.5
Total	2,330	39.4
Services and miscellaneous	35	0.6
Total	2,365	40.0
Mobile equipment	476	8.0
Total direct investment	2,841	48.0
Engineering design and supervision	288	4.9
Architect and engineering contractor	72	1.2
Construction expense	511	8.6
Contractor fees	212	3.6
Total	3,924	66.3
Contingency	785	13.3
Total fixed investment	4,709	79.6
Allowance for startup and modifications	423	7.2
Interest during construction	565	9.5
Total depreciable investment	5,697	96.3
Land	11	0.2
Working capital	209	3.5
Total capital investment	**5,917**	
$/kW	29.6	

Basis

New 200-MW midwestern plant with 30-year, 210,000-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-26. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(200-MW constant load)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50	328,500	13.1
Disposal equipment	26,280 man-hr	17.00	446,800	17.8
Plant maintenance - 4% of direct investment			114,000	4.6
Mine disposal operation				
Truck fuel and maintenance	224,400 tons	0.06	13,500	0.5
Earthmoving equipment fuel and maintenance	224,400 tons	0.12	26,900	1.1
Electricity	1,788,500 kWh	0.031	55,400	2.2
Analyses	1,000 hr	17.00	17,000	0.7
Total conversion costs			1,002,100	
Total direct costs			1,002,100	39.9
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			446,100	17.8
Average cost of capital and taxes at 8.6% of total capital investment			508,900	20.3
Overhead				
Plant, 50% of conversion costs less electricity			473,400	18.9
Administrative, 10% of total labor and supervision			77,500	3.1
Total indirect costs			1,505,900	60.1
Total annual revenue requirements			2,508,000	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.79	11.18		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-27. MINE DISPOSAL

CAPITAL INVESTMENT

(500-MW constant load)

	Capital investment, k$	% of total
Process equipment	1,985	24.8
Piping and insulation	139	1.7
Foundation and structural	242	3.0
Excavation and site preparation	53	0.7
Electrical	345	4.3
Instrumentation	56	0.7
Buildings	504	6.3
Total	3,324	41.6
Services and miscellaneous	50	0.6
Total	3,374	42.2
Mobile equipment	559	7.0
Total direct investment	3,933	49.2
Engineering design and supervision	322	4.0
Architect and engineering contractor	81	1.0
Construction expense	686	8.6
Contractor fees	272	3.4
Total	5,294	66.2
Contingency	1,059	13.2
Total fixed investment	6,353	79.5
Allowance for startup and modifications	579	7.2
Interest during construction	762	9.5
Total depreciable investment	7,694	96.2
Land	14	0.2
Working capital	288	3.6
Total capital investment	7,996	
$/kW	16.0	

Basis

New 500-MW midwestern plant with 30-year, 210,000-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-28. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(500-MW constant load)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	12.8
Disposal equipment	35,040 man-hr	17.00	595,700	17.4
Plant maintenance - 4% of direct investment			157,000	4.6
Mine disposal operation				
Truck fuel and maintenance	548,800 tons	0.06	32,900	1.0
Earthmoving equipment fuel and maintenance	548,800 tons	0.12	65,900	1.9
Electricity	2,652,800 kWh	0.029	76,900	2.2
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,383,400	
Total direct costs			1,383,400	40.3
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			602,400	17.6
Average cost of capital and taxes at 8.6% of total capital investment			687,700	20.0
Overhead				
Plant, 50% of conversion costs less electricity			653,300	19.1
Administrative, 10% of total labor and supervision			103,400	3.0
Total indirect costs			2,046,800	59.7
Total annual revenue requirements			3,430,200	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	0.98	6.25

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-29. MINE DISPOSAL

CAPITAL INVESTMENT

(1500-MW constant load)

	Capital investment, k$	% of total
Process equipment	4,152	25.5
Piping and insulation	214	1.3
Foundation and structural	1,264	7.8
Excavation and site preparation	85	0.5
Electrical	540	3.3
Instrumentation	80	0.5
Buildings	954	5.8
Total	7,289	44.7
Services and miscellaneous	109	0.7
Total	7,398	45.4
Mobile equipment	1,104	6.8
Total direct investment	8,502	52.1
Engineering design and supervision	438	2.7
Architect and engineering contractor	110	0.7
Construction expense	1,316	8.0
Contractor fees	488	3.0
Total	10,854	66.5
Contingency	2,171	13.3
Total fixed investment	13,025	79.8
Allowance for startup and modifications	1,192	7.3
Interest during construction	1,563	9.6
Total depreciable investment	15,780	96.8
Land	28	0.2
Working capital	498	3.0
Total capital investment	16,308	
$/kW	10.9	

Basis
New 1,500-MW midwestern plant with 30-year, 210,000-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash, and trucked 1 mile to surface mine; mid-1979 cost basis.

TABLE A-30. MINE DISPOSAL

ANNUAL REVENUE REQUIREMENTS

(1500-MW constant load)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50	547,500	8.6
Disposal equipment	61,320 man-hr	17.00	1,042,400	16.4
Plant maintenance - 4% of direct investment			340,000	5.4
Mine disposal operation				
Truck fuel and maintenance	1,646,100 tons	0.06	98,800	1.6
Earthmoving equipment fuel and maintenance	1,646,100 tons	0.12	197,500	3.1
Electricity	5,994,900 kWh	0.027	161,900	2.6
Analyses	1,500 hr	17.00	25,500	0.4
Total conversion costs			2,413,600	
Total direct costs			2,413,600	38.1
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			1,235,600	19.5
Average cost of capital and taxes at 8.6% of total capital investment			1,402,300	22.1
Overhead				
Plant, 50% of conversion costs less electricity			1,125,900	17.8
Administrative, 10% of total labor and supervision			159,000	2.5
Total indirect costs			3,922,800	61.9
Total annual revenue requirements			6,336,400	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	0.60	3.85

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-31. DRAVO LANDFILL

CAPITAL INVESTMENT

(Base case)

	Capital investment, k$	% of total
Process equipment	2,161	21.6
Piping and insulation	151	1.5
Foundation and structural	264	2.6
Excavation and site preparation	58	0.6
Electrical	367	3.7
Instrumentation	60	0.6
Buildings	654	6.5
Total	3,715	37.1
Services and miscellaneous	56	0.6
Total	3,771	37.7
Mobile equipment	790	7.9
Total direct investment	4,561	45.6
Engineering design and supervision	426	4.3
Architect and engineering contractor	107	1.1
Construction expense	752	7.5
Contractor fees	301	3.0
Total	6,147	61.4
Contingency	1,229	12.3
Total fixed investment	7,376	73.7
Allowance for startup and modifications	659	6.6
Interest during construction	885	8.9
Total depreciable investment	8,920	89.2
Land	581	5.8
Working capital	503	5.0
Total capital investment	10,004	
$/kW	20.0	

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-32. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(Base case)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,100 tons	64.00	966,400	19.2
Total raw material costs			966,400	19.3
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	8.7
Disposal equipment	43,800 man-hr	17.00	744,600	14.8
Plant maintenance - 4% of direct investment			182,000	3.6
Landfill operation				
Landfill preparation			15,100	0.3
Truck fuel and maintenance	563,900 tons	0.06	33,800	0.7
Earthmoving equipment fuel and maintenance	563,900 tons	0.16	90,200	1.8
Electricity	3,722,400 kWh	0.029	107,900	2.1
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			1,628,600	32.4
Total direct costs			2,595,000	51.6
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			698,400	13.9
Average cost of capital and taxes at 8.6% of total capital investment			860,300	17.1
Overhead				
Plant, 50% of conversion costs less electricity			760,400	15.1
Administrative, 10% of total labor and supervision			118,300	2.4
Total indirect costs			2,437,400	48.4
Total annual revenue requirements			5,032,400	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.44	8.9

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-33. DRAVO LANDFILL

CAPITAL INVESTMENT

(200 MW)

	Capital investment, k$	% of total
Process equipment	1,320	18.4
Piping and insulation	126	1.7
Foundation and structural	132	1.8
Excavation and site preparation	44	0.6
Electrical	300	4.2
Instrumentation	56	0.8
Buildings	564	7.9
Total	2,542	35.4
Services and miscellaneous	38	0.5
Total	2,580	35.9
Mobile equipment	707	9.9
Total direct investment	3,287	45.8
Engineering design and supervision	392	5.5
Architect and engineering contractor	98	1.4
Construction expense	549	7.6
Contractor fees	237	3.3
Total	4,563	63.6
Contingency	913	12.7
Total fixed investment	5,476	76.3
Allowance for startup and modifications	477	6.6
Interest during construction	657	9.2
Total depreciable investment	6,610	92.1
Land	242	3.4
Working capital	328	4.6
Total capital investment	7,180	
$/kW	35.9	

Basis:

New 200-MW midwestern plant with 30-year, 127,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-34. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(200 MW)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	6,300 tons	64.00	403,200	11.9
Total raw material costs			403,200	11.8
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50	328,500	9.7
Disposal equipment	35,040 man-hr	17.00	595,700	17.5
Plant maintenance - 4% of direct investment			131,000	3.7
Landfill operation				
Landfill preparation			6,200	0.2
Truck fuel and maintenance	230,700 tons	0.06	13,800	0.4
Earthmoving equipment fuel and maintenance	230,700 tons	0.16	36,900	1.1
Electricity	2,328,100 kWh	0.031	72,200	2.1
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,201,300	35.3
Total direct costs			1,604,500	47.2
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			517,600	15.2
Average cost of capital and taxes at 8.6% of total capital investment			617,500	18.2
Overhead				
Plant, 50% of conversion costs less electricity			564,600	16.6
Administrative, 10% of total labor and supervision			92,400	2.7
Total indirect costs			1,792,100	52.8
Total annual revenue requirements			3,396,600	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	2.43	14.72		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-35. DRAVO LANDFILL

CAPITAL INVESTMENT

(1500 MW)

	Capital investment, k$	% of total
Process equipment	4,498	21.7
Piping and insulation	234	1.1
Foundation and structural	1,389	6.7
Excavation and site preparation	95	0.5
Electrical	579	2.8
Instrumentation	87	0.4
Buildings	1,404	6.8
Total	8,286	39.9
Services and miscellaneous	124	0.6
Total	8,410	40.5
Mobile equipment	1,335	6.4
Total direct investment	9,745	46.9
Engineering design and supervision	438	2.1
Architect and engineering contractor	109	0.5
Construction expense	1,464	7.0
Contractor fees	542	2.6
Total	12,298	59.2
Contingency	2,460	11.8
Total fixed investment	14,758	71.1
Allowance for startup and modifications	1,342	7.1
Interest during construction	1,771	8.5
Total depreciable investment	17,871	86.7
Land	1,729	8.3
Working capital	1,032	5.0
Total capital investment	20,632	
$/kW	13.8	

Basis:
New 1,500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-36. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(1500 MW)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	45,200 tons	64.00	2,892,800	28.0
Total raw material costs			2,892,800	28.0
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50	547,500	5.3
Disposal equipment	70,080 man-hr	17.00	1,191,400	11.5
Plant maintenance - 4% of direct investment			390,000	3.8
Landfill operation				
Landfill preparation			45,400	0.4
Truck fuel and maintenance	1,691,200 tons	0.06	101,500	1.0
Earthmoving equipment fuel and maintenance	1,691,200 tons	0.16	270,600	2.6
Electricity	8,283,800 kWh	0.027	223,700	2.2
Analyses	1,500 hr	17.00	25,500	0.2
Total conversion costs			2,795,600	27.0
Total direct costs			5,688,400	55.0
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			1,399,300	13.6
Average cost of capital and taxes at 8.6% of total capital investment			1,774,400	17.2
Overhead				
Plant, 50% of conversion costs less electricity			1,286,000	12.5
Administrative, 10% of total labor and supervision			173,900	1.7
Total indirect costs			4,633,600	45.0
Total annual revenue requirements			10,322,000	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	0.98	6.10		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-37. DRAVO LANDFILL

CAPITAL INVESTMENT

(25 years remaining life)

	Capital investment, k$	% of total
Process equipment	2,202	22.1
Piping and insulation	152	1.5
Foundation and structural	260	2.6
Excavation and site preparation	59	0.6
Electrical	368	3.7
Instrumentation	61	0.6
Buildings	654	6.6
Total	3,756	37.7
Services and miscellaneous	56	0.6
Total	3,812	38.3
Mobile equipment	790	7.9
Total direct investment	4,602	46.2
Engineering design and supervision	426	4.3
Architect and engineering contractor	107	1.1
Construction expense	759	7.6
Contractor fees	306	3.1
Total	6,200	62.3
Contingency	1,240	12.4
Total fixed investment	7,440	74.7
Allowance for startup and modifications	665	6.7
Interest during construction	893	9.0
Total depreciable investment	8,998	90.4
Land	434	4.3
Working capital	528	5.3
Total capital investment	9,960	
$/kW	19.9	

Basis:
Existing 500-MW midwestern plant with 25-year, 92,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-38. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(25 years remaining life)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,400 tons	64.00	985,600	19.1
Total raw material costs			985,600	19.1
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	8.5
Disposal equipment	43,800 man-hr	17.00	744,600	14.5
Plant maintenance - 4% of direct investment			184,000	3.6
Landfill operation				
Landfill preparation			15,500	0.3
Truck fuel and maintenance	576,500 tons	0.06	34,600	0.7
Earthmoving equipment fuel and maintenance	576,500 tons	0.16	92,200	1.8
Electricity	3,722,400 kWh	0.029	107,900	2.1
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			1,633,800	31.8
Total direct costs			2,619,400	50.9
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 8.80% of total depreciable investment			791,800	15.4
Average cost of capital and taxes at 8.6% of total capital investment			856,600	16.6
Overhead				
Plant, 50% of conversion costs less electricity			763,000	14.8
Administrative, 10% of total labor and supervision			118,300	2.3
Total indirect costs			2,529,700	49.1
Total annual revenue requirements			5,149,100	

	Mills/kWh	$/ton waste
Equivalent unit revenue requirements	1.47	8.93

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-39. DRAVO LANDFILL

CAPITAL INVESTMENT

(20 years remaining life)

	Capital investment, k$	% of total
Process equipment	2,202	22.5
Piping and insulation	152	1.5
Foundation and structural	260	2.7
Excavation and site preparation	59	0.6
Electrical	368	3.8
Instrumentation	61	0.6
Buildings	654	6.7
Total	3,756	38.4
Services and miscellaneous	56	0.6
Total	3,812	39.0
Mobile equipment	790	8.0
Total direct investment	4,602	47.0
Engineering design and supervision	426	4.3
Architect and engineering contractor	107	1.1
Construction expense	759	7.8
Contractor fees	306	3.1
Total	6,200	63.3
Contingency	1,240	12.7
Total fixed investment	7,440	76.0
Allowance for startup and modifications	655	6.7
Interest during construction	893	9.1
Total depreciable investment	8,988	91.8
Land	277	2.8
Working capital	528	5.4
Total capital investment	9,793	
$/kW	19.6	

Basis:
Existing 500-MW midwestern plant with 20-year, 57,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-40. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(20 years remaining life)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,400 tons	64.00	985,600	19.0
Total raw material costs			985,600	19.0
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	8.5
Disposal equipment	43,800 man-hr	17.00	744,600	14.4
Plant maintenance - 4% of direct investment			184,000	3.5
Landfill operation				
Landfill preparation			15,500	0.3
Truck fuel and maintenance	576,500 tons	0.06	34,600	0.7
Earthmoving equipment fuel and maintenance	576,500 tons	0.16	92,200	1.8
Electricity	3,722,400 kWh	0.029	107,900	2.1
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			1,633,800	31.5
Total direct costs			2,619,400	50.6
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 9.30% of total depreciable investment			835,900	16.1
Average cost of capital and taxes at 8.6% of total capital investment			842,200	16.3
Overhead				
Plant, 50% of conversion costs less electricity			763,000	14.7
Administrative, 10% of total labor and supervision			118,300	2.3
Total indirect costs			2,559,400	49.4
Total annual revenue requirements			5,178,800	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.48	8.98		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-41. DRAVO LANDFILL

CAPITAL INVESTMENT

(15 years remaining life)

	Capital investment, k$	% of total
Process equipment	2,202	22.7
Piping and insulation	152	1.6
Foundation and structural	260	2.7
Excavation and site preparation	59	0.6
Electrical	368	3.8
Instrumentation	61	0.6
Buildings	654	6.8
Total	3,756	38.8
Services and miscellaneous	56	0.6
Total	3,812	39.4
Mobile equipment	790	8.2
Total direct investment	4,602	47.6
Engineering design and supervision	426	4.4
Architect and engineering contractor	107	1.1
Construction expense	759	7.8
Contractor fees	306	3.2
Total	6,200	64.1
Contingency	1,240	12.8
Total fixed investment	7,440	76.9
Allowance for startup and modifications	655	6.8
Interest during construction	893	9.2
Total depreciable investment	8,988	92.9
Land	161	1.6
Working capital	528	5.5
Total capital investment	9,677	
$/kW	19.4	

Basis:

Existing 500-MW midwestern plant with 15-year, 32,500-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-42. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(15 years remaining life)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,400 tons	64.00	985,600	18.6
Total raw material costs			985,600	18.5
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	8.3
Disposal equipment	43,800 man-hr	17.00	744,600	14.0
Plant maintenance - 4% of direct investment			184,000	3.5
Landfill operation				
Landfill preparation			15,500	0.3
Truck fuel and maintenance	576,500 tons	0.06	34,600	0.7
Earthmoving equipment fuel and maintenance	576,500 tons	0.16	92,200	1.7
Electricity	3,722,400 kWh	0.029	107,900	2.0
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			1,633,800	30.8
Total direct costs			2,619,400	49.4
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 10.8% of total depreciable investment			970,700	18.3
Average cost of capital and taxes at 8.6% of total capital investment			832,200	15.7
Overhead				
Plant, 50% of conversion costs less electricity			763,000	14.4
Administrative, 10% of total labor and supervision			118,300	2.2
Total indirect costs			2,684,200	50.6
Total annual revenue requirements			5,303,600	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.52	9.20		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-43. DRAVO LANDFILL

CAPITAL INVESTMENT

(2% sulfur in coal)

	Capital investment, k$	% of total
Process equipment	1,665	19.4
Piping and insulation	152	1.8
Foundation and structural	256	3.0
Excavation and site preparation	48	0.6
Electrical	353	4.1
Instrumentation	59	0.7
Buildings	594	6.9
Total	3,127	36.4
Services and miscellaneous	50	0.6
Total	3,177	37.0
Mobile equipment	790	9.2
Total direct investment	3,967	46.2
Engineering design and supervision	426	5.0
Architect and engineering contractor	107	1.2
Construction expense	644	7.5
Contractor fees	274	3.2
Total	5,418	63.1
Contingency	1,084	12.6
Total fixed investment	6,502	75.7
Allowance for startup and modifications	571	6.7
Interest during construction	780	9.1
Total depreciable investment	7,853	91.5
Land	364	4.2
Working capital	369	4.3
Total capital investment	8,586	
$/kW	17.2	

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 2.0% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-44. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(2% sulfur in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	6,700 tons	64.00	428,800	11.0
Total raw material costs			428,800	10.9
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	11.2
Disposal equipment	35,040 man-hr	17.00	595,700	15.2
Plant maintenance - 4% of direct investment			159,000	4.1
Landfill operation				
Landfill preparation			9,400	0.2
Truck fuel and maintenance	351,800 tons	0.06	21,100	0.5
Earthmoving equipment fuel and maintenance	351,800 tons	0.16	56,300	1.4
Electricity	2,743,300 kWh	0.029	79,600	2.0
Analyses	1,000 hr	17.00	17,000	0.4
Total conversion costs			1,376,100	35.1
Total direct costs			1,804,900	46.1
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			614,900	15.7
Average cost of capital and taxes at 8.6% of total capital investment			738,400	18.9
Overhead				
Plant, 50% of conversion costs less electricity			648,300	16.6
Administrative, 10% of total labor and supervision			103,400	2.6
Total indirect costs			2,105,000	53.9
Total annual revenue requirements			3,909,900	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.12	11.11		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-45. DRAVO LANDFILL

CAPITAL INVESTMENT

(5% sulfur in coal)

	Capital investment, k$	% of total
Process equipment	2,700	22.7
Piping and insulation	165	1.4
Foundation and structural	272	2.3
Excavation and site preparation	68	0.6
Electrical	416	3.5
Instrumentation	69	0.6
Buildings	704	5.9
Total	4,394	37.0
Services and miscellaneous	66	0.6
Total	4,460	37.6
Mobile equipment	873	7.3
Total direct investment	5,333	44.9
Engineering design and supervision	426	3.6
Architect and engineering contractor	107	0.9
Construction expense	865	7.2
Contractor fees	343	2.9
Total	7,074	59.5
Contingency	1,415	11.9
Total fixed investment	8,489	71.4
Allowance for startup and modifications	762	6.4
Interest during construction	1,019	8.5
Total depreciable investment	10,270	86.3
Land	795	6.6
Working capital	858	7.1
Total capital investment	11,923	
$/kW	23.9	

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 5.0% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-46. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(5% sulfur in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	23,500 tons	64.00	1,504,000	22.6
Total raw material costs			1,504,000	22.6
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	6.6
Disposal equipment	52,600 man-hr	17.00	893,500	13.4
Plant maintenance - 4% of direct investment			213,000	3.2
Landfill operation				
Landfill preparation			20,800	0.3
Truck fuel and maintenance	733,900 tons	0.06	44,000	0.6
Earthmoving equipment fuel and maintenance	733,900 tons	0.16	117,400	1.7
Electricity	4,717,200 kWh	0.029	136,800	2.1
Analyses	1,000 hr	17.00	17,000	0.2
Total conversion costs			1,880,500	28.1
Total direct costs			3,384,500	50.7
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			804,100	12.1
Average cost of capital and taxes at 8.6% of total capital investment			1,025,400	15.4
Overhead				
Plant, 50% of conversion costs less electricity			1,318,600	19.8
Administrative, 10% of total labor and supervision			133,200	2.0
Total indirect costs			3,281,300	49.3
Total annual revenue requirements			6,665,800	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.90	8.61		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-47. DRAVO LANDFILL

CAPITAL INVESTMENT

(12% ash in coal)

	Capital investment, k$	% of total
Process equipment	1,939	20.8
Piping and insulation	151	1.6
Foundation and structural	200	2.2
Excavation and site preparation	56	0.6
Electrical	332	3.6
Instrumentation	59	0.6
Buildings	634	6.8
Total	3,371	36.2
Services and miscellaneous	51	0.6
Total	3,422	36.8
Mobile equipment	790	8.5
Total direct investment	4,212	45.3
Engineering design and supervision	426	4.6
Architect and engineering contractor	107	1.1
Construction expense	694	7.5
Contractor fees	286	3.1
Total	5,725	61.6
Contingency	1,145	12.3
Total fixed investment	6,870	73.9
Allowance for startup and modifications	608	6.5
Interest during construction	824	8.9
Total depreciable investment	8,302	89.3
Land	497	5.3
Working capital	503	5.4
Total capital investment	9,302	
$/kW	18.6	

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 12% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-48. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(12% ash in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	14,000 tons	64.00	896,000	18.7
Total raw material costs			896,000	18.7
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	9.1
Disposal equipment	43,800 man-hr	17.00	744,600	15.5
Plant maintenance - 4% of direct investment			168,000	3.5
Landfill operation				
Landfill preparation			12,900	0.3
Truck fuel and maintenance	482,300 tons	0.06	28,900	0.6
Earthmoving equipment fuel and maintenance	482,300 tons	0.16	77,200	1.6
Electricity	3,615,300 kWh	0.029	104,800	2.2
Analyses	1,000 hr	17.00	17,000	0.4
Total conversion costs			1,591,400	33.1
Total direct costs			2,487,400	51.8
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			650,100	13.5
Average cost of capital and taxes at 8.6% of total capital investment			800,000	16.7
Overhead				
Plant, 50% of conversion costs less electricity			743,300	15.5
Administrative, 10% of total labor and supervision			118,300	2.5
Total indirect costs			2,311,600	48.2
Total annual revenue requirements			4,799,00	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.37	9.95		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-49. DRAVO LANDFILL

CAPITAL INVESTMENT

(20% ash in coal)

	Capital investment, k$	% of total
Process equipment	2,343	21.8
Piping and insulation	151	1.4
Foundation and structural	335	3.1
Excavation and site preparation	59	0.5
Electrical	367	3.4
Instrumentation	60	0.6
Buildings	684	6.4
Total	3,999	37.2
Services and miscellaneous	60	0.6
Total	4,059	37.8
Mobile equipment	873	8.1
Total direct investment	4,932	45.9
Engineering design and supervision	426	4.0
Architect and engineering contractor	107	1.0
Construction expense	800	7.4
Contractor fees	323	3.0
Total	6,588	61.3
Contingency	1,318	12.3
Total fixed investment	7,906	73.6
Allowance for startup and modifications	703	6.5
Interest during construction	949	8.8
Total depreciable investment	9,558	88.9
Land	676	6.3
Working capital	515	4.8
Total capital investment	10,749	
$/kW	21.5	

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 20% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-50. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(20% ash in coal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	16,100 tons	64.00	1,030,400	19.5
Total raw material costs			1,030,400	19.5
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	8.3
Disposal equipment	43,800 man-hr	17.00	744,600	14.1
Plant maintenance - 4% of direct investment			197,000	3.7
Landfill operation				
Landfill preparation			17,600	0.3
Truck fuel and maintenance	654,900 tons	0.06	39,300	0.7
Earthmoving equipment fuel and maintenance	654,900 tons	0.16	104,800	2.0
Electricity	4,759,000 kWh	0.029	138,000	2.6
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			1,696,300	32.0
Total direct costs			2,726,700	51.5
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			748,400	14.1
Average cost of capital and taxes at 8.6% of total capital investment			924,400	17.5
Overhead				
Plant, 50% of conversion costs less electricity			779,200	14.7
Administrative, 10% of total labor and supervision			118,300	2.2
Total indirect costs			2,570,300	48.5
Total annual revenue requirements			5,297,000	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.51	8.09		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-51. DRAVO LANDFILL

CAPITAL INVESTMENT

(5 miles to disposal)

	Capital investment, k$	% of total
Process equipment	2,161	20.4
Piping and insulation	151	1.4
Foundation and structural	264	2.5
Excavation and site preparation	58	0.6
Electrical	367	3.5
Instrumentation	60	0.6
Buildings	654	6.2
Total	3,715	35.2
Services and miscellaneous	56	0.5
Total	3,771	35.7
Mobile equipment	1,121	10.6
Total direct investment	4,892	46.3
Engineering design and supervision	426	4.0
Architect and engineering contractor	107	1.0
Construction expense	752	7.1
Contractor fees	321	3.0
Total	6,498	61.5
Contingency	1,300	12.3
Total fixed investment	7,798	73.8
Allowance for startup and modifications	668	6.3
Interest during construction	936	8.8
Total depreciable investment	9,402	88.9
Land	581	5.5
Working capital	590	5.6
Total capital investment	10,573	
$/kW	21.2	

Basis:

New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 5 miles to landfill; mid-1979 cost basis.

TABLE A-52. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(5 miles to disposal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,100 tons	64.00	966,400	16.8
Total raw material costs			966,400	16.8
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	7.6
Disposal equipment	61,320 man-hr	17.00	1,042,400	18.2
Plant maintenance - 4% of direct investment			196,000	3.4
Landfill operation				
Landfill preparation			15,100	0.3
Truck fuel and maintenance	563,900 tons	0.20	112,800	2.0
Earthmoving equipment fuel and maintenance	563,900 tons	0.16	90,200	1.6
Electricity	3,722,400 kWh	0.029	107,900	1.9
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			2,019,400	35.3
Total direct costs			2,985,800	52.1
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			736,200	12.8
Average cost of capital and taxes at 8.6% of total capital investment			909,300	15.8
Overhead				
Plant, 50% of conversion costs less electricity			955,800	16.7
Administrative, 10% of total labor and supervision			148,000	2.6
Total indirect costs			2,749,300	47.9
Total annual revenue requirements			5,735,100	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.64	10.17		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-53. DRAVO LANDFILL

CAPITAL INVESTMENT

(10 miles to disposal)

	Capital investment, k$	% of total
Process equipment	2,161	19.9
Piping and insulation	151	1.4
Foundation and structural	264	2.4
Excavation and site preparation	58	0.5
Electrical	367	3.4
Instrumentation	60	0.6
Buildings	654	6.0
Total	3,715	34.3
Services and miscellaneous	56	0.5
Total	3,771	34.8
Mobile equipment	1,286	11.9
Total direct investment	5,057	46.6
Engineering design and supervision	426	3.9
Architect and engineering contractor	107	1.0
Construction expense	752	6.9
Contractor fees	329	3.0
Total	6,671	61.5
Contingency	1,334	12.3
Total fixed investment	8,005	73.8
Allowance for startup and modifications	672	6.2
Interest during construction	961	8.9
Total depreciable investment	9,638	88.9
Land	581	5.4
Working capital	624	5.7
Total capital investment	10,843	
$/kW	21.7	

Basis:
New 500-MW midwestern plant with 30-year, 127,500-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 10 miles to landfill; mid-1979 cost basis.

TABLE A-54. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(10 miles to disposal)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,100 tons	64.00	966,400	15.6
Total raw material costs			966,400	15.6
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	7.1
Disposal equipment	70,080 man-hr	17.00	1,191,400	19.3
Plant maintenance - 4% of direct investment			202,000	3.3
Landfill operation				
Landfill preparation			15,100	0.2
Truck fuel and maintenance	563,900 tons	0.39	219,900	3.6
Earthmoving equipment fuel and maintenance	563,900 tons	0.16	90,200	1.5
Electricity	3,722,400 kWh	0.029	107,900	1.7
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			2,281,500	36.9
Total direct costs			3,247,900	52.5
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			754,700	12.2
Average cost of capital and taxes at 8.6% of total capital investment			932,500	15.1
Overhead				
Plant, 50% of conversion costs less electricity			1,086,800	17.6
Administrative, 10% of total labor and supervision			162,900	2.6
Total indirect costs			2,936,900	47.5
Total annual revenue requirements			6,184,800	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.77	10.97		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-55. DRAVO LANDFILL

CAPITAL INVESTMENT

(200-MW constant load)

	Capital investment, k$	% of total
Process equipment	1,320	18.0
Piping and insulation	126	1.7
Foundation and structural	132	1.8
Excavation and site preparation	44	0.6
Electrical	300	4.1
Instrumentation	56	0.8
Buildings	564	7.7
Total	2,542	34.7
Services and miscellaneous	38	0.5
Total	2,580	35.2
Mobile equipment	707	9.6
Total direct investment	3,287	44.8
Engineering design and supervision	392	5.4
Architect and engineering contractor	98	1.3
Construction expense	549	7.5
Contractor fees	237	3.2
Total	4,563	62.2
Contingency	913	12.5
Total fixed investment	5,476	74.7
Allowance for startup and modifications	477	6.5
Interest during construction	657	9.0
Total depreciable investment	6,610	90.2
Land	392	5.3
Working capital	328	4.5
Total capital investment	7,330	
$/kW	36.7	

Basis:
New 200-MW midwestern plant with 30-year, 210,000-hour life and 9,200 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-56. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(200-MW constant load)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	6,300 tons	64.00	403,200	11.8
Total raw material costs			403,200	11.8
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50	328,500	9.6
Disposal equipment	35,040 man-hr	17.00	595,700	17.5
Plant maintenance - 4% of direct investment			131,000	3.8
Landfill operation				
Landfill preparation			6,200	0.2
Truck fuel and maintenance	230,700 tons	0.06	13,800	0.4
Earthmoving equipment fuel and maintenance	230,700 tons	0.16	36,900	1.1
Electricity	2,328,100 kWh	0.031	72,200	2.1
Analyses	1,000 hr	17.00	17,000	0.5
Total conversion costs			1,201,300	35.2
Total direct costs			1,604,500	47.0
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			517,600	15.2
Average cost of capital and taxes at 8.6% of total capital investment			630,400	18.5
Overhead				
Plant, 50% of conversion costs less electricity			564,600	16.6
Administrative, 10% of total labor and supervision			92,400	2.7
Total indirect costs			1,805,000	53.0
Total annual revenue requirements			3,409,500	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	2.44	14.78		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-57. DRAVO LANDFILL

CAPITAL INVESTMENT

(500-MW constant load)

	Capital investment, k$	% of total
Process equipment	2,161	20.8
Piping and insulation	151	1.5
Foundation and structural	264	2.5
Excavation and site preparation	58	0.6
Electrical	367	3.5
Instrumentation	60	0.6
Buildings	654	6.3
Total	3,715	35.8
Services and miscellaneous	56	0.5
Total	3,771	36.3
Mobile equipment	790	7.6
Total direct investment	4,561	43.9
Engineering design and supervision	426	4.1
Architect and engineering contractor	107	1.0
Construction expense	752	7.2
Contractor fees	301	2.9
Total	6,147	59.1
Contingency	1,229	11.8
Total fixed investment	7,376	71.0
Allowance for startup and modifications	659	6.3
Interest during construction	885	8.5
Total depreciable investment	8,920	85.8
Land	949	9.1
Working capital	523	5.0
Total capital investment	10,392	
$/kW	20.8	

Basis:
New 500-MW midwestern plant with 30-year, 210,000-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-58. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(500-MW constant load)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	15,100 tons	64.00	966,400	19.1
Total raw material costs			966,400	19.1
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50	438,000	8.6
Disposal equipment	43,800 man-hr	17.00	744,600	14.7
Plant maintenance - 4% of direct investment			182,000	3.6
Landfill operation				
Landfill preparation			15,100	0.3
Truck fuel and maintenance	563,900 tons	0.06	33,800	0.7
Earthmoving equipment fuel and maintenance	563,900 tons	0.16	90,200	1.8
Electricity	3,722,400 kWh	0.029	108,000	2.1
Analyses	1,000 hr	17.00	17,000	0.3
Total conversion costs			1,628,700	32.1
Total direct costs			2,595,100	51.2
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			698,400	13.8
Average cost of capital and taxes at 8.6% of total capital investment			893,700	17.6
Overhead				
Plant, 50% of conversion costs less electricity			760,400	15.0
Administrative, 10% of total labor and supervision			118,300	2.3
Total indirect costs			2,470,800	48.8
Total annual revenue requirements			5,065,900	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	1.45	8.98		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TABLE A-59. DRAVO LANDFILL

CAPITAL INVESTMENT

(1500-MW constant load)

	Capital investment, k$	% of total
Process equipment	4,498	20.6
Piping and insulation	234	1.1
Foundation and structural	1,389	6.4
Excavation and site preparation	95	0.4
Electrical	579	2.7
Instrumentation	87	0.4
Buildings	1,404	6.4
Total	8,286	38.0
Services and miscellaneous	124	0.6
Total	8,410	38.6
Mobile equipment	1,335	6.1
Total direct investment	9,745	44.7
Engineering design and supervision	438	2.0
Architect and engineering contractor	109	0.5
Construction expense	1,464	6.7
Contractor fees	542	2.5
Total	12,298	56.4
Contingency	2,460	11.3
Total fixed investment	14,758	67.7
Allowance for startup and modifications	1,342	6.2
Interest during construction	1,771	8.1
Total depreciable investment	17,871	82.0
Land	2,828	13.0
Working capital	1,084	5.0
Total capital investment	21,783	
$/kW	14.5	

Basis:
New 1,500-MW midwestern plant with 30-year, 210,000-hour life and 9,000 Btu/kWh heat rate; 3.5% sulfur, 16% ash, 10,500 Btu/lb coal; 1.5 stoichiometry limestone scrubbing and ESP fly ash collection to NSPS; 15% solids slurry dewatered to 60% solids, blended with fly ash and Calcilox, and trucked 1 mile to landfill; mid-1979 cost basis.

TABLE A-60. DRAVO LANDFILL

ANNUAL REVENUE REQUIREMENTS

(1500-MW constant load)

	Annual quantity	Cost, $/unit	Annual revenue requirements, $	% of total
Direct Costs				
Delivered raw materials				
Calcilox	45,200 tons	64.00	2,892,800	27.8
Total raw material costs			2,892,800	27.8
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50	547,500	5.3
Disposal equipment	70,080 man-hr	17.00	1,191,400	11.4
Plant maintenance - 4% of direct investment			390,000	3.7
Landfill operation				
Landfill preparation			45,400	0.4
Truck fuel and maintenance	1,691,200 tons	0.06	101,500	1.0
Earthmoving equipment fuel and maintenance	1,691,200 tons	0.16	270,600	2.6
Electricity	8,283,800 kWh	0.027	223,700	2.2
Analyses	1,500 hr	17.00	25,500	0.2
Total conversion costs			2,795,600	26.8
Total direct costs			5,688,400	54.6
Indirect Costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total depreciable investment			1,399,300	13.4
Average cost of capital and taxes at 8.6% of total capital investment			1,873,300	18.0
Overhead				
Plant, 50% of conversion costs less electricity			1,286,000	12.3
Administrative, 10% of total labor and supervision			173,900	1.7
Total indirect costs			4,732,500	45.4
Total annual revenue requirements			10,420,900	
	Mills/kWh	$/ton waste		
Equivalent unit revenue requirements	0.99	6.16		

Basis: One-year, 7,000 hour operation of system described in capital investment summary; mid-1980 cost basis.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-80-022	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Economics of Disposal of Lime/Limestone Scrubbing Wastes: Surface Mine Disposal and Dravo Landfill Processes		5. REPORT DATE February 1980
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J.D.Veitch, A.E.Steele, and T.W.Tarkington		8. PERFORMING ORGANIZATION REPORT NO. EDT-105
9. PERFORMING ORGANIZATION NAME AND ADDRESS TVA, Office of Power Division of Energy Demonstrations and Technology Muscle Shoals, Alabama 35660		10. PROGRAM ELEMENT NO. INE624A
		11. CONTRACT/GRANT NO. IAG-D8-E721-BI
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 6/78 - 8/79
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Julian W. Jones, Mail Drop 61, 919/541-2489.

16. ABSTRACT The report gives results of economic evaluations of flyash and limestone scrubbing waste disposal in a surface mine and in a landfill after treatment with a Dravo Lime Co. chemical additive. For the base case (new 500 MW midwestern plant burning 3.5% S, 16% ash, 10,500 Btu/lb coal), capital investment for the mine disposal process is 16.0 $/kW and annual revenue requirements are 0.98 mill/kWh, compared to 20.0 $/kW and 1.44 mills/kWh for the landfill process, excluding dry flyash collection costs of 19.2 $/kW and 0.56 mill/kWh. A moderate cost reduction is obtained for mine disposal, compared to landfill disposal of the same waste, by eliminating disposal land requirements and reducing earthmoving equipment requirements. Purchasing and handling the chemical additive for the landfill process account for most of the cost differences between the two processes. Power plant size, coal sulfur and ash contents, and distance to the disposal site have major cost effects for both processes. Modular cost breakdowns show purchase and handling of fixatives, thickening, ESP units, and disposal labor to be major cost elements.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Fly Ash	Pollution Control	13B	21B
Economic Analysis	Surface Mining	Stationary Sources	05C	08I
Waste Disposal	Earth Fills	Dravo Landfill Process		13C
Gas Scrubbing	Additives		07A,13H	11G
Calcium Oxides			07B	
Calcium Carbonates				

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 173
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)