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CONTROLLING SO_2 EMISSIONS FROM COAL-FIRED STEAM-ELECTRIC GENERATORS: SOLID WASTE IMPACT (Volume I. Executive Summary)

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by

P.P. Leo and J. Rossoff

The Aerospace Corporation
P.O. Box 92957
Los Angeles, California 90009

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W. A. 6
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EPA Project Officer: Julian W. Jones

Industrial Environmental Research Laboratory
Office of Energy, Minerals and Industry
Research Triangle Park, N.C. 27711

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Office of Research and Development
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ABSTRACT

The Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards (OAQPS), Durham, North Carolina, is reviewing the New Source Performance Standards (NSPS) for sulfur dioxide (SO_2) emissions from coal-fired steam electric generators. A number of control strategies are defined, e.g., increased scrubbing efficiency and coal washing, for achieving several levels of SO_2 emission control with emphasis on levels more stringent than the current NSPS. In support of that review, this study is aimed at providing an assessment of technological, economic, and environmental impacts, projected to 1998, of the increased solid wastes resulting from the application of the various more-stringent controls as well as the current NSPS.

The study considers three alternative strategies (1.2 lb $SO_2/10^6$ Btu, 90 percent SO_2 removal, and 0.5 lb $SO_2/10^6$ Btu), three plant sizes (1000, 500, and 25 MW), and five flue gas desulfurization (FGD) systems (lime, limestone, double alkali, magnesium oxide, and Wellman-Lord). Typical eastern and western coals containing 3.5 percent and 0.8 percent sulfur, respectively, as well as coal washing are included. The range of variability of sulfur content in coals, while not considered explicitly, was assumed to result in the typical values defined when considered in a national aggregate. Additionally, the ground rules include the following: (a) the interval for the nationwide survey (1978 through 1998), (b) the new plant installed capacity during that interval (Federal Power Commission projection), (c) the establishment of 1980 as the effective date for the more stringent standards for purposes of this study, and (d) the quantity of western coal burned during the 1980-1998 period to be 45 percent of the total burned on a nationwide basis.

The application of more stringent standards would possibly affect the percentage of western coal burned. Because predictions of the impacts of these standards on western coal usage were not available, the quantities and volumes of wastes that would be produced nationally as a result of burning different fractions of western coal were computed on a parametric basis.

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CONVERSION TABLE

British	Metric
1 inch	2.54 centimeters
1 foot	0.3048 meter
1 mile	1.609 kilometers
1 square foot	9,290 square centimeters
1 acre	4,047 square meters
1 cubic foot	28,316 cubic centimeters
1 gallon	3.785 liters
1 cubic yard	0.7646 cubic meter
1 pound	0.454 kilogram
1 ton (short)	0.9072 metric ton
1 pound per square inch	0.0703 kilogram per square centimeter
1 pound per cubic foot	0.01602 gram per cubic centimeter
1 ton per square foot	9,765 kilograms per square meter
1 part per million	1 milligram per liter (equivalent)
1 British thermal unit (Btu)	252 calories
1 pound per million Btu	0.43 grams per million joules; 1.80 grams per million calories
1 Btu per pound	2.324 joules per gram; 0.555 calories per gram

SECTION I

INTRODUCTION

The Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards (OAQPS), Durham, North Carolina, is reviewing the New Source Performance Standards (NSPS) for sulfur dioxide (SO_2) emissions from coal-fired steam electric generators. A number of control strategies have been defined, e.g., increased scrubbing efficiency and coal washing, for achieving several levels of SO_2 emission control with emphasis on levels more stringent than the current NSPS. In support of that review, this study is aimed at providing an assessment of technological, economic, and environmental impacts, projected to 1998, of the increased solid wastes resulting from the application of the various more-stringent controls as well as the current NSPS.

The study considered three alternative strategies (1.2 lb $SO_2/10^6$ Btu, 90 percent SO_2 removal, and 0.5 lb $SO_2/10^6$ Btu), three plant sizes (1000, 500, and 25 MW), and five flue gas desulfurization (FGD) systems (lime, limestone, double alkali, magnesium oxide, and Wellman-Lord). Typical eastern and western coals, as well as coal washing, were included. Initially, the various study cases totalled 67; they were subsequently increased to 93 to improve visibility into the impact of the various alternatives. The study cases are summarized in Table 1. Additional groundrules and guidelines were developed in conjunction with the technical monitor during the course of the study (1, 2). These are also outlined in Table 1 and include the following: (a) the interval for the nationwide survey (1978 through 1998), (b) the new plant installed capacity during that interval (Federal Power Commission projection), (c) the establishment of 1980 as the effective date for the more stringent standards for purposes of this study, and (d) the quantity of western coal burned during the 1980-1998 period to be 45 percent of the total burned on a nationwide basis.

The application of more stringent standards would possibly affect the percentage of western coal burned. Because predictions of the impacts of these standards on western coal usage were not available, quantities and volumes of wastes that would be produced nationally as a result of burning different fractions of western coal were computed on a parametric basis.

TABLE 1. ALTERNATIVE CONTROL SYSTEMS FOR MODEL PLANTS[a, b]

Plant Sizes To Be Considered, MW	FGD Systems To Be Considered	Alternative Standards and Model Plant Systems
25; 500; 1000	5[c]	1. The existing NSPS of 1.2 lb $SO_2/10^6$ Btu heat input. a. 90-percent SO_2 removal on a plant burning a typical coal of 3.5 percent sulfur.
25; 500; 1000	Lime/limestone	b. A plant burning a typical 7-percent sulfur coal with 90-percent SO_2 removal by FGD.
25; 500	---	c. Low-sulfur coal without FGD for a typical eastern plant.
25; 500	---	d. Low-sulfur coal without FGD for a typical western plant.
500	Lime/limestone	e. 40-percent sulfur removal by coal washing of a 3.5-percent-sulfur coal followed by 65-percent SO_2 removal by FGD.
25; 500; 1000	5[c]	2. a. 90-percent SO_2 removal by FGD on a typical coal of 3.5 percent sulfur and a typical coal of 7 percent sulfur.
25; 500	Lime/limestone	b. 90-percent SO_2 removal by FGD on a plant burning a typical western coal of 0.8 percent sulfur (western plant).
25; 500	Lime-limestone	3. 0.5 lb SO_2 emissions/10^6 Btu heat input. a. 70- to 75-percent SO_2 removal by FGD on a 0.8-percent-sulfur western coal (western plant).
25; 500	Lime/limestone	b.1 40-percent sulfur removal by coal washing of a 3.5-percent-sulfur coal and 85-percent removal by FGD.
500	Lime/limestone	b.2 40-percent sulfur removal by coal washing of a 7-percent-sulfur coal and 95-percent removal by FGD.

[a]Reference 3.

[b]Per References 1 and 2.
- Study encompasses 1978-1998 period.
- More stringent standards to apply in 1980.
- New plant installed capacity per Federal Power Commission projections.
- For 1980 and thereafter, 45 percent of the coal burned nationally is western, low sulfur.

[c]The five systems to be considered are lime, limestone, magnesium oxide, double alkali, and Wellman-Lord.

SECTION II

EXECUTIVE SUMMARY

Solid wastes resulting from the scrubbing of flue gases from coal-fired steam-generating utility boilers were quantified for 1000-, 500-, and 25-MW units for nonregenerable (lime, limestone, and double alkali) and regenerable (magnesium oxide and Wellman-Lord) processes. Typical eastern and western coals were included in the study (Table 2). A number of control strategies were included, such as increased scrubbing efficiency and coal washing, to achieve several levels of emissions more stringent than the current New Source Performance Standards (NSPS). Table 3 is a cross reference of the alternative standards and model plants (from Table 1) with the study case numbers. The resultant waste or by-product quantities and volumes are presented in Table 2 for each case.

Land requirements and technological, economic, and environmental impacts were projected to 1998, with the application of the more stringent controls in 1980.

Physical and chemical characteristics of the wastes were identified with respect to the potential pollution of water supplies, resulting from disposal of the wastes.

The applicability and effectiveness of the various control strategies in conjunction with existing disposal and utilization techniques to minimize environmental impacts were assessed. The status of the technological developments for disposal and utilization methods are also discussed.

The findings developed during the study are in the categories of

- Quantification of solid wastes (paragraph 2.1)
- Characterization of untreated wastes (paragraph 2.2)
- Potential environmental impact (paragraph 2.3)
- Waste disposal (paragraph 2.4)
- Utilization (paragraph 2.5)
- Economics (paragraph 2.6)

and are summarized in this report.

TABLE 2. SUMMARY OF SOLID WASTES PRODUCED[a]

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
1	3.5	12,000	14	1000	Lime	90	0	80	1.2	222	210	432	448
2	3.5	12,000	14	500	Lime	90	0	80	1.2	115	108	223	232
3	3.5	12,000	14	25	Lime	90	0	80	1.2	6.4	6.1	12.5	13
4	3.5	12,000	14	1000	Limestone	80	0	80	1.2	222	229	451	468
5	3.5	12,000	14	500	Limestone	80	0	80	1.2	115	118	233	242
6	3.5	12,000	14	25	Limestone	80	0	80	1.2	6.4	6.7	13.1	14
7	3.5	12,000	14	1000	Na_2CO_3[b]	95[c]	0	80	1.2	222	206	428	444
8	3.5	12,000	14	500	Na_2CO_3[b]	95[c]	0	80	1.2	115	107	222	230
9	3.5	12,000	14	25	Na_2CO_3[b]	95[c]	0	80	1.2	6.4	6.0	12.4	13
10	3.5	12,000	14	1000	MgO[d]	5[f]	0	80	1.2	222	129[e]	42.2[e]	233
11	3.5	12,000	14	500	MgO[d]	5[f]	0	80	1.2	115	66.9[e]	21.8[e]	121
12	3.5	12,000	14	25	MgO[d]	5[f]	0	80	1.2	6.4	3.75[e]	1.22[e]	7

[a] Based on an average operating load factor of 50% (4380 hr/yr)

[b] Double-alkali process

[c] Regenerant (lime) utilization

[d] Magnesium-oxide process

[e] Sulfuric acid or sulfur produced, respectively

[f] Absorbent make-up

(continued)

TABLE 2. (Continued)

Case No.	Coal: % S	Coal: Btu/lb	Coal: % Ash	MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr: Ash	By-Products: Sulfur Sludge	By-Products: Total	Acre-Feet Required for Disposal, Annual
13	3.5	12,000	14	1000	Na_2SO_3[a]	5[c]	0	80	1.2	222	129[b]	42.2[b]	237
14	3.5	12,000	14	500	Na_2SO_3[a]	5[c]	0	80	1.2	115	66.9[b]	21.8[b]	122
15	3.5	12,000	14	25	Na_2SO_3[a]	5[c]	0	80	1.2	6.4	3.75[b]	1.22[b]	7
16	7.0	12,000	14	1000	Lime	90	0	90	1.2	222	472	694	719
17	7.0	12,000	14	500	Lime	90	0	90	1.2	115	244	359	372
18	7.0	12,000	14	25	Lime	90	0	90	1.2	6.4	13.7	20.1	21
19	7.0	12,000	14	1000	Limestone	80	0	90	1.2	222	515	737	764
20	7.0	12,000	14	500	Limestone	80	0	90	1.2	115	266	381	395
21	7.0	12,000	14	25	Limestone	80	0	90	1.2	6.4	15.0	21.4	22
22	0.8	13,500	6	500	None	N/A	0	None	1.2	43.8	N/A[d]	43.8	44
23	0.8	13,500	6	25	None	N/A	0	None	1.2	2.45	N/A	2.45	3
24	0.6	10,000	8	500	None	N/A	0	None	1.2	78.8	N/A	78.8	80
241	0.4	8,000	6	500	None	N/A	0	None	1.0	73.9	N/A	73.9	74

[a] Wellman-Lord process

[b] Sulfuric acid or sulfur produced, respectively

[c] Absorbent make-up

[d] Not applicable

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
25	0.6	10,000	8	25	None	N/A	0	None	1.2	4.42	N/A[a]	4.42	5
251	0.4	8,000	6	25	None	N/A	0	None	1.0	4.14	N/A	4.14	4
26	3.5	12,000	14	500	Lime	90	40	65	1.1	69	48	117[b]	121[b]
27	3.5	12,000	14	500	Limestone	80	40	65	1.1	71	50	121[b]	126[b]
28	3.5	12,000	14	1000	Lime	90	0	90	0.6	222	236	458	475
29	3.5	12,000	14	500	Lime	90	0	90	0.6	115	122	237	246
30	3.5	12,000	14	25	Lime	90	0	90	0.6	6.4	6.9	13.3	14
31	3.5	12,000	14	1000	Limestone	80	0	90	0.6	222	258	480	497
32	3.5	12,000	14	500	Limestone	80	0	90	0.6	115	133	248	257
33	3.5	12,000	14	25	Limestone	80	0	90	0.6	6.4	7.5	13.9	14
34	3.5	12,000	14	1000	Na_2CO_3[c]	95[d]	0	90	0.6	222	232	454	470
35	3.5	12,000	14	500	Na_2CO_3[c]	95[d]	0	90	0.6	115	120	235	243
36	3.5	12,000	14	25	Na_2CO_3[c]	95[d]	0	90	0.6	6.4	6.8	13.2	14

[a] Not applicable

[b] Does not include coal-wash tailings: 4.09×10^4 tons/yr (dry) and 28 acre-ft

[c] Double-alkali process

[d] Regenerant (lime) utilization

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/ 10^6 Btu	By-products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
37	3.5	12,000	14	1000	MgO[a]	5[c]	0	90	0.6	222	146[b]	47.5[b]	11
38	3.5	12,000	14	500	MgO[a]	5[c]	0	90	0.6	115	75.3[b]	24.6[b]	6
39	3.5	12,000	14	25	MgO[a]	5[c]	0	90	0.6	6.4	4.22[b]	1.38[b]	0.3
40	3.5	12,000	14	1000	Na_2SO_3	5[c]	0	90	0.6	222	146[b]	47.5[b]	11
41	3.5	12,000	14	500	Na_2SO_3	5[c]	0	90	0.6	115	75.3[b]	24.6[b]	6
42	3.5	12,000	14	25	Na_2SO_3	5[c]	0	90	0.6	6.4	4.22[b]	1.38[b]	0.3
43	7.0	12,000	14	1000	Lime	90	0	90	1.2	222	472	694	719
44	7.0	12,000	14	500	Lime	90	0	90	1.2	115	245	359	372
45	7.0	12,000	14	25	Lime	90	0	90	1.2	6.4	13.7	20.1	21
46	7.0	12,000	14	1000	Limestone	80	0	90	1.2	222	515	737	764
47	7.0	12,000	14	500	Limestone	80	0	90	1.2	115	266	381	395
48	7.0	12,000	14	25	Limestone	80	0	90	1.2	6.4	15.0	21.4	22
49	7.0	12,000	14	1000	Na_2CO_3[d]	95[e]	0	90	1.2	222	464	686	710
50	7.0	12,000	14	500	Na_2CO_3[d]	95[e]	0	90	1.2	115	240	355	367
51	7.0	12,000	14	25	Na_2CO_3[d]	95[e]	0	90	1.2	6.4	13.5	19.9	21

[a]Magnesium-oxide process

[b]Sulfuric acid or sulfur produced, respectively

[c]Absorbent make-up

[d]Double-alkali process

[e]Absorbent (lime) utilization

(continued)

TABLE 2. (Continued)

Case No.	Coal: % S	Coal: Btu/lb	Coal: % Ash	MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr: Ash	By-Products: Sulfur Sludge	By-Products: Total	Acre-Feet Required for Disposal, Annual
52	7.0	12,000	14	1000	MgO[a]	5[c]	0	90	1.2	222	291[b]	95[b]	22
53	7.0	12,000	14	500	MgO[a]	5[c]	0	90	1.2	115	150[b]	49.2[b]	11
54	7.0	12,000	14	25	MgO[a]	5[c]	0	90	1.2	6.4	8.43[b]	2.75[b]	1
55	7.0	12,000	14	1000	Na_2SO_3[d]	5[c]	0	90	1.2	222	291[b]	95[b]	22
56	7.0	12,000	14	500	Na_2SO_3[d]	5[c]	0	90	1.2	115	150[b]	49.2[b]	11
57	7.0	12,000	14	25	Na_2SO_3[d]	5[c]	0	90	1.2	6.4	8.43[b]	2.75[b]	0.6
58	0.8	10,000	8	500	Lime	90	0	90	0.2	79	33	112	116
581	0.8	8,000	6	500	Lime	90	0	90	0.2	74	42	116	120
59	0.8	10,000	8	25	Lime	90	0	90	0.2	4.42	1.87	6.29	7
591	0.8	8,000	6	25	Lime	90	0	90	0.2	4.14	2.34	6.48	7
60	0.8	10,000	8	500	Limestone	80	0	90	0.2	78	37	115	120
601	0.8	8,000	6	500	Limestone	80	0	90	0.2	74	46	120	124
602	0.8	8,000	6	500	Limestone	80	0	40	1.2	74	20	94.2	98
603	0.8	10,000	8	500	Limestone	80	0	25	1.2	79	10	89	92
6001	3.5	12,000	14	200	Limestone	80	0	80	1.2	47	48	95.4	99

[a]Magnesium-oxide process

[b]Sulfuric acid or sulfur produced, respectively

[c]Absorbent make-up

[d]Wellman-Lord process

(continued)

TABLE 2. (Continued)

Case No.	Coal: % S	Coal: Btu/lb	Coal: % Ash	MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr: Ash	Sulfur Sludge	Total	Acre-Feet Required for Disposal, Annual
61	0.8	10,000	8	25	Limestone	80	0	90	0.2	4.41	2.05	6.46	7
611	0.8	8,000	6	25	Limestone	80	0	90	0.2	4.14	2.56	6.70	7
62	0.8	10,000	8	500	Lime	90	0	70	0.5	79	26	105	109
621	0.8	8,000	6	500	Lime	90	0	75	0.5	74	35	109	113
63	0.8	10,000	8	25	Lime	90	0	70	0.5	4.41	1.46	5.87	6
631	0.8	8,000	6	25	Lime	90	0	75	0.5	4.14	1.95	6.09	6
64	0.8	10,000	8	500	Limestone	80	0	70	0.5	79	28	107	111
641	0.8	8,000	6	500	Limestone	80	0	75	0.5	74	38	112	116
65	0.8	10,000	8	25	Limestone	80	0	70	0.5	4.41	1.59	6.00	6
651	0.8	8,000	6	25	Limestone	80	0	75	0.5	4.14	2.13	6.27	7
66	3.5	12,000	14	500	Lime	90	40	85	0.5	69	63	132[a]	137[a]
661	3.5	12,000	14	500	Limestone	80	0	91.5	0.5	115	135	250	260
67	3.5	12,000	14	25	Lime	90	40	85	0.5	3.87	3.52	7.39[b]	8[b]
68	3.5	12,000	14	500	Limestone	80	40	85	0.5	69	69	138[a]	143[a]

[a]Does not include coal wash tailings: 4.09×10^4 tons/yr (dry) and 28 acre-ft

[b]Does not include coal wash tailings: 2.29×10^3 tons/yr (dry) and 1.5 acre-ft

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
69	3.5	12,000	14	25	Limestone	80	40	85	0.5	3.87	3.84	7.71[a]	8[a]
70	7.0	12,000	14	500	Lime	90	40	95	0.3	30	140	170[b]	176[b]
701	7.0	12,000	14	500	Lime	90	40	92.5	0.5	30	136	166[b]	172[b]
702	7.0	12,000	14	500	Limestone	80	0	96	0.5	115	284	399	414
71	7.0	12,000	14	500	Limestone	80	40	95	0.3	30	153	183[b]	190[b]
711	7.0	12,000	14	500	Limestone	80	40	92.5	0.5	30	149	179[b]	185[b]
712	7.0	12,000	14	500	Limestone	90	40	92.5	0.5	30	136	166[b]	172[b]
713	7.0	12,000	14	500	Limestone	80	30	93.5	0.5	51	180	231[c]	240[c]
714	7.0	12,000	14	500	Limestone	80	20	94.5	0.5	72	214	286[d]	296[d]
715	7.0	12,000	14	500	Limestone	80	40	92.0	0.5	50	148	198[e]	206[e]
716	7.0	12,000	14	500	Limestone	80	40	92.0	0.5	69	149	218[f]	226[f]

[a]Does not include coal wash tailings: 2.29 × 10^3 tons/yr (dry) and 1.5 acre-ft

[b]Does not include coal wash tailings: 8.58 × 10^4 tons/yr (dry) and 58 acre-ft

[c]Does not include coal wash tailings: 6.43 × 10^4 tons/yr (dry) and 43 acre-ft

[d]Does not include coal wash tailings: 4.28 × 10^4 tons/yr (dry) and 29 acre-ft

[e]Does not include coal wash tailings: 6.29 × 10^4 tons/yr (dry) and 42 acre-ft

[f]Does not include coal wash tailings: 4.09 × 10^4 tons/yr (dry) and 28 acre-ft

TABLE 3. CROSS REFERENCE OF ALTERNATIVE STANDARDS AND MODEL PLANTS WITH STUDY CASE NUMBERS

Alternative Standards and Model Plant Systems	Plant Sizes, MW	FGD Systems	Case Numbers
1. Meets existing NSPS of 1.2 lb $SO_2/10^6$ Btu heat input			
a. 80% SO_2 removal, plant burning typical coal with 3.5% sulfur, 12,000 Btu/lb, 14% ash	1000 500 25	Lime Limestone Double alkali Magnesium oxide Wellman-Lord	1 - 3 4 - 6 7 - 9 10 - 12 13 - 15
b. 90% SO_2 removal, plant burning coal with 7% sulfur, 12,000 Btu/lb, 14% ash	1000 500 25	Lime Limestone	16 17 18 19 20 21
c. No FGD, low sulfur coal, typical eastern plant, 0.8% sulfur, 13,500 Btu/lb, 6% ash	500 25	None	22 23
d.1 No FGD, low-sulfur coal, typical western plant, 0.6% sulfur, 10,000 Btu/lb, 8% ash	500 25	None	24 25
d.2 No FGD, low-sulfur coal, typical western plant, 0.4% sulfur, 8000 Btu/lb, 6% ash	500 25	None	241 251
e. 40% sulfur removal by coal washing of a 3.5% sulfur coal, followed by a 65% SO_2 removal by FGD. Prewash coal: 12,000 Btu/lb, 14% ash	500	Lime Limestone	26 27

(continued)

TABLE 3. (Continued)

Alternative Standards and Model Plant Systems	Plant Sizes, MW	FGD Systems	Case Numbers
2. 90% SO_2 removal by FGD			
a. 1 Plant burning typical 3.5% sulfur coal, 12,000 Btu/lb, 14% ash	1000	Lime	28 - 30
	500	Limestone	31 - 33
	25	Double alkali	34 - 36
		Magnesium oxide	37 - 39
		Wellman-Lord	40 - 42
a. 2 Plant burning 7% sulfur coal, 12,000 Btu/lb, 14% ash	1000	Lime	43 - 45
	500	Limestone	46 - 48
	25	Double alkali	49 - 51
		Magnesium oxide	52 - 54
		Wellman-Lord	55 - 57
b. 1 Western plant burning typical 0.8% sulfur western coal, 10,000 Btu/lb, 8% ash	500	Lime	58 - 59
	25	Limestone	60 - 61
b. 2 Western plant burning typical 0.8% sulfur western coal, 8000 Btu/lb, 6% ash	500	Lime	581 - 591
	25	Limestone	601 - 611
3. Meets more stringent standard of 0.5 lb $SO_2/10^6$ Btu heat input			
a. 1 70% SO_2 removal on 0.8% sulfur coal, 10,000 Btu/lb, 8% ash	500	Lime	62 - 63
	25	Limestone	64 - 65

(continued)

TABLE 3. (Continued)

Alternative Standards and Model Plant Systems	Plant Sizes, MW	FGD Systems	Case Numbers
3. (continued)			
a.2 75% SO_2 removal on 0.8% sulfur coal, 8000 Btu/lb, 6% ash	500 25	Lime Limestone	621 - 631 641 - 651
b.1 40% sulfur removal by coal washing of a 3.5% sulfur coal, followed by a 85% SO_2 removal by FGD. Pre-wash coal: 12,000 Btu/lb, 14% ash	500 25	Lime Limestone	66 - 67 68 - 69
b.2 40% sulfur removal by coal washing of a 7% sulfur coal, followed by a 95% SO_2 removal by FGD. Pre-wash coal: 12,000 Btu/lb, 14% ash	500	Lime Limestone	70 71

2.1 QUANTIFICATION OF SOLID WASTES

The amount of solid waste or by-products generated by flue gas desulfurization (FGD) systems is discussed with regard to the following parameters:

- The present new-source performance standard (1.2 lb $SO_2/10^6$ Btu)
- Effect of a 0.5 lb $SO_2/10^6$ Btu standard
- Effect of 90-percent SO_2 scrubbing
- Coal washing
- Plant size
- Coal sulfur content
- Scrubbing processes
- Nationwide projections to 1998

It should be noted that, for the various study cases, the coal properties are as summarized in Table 4. Therefore, the results represent typical values encompassing the range of variations for eastern and western coals. Assumptions made concerning the basic steam generating plant characteristics and FGD process characteristics are shown in Tables 5 and 6.

2.1.1 Current Federal Standards: 1.2 lb $SO_2/10^6$ Btu

The current standard of performance limits SO_2 emissions to 1.2 lb/10^6 Btu of heat input to the boiler. To achieve this emission limit with a typical 3.5-percent-sulfur eastern coal, 80 percent SO_2 removal by scrubbing is required. The amount of solid waste (ash and sludge) produced by a 500-MW power plant with a limestone scrubbing system (case 5) is 233,000 dry tons/year or 242 acre-feet by volume. This is the base case against which other variations in solid waste are considered. Figure 1 is a graphical presentation of the variations for a 500-MW plant.

TABLE 4. COAL CHARACTERISTICS USED IN STUDY

A. Typical Coals

Coal Type	Percent Sulfur	Heating Value, Btu/lb	Percent Ash
1. Typical eastern	3.5	12,000	14
2. High sulfur	7.0	12,000	14
3. Typical western low-sulfur			
a. High Btu	0.8	10,000	8
b. Low Btu	0.8	8,000	6
4. Eastern low-sulfur	0.8	13,500	6
5. Western coal meeting or bettering current NSPS.			
a. High Btu	0.6	10,000	8
b. Low Btu	0.4	8,000	6

B. Effect of Coal Washing

Coal Type	Sulfur Removed, Percent	Percent Sulfur		Heating Value, Btu/lb		Percent Ash	
		Unwashed	Washed	Unwashed	Washed	Unwashed	Washed
1. Typical eastern	40	3.5	2.1	12,000	13,200	14	9.2
2. High sulfur	40	7.0	4.2	12,000	13,200	14	4.0

TABLE 5. BASIC STEAM GENERATING PLANT CHARACTERISTICS USED IN STUDY

1. Energy Conversion Factors

   a. 1000 MW 8,700 Btu/kWh
   b. 500 9,000
   c. 25 10,080

2. Average Power Plant Operating Load Factor

   a. 50 percent
   b. 30-year operating lifetime

TABLE 6. BASIC SCRUBBER AND FGD PROCESS CHARACTERISTICS USED IN STUDY

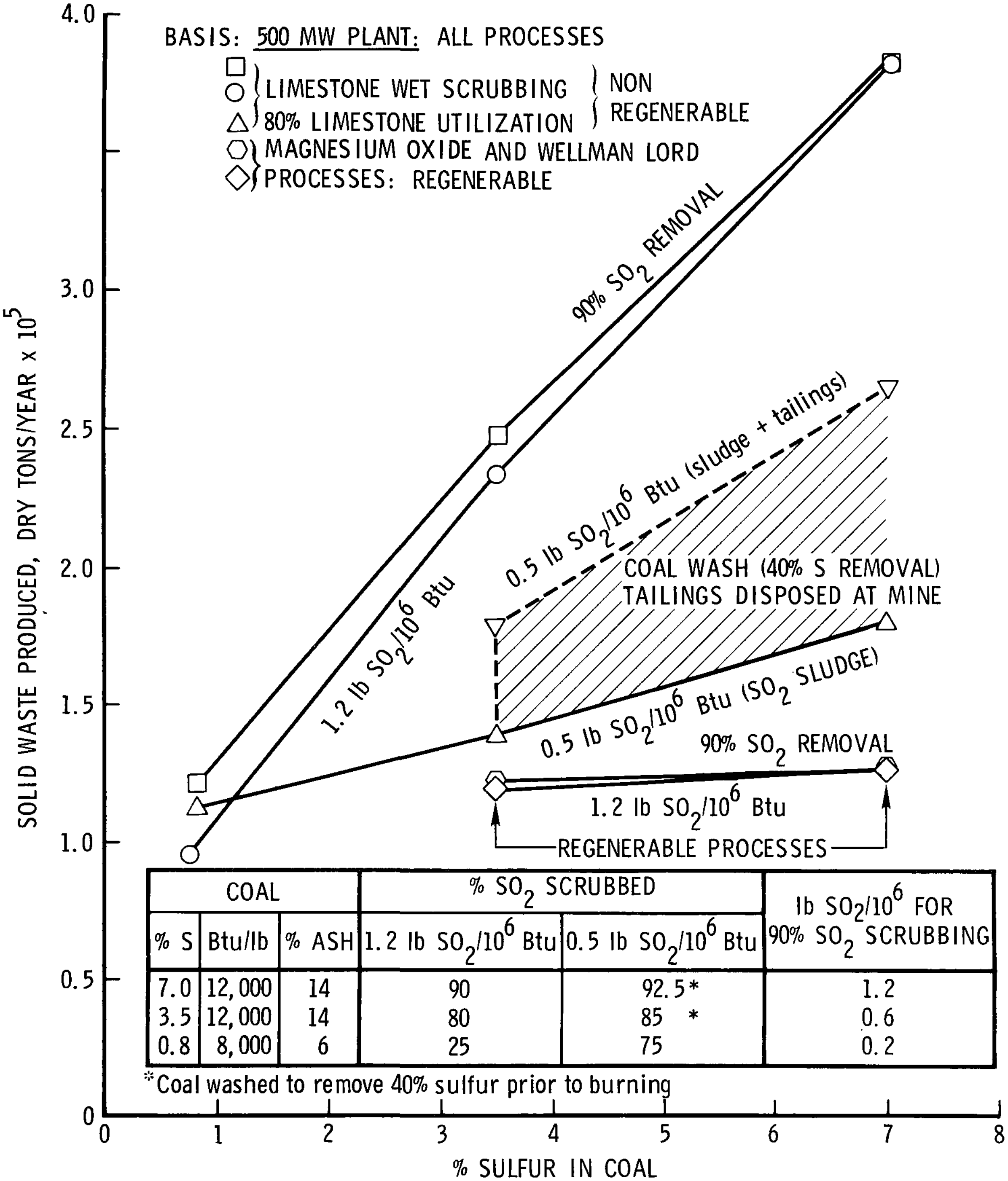
1. Absorbent Utilization

   a. Non-Regenerable
      (1) Lime 90%
      (2) Limestone 80%
      (3) Lime in double-alkali process 95%, with 3% Na_2CO_3 make-up[a]

   b. Regenerable
      (1) Magnesium oxide[b]
         (a) 3% absorbent make-up (MgO)
         (b) 95% separation efficiency
      (2) Wellman-Lord[b]
         (a) 3% absorbent make-up (Na_2SO_3)
         (b) 95% separation efficiency

[a]Percent (molar basis) of the absorbent lost in the regeneration process. Percentage based on the fraction of the amount of absorbent required to scrub the SO_2.

[b]Percent (molar basis) of the absorbent lost in the absorption, regeneration, and separation processes, including: 3% (absorbent equivalent) lost in the absorption-regeneration process due to its inefficiency and an additional 5% (absorbent equivalent) lost in the separation process due to its inefficiency (see Figure 3 for a schematic of the magnesium oxide and Wellman-Lord processes).



COAL			% SO_2 SCRUBBED		$lb\ SO_2/10^6$ FOR 90% SO_2 SCRUBBING
% S	Btu/lb	% ASH	1.2 lb $SO_2/10^6$ Btu	0.5 lb $SO_2/10^6$ Btu	
7.0	12,000	14	90	92.5*	1.2
3.5	12,000	14	80	85 *	0.6
0.8	8,000	6	25	75	0.2

*Coal washed to remove 40% sulfur prior to burning

Figure 1. Quantities of waste, including ash, produced by new plants for alternative standards

With a 7-percent-sulfur coal, 90 percent SO_2 removal by scrubbing is required. In this case (case 20) a 500-MW power plant with a limestone scrubbing system would produce 381,000 tons/year of ash and sludge or 395 acre-feet by volume. A coal with 0.6 percent sulfur and at a heating value of at least 10,000 Btu/lb is needed to avoid the necessity of a FGD system (case 24).

2.1.2 Effect of a 90 Percent SO_2 Removal Requirement

The quantities of solid waste or by-products resulting from 90-percent removal of SO_2 are presented in cases 28-61 and 581-611. The solid waste from a 500-MW plant burning 3.5-percent-sulfur coal with 90 percent SO_2 removal by limestone scrubbing (case 32) is increased 6 percent above the base case (case 5).

2.1.3 Effect of a 0.5 lb $SO_2/10^6$ Btu Standard

A performance standard of 0.5 lb $SO_2/10^6$ Btu heat input would necessitate the scrubbing of virtually all coal burned.

The quantities of solid waste or by-products resulting from a standard of 0.5 lb $SO_2/10^6$ Btu heat input are presented in cases 62-71 and 621-716. A 500-MW plant burning 3.5-percent-sulfur coal would require 91.5-percent sulfur removal by scrubbing to meet this emission limit. The solid waste from this system is only slightly greater than for the 90-percent removal requirement.

2.1.4 Effects of Coal Washing on Quantities of Waste Produced

Only the inorganic fraction, primarily from pyrite (FeS_2) of the sulfur content can be removed by coal washing. Organic sulfur is an integral part of the coal matrix and cannot be removed by physical separation. Organic sulfur is 30 to 70 percent of the total sulfur for most coals. It appears that the maximum sulfur removal that can be achieved by physically washing the coal is limited to about 40 percent.

Although coal washing would not eliminate the need for flue gas scrubbing, the required SO_2 removal could be reduced from 80 to 60 percent for the current standard (1.2 lb $SO_2/10^6$ Btu) and from 91.5 to 85 percent for a standard of 0.5 lb $SO_2/10^6$ Btu. Scrubber sludge and ash at a power plant burning washed coal (40 percent sulfur removed) would be about 56 percent (and wash tailings would be another 16 percent) of the amount of sludge, including ash, from a plant burning unwashed coal.

Iron combined with the sulfur and other ash constituents in the coal are removed by washing, reducing the ash in the washed coal considerably; i.e., 14 percent to 9.2 percent for a 3.5-percent-sulfur coal (Table 4). Although a loss in heating value is experienced in coal washing, it is accompanied by a greater proportionate loss in weight (inerts) and, therefore, the heat content per pound of washed coal increases. Based on sulfur reduction data, a nominal upgrading of 10 percent was used in the heat content after washing; i.e., the removal of 40 percent sulfur by washing of a 12,000-Btu/lb coal increased its heating value to 13,200 Btu/lb.

Although coal washing could apparently reduce solid waste (sludge plus ash) at the power plant about 44 percent, consideration must be given to:

a. Disposal of wash tailings (assumed to take place at the mine)

b. Disposal or treatment of the wash process water

c. The increased cost of washed coal over run-of-mine coal

d. The energy required to wash the coal

e. The cost tradeoff of using flue gas desulfurization (FGD) alone versus coal washing plus FGD.

These aspects of coal washing are covered in this and other reports prepared as part of the EPA review process.

If a 3.5-percent-sulfur coal is physically washed to remove 40 percent of the pyritic sulfur, sulfur removal by scrubbing could be reduced to 65 percent to meet the present NSPS (1.2 lb $SO_2/10^6$ Btu). The quantity of scrubber sludge generated in case 27 is 48 percent below case 5, while tailings [pyrites (FeS_2) and ash] at the wash site amount to 21 percent of the waste produced in case 5.

If 40 percent of the sulfur is washed from a 3.5-percent-sulfur coal, 85-percent-removal by scrubbing is required to meet a standard of 0.5 lb $SO_2/10^6$ Btu. The solid waste (sludge, ash, and tailings) produced (case 68) would be 77 percent of that in case 5.

2.1.5 Effect of Plant Size on Quantities of Waste Produced

The wastes generated by power plants of different sizes are not directly proportioned to size (Figure 2). This is the result of higher operating efficiencies achieved by the larger plants. Therefore, a single 1000-MW plant produces wastes totalling approximately 96.5 percent of two 500-MW plants, and two 250-MW units produce about 1.8 percent more waste than one 500-MW unit. Therefore, in the range of most utility steam generating plants; i.e., 200 to 1000 MW, the amount of waste generated and disposal area required is within +2 to -4 percent of that produced by equivalent numbers of 500-MW units. This observation

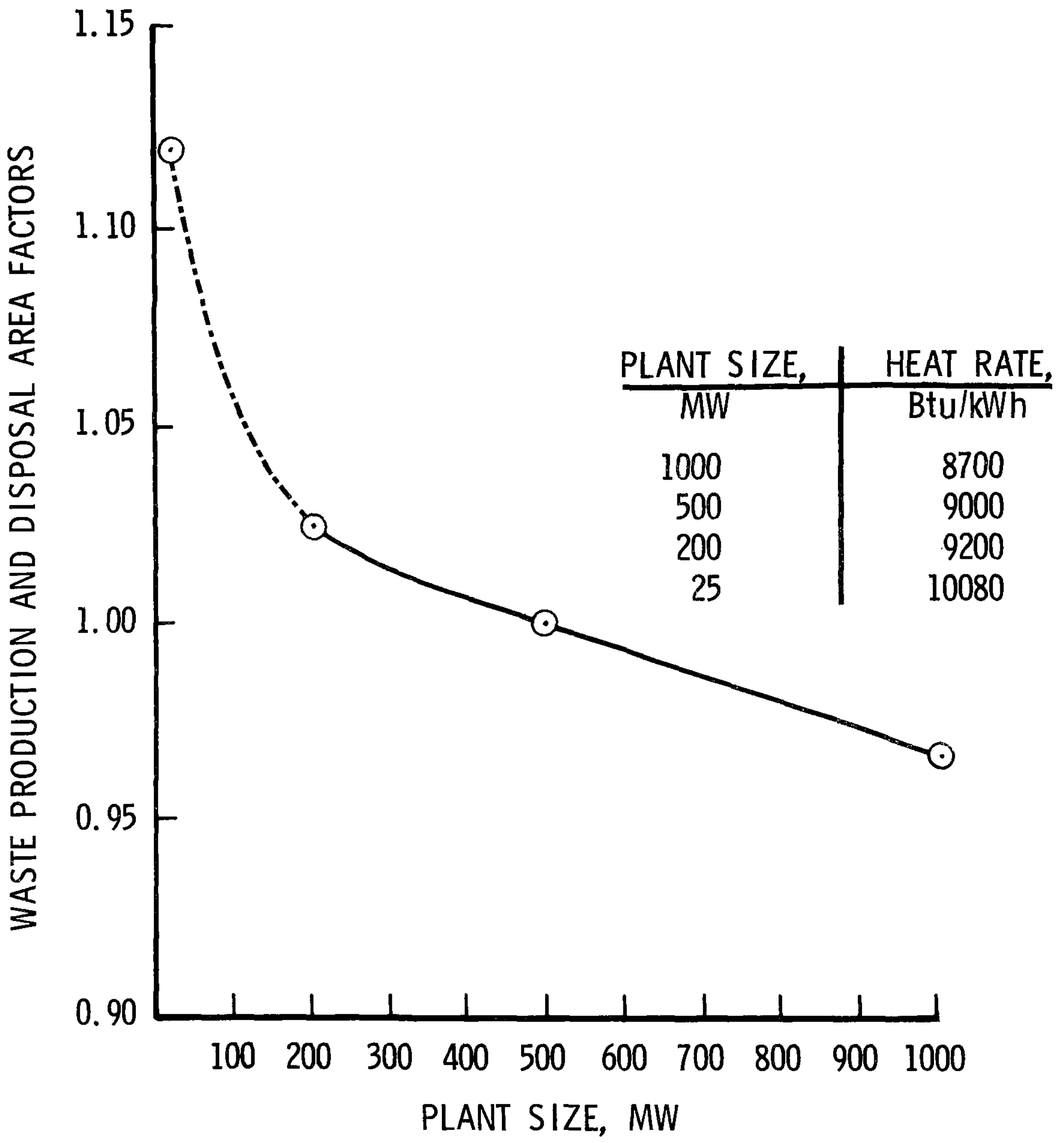


Figure 2. Effect of power plant size and equivalent capacities on the amount of solid wastes produced (includes ash).

is important in the nationwide assessment of total quantities of waste produced because it substantiates the assumption that all the installed generating capacity can be characterized by an equivalent 500-MW plant and the study does not require a plant-by-plant summation.

2.1.6 Effects of Coal Sulfur on Quantities of Waste Produced

The coals specified for the study (3) were typical. The eastern coals contained 3.5 percent sulfur and high sulfur (7.0 percent), both containing 14 percent ash and a heat content of 12,000 Btu/lb. The western coals contained 0.8 percent sulfur[1] and included both high- and low-Btu: 10,000 Btu/lb (8-percent ash) and 8,000 Btu/lb (6-percent ash), respectively.

Since sulfur content is the primary variable, its influence on the quantities of waste requiring disposal as a function of both current and more-stringent NSPS federal standards is depicted in Figure 1. Limestone scrubber wastes are represented as typical of nonregenerable processes; the quantities being about 6 percent more than lime or double alkali. Because of the differences in ash and heat content, boiler heat rates, and SO_2 scrubbing requirements, the quantities and disposal area are not directly proportional to the sulfur content. However, as a first approximation, they may be estimated as being linearly related.

The waste quantities resulting from the application of regenerable processes are relatively unaffected for the 3.5- and 7.0-percent sulfur cases studied. The wastes are primarily ash recovered from the combustion of the coal; both coals containing 14 percent ash. The slightly higher quantity of wastes for a 7-percent sulfur coal is attributed to the slightly higher quantities of absorbent make-up showing up in the waste because of the larger quantities of SO_2 being scrubbed (the percent absorbent make-up was held constant at 3 percent).

The low-Btu western coal (8000 Btu/lb) was used in all calculations for western coal because it produces only about 5 percent more wastes than the higher (10,000 Btu/lb) coal (Table 7). In general, these two coals represent the high and low extremes expected for western coals. Because of

[1]The coal sulfur values used are base-case averages. Any coals that may contain these average sulfur contents would meet the NSPS (1.2 lb/10^6 Btu) on the average if subjected to appropriate scrubbing conditions, but may violate it occasionally because of variations in the coal. This factor does not impact the values for sludge quantities derived herein.

TABLE 7. EFFECT OF HIGH- AND LOW-BTU WESTERN COAL ON WASTE GENERATED AND DISPOSAL AREA REQUIRED

A. 90% SO_2 Removal, Wet Limestone Scrubbing, 0.8% Sulfur Coal

Case No.	Coal		Emissions, lb $SO_2/10^6$ Btu	Scrubber Dry Waste[a], tons x 10^5/yr	Disposal Area Req'd[b], acres	Quantity and Volume Factor
	Btu/lb	% Ash				
60	10,000	8	0.16	1.154	150	0.965
601	8,000	6	0.20	1.196	155	1.000

B. Emissions = 1.2 lb $SO_2/10^6$ Btu, Wet Limestone Scrubbing, 0.8% Sulfur Coal

Case No.	Coal		% SO_2 Scrubbed	Scrubber Dry Waste[a], tons x 10^5/yr	Disposal Area Req'd[b], acres	Quantity and Volume Factor
	Btu/lb	% Ash				
603	10,000	8	25	0.890	115	0.945
602	8,000	6	40	0.942	122	1.000

[a]500-MW plant, 50-percent operating load factor, includes ash.

[b]50-percent solids, 30 years, 50-percent load factor, 30 ft deep.

this small difference in quantities produced as a result of burning these extremes of western coal, no attempt was made in the nationwide compilation to estimate the fraction of each that may be burned in the future, and the low-Btu coal was used in all of the projections.

In reviewing the effects of the use of western coal, the low-Btu coal (0.8% sulfur, 8000 Btu/lb, 6% ash) produces scrubber waste quantities of 40 to 50 percent of the corresponding limestone-scrubbed 3.5-percent coal.

2.1.7 Effects of the Scrubbing Process on Quantities of Waste Produced

The basic types of wet scrubbing processes examined were the nonregenerable and regenerable processes. The nonregenerable produce a calcium sulfite/sulfate waste that is discarded, while in the regenerable the SO_2 in the flue gas is absorbed and subsequently released as SO_2 in the regeneration of absorbent. The SO_2 may be processed further to form sulfuric acid or elemental sulfur.

The types of nonregenerable processes studied were those using lime and limestone absorbents. The double-alkali process uses a sodium carbonate (Na_2CO_3) absorbent, which is then regenerated by lime. The waste produced is similar to that produced by the direct lime scrubbing except that it contains Na_2CO_3 that is equivalent to the amount of make-up required (3 percent).

Figure 3 provides the quantities of waste produced from the five processes as a result of applying the current and alternative federal NSPS standards with 3.5-percent coal.

2.1.7.1 Nonregenerable Processes --

Use of the limestone wet scrubbing processes results in approximately 6 percent more scrubber waste than the lime or double-alkali processes. The slightly lower quantities are primarily the result of the higher lime utilization in the latter two processes. An absorbent utilization of 80 percent was considered typical for limestone, whereas 90 percent was used for the lime process and 95-percent regenerative efficiency for lime in the double-alkali application.

2.1.7.2 Regenerable Processes --

The wastes produced as a result of applying the regenerable processes are approximately 50 percent of those from the nonregenerable. The wastes are primarily ash and are nearly independent of the process. A regenerative-separation efficiency of 95 percent was assumed. Therefore, the waste was assumed to include sulfate of magnesium and sodium equivalent to 5 percent of the magnesium sulfite ($MgSO_3$) or sodium bisulfite ($NaHSO_3$) which was assumed as not being regenerated.

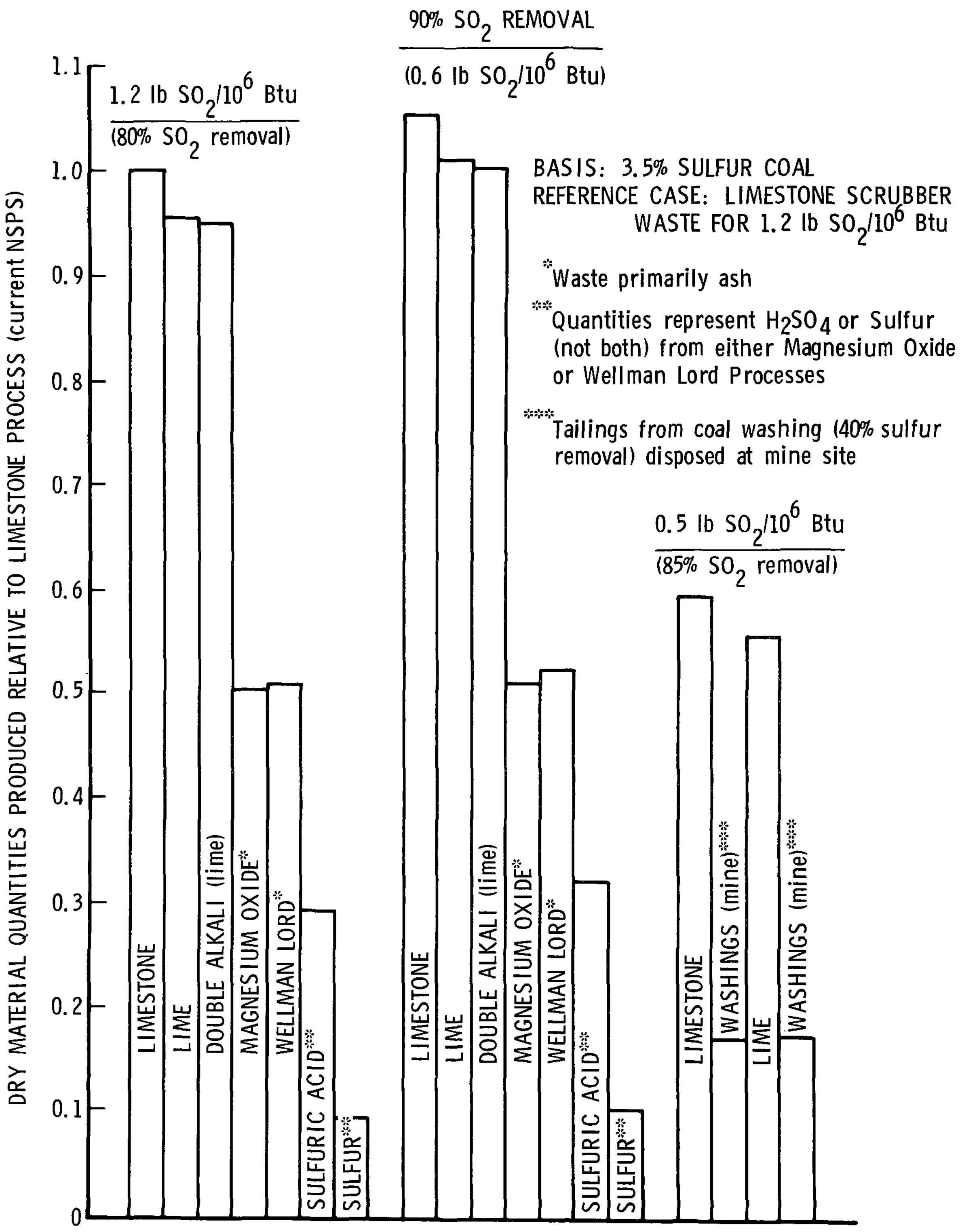


Figure 3. Solid waste, including ash, and useable by-products (nonregenerable and regenerable systems)

2.1.8 Nationwide Projections to 1998

Applying a 90-percent SO_2 removal requirement to all new plants in 1980 will result in the production of approximately 173 million short tons (dry) of wastes in the year 1998 (Table 8). The actual quantities of untreated wastes that would require disposal are approximately double that quantity, assuming that they contain approximately 50-percent moisture. This results in a volume of 179, 000 acre-feet (wet) produced in those plants in 1998. The estimate is based on the assumption that eastern (3.5 percent sulfur) coal will be burned in 55 percent of the new boiler installations and 45 percent will consume western coal (0.8 percent sulfur (Table 1).

These values were computed on the basis that 45 percent of the coal burned on a nationwide basis is western coal (4). However, application of more stringent standards would possibly affect the percentage used. Since predictions of the impacts of these standards on western coal usage were not available, the waste quantities resulting from the use of discrete fractions of eastern coal were computed and are summarized in Figure 4. For example, if the amount of coal from eastern sources were increased from 55 to 70 percent (western coal use reduced from 45 to 30 percent), the tonnages of eastern waste would increase from 73 to 83 percent of the nationwide total,for 90 percent SO_2 removal.

The wastes to be disposed of at the generating plants in the year 1998 to meet a 0.5 lb SO_2 standard are 118 million short tons (dry) (see Figure 5). This considers that the eastern coal (3.5 percent sulfur) comprises 55 percent of the total coal used nationally and is washed to remove 40 percent of its sulfur.

Comparable quantities, if the current NSPS were maintained in 1998, are 156 million short tons (dry). Volumes produced are proportional to those given above.

The volume in acre-feet of nonregenerable scrubber wastes, primarily ash, produced during a 30-year steam generating plant lifetime is shown in Table 9 for 1000-, 500-, and 25-MW plants burning eastern and western coal, and assuming that current and two alternative emission standards apply.

2.2 CHARACTERIZATION OF UNTREATED WASTES

The published data available on the chemical and physical characteristics of untreated sludges produced in eastern and western plants using lime, limestone, and double-alkali systems are provided in this report. The waste streams from regenerable systems are primarily fly ash, which is discussed briefly in Volume II, and purged liquid effluents, the properties of which are not discussed in this report. Properties discussed are: solids composition and concentrations in the liquor of major species and trace elements; pH; total dissolved solids; leaching characteristics; water retention; bulk density; compressive strength; permeability, viscosity; compaction; and porosity. All properties are widely variant depending on parameters such as types of: coal, absorbent, scrubber, scrubber operating parameters, and ash collection. The characteristics included in this report are summarized from various sources. Key items from that summary are given in the following pages.

TABLE 8. QUANTITY AND VOLUME OF NONREGENERABLE SO_2 SCRUBBER WASTES PRODUCED IN 1998 BY NEW COAL-BURNING PLANTS CONSTRUCTED BETWEEN 1978 AND 1998[a]

NSPS Alternatives	Dry Waste Quantities[b, c, d] (short tons)	Total Wet Volume[e] (acre-ft) For Sludge Produced in 1998
90% SO_2 Removal	172.8×10^6	1.79×10^5
0.5 lb $SO_2/10^6$ Btu[f]	118.3×10^6	1.22×10^5
1.2 lb $SO_2/10^6$ Btu	156.2×10^6	1.62×10^5

[a]Data derived from Appendix B, Vol II.

[b]Quantities produced, based on:
- 500-MWe average plant size.
- 50-percent average operating load factor.
- Limestone absorbent, 80% utilization.
- Waste includes ash.
- Eastern[c] coal burned: 55% of total.
- Western[d] coal burned: 45% of total.

[c]Eastern coal: 3.5% S, 12,000 Btu/lb, 14% ash

[d]Western coal: 0.8% S, 8000 Btu/lb, 6% ash

[e]Based on sludge containing 50% solids.

[f]40% of sulfur in eastern coal removed by washing prior to burning, 85% SO_2 from eastern plants removed by scrubbing, and 40% SO_2 from western plants removed by scrubbing.

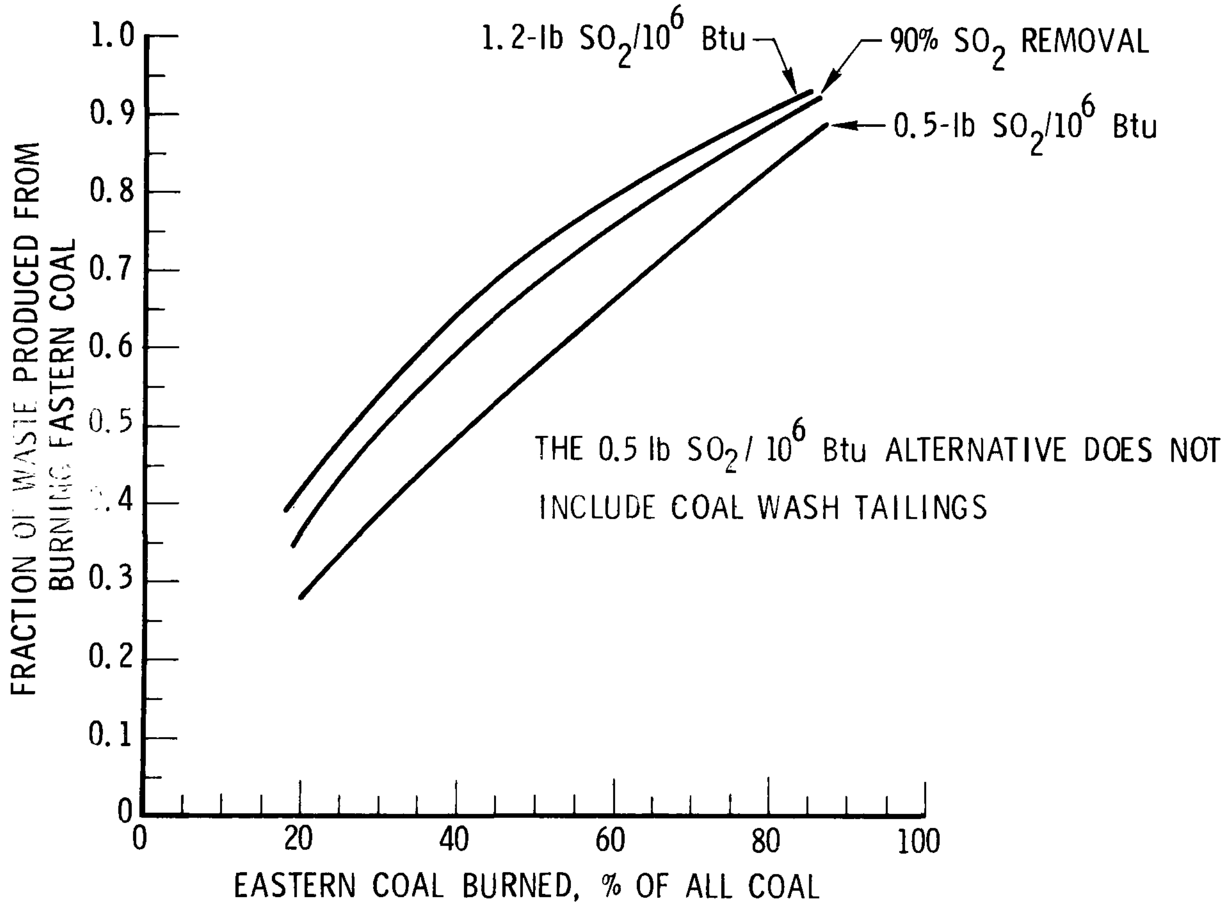


Figure 4. Effect of eastern coal use on the fraction of waste quantities, including ash, produced nationally by new plants

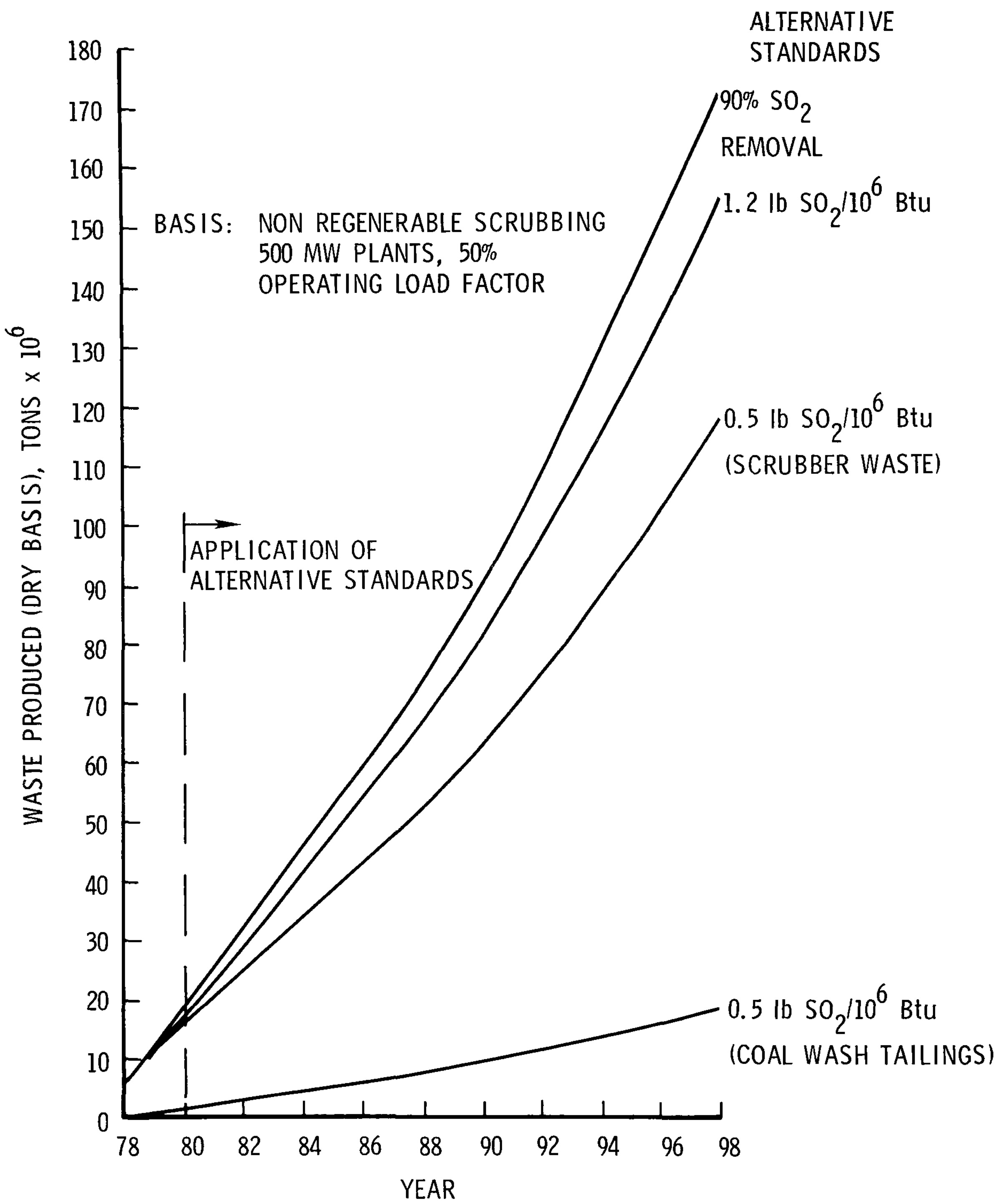


Figure 5. Total annual waste quantities, including ash, produced nationwide by all new plants coming on line beginning in 1978

TABLE 9. VOLUME (ACRE-FEET) OF NONREGENERABLE SO_2 SCRUBBER WASTES PRODUCED IN A 30-YEAR[a] GENERATING PLANT LIFETIME

Plant Size, MW	Eastern Coal[b]				Western Coal[b]		
	NSPS Alternatives						
	1.2 lb SO_2 per 10^6 Btu[c]	90% SO_2 Removal[d]	0.5 lb SO_2 per 10^6 Btu[e]		1.2 lb SO_2 per 10^6 Btu[f]	90% SO_2 Removal[g]	0.5 lb SO_2 per 10^6 Btu[h]
			Sludge	Coal wash Tailings			
1000	14,030	14,920	NR	--	NR	NR	NR
500	7,260	7,720	4280	830	2930	3720	3480
25	405	430	240	45	NR	210	195

[a] 50-percent average operating load factor; limestone absorbent, 80% utilization; waste includes ash.

[b] Eastern coal: 3.5% S, 12,000 Btu/lb, 14% ash; Western coal: 0.8% S, 8000 Btu/lb, 6% ash.

[c] 80% SO_2 removal by scrubbing

[d] 0.6 lb $SO_2/10^6$ Btu

[e] 40% sulfur removal by coal washing, 85% SO_2 removal by scrubbing

[f] 40% SO_2 removal by scrubbing

[g] 0.2 lb $SO_2/10^6$ Btu

[h] 75% SO_2 removal by scrubbing

NR - Not required (see Table 3)

2.2.1 Effect of Scrubbing Process Variables on Sludge Chemistry

Process variables affect the concentrations of soluble chemical species in system liquors through changes in process chemistry:

a. The concentration of major chemical species and trace elements in flue gas desulfurization (FGD) waste decreases as the sludge passes from the scrubber to the clarifier underflow for disposal. Concentrations of sludge constituents for disposal are given in Table 10.

b. The pH in the scrubber is responsible for trace elements leaching from fly ash; the pH of the system downstream of the scrubber does not affect the concentration of these trace elements in the scrubber liquor.

2.2.2 Trace Element Content

The trace element content in FGD sludge is a direct function of the combustion products of coal:

a. A direct correlation exists between the trace element content of coal and the trace element content in FGD wastes (see Figure 6).

b. Fly ash represents the major source of trace elements in all but the most volatile elemental species (e.g., mercury and selenium) that are scrubbed from flue gases.

2.2.3 Physical Properties

The behavior of FGD wastes in a disposal site is a function of the unique physical properties of the wastes:

a. The permeability coefficients of untreated FGD wastes are typically 10^{-4} cm/sec and of treated wastes are 10^{-5} cm/sec or less [based upon sample materials fixed by Chemfix, Dravo, and IU Conversion Systems (IUCS)].

b. Pumpability (<20 poise) was found for untreated wastes having a solids content that ranged between 32 and 70 percent.

c. Bulk densities of untreated wastes as a function of dewatering techniques and material characteristics varied between 1.30 and 1.87 g/cc.

TABLE 10. RANGE OF CONCENTRATIONS OF CHEMICAL CONSTITUENTS IN FGD SLUDGES FROM LIME, LIMESTONE, AND DOUBLE-ALKALI SYSTEMS

Scrubber Constituent	Sludge Concentration Range[a]			
	Liquor, mg/ℓ (except pH)[b]		Solid, mg/kg[c]	
Aluminum	0.03	- 2.0	-	-
Arsenic	<0.004	- 1.8	0.6	- 52
Beryllium	<0.002	- 0.18	0.05	- 6
Cadmium	0.004	- 0.11	0.08	- 4
Calcium	180	- 2600	105,000	- 268,000
Chromium	0.015	- 0.5	10	- 250
Copper	<0.002	- 0.56	8	- 76
Lead	0.01	- 0.52	0.23	- 21
Magnesium	4.0	- 2750	-	-
Mercury	0.0004	- 0.07	0.001	- 5
Potassium	5.9	- 100	-	-
Selenium	<0.0006	- 2.7	2	-17
Sodium	10.0	- 29,000	-	- 48,000
Zinc	0.01	- 0.59	45	- 430
Chloride	420	- 33,000	-	- 9,000
Fluoride	0.6	- 58	-	-
Sulfate	600	- 35,000	35,000	- 473,000
Sulfite	0.9	- 3500	1600	- 302,000
Chemical oxygen demand	<1	- 390	-	-
Total dissolved solids	2800	- 92,500	-	-
pH	4.3	- 12.7	-	-

[a]Data derived from Appendix D, Vol II.

[b]Liquor analyses were conducted on 13 samples from seven power plants burning eastern or western coal and using lime, limestone, or double-alkali absorbents.

[c]Solids analyses were conducted on 6 samples from six power plants burning eastern or western coal and using lime, limestone, or double-alkali scrubbing processes.

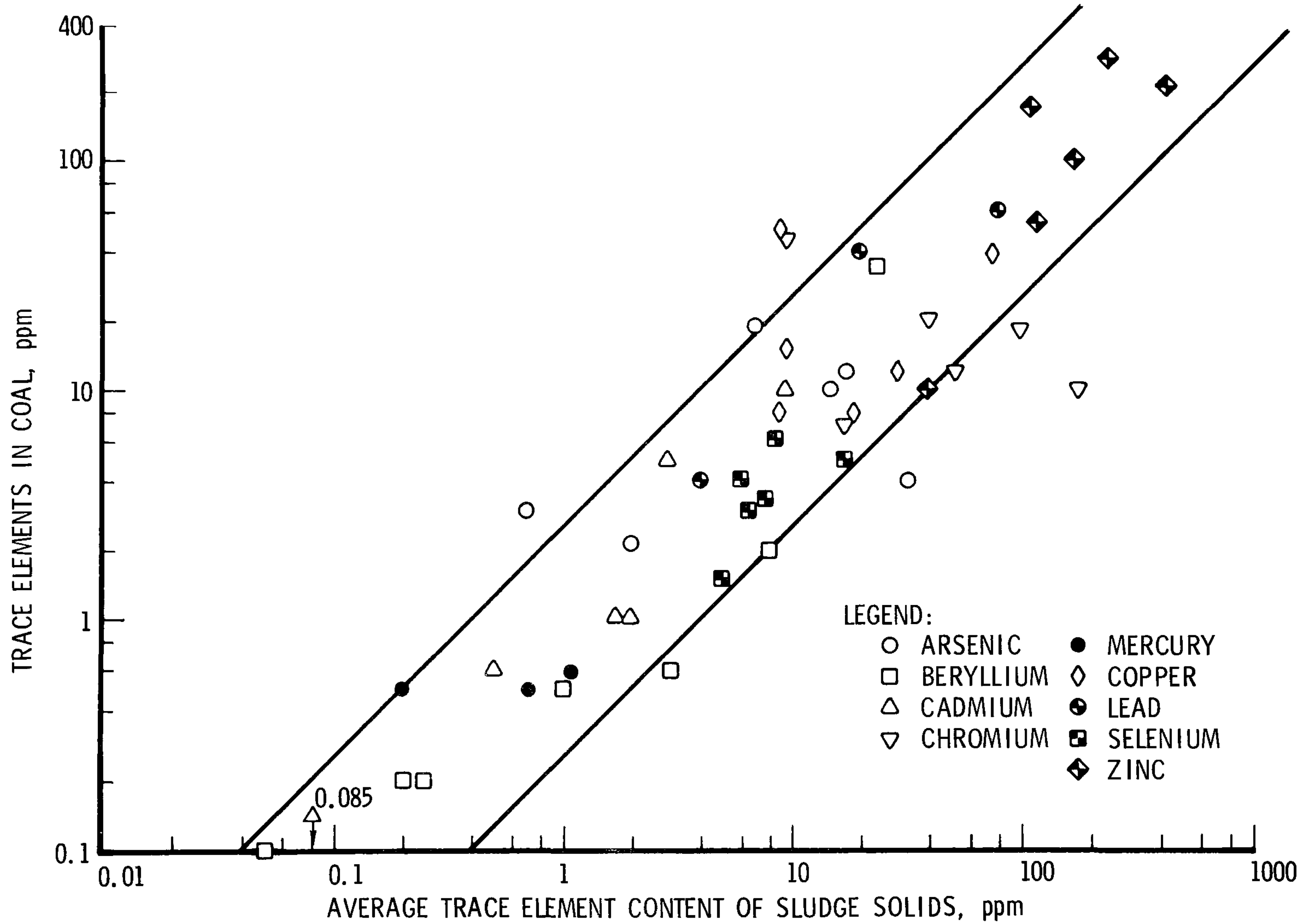


Figure 6. Average trace element content of sludge solids.

d. Compaction of untreated sludges dewatered to about 80 percent solids produced permanent displacement of 1 to 4 percent.

e. Treated wastes have unconfined compression strength greater than 1.8 tons per square foot (25 psi).

2.2.4 Chemical Properties

Lime and limestone FGD sludge liquors typically have approximately 10,000 mg/ℓ total dissolved solids (TDS). Double alkali scrubber sludge liquors from unwashed filter cake leave a much higher TDS, in excess of 50,000 ppm. When the cake is washed with water to remove soluble sodium salts, the TDS concentration tends to approach that of the lime and limestone sludge liquors. Trace elements lie typically between 0.01 and 1 mg/ℓ depending on coal content and fly ash collection techniques.

The leachate quality of rainwater percolated through untreated FGD waste attains a nearly constant TDS content of 2000 mg/ℓ, primarily sulfate salts, after passage of five pore volume displacements (PVD). Initial leachate content is as high as the soluble chemical content and is dependent upon the type of FGD system.

Chemical treatment has been found to have major benefits which effectively minimize (and possibly, in some cases, virtually eliminate) the release of leached sludge constituents to the subsoil through (a) the decreased permeability of the treated material, and (b) the amenability of the treated material to compaction and contouring during placement so that standing water does not occur on the disposal site. The prevention of standing water avoids having a hydraulic head on the site and, therefore, seepage through the pores does not occur as a result of hydraulic pressure. This is accomplished by managing the site so that a major portion of the rainfall on such a site runs off and is collected in a peripheral ditch which directs the water to a settling pond, from which decanted liquor is disposed of in an adjacent stream, if acceptable, or returned to the power plant water reuse system.

2.3 POTENTIAL ENVIRONMENTAL IMPACTS OF DISPOSAL PROCESSES AND PRACTICES

It has been determined that the chemical and morphological properties of untreated waste tend to be a function of the coal and, more importantly, a function of the scrubbing process variables. The morphology tends to establish the settling and dewatering characteristics of a particular slurry. Detailed characterization of scrubber solids as a function of scrubber operating parameters on the properties and work in that area is being conducted (4) under EPA funding. Furthermore, chemically treated waste characteristics are also dependent on the treatment process itself.

Prime factors to be considered in the disposal of FGD wastes are as follows:

a. Structural Strength: Because of the rheological and structural characteristics of untreated wastes, personnel and equipment safety cannot be ensured. Treated material, depending on the treatment process and the solids content, can be expected to achieve strengths in excess of those considered minimal for supporting personnel and equipment and, in some cases, building structures. The long-range effect of weathering on strength, i.e., wet-dry and freeze-thaw cycling, is yet to be defined.

b. Permeability. Permeability coefficients of untreated materials range from 2×10^{-4} to 5×10^{-5} cm/sec. Chemical treatment tends to lower these values over a broad range (from negligible to several orders of magnitude) depending on the process, chemical additive, and the solid content of the treated material. The long-range effect of weathering on permeability is yet to be determined.

c. Leachate Concentration. Laboratory and field leaching data show that leachate concentrations of major species in the leachate from fixed materials are about 25 to 50 percent of the concentrations of major species in untreated materials.

d. Leachate Mass Release. The mass release of major constituents into the soil from chemically fixed materials is reduced as a result of lower permeability of the treated wastes, a reduction of the solubility of major pollutant constituents, and, in some cases, a minimization of seepage by controlled runoff. The treatment process and mode of disposal, i.e., landfill or lake, determine the mass loading of pollutants into the soil, which can amount to reductions of one to several orders of magnitude when compared to untreated materials.

e. Soil Attenuation Effects. The extent that trace elements and other chemical constituents of FGD wastes may be attenuated in soils or their mobility to migrate through soils at land disposal sites is being studied by the U. S. Army under EPA sponsorship (4). Soil and waste characterization tests are complete. However, work has not progressed to the point where quantitative information on the migration and attenuation of FGD waste constituents has been determined.

f. Liner Evaluation. An experimental program to determine the compatibility and effectiveness of 18 liner materials with FGD wastes, liquors, and leachates is under way. Material screening tests have been conducted. Materials have been selected, and testing has begun in test cells. Since the exposure of materials to various wastes has been limited and definitive information is not available at present, a 2-yr exposure is planned. The economics of FGD disposal by ponding will also be assessed.

g. Waste Dewatering Methods. Studies are being conducted to determine dewatering characteristics of FGD wastes and to define areas where improvements can be made in dewatering equipment or techniques. Since the program is in its early stages, quantitative information is not available. However, results from this work are expected to be used in assessing benefits derived from a reduction of: dewatering equipment size, waste volume handled, disposal acreage, and chemical additives.

h. Field Disposal Evaluation. A project to evaluate and monitor the field-site disposal in indigenous soil impoundments of untreated and treated FGD wastes has been under way for over 3 yr at the TVA Shawnee power plant site (5). Its purpose is to determine the effects of several scrubbing operations, waste treatment methods, disposal techniques, soil interactions, and field operation procedures. Test samples of treated and untreated wastes, groundwater, surface water, leachate, and soil cores are being analyzed in order to evaluate the environmental acceptability of current disposal technology.

The analysis of groundwater shows no indications of increases in concentration levels attributable to the presence of any of the ponds.

The total dissolved solids (TDS) and the concentration of major constituents in the supernates of the untreated ponds decreased with time from initial values corresponding to the values measured in the input liquor. After the initial decrease, fluctuations were observed in which concentrations increased during dry weather and decreased again when increased rainfall caused additional dilution. For the treated ponds the concentrations of major constituents and TDS in the supernate varied as a function of dry and wet weather during the monitoring period and did not exceed values of one-half to two-thirds of the corresponding concentration of the constituents in the input liquor.

Generally, the TDS, SO_4, Ca, and Cl in the leachate from untreated ponds reached the input concentration and decreased steadily thereafter to a level approximately one-half the concentration of the input liquor. Minor constituents whose concentrations span a range of six orders of magnitude were relatively constant over the period monitored. The analyses of leachate from the ponds containing treated sludge show data trends similar to the untreated ponds; however, TDS levels consistently remain at a level approximately one-half of the levels found in the input liquor. Six minor constituents remained at relatively constant levels throughout the monitoring period, with the exception of the boron level in one treated site which increased steadily to a level approaching that of the input liquor.

An evaluation of the environmental effects of settling and the structural characteristics of disposing of untreated lime wastes in underdrained field impoundments at the Shawnee site were initiated in late 1976. Monitoring of underdrained limestone and gypsum evaluation sites started in early 1977.

Other field evaluations of FGD waste test impoundments and full scale disposal sites are in early stages of implementation by Louisville Gas and Electric and the U.S. Army Corps of Engineers (4).

It is apparent that each disposal site and the material placed in it have individual characteristics different from most others. These include waste material properties, weather, topography, soil characteristics, and nearby stream quality and flow characteristics. Therefore, the disposal method chosen for any site will generally be selected on site-specific conditions. Because of this, the establishment of a single criterion for all cases may be overly conservative in one location and not stringent enough in another.

Various disposal and waste conversion processes and practices are capable of minimizing environmental impacts on aquifers and groundwaters. These are discussed in subsequent sections and include:

a. Ponding of untreated waste, with various alternatives

b. Chemical treatment of waste, and landfill disposal

c. Mine disposal of untreated waste

d. Ocean disposal of treated waste.

Processes that produce useable products that minimize or reduce the disposal of wastes include:

a. Conversion to gypsum for wallboard and other uses

b. Production of sulfur or sulfuric acid

c. Use as a synthetic aggregate

2.3.1 Ponding

The method that represents the least deviation from state-of-the-art fly ash disposal is direct ponding of untreated wastes into a disposal basin. The environmental impact of pond disposal is strongly dependent upon the ability (a) to contain the components of a sludge so as to prevent environmental pollution, and (b) to retire the disposal site in a manner that does not create a safety hazard or nuisance in subsequent land use. For pond disposal the environment can be protected from chemical pollution, principally from leachate contamination of groundwater, by lining the pond basin with elastomeric material or impermeable clay. Some natural clay deposits have sufficiently low permeabilities (effectively impermeable) that sludge disposal can be safely contained in a natural basin. If an impermeable base is not used, it is expected that not all trace elements will be attenuated by the subsoil. Additionally, soils do not significantly attenuate chloride or sulfate ions.

The disposal site may be reclaimed either by maintaining the pond as a lake or by allowing the sludge to dry and covering it with soil overburden. To maintain the retired disposal basin as a lake, it is necessary to provide a balance between water loss and water input. The water loss will be by evaporation, and, when no liner is used or when a breach is developed in the liner, loss also occurs by percolation through the subsoil. Precipitation in excess of loss requires a means for eliminating excess water, which must be monitored.

If a pond is reclaimed by air-drying the sludge and covering it with a soil overburden, certain restrictions may limit reuse of the land. Proper contouring to control rainfall runoff to minimize percolation of water through the overburden will be necessary to avoid resaturating the sludge. Therefore, using site management, it may be possible to dispose of untreated FGD sludge by ponding in an environmentally acceptable manner.

Another ponding alternative to dispose of untreated FGD waste is by including provision for pond underdrainage. This method retains the advantage of transferring the sludge to the disposal site by liquid transfer.

The leachate from the base of the sludge is returned to the scrubber. The advantages of this method may be economic and environmental. By eliminating a supernate head above the sludge most of the time, and minimizing it for short periods after rainfalls, percolation of sludge leachate into the subsoil can be avoided during the active fill period. Tests have shown drained sludge to have structural qualities adequate to support lightweight construction equipment. To retire the disposal site, only several days of air drying after a rainfall are needed before covering with topsoil. Subsequent cover contouring is necessary for the reasons discussed in ponding, but the underdrainage system provides a means of sampling and elimination of leachate if required to prevent groundwater contamination. Significant economic advantages of this method could be its relative reclamation potential and the elimination of the requirement for a disposal basin liner. Evaluation of this technique is continuing in EPA programs (5, 6).

2.3.2 Chemical Treatment

FGD sludge may be treated chemically by several processes, and can typically be used in landfill applications. Chemical treatments such as those offered by IU Conversion Systems, Inc. (IUCS), Dravo, Inc., and the Chemfix process vary in terms of the chemical additives used to physically stabilize the sludge, reduce its permeability, and also reduce the release of chemical constituents into water permeating through the treated material.

An evaluation of these three processes (7) indicates that the soluble salt content in the leachate from treated sludges is typically one-half or less than that of the untreated sludge. Additionally, the permeability of the treated sludge appears to be at least one order of magnitude less than that of the untreated sludge. Therefore, the dissolved salts that may be leached from chemically treated sludge and available to the environment are considerably less in concentration and mass than from untreated sludge.

For every process examined, the structural stability of the treated sludge exceeded that of the untreated sludge. The treated sludge texture ranged from soil-like to concrete-like and developed strength equal to or in excess of natural soils. Restrictions on subsequent land use will depend upon local conditions and the long-time stability of the treated sludge. Laboratory data have not been developed by any source from which it would be possible to predict the time-dependent stability of treated sludge.

Chemically treated sludges can be used as landfill in submerged and above-grade conditions. In the submerged condition, the sludge may serve as a lake bottom; however, the constant hydraulic head requires a continuing monitoring of local streams to detect any possible leakage from the site. In an above-grade condition, the material can be placed and compacted such that rainwater does not penetrate the surface and a leachate is not produced. However, provisions are generally required to manage run-off from these sites. The potential environmental impact of treated sludge is less than that of untreated sludge under most disposal methods, although the added assurance afforded by the chemical process increases the cost of disposal.

2.3.3 Mine Disposal

In a study (8) assessing the technical, environmental, and economic factors associated with mine disposal of FGD wastes, four general categories of mines were examined: active surface-area coal mines, active underground coal mines, inactive or mined-out portions of lead or zinc mines, and inactive or mined-out portions of active underground limestone mines. In addition to the environmental impacts, each category was reviewed with regard to: the alternatives for placement, the physical properties of FGD wastes that would be suitable, the operational impacts, the capacities, and the availability and accessibility (via transportation systems) for FGD waste disposal. As a result of this review, the following mines were determined most promising:

a. Active Interior Region surface-area coal mines

b. Active Eastern and Interior Region room-and-pillar underground coal mines

In general, Interior region surface-area coal mines appear to be more promising than western (Rocky Mountain and Pacific Coast) surface-area coal mines. However, surface-area mines both in the Interior and the West were considered much more promising than eastern surface contour mines, because of the latter's relatively low capacity for FGD wastes and, in many cases, the difficulty for waste placement in contour mines.

Individual Interior region surface-area mines have substantial capacity for receiving FGD wastes, and disposal is considered technically feasible within existing mine operations. The wastes must be dewatered to the extent necessary for landfill operations, so that they can be dumped into a mined-out strip (which can be adjacent to one being mined) and covered with overburden. Placing FGD waste in the mine void assists in returning the terrain to its original elevation.

The principal environmental impact anticipated from this disposal method is an increase in total dissolved solids (TDS) in waters that are recharged by leachate from the disposal site. This impact may be lessened by placing part of the overburden in the mined-out strip prior to placing the FGD waste, thereby elevating the waste above the groundwater table. In addition, dilution to acceptable TDS levels can be encouraged by maintaining a suitable distance between the disposal site and the stream, or by ensuring that the receiving streams have a sufficiently high flowrate.

2.3.4 Ocean Disposal

In a study assessing the ocean disposal of FGD wastes (8) various methods of transportation and disposal were examined, including surface craft (e.g., bottom-dump barge and slurry dispersion) and pipeline (outfall). Various chemical and physical forms of the FGD wastes were also considered, i.e., sulfite-rich wastes, sulfate-rich wastes, and chemically treated wastes in both "soil-like" and "brick-like" forms. Both continental shelf and deep ocean disposal of the wastes were examined.

Until more definitive data are available, disposal of sulfite-rich FGD wastes on the Continental Shelf or in the deep ocean was not considered to be advisable. In addition, the study concluded that all soil-like FGD wastes, whether sulfite or sulfate and treated or untreated, should not be disposed of by quick-dumping surface craft or pipeline (outfall) on the Continental Shelf. Several options using surface craft appeared promising:

a. Dispersed disposal of sulfate-rich FGD wastes on the Continental Shelf

b. Concentrated disposal of chemically treated brick-like FGD wastes on the Continental Shelf

c. Dispersed disposal of sulfate-rich FGD wastes in the deep ocean

d. Concentrated disposal of both sulfate-rich and chemically treated FGD wastes in the deep ocean

However, the environmental effects of layering the bottom with wastes described in a, c, and d above have yet to be defined. In addition, their environmental effect while traveling down the water column is also unknown.

A more promising method is considered to be item b above. This is based on the favorable characteristics of treated materials in laboratory leaching and permeability tests. Long-term effects on the volumetric and structural integrity of the material as affected by submergence in sea water are unknown.

Experiments sponsored by the New York State Energy Research and Development Authority (NYSERDA) are evaluating the physical, chemical, and biologic characteristics of blocks of chemically treated scrubber wastes (9). Laboratory experiments have been encouraging, and a 10 ft^3 reef constructed of blocks of chemically treated wastes will be placed in Long Island Sound. The physical stability of the reef and its effects on the local marine biology will be studied, and other related assessments will be made.

2.3.5 Conversion to Gypsum

Experiments on the forced oxidation of sulfite sludges to form gypsum for potential use in wallboard were conducted by EPA at Research Triangle Park and by Southern Services at Plant Scholz using the Chiyoda process. Wallboard has been fabricated using a 50/50 blend of Chiyoda gypsum and the natural material (10). However, evaluations of the properties of FGD gypsum specifically related to manufacturing wallboard and its application were not available.

Wallboard produced from SO_2 scrubbing processes has had extensive application in Japan, and properties relative to this material have been reported (11). However, the material has been produced from scrubbing of flue gases from oil-fired boilers, and the relationship between SO_2 concentration in the flue gas and scrubber operating conditions on the properties of the gypsum from the oil-fired units in Japan and from the coal-fired applications in the U.S. are unknown. Estimates for the cost increment required to adapt to new scrubber systems during construction have been made (10) and reported. Since no data were available, in that analysis it was assumed that the resultant properties of the ash-free gypsum would be satisfactory for wallboard use.

2.3.6 Conversion to Sulfuric Acid or Sulfur

Regenerable FGD processes are, in reality, chemical processing plants which, if applied to power plants, add new dimensions to the plant operating and marketing programs.

Both the magnesium oxide and Wellman-Lord processes require a complex plant to regenerate the SO_2 from the absorbent, and to reduce the SO_2 to sulfur or convert it to sulfuric acid. The Wellman-Lord process uses an evaporator to regenerate the absorbent and form SO_2. It then requires methane and H_2S in the plant devoted to the reduction of SO_2 to sulfur. The magnesium oxide process requires a fluidized bed reactor and coke to regenerate the SO_2, which then must be processed further to form the sulfur or sulfuric acid by-products.

A brief discussion of the technology based on recent surveys and operational status of existing plants is provided below.

2.3.6.1 Magnesium Oxide--

Three MgO plants have been tested (Table 11). Two have shut down completely as SO_2 scrubbers, and a third is in a particulate scrubber mode only since February 1976 because of the difficulty in locating a chemical plant to process the spent absorbent (it is scheduled to start up again as an SO_2 scrubber in mid-1977). The two shut-down plants experienced the same problem (12). In general, it is considered (13), that the scrubbing process has been demonstrated; experiencing the usual corrosion and mechanical problems typical of placing a scrubber system into operation (12). The major problem has been in the accessibility of a $MgSO_3$ regenerating plant. To operate effectively, an on-site or central regenerating plant servicing nearby scrubber operations may be needed.

2.3.6.2 Wellman-Lord--

The Wellman-Lord system has been successfully operated on tail gas from Claus and H_2SO_4 plants and an oil-fired flue gas, but not coal-fired boiler flue gas (13).

A retrofit system is scheduled to go into operation in mid-1977 on the 115-MW boiler at the Dean Mitchell Station of Northern Indiana Public Service burning 3- to 3.5-percent sulfur coal. Elemental sulfur (99.5 percent purity) is expected.

TABLE 11. STATUS OF MAGNESIUM-OXIDE SCRUBBING PLANTS

Installation Site, Size, and Fuel	Status
Boston Edison, Mystic No. 6, 150 MW, oil, 2.5% sulfur	Start-up 4/72, shutdown since 6/74
Potomac Electric, Dickerson No. 3, 95 MW, coal, 2% sulfur	Start-up 9/73, shutdown since 8/75
Philadelphia Electric, Eddystone No. 1, 120 MW, coal, 2.5% sulfur	Start-up 9/75, shutdown SO_2 scrubber 2/76[a]

[a]Shutdown—acid plant regeneration facility ceased operations. Another facility located. Expect to resume SO_2 scrubbing and $MgSO_3$ regeneration in mid-1977.

Public Service of New Mexico is installing Wellman-Lord systems at its San Juan No. 1 and 2 stations, which generate in excess of 700 MW. Start-up is expected in November 1977. Low sulfur (0.8 percent) coal will be used in the boilers.

2.3.7 Use as a Synthetic Aggregate

Chemically treated waste has been used in limited instances as synthetic aggregate for road base materials.

Poz-o-tec® is a process that is used by IU Conversion Systems Inc., to chemically treat wastes capable of being processed as synthetic aggregate. Its application has been used primarily in road base construction materials, with some application as dikes and liner material at a disposal site (14) in the greater Pittsburgh area and in Mohave County, Arizona. It has also been used to reclaim land in a housing tract. Ross Township, Pennsylvania, has approved a specification for its use in road base construction.

The economics of its use appear to be highly site specific relative to its source and end use; however, no cost data have been published.

2.4 WASTE DISPOSAL

Various forms of disposal are available, and a selection depends on processing cost in combination with the following factors, which are generally site specific: characteristics of the waste, climate, geology, topography, hydrology, and disposal site availability and proximity. Possible types of disposal are: ponding on indigenous clay soil; ponding with a flexible liner or a liner of impervious soil; ponding with underdrainage; mine disposal; ocean disposal; and chemical treatment with landfilling. There are specific cases where each of these methods is applicable; environmentally and structurally. Although the chemical treatment approach is universally applicable, it is not necessarily the best choice in all cases if a ponding or mine disposal approach is environmentally acceptable and less expensive. All disposal methods require monitoring, and land disposal sites require management throughout their active life, including special provisions such as covering the site with soil and the growth of vegetation to prevent either rewetting the material or runoff problems, as applicable.

2.5 UTILIZATION

Three major products which can be produced from flue gas scrubbing are gypsum from nonregenerable systems and sulfur and sulfuric acid from regenerable systems. Although the quality of the products produced may be equivalent to those obtained from current sources, the economics, however, are generally not favorable when compared with current sources of supply. Gypsum is not directly cost competitive; however, in consideration of sludge disposal credits for disposal under certain conditions, it can be shown to be a cost-effective commercial item. Sulfuric acid would have to compete in an industry that is currently capable of producing 30 percent over demand. However, there may be site-specific instances where the production of sulfur or sulfuric acid from regenerable scrubber systems may be economically feasible. Attempts are being made to develop other products from sulfur sludge, such as fertilizer and building materials.

2.6 ECONOMICS

Cost estimates have been made for disposal of sulfur sludges by various methods, as well as projected costs on a national basis to 1998 for the same methods considering current NSPS, and the two alternative revisions, i.e., 90 percent SO_2 removal and 0.5 lb $SO_2/10^6$ Btu. A summary of disposal costs, including conversion to gypsum and its disposal, is as follows:

DISPOSAL COSTS (mills/kWh)[a, b] (1977 DOLLARS)

Untreated Waste		Landfill-Chemical Treatment	Mine[c]	Ocean[d]	Gypsum[e]
Liner Added	Indigenous Clay				
1.02	0.70	1.33	0.37	2.38	1.39

[a]500-MW plant, 3.5% sulfur coal, 90% SO_2 removal. Disposal site within 1 mile from plant, except as noted.

[b]All disposal includes ash.

[c]Untreated waste, site located 4 miles from power plant.

[d]Treated sludge, on the continental shelf, 25 miles from the eastern seaboard.

[e]Cost of forced oxidation and disposal of gypsum including fly ash in an indigenous clay-lined pond.

An example is given below of the costs for disposal that would be incurred in 1998 if all new plants used nonregenerable scrubbing.

TOTAL COSTS IN 1998 - BILLIONS (1977 DOLLARS)[a, b]

Emission Standard	Liner Added	Indigenous Clay	Landfill - Chemical Treatment	Mine[c]	Ocean[d]
1.2 lb $SO_2/10^6$ Btu	1.41	0.95	1.89	0.58	2.84
90% SO_2 removal	1.54	1.04	2.07	0.64	3.12
0.5 lb $SO_2/10^6$ Btu	1.06	0.72	1.43	0.44	2.15

[a]500-MW plant, 3.5% sulfur coal, 90% SO_2 removal. Disposal site within 1 mile from plant, except as noted.

[b]All disposal includes ash.

[c]Untreated waste, site located 4 miles from power plant.

[d]Treated sludge, on the continental shelf, 25 miles from the eastern seaboard.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT The study assesses the technological, economic, and environmental impacts, projected to 1998, of the increased solid wastes resulting from the application of various more-stringent controls as well as of the current New Source Performance Standards (NSPS) for SO2 emissions from coal-fired steam-electric generators. The study supports a review of the NSPS, by EPA's Office of Air Quality Planning and Standards, that defines a number of control strategies (e.g., increased scrubbing efficiency and coal washing) for achieving several levels of SO2 emission control, with emphasis on levels more stringent than the current NSPS. The study considers three alternative strategies (1.2 and 0.5 lb SO2/million Btu, and 90% SO2 removal), three plant sizes (1000, 500, and 25 MW), and five flue gas desulfurization (FGD) systems (lime, limestone, double alkali, magnesium oxide, and Wellman Lord). Typical eastern and western coals, as well as coal washing, are included. The study groundrules include: (1) the nationwide survey to be 1978-1998; (2) new-plant-installed capacities during that interval (FPC projection); (3) 1980 as the effective date for the more stringent standards; and (4) western coal burned during the 1980-1998 period to be 45% of the total burned nationwide (variations in the western coal percentage were also evaluated).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Combustion	Pollution Control	13B	
Sulfur Dioxide	Steam-Electric	Stationary Sources	07B	
Flue Gases	Power Generation	Solid Wastes	21B	10A
Desulfurization	Scrubbers		07A,07D	
Wastes	Coal Preparation			08I
Coal	Washing		08G,21D	13H

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