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Coal Cleaning with Scrubbing for Sulfur Control:

An Engineering/ Economic Summary

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**Bureau of Mines, U. S. Department of Interior

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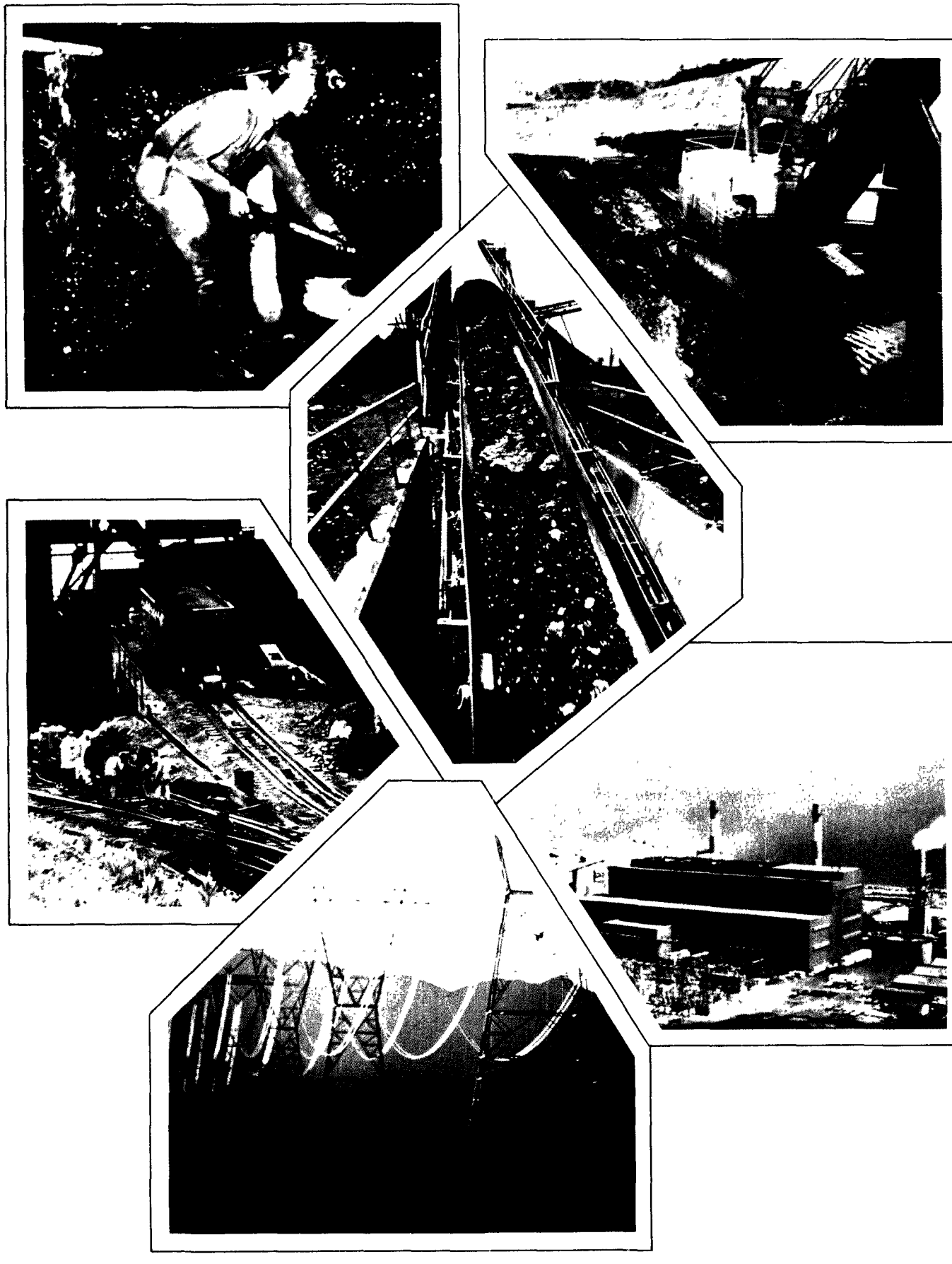


"In many cases, the net cost of physical coal cleaning followed by partial scrubbing to meet standards is substantially less than that associated with using only a full scale scrubbing system."

Introduction

In this country, the continued generation of power in a reliable, cost-effective, and environmentally acceptable fashion is critical to economic and social stability. Much of this power is produced by coal-fired plants. During 1975, fifty-five percent of the utility industry's fossil fuel requirements were met with coal. In view of the rapidly diminishing reserves and rising prices of alternate fossil fuels, the percentage provided by coal will increase. If these plants are going to adhere to the environmental standards set forth by EPA and others relative to SO_x emissions, it will often be necessary to consume coals of less than 1% sulfur and/or invest in costly flue gas desulfurization systems. Therefore, in the interest of overall national economics and preserving our limited Eastern supply of low sulfur coal, it is important that economic means be found and quickly implemented to encourage the utility industry to make use of our vast resources of higher sulfur-content coal.

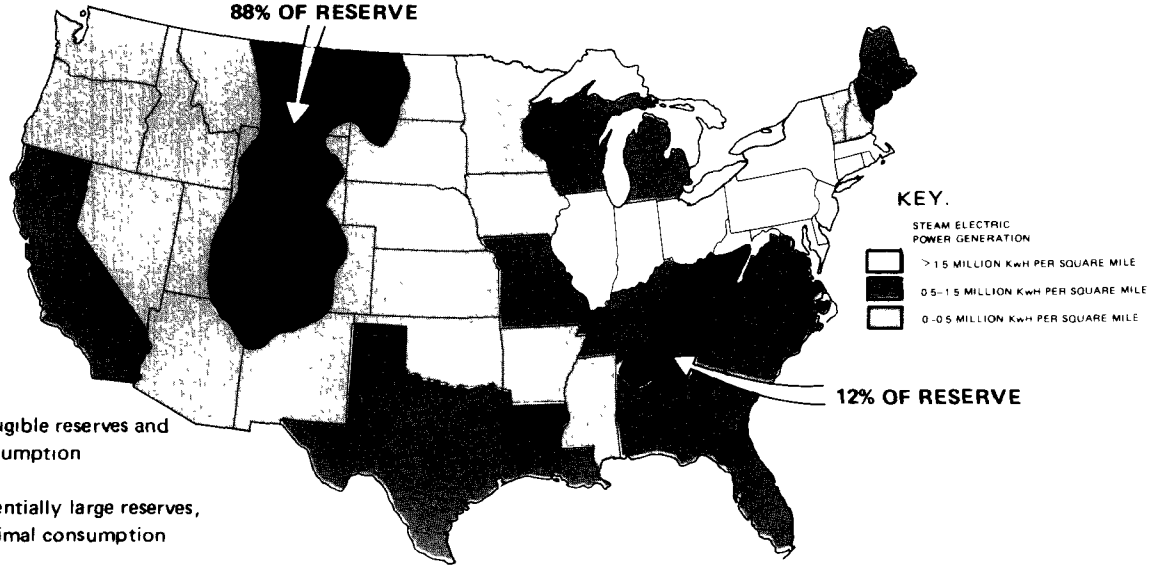
According to data published by the Bureau of Mines, the United States had minable underground and surface coal reserves of nearly 437 billion tons on 1 January 1974. Of this number, approximately 386 billion tons had been categorized according to sulfur content; 52% had 1% or less, 24% had between 1.0 and 3.0%, and 24% had greater than 3.0%. Although over half of these reserves fall into the low sulfur content range, 88% of the low sulfur coal is found west of the Mississippi (concentrated in such states as Montana and Wyoming), far removed from the electric power demand centers of the east. In the east only 24% of the coal is low sulfur. Therefore, in developing a reliable source of coal (long term supply not too far from point of consumption) to meet the demands of the eastern utilities, the medium and high sulfur content coals must be considered. It was the purpose of this study to identify an economic means of keeping such higher sulfur content coals in the energy market.

Data generated by the Bureau of Mines under the Federal Interagency Energy/Environment Research and Development Program indicate that some Eastern coals will show a significant reduction in ash and sulfur contents when physically cleaned to a 90% weight yield. With current technology, this level of physical cleaning can often be accomplished at an attractive cost. These coals with reduced ash and sulfur levels are often not too far removed from the sulfur content required to meet environmental standards in the geographic areas historically served by these coals.

When coal can be physically cleaned to a sulfur content close to that required to meet governing emission standards, a flue gas desulfurization (FGD) system treating only a portion of the flue gas would permit the coal burning facility to comply with such emission regulations. In many cases, the net cost of physical cleaning followed by FGD is substantially less than that associated with meeting standards exclusively with a larger capacity FGD system. This results from the fact that the savings associated with being able to use a smaller FGD system more than cover the net cost of physically cleaning the coal. Our study quantified this relationship under assumed conditions based upon current environmental standards being met by utility power plants using specific coals which are economically obtainable in the particular geographic areas considered.

The overall study findings covering new utility plants using physically cleaned coal followed by FGD indicated a savings of 2% to 112% as compared to meeting standards by FGD alone. The results were even more impressive for existing plants, where study assessments indicated a 13% to 140% savings for physical cleaning followed by FGD as compared to FGD alone.

LOW SULFUR COAL RESERVES VS. STEAM ELECTRIC POWER GENERATION



Hawaii: Negligible reserves and consumption

Alaska: Potentially large reserves, minimal consumption

Background

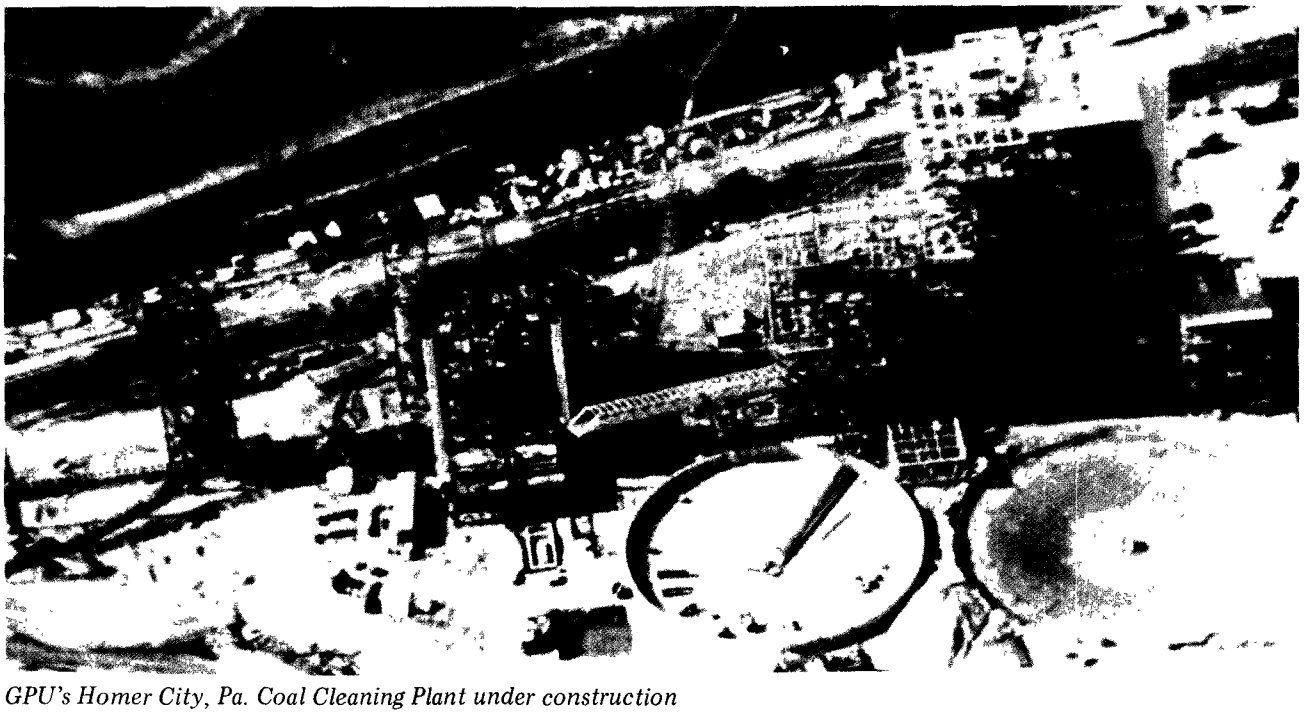
Coal is a heterogeneous material containing organic combustible matter and mineral matter. The mineral matter (i.e., impurities) may be broadly divided into two categories; those forming ash and those that contribute sulfur. Such ash-forming and sulfur-containing impurities may be further divided into two groups; 1) those that are chemically a part of the coal and cannot be removed by mechanical processes, and 2) those that are not chemically bound to the coal and can be removed to varying degrees by mechanical means. It is toward this latter category that physical coal cleaning (coal beneficiation, preparation, or washing) is directed.

Physical Cleaning

Physical cleaning is accomplished by first crushing the coal to liberate those impurities that are not chemically bound with the coal. These impurities are set free upon crushing since the seam where they are stuck to the coal is generally weaker than either the coal or the impurity. After the raw material (as mined coal) is crushed, the impurities can be separated out by mechanical means. The most common processes for achieving this separation are based upon the difference between the specific gravities of the impurities and that of the coal. Simply stated, coal has a specific gravity of around 1.3 which is less than that of its impurities. Thus, when the crushed particles (coal and impurities) are distended in water or other media a separation occurs as the heavier undesirable particles settle at a faster rate than the coal. In commercial scale cleaning operations, it is not uncommon to process 500 to 1000 tons of coal per hour using a variety of equipment designed and arranged around the makeup of the particular raw coal and the desired end product.

Physical cleaning of coal has been used for many years. In the past its principal purpose was to reduce the ash-forming impurities. However, today cleaning is of significant value in reducing the sulfur content of certain coals. Its applicability in this regard is not universal due to the various forms that sulfur occurs in coal. Sulfur exists in coal in two principal forms; organic and inorganic. Organic sulfur is one of those impurities referred to earlier which is chemically bound to the coal and cannot be removed by physical means. On the other hand, inorganic sulfur (pyritic sulfur) is not bound chemically and may be physically removed to varying degrees from the coal. The extent to which pyritic sulfur can be removed economically is a function of pyrite size and distribution. Once this information is obtained through careful laboratory analysis, then economic considerations will influence the level to which the coal is crushed and subjected to the cleaning operation.

Physical cleaning processes, while removing impurities from the coal, also reduce the total Btu available (i.e., a portion of the heat content of the raw coal is lost with



GPU's Homer City, Pa. Coal Cleaning Plant under construction

the impurities). However the Btu content per unit weight of the cleaned coal increases due to the removal of the lower heat value impurities. In practice, an economic balance must be achieved between the Btu loss and the improvement in coal quality for various coals and applications. Certainly, this balance is further influenced by market and environmental considerations.

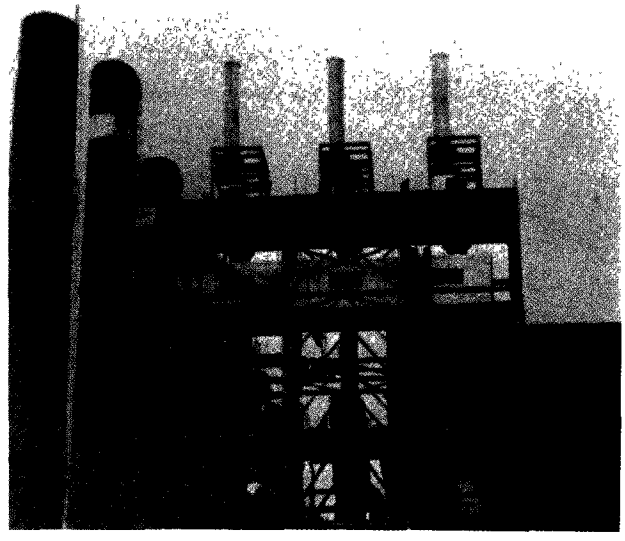
Problems

With regard to the environmental aspects, the oxides of sulfur (SO_x) created when coals are burned have long been recognized as a real threat to both the ecosystem and human health. Federal Standards, designed to protect against serious harm, have been established for new electric power plants which burn coal. To meet these standards, several methods are available to control sulfur oxides emissions from coal-fired combustion sources. These control methods include:

1. The use of low sulfur coal, either naturally occurring or physically cleaned;
2. Chemical treatment to extract sulfur from coal;
3. Removal of sulfur oxides from the combustion flue gas (stack gas scrubbing);
4. Conversion of coal to clean fuel by such processes as gasification and liquefaction.

Of these methods, for certain coals, physical cleaning to reduce sulfur content is the lowest cost and has the most developed technology. However, as noted earlier, physical cleaning can remove significant amounts of inorganic sulfur (pyritic) from certain coals, but has no influence upon the organic sulfur content. Therefore, when trying to come up with an environmentally acceptable product, physical cleaning may only be a partial step. This leads to another approach to controlling SO_x emissions, which could be the combined use of physical cleaning followed by stack gas scrubbing (i.e., flue gas desulfurization).

The purpose of a flue gas desulfurization (FGD) system is to limit the sulfur compounds escaping into the atmosphere. One of the most common FGD systems accomplishes its mission by forcing the SO_x in the flue gas to react with a limestone slurry. The cost of these systems goes up substantially with the amount of flue gas treated, which, in turn, is a function of the sulfur concentration of the flue gas stream. Therefore, significant savings can be realized if the sulfur concentration of the stream can be limited to the point where less than half of the total flue gas needs to be treated by the FGD system to meet standards. This becomes the basic economic concept of combining the two sulfur reduction technologies since such a combined approach could mean the ability to use higher sulfur content coals and minimal to moderate stack gas scrubbing.



Lime-Limestone Scrubber at TVA Power Plant

Physical Cleaning with Scrubbing

This concept of physical coal cleaning combined with flue gas desulfurization is not new. For some time there have been discussions, speculations, and some very preliminary assessments addressing the possible benefits of physical coal desulfurization followed by FGD. Past opinions based on a general appreciation of some of the cost and benefit factors associated with such an approach have led to the expressed belief that economic advantage in many instances could be attained. However, the associated specific economics had not previously been fully addressed. Therefore, to more completely define the potential economics associated with such a combined approach as a means of increasing the usefulness of some of our higher sulfur content coals, this study was initiated. It was conducted by the Bureau of Mines under the auspices of the EPA-coordinated Federal Interagency Energy/Environment R&D Program.

For purposes of this study, higher sulfur coals from the Northern Appalachian and Eastern Interior Regions were selected since they have been shown to have reasonable physical cleaning potential (i.e., economic ash and pyritic sulfur reduction). Then, possible users of these coals in the electric power generating industry were identified along with the current environmental constraints in their respective localities. This realism provided the framework within which to study and compare the economics associated with meeting sulfur emission standards in two alternative ways. The study considered both new and existing plants using either physically cleaned coal followed by stack gas scrubbing, or sulfur clean-up exclusively by stack gas scrubbing.

Economic Analyses

In order to determine the relative economics of meeting environmental standards via two different approaches, the factors influencing the costs and benefits of each element were identified. These are summarized as Table I.

For physical coal cleaning, the costs are principally dependent upon such factors as coal composition and plant size/cost. Offsetting these costs somewhat are the benefits of using cleaned coal. The magnitude of these benefits is influenced most by the increased heat content of the processed product brought on by the removal of some of the low heat content impurities. In the case of flue gas desulfurization (FGD), costs are sensitive to the sulfur composition of the flue gas stream.

TABLE I
KEY COST/BENEFIT FACTORS

COST OF CLEANING COAL

–Amortization of Cleaning Plant Capital Cost
–Operation and Maintenance Cost of Cleaning Plant
–Cost of Raw Coal Lost in Cleaning Process
–Taxes and Insurance Costs of Cleaning Plant

COSTS OF FLUE GAS DESULFURIZATION

–Amortization of Flue Gas Desulfurization (FGD) System Capital Cost
–Fuel and Electricity Cost Associated with FGD System
–Operating and Maintenance Costs of FGD System, Including:

Limestone • Fixation Chemicals • Operating Labor
Maintenance (Labor and Materials) • Supplies • Overhead

BENEFITS OF USING CLEANED COAL

–Increased Heat Content of Cleaned Coal
(Greater BTU Content Per Unit Weight)
–Transportation Savings (Less Weight to Ship for Same BTU Content)
–Ash Disposal Cost Saving (Clean Coal Leaves Less Ash)
–Pulverizing Cost Savings
(Less Cleaned Coal Needs to be Pulverized for Same BTU Content Required to Meet Output)
–Boiler and Related Equipment Maintenance Savings
(Clean Coal Is Less Corrosive)

Having identified the key cost/benefit factors associated with the two approaches, case analyses were performed based, in part, upon the major study factors appearing in Table II. As appropriate, these factors were based upon actual industry performance and practice.

TABLE II
MAJOR STUDY FACTORS

- The coals considered were those for which the Bureau of Mines has performed float-sink analyses. Bureau of Mines estimates of ash and sulfur levels versus top size and yield values were used.
- The top size coal considered was 3/8 inch.
- Economic assessments were based on a range of raw coal selling prices and a range of mining costs for a ton of coal.
- A coal cleaning plant cost of $18,000 per ton hour input capacity for plants of 500 tons per hour or greater
- A coal cleaning plant financed by a 15-year equal payment self-liquidating loan.
- A coal cleaning plant use factor of 38.5 percent (i.e., plant operates 260 days per year at 13 hours per day).
- A coal cleaning plant property tax and insurance level equal to two percent of the initial investment.
- A power plant ash disposal cost of $4 per ton.
- A power plant coal pulverizing cost of $0.50 per ton.
- Annual stack gas scrubber capital charges that are based on the original investment and the remaining boiler life.
- Stack gas scrubber size/cost values based on recent EPA funded studies and a size/cost exponential relationship of 0.8.
- Stack gas scrubber operating labor cost that does not vary with plant size (i.e., there is a minimum practical labor level).
- General power plant locations that are consistent with actual conditions.
- Coal producing areas serving assumed user locations consistent with past patterns.
- Coal transportation parameters consistent with historical patterns and economical coal delivery (to insure conservative economic relationships).
- An assumed power plant boiler size of 500 Mw with an annual utilization of 7000 hours for a new plant and 5000 hours for a 10 year old plant.
- Stack gas scrubber systems of the minimum "practical" sizes necessary to meet standards.

A sample case study is presented as Table III. The key element in showing economic advantage in favor of the combined approach is in the significant difference in FGD costs. This significant difference results from only 21% of the flue gas being processed by the FGD system as opposed to 85% when cleaned coal is not used. A graphic representation of these two approaches is presented in the diagram opposite.

TABLE III
CASE STUDY

Problem:

Determine most cost-effective approach for new coal burning utility plant to meet emission standard of 1.2 lbs SO_2 per million Btu (MBTU)

Case Conditions:

Coal Use Area: Tonawanda (Buffalo), New York
Coal Source Area: Cambria County, Pennsylvania Coalbed: Lower Freeport
Raw Coal Characteristics: 11.4% Ash, 2.4% Sulfur
Cleaned Coal Characteristics: 6.7% Ash, 1.01% Sulfur

Costs of Alternate Approaches to Meeting Standard:

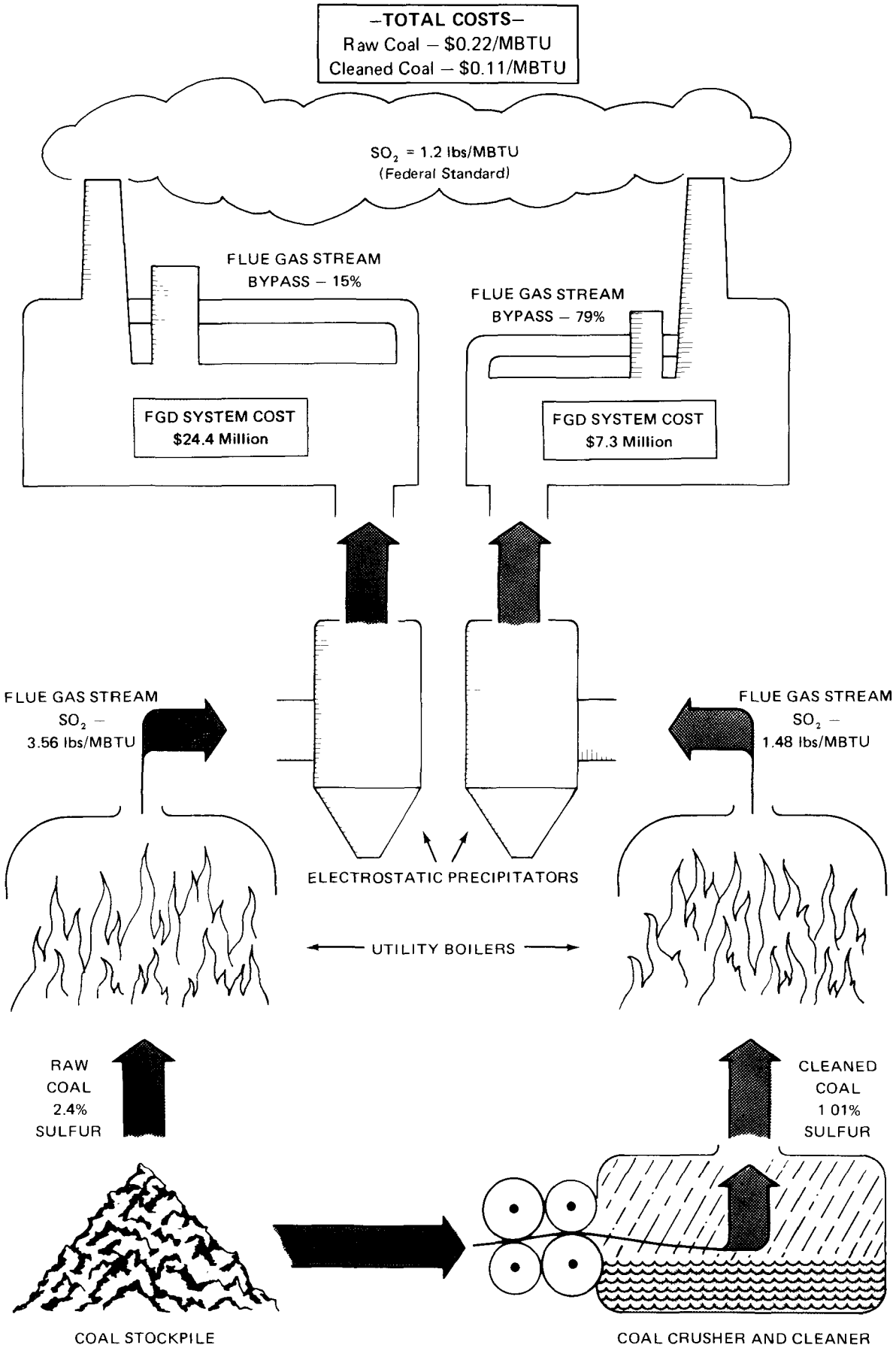
	Physical Cleaning Followed by FGD	*FGD Alone*
Coal Cleaning Cost		
Amortization of Cleaning Plant Capital Cost	$ 0.68/Ton	$ -0-
O & M Cost of Cleaning Plant	0.75/Ton	-0-
Cost of Coal Lost During Cleaning	1.56 To 2.00/Ton	-0-
Taxes & Insurance of Cleaning Plant	0.12/Ton	-0-
Total Cleaning Cost	$ 3.11 To 3.55/Ton	$ -0-
Cost of Flue Gas Desulfurization (FGD)		
Amortization of FGD Capital Cost	$ 0.92/Ton	$2.92/Ton
Fuel & Electricity of FGD System	0.17/Ton	0.66/Ton
O & M Cost of FGD System	0.72/Ton	2.24/Ton
Total FGD Cost	$ 1.81/Ton*	$5.82/Ton*
Benefits of Using Cleaned Coal		
Increased Heat Content	$ 1.21 To 1.40/Ton	$ -0-
Transportation Savings	0.30/Ton	-0-
Ash Disposal Savings	0.21/Ton	-0-
Pulverizing Savings	0.02/Ton	-0-
Maintenance & Other Savings	0.23/Ton	-0-
Total Benefit of Cleaning	$ 1.97 To 2.16/Ton	$ -0-
Net Cost (Costs Less Benefits)	$ 2.76 To 3.39/Ton	$5.82/Ton
Converted to per MBTU	$ 0.10 To 0.12	$0.22

SOLUTION:

The combined approach is the most cost-effective, compared to a 100% additional cost for meeting the standard by FGD alone.

*Significant difference in cost of FGD results from 21% of the flue gas being processed versus 85% in the more expensive approach to meet the required emission standard.

PHYSICAL COAL CLEANING WITH FLUE GAS DESULFURIZATION VS. FLUE GAS DESULFURIZATION ALONE



Additional Benefits

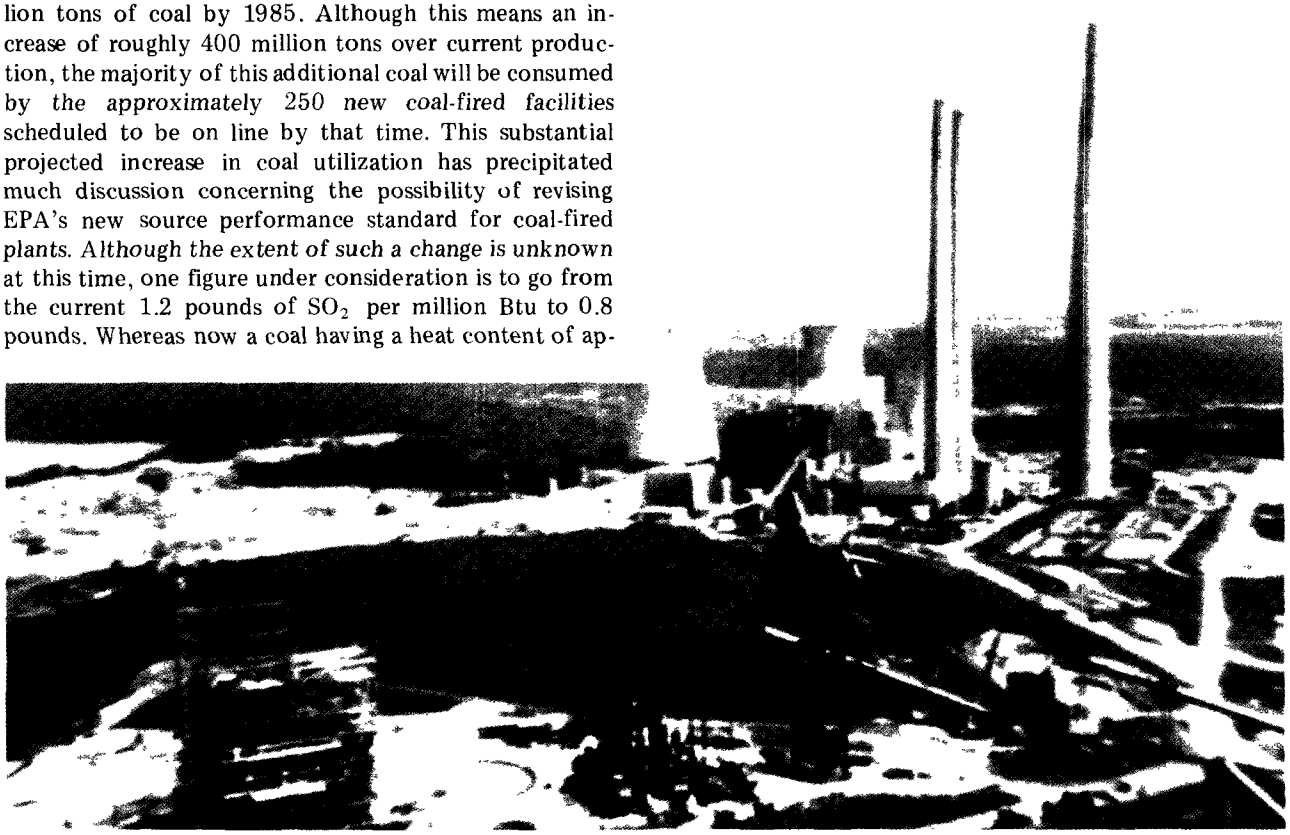
In addition to the benefits covered by this study, there are other positive features associated with combining physical desulfurization and FGD to meet emission standards. Such a benefit accruing from the combination of these two technologies is a decrease in the time required for FGD installation. This occurs for two reasons. First, the total sludge disposal at the plant site can be reduced to about one-quarter of what it would be in the absence of coal cleaning. This will, in some cases, reduce the time required for, and the difficulty with, obtaining legal permits and site acquisition for ponding and/or landfill. Second, as covered by this study, the cleaned coal reduces the volume of flue gas which must be scrubbed to meet emission standards, thereby requiring a smaller, or fewer, FGD units with an associated reduction in construction requirements and time.

Another benefit is the more intangible aspect of physical cleaning in the event of FGD shut-down. Although it cannot be readily quantified, there is a definite environmental benefit associated with the use of physically cleaned coal in the event of a failure in the SO_2 scrubbing system. This benefit is in the form of lower toxic emissions, particularly SO_2, than would have been the case if some sulfur and other contaminants had not been previously removed through physical cleaning.

Continued Prospects

The Federal government as well as the coal industry has established a production goal of more than one billion tons of coal by 1985. Although this means an increase of roughly 400 million tons over current production, the majority of this additional coal will be consumed by the approximately 250 new coal-fired facilities scheduled to be on line by that time. This substantial projected increase in coal utilization has precipitated much discussion concerning the possibility of revising EPA's new source performance standard for coal-fired plants. Although the extent of such a change is unknown at this time, one figure under consideration is to go from the current 1.2 pounds of SO_2 per million Btu to 0.8 pounds. Whereas now a coal having a heat content of approximately 25 million Btu's per ton and a sulfur content of 0.8% can meet standard, only those coals of 0.5% or less sulfur content could meet the 0.8 pounds of SO_2 per million Btu standard. If the standard is revised in this manner, there will be a significant reduction in the amount of coal which can be consumed without the use of SO_2 emission control devices. This would include both the coals naturally occurring with a low enough sulfur content and those capable of meeting the current standard through physical cleaning alone.

However, should the standard be amended, it will not negate the benefits associated with coal cleaning as set forth in this report (Table I). What it will mean is a reevaluation of emission control strategy on the part of potential coal users. Since coal having a sulfur content of 0.5% or less (either occurring naturally or after cleaning) is in limited supply and high in price due to pressure from the metallurgical market, it is impractical to consider the widespread burning of coal in new facilities without any SO_2 emission control devices under a 0.8 pounds of SO_2 per million Btu standard. This being the case, in searching for the most cost-effective approach to meeting any revised standard, the impact of coal preparation on reducing emission control costs as outlined by this report should be carefully considered. After such appraisal, users may find that, under their particular circumstances, the use of physically cleaned coal in combination with stack gas scrubbing will show a definite economic advantage even under more restrictive emission standards.



Summarization of Case Results

A total of forty-eight case analyses were performed. Each case examines one of twelve selected coals and possible use areas from the standpoint of both a new and an existing utility plant using either a combination of physically cleaned coal followed by stack gas scrubbing, or sulfur cleanup exclusively by stack gas scrubbing (i.e., flue gas desulfurization). The cases are grouped according to coal and use area. This permits ease of comparison between like plants using the same coal in the same area but utilizing two different approaches to meeting existing or projected environmental standards. In most cases, the emission standards used were applicable as of January 1976. However, where knowledge of projected changes was present, those standards were used and identified accordingly.

Included as part of this paper are summaries of each of the forty-eight cases analyzed. As stated above, these summaries are grouped in sets for comparison of the costs associated with meeting emission standards by the two alternate approaches. For example, Case Numbers 1A, 1B, 1C and 1D are based upon an actual coal coming from Sullivan County, Indiana which is assumed being used in a utility plant in the Knoxville, Tennessee area. Cases 1A and 1B approach the analysis on the basis of an assumed new facility, whereas Cases 1C and 1D assume an existing facility. However, Case Numbers 1A and 1C address the analysis using a combination of physically cleaned coal followed by stack gas scrubbing, whereas Case Numbers 1B and 1D approach the situation from the standpoint of using stack gas scrubbing alone. As can be readily seen from the summarization of these cases, the cost to meet the applicable sulfur emission standard is less in Case Numbers 1A and 1C which are the plans using physically cleaned coal followed by flue gas desulfurization (FGD) in new and existing facilities, respectively. In each set of cases, the relative economic advantage (or disadvantage) is expressed as a percent for comparative purposes. The manner of stating economic advantage (*less* costly) or disadvantage (*more* costly) is dependent upon what if any action the coal-using plant has taken to meet environmental standards. For example if, as in the case of 1C, the utility is using physically cleaned coal followed by FGD, then economic advantage could be stated as their cost is 25% less than by FGD alone. If, as in case 1D, the utility is using FGD alone, then economic disadvantage could be stated as their cost is 33% more than by the combined FGD/coal cleaning approach.

CASE RESULTS
[Sample Form]

Case Numbers:

Case Conditions

Coal Use Area: _____

Coal Source Area: _____ Coalbed: _____

Raw Coal Characteristics: _____ % Ash _____ % Sulfur

Clean Coal Characteristics: _____ % Ash _____ % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
_	New Plant PC Followed by FGD			
_	New Plant FGD Alone			
_	Existing Plant PC Followed by FGD			
_	Existing Plant FGD Alone			

CASE RESULTS

Case Numbers: 1A, 1B, 1C, & 1D

Case Conditions

Coal Use Area: Knoxville (Clinton), Tennessee

Coal Source Area: Sullivan County, Indiana Coalbed: Number VII

Raw Coal Characteristics: 10.5 % Ash 1.87 % Sulfur

Clean Coal Characteristics: 7.3 % Ash 1.11 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
1A –	New Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.15-0.17 per MBTU	16% less than by FGD alone
1B –	New Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.19 per MBTU	19% more than by PC & FGD
1C –	Existing Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.23-0.25 per MBTU	25% less than FGD alone
1D –	Existing Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.32 per MBTU	33% more than by PC & FGD

Case Numbers: 2A, 2B, 2C, & 2D

Case Conditions

Coal Use Area: Tonawanda (Buffalo), New York

Coal Source Area: Cambria County, Pennsylvania Coalbed: Lower Freeport

Raw Coal Characteristics: 11.4 % Ash 2.4 % Sulfur

Clean Coal Characteristics: 6.7 % Ash 1.01 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
2A –	New Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.10-0.12 per MBTU	50% less than by FGD alone
2B –	New Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.22 per MBTU	100% more than by PC & FGD
2C –	Existing Plant PC Followed by FGD	1.4 lbs SO_2 per MBTU	$0.06-0.09 per MBTU	50% less than by FGD alone
2D –	Existing Plant FGD Alone	1.4 lbs SO_2 per MBTU	$0.15 per MBTU	100% more than by PC & FGD

CASE RESULTS

Case Numbers: 3A, 3B, 3C & 3D

Case Conditions

Coal Use Area: Essexville (Saginaw), Michigan

Coal Source Area: Harrison County, Ohio Coalbed: Lower Freeport

Raw Coal Characteristics: 10.4 % Ash 2.30 % Sulfur

Clean Coal Characteristics: 4.8 % Ash 1.26 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
3A –	New Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.12-0.14 per MBTU	38% less than by FGD alone
3B –	New Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.21 per MBTU	62% more than by PC & FGD
3C –	Existing Plant PC Followed by FGD	1.6 lbs SO_2 per MBTU	$0.11-0.14 per MBTU	58% less than FGD alone
3D –	Existing Plant FGD Alone	1.6 lbs SO_2 per MBTU	$0.30 per MBTU	140% more than by PC & FGD

Case Numbers: 4A, 4B, 4C, & 4D

Case Conditions

Coal Use Area: Boston, Massachusetts

Coal Source Area: Clearfield County, Pennsylvania Coalbed: Upper Kittanning

Raw Coal Characteristics: 9.3 % Ash 0.85 % Sulfur

Clean Coal Characteristics: 7.0 % Ash 0.45 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
4A –	New Plant PC Followed by FGD	0.28 lbs sul. per MBTU	$0.12-0.14 per MBTU	24% less than by FGD alone
4B –	New Plant FGD Alone	0.28 lbs sul. per MBTU	$0.17 per MBTU	31% more than by PC & FGD
4C –	Existing Plant PC Followed by FGD	0.28 lbs sul. per MBTU	$0.17-0.19 per MBTU	38% less than by FGD alone
4D –	Existing Plant FGD Alone	0.28 lbs sul. per MBTU	$0.29 per MBTU	61% more than by PC & FGD

CASE RESULTS

Case Numbers: 5A, 5B, 5C, & 5D

Case Conditions

Coal Use Area: Grand Rapids, Michigan

Coal Source Area: Preston County, W. Virginia Coalbed: Upper Freeport

Raw Coal Characteristics: 18.5 % Ash 2.24 % Sulfur

Clean Coal Characteristics: 11.9 % Ash 1.25 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
5A –	New Plant PC Followed by FGD	1.6 lbs SO_2 per MBTU	\$0.07-0.10 per MBTU	53% less than by FGD alone
5B –	New Plant FGD Alone	1.6 lbs SO_2 per MBTU	\$0.18 per MBTU	112% more than by PC & FGD
5C –	Existing Plant PC Followed by FGD	1.6 lbs SO_2 per MBTU	\$0.12-0.14 per MBTU	57% less than FGD alone
5D –	Existing Plant FGD Alone	1.6 lbs SO_2 per MBTU	\$0.30 per MBTU	131% more than by PC & FGD

Case Numbers: 6A, 6B, 6C, & 6D

Case Conditions

Coal Use Area: Springfield, Massachusetts

Coal Source Area: Armstrong County, Penn. Coalbed: Upper Freeport

Raw Coal Characteristics: 13.0 % Ash 2.53 % Sulfur

Clean Coal Characteristics: 7.2 % Ash 1.09 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
6A –	New Plant PC Followed by FGD	0.55 lbs sulfur per MBTU	\$0.11-0.13 per MBTU	48% less than by FGD alone
6B –	New Plant FGD Alone	0.55 lbs sulfur per MBTU	\$0.23 per MBTU	92% more than by PC & FGD
6C –	Existing Plant PC Followed by FGD	0.55 lbs sulfur per MBTU	\$0.18-0.21 per MBTU	49% less than by FGD alone
6D –	Existing Plant FGD Alone	0.55 lbs sulfur per MBTU	\$0.38 per MBTU	95% more than by PC & FGD

CASE RESULTS

Case Numbers: 7A, 7B, 7C, & 7D

Case Conditions

Coal Use Area: Lansing, Michigan

Coal Source Area: Jefferson County, Ohio Coalbed: Pittsburgh

Raw Coal Characteristics: 9.8 % Ash 2.82 % Sulfur

Clean Coal Characteristics: 6.0 % Ash 2.03 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
7A –	New Plant PC Followed by FGD	1.6 lbs SO_2 per MBTU	$0.19-0.22 per MBTU	6.8% less than by FGD alone
7B –	New Plant FGD Alone	1.6 lbs SO_2 per MBTU	$0.22 per MBTU	7.3% more than by PC & FGD
7C –	Existing Plant PC Followed by FGD	1.6 lbs SO_2 per MBTU	$0.30-0.32 per MBTU	11% less than FGD alone
7D –	Existing Plant FGD Alone	1.6 lbs SO_2 per MBTU	$0.35 per MBTU	13% more than by PC & FGD

Case Numbers: 8A, 8B, 8C, & 8D

Case Conditions

Coal Use Area: Nashville (Gallatin), Tennessee

Coal Source Area: Vigo County, Indiana Coalbed: Number VII

Raw Coal Characteristics: 12.0 % Ash 1.54 % Sulfur

Clean Coal Characteristics: 7.7 % Ash 0.90 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
8A –	New Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.11-0.13 per MBTU	25% less than by FGD alone
8B –	New Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.16 per MBTU	33% more than by PC & FGD
8C –	Existing Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.16-0.18 per MBTU	39% less than by FGD alone
8D –	Existing Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.28 per MBTU	65% more than by PC & FGD

CASE RESULTS

Case Numbers: 9A, 9B, 9C, & 9D

Case Conditions

Coal Use Area: Burlington, New Jersey

Coal Source Area: Garrett County, Maryland Coalbed: Upper Freeport

Raw Coal Characteristics: 13.8 % Ash 2.37 % Sulfur

Clean Coal Characteristics: 8.8 % Ash 1.6 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
9A –	New Plant PC Followed by FGD	0.30 lbs SO_2 per MBTU	This coal will not meet emission standards for new plants in the State of New Jersey with either combined physical cleaning and FGD or FGD alone.	
9B –	New Plant FGD Alone	0.30 lbs SO_2 per MBTU		
9C –	Existing Plant PC Followed by FGD	1% sulfur by weight per MBTU	$0.23-0.25 per MBTU	25% less than FGD alone
9D –	Existing Plant FGD Alone	1% sulfur by weight per MBTU	$0.32 per MBTU	33% more than by PC & FGD

Case Numbers: 10A, 10B, 10C, & 10D

Case Conditions

Coal Use Area: Milwaukee, Wisconsin

Coal Source Area: Franklin County, Illinois Coalbed: Number 6

Raw Coal Characteristics: 14.8 % Ash 1.12 % Sulfur

Clean Coal Characteristics: 7.1 % Ash 0.95 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
10A –	New Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.07-0.10 per MBTU	29% less than by FGD alone
10B –	New Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.12 per MBTU	41% more than by PC & FGD
10C –	Existing Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU	$0.12-0.15 per MBTU	33% less than by FGD alone
10D –	Existing Plant FGD Alone	1.2 lbs SO_2 per MBTU	$0.20 per MBTU	48% more than by PC & FGD

CASE RESULTS

Case Numbers: 11A, 11B, 11C, & 11D

Case Conditions

Coal Use Area: Concord, New Hampshire

Coal Source Area: Greene County, Pennsylvania Coalbed: Sewickley

Raw Coal Characteristics: 11.4 % Ash 3.45 % Sulfur

Clean Coal Characteristics: 8.1 % Ash 2.20 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
11A –	New Plant PC Followed by FGD	1.2 lbs SO_2 per MBTU (projected standard)	$0.25-0.28 per MBTU	2% less than by FGD alone
11B –	New Plant FGD Alone	1.2 lbs SO_2 per MBTU (projected standard)	$0.27 per MBTU	2% more than by PC & FGD
11C –	Existing Plant PC Followed by FGD	1.5 lbs sulfur per MBTU	$0.12-0.14 per MBTU	54% less than FGD alone
11D –	Existing Plant FGD Alone	1.5 lbs sulfur per MBTU	$0.28 per MBTU	115% more than by PC & FGD

Case Numbers: 12A, 12B, 12C, & 12D

Case Conditions

Coal Use Area: Dickerson (Montgomery County), Maryland

Coal Source Area: Marion County, W. Virginia Coalbed: Pittsburgh

Raw Coal Characteristics: 11.0 % Ash 3.80 % Sulfur

Clean Coal Characteristics: 5.9 % Ash 2.16 % Sulfur

Comparison of Costs

CASE NO.	*TYPE OF PLANT & APPROACH*	*EMISSION STANDARD*	*COST TO MEET EMISSION STD.*	*ECONOMIC ADVANTAGE*
12A –	New Plant PC Followed by FGD	1% sulfur by weight	$0.20-0.23 per MBTU	20% less than by FGD alone
12B –	New Plant FGD Alone	1% sulfur by weight	$0.27 per MBTU	26% more than by PC & FGD
12C –	Existing Plant PC Followed by FGD	1% sulfur by weight	$0.32-0.34 per MBTU	23% less than by FGD alone
12D –	Existing Plant FGD Alone	1% sulfur by weight	$0.43 per MBTU	30% more than by PC & FGD

FOR FURTHER READING

Engineering/Economic Analyses of Coal Preparation with SO_2 Clean Up Process for Keeping Higher Sulfur Coals In the Energy Market. Final report under U.S. Bureau of Mines, Contract no. J-0155-171. November 1976.

This report is a comprehensive study of 48 actual cases where either a combination of physical coal cleaning and scrubbing was used, or sulfur clean up was accomplished entirely by flue gas scrubbing. The full report will be published by EPA in mid-1977 and will be available from the Office of Energy, Minerals, and Industry, RD-681, U.S. EPA, Washington, D.C. 20460.

Sulfur Reduction Potential of the U.S. Coals: A Revised Report of Investigations EPA-600/2-76-091

This report presents the results of a washability study of 455 raw coal samples from major United States coal production regions. The emphasis was on sulfur reduction potential with summary data of the number of samples meeting the EPA new source performance standard under varying degrees of preparation (cleaning).

Steam—Electric Plant Factors, 1975 Edition, National Coal Association, Washington, D.C. 20036.

From this NCA publication, existing and planned electric power plant generation capacity can be observed by specific location. Additionally the type of fuel being consumed by the specific plant is given with heat content and price. From this information, future demand patterns can be projected.

Demonstrated Coal Reserve Base of the United States, By Sulfur Category, On January 1, 1974. U.S. Bureau of Mines, Mineral Industry Surveys, Washington, D.C. 20241. May 1975.

This report presents a concise geographic summary of U.S. coal reserves according to three ranges of sulfur content.

"All That An Oil Company President Needs To Know About Washing Bituminous Coal," Special Issue of *B.T.U.*, McNally Pittsburg Manufacturing Corp., Pittsburg, Kansas, 66762. May 1972.

An extremely well-written, non-technical description of the major coal cleaning methods. Also includes easy to understand definitions of industry terms.

The Effect of Coal Quality on the Operation and Maintenance of Large Central Station Boilers. Paper written by John G. Holmes, Jr. of TVA for presentation at Annual Meeting of American Institute of Mining, Metallurgical, and Petroleum Engineers, Washington, D.C. February 16-20, 1969.

Presents comparative data on maintenance records of two boilers utilizing coals of different ash and sulfur contents. These data demonstrate a definite reduction in O & M costs as a function of reduced impurities. This publication may be obtained by writing to American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 345 E. 47th Street, N.Y., N.Y. 10017.