EPA'S COAL CLEANING PROGRAM
STATUS AND STRATEGY

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INTRODUCTION

Sulfur oxide air pollution emissions from coal combustion exceeded 20.5 million tons in 1974. With the increasing use of coal as an energy source, improved methods are needed for the control of this pollutant. Major strategies for the control of SO_2 emissions include the use of coal cleaning, the combustion of coal in chemically active fluidized beds, the removal of pollutants by flue gas scrubbing and the generation of clean synthetic fuels. An economically attractive control strategy is coal cleaning. This paper presents the current status of coal cleaning technology, and discusses barriers which must be overcome before this technology can be widely implemented for SO_2 emission control.

TECHNICAL STATUS

Coal Cleanability

The sulfur content of coal normally ranges from less than 1 to more than 7 percent. Sulfur appears in coal in three forms: mineral sulfur in the form of pyrite (FeS_2), organically bound sulfur and trace quantities of "sulfate" sulfur. Sulfate sulfur occurs in coal as a result of the attack of oxygen on the mineral pyrite. It is soluble in water and can be removed in wet coal preparation plants. Organic sulfur occurs as part of the organic coal structure and cannot be removed by physical coal preparation techniques. Pyrite occurs in coal seams in sizes ranging from small discrete particles to large lumps. It can be found intimately dispersed in the coal substance, in bands, in layers or in large pieces.

Physical preparation or cleaning techniques are capable of removing varying fractions of the coal pyritic sulfur as determined by the properties of each coal. Chemical processes are capable of removing over 95 percent of the pyritic sulfur and up to about 70 percent of the organic sulfur.

Laboratory float-sink studies have been performed on over 455 U.S. coals to determine their physical cleanability.(1) The samples tested were from mines in the six major coal producing regions of the U.S., the mines which provide more than 70 percent of the coal used in U.S. utility boilers.

The results of these float-sink tests indicate that in general pyrite removal increases with reduced particle size and specific gravity of separation. This fact is extremely important. It implies that to enhance pyritic sulfur removal more of the coal must be crushed and and processed at finer particle sizes than historically practiced in coal preparation. A second important fact determined by these studies is that the final sulfur levels to which coals can

(1) Superior numbers refer to similarly numbered references at the end of this paper.

be cleaned vary from coal region to coal region and from one coal bed to another within the same region (coal cleanability also varies to a lesser extent from location to location within the same mine). These differences in physical cleaning potential are the result of variations in the organic and pyritic sulfur levels and the morphology of the coal-pyrite matrix.

Sulfur removal by chemical methods is dependent upon coal properties and process conditions--time, pressure, temperature, and chemical reagents. A number of experimentors have studied these relationships [2][3]. In other instances the availability of information is limited because it is considered to be proprietary. Process costs will probably limit the amount of sulfur which can be removed to about 95 percent of the pyritic sulfur and 40 percent of the organic sulfur.

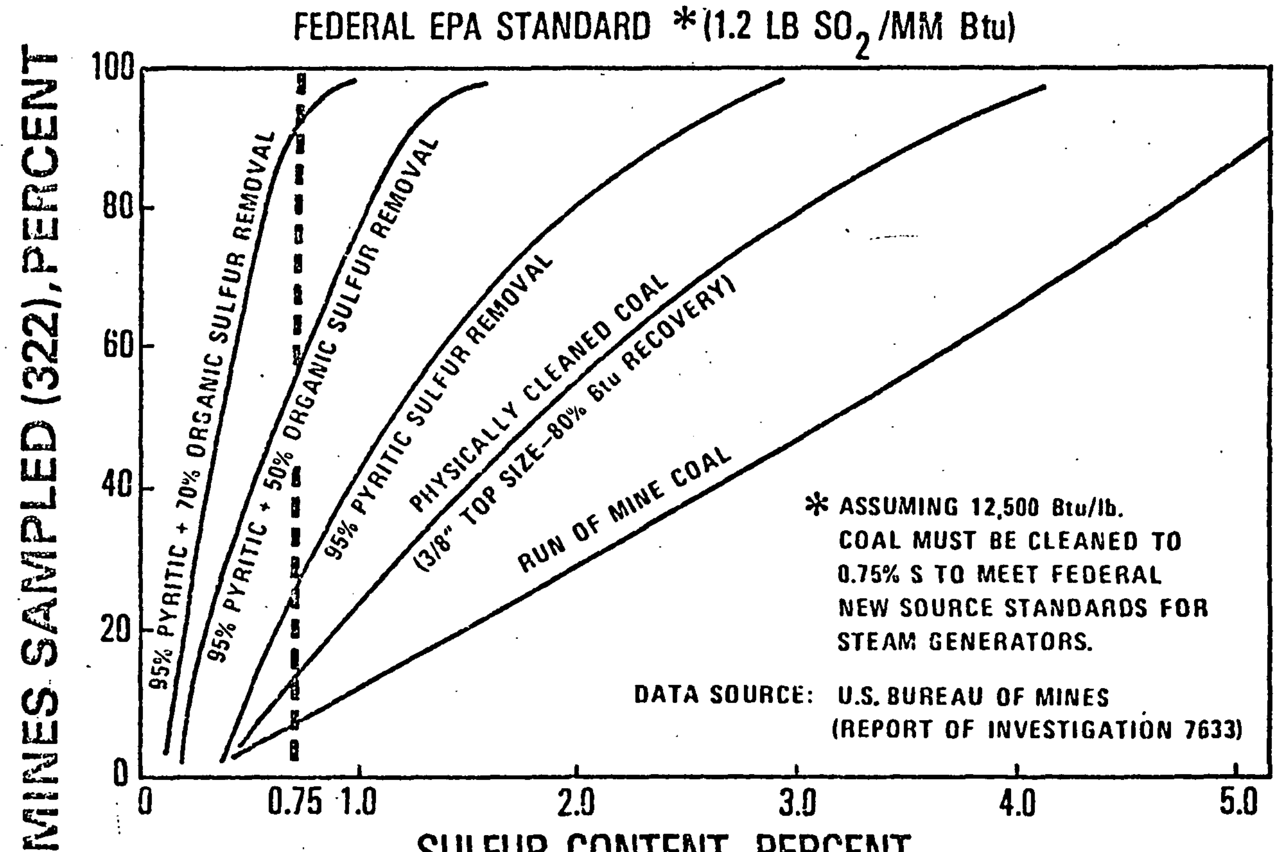
Figure 1 presents parametric relationships between the degree of cleaning (pyritic and organic sulfur reduction), the sulfur level of the cleaned coal and the percentage of utility coals which can be cleaned to a specified sulfur content.

Coal Cleaning Costs

The costs of physical and chemical coal cleaning for sulfur removal are to a large extent undefined. Physical cleaning has traditionally been used to remove ash and mining residues from coals. There is virtually no data correlating costs and sulfur removal in commercial coal cleaning equipment. However, substantial data exists on the costs of cleaning for ash removal. Using this data one can deduce the costs of sulfur removal from correlations between ash and sulfur removal in commercial equipment. While these correlations are few and tenuous they do provide estimates which indicate that in many cases physical coal cleaning will be a more cost effective emission control technique than flue gas desulfurization (FGD). However, physical cleaning is not a panacea since it cannot remove organic sulfur from coal or in some cases sufficient pyritic sulfur.

Chemical coal cleaning is capable of removing nearly all the pyritic sulfur and a substantial fraction of the organic sulfur. However, chemical cleaning is more costly than physical cleaning. Costs for its use may range from the costs of FGD to the costs of producing synthetic fuels from coal. Further because of its early state of development the stated costs for chemical cleaning coal are less certain than those for physical cleaning.

Cost estimates for physical coal cleaning, chemical coal cleaning and FGD are presented in Table 1. The wide range in costs results from different site specific factors, such as coal cleanability, plant capacity, and sulfur emission regulation, which must be accounted for. While a detailed discourse of costs is beyond the scope of this paper one must conclude that for those instances where physical cleaning is applicable it will be more cost effective than FGD. One cannot currently draw conclusions on the applicability of chemical coal cleaning as an SO_2 emission control method based solely upon economic arguments. These costs must first be placed upon a firmer foundation by additional research, development and demonstration activities.



POTENTIAL LEVELS OF DESULFURIZATION FOR U.S. UTILITY COALS.

Figure 1

TABLE 1

COMPARATIVE TECHNOLOGY COSTS

	Capital Costs ($/kW)	Operating Cost (mills/kWh)	Total Annualized Costs (mills/kWh)	Sulfur Removal Efficiency (%)	Energy Penalty (%)
FLUE GAS DESULFURIZATION					
Regenerable[a] (Sodium or Magnesium)	70-85[b]	2.5-3.6[c,e]	4.0-5.4[c]	>85	∿5
Nonregenerable[a]	60-70[b]	2.1-2.2[c,e]	3.4-3.7[c]	>85	∿3
COAL CLEANING	9.3-22.1	0.15-1.19[d]	1.2-2.4[d]	30-50	3-10

a. 500 MW, new plant, using 3.5% sulfur coal, 90% SO_2 removal.

b. Average cost basis for 1977 dollars, includes sludge disposal pond with clay liner.

c. Average cost basis for 1978 dollars, amortized over 30 years, power unit on stream 7000 hrs/yr, investment and revenue requirements for disposal of fly ash excluded.

d. Assume 3960 operational hours/year, 10,000 BTU's/kWh, and 11,000 BTU/lb for Eastern coal, 5% coal cleaning BTU loss, and coal energy cost of $0.6 per 10^6 BTU.

e. Calculated from annualized cost data assuming a 15 percent rate of return (with adjustment for depreciation, taxes, replacement, and insurance.)

Status of Coal Cleaning Technology

Coal preparation processes for steam coal are oriented toward the removal of ash and mining residue. Chemical coal cleaning is in the early stages of development and it is estimated that a commercial plant could not be put into operation for at least 5 to 10 years. Figure 2 summarizes several chemical coal cleaning processes now under development. The remaining discussions will deal primarily with the use of physical coal cleaning as an SO_2 pollution control method.

The physical removal of pyritic sulfur from steam coal has not been commercially used as a method of SO_2 emission control. The physical removal of pyrite from many coals will require crushing to fine particle sizes prior to separation. Separation at these fine sizes while not impossible represents a shift to a mix of equipment and operating conditions which is different from those traditionally

PROCESSES UNDER DEVELOPMENT	DESCRIPTION	MAX. SULFUR REDUCTION, PERCENT		STATUS
		PYRITIC	ORGANIC	
ARCO	CATALYTIC DEMETALLIZATION	95	40	LABORATORY EXPERIMENTS
BATTELLE HYDROTHERMAL	CAUSTIC LEACHING [$NaOH$-$Ca(OH)_2$]	95	40	0.25 tpd MINI-PLANT
ERDA, BRUCETON, PA	OXI-DESULFURIZATION (AIR-STEAM)	99	40	LABORATORY EXPERIMENTS; DESIGN OF CONTINUOUS UNIT
TRW	AQUEOUS FERRIC SULFATE LEACHING [$Fe_2(SO_4)_3$]	95	NIL	LABORATORY EXPERIMENTS; CONSTRUCTION OF A 667LB/HR TEST UNIT

STATUS OF SELECTED CHEMICAL TREATMENT PROCESSES

Figure 2

used for steam coal preparation. Dewatering and drying of a large percentage of fine coal may be required for many of the new plants.

The variability of sulfur forms within a coal bed or mine presents a special problem which will require the development of improved technology if coal cleaning is to be used for SO_2 emission control. Methods are needed for controlling the sulfur variation in the plant feed, and process instrumentation is needed to control the product sulfur level.

The coal preparation plant performance in removing pyritic sulfur can be seriously affected by wide variations in feed coal properties. Development of mining and blending schemes to minimize the pyritic sulfur variations in the feed coal will be needed to insure a product coal which consistently meets fuel sulfur requirements. Currently there is little published data on the variability of fuel sulfur forms in coal beds. The effects of mining, blending and preparation plant operations in "averaging out" the cleaned coal sulfur level are unknown. Because of these factors, the cleaning plant must now be designed to remove sufficient pyritic sulfur so that even at peak raw coal sulfur levels (both organic and pyritic) the product coal sulfur will be maintained below that required by the fuel sulfur emission regulation. This approach may not be practical in some cases as it would require the reject of large quantities of fuel which do not exceed the emission regulation.

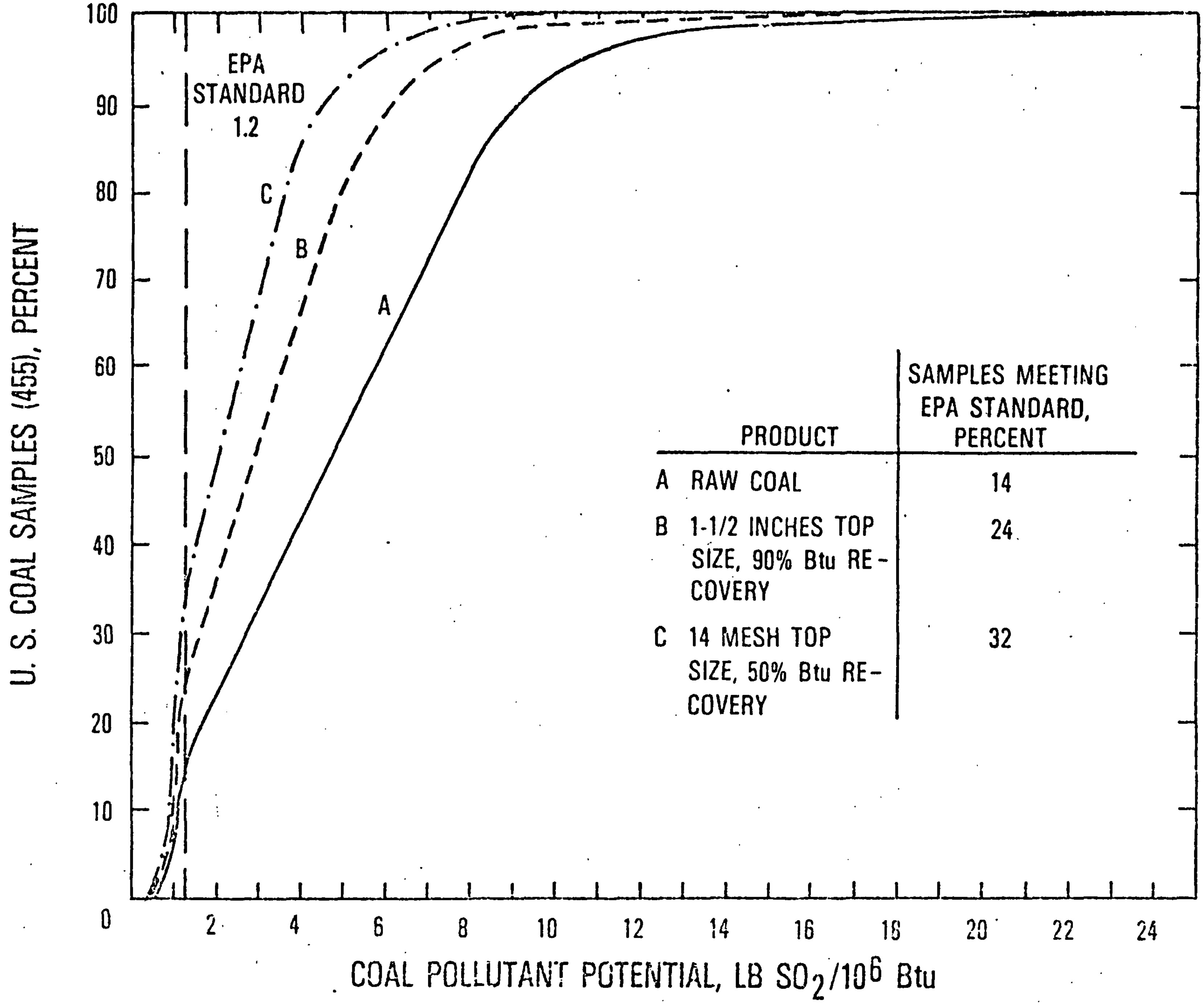
A long term objective would be to develop process instruments and controls which could be used to adjust plant operating conditions in response to the changes in the feed coal sulfur content. This method of control would allow optimization of sulfur removal and BTU recovery. Unfortunately instruments which can be used for a real time determination of coal sulfur, ash and BTU values are not commercially available.

Options for Using Coal Cleaning

Physical coal cleaning can be used on a limited number of U.S. coals to meet federal new source performance standards (NSPS) for steam generators. Moreover a large number of coals can be physically cleaned and used:

1. To meet less stringent state SO_2 emission standards.
2. In conjunction with flue gas desulfurization (FGD) to lower emission control costs.
3. To produce a multiplicity of product coal fractions, each with a different fuel sulfur value.

Only 14 percent of the 455 U.S. coals tested by the Bureau of Mines are capable of meeting NSPS standards without cleaning[1]. Physically cleaned at a top size of 1-1/2 in. and with a BTU recovery of 90 percent (10 percent of the heat from the mined coal would be lost) a total of 24 percent of these coals



EFFECT OF CLEANING VARIABLE ON COAL POLLUTION POTENTIAL

FIGURE 3

CUMULATIVE ANALYSES OF FLOAT 1.60 PRODUCT FOR 3/8" TOP SIZE

COAL REGION	NO. SAMPLES	PERCENT				POUNDS SO $/10^6$ Btu	CALORIFIC CONTENT, Btu PER POUND
		Btu RECOVERY	ASH	PYRITIC SULFUR	TOTAL SULFUR		
NORTHERN APPALACHIAN	227	92.5	8.0	0.85	1.96	2.7	13,766
SOUTHERN APPALACHIAN	35	96.1	5.1	0.19	0.91	1.3	14,197
ALABAMA	10	96.4	5.8	0.49	1.16	1.7	14,264
EASTERN MIDWEST	95	94.9	7.5	1.03	2.74	4.2	13,138
WESTERN MIDWEST	44	91.7	8.3	1.80	3.59	5.5	13,209
WESTERN	44	97.6	6.3	0.10	0.56	0.9	12,779
TOTAL U. S.	455	93.8	7.5	0.85	2.00	3.0	13,530

SUMMARY OF THE PHYSICAL DESULFURIZATION POTENTIAL OF COALS BY REGION

TABLE 2

could meet NSPS. The percentage of coal which will be cleaned to NSPS levels could be increased by either a reduction in the particle size of coal being cleaned or a reduction in the BTU recovery value of the cleaned product. In the latter case the reject coal could probably be used in a boiler with FGD. It should be pointed out that the percentages given are based on existing coal production and not on the quality of reserves. Additionally, the values are nominal and do not account for the variability of sulfur in coal. Both of these factors should tend to reduce the percentage of coals capable of meeting the NSPS.

A much larger percentage of coals are capable of meeting widely varying state standards. Table 2 presents data on the amounts of pyritic sulfur which can be removed from coal samples from six regions by cleaning at conditions typically used in commercial coal preparation plants for ash reduction. As illustrated the average fuel sulfur values for the cleaned coals from these six regions range from 0.9 to 5.5 lb $SO_2/10^6$ BTU. In all cases the BTU recovery exceeds 91 percent. Many states have emission regulations which range from 2.0 to 5.0 lb $SO_2/10^6$ BTU and a large portion of the tested coals can be cleaned to meet these regulations. Figure 3 presents the relationship between selected cleaning conditions and the number of samples which can be cleaned to meet specific emission standards.

The use of physical coal cleaning in combination with flue gas desulfurization (FGD) represents an approach where the advantages of each technique can be used to minimize emission control costs while permitting the most effective use of U.S. coal resources. A recent study on the use of a combination of physical coal cleaning and flue gas desulfurization shows significant economic advantages to this combined pollution control method.[(4)] In 36 case studies in areas where local regulations for SO_2 emissions vary from 1.2 to 1.6 lb $SO_2/10^6$ BTU, the cost of using a combination of <u>conventional</u> coal cleaning and flue gas desulfurization was 2 to 55 percent lower than flue gas desulfurization alone for new plants and 10 to 60 percent lower for existing plants. The arithmetic average for the cases cited showed costs which were about 30 percent lower for new plants and 40 percent lower for existing plants.

An alternative strategy which would make greater utilization of our coal resources would be to prepare (clean) coal in such a fashion that it is divided into a number of fractions - each with a different sulfur content. Each coal fraction could thus be used in a different boiler to meet different sulfur emission regulations. The multi-stream coal cleaning strategy being used at the Pennsylvania Electric Company's (PENELEC) Homer City plant for the physical desulfurization of coal is an example of this approach to pollution control. At the Homer City plant, the product coals will include 800 tons per hour (tph) of coal with an equivalent sulfur emission value of 4.0 lb $SO_2/10^6$ BTU and 400 tph of coal with a sulfur emission value of 1.2 lb $SO_2/10^6$ BTU.

The production of multiple coal streams in commercial plants to produce fuel for several non-utility markets has significant potential. Mine-mouth preparation plants of advanced design could produce a number of product coals with different fuel sulfur levels. The lower sulfur fuels could be sold for use in commercial or industrial boilers in which the scale of operation makes FGD uneconomical. The higher sulfur coals could be used in existing boilers which are not subjected to stringent standards or they could be burned in large boilers equipped with FGD systems.

EPA'S COAL CLEANING PROGRAM

IERL-RTP and its predecessor organizations have been involved in the development of coal cleaning as an emission control technique since 1965. R&D supported by these organizations has provided the data base for the assessment of coal cleaning as an air pollution control strategy. The current IERL-RTP coal cleaning program is structured under three main program headings: (1) the assessment and development of coal cleaning as an air pollution control technology; (2) the evaluation of pollution which results from coal cleaning processes and (3) the development of improved pollution control techniques for coal cleaning processes.

In addition to the management of contract work, IERL-RTP is responsible for directing cooperative interagency work with the Department of Interior (U.S. Bureau of Mines and U.S. Geological Survey) and the Energy Research and Development Administration. Total support for these interagency programs from FY 75 to FY 77 has exceeded $3.9 million. These programs have encompassed more than 20 individual projects. Principal contract work now directed by IERL-RTP includes: a coal cleaning demonstration test and evaluation program at PENELEC's Homer City Power Complex; the construction and operation of the TRW chemical coal cleaning reactor at Capistrano, California; a project assessing pollutant emission from commercial coal cleaning plants; and a project evaluating the performance of commercial coal cleaning equipment in removing sulfur.

At Homer City tests will be made to determine the performance of the advanced technology, 1200 tph coal preparation plant in removing pyritic sulfur from central Pennsylvania coals. Environmental tests will also be made to assess pollution from the coal cleaning process and determine the effects of using cleaned coals on power plant operation.

The pilot scale chemical coal cleaning work at TRW will evaluate the performance and costs of aqueous ferric sulfate in leaching pyritic sulfur from coal. A 10 month test and evaluation program is scheduled to start this May at the 1/3-tph test facility.

Two major multi-year contracts with the objectives of evaluating the environmental impacts from coal cleaning processes and in developing costs and performance data for these processes are in their first year of operation.

BARRIERS TO THE IMPLEMENTATION OF COAL CLEANING TECHNOLOGY

Technical and Regulatory Uncertainties

There is still considerable economic risk related to technical and regulatory uncertainties which act as effective barriers to the implementation of physical coal cleaning as an SO_2 emission control strategy. The use of coal cleaning as a tool for meeting SO_2 emission regulations is based upon engineering and scientific judgment. This pollution control strategy has been used only in a few isolated cases, generally with easily cleaned coals. The unknown economic risks are primarily related to the requirement for meeting consistent fuel sulfur specifications. In a given plant the mix of equipment or the process controls may not prove to be adequate to consistently remove pyritic sulfur to the required degree. Technical solutions to this problem would involve a number of economically unattractive alternatives:

1. Adjust the preparation plant operating conditions in a manner which would reduce the fuel recovered from the plant feed.

2. Make extensive equipment modifications.

3. Add a partial FGD system to the boiler.

A great deal of this economic risk could be reduced by more flexible regulatory activities. The modification of existing emission regulations to permit emissions to be averaged over a moderate time period, say 8 hours, would greatly alleviate this risk. In cases where a mix of emission regulations applies to a single site, the use of a site average emission regulation could in some instances reduce control costs and risks.

Other technical or regulatory uncertainties include:

1. The costs of pollution control requirements for advanced coal preparation plants.

2. Changes in boiler operating and maintenance costs which result from the firing of cleaned coal.

3. The effects of firing cleaned coal on the performance of electrostatic precipitators.

Extensive commercialization of physical coal cleaning for SO_2 emission control probably cannot be expected until these uncertainties are resolved.

Institutional and Economic Barriers

A number of institutional and economic barriers block implementation of the use of coal cleaning for SO_2 emission control. Among these barriers are existing investments and contracts, the dependency of the utility industry upon other organizations for its fuel supply, a limited supply of personnel familiar with coal cleaning, and the high cost of capital.

Vertical integration in the utility industry is not common. Few utilities own their own fuel resources. A large percentage of coal resources are owned by railroads, steel companies, coal companies, oil companies and private owners. The common practice is to obtain coal through short or long term contracts. Further, the coal supplier has traditionally cleaned his coal primarily to remove ash and mining residue. In today's coal market there is not a clear recognition by the supplier of clear cost differentials based upon the coal sulfur levels. The supplier thus does not have an economic incentive to clean his coal with the objective of removing sulfur. While the coal industry enjoys a healthy market with high profits, investment is largely directed to expansion of capacity through mechanization and to the use of goods and services needed to meet new mine safety and environmental regulations. Incentives for coal cleaning in the coal industry must come from the market (utilities), regulatory activities or tax laws. None of these incentives is now operable.

Utilities can contract with coal suppliers for coal cleaning or they can clean the coal themselves. However in some instances current investments and contract commitments are disincentives to this action. An example of these disincentives is the extensive use of Pittsburgh bed coal by utilities in the Appalachian region. A number of coal companies have high investments in existing mines and a number of utilities have long term contracts for this Pittsburgh bed coal. This coal is high in organic and pyritic sulfur and cannot be easily cleaned for sulfur removal. There are other coals in the region which can be used to meet emission standards with little or no cleaning. However, the costs of breaking existing contracts, developing new mines and constructing coal preparation plants may be more costly than the use of FGD on either existing or new generating units.

Another problem in implementing coal cleaning technology is that of identifying coal reserves that are adaptable to physical cleaning. Although cleanability studies have been performed by the Bureau of Mines, their work has been restricted to coals available from existing mines. Cleanability data is also needed on coal seams and geographic areas not currently developed. In this way promising new resources can be identified for development.

Difficulties which utilities may experience in raising capital may also serve as a barrier to implementation. Investors may be reluctant to support the capitalization of coal cleaning facilities because of the technical and regulatory uncertainties involved. Existing tax credits for equipment depreciation may also favor FGD over coal cleaning. Low interest rate government loans, positive environmental regulations and modified tax laws could eliminate this economic barrier.

The lack of familiarity of the utility industry with coal cleaning as a pollution control may also serve as barrier to implementation. New technology is adopted in an industry only after it has been adequately demonstrated and accepted as a viable technology by a majority of the industry members. This barrier to implementation can best be overcome by joint government-industry research, development and demonstration activities. Recent events indicate an increasing acceptance by the utility industry of coal cleaning as a pollution control strategy. PENELEC is constructing a 1200 tph coal cleaning plant at Homer City, Pa. for the purpose of removing pyritic sulfur from coal for SO_2 emission control. The TVA has announced plans to construct a 2000 tph preparation plant with the objective of removing sulfur for SO_2 emission control purposes. The Electric Power Research Institute (EPRI) is placing increased emphasis on R&D activities for coal cleaning. The prognosis for overcoming the reluctance of the energy industry in accepting coal cleaning as a SO_2 emission control strategy is good.

CONCLUSIONS

Physical coal cleaning can be used to meet a variety of state and federal SO_2 emission regulations, singly or in combination with flue gas desulfurization. There is an increasing awareness by the coal and utility industries of coal cleaning as a method of SO_2 emission control. For readily cleaned coals, physical coal cleaning will probably be the most cost effective method for meeting state and federal standards for SO_2 emission control in power boilers. In other cases combinations of physical coal cleaning and FGD may be more cost effective than FGD alone.

The acceptance of coal cleaning as a SO_2 emission control strategy is dependent upon additional research, development and demonstration activities. EPA's program will provide for:

1. The development of improved physical and chemical processes for the removal of contaminants from coal.

2. The identification of air, water and solid pollutants which result from coal cleaning.

3. The development of improved pollution control techniques for coal cleaning processes.

4. The development of the environmental impacts and economic costs of coal cleaning.

Economic and regulatory activities are the driving forces which determine the mix of technologies which we apply to the use of our resources. The results of EPA's coal cleaning program will provide information upon which we can make sound technical, economic and regulatory decisions concerning yhe use of our coal resources.

REFERENCES

1. Cavallaro, J. A., M. T. Johnston and A. W. Deurbrouck, Sulfur Reduction Potential of U. S. Coals: A Revised Report of Investigation, EPA-600/2-76-091 or Bureau of Mines RI 8118, Washington, D.C., April 1976.

2. Hamersma, J. W. and M. L. Kraft, Applicability of the Meyers Process for Chemical Desulfurization of Coal: Survey of Thirty-Five Coals, EPA-650/2-74-025-a, Washington, D. C., September 1975.

3. Reggel, et al., Preparation of Ash-free, Pyrite-free Coal by Mild Chemical Treatment, presented at American Chemical Society (Division of Fuel Chemistry) National Meeting, New York City, August 27 - September 1, 1972.

4. Aresco, S. J., L. Hoffman and E. C. Holt, Jr., Engineering/Economic Analyses of Coal Preparation with SO_2 Cleanup Processes for Keeping Higher Sulfur Coals in the Energy Market, Preliminary Report on U. S. Bureau of Mines contract J0155171, The Hoffman-Munter Corporation, Silver Spring, Maryland, June 1976.