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EPA PROGRAM STATUS REPORT–
FUEL CLEANING PROGRAM

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Interagency
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Research and Development
Program Report

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August 1976

EPA PROGRAM STATUS REPORT
FUEL CLEANING PROGRAM

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CONTENTS

1. SUMMARY 1

2. PROGRAM OVERVIEW 5

   2.1 Program Rationale 5
   2.2 Program Objectives 5
   2.3 Technology Involved: Its Importance and Advantages 6
   2.4 Program Benefits 6

3. CURRENT PROGRAM STATUS 8

   3.1 Physical Cleaning of Coal 8

      3.1.1 Characterization of the Cleanability of American Coals 9
      3.1.2 Trace Element Characterization of Coal and Coal Processing Wastes 9
      3.1.3 Process Evaluation and Development 10

   3.2 Chemical Cleaning of Coal 15
   3.3 Liquid Fuels Cleaning 17
   3.4 Environmental Assessment of Coal Cleaning Processes and Analysis of Resource Recovery Potential of Coal Cleaning Wastes 18

APPENDIX A — Funding Levels of Program Areas

APPENDIX B — EPA Reports on Fuel Cleaning

1. SUMMARY

The Environmental Protection Agency (EPA) Fuel Cleaning Program is one of several programs designed to assess and advance the state-of-the-art of new technology to meet both near-term and long-term United States energy requirements in an environmentally acceptable manner. Because coal is the most abundant energy resource in the United States, the benefits of reducing the environmental impacts of the production of useful energy from coal are enormous. Methods for producing clean energy from coal include reducing pollutant emissions before combustion (using coal cleaning processes), during combustion or coal conversion (using process changes or new conversion processes), or after combustion (using abatement technology to reduce emissions from stack gases). The EPA Fuel Cleaning Program is directed at improving the methods of removing impurities from coal prior to the combustion process. In many cases, the methods developed in this program may be used in concert with other cleanup procedures to minimize costs of reducing emissions from coal. The program emphasizes coal cleaning, although research is underway to improve techniques for removing sulfur and nitrogen compounds and metals from oil.

The Fuel Cleaning Program has been conducted since the mid-1960's by the Environmental Protection Agency and its predecessor organizations with support from the U.S. Bureau of Mines, state geological agencies, and other research institutions. An early study, performed in 1965, attempted to identify the degree to which coal cleaning could be applied to the reduction of pyritic sulfur in coal, thereby reducing sulfur oxide emissions. Prior to that time, the primary purpose of coal cleaning had been to reduce the ash content of coal, but by 1965 it was recognized that the process could be optimized to remove the sulfur that was not chemically bound to the coal. The 1965 study found that insufficient data existed to assess the potential of coal cleaning for reducing sulfur oxide emissions. However, the realization that the design and optimization of coal cleaning technology for pyritic sulfur removal might result in a new, cost effective method for sulfur reduction in certain coals initiated a second substantial effort to assess the potential of coal cleaning. This effort required research to fill in the large data gaps identified in the 1965 study. The required information included:

- Distribution of sulfur forms in the major coal beds in the United States
- Effectiveness of available commercial coal cleaning methods in removing pyritic sulfur
- Identification of processes that could economically utilize reject material from the coal cleaning process for product recovery, thereby increasing the utilization of resources and reducing pollution.

This second phase of the Fuel Cleaning Program emphasized obtaining the information that was unavailable for the 1965 study. The method chosen to analyze the distribution of sulfur forms in coal was the float-sink test. In this test, in which the crushed coal is placed into solutions of varying specific gravities, the heavier pyritic particles sink to the bottom of the solution. Because the float-sink test is a laboratory procedure that simulates the action of commercial coal cleaning processes, results of such float-sink tests are indicative of the sulfur removal potential of actual physical coal cleaning methods. A

major program of characterization of U.S. coals using the float-sink test was initiated in 1967, with the research carried out by the Bureau of Mines.

Two investigations of coal cleaning techniques were also begun in 1967 and following years. One of these analyzed the effectiveness of pyrite separation using commercially available techniques such as the wet concentrating table, the compound water cyclone, and the concentrating spiral. The other investigation evaluated changes in the operating procedure and design of convential coal cleaning techniques to maximize sulfur removal.

To fill the third data gap that had been identified, EPA initiated studies of the economics of by-product recovery from coal cleaning reject material. These studies indicated that among a number of processes the most promising method for recovering the by-products was a high-sulfur combustor that generated power and recovered either sulfuric acid or elemental sulfur from the reject material.

The major achievements of this second phase of the Fuel Cleaning Program, which can be termed primarily a data gathering phase and which had filled the most important data gaps by 1970, include:

- Definition of the characteristics of some 300 different U.S. coals in an easily accessible computerized data base
- Demonstration that existing technology used for removal of inert material in coal can be effectively used for removal of pyritic sulfur
- Establishment of the costs and benefits of alternative processes for recovering sulfur and energy values from coal cleaning reject material
- Preliminary designs for a prototype coal cleaning plant and for a reject materials recovery plant, as well as estimates of capital and operating expenses.

A third phase of the Fuel Cleaning Program was begun in 1970. This phase not only continued the efforts in phase two, but also greatly extended the objectives of the program. New areas of investigation included:

- A study of *chemical* coal cleaning methods
- An analysis of processes for removing impurities from liquid fuels
- A characterization of the potential for reducing trace metal emissions from coal
- Detailed process evaluations of a large number of coal cleaning techniques.

The thrust of this third phase is:

- To enhance the capabilities of fuel cleaning methods by expanding the range of pollutants that these methods can effectively remove

- To bring fuel cleaning to the stage of commercial implementation through laboratory experiements, design studies, economic analyses, and the construction of test units

- To assess and reduce any adverse environmental impacts resulting from the use of fuel cleaning.

The major accomplishments to date of this third phase of the EPA Fuel Cleaning Program include:

- In the chemical coal cleaning area:

  - Demonstration at bench scale of the effectiveness of pyrite leaching in removing pyritic sulfur from a variety of coals

  - Identification of specific U.S. coals amenable to chemical treatment methods

  - Preliminary design of a pilot plant scale facility to demonstrate pyrite leaching

  - Initiation of construction of a test unit facility to chemically extract pyrite from coal.

- In the liquid fuel area:

  - Evaluation of a number of demetallization catalysts

  - Economic analysis for the use of demetallization catalysts in desulfurization processes

  - Determination of the characteristics and kinetics of simultaneous hydrodesulfurization and hydrodenitrification reactions.

Current research efforts in EPA's Fuel Cleaning Program include a continuation of the past research that is promising and an increased emphasis on the assessment and reduction of environmental impacts resulting from fuel cleaning technologies. An approach has been designed to provide and apply criteria for the environmental assessment of the full range of coal cleaning process cycles and to develop improved control technologies and control strategies for the implementation of coal cleaning. Similarly, EPA is supporting work by the Bureau of Mines to build a coal cleaning test facility at Bruceton, Pennsylvania that will be used to analyze environmental benefits and costs of different components of a coal cleaning system. EPA has contracted with TRW to build a reactor test unit of the Meyers chemical coal cleaning process. A very recent contract (July 1976) has initiated an environmental assessment of a physical coal cleaning system to be constructed by the General Public Utilities in conjuction with a new electric generating unit at the Penn Electric Company's facility at Homer City, Pennsylvania.

Continuation of EPA's Fuel Cleaning Program along currently planned lines with subsequent implementation of the technology will permit increased use of coal by the utility and other industries, especially in areas where air quality regulations allow the combustion of medium sulfur (one to two

percent) coal. The increased use of coal will thus promote the use of our most abundant energy resource, a goal desirable in the context of our national energy picture, as well as increase the availability of inherently clean fuels to other users and improve the means for meeting Air Quality Act environmental standards. Other benefits of a successful fuel cleaning program include more cost effective methods of reducing emissions of sulfur and other impurities for many types of U.S. coal, increased by-product recovery from coal, and the increased use of coal in an environmentally acceptable manner in numerous small industrial applications where abatement technology has not been practicable.

2. PROGRAM OVERVIEW

The nation has a growing demand for fuels to meet increasing energy requirements in an environmentally acceptable manner. Under the mandate of the Air Quality Act of 1963, EPA initiated a program to develop methods of reducing air pollutant emissions while providing an adequate, reliable fuel supply.

2.1 Program Rationale

An obvious solution to the problem of reducing pollutants emitted as the result of combustion is to burn a clean (low-polluting) fuel. For example, emissions of sulfur oxides can be reduced by burning fuels of low sulfur content. Unfortunately, supplies of low sulfur fuels are limited in the eastern coal regions that supply most of the combustion coal. The largest low sulfur coal reserves are in the western regions, far from major utilization points. Removal of sulfur from certain types of oils (residual oils) that are used as power plant fuel is difficult because trace metal contaminants tend to poison the catalysts commonly used in sulfur removal processes.

If there is no ready supply of clean fuel, an alternative is to burn fuel that has been cleaned sufficiently to conform to established pollution criteria. Although liquid fuel desulfurization technology has been developed extensively by the petroleum industry, the coal industry has done only limited work in this area. Coal cleaning can provide relief in areas of severe SO_x pollution where it is impractical for industrial coal burners to use such controls as flue gas desulfurization. Removal of trace metallic contaminants from residual oil will permit desulfurization to be performed more easily and economically, thereby further increasing the availability of low sulfur fuels. *The Fuel Cleaning Program has, accordingly, been developed and structured with emphasis on the advancement of technologies that will most effectively and economically remove sulfur and other impurities from coal and liquid fuels.*

2.2 Program Objectives

The overall objective of the Fuel Cleaning Program is to increase the availability of environmentally acceptable fuels for combustion uses through the removal of pollutant forming constituents. This is to be accomplished by advancing the state-of-the-art of fuel cleaning, while not altering the basic form of the processed fuel, to a level where low-pollutant fuels can be produced in a cost effective manner in commercial scale quantities. To achieve this objective, an orderly progression of major goals has been defined as follows:

- First, characterize U.S. fossil fuels with respect to their polluting constituents
- Next, define the technical and economic suitability of cleaning processes to these fuels

- Then, develop the promising cleaning processes from bench scale through pilot scale to commercial scale units.

These goals have been used as the basis for defining and shaping the individual projects of the Fuel Cleaning Program.

2.3 Technology Involved: Its Importance and Advantages

A substantial part of the growing demand for clean fuels can be satisfied by coal that has been physically cleaned of sulfur by techniques that have been used in the coal and utility industry to remove excessive inert constituents, provided the techniques can be suitably modified for the removal of sulfur. Two principal reasons for concentrating initial attention on the adaptation of existing coal cleaning techniques for sulfur removal are: the equipment and "know-how" for applying the methods is readily available, and the techniques can therefore be quickly implemented for rapidly obtaining supplies of clean coal.

On laboratory and/or pilot scale, these techniques have been demonstrated to remove a substantial portion of the pyritic sulfur in many coals. As they do not, however, remove organically bound sulfur or certain forms of inorganic sulfur, they can be applied effectively only to selected types of coals. The EPA program has been subsequently expanded to include research on experimental and developmental techniques using both physical and chemical methods for coal desulfurization. The program was subsequently further expanded to develop techniques for removing polluting constituents from other types of fuels, particularly fuel oil and residual oil.

2.4 Program Benefits

There are a number of benefits which derive from the Fuel Cleaning Program and which impact on the national energy picture on both a near- and long-term basis.

The key benefit of the program relates to anticipated increased use of U.S. coals which should result from implementation of viable physical and chemical cleaning technologies. These technologies are to some extent available as a near-term solution, and could provide more than 60 million tons of clean coal to help fill a national deficit of clean fuels. Application of an integrated physical/chemical cleaning technology to the coals of the Appalachian states (West Virginia, Virginia, Maryland, Ohio, Pennsylvania, Tennessee, and Alabama) could result in effective reduction of sulfur levels to 0.75% or less for approximately 50% to 60% of the coal. Application of the technology to specific coal beds can have an even greater impact. Additionally, large quantities of coal could have their sulfur content substantially reduced, probably not to the 0.75% level but enough to improve the environmental quality concommitant with an increased use of coal. This is a significant contribution toward the goal of meeting near-term energy requirements in an environmentally acceptable manner.

A second major benefit derives from this key benefit, and relates to the pattern of usage of U.S. coals. By far, the major uses of coal are for electrical power generation and for industrial consumption. Approximately 72% of the total coal consumed in the U.S. for fuel and power in 1975 was for electrical power generation (that is, 404 million tons out of a total of 562 million tons consumed). Coal utilized by the industrial sector constituted approximately 26% of the total consumption (that is, 146 million tons out of the total consumed). Use of cleaned fuels for electrical power production will take available supplies of inherently clean fuels (natural gas and low sulfur oils) to

industrial users and other consuming sectors where other emission control strategies are either impractical or prohibitively expensive. This is particularly true for the category of small industrial boilers of less than 10 MW size where post-combustion SO_x control systems are not economically viable. Thus, the program will provide a direct and immediate contribution toward the goal of meeting environmental standards for clean air.

A related third benefit derives from the liquid fuels cleaning portion of the program. Successful completion of the liquid fuels cleaning projects will permit the production of a clean petroleum fuel from a petroleum fuel with high concentrations of trace metallic "poisons." This will serve to increase the availability of cleaner premium fuels that can be used in the smaller industrial boilers and possibly in the residential sector.

A fourth benefit derives from the emphasis of the program on coal resources. The program serves to promote increased use of U.S. coals with technology that is familiar to the current coal mining and processing industry. The coal cleaning processes could thus be easily implemented by this group. Thus, the program has the ability of contributing to a near-term as well as longer-term expansion of the use of environmentally acceptable coal.

3. CURRENT PROGRAM STATUS

The FY'76 Fuel Cleaning Program of EPA involves four major activity categories:

1. Physical cleaning of coal to reduce the content of sulfur and other pollutants
2. Chemical cleaning of coal to reduce sulfer content
3. Cleaning of liquid fuels to remove toxic trace metals and nitrogen and sulfur compounds
4. Assessment of environmental impacts of physical and chemical fuel cleaning methods; resource recovery of waste products from coal.

EPA and predecessor agencies have supported research into methods of physical coal cleaning since the mid-1960's and have made a number of significant accomplishments to date. EPA did not initiate chemical coal cleaning research and development until the early 1970's. Already, however, EPA funding of the TRW Meyer's Process has brought a promising technology from the laboratory research stage to the initiation of a test unit facility designed to evaluate its commercial potential. The oil cleaning activity, also begun in the early 1970's, has progressed in spite of a relatively low funding level to the point where it provides supplemental information to that obtained from industry-supported research. The environmental assessment activity has recently been undertaken by the Fuel Cleaning Program to ensure that wastes from coal cleaning can be handled in an acceptable manner so as to reduce impacts on air, land, and water and to provide methods for reuse of resource values in the wastes. Each of these activities is described below in terms of its objectives and current status.

3.1 Physical Cleaning of Coal

The use of physical (mechanical) techniques for reducing the pyritic sulfur content of coal was investigated early in the Fuel Cleaning Program because such techniques were already in routine use in the coal and utility industries to remove ash, rock, and other inert materials. These techniques utilized the difference in specific gravity between such materials and coal to effect a separation. The application of such techniques to the removal of pyrites (and other iron sulfides) appeared to be a straightforward and logical extension of physical coal cleaning techniques, because the specific gravity of pyrites also differs from that of the carbonaceous components of coal. In addition, pyrites exhibit other differences in physical characteristics that provide a potential basis for separation: for example, pyrites are magnetic, while coal is non-magnetic, and finely divided coal has a tendency to agglomerate or form clusters in certain liquid media while pyrite particles do not. One major element of EPA's program for physical desulfurization has, therefore, been a determination of the effectiveness of a variety of techniques, both conventional and experimental, for separating pyrites from the carbonaceous components of various types of coal.

However, before separation of sulfur from coal is undertaken by either physical or chemical means, it is necessary to know important physical characteristics of the specific type of coal to be processed in order to determine which separation techniques are best suited. For this reason, EPA undertook to characterize U.S. coal resources in terms of the total sulfur content, pyritic sulfur content, Btu content, ash content, and other properties of the coal, and thus to establish the amenability of different coals for sulfur removal by various techniques. This characterization of coals constitutes another major element of EPA's physical coal cleaning program.

The major elements of the physical coal cleaning activity are described below, in terms of specific contract activities.

3.1.1 Characterization of the Cleanability of American Coals

EPA and the U.S. Bureau of Mines have supported work to characterize the cleanability of U.S. coals since 1967. Most of the work has been carried out by the U.S. Bureau of Mines and the Illinois Geological Survey. The method of testing involves grinding samples from different coal beds to three different degrees (1–1/2 inches top size, 3/8 inch top size, and 14 mesh top size). This is followed by float-sink tests on the samples at varying specific gravities. The float-sink test is a good indicator of the pyritic sulfur content of coal, as it uses the higher specific gravity of pyrite as a basis for gravimetric separation. The separated products are then analyzed for ash, pyritic sulfur, total sulfur, Btu/lb, and Btu recovery of the coal from the washability test. The Bureau of Mines issued a revised report in April 1976, presenting the characterization of coal from 455 seams. This represents approximately 70% of current coal production in the United States. EPA is continuing to support this project as the task of analyzing coal from the largest coal mines is completed and emphasis is shifted to coal beds most likely to be mined in the near future.

To facilitate the application of coal cleaning techniques to coal in different locations where coal cleaning can provide beneficial results, EPA has sponsored the development of a computerized data bank containing the characteristics of coals throughout the eastern and central United States. This data bank is currently operational and is being updated as additional coals are characterized. The U.S. Geological Survey (USGS) and the U.S. Energy Research and Development Administrations (ERDA) are currently extending this data bank to set up a comprehensive computerized listing of the elemental composition of U.S. coals.

3.1.2 Trace Element Characterization of Coal and Coal Processing Wastes

Two current research efforts are directed at characterizing the trace element composition of coal and coal cleaning wastes: one project is using a variety of methods, including column leaching of coal products after low temperature ashing and electron microscopy, to analyze the ways in which trace elements are bonded within different coal samples. This research will determine the maximum degree to which different trace elements can be removed by physical coal cleaning techniques. A second project is studying the wastes from physical coal cleaning facilities to determine the trace element composition of the residuals and the potential for these elemnets to leach into the environment.

A study designed to support the reasearch on trace element characterization is underway. This is an exhaustive literature search summarizing current knowledge of pollutants in coal, oil, and oil shale, reviewing contaminant removal techniques to determine effectiveness and applicabil-

ity of current technology, and analyzing research and development needs with respect to trace element removal from fuels.

3.1.3 Process Evaluation and Development

The degree of separation of pyritic sulfur and other impurities from the carbonaceous component of coal depends both on the properties of the coal sample (composition, hardness, rank, etc.) and on the fineness to which the coal is crushed prior to cleaning. For this reason, one coal cleaning process may be more suited to certain types of coal than others. In the past, therefore, EPA and predecessor agencies have supported the evaluation of a number of coal cleaning processes, ranging from conventional and available equipment (for example, Deister Tables) to new and developmental techniques (such as electrokinetics). This process testing established (1) the techniques that were most promising and (2) the fineness of coal crushing necessary to optimize pyrite separation. Results of these process tests are described briefly below.

Diester Table (wet concentrating table). The Deister Table is a riffled deck operated in essentially a horizontal plane. A drive mechanism shakes the table rapidly along its long axis while water flows by gravity along the short axis of the table. The rapid shaking motion and the flow of water cause particles of different densities to migrate to different zones on the periphery of the table. The tests showed that the Deister Table was effective in removing free pyrite and ash from coal. Coals with a high proportion of pyritic sulfur are particularly suitable to coal cleaning using a Deister Table. Removal efficiencies of up to 84% of the pyritic sulfur have been obtained. Two-stage cleaning tests, in which a clean fraction was pulverized and retabled, have demonstrated that pyrite removal can be enhanced by using a wet concentrating table in two stages.

Concentrating spiral. Crushed coal in a water medium is dropped into the top of a metallic spiral. As the coal flows downward, centrifugal forces cause the heavier particles to concentrate in a band along the center of the spiral. Prior to research funded by EPA and predecessor agencies on the applicability of the concentrating spiral to coal cleaning, the process had been widely used for ore dressing but not for coal preparation. Results of the EPA studies indicate that the method holds promise because of its low operating and capital costs and its effectiveness in removing pyritic sulfur for certain size ranges of crushed coal.

Hydrocyclone. A hydrocyclone uses water to impart a rotary motion to coal particles that have been injected into a vessel consisting of cylindrical and conical sections. Centrifugal forces are responsible for separating particles into an ascending or descending vortex, depending on the specific gravity of the particles. For the coal sample sizes tested, the results indicated that the hydrocyclone is generally not as efficient in removing pyritic sulfur as the wet concentrating table. However, the hydrocyclone may be appropriate for coals containing fine pyrite particles.

Air classifier. An air classifier uses pulsating air to stratify a relatively coarsely ground coal into a fine fraction and a coarse, pyrite-rich fraction as the coal flows down an inclined chamber. A second stage, using wet coal preparation techniques, is required to remove the pyrite from the coarse fraction. Results from ten coal samples tested suggested that significant improvement in the removal of pyritic sulfur do not accrue from the addition of the extra air separation stage, although some reduction of water pollution from coal preparation by this method can be expected.

Electrokinetics. Under certain conditions, coal particles are more negatively charged than pyrite particles in an electrical field. A laboratory scale investigation was conducted using a cell with platinum electrode wires designed to take advantage of both the differential charges and the

differential specific gravities of the coal and pyrite particles. Although the experiment achieved success in separating coal and pyrite particles, economic assessments have shown that the method is too costly for commercial application.

Agglo-separation using oil. High energy mixing is used to disperse light oil in a coal-water slurry. The oil selectively coats the coal particles causing them to agglomerate and, with an assist from entrained air, float to the surface. Both laboratory and pilot plant studies indicate that the method, while effective for removing ash from coal, is ineffective for pyrite removal because the oil coated the pyrite as well as the coal particles.

Froth flotation. Froth flotation is a process that uses selective adhesion of air to coal particles and the adhesion of water to other solids as a basis for separating impurities from coal particles. Chemicals called frothing agents are added to a coal-water slurry to increase the adsorption of air bubbles to the surface of coal particles. Air is bubbled through the mixture causing a froth (foam) to be produced at the surface, and the coal particles float to the surface where they can be removed. In practice, it has been found that froth flotation must be performed in two stages to yield satisfactory separation of pyrite particles. In the second stage, the coal particles collected in the froth are treated with a chemical agent that interferes with the adhesion of air bubbles to the coal surface, thereby causing the coal to sink and permitting the removal of fine pyrite particles. *The two-stage froth flotation method shows great potential for scale-up to commercial operation, because it is the only physical coal cleaning process that has been shown capable of removing the pyrite from fine coals.*

In addition to the tests and evaluations of specific physical coal cleaning technologies, EPA has funded a wide range of supporting studies in this area. These studies include:

- Comparisons of the economics of coal cleaning processes
- An analysis of the applicability of coal cleaning to Iowa coal
- Two independent and competitive designs of prototype coal cleaning plants of 50–100 tons per hour capacity
- Analysis of the economic impact of deep cleaned coal on electric utilities
- A manual for physical coal cleaning
- Development of computer programs to facilitate data analysis to correlate physical parameters of coal with identification of the most appropriate coal cleaning process and product parameters.

Current EPA research on physical methods of coal cleaning is primarily directed at bringing the most promising of the methods to the point of commercial acceptance. This involves improving the operating characteristics of coal cleaning techniques (for example, increasing carbon recovery and overall process efficiency at high removal of pyritic sulfur and other impurities) and constructing test and demonstration facilities to assess scale-up problems that may be associated with the commercial application of the methods. These efforts, currently pursued through EPA funded research at the Bureau of Mines or contracted by the Bureau of Mines, includes:

FIGURE 1.
BUREAU OF MINES COAL PREPARATION TEST FACILITY
AT BRUCETON, PENNSYLVANIA

- Design, construction, and operation of a coal cleaning test facility at Bruceton, Pennsylvania (shown in Figure 1)

- Demonstration of two-stage froth-flotation circuitry in a commercially operating plant (contract currently being negotiated)

- Development of a computer simulation model of coal preparation plants

- Research on magnetite recovery to improve the separation of fine pyrite particles for coal

- Development of equipment for the magnetic separation of pyrite from coal

- Improvement of dense medium cyclone processing at Homer City, Pennsylvania

- Commercial evaluation of a technique for agglomeration and dewatering of coal preparation wastes

- Surface phenomena in the dewatering of coal

- Adsorption/desorption reactions in the desulfurization of coal by pyrite flotation.

Additionally, EPA is in the process of initiating a large three-year contract (approximately 40,000 manhours) to assess and develop coal cleaning technology. The major research tasks under this contract will include:

- Experimental work to assess the degree to which pyritic sulfur is separated from coal in commercial coal cleaning plants.

  - This work will evaluate techniques for removing pyrite from fine coal, correlate data between laboratory tests and the performance of commercial equipment, and generate new data by performing tests on commercial coal cleaning equipment at approximately ten different test sites.

- An evaluation of fine coal dewatering and handling techniques.

  - This evaluation will include a determination of the energy, cost, and pollution penalties associated with dewatering techniques that may be required if the efficient removal of pyrite with an acceptable Btu recovery necessitates the use of coal fines.

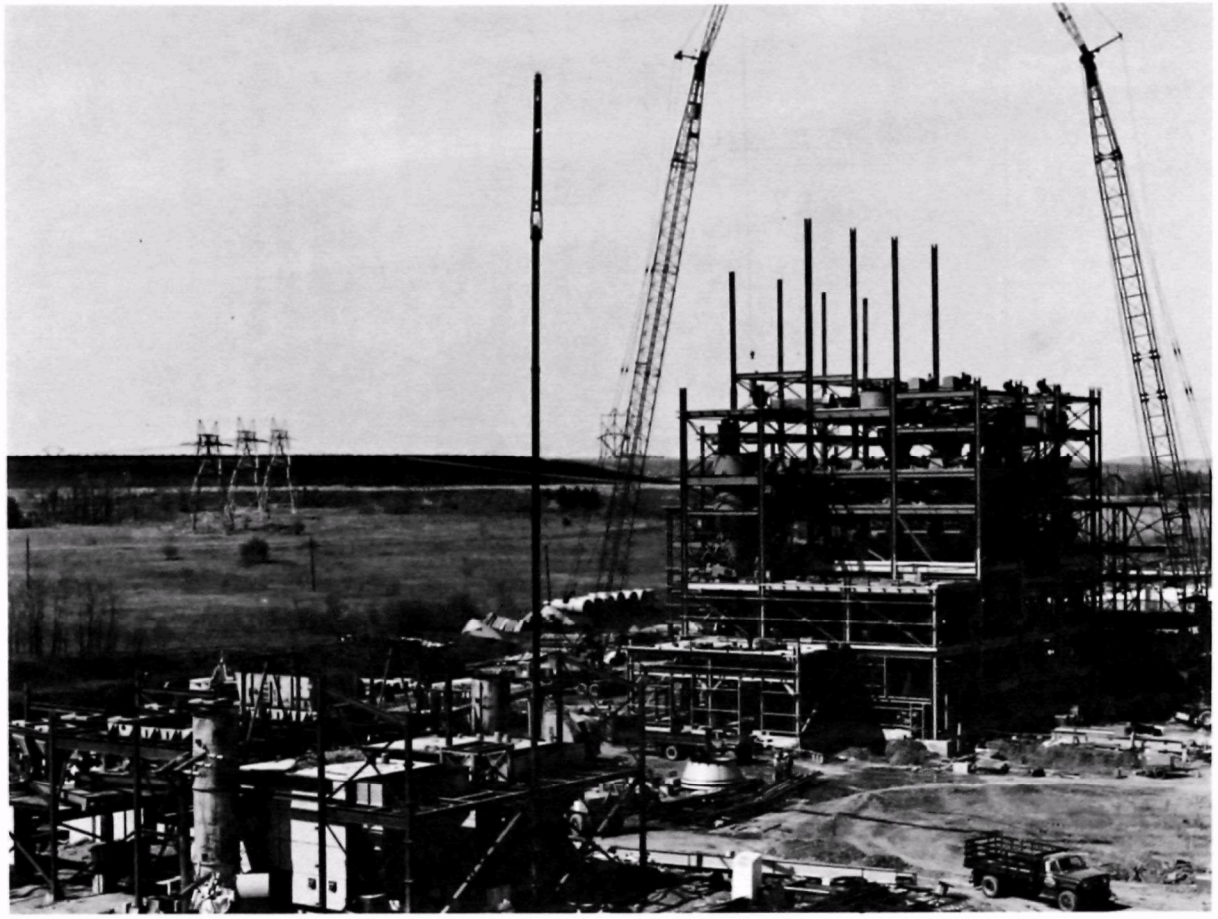


FIGURE 2.
COMMERCIAL COAL PREPARATION PLANT UNDER CONSTRUCTION
BY THE GENERAL PUBLIC UTILITIES CORPORATION
IN HOMER CITY, PENNSYLVANIA

- An evaluation of the coal preparation requirements for synthetic fuel conversion processes.

- An evaluation of the effects of coal cleaning on the performance of user systems.

  - Reduction of the sulfur content of coal can adversely affect the performance of electrostatic precipitators and other control technologies that remove flyash. Similarly, removal of certain minerals from coal can increase the corrosion and fouling of boilers.

- Trade-off studies to compare costs and performance of coal preparation equipment and processes; comparisons of the costs and performance of coal cleaning with other clean fuel strategies.

This contract also includes tasks to evaluate chemical coal cleaning processes and pollution control techniques for coal preparation processes.

In addition to the above activities, EPA has recently entered into a contract to support an environmental assessment of the General Public Utilities (GPU) Corporation Multi-stream Coal Cleaning System. This system, which GPU plans to install in conjunction with a new 650 megawatt electric generating unit of the Penn Electric company's facility in Homer City, Pennsylvania, will use physical coal cleaning to produce two coal streams containing 0.8% and 2.2% sulfur and one waste stream. The low sulfur coal stream will be used in the new boiler to satisfy federal New Source Performance Standards (NSPS); the higher sulfur coal stream will be used in two existing boilers to satisfy the Pennsylvania emission standards. The data acquisition and testing program recently initiated by EPA at the Homer City facility has been designed to establish both the effectiveness of the multi-steam strategy and the applicability of physical coal cleaning to other locations.

3.2 Chemical Cleaning of Coal

Physical cleaning of coal can remove only a portion of the pyritic sulfur content. The percentage that is removed by any given technique depends on the size and distribution of pyrite grains within the coal. In some cases, where the pyrite exists in large relatively discrete crystals, a high degree of separation is easily obtained. When the pyrite consists of small grains mixed intimately through the coal matrix, separation by physical means can be extremely difficult and is accompanied by high losses of the carbonaceous components.

The objective of the chemical desulfurization program is to provide techniques for removing sulfur and other constituents that may be more effectively removed by chemical than by physical methods. The program initially addressed the problem of removing pyritic and other inorganically bound sulfur from coal. More recently, the program was expanded to include removal of organically bound sulfur.

One approach to pyritic sulfur removal by chemical means involves leaching of the pyrites from other components of the coal. In one promising leaching process (TRW's Meyers Process), the coal is brought into contact with an aqueous ferric sulfate solution that reacts with the pyrite. A part

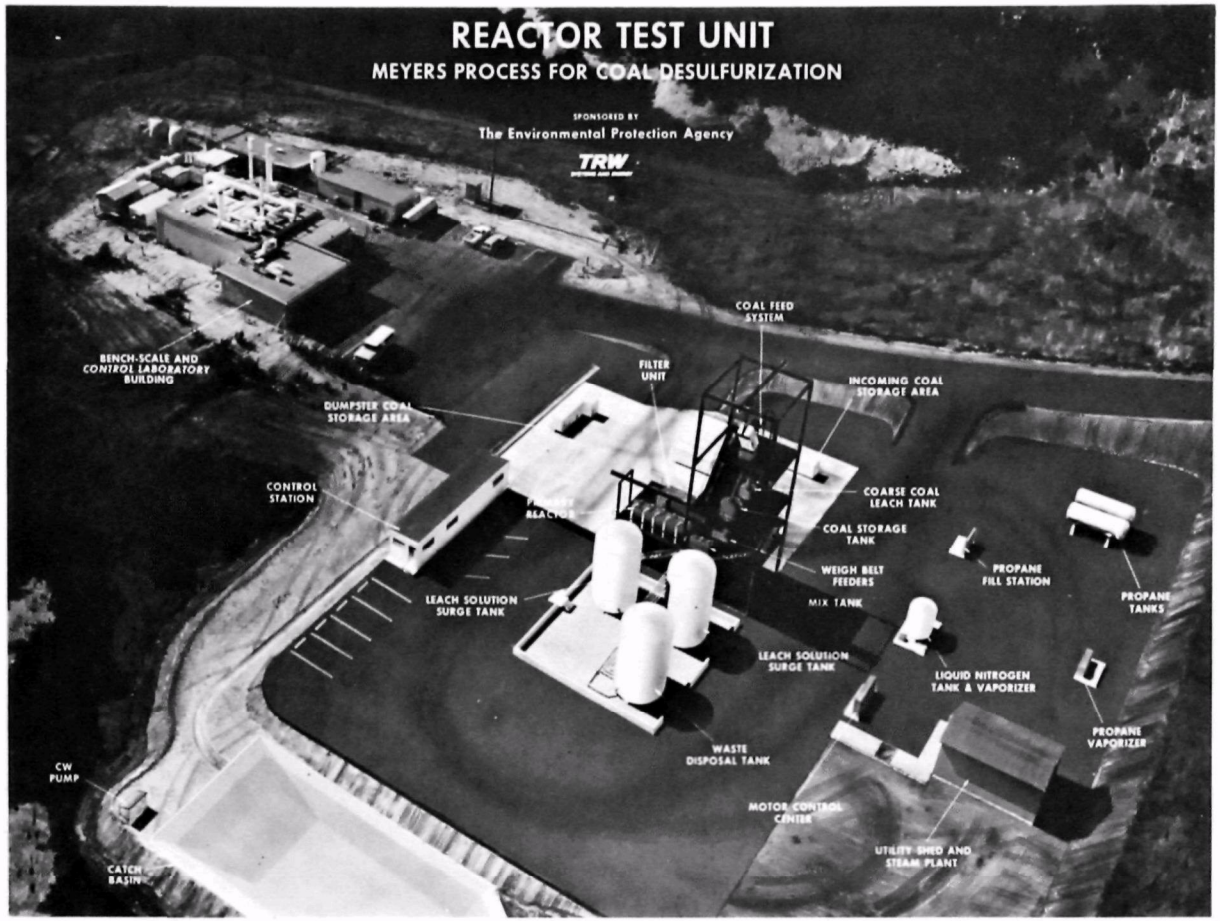


FIGURE 3.
ARTIST'S CONCEPTION OF REACTOR TEST UNIT
FOR THE MEYERS PROCESS FOR COAL DESULFURIZATION

of the pyrite is converted to soluble salts that remain in solution after the liquid is separated from the coal, whereas another part is decomposed to form elemental sulfur that can be recovered using an appropriate solvent. The Meyers Process has been able to remove 90 to 95% of the pyritic sulfur. Because essentially no reaction takes place between the ferric sulfate solution and the carbon coal matrix, organically bound sulfur is not removed by the process.

EPA initiated support for the development of the Meyers Process in the early 1970's. The process has been demonstrated at the bench scale. A pilot plant has been designed and reviewed and the construction of an 8 ton per day reactor test unit has begun. The present timetable calls for the completion of the test unit in early 1977. By co-funding the construction of a Meyers Process reactor test unit, EPA is supporting a major chemical coal cleaning activity in the anticipation that it will obtain commercial acceptance in the near future (i.e., if the test unit is able to demonstrate its technical and economic viability).

Another approach to chemical coal cleaning has been developed with EPA funding by the Institute of Gas Technology (IGT). This method treats coal with hydrogen, at relatively low pressures and termperatures. The hydrotreatment of coal is carried out in the presence of a sulfer acceptor material which promotes the preferential hydrogenation of organic and pyritic sulfur in coal. The bench scale experiments funded by EPA have demonstrated the viability of this reaction in the removal of both organic and pyritic sulfur. In current research on the IGT process, the bench scale experiments are continuing in order to establish overall requirements for a scale-up of the process.

EPA has also funded a program to assess the Battelle Hydrothermal Process. This process involves the addition of a chemical leachant to a coal-water slurry at moderate temperatures. The chemical leachant—sodium hydroxide, calcium hydroxide, or a combination of both—selectively converts the sulfur and some of the ash to soluble form, thereby making separation possible. Experiments have been reported showing removal of up to 99% of the pyritic sulfur and up to 70% of the organic sulfur from a selected coal sample. Although the Battelle process is being developed privately, EPA has funded an environmental assessment effort to analyze the process and its products. This effort includes assessment of trace element removal, of properties of the organic residual to determine if it is or can be converted into a combustible product, and of the effect of different reaction conditions on the removal of sulfur and other impurities.

EPA is currently evaluating several novel concepts for organic and inorganic sulfur removal. If any of these or other chemical coal cleaning methods appear promising, EPA will support feasibility test programs to establish the overall merit of the processes. The support contract to assess and develop coal cleaning technology (described in Section 3.1.3) provides for the evaluation of chemical coal cleaning processes. Previous studies supporting chemical coal cleaning (1) have identified specific U.S. coals amenable to desulfurization by pyrite leaching, (2) have performed independent reviews of pilot plant designs and (3) have analyzed the engineering and economic feasibility of commerical scale applications of pyrite leaching.

3.3 Liquid Fuels Cleaning

The Fuel Cleaning Program includes research, development, and demonstration of procedures for removing metals, sulfur, and other potential pollutants from liquid fuels. Attention is currently focused on residual oils derived from petroleum, which are widely used as power plant fuels. The program includes identification of potential pollutants in oils and the development of methods for their removal.

A literature survey has assembled and analyzed the available data on domestic and imported crude oils. These data provide the initial basis for an inventory of potential pollutants whose fate must be followed in further oil processing and utilization.

Much of the oil used in the United States is residual oil of high sulfer and metallic content. Currently, much residual oil cannot be desulfurized economically to meet environmental requirements because metals in the oil poison the desulfurization catalyst. Since vanadium and nickel are two of the major poisons, a project is underway to develop a low cost method of removing them prior to conventional desulfurization. This project is evaluating various scavenger and catalyst combinations. The residual oils being used in the investigations contain 3 to 3.5% sulfur and 400 to 1,000 ppm (parts per million) total vanadium and nickel. Successful completion of this project will result in a clean fuel for use in existing commercial installations. It should be noted that industry is putting forth a large effort into smaller areas of research aimed primarily at methods for making quality products from poor feedstocks. In this regard, it is necessary to purify the refinery feedstock by removing metals, sulfur and nitrogen before it can be upgraded to a high-octane gasoline. The EPA program complements this work.

A research project is underway to investigate the kinetics of simultaneous hydrodesulfurization and hydrodenitrification of liquid fuels. These reactions are being studied to determine the conditions under which they compete for the same supply of hydrogen and those under which they may be aiding each other. By removing such compounds from the fuel prior to combustion, part of the potential for producing air polluting oxides of sulfer and nitrogen is removed. Results of this type of work are aimed at long-term applications and may be useful in producing clean fuels from liquids derived from coal or oil shale.

3.4 Environmental Assessment of Coal Cleaning Processes and Analysis of Resource Recovery Potential of Coal Cleaning Wastes

Any fuel cleaning will have associated costs and will also produce some reject material, usually in the form of sulfur or sulfur compounds, ash or other inert substances, and small quantities of carbonaceous materials. Each such material may, under appropriate conditions, have some economic value. Beginning in 1968, an investigation of the technical and economic feasibility of several methods for recovering economic value from refuse materials was begun. The results of this investigation suggested that, of the alternative approaches, the high sulfur combustor had the greatest potential for economic viability. EPA then funded a feasibility study of the high sulfur combustor. This study produced an engineering design and cost analysis of the utilization of high sulfur reject material to generate power and recover sulfuric acid or elemental sulfur. Current research on resource recovery from coal cleaning wastes supported by EPA includes the recovery of trace metals from wastes (discussed in Section 3.1.2) and the experiments to dewater coal preparation wastes being carried out by the Bureau of Mines (discussed in Section 3.1.3).

EPA has just started to conduct a comprehensive assessment of the environmental pollution resulting from all phases of the coal cleaning system, including coal transportation, storage, cleaning, and waste disposal. A large support contract will be awarded in 1976 for the following research tasks:

- Technology overview
  - This task includes the definition of characteristics of coal cleaning processes, environmental assessment of process modules,

and characterization of pollutants associated with the processes.

- Detailed process descriptions

- Environmental assessment criteria

  - The purpose of this task is to establish rating criteria to define the relative importance that should be placed on the identification and control of specific pollutants.

- Pollution control trade-off studies

  - These studies will identify cost and performance trade-offs associated with various pollution control techniques.

- Clean fuel strategy studies

  - These studies will evaluate the energy and environmental implications of using various combinations of flue gas cleaning and fuel cleaning technologies.

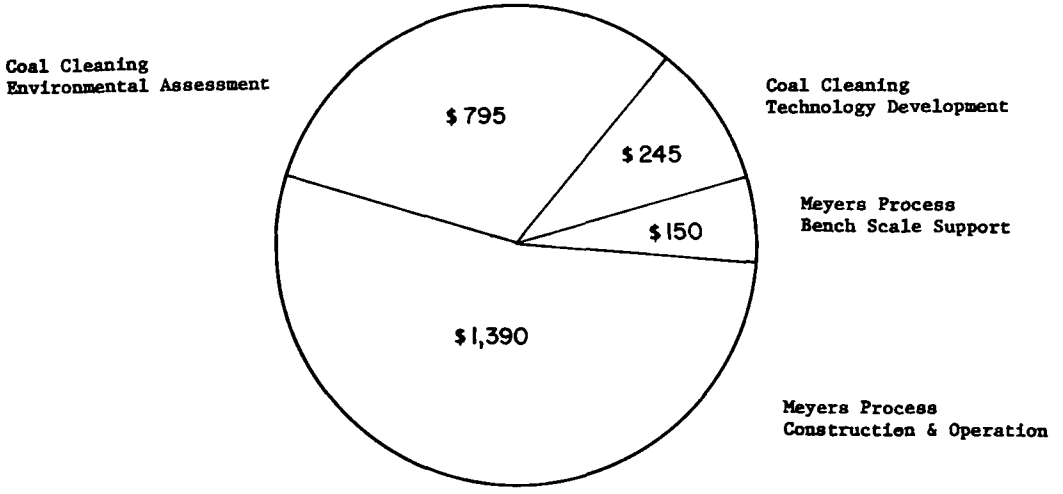
- Development and implementation of environmental test programs

  - This consists of identifying control equipment, plant and process types, and types of tests to be performed; selecting evaluation sites; developing experimental techniques; developing a test plan; performing tests and reporting results.

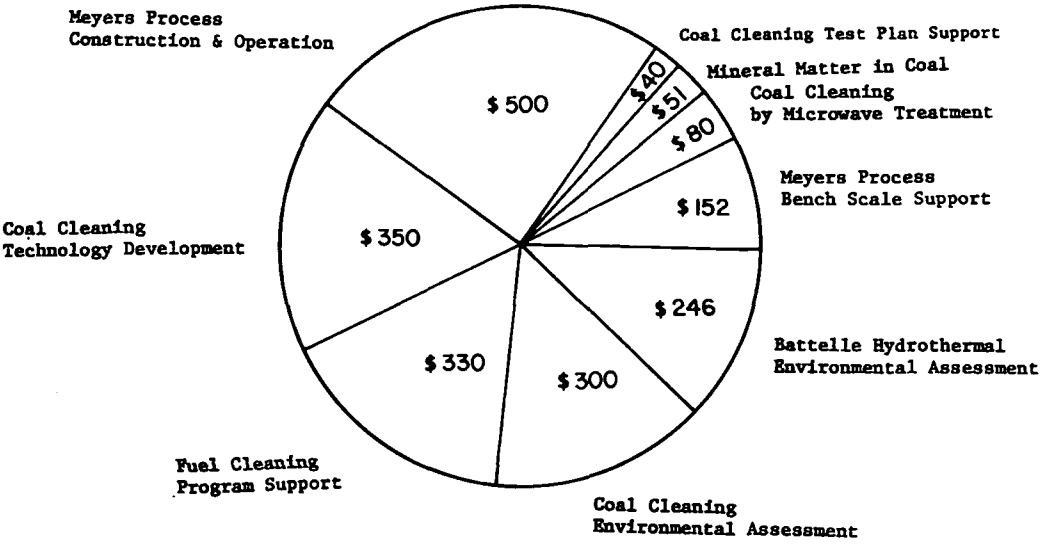
Appendix A

FUNDING LEVELS OF PROGRAM AREAS
(in thousands of dollars)

FISCAL YEAR '75



FISCAL YEAR '76



Appendix B

EPA REPORTS ON FUEL CLEANING

The following reports were published before August, 1976:

EPA Number	NTIS Number	
APTD 1246	PB 166–443	"The Economics of Residual Fuel Oil Desulfurization," Bechtel Corporation (June 1964)
APTD 1253	PB 185–466	"Feasibility Study—Hydrodesulfurization of Fuels under Corona Discharge Catalysis," General Electric Company (March 1965)
APTD 1245	PB 176–845	"An Economic Feasibility Study of Coal Desulfurization," Volume I, Paul Weir Company, Inc. (October 1965)
APTD 1245	PB 176–846	"An Economic Feasibility Study of Coal Desulfurization," Volume II, Paul Weir Company, Inc. (October 1965)
APTD 1255	PB 176–844	"A Feasibility Study of the Recovery of Sulfur and Iron from Coal Pyrites," Paul Weir Company, Inc. (May 1966)
APTD 1274	PB 182–303	"A Study of Process Costs and Economics of Pyrite-Coal Utilization," Arthur D. Little (March 1968)
APTD 1272	PB 184–652	"Study of the Applicability of Physical Methods of Separation to the Development of New Processes for the Control of SO_2 Pollution", Westinghouse Corp. (January 1969)
APTD 0606	PB 196–631	"A Study on Design and Cost Analysis of a Prototype Coal Cleaning Plant," Parts 1–6, McNally Pittsburgh (July 1969)
APTD 0607	PB 196–632	"Coal Cleaning Plant Prototype Plant Specification," Part 7, McNally Pittsburgh (July 1969)

APTD 0608	PB 196–633	"Coal Cleaning Plant Prototype Plant Design Drawings," Part 8, McNally Pittsburgh (July 1969)
APTD 0609	PB 196–634	"Design and Cost Analysis of a Prototype Coal Cleaning Plant," Supplement, McNally Pittsburgh (July 1969)
APTD 0915	PB 206–464	"Sulfur Varieties in Illinois Coals Float Sink Tests (Phase I)," Illinois State Geological Survey (August 1969)
APTD 0605	PB 220–700	"Design and Cost Analysis Study for a Prototype Coal Cleaning Plant," Volume I, Roberts & Schaefer (Revised August 1969)
APTD 0605	PB 220–701	"Design and Cost Analysis Study for a Prototype Coal Cleaning Plant," Volume II, Roberts & Schaefer (Revised August 1969)
APTD 0579	PB 193–484/193–532	"An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal," Bituminous Coal Research (February 1970)
—	—	"The Reduction of SO_2 by H_2S in Liquid Solvents (Task 4)," Massachusetts Institute of Technology (October 1970)
—	—	"Cost and Availability of Low Sulfur Fuel Oil (Task 5)," Massachusetts Institute of Technology (October 1970)
APTD 0844	PB 210–373	"The Physical Desulfurization of Coal—Major Considerations for SO_2 Emission Control," Mitre (November 1970)
APTD 0768	PB 203–958	"High Sulfur Combustor Study;" Volume I, Narrative Summary; Chemical Construction (February 1971)
APTD 0769	PB 203–959	"High Sulfur Combustor Study;" Volume II, Descriptive Detail; Chemical Construction (February 1971)
APTD 0842	PB 205–185/199–484	"An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal," Bituminous Coal Research (April 1971)
APTD 0845	PB 204–863	"Chemical Removal of Nitrogen and Organic Sulfur from Coal," TRW (May 1971)
APTD 0841	PB 205–952	"Sulfur Reduction of Illinois Coal Washability Studies (Phase II)," Illinois State Geological Survey (July 1971)
—	—	"Mathematical Model of the Reaction between Sulfur Dioxide and Calcine Particles (Task 2)," Massachusetts Institute of Technology (September 1971)

APTD 1066	PB 208–236	"Recent Developments in Desulfurization of Fuel Oil and Waste Gas in Japan, 1972 (Task 16)," Processes Research (January 1972)
—	—	"Flotation of Pyrite from Coal," U.S. Bureau of Mines (February 1972)
APTD 1160	PB 210–821	"An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal," Bituminous Coal Research (April 1972)
R2–72–022	PB 211–505	"Survey of Coal Availabilities by Sulfur Content," Mitre (May 1972)
—	RI 7608	"Washability Examinations of Core Samples of San Juan Basin Coals, New Mexico and Colorado," U.S. Bureau of Mines (1972)
APTD 1365	RI 7633	"Sulfur Reduction Potential of the Coals of the U.S.," U.S. Bureau of Mines (1972)
R2–73–154	—	"Research Program for the Prototype Coal Cleaning Plant," Roberts & Schaefer (January 1973)
R2–73–173a	PB 221–405	"Chemical Desulfurization of Coal: Report of Bench-Scale Developments," Volume I, TRW (February 1973)
R2–73–229	PB 221–439	"Recent Developments in Desulfurization of Fuel Oil and Waste Gas in Japan (Task 11)," Processes Research (May 1973)
650/2–73–041	PB 227–568	"Demetallization of Heavy Resideual Oils," Hydrocarbon Research Corporation (December 1973)
650/2–74–025	PB 232–083/AS	"Applicability of the Meyers Process for Chemical Desulfurization of Coal: Initial Survey of Fifteen Coals," TRW (April 1974)
650/2–74–030	PB 232–011/AS	"An Interpretative Compilation of EPA Studies Related to Coal Quality and Cleanability," Mitre (May 1974)
650/2–74–054	PB 238–091/AS	"Occurrence and Distribution of Potentially Volatile Trace Elements in Coal," Illinois State Geological Survey (July 1974)
600/2–75–051	PB 248–199/AS	"Conceptual Design of a Commercial Scale Plant for Chemical Desulfurization of Coal," Dow Chemical Company (September 1975)

650/2–74–009k	PB 246–311/AS	"Evaluation of Pollution Control in Fossil Fuel Conversion Processes—Coal Treatment; Section I: Meyers Process," Exxon (September 1975)
600/2–75–063	PB 248–101/AS	"Catalytic Desulfurization and Denitrogenation," Massachusetts Institute of Technology (October 1975)
600/2–76–091	PB 252–965/AS	"Sulfur Reduction Potential of U.S. Coals: A Revised Report of Investigations," U.S. Bureau of Mines (April 1976)

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

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4. TITLE AND SUBTITLE EPA Program Status Report--Fuel Cleaning Program		5. REPORT DATE August 1976
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Mark D. Levine, William N. McCarthy, Jr., and Gary J. Foley		8. PERFORMING ORGANIZATION REPORT NO.
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16. ABSTRACT

The status of EPA's Fuel Cleaning Program as of August, 1976, is presented in non-technical language. This program is a part of EPA's research directed toward providing the necessary technology for meeting near-term and long-term energy requirements in an environmentally acceptable manner. The objective of the program is to reduce environmental pollution by advancing the state-of-the-art of fuel cleaning technologies so that low-pollutant fuels can be produced in a cost-effective manner in commercial-scale quantities. Significant accomplishments of the program are summarized and the thrust of the current research effort is discussed. A bibliography of R&D reports related to the fuel cleaning program is attached.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Physical coal cleaning Chemical coal cleaning Environmental Impacts Control Technology Air Pollution Waste Management	Program Status Program Objectives	

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