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Environmental Assessment of Coal Cleaning Processes: Technology Overview

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Environmental Assessment of Coal Cleaning Processes: Technology Overview

by

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FOREWORD

Many elements and chemical compounds are known to be toxic to man and other biological species. Our knowledge concerning the levels and conditions under which these substances are toxic is extremely limited, however. Little is known concerning the emission of these pollutants from industrial processes and the mechanism by which they are transported, transformed, dispersed, or accumulated in our environment.

Portions of the Federal Clean Air Act, the Resource Conservation Recovery Act, and the Federal Water Pollution Control Act require the U.S. Environmental Protection Agency (EPA) to identify and regulate hazardous or toxic substances which result from man's industrial activities. Industrial pollutants are often identified only after harmful health or ecological effects are noted. Remedial actions are costly, the damage to human and other biological populations is often irreversible, and the persistence of some environmental contaminants may endanger future populations.

EPA's Office of Research and Development (ORD) is responsible for health and ecological research, studies concerning the transportation and fate of pollutants, and the development of technologies for controlling industrial pollutants. The Industrial Environmental Research Laboratory, an ORD organization, is responsible for development of pollution control technology and conducts a large environmental assessment program. The primary objectives of this program are:

- The development of information on the quantities of toxic pollutants emitted from various industrial processes--information needed to prioritize health and ecological research efforts.

- The identification of industrial pollutant emissions which pose a clearly evident health or ecological risk and which should be regulated.

- The evaluation and development of technologies for controlling pollution from these toxic substances.

The coal cleaning environmental assessment program has as its specific objectives the evaluation of pollution control problems which are unique to coal preparation, storage, and transportation. The coal preparation industry is a mature yet changing industry and in recent years significant achievements have been made in pollution abatement. Specifically, this report provides an overview of physical coal cleaning technology and its environmental impacts.

ABSTRACT

This report reviews U.S. coal cleaning process technologies and related technologies for environmental control. It provides a background against which requirements for further developments of coal cleaning technology and control techniques for the associated pollutants can be established.

The state of the art of physical coal cleaning is summarized. The status of coal cleaning technology is summarized with respect to cost, energy efficiency, applicability, extent of development, and commercialization prospects. Current technologies are described. The various physical coal cleaning operations necessary to produce systems capable of producing minimum, intermediate, and maximum effectiveness of coal cleaning are discussed.

The coverage of the subject is felt to be complete in the sense that all applications of the technology and all potentially polluting discharges have been considered. The report does not, however, present detailed information on composition of discharges, control technologies, economics, and the like. It is designed for use in development of programs and studies needed to quantify potential pollution control problems, prioritize environmental protection needs, and related activities. It was felt that inclusion of all background data would detract from, rather than enhance, its usefulness for broad analysis. For those needing more detailed information, references to background documents have been supplied.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF TABLES

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1.0 INTRODUCTION

The Environmental Protection Agency's Industrial Environmental Research Laboratory (IERL), Research Triangle Park, North Carolina, is conducting a series of environmental assessments. These activities involve continuing iterative studies to (1) identify and characterize industrial process discharges, (2) evaluate pollution control and waste disposal options, (3) compare estimates for environmental loadings with applicable standards and projected environmental goals, and (4) prioritize potential pollution problems and control technology needs. This overview report deals with physical coal cleaning (PCC)* and is one of a series of reports being developed for coal processing technologies. It was developed in connection with activities to evaluate current process technology for the overall assessment program, which is described in Figure A-1 of Appendix A.

The objective of this report is to describe the systems** or combinations of processes that are likely to be used for physical cleaning of coal for boiler firing. This involves making judgments as to types of coal that will be processed, types of equipment (and auxiliary processes) that will be employed, and markets that will develop for physically cleaned coal.

Data supporting statements in this overview report generally are from reports prepared by Battelle's Columbus Laboratories under Contract No. 68-02-2163 with the U.S. Environmental Protection Agency (EPA). Where other sources of information were used, they are cited in the text.

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* Physical coal cleaning processes are those that remove ash*** and pyritic sulfur from coal without chemical modification or destruction of the coal or other mineral matter.

** Certain terms, such as "systems", which have a number of commonly accepted meanings, have been defined specifically for use in environmental assessment activities of the U.S. EPA-IERL/RTP. A glossary of these terms is included in Appendix B.

*** PCC does not remove ash; it removes ash-forming minerals. However, common usage of the word "ash" in the coal cleaning industry to denote ash-forming minerals will be followed subsequently in this report.

The balance of this overview report is divided into three sections. Section 2, "Status of Technology", presents information intended to define the future prospects for physical coal cleaning in relatively broad terms. Section 3, "Description of Technology", presents more information on individual processes that are considered likely to be employed commercially. Section 4, "Environmental Impacts", discusses the kinds of pollutant discharges that must be anticipated.

2.0 STATUS OF TECHNOLOGY

Commercially available physical coal cleaning (PCC) processes have been used worldwide for many years to upgrade coal quality. Relatively simple systems were used to remove ash-forming constituents from coals supplied for boiler fuels. More elaborate systems were used to remove pyritic sulfur from metallurgical coals. In the mid-1960's the U.S. Environmental Protection Agency (EPA) initiated programs to develop information on the usefulness of physical coal cleaning for reducing sulfur oxide emissions from utility boilers. It was soon determined that such information was not available. As a result, the U.S. EPA, working with the U.S. Bureau of Mines and others, conducted numerous projects aimed at (1) evaluating the degree to which steam coals of the U.S. could be desulfurized using physical coal cleaning techniques, (2) determining the effectiveness of commercially available coal preparation equipment for sulfur removal, and (3) evaluating processes that could utilize the coal associated with the rejected mineral matter and thereby increase the degree to which coal could be economically cleaned with physical methods.

These activities, along with the work of others, has led to a growing appreciation of the possibilities for using physical coal cleaning, alone or in combination with other methods, to minimize sulfur oxides pollution. In addition, there is interest in using PCC for minimizing other potential pollutants (e.g., fly ash and trace metals) and for realizing other economic benefits such as reduced transportation costs and reduced boiler maintenance. While physical coal cleaning systems are commercially available and have been in use for many years for traditional applications, only one system (discussed in Section 2.4) has been designed and operated specifically to reduce the sulfur content in coal burned by a utility.

There has been considerable testing of U.S. coals to estimate what sulfur and ash reductions are economically achievable. The U.S. Bureau of Mines conducted washability studies of 455 raw coal channel samples from six major coal producing regions.[1] These samples were obtained from mines which provide more than 70 percent of the annual U.S. utility coal production. The results of these studies indicate that substantial reductions in sulfur and ash content can be attained for numerous coals. They also indicate, however, that maximizing the effectiveness of PCC will require modified approaches to accommodate variations in the properties of U.S. coals as they occur in different regions, different coal beds within regions, and within individual coal beds.

Table 1 shows the differences in results obtained when different coals are given similar processing. These results were obtained from Battelle's RPAM (Reserve Processing Assessment Model) computer program for a process equivalent to a physical separation at a specific gravity of 1.6 after crushing to a maximum size of 3/8 inch. As will be noted, sulfur removal levels are high except for Southern Appalachia and Alabama regions. The variations shown are attributable to the differences in coal characteristics and indicate the need to optimize the cleaning process used in terms of the coal properties.

Estimating the degree to which PCC is applicable to boiler fuel production is further complicated by uncertainties regarding the levels of future pollution control standards. Physical coal cleaning is by far the cheapest method per unit of sulfur removal for "cleanable" coals, and for some small industrial and commercial boilers it may be the only economically feasible route to control. However, precise control of product sulfur content at a particular level, on a continuous basis, is not presently possible due to sulfur variability within a coal seam.

In summary, PCC technology is an established technology which is now being adopted and applied as a pollution control method. While a considerable amount of information relative to this usage has been accumulated, there is still much to learn.

2.1 Energy Efficiency

The overall energy efficiency of PCC is influenced by the energy required to operate the process and by the energy value of the coal lost with the refuse. Power consumption by a PCC facility would be the equivalent to something less than 1 percent of the Btu input to the process. Btu's lost

TABLE 1. VARIATION IN CLEANING PERFORMANCE BY REGION

Region	Btu Recovery, percent	Mass Recovery, percent	Percent Sulfur in Raw Coal	Percent Sulfur in Cleaned Coal	Percent Reduction in Sulfur	lb $SO_2/10^6$ Btu in Raw Coal	lb $SO_2/10^6$ Btu in Cleaned Coal	Percent Reduction in lb $SO_2/10^6$ Btu	Percent Ash in Raw Coal	Percent Ash in Cleaned Coal	Percent Ash Reduction
1. (N. Appalachia)	96.0	93.4	2.79	1.93	30.8	4.25	2.86	32.7	11.87	7.32	38.3
2. (S. Appalachia)	97.0	95.0	1.04	0.90	13.5	1.51	1.28	15.2	8.78	5.07	42.3
3. (Alabama)	96.5	94.2	1.28	1.13	11.7	1.90	1.64	13.7	10.82	6.61	38.9
4. (E. Midwest)	96.4	93.5	3.89	2.80	28.0	6.32	4.41	30.2	13.51	8.04	40.5
5. (W. Midwest)	95.2	90.3	4.42	3.23	26.9	7.23	5.01	30.7	15.54	7.96	48.8
6. (Western)	97.9	97.3	0.65	0.45	30.8	1.09	0.75	31.2	8.07	5.84	27.6
7. (Entire USA)	97.1	95.3	1.90	1.35	28.9	3.07	2.14	30.3	10.27	6.57	36.0

with the refuse are by far the more important of the two and might amount to as much as 5 to 15 percent in practice. It should be noted, however, that while there has been a tendency to consider Btu's in the waste material as equal in value to Btu's in the coal, this is misleading. Much of the carbonaceous matter which is rejected is low-grade material. Further, being in association with other unwanted minerals, it is of limited value for high efficiency combustion processes. Also, the removal of such constituents, which is the primary purpose of physical coal cleaning, provides monetary benefits to operators of coal-fired boilers in terms of lower costs for coal transportation and handling, ash disposal, coal pulverizing, and boiler maintenance. Other cost benefits result from increases in boiler capacity factor and availability. Normally, the monetary vlaue of the Btu's associated with the unwanted coal constituents is charged as a cost of coal cleaning, but, unless credits for the monetary benefits of using cleaned coal are also considered, the true cost (or value) of coal cleaning would not be properly assessed. The importance of these credits are discussed in Section 2.2.

It is also important to appreciate that while the loss of coal in PCC refuse is a significant economic factor, the losses are not large when compared to those associated with other possible techniques for sulfur control. For example, flue gas desulfurization (FGD) systems consume energy in amounts equal to 3 to 10 percent of the fuel input to the boiler.[(2)] Technologies being developed to produce low-sulfur gaseous or liquid fuels from coal may attain efficiencies of 75 to 80 percent, but gasification or liquefaction technologies that can be used today are more likely to have efficiencies of 60 to 70 percent.

2.2 Costs

2.2.1 Introduction

Evaluation of the economics of PCC requires consideration of both costs and benefits which are highly specific to individual coal supply/coal user combinations. Further, some of the most important factors are difficult to quantify, e.g., the value of improved boiler operability and efficiency which may result from lower throughput of inert mineral matter and sulfur. Also where PCC is being assessed as an approach to control of sulfur oxide pollution, it must be compared with available alternatives including flue gas desulfurization (FGD), the use of naturally occurring low-sulfur coals, and the use of PCC in combination with FGD. Finally, the economic factors can be assessed from several perspectives, e.g., that of a coal producer evaluating the return on investment that might be realized by selling cleaned coal or that of a coal user evaluating what might be saved using physically cleaned coal. All of these factors combine to make generalization relative to costs difficult. However, one recent study[3] demonstrates a definite economic advantage for PCC combined with FGD for SO_2 emission control, as compared to the exclusive use of FGD. Other data which have been accumulated have made it increasingly apparent that PCC can be very attractive economically in many situations, and it can ease the problems in meeting environmental objectives.[4] Some of the findings considered most significant are presented in this section.

2.2.2 Physical Coal Cleaning Costs

For simplicity, only those costs which would be incurred by the operator of a PCC plant are considered here. No attempt is made to estimate the incentives for selling ROM coal, as opposed to physically cleaned coal, or the probable selling price of physically cleaned coal. Also, it should be noted that the overall cost of coal preparation may be expressed in units such as \$/ton of clean coal, \$/ton of raw coal, \$/10^6 Btu, or \$/lb of sulfur removed. In this report, costs are frequently stated in several ways in an attempt to prevent confusion associated with the use of different terms.

The total cost of PCC includes three main elements, i.e., capital charges, operating and maintenance (O&M) costs, and the costs of the Btu's lost when combustible matter is rejected in the refuse stream from PCC processes.

Capital Charges. Annualized capital charges depend on three factors, i.e., capital investment, estimated useful life of the plant, and the interest or discount rate.

The capital investment required for a PCC plant is heavily dependent upon its size and complexity. With new plants being designed to achieve economy of scale, the complexity is probably the dominant cost-related factor for modern plants. Complexity is in turn dependent upon the cleanability of the coal and product requirements. The complexity-cost relationship can be illustrated by considering a range of costs* which have been reported. For a simple jig plant processing, a 6-inch x 0 coal with the 48 mesh x 0 fraction processed in hydrocyclones to produce a 48 x 120 mesh clean coal fraction, the cost was $6,600[5] per ton/hour of feed capacity. For the multistream coal cleaning plant which has been built to help control emissions from a power plant (see Section 2.4), the reported cost was $42,000 per ton/hour of capacity.[6]

Capital investment costs are converted to fixed annual charges on capital by using appropriate estimates for the useful life, L, of the facility (in years) and the interest or discount rate, i (annual percentage). The values of L and i determine the capital recovery factor (CRF) which is multiplied times the capital investment cost to obtain the fixed annual charges on capital. These charges allow for amortization of the capital investment and the time value of the moeny invested over the useful life of the physical asset. The approximate PCC capital investment cost range of $6,600 to $42,000 per ton/hour of capacity can be converted to a range for charges on capital as follows. With a plant useful life of 15 years and a discount rate of 18 percent**, the capital recovery factor (CRF) is 0.19640, which yields a range for fixed annual charges on capital of approximately $1,296 to $8,249 per ton/hour of capacity. With a plant capacity of 1000 tons/hour and a plant utilization of 42 percent, or 3690 hours/year, the range for charges on capital is approximately $0.35 to

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* 1977 dollars.

** Based on a combination of interest on borrowed funds and return on equity.

$2.24/ton of feed coal or $0.44 to $2.79/ton of clean coal if the weight yield is 0.8.*

Operating and Maintenance Cost. O&M costs for PCC typically include raw materials and supplies, utilities, labor, and overhead. Other costs which may be included are payments to union welfare fund, insurance, payroll taxes, and property taxes. O&M costs** for PCC may range approximately from $0.60[7] to $4.00[8] per ton of feed coal ($0.75 to $5.00 per ton of clean coal if the weight yield is 0.8). The lower figure is for coarse beneficiation, i.e., washing of +3/8-inch material only with the 3/8-inch x 0 fraction being shipped dry as is. The higher figure applies to full beneficiation of a coal with large amounts of -28-mesh material (above 20 percent) using heavy-medium circuits and full treatment of the fines.

Cost of Btu Loss. The cost of Btu loss is a function of the cost and heating value of the feed coal and the Btu recovery. Formulas for calculating and reporting these costs have been shown by Battelle[9]. The costs for Btu loss as a function of these two variables is shown in Table 2.

TABLE 2. COST OF BTU LOSS FOR R = 0.95
$/ton of Clean Coal

F, Cost of Feed Coal, $/ton	100 Y, Weight Yield, Percent				
	60	70	80	90	95
10	0.83	0.71	0.63	0.56	0.53
15	1.25	1.07	0.94	0.83	0.79
20	1.67	1.43	1.25	1.11	1.05
25	2.08	1.79	1.56	1.39	1.32

* Cost per ton of cleaned coal is obtained by dividing the cost per ton of feed coal by the weight yield.

** 1977 dollars.

The values in Table 2 reflect a cost which assumes that the value of Btu's associated with coal in refuse is equal to that of Btu's in clean coal. It should be recognized, however, that, as indicated earlier, this is not a true relationship because constituents removed by PCC have a relatively low heating value and, being associated with sulfur compounds and inert mineral matter, they are difficult to utilize effectively. However, calculation of the cost for Btu loss without differentiation with respect to the actual value of Btu in the coal product versus those in the refuse gives a good approximation. It should be noted also that the cost of coal after washing is not simply a function of the cost of input coal and the amount of coal lost. For example, with a $20/ton cost of feed coal and an 80 percent weight yield, the cost of "raw materials" per ton of clean coal is $25.00. With a Btu recovery of 95 percent and a weight yield of 80 percent, the cost of Btu loss is $1.25/ton of clean coal as shown in Table 2. Part of the increase in raw material of $5.00 is offset by a $3.75/ton increase in the value of the coal product (attributable to its higher heating value) giving a net cost of $1.25 per ton of cleaned coal.

Total PCC Costs. The range in costs previously cited are summarized in Table 3.

TABLE 3. APPROXIMATE RANGES OF PCC COSTS

Cost Category	Approximate Cost Range, $/ton of clean coal
Capital Charges	0.44 - 2.79
O&M	0.75 - 5.00
Btu Loss	0.53 - 2.08
Total	1.72 - 9.87

The calculated value of fixed annual charges on capital is very sensitive to the estimated useful plant life and discount rate. Both the capital and O&M costs per ton of feed or clean coal are very sensitive to the estimated plant utilization. Thus, while most plants would fall in the cost range shown, the costs in specific situations are subject to further variation as estimates for these parameters differ from the representative values used here.

2.2.3 Case Studies of PCC Costs

A recent report[5], based on a study by The Hoffman-Muntner Corporation, presents the results of detailed case studies of the costs of eight PCC plants. These plants represent a sepctrum of PCC technology from a relatively simple jig process to relatively complex circuits involving heavy medium cyclones, froth flotation cells, and thermal dryers. These configurations were considered to be typical of those currently in use. The estimated capital investment costs are given in Table 4, and the annualized costs, which include operating and miantenance costs, capital charges, and cost of Btu loss, are shown in Table 5. The data are all within the ranges shown in Table 3 except for the cost of Btu's lost in Plant No. 3. For this plant, coal losses combined with high rejection of mineral matter, give a low yield. As a result, the high cost per ton of raw coal, when converted to cost per ton of cleaned coal comes to $4.49/ton, a value more than twice that for any other plant in the study. This is a good illustration of the degree to which site-specific factors can cause wide variations from any rule of thumb even though it may be generally applicable. The assumptions made in the Hoffman-Muntner study[5] to determine a capital recovery factor varied widely from those used for the Battelle study[9], but the differences were in large part offsetting and, when adjusted to a common basis, the agreement was good.

2.2.4 Benefits of Physical Coal Cleaning

The benefits associated with the use of physically cleaned coal include the following.

TABLE 4. DESCRIPTION OF COAL PREPARATION PLANTS[5]

Plant No.	Type of Process	Raw Coal Capacity (TPH)	Complexity	Estimated Capital Investment, $\$ \times 10^3$ (mid-1977)	Btu Recovery, %	Weight Yield, %	Moisture Content in Clean Coal, %	Heating Value of Clean Coal, Btu/lb (Moisture Free)	Total Sulfur Content in Raw Coal, %	Ash Removal,[a] lb/T	Sulfur Removal[a] lb/T
1	Jig	600	Simple	3,946	91.6	59.0	8 - 9	13,236	0.65	651	3.7
2	Jig	1,000	Intermediate	13,681	96.4	71.4	6.9	12,974	3.42	472	23.3
3	Jig	1,000	Intermediate	12,084	83.0	56.6	4.6	13,056	4.30 (3.01)	606	27.7
4	Jig	1,600	Complex	22,886	93.7	59.6	5.8	14,244	1.0	678	9.0
5	Heavy Medium	1,400 (720)[b]	Simple	9,962	94.6	74.0	7.5	10,992	4.56	260	29.5
6	Heavy Medium	600	Complex	13,449	89.2	73.3	5.0	14,336	4.38	338	55.2
7	Heavy Medium	600	Complex	8,420	93.1	60.0	4.9	13,348	1.0	660	6.3
8	Heavy Medium	900	Complex	20,916	94.3	86.0	5.0	13,130	2.45	145	18.0

(a) lb removed/ton of raw coal processed.

(b) 680 tph of raw coal is not processed by the cleaning plant.

TABLE 5. TOTAL ANNUALIZED COSTS FOR EIGHT COAL PREPARATION PLANTS[5]
(Mid-1977 Dollars)

Plant No.	Operating and Maintenance Cost[a]		Capital Charges[b]		Cost of Btu Loss		Total Annualized Cost				
	$/Ton of Raw Coal	$/Ton of Clean Coal	$/Ton of Raw Coal	$/Ton of Clean Coal	$/Ton of Raw Coal	$/Ton of Clean Coal	$/Ton of Raw Coal	$/Ton of Clean Coal	$/10^6 Btu Recovered	$/Ton of Ash Removed	$/Ton of Sulfur Removed
1	1.59	2.70	0.38	0.65	1.26	2.14	3.23	5.49	0.227	9.92	1,746
2	1.82	2.55	0.80	1.12	0.54	0.75	3.16	4.42	0.183	13.39	271
3	1.51	2.67	0.71	1.25	2.54	4.49	4.76	8.41	0.338	15.71	344
4	1.76	2.96	0.84	1.40	0.95	1.60	3.55	5.96	0.222	10.47	789
5[c]	2.37	3.20	0.42	0.56	0.81	1.10	3.60	4.86	0.239	27.69	244
6	2.23	3.04	1.31	1.79	1.62	2.21	5.16	7.04	0.258	30.53	187
7	1.27	2.12	0.82	1.36	1.06	1.76	3.15	5.24	0.206	9.55	1,000
8	2.10	2.44	0.81[d]	0.94[d]	0.88	1.02	3.79	4.40	0.176	52.28	421

(a) Includes labor, supervision, overhead, supplies, fuel, electricity, and subcontract services.

(b) Based on a 10-year amortization period, 9 percent discount rate, and 30 percent utilization factor, except as noted.

(c) Costs shown for Plant No. 5 are based on 1400 TPH.

(d) Fifty percent utilization factor.

(1) Reduced coal transportation cost

(2) Reduced coal handling and coal pulverization cost

(3) Reduced ash collection and disposal cost

(4) Increased boiler efficiency, capacity, and availability

(5) Reduced O&M costs

(6) Savings in cost for control of sulfur oxide pollution.

Items (1) through (5) above are savings in operating cost which result from general upgrading of coal quality. Item (6) is a savings which is realized where PCC is used to minimize sulfur pollution control costs. To date there has been no comprehensive assessment of the value of all these benefits. A number of relevant studies have been conducted, however, and some understanding of the potential importance of some of the factors above is being developed.[4]

Penalties Associated With Poor Quality Coal. According to a recent study, power plants can experience incremental costs from poor coal quality starting at about $1.00 per ton for coal containing 13 percent minerals (ash + sulfur) and ranging to about $8.00/ton for coal containing 25 percent minerals.[10] These costs, which could be minimized by reducing the mineral content of the coal, are approximately in the range of costs shown in Table 3 for PCC. Based upon the study of cost penalties for poor quality coal[10], power plants using clean coal produced by the PCC plants listed in Tables 4 and 5 could expect to realize substantial cost reductions because of the amounts of ash and sulfur removed from the raw coal. However, accurate estimates of these cost reductions cannot be made because of insufficient data. Some but not all of the six benefits listed above were considered in the referenced study[10], the most notable exception being savings in cost for control of sulfur oxide emissions. This factor is discussed in the section following.

Savings in Sulfur Pollution Control. The control of sulfur oxide emissions from fossil-fuel-fired combustors currently is achievable by the use of one of four methods: (1) naturally-occurring low-sulfur coal; (2) flue gas desulfurization (FGD); (3) physical coal cleaning (PCC); and (4) combinations of these three approaches. Evaluation of the relative merits of the different approaches requires that they be assessed from the standpoint of their impact on the cost of boiler output. One such comparison which considers the impact of sulfur control on power generation was reported recently by Battelle.[9] Data derived from that report are presented below to illustrate the possible magnitude of savings which could be realized using PCC alone, or with FGD, for sulfur oxide control.

The cost of power generation is determined by the capital charges, fuel cost, and O&M costs for the power plant. All three components are influenced in different ways by the method selected for sulfur oxide pollution control. Application of FGD increases both fixed charges and O&M costs but makes it possible to use readily available fuels. The use of PCC likewise increases both fixed and O&M costs for the total system but, when used in combination with FGD, reduces costs for the gas cleaning system. Also, it upgrades the quality of the fuel. The use of low-sulfur western fuels has no impact as far as increased fixed costs are concerned. Its use in boilers designed for eastern bituminous coal is judged, because of lower heating value and other properties, to reduce boiler availability from 0.8 to 0.7 for purposes of the Battelle comparison. Some increased boiler maintenance might also be anticipated, but none is assumed for purposes of this comparison.

Because costs for generation of electricity are greatly dependent upon the hours the plant is operated, any comparison of sulfur oxide control methods must consider their effect on plant availability. The differences in availability reflect differences in coal quality on boiler and scrubber operation and the effect of scrubber operability on system availability. The effect of scrubbers was estimated for different degrees of redundancy as far as spare scrubber modules were concerned. The availabilities estimated for the earlier study are shown in Table 6.

Assumptions made for cost factors for the system configurations shown in Table 6 are shown in Table 7. The costs and benefits for PCC are generally consistent with data presented earlier. The relationship for incremental maintenance and mineral content is based on recent work reported for TVA boilers.[10] Other costs are considered reasonable in light of the latest estimates. The direct benefits shown for PCC include those discussed earlier such as reduced transportation costs, etc. The indirect benefits are associated with FGD, e.g., reduced energy requirements for reheat of stack gases.

TABLE 6. POSTULATED CONDITIONS OF AVAILABILITY[9]

Case No.	Case Description*	System Availability
1	Raw high-sulfur eastern coal, no FGD (baseline)	0.8
2	Raw low-sulfur western coal, no FGD	0.7
3	Cleaned high-sulfur eastern coal, no FGD	0.9
4	Raw high-sulfur eastern coal, with FGD (4 modules + 1 spare)(Boiler = 0.8, FGD = 0.65/module)	0.627
5	Cleaned high-sulfur eastern coal, with FGD (3 modules + 1 spare)(Boiler = 0.9, FGD = 0.75/module)	0.806
6	Cleaned high-sulfur eastern coal, with FGD (3 modules + 2 spares)(Boiler = 0.9, FGD = 0.75/module)	0.864

* Individual availabilities for boilers and FGD modules are given in parentheses where applicable.

The overall comparison for the six system configurations is shown in Table 8. From results for the two cases comparing the use of ROM eastern coal and cleaned eastern coal (1 and 3), it is apparent that burning cleaned coal is the cheapest way to produce power. For those cases which achieve desired levels of sulfur oxide control, the advantage is even greater, ranging from 0.241 ¢/kWh to 0.563 ¢/kWh, even in situations where supplemental control with FGD is needed. These results are confirmed by a paper[11] discussing a partially completed study being conducted by Bechtel National, Inc., for the Electric Power Research Institute. The paper concludes that "from the results obtained so far, it is judged that the cost of coal cleaning can be offset by savings in transportation costs, power plant capital costs, and operating and maintenance costs."

In the development of those cost comparisons, a number of simplifying assumptions were made which require that any conclusions reached be substantially qualified. First of all, the analysis applies only to utility boilers which are required to meet the former NSPS of 1.2 lb $SO_2/10^6$ Btu or SIP

TABLE 7. SUMMARY OF COSTS FOR A 500-MW COAL-BURNING POWER PLANT

Power Plant

Annual Fixed Charges - (0.235)($215,375,000) = $50,663,000

Fuel
- Eastern high-sulfur coal - $0.84/10^6 Btu
- Western low-sulfur coal - $1.41/10^6 Btu

Production - (0.176)(Fuel Costs)/10^6 Btu

Incremental Maintenance - $0.15 (% ash + % sulfur - 12.5)/ton of coal

Flue Gas Desulfurization System

Annual Fixed Charges
- Five modules - (0.235)($45,435,000) = $10,688,000
- Four modules - (0.235)($40,485,000) = $9,523,000

Operating and Maintenance - $0.23/10^6 Btu

Physical Coal Cleaning

Capital Cost - $15,870 per ton/hr

Annual Fixed Charges - (0.235)($6,852,500) = $1,612,000

Operating and Maintenance - $0.089/10^6 Btu

Direct Benefits - $0.041/10^6 Btu

Indirect Benefits (when used with FGD) - $0.031/10^6 Btu

TABLE 8. SUMMARY OF COSTS FOR POWER GENERATION USING VARIOUS CONTROL MODES

Number	Case Description	Operating Hours per Year[b]	Power Plant Costs, ¢/kWh				FGD Costs, ¢/kWh		Coal Cleaning Costs and Savings, ¢/kWh				Total Costs, ¢/kWh
			Fixed	Fuel	Production	Incremental Maintenance	Fixed	O&M	Fixed	O&M	PCC Savings	PCC/FGD Savings	
1[a]	Raw high-sulfur eastern coal, no FGD (baseline)	7008	1.446	0.840	0.148	0.093	--	--	--	--	--	--	2.527
2	Raw low-sulfur western coal, no FGD	6132	1.652	1.410	0.248	--	--	--	--	--	--	--	3.310
3[a]	Cleaned high-sulfur eastern coal, no FGD	7884	1.285	0.898	0.158	0.015	--	--	0.041	0.089	-0.041	--	2.445
4	Raw high-sulfur eastern coal, with FGD (4 modules + 1 spare) (Boiler = 0.8, FGD = 0.65/module)	5493	1.845	0.840	0.148	0.093	0.389	0.230	--	--	--	--	3.545
5	Cleaned high-sulfur eastern coal, with FGD (3 modules + 1 spare)(Boiler = 0.9, FGD = 0.75/module)	7061	1.435	0.898	0.158	0.015	0.270	0.230	0.046	0.089	-0.041	-0.031	3.069
6	Cleaned high-sulfur eastern coal, with FGD (3 modules + 2 spares)(Boiler = 0.9, FGD = 0.75/module)	7569	1.339	0.898	0.158	0.015	0.282	0.230	0.043	0.089	-0.041	-0.031	2.982

(a) Not in compliance with NSPS promulgated December 23, 1971 (36FR24876).
(b) Based on Tables 6 and 7.

regulations in this same range. Additional analysis will be needed to determine definitely that similar conclusions will apply to operation of commercial/industrial boilers and those utility boilers which will be subject to the recent NSSPS (June 11, 1979).

Also, at least two areas of uncertainty are evident in the estimates of costs and benefits. First, the savings estimated for reduced boiler O&M costs (and associated increases in boiler availability) assume that these costs are a function of only the amount of ash and sulfur present in the coal. They are not based on results of operation with run-of-mine coal versus cleaned coal from the same source. Second, the estimates for the fixed, operating and maintenance cost for the FGD systems were based on average conditions and not related specifically to flue gas volumes to be treated, amount of sulfur oxide to be removed, etc. In any future analyses, a more rigorous approach based on recent work by Kilgroe[12] would be possible.

It does not appear, however, that the elimination of uncertainties would substantially change the results. And the cost advantage for PCC indicated in Table 8 represents a potential annual savings of $9 million to $21 million for a 500 MW plant. The magnitude of national savings which appear to be possible is such that activity to promote the use of PCC would be in the national interest.

2.3 Applicability

Potential markets for low-sulfur, low-ash coal appear to be large, but the availability of cleanable coals in proximity to potential users is ill-defined. Further, the extreme sensitivity of coal cleaning economics to highly variable site-specific requirements is such that generalities can be misleading. It appears, however, that some comment in this connection is appropriate.

Potential market areas for physically cleaned coals include (1) utility boilers, (2) industrial and commercial boilers producing process steam or providing space heating, (3) metallurgical applications, and (4) systems converting coal into gaseous or liquid fuels. In 1975, U.S. boiler fuel consumption was approximately 26 x 10^{15} Btu (about 1/3 of the total for fossil fuels),[13] exceeding even transportation (19 x 10^{15} Btu) which is by far the next largest fuel use.[14] Coal-fired utility boilers burned about 430 x 10^6 tons of coal. Coal-fired boilers for industrial or commercial applications burned about 44 x 10^6 tons. Table 9 breaks down the estimated fuel consumption, by usage sector and fuel type for the U.S. in 1975. From these data it is apparent that, despite the large amounts of coal burned, gas is used in about equal quantities as a boiler fuel, and gas and oil combined provided about 60 percent of the total. The ways in which patterns will change as gas and oil become unavailable or prohibitively expensive are very uncertain. It seems certain, however, that the use of coal will increase substantially, and it seems reasonable to assume that considerably more will be burned in small boilers which make up the industrial/commercial sectors where gas and oil consumption is now the dominant fuel.

TABLE 9. ESTIMATED FUEL CONSUMPTION FOR U.S. BOILERS (1975)[13]

Use Sector Fuel Type	Fuel Consumption, 10^{12} Btu
Utility	
Coal	9,310.0
Residual Oil	2,590.8
Distillate Oil	129.7
Natural Gas	3,016.7
	15,047.2
Industrial/Commercial	
Coal	1,101.6
Residual Oil	1,762.3
Distillate Oil	1,129.6
Natural Gas	6,381.2
	10,374.7

PCC is a potentially useful SO_2 emission control method for existing utility and large industrial boilers that are subject to state and local regulations but not subject to New Source Performance Standards (NSPS). For boilers where present NSPS are applicable, PCC is useful as a complementary control technique (e.g., along with FGD) in a number of situations.

For many of the smaller coal-burning boilers not subject to NSPS (those less than 250 x 10^6 Btu/hr heat input), PCC may be the only feasible near-term method for minimizing SO_2 emissions and, therefore, may be used, or at some point even required, for control of such boilers. Boilers of this class represent an estimated 40 percent of the existing boiler fuel-burning capacity[13] and, with pressure to convert the 85 percent that are oil- or gas-fired to coal, the number of small coal-burning boilers can be expected to increase. Burning physically cleaned coal could be helpful in minimizing the pollution from such boilers by removing potential pollutants prior to combustion.

As conversion processes for generating gas or oil from coal begin to find application, it seems reasonable to suppose that they will create additional demand for physically cleaned coals. Removal of substantial amounts of sulfur, trace elements, and ash-forming minerals from the coal prior to conversion is likely to be less expensive than putting such impurities through the system and having to remove them from discharge streams. In addition, there may be process-reaction reasons for using PCC. While such markets are likely to develop some years in the future, it seems reasonable to consider such applications as a part of the contribution that PCC can make to future environmental control.

2.4 Extent of Development

Physical coal cleaning systems can be designed with reasonable confidence for well-characterized coals. Systems designed for removal of ash and pyritic sulfur may have circuits for treatment of three size fractions of coal: (1) coarse (e.g., 3 x 3/8 inch)*, (2) fine (e.g., 3/8 inch x 28

* In practice, the size of coal fractions processed may vary widely. For purposes of this report, size ranges shown as examples are considered to be representative of coarse, fine, and ultrafine coal.

mesh [M]), and (3) ultrafine (e.g., 28 M x 0). Such arrangements are characteristic of systems which have been used for preparation of metallurgical coals. A more advanced system, alluded to earlier, which has been installed near the Homer City power generating plant and is jointly owned by Pennsylvania Electric Company and the New York State Electric and Gas Corporation is the first multistream coal cleaning system (MCCS) designed to provide an optimized strategy for meeting emission stnadards and utilizinh coal resources. In this facility, two clean coal products, with low and medium sulfur contents, are developed for consumption in separate boilers which are regulated under different sulfur limitations. This system meets emission levels and maximizes recovery of Btu's from the raw coal.

This facility, now in the start-up phase, has a design capability of 1,200 tons per hour and will process 5.2 million tons of ROM coal per year. It has a number of unique design features and incorporates four processing circuits which utilize heavy medium cyclones for processing of coarse and fine coal and hydrocyclones combined with wet concentrating tables for very fine coal. The plant is expected to produce a medium sulfur coal and a low sulfur coal. The characteristics of the output streams are shown in Table 10. The medium sulfur coal will be used in two existing 600 MW generating units to meet the Federal and state emission regulation of

TABLE 10. HOMER CITY PLANT PERFORMANCE[(6)]

	Medium-Sulfur Coal	Low-Sulfur Coal	Refuse
Yield, weight percent	56.2	24.7	19.1
Recovery, Btu percent*	61.6	32.9	5.5
Product Btu/lb (dry basis)	12,549**	15,200	3,367
Ash, in Product, weight percent	17.8	2.8	69.7
Sulfur, in Product, weight percent	2.2	0.9	6.2
Pounds $SO_2/10^6$ Btu	3.6	1.2	36.5
Total Sulfur Reduction, weight percent	52.6	91.8	

* Figures account for 94.5 percent of Btu recovery. Overall plant Btu recovery is 93.5 percent which includes 1 percent loss for thermal drying.
** Mixture of middling and deep-cleaned coal.

4.0 lb $SO_2/10^6$ Btu for existing boilers. The low sulfur coal will be used for a new 650 MW unit to meet the New Source Performance Standards (NSPS) of 1.2 lb $SO_2/10^6$ Btu without the use of a flue gas desulfurization (FGD) system.

The original plan for the new Homer City unit called for installation of an FGD system for SO_2 emission control. However, following comparative studies of the effectiveness and costs of FGD and MCCS for controlling SO_2 emissions, the plan to install FGD was dropped.

As a sequel to the design and construction of this facility, a program to evaluate the performance of this advanced design will be undertaken. A cooperative program for this evaluation will involve the owners, the U.S. Environmental Protection Agency (IERL-RTP), the U.S. Department of Energy, and the Electric Power Research Institute. A 3-year period of performance for the evaluation is anticipated. It is expected that the results of the evaluation program will confirm the soundness of the design principles on which the plant is based.

The use of PCC systems for ash and pyritic sulfur removal is not, however, without technical limitations. Research and development aimed at improving these systems is being conducted by the U.S. EPA, the U.S. Department of Energy, and others. This work is intended to:

1. Define and evaluate the potential sources of pollution that are associated with PCC systems and assess the environmental impacts that might be associated with widespread application of the technology.
2. Collect additional information needed for full characterization of the washability of both existing coal supplies and reserves. While a substantial amount of testing has been completed for some operating mines, all deposits now being mined have not been intensively analyzed. Very little work has been done to evaluate the washability of reserves not being mined.
3. Develop information needed to better understand the relationship between variability in the amount and type of ash and sulfur in the input coal and to develop improved systems for controlling the quality of the cleaned coal.

4. Generate background information needed to define the potential of new systems which employ presently available technology in configurations that involve crushing of the entire coal feed to a relatively fine size such as 3/8 inch x 0.
5. Develop information needed to define all the benefits associated with PCC including savings in pollution control costs, transportation costs, and boiler maintenance costs as well as savings associated with boiler availability.
6. Reduce the coal losses associated with coal cleaning and investigate ways to recover, or otherwise utilize, coal rejected by the cleaning process.
7. Determine the possible role of PCC in combination with, or in competition with, other emission control techniques such as flue gas desulfurization (FGD) systems or using clean fuels produced by advanced coal conversion systems.

2.5 Prospects for Commercialization

Physical coal cleaning is a long-established but still developing technology whose commercial application is being expanded at a low rate in light of the magnitude of previously discussed economic and environmental benefits that are attainable where coals with good washability characteristics are available. Some factors cited as retarding the rate of application of PCC are:

1. Coal companies that could operate PCC processes at the mine site may prefer to use available capital to open new mines unless there is a clear financial incentive for their use of PCC.
2. Utility and other industrial groups, because coal cleaning is most practical near the mine, may have to go into the mining business if they want to produce their own physically cleaned coal. This is considered unlikely to happen in many situations.

3. The costs and benefits of PCC, being highly specific to each coal producer and coal user combination, require careful evaluation. Many users, being unfamiliar with PCC technology, may find evaluation difficult. Unless the benefits can be demonstrated, it is unlikely that users will offer a premium price for cleaned coal.
4. While washability data are available for many of the present coal supplies, it is difficult to draw conclusions with respect to the overall potential impact of PCC. Additional information on the washability of coal reserves is needed so that future applicability can be predicted with more confidence.
5. Uncertainties with respect to sulfur oxide emission standards make PCC difficult to evaluate as a pollution control measure. Further, it is uncertain what pollution control measures will be required for the PCC plants themselves. Since some PCC plants will be large (1500 T/hr capacity or more) and expensive (perhaps $40,000,000 and up), uncertainties of any kind are a great deterrent to building a plant.
6. There is a considerable investment in existing mines, many of which are producing coal whose sulfur is not significantly lowered by PCC. Further, many utilities have long-term purchase contracts for coals that are not amenable to substantial sulfur reduction by physical cleaning. Whether other benefits associated with PCC could be realized in such situations has not been established. Hence, there appears to be little documented incentive to change the status quo in such situations.
7. A significant amount of our total coal production comes from small companies which could not afford to invest in PCC systems.

This list of barriers to commercialization suggests that positive coordinated actions on the part of authorities on the Federal and state levels will be necessary if the apparent benefits from use of PCC are to be realized. This situation has been analyzed by Battelle[9] and the following recommendations were presented.

1. Federal and state Environmental Protection Agencies should take actions needed to define SO_2 emission standards so that the long-term usefulness of PCC for control of SO_2 can be assessed. In addition, environmental regulations applicable to operation of PCC systems must be defined. Removal of these environmental uncertainties will make it possible to make meaningful investment decisions.
2. The authority conferred by the "Energy Policy and Conservation Act" should be used to provide loan guarantees for central coal cleaning facilities to process the output of small producers.
3. Congress should appropriate funds to construct PCC plants which would be paid back out of profits when the plant is in operation. (A program similar to the "Rubber Reserve" program during World War II is envisaged.)
4. The Internal Revenue Service should rule that PCC plants qualify as pollution control investments for tax purposes. This would qualify the investment for accelerated depreciation and tax credit, and it would permit financing with the proceeds from tax exempt pollution control bonds.
5. The Interstate Commerce Commission should change its regulations to allow shipment of cleaned coal at unit train rates.
6. EPA should take action to develop a public information program to educate coal producers and users to the advantages of using PCC.
7. Research and development needed to further improve PCC and generate firm data for economic evaluations should be pursued vigorously so that the advantages offered by PCC can be maximized.

In summary, it appears that PCC has considerable potential for producing overall benefits nationally. The national benefits would be in the form of reduced pollutant emissions and also reduced costs for (1) transportation of coal, (2) pollution control, and (3) generation of electricity or production of steam for process or space heating. Realization of these benefits would require development of PCC systems tailored to meet the requirements of many unique coal production-usage combinations and would require actions of the type discussed above by responsible government agencies.

3.0 DESCRIPTION OF TECHNOLOGY

Physical coal cleaning (PCC) systems that might be employed today range in complexity from simple systems for removing coarse refuse to highly sophisticated systems designed for maximum removal of sulfur and ash from a specific coal supply. The simple systems have been employed widely in the past and may need to be considered from the standpoint of their environmental impacts. They are of little interest, however, for their potential for minimizing the environmental impacts associated with coal combustion. The more sophisticated systems that are designed for maximum removal of sulfur and ash are identified in this section, and feedstock and product characteristics are discussed.

3.1 Physical Coal Cleaning Systems

The separation processes that divide the product stream from the refuse fraction are the central components of PCC systems, which involve three primary operations--coal pretreatment, coal cleaning, and product conditioning. Other auxiliary processes are employed for coal handling, water treatment, and solid waste disposal. All operations employ a variety of processes with different potentials for discharging pollutants. These processes and associated waste streams are discussed individually in Appendix D. Figure 1 schematically displays the processes and operations which are incorporated in PCC systems. The indicated sizes may vary in practice and are shown only as typical size ranges for coarse, fine, and ultrafine coal cleaning circuits.

Cleaning effectiveness is a function of the effectiveness of a PCC system in removing impurities (inorganic sulfur compounds and other mineral matter) and the effectiveness in recovering high percentages of the Btu's available in the raw coal. Unfortunately, these two objectives are often difficult to achieve simultaneously and can be mutually exclusive. Three levels of cleaning effectiveness which involve a compromise between ash and sulfur removal and Btu recovery are currently practiced:

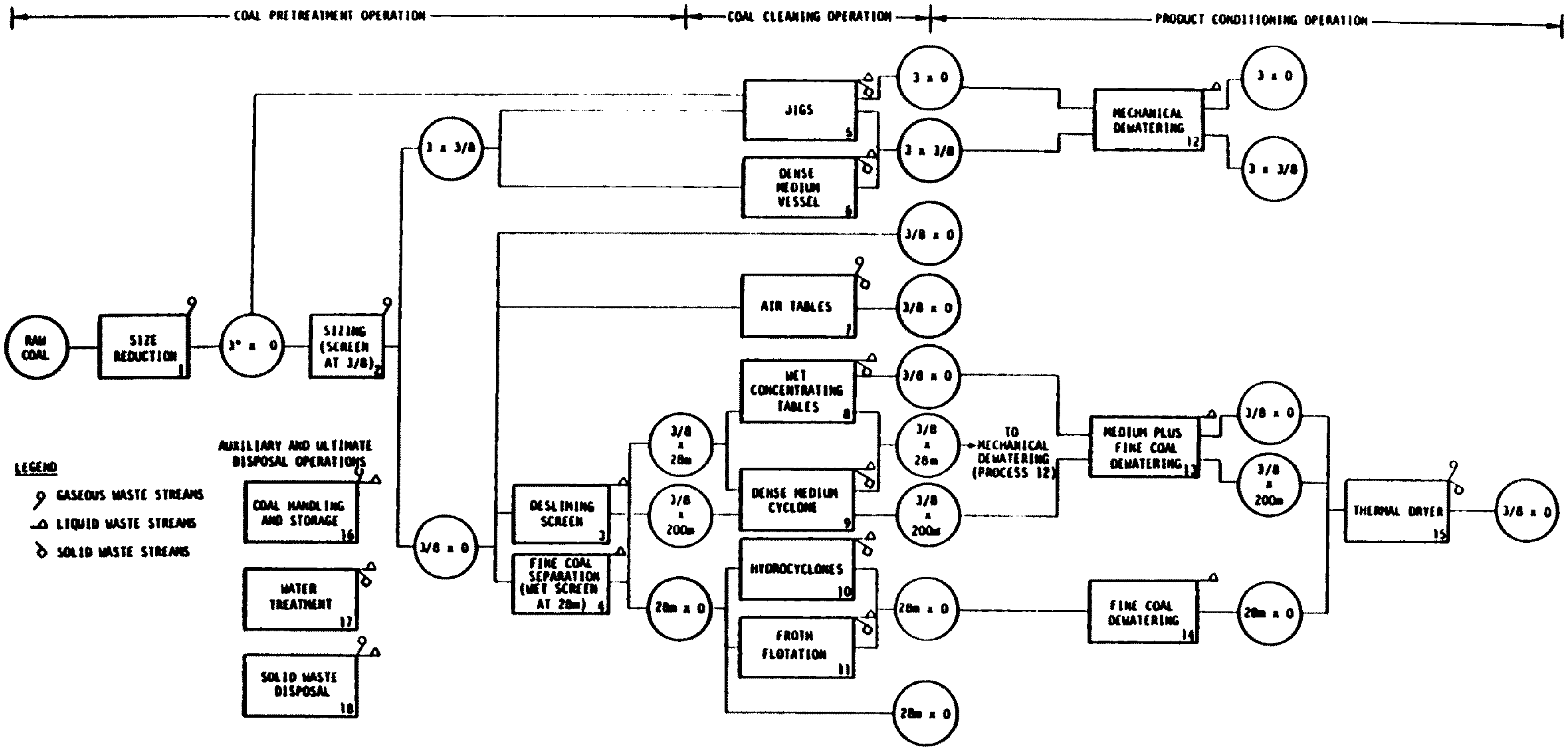

FIGURE 1. PROCESS FOR PHYSICAL COAL CLEANING SYSTEMS

1. Minimum cleaning effectiveness involves crushing and sizing of raw coal, cleaning the coarse fraction (3 x 3/8 inch) in jigs or dense-medium vessels, and then combining or not combining the uncleaned fine and ultrafine fractions (3/8 inch x 0) with the cleaned coarse fraction. With this level, it is possible to obtain either a high quality coal product or a high Btu recovery, but not both. A high quality coal product may be obtained by use of a low specific gravity of separation (near 1.3) for the coarse fraction and by not combining it with the uncleaned fine and ultrafine fractions. A high Btu recovery may be obtained by use of a high specific gravity of separation (say 1.8) for the coarse fraction and by combining it with the uncleaned fine and ultrafine fractions.
2. For the intermediate level of cleaning effectiveness, the coarse fraction is cleaned as in Level 1, and the combined fine and ultrafine fraction is cleaned with air tables, wet concentrating tables, or dense medium cyclones. Where dense medium cyclones are used, the 3/8 inch x 0 feed may be passed over desliming screens which yield a 3/8 inch x 200 M material, which is fed to the dense medium cyclones.
3. Maximum effectiveness in cleaning is obtained by cleaning the coarse fraction as in Level 1, splitting the 3/8 inch x 0 fraction into two fractions (e.g., 3/8 x 28 M and 28 M x 0), and cleaning the two fractions separately with equipment designed for maximum removal of sulfur and ash from fine and ultrafine size coals. The 3/8 inch x 28 M fraction is cleaned with wet concentrating tables or dense-medium cyclones. The 28 M x 0 fraction is cleaned using either hydrocyclones or froth flotation. PCC plants which incorporate processing of the 28 M x 0 fraction tend to employ thermal drying.

Table 11 illustrates eight basic systems that may be employed.

3.1.1 Coal Pretreatment Processes

Coal pretreatment processes are employed to generate feed streams with liberated impurities and particle size distributions that have been shown

TABLE 11. PHYSICAL COAL CLEANING PLANT TYPES*

System	Level of Cleaning Effectiveness	Coal Size and Process: Coarse, 3" x 3/8"	Fine, 3/8" x 28M	Ultrafine, 28 M x 0
1	Minimum	CS+J or DMV	---------None---------	
2	Intermediate	CS+J or DMV	----------AT----------	
3	Intermediate	CS+J or DMV	----------WT----------	
4	Intermediate	CS+J or DMV	---------DMC----------	
5	Maximum	CS+J or DMV	WT	HC+TD
6	Maximum	CS+J or DMV	WT	F+TD
7	Maximum	CS+J or DMV	DMC	HC+TD
8	Maximum	CS+J or DMV	DMC	F+TD

Legend:

CS	Crushing and Sizing
J	Jigs
DMV	Dense Medium Vessels
AT	Air Tables
WT	Wet Concentrating Tables
DMC	Dense Medium Cyclones
HC	Hydrocyclones
TD	Thermal Dryers
F	Froth Flotation Units

Note: All wet separation processes will have associated dewatering processes as shown in Figure 1.

* The eight types of coal cleaning plants listed are representative, but many other types exist or may be constructed. For example, in some cases jigs have been used for 3" x 0 coal instead of 3" x 3/8" coal at the minimum cleaning effectiveness levels. The raw coal may be crushed to a finer top size than 3" to maximize impurity liberation. At the maximum cleaning effectiveness level, hydrocyclones and froth flotation units may be used in combination for treatment of fine coal.

to be most effective for processing in the available coal cleaning processes. Raw coal is crushed to a top size of about 3 inches and screened to provide a coarse stream and a fine to ultrafine stream. The latter is either sold, processed directly, or further divided into fine and ultrafine size fractions for wet cleaning. The initial screening of crushed raw coal may be either wet or dry. Dry screening is used if air tables are to be used for coal cleaning. Wet screening is used where fine and ultrafine size streams are processed by wet cleaning processes.

3.1.2 Coal Cleaning Processes

A number of approaches have been studied for non-destructive separations of coal from unwanted, associated mineral matter. These include methods based on specific gravity differences, surface properties, and responses to electrical fields or magnetic forces. Almost all methods with demonstrated commercial potential are based on specific gravity differences between the coal and other mineral matter. The only exception is froth flotation where differences in surface properties of coal allow it to be removed from aqueous suspensions of coal and inert minerals with air and organic flotation reagents.

The specific gravities of the principal coal constituents are: organic constituents--1.2 to 1.7, non-combustible ash (clay, shale, sandstone, etc.)--2.0 to 2.6, and pyrite--4.9 to 5.0. With differences of this magnitude, methods that separate fractions by specific gravity can be very effective where the components can be isolated from each other in reasonably pure form. Unfortunately, some impurities, pyritic sulfur in particular, are often present in very small, highly disseminated forms that require extensive size reduction to separate them from the coal. For very fine materials, the effectiveness of separation based on specific gravity decreases because of immobility of particles, particle-to-particle attractions, etc. Hence, froth flotation is finding increased application and other methods for fine coal cleaning are being studied.

Some historical trends, including the growth of froth flotation usage, are illustrated in Table 12. Pneumatic methods, because of ineffectiveness and problems associated with dust, moisture content, and size of equipment, have declined in use from 14 percent in 1942 to 4 percent in 1972.

TABLE 12. PROCESSES EMPLOYED FOR PHYSICAL CLEANING OF COAL (Percentage of Clean Coal Produced, Year)(15)

Process	1942	1952	1962	1972
Jigs	47.0	42.8	50.2	43.6
Dense Medium Processes (Dense Medium Vessels and Cyclones)	8.8	13.8	25.3	31.4
Wet Concentrating Tables	2.2	1.6	11.7	13.7
Froth Flotation	-	-	1.5	4.4
Pneumatic (Air Tables, etc.)	14.2	8.2	6.9	4.0
Other (Classifiers and Launders)	20.5	13.7	4.3	2.9

3.1.3 Product Conditioning Processes

The product conditioning processes are primarily for removal of excess water. The processes employed vary with the size of coal being processed. For coarse coal, simple mechanical dewatering which involves the use of natural drainage from perforated bucket elevators or dewatering screens is employed. For finer coal, the surface area is much larger and the amount of moisture retained per unit of surface area is also larger. Tight packing and capillary action tends to hold water in void spaces. Hence, finer coals (less than 1/4 inch) require something more effective than natural drainage.

For coals which contain both fine and ultrafine fractions, e.g., 3/8 inch x 0 or 3/8 inch x 200 M, a sieve bend combined with a centrifuge for additional water removal may be used. For fractions made up exclusively of ultrafine materials (e.g., 28 M x 0) vacuum filtration is required. Fine and ultrafine materials are thermally dried.

3.1.4 Auxiliary Processes

Auxiliary processes, i.e., processes that are in some way incidental to the main functions involved in PCC but are still of great importance to plant operation, are coal storage and handling, water handling, and solid waste disposal.

A typical coal cleaning plant with a cpaacity of 1000 tons/hr will operate 16 hr/day and can process over 5,000,000 tons of raw coal annually. Storage of raw coal and cleaned coal often is necessary to assure continuity of operation and continuous availability of coal for shipment to market. As production and transportation capacity increase, coal cleaning plants require larger storage facilities to achieve the maximum utilization of coal cleaning and transportation equipment. Coal is stored in open piles or enclosed bins and silos.

Transportation of coal from mines or preparation plants to the point of consumption is one of the most important factors affecting coal utilization. Transportation modes are rail, waterway, truck, pipeline, and belt conveyor. Often, more than one mode of transportation is used to convey coal from the mine to the consumer.

In conjunction with transportation and storage of coal, a wide variety of material handling operations is needed. This includes loading and unloading, stacking and reclaiming, and transferring coal in a plant. As the amounts of coal to be handled have grown larger, the material handling systems have become more mechanized and tend to be equipped with more automatic and integrated control systems. Movement of coal in and out of storage and in-process transfer of coal on such a scale makes coal handling one of the most important of the activities associated with PCC.

The high process-water requirement (up to about 10,000 gal/min for a 1000 ton/hr plant) makes overall water management another important consideration. Recycling of water is necessary to minimize consumption and the release of contaminated water to the environment. Water treatment is required to meet process requirements for recycling or environmental standards for discharge. The total requirement for PCC plants in the U.S. amounts to hundreds of billions of gallons per year. About 80 percent is recycled water. Most of the remainder is retained on the clean coal or refuse surfaces. Some is also discharged to the atmosphere from the thermal dryer. This loss must be replaced by fresh or make-up water.

PCC plants represent one of the largest sources of solid waste in the U.S. It has been estimated that 25 percent of raw coal is disposed as waste. In 1974, U.S. coal production was 590 million tons. Of this, 289 million tons were washed, producing 96 million tons of refuse for disposal. A single 1000-ton/hr plant would produce in the neighborhood of 1,000,000 tons/year of refuse. The disposal of ultrafine coal refuse is especially costly and difficult, and it presents complex environmental control problems.

3.2 Raw Materials

The characteristics of coal that are most relevant to the potential suefulness of physical coal cleaning in minimizing the pollution from coal combustion are as follows.

1. Specific Gravity. The specific gravity of coal varies from 1.2 to 1.7 as compared to 2.0 to 2.6 for non-combustible ash and 4.9 to 5.0 for pyritic sulfur. Differences in specific gravity provide the basis for most separation processes.
2. Washability. Coal washability is a measure of the degree to which pyritic sulfur and other non-coal minerals can be liberated, isolated from the coal, and removed using methods which discriminate between materials with different specific gravity. Only the sulfur contained in pyrite may be rejected from the ROM coal by PCC processes. The relative amount rejected from any coal seam varies widely with the nature of the coal and the processing technology employed.
3. Surface Properties. Differences in the hydrophobic or hydrophilic character of coal and ash particles influence the effectiveness of froth flotation for separation of fine coal from fine ash.
4. Grindability. This characteristic is a measure of the ease with which size reduction can be accomplished; it varies widely among coals and among components in a given coal.
5. Friability. The tendency of coal to degrade in size upon handling is termed friability.
6. Weatherability. The resistance of coal to disintegration or "slacking" on exposure to weather is called weatherability. Weatherability is an important factor in coal storage.

7. Trace Metal Content. Many potentially hazardous trace metals are present in mineral forms which tend to be removed by PCC. Properties of great interest from the standpoint of environmental protection are trace element content, leachability, and washability. These properties have all received a substantial amount of study but greatest emphasis has been centered on washability.

3.2.1 Washability

The previously-mentioned studies of washability by the U.S. EPA and the U.S. Bureau of Mines have been combined with data from the U.S. Bureau of Mines on the coal reserves of the U.S., using Battelle's Reserve Processing Assessment Model (RPAM).[9] This model computes, by region, the cleanability of the coal reserves for different coal cleaning processes. Major results from RPAM are as follows.

1. Thirty-seven percent, by weight, of the U.S. coal reserves (excluding Pennsylvania anthracite and Alaskan coals, for lack of appropriate data) meet an SO_2 emission standard of 1.2 $lb/10^6$ Btu without any cleaning prior to combustion.
2. If the reserves that do not meet an SO_2 emission standard of 1.2 $lb/10^6$ Btu are cleaned by physical separation at 1.6 specific gravity after crushing to 1-1/2-inch top size, then an additional 9 percent of the reserves will meet the standard, giving 46 percent in total.
3. Coal from the western region is of low sulfur content, and 71 percent of the raw coal meets an SO_2 emission standard of 1.2 $lb/10^6$ Btu. If the remaining coal is separated at 1.6 specific gravity after crushing to 1-1/2-inch top size, then, in total, 86 percent of the coal meets the standard.
4. Northern Appalachian, Eastern Midwest, and Western Midwest coals are high in sulfur, and only 6, 1, and 6 percent, respectively, of the raw reserves in the regions would meet an SO_2 emission standard of 1.2 $lb/10^6$ Btu. Pyritic sulfur has limited liberation potential in the coal, and, even after crushing to 1-1/2-inch top size and separating at 1.6 specific gravity, the percentages of the reserves

that will meet the standard overall are only 12, 3, and 7 percent, respectively.

5. Southern Appalachian coal is low in sulfur, and 53 percent of the raw coal meets an SO_2 emission standard of 1.2 lb/10^6 Btu. After cleaning at 1.6 specific gravity and 1-1/2-inch top size, 63 percent of the reserves meet the standard.
6. Twenty-seven percent of the reserves in Alabama meet an SO_2 emission standard of 1.2 lb/10^6 Btu without cleaning while 36 percent meet the standard after cleaning at 1.6 specific gravity and 1-1/2-inch top size.

From these results, it is seen that for many coal reserves, physical coal cleaning at 1.6 specific gravity will produce low sulfur levels.

However, in meeting the New Stationary Sources Performance Standards (NSSPS) (promulgated June 11, 1972) which require a 90 percent sulfur removal between 1.2 and 0.6 lb $SO_2/10^6$ Btu and a 70 percent removal below 0.6 lb $SO_2/10^6$ Btu, physical coal cleaning essentially will be eliminated as a single control technology for compliance. For meeting this regulation, physical coal cleaning must be supplemented with flue gas desulfurization. Also, it should be noted that some of the reserves of low-sulfur coal in the eastern U.S. are dedicated to use as metallurgical coal, and they should not be assumed to be available for combustion.

3.2.2 Trace Element Content

The trace element content for 101 coals is shown in Table 13. While it is not known if utilization of coal results in serious environmental impacts when these materials are liberated to the environment, concentrations are such that potentially harmful effects must be considered. Removal of significant quantities of trace elements using PCC prior to combustion may prove to be a substantial benefit. This thought is duscussed further in Section 3.3.

3.2.3 Leachability

The leachability of coal is a poorly understood function of its chemical composition. The presence of oxidizable sulfur compounds which

TABLE 13. TRACE ELEMENTS IN 101 COALS[16]

Constituent	Mean Value	Unit	Standard Deviation	Minimum Value	Maximum Value
As	14.02	PPM	17.70	0.50	93.00
B	102.21	PPM	54.65	5.00	224.00
Be	1.61	PPM	0.82	0.20	4.00
Br	15.42	PPM	5.92	4.00	52.00
Cd	2.52	PPM	7.60	0.10	65.00
Co	9.57	PPM	7.26	1.00	43.00
Cr	13.75	PPM	7.26	4.00	54.00
Cu	15.16	PPM	8.12	5.00	61.00
F	60.94	PPM	20.99	25.00	143.00
Ga	3.12	PPM	1.06	1.10	7.50
Ge	6.59	PPM	6.71	1.00	43.00
Hg	0.20	PPM	0.20	0.02	1.60
Mn	49.40	PPM	40.15	6.00	181.00
Mo	7.54	PPM	5.96	1.00	30.00
Ni	21.07	PPM	12.35	3.00	80.00
P	71.10	PPM	72.81	5.00	400.00
Pb	34.78	PPM	43.69	4.00	218.00
Sb	1.26	PPM	1.32	0.20	8.90
Se	2.08	PPM	1.10	0.45	7.70
Sn	4.79	PPM	6.15	1.00	51.00
V	32.71	PPM	12.03	11.00	78.00
Zn	272.29	PPM	694.23	6.00	5350.00
Zr	72.46	PPM	57.76	8.00	133.00
Al	1.29	Percent	0.45	0.43	3.04
Ca	0.77	Percent	0.55	0.05	2.67
Cl	0.14	Percent	0.14	0.01	0.54
Fe	1.92	Percent	0.79	0.34	4.32
K	0.16	Percent	0.06	0.02	0.43
Mg	0.05	Percent	0.04	0.01	0.25
Na	0.05	Percent	0.04	0.00	0.20
Si	2.49	Percent	0.80	0.58	6.09
Ti	0.07	Percent	0.02	0.02	0.15

can form acidic runoff when exposed to the elements is a factor of known importance. The presence of compounds containing potentially hazardous metals such as arsenic, beryllium, and selenium, which can react with acidic runoff and pollute surface or underground water, is also a matter of concern as far as adverse effects of leaching are concerned. Other soluble materials can contribute to runoff high in dissolved solids, and finely divided insoluble materials can be leached out producing water polluted with suspended solids.

3.3 Products

As indicated earlier, coals are physically cleaned at any of three levels of intensity. Each type of cleaning can be considered to yield a different product which has been given minimum cleaning, intermediate cleaning, or maximum cleaning. The primary uses of cleaned coals are for boiler firing and as metallurgical coals. In the past, only metallurgical coals were given maximum cleaning. Boiler fuels (steam coals) were given minimum or intermediate level cleaning. At present, two factors have changed, thereby providing new incentives for the use of PCC for steam coals. Coal prices increased in the 1969 to 1974 period with steam coal cost tripling and that for metallurgical coals doubling. This increase in value of the coal provides additional justification for coal cleaning facilities which will upgrade coal quality and increase product yield. In addition, the growing pressure to minimize sulfur oxide pollution gives impetus to the application of PCC to production of steam coals. As a result, most new PCC plants probably will be designed for maximum reduction of ash and sulfur consistent with cost constraints and high Btu recovery.

For coals that are "washable", significant quantities of the potential pollutants can be removed in more concentrated form. As much as 25 to 30 percent of the raw coal feed will be rejected as refuse by PCC systems. The sulfur content of the refuse might be 10 to 15 percent and trace elements generally will have larger concentrations in the rejected material than in the clean coal. The effect of float-sink separation on trace elements for selected Illinois coals is illustrated in Table 14, which shows "concentration factors" for clean coal and refuse where concentration factor for an element is defined as:

$$\text{Concentration Factor for Element in Clean Coal} = \frac{\text{Concentration in Clean Coal}}{\text{Concentration in Raw Coal}}$$

$$\text{Concentration Factor for Element in Refuse} = \frac{\text{Concentration in Refuse}}{\text{Concentration in Raw Coal}}$$

From these data, it is apparent that, on the whole, trace elements generally will tend to concentrate heavily in the refuse.

TABLE 14. DISTRIBUTION OF ELEMENTS IN FLOAT-SINK SEPARATION OF ILLINOIS COALS AT VARYING SPECIFIC GRAVITY TO ACHIEVE 75 PERCENT WEIGHT RECOVERY(16)

	Concentration, ppm unless otherwise stated			Concentration Factor	
Element	Raw Coal	Clean Coal	Refuse	Clean Coal	Refuse
Al	2.3 %	0.5 %	7.8 %	0.22	3.39
Ca	0.38%	0.07%	1.32%	0.19	3.47
Fe	2.9 %	0.80%	9.3 %	0.28	3.21
K	0.28%	0.09%	0.87%	0.32	3.11
Mg	81.2	34.5	215.1	0.42	2.65
Na	400.	200.	1000.	0.50	2.50
P	20.9	19.2	26.2	0.92	1.25
S	4.4 %	1.6 %	12.9 %	0.36	2.93
Si	4.2 %	0.9 %	14.2 %	0.21	3.38
Ti	1300.	450.	3900.	0.35	3.00
As	11.5	1.5	41.0	0.13	3.57
B	28.7	31.7	19.8	1.10	0.69
Be	3.0	2.9	3.3	0.97	1.10
Cd	2.0	0.2	7.2	0.10	3.60
Co	5.8	3.0	14.2	0.52	2.45
Cr	14.0	8.7	29.9	0.62	2.14
Cu	29.1	16.2	68.1	0.56	2.34
Ga	3.0	2.7	4.1	0.90	1.37
Ge	6.7	8.1	2.3	1.21	0.34
Hg	0.28	0.07	0.92	0.25	3.29
Mn	69.6	7.4	258.	0.11	3.71
Mo	11.5	3.8	34.8	0.33	3.03
Ni	30.5	19.6	63.5	0.64	2.08
Pb	110.	22.	377.	0.20	3.43
Sb	0.57	0.34	0.87	0.60	1.53
Se	2.8	1.3	7.3	0.46	2.61
V	15.2	9.1	33.4	0.60	3.67
Zn	510.	12.0	2019.	0.02	3.96
Zr	3.6	1.9	8.8	0.53	2.44

4.0 ENVIRONMENTAL IMPACTS

Coal is inherently a "dirty" source of energy. Raw coal contains non-coal minerals that will be released as polluting discharges at some point in the extraction and use cycle unless precautions are taken to collect and dispose of them in a controlled way. Pyrite is probably the most pervasive source of pollution. It can contribute to acid mine drainage in extraction operations, sulfur oxide air emissions from ignited coal refuse piles, acid drainage with leaching of potentially toxic materials from coal refuse or coal storage piles, and emissions of sulfur compounds from utilization operations. Also, trace elements are, as indicated earlier, present in amounts that might pollute if they are discharged from coal processing systems under the wrong conditions. The trace constituents of major concern include arsenic, beryllium, cadmium, lead, manganese, mercury, and selenium, as well as radioactive materials. The extent to which humans and the environment could be exposed to potentially hazardous concentrations of such materials where coal is being consumed has not been established. But with coal likely to be consumed in steadily increasing quantities, all possibilities of harmful environmental impacts must be considered.

While removing pollutants before the coal is used is an effective way to contain them, the greater concentrations in the refuse require that it be disposed of in ways that will not allow leaching by rainwater or surface flows, lead to spontaneous combustion, or lead to future collapse of unstable waste piles.

Potential pollutants which are not removed prior to combustion will exit from boilers in the slag or ash or as particulates and/or gaseous discharges into the atmosphere. Air discharges can be minimized using control equipment in some situations. For large boilers, scrubbers can be employed for sulfur oxide and particulate control. For control of particulates only, electrostatic precipitators are generally used. Where particulates are controlled, most of the trace metals which would otherwise be discharged to the atmosphere are collected and can be disposed of as solid waste.

Table 15 gives an indication of the typical fractions of elements in feed coal which are released to the environment by combustion in boilers equipped with electrostatic precipitators. If cleaned coal is burned, the fractions of elements in the raw coal released to the atmosphere generally are further reduced, as indicated by Table 14. Efficient wet scrubbers may reduce these levels even further.

TABLE 15. TYPICAL COAL TRACE ELEMENT FRACTIONS RELEASED BY COMBUSTION PROCESS(17)

Element	Fraction in Slag Ash	Fraction in Gaseous and Particulate Combustion Products	Electrostatic Precipitator Removal Efficiency, Fraction	Fraction Emitted to Air
Al	0.293	0.707	0.996	0.003
As	0.109	0.891	0.981	0.017
Be	0.000	1.000	0.000	1.000
Ca	0.322	0.678	0.994	0.004
Cd	0.067	0.933	0.970	0.028
Co	0.216	0.784	0.992	0.006
Cr	0.256	0.744	0.986	0.010
Cu	0.072	0.928	1.000	0.000
Fe	0.311	0.689	0.994	0.004
Hg	0.007	0.993	0.116	0.878
Mg	0.310	0.690	0.997	0.002
Mn	0.263	0.737	0.993	0.005
Ni	0.159	0.841	1.000	0.000
Pb	0.041	0.959	0.964	0.035
Sb	0.040	0.960	0.979	0.020
Ti	0.243	0.757	0.992	0.006
V	0.275	0.725	0.988	0.009
Zn	0.040	0.960	0.981	0.018

While collection of pollutants after combustion is possible, but costly, control equipment which is economically feasible for large boilers is not applicable to small boilers, as discussed in Section 2.3. For this portion of the total boiler population, PCC may be the only practical near-term method for pollution reduction.

While PCC is effective in reduction of pollution, all operations associated with PCC systems produce some form of potential pollution. All are, however, amenable to effective control.

Unfortunately, undesirable practices in the past have resulted in serious environmental damage. Examples include the Buffalo Creek disaster, which resulted from a coal-waste embankment failure in 1972; many burning refuse piles, which are continuing sources of air pollution; and many streams which are polluted with runoff from abandoned refuse piles. At present, about 100 million tons per year of refuse are being generated by coal preparation plants.[(18]
This figure will continue to grow as more coal is used and the percent which is cleaned increases. It is, therefore, important to employ good refuse management and pollution control technology.

The specific discharges and methods for control are as follows.

4.1 Coal Pretreatment Operations

Fugitive dust emissions from size reduction, dry screening, and coal handling are potential pollutants from coal pretreatment operations. Dust control measures that can be employed are wet scrubbers, and enclosure and hooding of equipment with exhaust to fabric (bag) filters. The use of chemical surfactants (polymers and hydrocarbons) are being used with increasing frequency to minimize dust release. Contaminated water is generated by wet separation processes and is passed on to coal cleaning processes where it is discharged. Hence, the separation processes usually are not a source of waste water per se. The exception to this is the desliming process, which generates a wastewater stream containing dissolved and suspended solids. This material is sent to water treatment facilities along with other aqueous discharges.

4.2 Coal Cleaning Operations

The coal cleaning operations generate coarse solid waste when coarse coal is cleaned in jigs or dense medium vessels. Finer waste, which is rejected by air tables, wet concentration tables, dense medium cyclones, hydrocyclones, or froth flotation units, may be combined with coarse waste for disposal or disposed of separately. These materials, containing substantial amounts of finely divided mineral matter, are a potential source of contaminated leachate or fugitive dust emissions unless disposal areas are well designed. Also, the disposal sites must be designed to provide structural integrity and prevent spontaneous combustion of coal residues.

Where air tables are used for coal cleaning, off-gases amounting to an estimated 240,000 cfm would be generated in a 1000 ton/hr plant. For control of dust emissions, a dry bag collector or a high-efficiency wet scrubber preceded by cyclones for primary dust collection would be employed.

4.3 Product Conditioning Operation

Dewatering and drying of coal produces large amounts of water containing dissolved solids and suspended particulate matter, and, where thermal drying is used, potential air pollutants are generated.

The composition of the dissolved solids and suspended matter will reflect the character of the non-coal minerals present in the raw coal feed but they often will tend to be acidic and will contain trace metals.

Because large amounts of water are required, any modern coal cleaning plant recycles process water. A 1962 estimate placed the total annual water requirement for coal preparation at 170 billion gallons which included 81 percent recirculated water and 19 percent fresh water.(19) When the increases in total water requirements for coal preparation since 1962 and the projected increases in the years ahead are considered, it becomes apparent that water management for coal cleaning plants is a very important economic factor.

Water for recycling should contain less than 5 percent solid matter and have a neutral pH. Removal of suspended solids by agglomeration and sedimentation is necessary to separate slimes from the water circuit, as slimes can accumulate when water is recycled. The preferred practices for solids removal involve the use of cyclones and/or thickeners for partial dewatering. The underflow from these devices, which may contain 40 percent or more water, is usually sent to settling ponds. Where space is unavailable for settling ponds, dewatering equipment (centrifuges or vacuum filters) may be used to process the slime. The dewatered fine refuse is then disposed of with the coarse solid waste.

Thermal dryers are the greatest source of potential air pollution in a coal cleaning plant. The drying involves contacting combustion gases, usually from the burning of coal, with fine wet coal to evaporate excess water. Particulates entrained in the exit gases may amount to 15 to 25 pounds per ton of dried coal. The combustion gases also contain the usual pollutants associated with combustion. Wet scrubbers are used for particulate removal. Where high sulfur fuels are used as a heat source, scrubbing of sulfur oxides may be needed. For a 1000 ton/hr plant, the thermal dryer off-gases amount to an estimated 300,000 cfm.[20] High efficiency wet scrubbers, preceded by cyclones, are used for control of particulate emissions from thermal dryers.

4.4 Auxiliary and Ultimate Disposal Operations

The auxiliary and ultimate disposal processes for PCC plants are (1) coal handling and storage, (2) water treatment, and (3) solid waste disposal. These are of great importance because of the very large amounts of materials which are involved. At present, almost 300 million tons per year of coal are processed by PCC plants. This is a materials handling problem of major proportions. Water use runs to billions of gallons per year, an amount comparable to that used by the utilities and other major industries consuming water. Solid waste is produced in amounts approaching 100 million tons per year at present levels of application of PCC. This is an amount comparable to that from utilities and other major sources of solid waste. All of these activities involve demonstrated potential for environmental impact if precautions are not taken. The control options are discussed below.

4.4.1 Coal Handling and Storage

The principal waste stream from coal handling is fugitive coal dust. Waste streams from the storage of coal are fugitive coal dust and precipitation runoff and leachate.

Long, open conveyor belts carrying dry coal can be a significant source of dust and all drop points onto or off conveyors are sources of dust emissions. Fugitive dust can be suppressed by water spraying and dust proofing.

Outdoor coal piles have very large surface areas, and coal residence times in them are relatively long so that rainwater has a chance to react and form acids or extract sulfur compounds and soluble metal ions. Coal pile leachate is generally similar to acid mine drainage. The quantity of coal pile leachate is highly variable, both in an absolute sense and with time, depending upon the topography and drainage area of the coal pile site, the configuration and the volume of the stock pile, and the type and intensity of precipitation.

The quality of leachate also varies with time and is dependent upon the factors listed above plus the coal type and composition, the particle size, and the reaction time which varies according to precipitation conditions. The pyrite content of the coal is particularly important in determining the amount of metal sulfates and sulfuric acid produced. The sulfuric acid dissolves many other complex sulfides and metal salts, releasing many metals as ions, including aluminum, zinc, copper, cadmium, beryllium, nickel, chromium, vanadium, silver, and lead.

Because of the site dependence of coal pile drainage, it is extremely difficult to generalize the emission characteristics from coal storage piles. Table 16 tabulates the composition of drainage from coal piles at 11 steam electric power generating plants. The national coal pile drainage volume is reported to be approximately 7.9 x 10^9 gallons (30 x 10^6 m^3) per year, based on average rainfall rates and total coal storage of 93 million tons.[21]

Dust control methods for coal handling or open storage include spraying with water or surfactants; dust-proofing by treating the surface with oil or calcium chloride; and providing wind screens. Float dust from loading operations can be minimized by use of a telescoping chute.

The area around preparation plants should be properly designed with diversion and drainage ways through proper slopes and collection sumps. These waters must be collected for treatment and not be permitted to escape to the environment.

Runoff from storage areas should be collected and sent to a retention pond to settle out solids or to a water treatment facility. Lime can be used in either case to neutralize acidity.

4.4.2 Water Treatment

Process and scrubbing water effluents from coal cleaning operations contain two types of pollutants: suspended materials (solid or liquid) and dissolved substances. The technology available for removing suspended materials from the water includes mechanical dewatering, sedimentation, and

TABLE 16. COMPOSITION OF DRAINAGE FROM COAL PILES AT ELEVEN STEAM ELECTRIC POWER GENERATING PLANTS[21]

Parameter	Concentration range, mg/l[a]
Alkalinity (as $CaCO_3$)	0 - 82
BOD	3 - 10
COD	85 - 1,099
Total solids	1,330 - 45,000
Total suspended solids	22 - 3,302
Total dissolved solids	247 - 44,050
Ammonia	0.4 - 1.8
Nitrate	0.3 - 2.3
Phosphorus	0.2 - 1.2
Turbidity	2.8 - 505
Acidity (as $CaCO_3$)	0 - 27,810
Total hardness (as $CaCO_3$)	130 - 1,850
Sulfate	133 - 21,920
Chloride	3.6 - 481
Aluminum	825 - 1,200
Chromium	0.1 - 15.7
Copper	1.6 - 3.4
Iron	0.1 - 93,000
Magnesium	89 - 174
Zinc	0 - 23
Sodium	160 - 1,260
pH	2.1 - 7.8

(a) Appropriate for all values except pH.

flotation. Dissolved substances can be removed from water or converted to less objectionable forms by neutralization, adsorption, ion exchange, reverse osmosis, freezing, or biological treatment. Table 17 lists the methodology currently in use or contemplated for use in treating coal cleaning wastewater.

TABLE 17. CLASSIFICATION OF WATER TREATMENT TECHNOLOGIES USED IN COAL CLEANING

Control of Suspended Materials	Control of Dissolved Materials
Mechanical Dewatering	Neutralization
Centrifuges	
Filters	
Sedimentation	
Settling Ponds	
Sedimentation Tanks (Thickeners)	
Flocculation	

4.4.3 Solid Waste Disposal

The disposal of coal cleaning plant waste is a worldwide problem of increasing magnitude. Over 3 billion tons of solid waste have accumulated in the United States, and the total number of active and abandoned coal waste dumps is estimated to be between 3000 and 5000.[22] About one-half of these dumps pose some type of health, environmental, or safety problem.

In 1974, some 290 million tons of coal were cleaned by mechanical means, resulting in an estimated 96 million tons of coal preparation refuse.[18] Although the refuse varies physically and chemically, depending upon coal source, preparation process, and other factors, the refuse generally contains waste coal, slate, carbonaceous and pyritic shales, clay, and other impurities associated with a coal seam.

Depending upon the degree of size reduction employed in the coal cleaning process, refuse may be coarse (+28 mesh) or fine (-28 mesh). Coarse refuse may be generated dry or, if generated in a wet process, it drains fairly readily. Coarse refuse is usually disposed of in an embankment or landfill. Fine refuse is generated by wet processes and is generally removed from the preparation plant as a thickener underflow and impounded into nearby settling ponds. In many cases, the settling pond embankment is constructed with coarse refuse.

Since the 1972 Buffalo Creek disaster at Saunders, West Virginia, in which a coal waste embankment failure caused heavy losses in lives and property, greater emphasis has been placed on stability of coal waste embankments. This consideration, as well as Federal water pollution and solid waste regulations, now are causing most preparation plants to employ dewatering methods for the fine refuse and to dispose of the dewatered fine refuse along with the coarse refuse in landfills or non-impounding embankments.

In addition to acids in eastern and interior regions, the drainage from coal refuse dumps contains high concentrations of Fe, Al, Ca, Mg, and SO_4 ions. The concentrations of total dissolved species are up to 5 percent (weight) in the highly acidic solutions. Another potential class of water pollutants is trace or minor elements in coal refuse. Nearly every naturally occurring element is likely to be present in coal refuse, and concentrations of most elements of potential environmental concern are higher in the refuse than in the raw coal, as shown in Table 9. Some of those elements are carried into the environment by the aqueous leaching of refuse.

The chemical characteristics of refuse pile drainage are highly variable depending upon local and regional geology of the coal and associated mineral matter. Depending on meteorological and hydrologic conditions, the volume of drainage water can vary from zero to millions of cubic meters per day. Therefore, the emission characteristics of waste disposal areas must be defined for each specific site.

In contrast to the highly acidic nature of drainage from coal fields in eastern and interior regions, the runoff from western coal refuse may be slightly alkaline and typically is rather high in dissolved solids. This aspect may create problems in semi-arid or arid regions by affecting surface and/or groundwaters. However, the annual precipitation in western coal fields is generally so low that the chances of significant drainage of water through those waste materials are remote.

Current research in waste disposal has been aimed at finding means of utilizing the coal, pyrite, and other mineral values in the wastes in addition to the improvement of disposal practices.

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APPENDIX A

ENVIRONMENTAL ASSESSMENT/CONTROL TECHNOLOGY DEVELOPMENT DIAGRAM

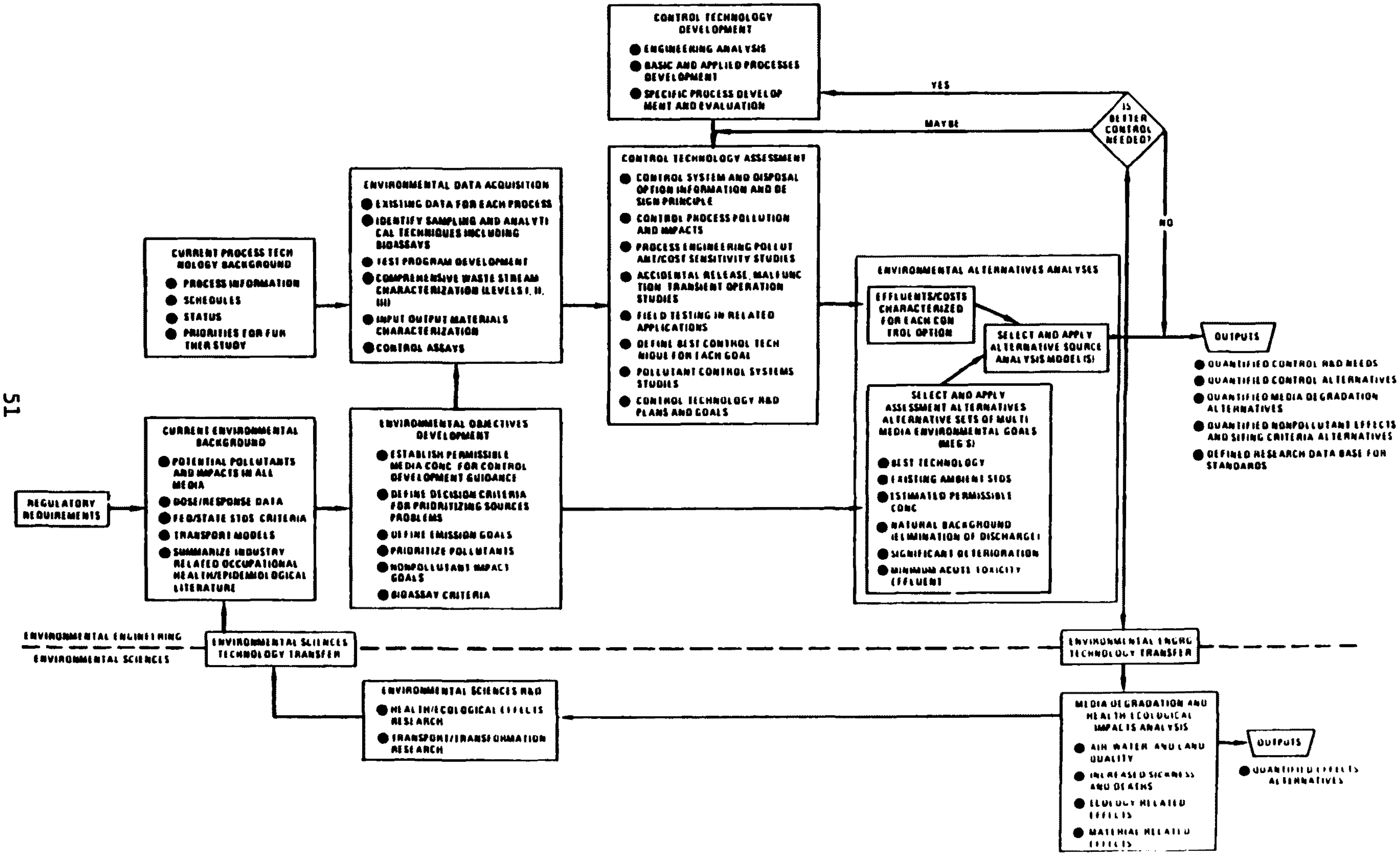

FIGURE A-1. ENVIRONMENTAL ASSESSMENT/CONTROL TECHNOLOGY DEVELOPMENT DIAGRAM

APPENDIX B

NOMENCLATURE DEFINITIONS FOR ENERGY TECHNOLOGIES

Accidental Discharge - An accidental discharge is an abnormal discharge (solid, liquid, gaseous, or combinations) which occur as a result of upset process conditions.

Auxiliary Process - An auxiliary process is a process associated with a technology, incidental to the main functions transforming raw materials into end-products. Auxiliary processes are used to recover by-products from waste streams, to furnish necessary utilities, and to furnish feed materials for producing the end-product. Examples: some auxiliary processes for physical coal cleaning include (a) water neutralization for water treatment and (b) solid waste disposal.

By-product - A by-product is an output stream produced from waste streams and marketed or consumed in the form in which it exits the process.

Control Equipment - Control equipment has the primary function of minimizing the pollution to air, water, or land, from process discharges. While the collected materials may be sold, recycled, or sent to final disposal, control equipment is not essential to the economic viability of the process. Where such equipment is designed to be an integral part of the process, e.g., scrubbers which recycle process streams, they are considered a part of the basic process. Examples: electrostatic precipitators, wet scrubbers, and adsorption systems.

Effluent Stream - An effluent stream is a confined liquid waste stream (discharged from a source) which is potentially polluting.

Emission Stream - An emission stream is a confined gaseous waste stream (discharged from a source) which is potentially polluting.

Energy Technology - An energy technology is made up of systems which are applicable to the production of fuel, electricity, or chemical feedstocks from fossil fuels, radioactive materials, or natural energy sources (geothermal or solar). A technology may be applicable to extraction of fuel, e.g., underground gasification; or processing of fuel, e.g., low-Btu gasification, light water reactor, and conventional boilers with flue gas desulfurization.

Final Disposal Process - A final disposal process is used to ultimately dispose of liquid and solid wastes from processes, auxiliary processes, and control equipment employed in a technology. Examples: landfills and evaporation ponds.

Fugitive Effluent - A fugitive effluent is an unconfined discharge (including accidental discharges) of potential water pollutants which are released as leaks, spills, washing waste, etc., or as effluents in abnormal amounts when accidents occur. These may be associated with storage, processing or transport of materials as well as unit operations associated with industrial processes. They may be disposed of in municipal sewers and can lead to generation of contaminated runoff waters. They will escape from a source.

Fugitive Emission - A fugitive emission is an unconfined discharge (including accidental discharges) of potential air pollutants. These may escape from pump seals, vents, flanges, etc., or as emissions in abnormal amounts when accidents occur. These may be associated with storage, processing, or transport of materials as well as unit operations associated with a process. They will escape from a source.

Input Stream - An input stream is a material that must be supplied to a process for performance of its intended function. Input streams include primary and secondary raw materials, streams from other processes, chemical additives, etc. For auxiliary processes, a waste stream from which a by-product is recovered is an input stream. Example: the input streams to a flotation cell are the sized coal, water, air, and chemical flotation agent.

Operation - An operation is a specific function consisting of a set of processes that are used to produce specific products from specific raw materials. Example: the operations for physical coal cleaning are coal pretreatment, coal cleaning, and product conditioning. The processes used in each of these operations are:

Coal pretreatment operation - size reduction, screening, desliming, and fine coal separation.

Coal cleaning - separation of coal from waste by use of jigs, dense medium vessels, air tables, wet concentrating tables, dense medium cyclones, hydrocyclones, and froth flotation units.

Product conditioning operation - mechanical dewatering, medium plus fine coal dewatering, fine coal dewatering, and thermal drying.

Output Stream - An output stream is a confined discharge from a process. Output streams can be products, waste streams, streams to other processes, or by-products. Examples: output streams from a physical coal cleaning plant include waste water, solid wastes, and cleaned coal.

Plant - A plant is an existing system used to produce a specific product of the technology from specific raw materials. A plant is comprised of some combinations of processes which make up the technology. Example: the Homer City coal cleaning plant, jointly owned by Pennsylvania Electric Company and New York State Electric and Gas Corporation, is designed to reduce the sulfur content in coal burned by the associated electric power generating station.

Process - Processes are the basic units that make up a technology. A process is used to transform, chemically or physically, input materials into specific output streams. Every process has a definable set of unique waste streams. The term "process" used without modifiers is used to describe the generic processes. Where the term "process" is modified (e.g., the Lurgi process), reference is made to a specific process which falls in some generic class consisting of a set of similar processes. Examples: a generic process in low/medium-Btu gasification technology is the fixed-bed/atmospheric/dry ash gasification process. Specific processes which are included in this generic class are Wellman-Galusha, Woodall-Duckham/Gas Integrale, Chapman (Wilputte), Riley-Morgan, Foster Wheeler/Stoic and Wellman-Incandescent.

Process Module - A process module is a method used to display input and output stream characteristics of a process. A combination of process modules can be used to describe a technology, a system, or a plant. One example of the "process module" approach to environmental studies of energy technologies involved a study of emissions for petroleum refineries. A description of each basic process of a petroleum refinery was developed, e.g., atmospheric distillation, catalytic cracking, etc. Data on air emission as a function of throughput were collected for each process, as part of the description of each process module. Individual process modules were assembled to describe plants with process configurations typical of specific areas of the U.S., e.g., a refinery in the Southwest which maximized gasoline output and another in the Northeast which produced more distillate fuel.

Process Streams - Process streams are output streams from one process which are input streams to another process in the technology. Example: the fine coal from a fine coal dewatering process is an input stream to the thermal dryer.

Product - A product is an output stream marketed for use or consumed in the form in which it exited the process. Example: the cleaned coal is the product from the physical coal cleaning plant.

Raw Materials - Raw materials are feed materials for processes. They are of two types: (1) primary raw materials that are used in the chemical form in which they were taken from the land, water, or air, and (2) secondary raw materials that are produced by other industries or technologies. Examples: primary raw materials for PCC technology include coal and water. Secondary raw materials include neutralizing chemicals, flocculation reagents, flotation reagents, and magnetite.

Residual - A residual is a gaseous, liquid, or solid discharge from control equipment and final disposal processes. Examples: gaseous emissions from control equipment, such as scrubbers, and vapors from an evaporation pond.

System - A system is a specified set of processes that can be used to produce a particular end-product of a technology. A technology is comprised of several systems. Examples: in the PCC technology, the simplest system produces cleaned coal using crushing and sizing coupled with jigs or dense-medium vessels. More complex systems will further clean medium and fine coal using dense medium cyclones and froth flotation with thermal drying in addition to the coarse coal cleaning.

Source - A source is a specific piece of equipment which discharges either confined gaseous, liquid, or solid waste streams or significant quantities of unconfined, potentially polluting substances in the form of leaks, spills, and the like. Examples: coal storage and refuse piles are sources for discharges of windblown dusts and of acidic runoff.

Unit Operation - Unit operations, like processes described above, are employed to perform a specific physical or chemical transformation on input materials. The equipment making up a unit operation may have one or more unit operations which have at least one source of waste stream(s). Examples: distillation, evaporation, crushing, screening, etc.

Waste Stream - A waste stream is a confined gaseous, liquid, or solid stream sent to auxiliary processes for recovering by-products, to pollution control equipment, or to final disposal processes. Unconfined "fugitive" discharges of gaseous or aqueous waste and accidental process discharges are also considered waste streams. Example: the water drawn off from the fine coal dewatering process is a waste stream in PCC technology.

APPENDIX C

GLOSSARY OF TERMS ASSOCIATED WITH PHYSICAL COAL CLEANING (PCC)

air tables: A particle sorting device utilizing air currents to separate coal and mineral particles based upon mass differences.

biological treatment: Certain autotrophic bacteria under limited conditions will enhance the oxidation of metal sulfides - as the dissolution of pyrite to form coal mine drainage. Processes applying these principles have been applied to coal mine drainage treatment and have been research topics for pyrite removal from ROM coals.

centrifuge: A device designed to remove water in a continuous process from the surface of coal and refuse particles by application of centrifugal force.

cleanable coal: A coal type which is suitable for sulfur and ash removal by physical techniques.

coarse coal: A term applied to coal particles whose size is greater than 3/8 inch.

concentration factors for element in clean coal: The ratio of the concentration of the element in the clean coal to its concentration in the raw coal.

concentration factor for element in refuse: The ratio of the concentration of the element in the refuse to its concentration in the raw coal.

crushing: A size reduction (comminution) process, applied to coal particles, whose product top size particles are less than 14 mesh.

cyclones: A type of particle separating device utilizing centrifugal force in which particles, entrained in fluid (liquid or gases), are separated on a basis of size and density.

deep cleaned coal: A cleaned coal product that has been subjected to extensive liberation and separation under conditions designed to provide maximum economic rejection of minerals and sulfur-bearing components. A very high quality (grade) of coal.

dense medium vessel: A coarse particle separating system utilizing a suspension of water and a finely-divided, insoluble dense mineral (usually magnetite) as the separating medium.

desliming screens: A wet screen sizing system designed to remove particles smaller than 28 M (0.6 mm) from a coal stream. They usually utilize parallel rod, profile wire screen media arranged perpendicular to the stream flow.

dewatering cyclones: A cyclone system designed to direct the bulk of solid particles in the feed stream to the underflow orifice where pulp densities may exceed 50 percent by weight.

fabric filter: A medium (synthetic polymers or fiber glass) designed to remove particles with dimensions as small as 0.1 micron from a gaseous stream.

fine coal: Coal particles whose dimensions are less than 3/8 inch. Such a stream may or may not include particles smaller than 28 M (0.6 mm).

flocculation: A process in which existing charges on the surface of particles are modified (usually with chemical reagents) to allow particles to form larger-sized agglomerates.

freezing: The change in state from the liquid to the solid phase resulting from the removal of energy. In stored coal products, coal will solidify to larger particles when its moisture content exceeds about 5 percent and temperatures are sustained below 0°C.

friability: Tendency of coal to degrade in sizes is a function of its friability. The tendency for coal to break during handling increases with greater friability.

grindability: Characteristic which measures the ease with which size reduction can be accomplished.

hydrocyclones: A cyclone system applied to fine coal suspended in water designed to separate particles based upon particle density rather than particle size.

hydrophilic: A solid, such as certain clays, whose surface properties have a strong affinity for water.

hydrophobic: A solid, such as certain coal components, whose surface properties repel water.

intermediate cleaning effectiveness: A level of cleaning in which the raw coal is crushed and sized, and the coarse coal is cleaned in jigs or dense medium vessels while the combined fine and ultrafine coal fractions are cleaned together using air tables, wet concentrating tables, or dense medium cyclones.

ion exchange: A separating system designed to either remove or exchange dissociated ionic species from solution (usually aqueous) by the use of an insoluble solid medium (as natural zeolites, soils, or synthetic resin polymers) whose structure has a reversible lattice holding ionic species by relative weak forces. Used in water purification and demineralization.

jig: A device used to continuously beneficiate coal (and other minerals) by developing a particle bed (supported by a screen) segregated horizontally from top to bottom with increasing particle density. The segregation is accomplished by repeated expansion and contraction of the particle bed by water velocities moving perpendicular to the bed flow. More coal is processed in a wider particle size range by this technology than any other.

maximum cleaning effectiveness: A level of cleaning in which the raw coal is crushed and sized, and the coarse coal is cleaned in jigs or dense medium vessels. The 3/8-inch x 0 fraction is split into fine and ultrafine fractions. The medium fraction is cleaned with wet concentrating tables or dense medium cyclones, and the fine fraction is cleaned with hydro-cyclones or froth flotation.

mechanical dewatering: The removal of surface water from coal or refuse particles by any process other than increasing vapor pressure. Typical systems utilize vibrating screens, centrifugal force, cyclones, thickeners, filters, etc.

mesh size: An expression of the number of openings per linear inch used in woven wire screen cloth. See ASTM Designation E-11-70.

middling: A coal product of intermediate quality between the clean coal and the refuse products. It may be saleable, rejected, or further processed.

minimum cleaning effectiveness: A level of cleaning in which the raw coal is crushed and sized, and only the coarse coal is cleaned, using jigs or dense-medium vessels. The cleaned coarse fraction may or may not be combined with the uncleaned fine and ultrafine fractions.

neutralization: A chemical process utilized in water quality control in which excess hydronium, hydroxyl, carbonate, or bicarbonate ions are reacted with appropriate reagents to result in a water whose pH is near 7.0.

physical coal cleaning: The technologies which remove sulfur and ash from coal using nonchemical techniques, such as screening, concentrating, and froth flotation.

recovery, Btu %: The percentage of the heat content present in the ROM feed to a PCC process that is recovered in the clean coal based on British thermal units.

reverse osmosis: A water purification process utilizing specially prepared semi-permeable membranes which constrain the passage of ionic species across the membrane based upon differences in ionic concentrations and osmotic pressures of the feed water. The process results in a highly concentrated brine containing the ionic species (impurities) and a purified water stream of low conductivity.

sedimentation: A process designed to remove suspended solids from a water stream by settling under the influence of gravity; as a thickener, clarifier, classifier, or settling pond.

settling pond: An earthen enclosure developed by forming a flow constriction (dam) or by excavation to create a static water storage volume having minimal horizontal velocity, to allow the settling of suspended solids and create a clarified effluent.

sieve bend: A specific type of stationary dewatering screen containing a 60° arc used to dewater and deslime particulate suspensions of coal, refuse, and dense media suspensions. It was developed by the Dutch State Mines in 1950.

sizing: A separation process creating product particles of specified physical dimensions. May utilize screening or sedimentation principles.

slimes: Particles of coal and coal-minerals in aqueous suspension having particle sizes less than about 28 mesh (0.6 mm).

sulfur forms: Sulfur in coal is reported in detailed chemical analyses as organic, pyritic, and sulfate sulfur. Sulfate sulfur usually is of only minor importance. The ratio of pyritic sulfur to organic sulfur is important in determining the amount of sulfur removable with physical coal cleaning.

surface properties: Difference in the hydrophobic or hydrophilic character of coal and mineral particles which influence the effectiveness of froth flotation for the separation of fine coal from ash.

thermal dryer: A device used to increase the vapor pressure of surface water (thus enhance water removal) on coal particles by transferring heat preferentially to the water than to the coal from hot combustion gases.

trace metal content: A metal occurring in coal (associated with either the organic or mineral components) at concentrations expressed in μg/g (ppm). Many such metals may be considered toxic to some degree. Such components associated with the minerals may be rejected by PCC.

ultrafine coal: Coal particles whose dimensions are less than 28 mesh (0.6 mm).

vacuum filtration: A process used to remove surface water from fine coal or refuse particles by continuously drawing water, from an aqueous coal suspension, through a fabric (which traps the solid particles) to a receiving chamber maintained at low pressure by a vacuum pump. The coal filter cake typically contains about 25 percent water.

washability: A measure of the degree to which pyritic sulfur and other inorganic minerals can be removed from coal using methods which discriminate between materials with different densities.

weathering: Tendency of coal to disintegrate or "slack" on exposure to weather. Weathering is an important factor considered in coal storage.

wet concentrating table: A device used to separate fine coal and mineral particles based on hindered settling and flowing film concentration. A rhomboid-shaped, near horizontal deck fitted with surface riffles is fed with an aqueous suspension of particles at the rate of 12 to 15 tons/hr while the table is subject to 300 horizontal (3/4-inch) strokes per minute. The low density particles are discharged from the table side into a launderer.

wet screening: A screening system employing spray and feed body water to separate small particles through apertures.

yield, weight %: The percent weight (mass) of saleable, clean coal product developed from a process ROM feed.

APPENDIX D

DESCRIPTION OF PROCESSES FOR PHYSICAL COAL CLEANING

Coal Pretreatment:	No. 1 - Size Reduction
	No. 2 - Sizing
	No. 3 - Desliming Screen
	No. 4 - Fine Coal Separation
Coal Cleaning:	No. 5 - Jigs
	No. 6 - Dense Medium Vessels
	No. 7 - Air Tables
	No. 8 - Wet Concentrating Tables
	No. 9 - Dense Medium Cyclones
	No. 10 - Hydrocyclones
	No. 11 - Froth Flotation
Product Conditioning:	No. 12 - Mechanical Dewatering
	No. 13 - Medium Plus Fine Coal Dewatering
	No. 14 - Fine Coal Dewatering
	No. 15 - Thermal Dryers
Auxiliary and Ultimate Disposal Operations:	No. 16 - Coal Handling and Storage
	No. 17 - Water Handling
	No. 18 - Solid Waste Disposal

COAL PRETREATMENT

Process No. 1 - Size Reduction

General Information

Raw coal is crushed to sizes suitable for cleaning and shipment to market. The main purpose is to liberate impurities so that they can be removed in the coal cleaning operation.

Process Information

Size reduction usually involves stage processing in a series of crushers. The extent of the size reduction depends on the type of coal being processed and the desired product characteristics. Raw coal with fines removed is generally fed first to a roll-type crusher (rotary screen-type breakers may be employed for rough cleaning) which reduces it to a top size of 3 to 8 inches. When secondary crushing is used, the coal is reduced to a top size of 1-1/2 to 1-3/4 inches. A third stage, in which crushers further reduce the top size to 1 to 3/8 inch, may be employed. The three-stage layout represents the most economical arrangement for a majority of preparation plants. Between crushing stages, scalping screens are often employed to remove coarse rocks and other foreign materials.

Waste Streams

Size reduction of dry coal can be a major source of dust generation. The quantity of dust generated during crushing operations varies depending upon the friability, size, and surface moisture of coal and type of crusher. The more friable coal produces larger percentages of fines. As the coal is crushed to smaller sizes and as moisture decreases, more dust is generated.

Crushing operations are usually carried out in partially enclosed spaces provided with sub-ambient pressure using exhaust hoods and suitable dust collectors such as cyclones, bag filters, and wet scrubbers.

Process No. 2 - Sizing

General Information

Sizing is the process of separating particles of mixed sizes into groups in which, for each size fraction, all particles range between certain definite maximum and minimum sizes. There are three general reasons for sizing prior to coal cleaning operations:

1. To separate raw coal into various sizes for marketing,
2. To feed various types of washing units, and
3. To recover fines in the original feed and fines produced by the size reduction process.

Process Information

Sizing of coal particles may be carried out by either wet or dry screens. Screens may be stationary or moving. The screening surface may be a perforated plate, a woven wire cloth, formed bars, or nonstationary parallel bars. By far the most common screens are vibrating perforated plate and square-opening woven wire screens.

Waste Streams

The major waste stream from sizing operations is fugitive dust generated from dry screening, but this usually is minimal since ROM coals have increasing levels of moisture. Dust can be controlled by the same techniques as described for Process 1. Contaminated water is produced from wet screening, but the contaminated water streams are generally directed to coal cleaning units and are not considered waste streams.

COAL PRETREATMENT (continued)

Process No. 3 - Desliming Screen

General Information

The objective in "desliming" is to remove ultrafine coal (less than 28 M) which may interfere with fine coal processing and to collect the slimes for direct recovery or separate processing. The size of separation may vary between 28 and 100 M.

Process Information

Vibrating screens, stationary cross flow screens, sieve bends, Vor-Sivs, etc., are used for slimes removal. Although tonnages vary over a wide range, as an example for a 1000-ton/hr plant, about 300 tons/hr of 3/8-inch x 0 material may exit from wet screening and be input to desliming screens. Streams from these screens in this case could be about 270 tons/hr of cleaned 3/8-inch x 200 M coal and 30 tons/hr of reject material consisting of wet coal and ash less than 200 M.

Waste Streams

Wastewater containing the rejected slimes and dissolved impurities associated with the raw coal is generated. This stream is sent to a thickener along with other process waters. The overflow water is recycled or treated and discharged. The underflow slimes generally are reclaimed and processed by froth flotation or hydrocyclones.

Process No. 4 - Ultrafine Coal Separation

General Information

Separation of fine raw coal from ultrafine raw coal permits more efficient isolation of the coal in both streams. The fine fraction is fed to wet concentrating tables, dense medium cyclones, or hydrocyclones, and the ultrafine fraction is fed to hydrocyclones or froth flotation cells.

Process Information

Sieve bends followed by wet vibrating screens are used to separate the 3/8-inch x 0 material into 3/8-inch x 28 M and 28 M x 0 fractions.

Waste Streams

The screening process generates contaminated water, but all process streams are directed to coal cleaning units, and no waste is discharged from the screening step.

Process No. 5 - Jigs

General Information

Jigs are mechanical devices used for separating materials of different specific gravities by the pulsation of a stream of liquid flowing through a bed of the materials. The liquid pulsates up and down, causing the heavy material to settle to the bottom of the bed and the lighter material to rise to the top. Following the particle stratification, the particle is physically "cut" at any desired particle density plane, thus producing the desired quality products. Jigs are most widely used in coal cleaning. Over 125 million tons of coal are cleaned by jigs annually in the United States.

Process Information

In coal preparation, jigs are applied to a wide size range of particles with top sizes up to 8 inches and down to zero. With a very wide size range, however, the efficiency of separation decreases with a decrease in size. Effective separation can be obtained in the size range from 4 to 1/4 inch. Other jig designs utilizing feldspar ragging beds will efficiently clean coal to much smaller sizes (about 48 mesh). Jigs are simple in operation and require low capital cost; however, power and water consumption are high. For a 1000-ton/hr plant, the feed stream to jigs could amount to about 690 tons/hr. Outputs then would be about 520 tons/hr of clean coal and 170 tons/hr of refuse.

Waste Streams

Waste streams from the jigging operation are contaminated process water and solid waste. The solid waste is primarily coarse refuse containing waste coal and minerals such as silicates, sulfides, and carbonates associated with the coal seam. The coarse refuse is normally disposed of in waste heaps or embankments by dumping.

The principal pollutant present in process water is suspended solids. A major portion of process water is recirculated through a suitable water clarification circuit. Vibrating screens are usually employed for draining the water from coal larger than 3/8 inch. The drained water may be directly recirculated without further treatment. If the solids concentration is too high, thickeners or settling ponds are used to remove fines. In some instances, treatment with lime is needed to maintain a neutral pH of process water.

Process No. 6 - Dense Medium Vessels

General Information

The application of dense medium separation is a practical extension of the laboratory float-sink test. The dense medium used is usually a water suspension containing finely ground magnetite (-325 M) to provide the desired suspension density. Magnetite is used because it can be recovered with magnetic separators. Besides the magnetite, water solutions of calcium chloride and suspensions of sand have been used as dense media. The use of magnetite (5.0 specific gravity) permits practical suspension densities ranging from 1.3 to 2.0 specific gravity. Dense medium vessels for washing coals are three basic types: cones, drums, and troughs.

Process Information

Theoretically, any size particle can be treated by dense medium vessels; practically, however, they are used for cleaning sizes from 6 to 1/6 inch. The benefits of washing material finer than 1/6 inch are usually offset by the increased medium loss and reduced cleaning capacity. Laminar-flow, dense medium separators are efficient on coal coarser than 1/4 inch and coal recovery is between 95 and 99 percent of the values expected from laboratory float-sink tests. The magnetite used in the dense medium is recycled through a recovery circuit which consists of a sump for collection of the dilute medium, classifying cyclones, a magnetite thickener, and a magnetic separator. About 0.5 pound of magnetite per ton of coal washed is usually lost in the recovery circuit. For a 1000 ton/hr plant, the feed stream and output tonnages for dense medium vessels would be approximately the same as those for jigs (Process No. 5).

Waste Streams

The waste streams generated from the dense medium vessels are the same as those from the jigs (see Process No. 5), except that some of the unrecovered magnetite ends up as solid waste. (The remainder of the unrecovered magnetite is part of the clean coal product.)

Process No. 7 - Air Tables

General Information

Air tables are somewhat similar to jigs (Process No. 5), except that, instead of water acting as the separating medium, a blast of air is driven through a perforated deck.

Process Information

Air tables have been used for cleaning 3/8-inch x 0 and 1/4-inch x 0 coal. However, their use has declined because of problems with processing wet coals and the associated dust problems. Close sizing is necessary to obtain good results. Dry cleaning is difficult when surface moisture reaches over 5 percent. For a 1000 ton/hr plant, air tables could process 300 tons/hr of 3/8-inch x 0 material to produce 225 tons/hr of cleaned coal and 75 tons/hr of refuse.

Waste Streams

Waste streams from the air tables are dust-laden air and dry solid waste. Dust created by the pulsating air is sucked into an overhead hood and is recovered in a cyclone collector followed by a cloth filter. This dust usually is recovered, as typically it is a rather high-quality product. The dry solid waste can be disposed of by dumping in refuse piles.

Process No. 8 - Wet Concentrating Tables

General Information

Tabling is a concentration process whereby a separation between two or more minerals is effected by vibrating a ribbed, tilted surface. The separation depends mainly on the difference in specific gravity and to a lesser degree on the shape and size of the particles.

Process Information

A normal feed size consistency is about 3/8-inch x 0; but with widespread acceptance of flotation, it is becoming quite common to remove the minus 48- or 100-mesh material prior to tabling. Essential factors for good table operation are feed rate, as to volume of both coal and water; slope of the table; and the frequency and amplitude of the stroke. The water-to-solids weight ratio normally used on a table is two to one. About 90 percent of the water reports to the clean coal side of the table. For a 1000-ton/hr plant, the concentrating tables could process 300 tons/hr of wet 3/8-inch x 0 material producing 225 tons/hr of product and 75 tons/hr of wet refuse containing 10 tons/hr of drainable water.

Waste Streams

Waste streams generated from wet tabling are contaminated process water and solid waste. The characteristics of the process water are similar to those of the water from jigs (Process No. 3); however, the volume of water from tables is larger, and it contains a higher concentration of suspended solids. The solid waste consists of fine refuse which is normally impounded into a nearby settling pond or disposed of with coarse refuse after dewatering.

Process No. 9 - Dense Medium Cyclones

General Information

Dense medium cyclones employ centrifugal forces to accelerate the separation of particles of different specific gravities. In the dense medium cyclone, a mixture of the medium and the raw coal enters tangentially near the top of the cylindrical section thus forming a vortex. The heavy refuse moves along the wall of the cyclone and is discharged through the underflow orifice. The clean coal moves toward the longitudinal axis of the cyclone and passes through the vortex finder to the overflow chamber.

Process Information

Dense medium cyclones are generally operated at 12 to 14 psi. A medium-to-coal weight ratio of about 5 to 1 is recommended. The dense medium cyclones often have been used to treat a comparatively narrow size range, typically 3/8 or 1/4 inch to 1/2 mm. However, current practice is deviating from this concept. Some units process coals from 1-1/2" to 100 M or even a larger size range. Average loss of magnetite amounts to one pound/ton of feed coal. For a 1000-ton/hr plant, a 270-ton/hr feed stream of wet 3/8-inch x 0 material could be processed by dense medium cyclones to produce 203 tons/hr of clean coal and 67 tons/hr of refuse containing 5 tons/hr of drainable water.

Waste Streams

Waste streams from dense medium cyclones are contaminated process water and solid waste. The characteristics of waste streams are similar to those of the wet tables (Process No. 8), except that some lost magnetite ends up in the waste streams. The contaminated water is sent to a thickener. The refuse is dewatered and sent to solid waste disposal.

Process No. 10 - Hydrocyclones

General Information

The hydrocyclone does not employ an artificial gravity suspension, but it utilizes an autogenous dense medium developed from the raw coal being cleaned. The specific gravity of separation of a hydrocyclone is regulated by varying the dimensions of the discharge orifices or changing pressure.

Process Information

Hydrocyclones are used to clean flotation-size coal (-48 M) but can be used for coal as coarse as 1/4 inch to 0. The size classification effect of hydrocyclones is pronounced; therefore, best results can be obtained with narrow-sized feed coal. The hydrocyclone can process large tonnages at relatively low capital investment; however, power and water consumption is high. For a 1000-ton/hr plant, hydrocyclones could process 100 tons/hr of 28 M x 0 material to produce 75 tons/hr of product and 25 tons/hr of refuse.

Waste Streams

Waste streams from the hydrocyclones are contaminated process water and solid waste. The characteristics of the waste streams are similar to those from the dense medium cyclones (Process No. 9), except that no magnetite is present. Contaminated water is sent to a thickener. The overflow water is recycled or treated and discharged.

Process No. 11 - Froth Flotation

General Information

In froth flotation, separation is effected by the difference in surface characteristics between particles. This process consists of mixing the finely divided coal and mineral suspensions with small amounts of reagents (typically from 0.1 to 1.0 lb of reagent per ton of coal feed) in the presence of water and air. The reagents respond with the particle surfaces and with the water to create conditions conducive to selective attachment of the small air bubbles to the hydrophobic coal particles and carry them to the surface, while the hydrophilic mineral matter is wetted by water and drawn off as tailings. Certain agents in the water modify surface tension to assist in forming air bubbles of proper stability.

Process Information

Froth flotation is used for both increased recovery and beneficiation of ultrafine coals usually defined as 28 M x 0. The major factors affecting coal flotation are particle size, solids concentration, pH value, and the flotation agents. The optimum size for froth flotation is between 28 and 200 mesh. For coarser sizes, conventional gravity separation methods are easier and less expensive. Below 200 mesh, separation efficiency decreases because, for very fine particles, froth flotation becomes increasingly less selective and consumes excessive amounts of reagent due to large total surface areas. In current coal flotation practice, the solids concentration varies from 3 to 10 percent by weight. As a general rule, the coarser the coal particles, the higher the solids concentration. For a 1000 ton/hr plant using froth flotation, the input and output tonnages would be similar to those for hydrocyclones (Process No. 10).

Waste Streams

Waste streams from froth flotation are contaminated process water and solid waste. The characteristics of waste streams are similar to those from the hydrocyclones, except that these contain reagents used in the froth flotation process. However, most reagent remains with coal and refuse. Wastewater is sent to a thickener, and typically the overflow is recycled, but it may be discharged after treatment. Concentrations of reagents released to streams are likely to be very small.

PRODUCT CONDITIONING

Process No. 12 - Mechanical Dewatering

General Information

Following the coarse coal wet cleaning process (jigs or dense medium vessels), the product coal requires dewatering. Moisture left in the coal decreases the combustion heat available and also causes shipping and handling problems. For coarse coal with particle sizes greater than 1/4 inch, the coal can be dewatered readily by natural drainage using perforated bucket elevators or dewatering screens. For fine coal, the dewatering is considerably more difficult and costly. .

Process Information

Dewatering methods commonly used for coarse coal are:

1. Drainage Methods. Natural drainage is rapid for coals coarser than 1/2 inch when little or no fine coal is contained therein. Under such conditions, drainage conveyors or perforated bucket elevators can be used to combine dewatering and transferring.
2. Dewatering Screens. Vibrating screens can dewater coal larger than 1/4 inch to the extent required to meet market requirements. Coarse coal may be sized and dewatered on the same screen.

Waste Streams

The principal waste stream from mechanical dewatering operations is contaminated water with suspended and dissolved solids containing ultrafine coal and other minerals. This stream typically would be discharged to a thickener, along with other process waters, with the overflow being recycled.

Process No. 13 - Fine Plus Ultrafine Coal Dewatering

General Information

Dewatering of coal which contains slimes (less than 28 mesh) requires a greater driving force for water removal than is obtained with simple mechanical dewatering even if a substantial amount of coarse material is present. Product streams requiring such dewatering are generated by wet cleaning of 3/8-inch x 0 or 3/8-inch x 200 M material with wet concentrating tables or dense medium cyclones.

Process Information

Dewatering of products containing both fine and ultrafine coal is accomplished with a variety of profile wire dewatering screens in series with centrifuges. A 1000-ton/hr plant would produce around 225 tons/hr of cleaned 3/8-inch x 0 material if concentrating tables are used or 200 tons/hr of 3/8-inch x 200 M material when deslimed material is processed in dense medium cyclones.

Waste Streams

The main waste stream is contaminated water which is similar to that produced by mechanical dewatering. Because the coal is much finer, the loadings of both dissolved and suspended solids may be higher. This stream is sent to a thickener and the overflow water is recycled or treated and recycled.

Process No. 14 - Ultrafine Coal Dewatering

General Information

Wet ultrafine coal (28 M x 0) is beneficiated by hydrocyclones and froth flotation. This very fine material has high surface area and has a tendency to pack tightly so that dewatering is not sufficiently effective.

Process Information

Ultrafine coal streams are dewatered using solid bowl centrifuges and vacuum filters. For a 1000-ton/hr plant, about 75 tons/hr of fine material could be processed with about 5 tons/hr of contaminated water removed. The dewatered product may be sent to thermal dryers or blended with larger-size clean coal products with lower moisture content.

Waste Streams

The vacuum filter produces contaminated water that would be the same as that produced by mechanical methods except that it will contain flocculation agents. However, most agent remains with the coal and refuse. This stream is sent to a thickener along with other waste waters; typically, the overflow is recycled, but it may be discharged after treatment. Concentration of agents released to streams are likely to be very small.

Process No. 15 - Thermal Dryers

General Information

Thermal drying is a process of accelerated evaporation where wet coal and hot gases are brought into intimate contact with each other. The hot gases are usually the gaseous combustion effluent from a coal burner but excess "tempering" air is added to the off-gas to control inlet dryer gas temperature to achieve the optimum range for coal drying. After loading, the thermally dried coal must be kept below its critical ignition temperature of 130 to 150 F to prevent spontaneous combustion. Other important aspects in product coal temperature control are oxidation and devolatilization which will adversely affect coal quality if not controlled.

Process Information

Thermal dryers used in coal preparation can be grouped into six basic types:

1. Rotary Dryers. The rotary-type dryer consists of cylindrical drums in which the wet coal travels slowly from the feed to the discharge end. The hot combustion gases usually travel in the reverse direction in intimate contact with the coal.
2. Screen-Type Dryers. Screen-type dryers carry the coal on reciprocating screens which promote evaporation by passing hot gases through the bed. The gas flow is usually alternated so as to transfer the suction from one screen to the other section.
3. Multi-Louver Dryers. In the multi-louver dryer, the coal falls in a thin stream over the face of the ascending louver, and hot gases are passed between the filled louvers and through the layers of solids descending in free fall.
4. Cascade Dryers. Cascade dryers accomplish their heat transfer by introducing hot gases through and between the wedge-wire shelves which are arranged to cause the coal to cascade. The coal forms a curtain of flowing coal, and hot gases are passed through it to impart heat for evaporation.
5. Suspension-Type Dryers. Suspension-type dryers introduce the wet coal into a moving stream of hot gases which

pneumatically convey and dry the material in transit. Cyclone collectors separate the coal from the moisture-laden spent gases.

6. Fluidized-Bed Dryers. In fluidized-bed dryers, the wet coal is fed into a perforated or bar-type retention plate where hot gases are blown or drawn through the bed. Fluidized beds are characterized by a loose pulsating mass which is made to act as a liquid by the gas stream. Fluidized bed dryers are the most commonly used in coal cleaning plants. For a 1000-ton/hr plant, thermal dryers could process 220 tons/hr of dewatered coal from the medium and fine coal cleaning circuits.

In addition to these six types of thermal dryers, there is a new set of dryer designs which carry the heat by means other than hot gases to minimize dust control problems.

Waste Streams

Thermal dryers are the largest single source of air pollution in coal cleaning plants. In thermal drying, uncontrolled emissions of particulate matter may be in the range of 15 to 25 pounds per ton of thermally dried coal. Thermal dryers also generate gaseous pollutants including sulfur dioxide, nitrogen oxides, carbon monoxide, and hydrocarbons. These emissions are variable depending on the coal used for combustion and the type of dryer.

Emissions from thermal dryers are universally controlled by cyclones and wet scrubbers. Cyclones are integral parts of thermal dryers and are used for recovery of fine coal particles. Venturi scrubbers are commonly employed as secondary collectors. A consequence of wet scrubbing is the generation of contaminated scrubber water, which is usually sent to thickeners or settling ponds for clarification, after which chemical treatment commonly is required prior to plant recirculation.

Coal-fired thermal dryers produce ash from combustion which must be disposed of as solid waste.

AUXILIARY AND ULTIMATE DISPOSAL OPERATIONS

Process No. 16 - Coal Handling and Storage

General Information

In conjunction with transportation and storage of coal, a wide variety of material handling operations is needed. These include unloading, stacking and reclaiming, and transferring coal in a plant. As the amounts of coal to be handled have grown, the material handling systems have become more mechanized and equipped with more automatic and integrated control devices.

Storage of coal is an economic necessity in coal preparation to provide a reserve against production interruptions and also to facilitate intermittent shipment. Coal is stored in huge open piles or enclosed bins and silos.

Process Information

Coal handling systems which relate to coal transportation are loading and unloading facilities. The facilities required for coal loading and unloading are different depending on the modes of transportation.

Coal storage can be divided into two categories according to purpose: active storage, which supplies processing directly, and reserve storage to guard against delays in shipments.

Active coal storage is generally in a covered structure such as a bin, silo, or bunker, depending on the storage capacity required. Reserve coal storage is usually in outdoor piles. Storage areas should be well drained and raised to be protected from flooding. Drainage ditches should be installed alongside the pile. Coal piles are constructed with the steepest slopes possible to prevent rain or melting snow from penetrating into the pile.

Stacking, reclaiming stored coal, and movement of coal between processing units involves the use of various types of equipment ranging from belt and bucket conveyors to bulldozers. The type of equipment used for coal handling will depend on plant specific variables such as plant capacity, storage capacity requirements, and configuration of available land.

Waste Streams

Waste streams from the storage of coal are fugitive coal dust and precipitation runoff or leachate. The amount of dust generated from the open storage piles varies widely depending on climate, topography, and characteristics of the stored coal. The generation of dust may occur at any transfer point; control is critical at such locations. Outdoor piles have large surface areas and rainwater has a chance to react with pyrite and other mineral matter to form acids and to extract soluble metal ions, resulting in acid water drainage. The area around preparation plants should be properly designed with diversion and drainage ways through proper slopes and collection sumps. These waters must be collected for treatment and not be permitted to escape to the environment.

Dust control methods for open storage include spraying with water or surfactants; dust-proofing by treating the surface with oil or calcium chloride; and providing wind screens. Runoff from storage areas should be collected and sent to a retention pond to settle out solids or to a water treatment facility. Lime can be used in either case to neutralize acidity.

The principal waste stream from coal handling is fugitive coal dust. Long, open conveyor belts carrying dry coal can be a significant source of dust and all drop points onto or off conveyors are sources of dust emissions. Fugitive dust can be suppressed by water spraying and dust proofing. Float dust from loading operations can be minimized by use of a telescoping chute.

Process No. 17 - Water Handling

General Information

Coal washing operations require large amounts of water. In 1962, coal cleaning plants in the U.S. used over 170 billion gallons of water which included 81 percent recirculated water and 19 percent fresh water. Water handling in coal cleaning plants can be divided into two main areas: (1) obtaining a reliable source of fresh water for utilization in the coal cleaning operations, and (2) treatment of waste water from the plant so that it can be recirculated or discharged without presenting water pollution problems.

Process Information

Possible sources of fresh water are municipal water, deep wells, man-made lakes, nearby streams, and mine water. It is desirable for plant usage that the process water contain less than 5 percent suspended solids for most purposes. However, for rinse water these levels are generally unacceptably high. Pump gland water should be essentially free of suspended solids and of high quality. Process water should have a near neutral pH and low conductivity, i.e., low dissolved solids. Although low conductivity water is desirable, it is seldom attained due to the presence of varying levels of soluble components in the ROM coal. Technology to remove dissolved solids from process water are available, but unacceptably costly for coal preparation systems.

As a result of stream pollution regulations and the coal industry's desire to improve fine coal recovery, recirculation and treatment of wash water are integral parts of the operation of a modern coal cleaning plant. In particular, closed water circuits have grown in popularity because they eliminate discharge to streams, reduce makeup water, and allow for recovery of coal. Since closing the circuit results in the buildup of slimes, it is necessary to remove a certain portion of these fine solids. Standard equipment generally applied in a closed water circuit consists of thickeners, cyclones, filters, and/or solid bowl centrifuge.

Waste Streams

The major waste stream from water handling operation is the solid waste generated from water clarification. Since the solid waste consists of extremely fine size materials and considerable amounts of water, the disposal of it requires special care. Water pollution problems may be encountered from acid water drainage and dust may be generated if the waste is completely dried. In addition, accidental overflow of settling ponds may create serious water pollution.

Waste streams from plant cleanup (wash down) are also significant. Coal preparation plants should be frequently washed down with fresh water to remove solids from accidental spills and settled dust, etc. These waters and solids are collected in plant sumps and combined with slime streams for solids removal and water recycle.

Process No. 18 - Solid Waste Disposal

General Information

The disposal of coal cleaning plant waste is a worldwide problem of increasing magnitude. Coal refuse consists of waste coal, slate, carbonaceous and pyritic shales, and clay and rock associated with a coal seam. It is estimated that about 25 percent of the raw coal mined is disposed of as waste. This enormous quantity of refuse varies considerably in physical and chemical characteristics depending on the coal source and the nature of the preparation process.

Process Information

The disposal of coal refuse involves two quite separate and distinct materials--a coarse to fine refuse (+28 mesh) and an ultrafine refuse (-28 mesh). Coarse to fine refuse is transported to the disposal area by a variety of material handling systems, which include aerial trams, conveyors, trucks, side-dump mine cars, scrapers, and bulldozers. In mountain regions, the types of disposal used include cross-valley fill, valley-fill dump, and side-hill dump.

In flat land, the refuse is simply deposited in waste heaps, usually ending up in the general shape of a truncated cone. Active and abandoned strip mines can be used for the disposal of both slurry refuse and coarse refuse from preparation plants. Layering, compaction, and revegetation may be used to reclaim the disposal area.

Disposal of ultrafine refuse may be by slurry impoundment, underground disposal, and disposal after dewatering. Transportation by pipeline may be employed before disposal.

Waste Streams

Solid waste is the largest single source of potential pollution from coal preparation. Adverse effects associated with coal refuse disposal include air pollution, water pollution, land pollution, safety hazards, and ecological and psychological impacts. Fugitive dust can pollute the air and leachate can pollute surface or underground water. Methods for fugitive dust control and leachate collection and treatment discussed for coal storage, as part of the description of Process No. 16, are applicable to solid waste also.

Burning refuse piles can be especially troublesome sources of air pollution. In 1968, the U.S. Bureau of Mines conducted a survey to locate and examine coal refuse piles in 26 coal-producing states. At that time, they located 292 burning piles in 13 states. Of these, at least 66 were believed to be spontaneously ignited by air flowing through the pile.[a]

(a) Magnuson, M. O., and Baker, E. C., State of the Art in Extinguishing Refuse Pile Fires, presented at First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky (October, 1974).

There are several ways of controlling coal refuse pile fires such as digging out and cooling the affected material, covering up and sealing the pile against air circulation, and grouting to solidify the affected material; however, the most effective way to control coal refuse fires is to prevent them. Important measures stressed for coal refuse pile fires include locating refuse piles a safe distance from active mining operations and facilities and from abandoned mine openings, cleaning vegetation from the disposal site, compacting every 2-foot layer of refuse, and sealing the open slopes with clay or other inert materials to prevent air circulation. Current Federal regulations, if followed, should end fires in new coal refuse piles.

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16. ABSTRACT

The report gives a background against which requirements for further developments of coal cleaning technology and control techniques for the associated pollutants can be established, as part of a review of U.S. coal cleaning process technologies and related technologies for environmental control. It summarizes the state of the art of physical coal cleaning. It summarizes the status of coal cleaning technology with respect to cost, energy efficiency, applicability, extent of development, and commercialization prospects. It describes the manner in which various physical coal cleaning operations (e.g., coal pretreatment, coal separation, product conditioning, and auxiliary processes) are combined to produce systems capable of producing minimum, intermediate, and maximum levels of coal cleaning. It describes the physical and chemical properties of coal, and cites the pertinent literature on washability of many U.S. coals. It gives technological descriptions of coal cleaning processes (e.g., size reduction, sizing, desliming screens, fine coal separation, jigs, dense-medium vessels, air tables, and wet concentrating tables). It identifies potential pollutants evolved from these processes and methods used for their control.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Jigs	Pollution Control	13B
Coal		Stationary Sources	08G
Coal Preparation		Coal Cleaning	08I
Assessments		Environmental Assessment	14B
Comminution		Air Tables	13H, 07A
Size Separation		Wet Concentrating Tables	
Wet Classifiers			13I

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