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# FEASABILITY OF ALTERNATIVES FOR SURFACE UTILIZATION OF COAL WASTES

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## Abstract

This report examines above-ground utilization of coal wastes generated in the mining and preparation of underground coal. Background information covers environmental impacts of surface disposal methods (Task 1), available techniques for coal waste utilization (Task 2), properties of coal refuse (Task 3), and quantities to be generated in eastern and midwestern coal fields through 1985 (Task 3). The main objective of the study was to assess the economic and environmental feasibility of a selected utilization technique in a representative mining district. The feasibility of using coarse coal refuse in combination with power plant fly ash to form subbase course material for roadway construction is evaluated for the Monongalia County region in northern West Virginia. On the basis of technical, environmental and economic factors, it it concluded that using coal refuse/fly ash material for roadway subbase construction is feasible in the study area. The key technical and environmental considerations are related to the compaction characteristics of the material. Chemical and physical testing of the material to establish properties, in-place performance, and optimum refuse/fly ash blends followed by proper mixing, handling and compaction during construction will result in a strong, environmentally benign subbase course. The costs of subbase construction with refuse/fly ash and with conventional materials were compared using cost factors in the 1978 Dodge Guide. The cost comparison revealed that a 20-mile haul for refuse/fly ash could compete favorably with a 5-mile haul for conventional materials. Lower materials costs for refuse/fly ash more than offset higher handling and mixing costs. Maximum usage of coal refuse/fly ash (3/1 ratio) on the 127 miles of new roadway planned through 1985 would utilize about 2.3 million tons of an estimated 7.5 million tons of refuse to be generated in the study area. An annotated bibliography is included.

# FEASIBILITY OF ALTERNATIVES FOR SURFACE UTILIZATION OF COAL WASTES

## Executive Summary

### Introduction

This report presents the results of an assessment of the environmental and economic feasibility of using coarse coal refuse in combination with power plant fly ash for subbase and base course material in roadway construction. The feasibility assessment was performed for Monongalia County in West Virginia, which was selected during the study to serve as a representative mining district for Eastern and Interior Coal Provinces. In addition to the feasibility assessment, the study included detailed reviews of the environmental and economic impacts of current surface disposal methods, the alternative techniques for coal waste utilization, and the properties of coal waste materials.

### Background

Historical disposal practices for coal refuse have consisted of (1) depositing dry refuse in an embankment suited to local topography, and (2) sluicing wet refuse into impoundments created by the embankments. The amount that has accumulated over the years is staggering; active and abandoned waste piles and impoundments in the eastern coal fields alone have been estimated to contain over 3 billion tons of refuse. In 1975, about 107 million tons (dry) of coal refuse was generated in the United States. With increasing coal production and demand for higher quality coals, annual coal waste generation rates will continue to rise, perhaps reaching 200 million tons per year by 1985.

Coal refuse piles and impoundments can present serious environmental problems, ranging from severe local air pollution from burning refuse banks to stream and groundwater quality degradation from siltation, acid runoff and leaching of heavy metals. Coal refuse piles have, in the past, often been constructed without adequate planning for safety considerations. Embankment failures have resulted in two major disasters in recent years - in Wales in 1966 and in West Virginia in 1972 - with over 260 deaths recorded.

Surface disposal methods are used to dispose of the vast majority of coal refuse produced in the United States.

If the coal is not processed, or is pneumatically cleaned, the refuse is simply transported to refuse piles. Embankments of the following types may then be formed with the coal piles:

1. Valley-fill: where an existing valley is filled with refuse, and the surface leveled and graded on site abandonment.

2. Cross-valley: where the embankment is constructed across an existing valley, but not entirely filling the valley.

3. Sidehill: where wastes are dumped alongside of an existing hill or ridge, so that the original ridge is essentially expanded in a sideways direction.

4. Ridge dump: where an embankment is created by continuously dumping wastes on the pile's ridge, thus extending the existing pile.

5. Heaped: where, as the name suggests, the wastes are haphazardly heaped into an amorphous mound.

If the coal is processed through wet cleaning, suitable refuse disposal is somewhat more complicated and costly. There are three primary choices for refuse disposal from a wet cleaning plant:

1. Mechanically dewater fine refuse at preparation plant, mix the dewatered fines with coarse refuse and transport combined refuse to refuse pile.

2. Pump fine refuse slurry from clarifier into settling ponds, remove sediment with drag line, transport coarse refuse and sediment to disposal area and dump sediment into pits excavated in the coarse refuse.

3. Simultaneously construct a dam with coarse refuse and pump fine refuse slurry behind the coarse refuse dam.

Refuse piles may occupy from 1 acre to more than 100 acres of surface area, and can be from 20 to 300 feet in depth. Most refuse piles are small (less than 500,000 cubic yards of material), but the majority of refuse is disposed in very large (more than 1.5 million cubic yards) piles. Currently, there are about 5,000 active and abandoned coal refuse piles and ponds in the United States, mainly in the eastern coal regions.

Two types of waste are generated in coal preparation plants: dry, coarse material and fine particles (smaller than 1 millimeter in size) that are typically handled in a wet slurry. Once coal has been removed from the ground, it is crushed into pieces of 6 inches or less in diameter, and then sized as needed. Much of the material withdrawn with the coal from the ground is unwanted mineral matter, which is separated, initially by dry separation techniques, to produce the coarse waste product. The coal is then washed with water to remove remaining fine particles of foreign material and dust. This process produces the slurry wastes. The exact characteristics of the two wastes produced depend on the nature of the coal itself and the geology of the formation. Approximately 70 to 80 percent of the total waste generated comprises the coarse fraction; the remaining 20 to 30 percent is comprised of fines (dry weight basis).

The components of coal waste vary according to the mineralogical constituents of the waste rock contained in non-coal bands within the coal, the composition of the adjacent strata, the method of mining the coal, the method and efficiency of the cleaning operation, and the quality of the coal and the market for which it is cleaned.

Coarse refuse commonly contains coal, rock, carbonaceous shales and pyrites, siltstone, claystone, sandstone, and limestone, in addition to such foreign elements as wood, machine parts, wire and electrical cables, paper, cloth, grease, and oil. Iron, magnesium, potassium, and sodium are all found in coarse refuse. Particles generally range in diameter from 10 to 220 mm. Slurries produced by water washers contain materials ranging from fine silts and clays to find sands, in suspension in water. Particles are usually less than 80 mm in diameter. Typical fines composition is 60 percent silica ($SiO_2$), 25 percent alumina ($Al_2O_3$), and 7 percent iron oxide ($Fe_2O_3$).

From a physical properties standpoint, coal refuse behaves generally as a soil-like material. Grain size distributions for refuse are quite variable and refuse is usually not well-graded. For construction uses, the potential degradation of coarse refuse fractions to finer gradations must be determined through durability, hardness, friability and weathering tests. Specific gravity values for refuse range from about 1.6 to 2.7 (the higher value being within the range for soil) while density values for refuse range from about 68 to 124 pounds per cubic foot. The optimum moisture content for achieving maximum density has been reported to range from 5 to 23 percent. Permeability is an important refuse property that exhibits great variability - from as high as $10^{-2}$ feet per minute to as low as $10^{-8}$ feet per minute - but can be engineered to achieve desired performance through compaction, controlled degradation and mixing with additives for stability. Shear strength characteristics of refuse are very similar to soil, although careful testing and construction practices are necessary to avoid low-strength conditions in foundation and embankment uses.

From a chemical properties standpoint, refuse has been found to contain from 20 to 78 percent ash, with only fine refuse fractions having ash values below 36 percent. Sulfur content in refuse is generally higher in the Interior Coal Provinces than in the Eastern, but values from 1 to 8 percent sulfur have been reported for refuse in both areas. The heat content of refuse is widely variable - from 2,000 to 12,000 Btu/lb - but fine refuse fractions consistently have much higher heat value than coarse fractions. The major cationic elements in refuse are silica, alumina, and iron. Alumina content is typically about 20 percent, but reported values range from 3 to 37 percent. Iron content is usually less than 10 percent, although reported values for iron as $Fe_2O_3$ range from 1 to 43 percent. Silica content can range from 9 to 69 percent. Refuse also can be expected to contain varying concentrations of minor trace elements such as boron, nickel, lead, zinc, and others.

The refuse generated in the Monongalia County study area is typical of refuse generated in the entire northern section of West Virginia. The major coal producing seam is the Pittsburgh seam and three-fourths of the coal produced in this area is deep-mined with subsequent preparation methods including crushers, washers, sand cones, and heavy media separators. Refuse produced at the Humphrey preparation plant, the specific refuse source considered in this study, is typical for the region. Coarse Humphrey refuse is high in ash, sulfur, volatile matter and mineral content, and low in heat value. Compacted bulk density values for the Humphrey refuse range from 75 to 90 pounds per cubic foot. Grain size data for Humphrey refuse show a primarily coarse texture of relatively uniform grading, but the fine portions encompass a broad range of fine grain sizes. This gradation suggests that achievement of maximum densities during construction would require breaking down the coarse fraction somewhat to provide an overall better graded material.

## Alternative Refuse Utilization Techniques

Attempts to find productive uses for coal refuse are not a recent phenomena. Through the latter half of the nineteenth century, coal refuse disposal and utilization stimulated a great deal of study and experimentation. In 1889, the Commonwealth of Pennsylvania appointed a commission to investigate coal refuse production and the potential for its utilization. The Commission's report included 134 references to reports, journals and books published between 1884 and 1892 discussing the productive use of coal waste, 82 patents for utilizing or burning fine coal sizes and coal waste, and 89 patents for manufacturing artificial fuels by combining coal fines and waste with other materials. Much of the early work focused on ways to use fine coal sizes, but other modes of utilization were also being investigated.

In this study, a review of the literature on coal refuse utilization was performed to identify the full range of utilization techniques that have been employed and/or considered in the United States and elsewhere. It was found that coal refuse disposal and utilization has been under study for more than 100 years and that a wide variety of uses have been proposed and, in many cases, implemented. A list of these coal refuse utilization techniques is given below:

1. Secondary fuel recovery
   - High grade fuel (low ash, high Btu content)
   - Low grade fuel (high ash, low Btu content)

2. Secondary mineral recovery
   - Alumina
   - Sulfur
   - Trace metals

3. Construction materials manufacture
   - Lightweight aggregate in Portland cement, bituminous concrete and concrete block
   - Coal-crete (low quality concrete)
   - Bricks and ceramics
   - Mineral wool (insulation)

4. Construction and highway uses
   - Landfill
   - Embankments
   - Base course
   - Anit-skid material

5. Horticultural uses
   - Soilless medium
   - Landscape fill and filler material
   - Soil nutrient (mixed with manure)

Included in the review was consideration of the physical and chemical characteristics of coal refuse, in terms of the properties required for the utilization methods, and the preparation/processing associated with the various utilization methods. The main body of this report presents a list of critical physical and chemical parameters for each alternative refuse utilization technique as well as additional information on the technology, economics and experience of each technique.

## Feasibility Study Description and Results

### Selection of Refuse Utilization Technique

The list of candidate refuse utilization schemes was screened to initially remove from consideration those schemes incompatible with either the refuse in the study area or the overall objectives of this study. For initial screening, three primary and three secondary criteria were established:

1. Primary criteria

    - Technical feasibility

      General comparison of physical/chemical characteristics of coal refuse from the study area with technical requirements of utilization technique.

    - Performance

      Expected or demonstrated performance of refuse-based materials or products vis-a-vis that of ocnventional materials or products.

    - Cost

      Expected or estimated cost of refuse-based materials or products relative to cost of conventional materials or products.

2. Secondary criteria

    - Market size and potential demand

      Estimated percentage of total demand for specific materials or products in study area that could be met with refuse-based materials or products.

- Consumptive use

  Utilization techniques of most interest are those that consume large-volumes of refuse with little remaining for disposal.

- Experience

  Experience in the United States and abroad with the particular utilization technique for coal refuse.

The primary criteria were considered to be somewhat critical in that if a utilization method did not appear to satisfactorily meet all three criteria, then it was considered very doubtful as a viable, widely applicable coal refuse utilization method. The secondary criteria provided a further indication of the potential of the various techniques. The preliminary screening revealed that three uses show the most promise: use in highway fills and embankments, use in road base construction, and use as an input to the manufacture of lightweight aggregate. All three uses have been demonstrated to be technically feasible, structurally satisfactory, and involve costs of the same order of magnitude compared to conventional materials.

The coal refuse utilization technique chosen for further consideration in this study involves the use of a combination of coarse coal refuse and power plant fly ash to form subbase and base course material for highway pavements. Related applications of the refuse/fly ash material include airports, parking lots and shopping centers.

In a flexible pavement structure (bituminous concrete), the layers of the roadway, beginning at the subgrade and following in order upward, are typically designated as subbase course, base course, and surface course.

The subbase course is between the subgrade and base course, and usually consists of a compacted layer of granular material, either treated or untreated, or a layer of soil treated with a suitable admixture. Apart from its position in the pavement structure, it is distinguished from the base course material by less stringent specification requirements for strength, aggregate types and gradation. The subbase course is usually used to economically build up the pavement strength above that provided by the subgrade soils. In addition, subbase courses may have secondary functions, such as:

1. Preventing intrusion of fine-grained roadbed soils into base courses (this requires well-graded subbase material).

2. Minimizing the effects of frost action.

3. Preventing accumulation of free water within or below the pavement structure (free-draining subbase material is needed here, along with a water collection system).

4. Providing a working platform for construction equipment.

The base course is located immediately beneath the roadway wearing surface and is constructed directly on the subbase course. It performs its major function as a structural portion of the pavement. The base course usually consists of aggregates such as crushed stone, crushed slag, crushed or uncrushed gravel and sand, or combinations of these materials. The aggregates may be untreated or treated with stabilizing admixtures such as Portland cement, asphalt, lime and fly ash. Generally, specifications for base course materials are considerably more stringent than those for subbase materials in terms of strength, stability, hardness, aggregate type and gradation requirements.

In view of increasing demand and costs for natural materials, the influences of inflation on material processing and handling costs, and the rising costs of waste disposal, the use of coal-associated wastes in construction is becoming more and more attractive. In certain areas of the country, large supplies of coal refuse and fly ash (coupled with high prices for local conventional materials) could result in cost savings plus environmental benefits if these wastes were utilized in roadway construction.

Technical considerations. The key technical considerations for coal refuse/fly ash utilization as subbase and base course material are related to the compaction characteristics of the materials. In general, what is required to meet highway specifications is a "good recipe for strength and stability." The refuse/fly ash material would typically be used in place of mechanically stabilized material, i.e., material physically processed to consist of primarily crushed stone with 8 to 10 percent fines. Roadway specifications generally limit the maximum size of the aggregate, the percent fines, and the plasticity of the fine fraction.

The design of roadways using refuse/fly ash material requires data on the chemical, physical and engineering properties of the coal refuse and the fly ash. Key chemical properties include composition, loss on ignition, pozzolanic reactivity and pH. Physical characteristics critical to construction uses include gradation, specific gravity, moisture content, Atterberg limits, and moisture absorption. Engineering properties to be determined include moisture-density relationships, friability/durability during compaction, shear strength, permeability, and self-hardening performance.

Considerable testing is indicated to identify optimum blends of refuse and fly ash. In particular, it is necessary to evaluate mixture strength and strength development properties as well as mixture durability and frost susceptibility. For specific refuse and fly ash materials, it may become necessary to examine the further stabilizing effects of adding lime, asphalt or cement to the refuse/fly ash mixture. From an economics standpoint, the most important factor will be materials handling costs, but the amounts and costs of additional stabilizers used could become critical in certain instances.

Experience. European experience in using coal refuse in construction is more extensive than in the United States. Raw coal refuse has been used in England as landfill for a variety of construction purposes. The National Coal Board of Great Britain has developed the art and science of coal refuse utilization as fill material to a fine degree. The most significant United States experience in coal waste utilization is by the Pennsylvania Department of Transportation program to study the engineering properties of coal waste and to use the material in highway construction whenever it is economically feasible to do so. Coal waste has been selectively used in construction of highways in the Anthracite Region since at least the 1960's, but it has not been a standard practice. It was mostly used for fill and embankment construction in areas where the only material available for construction within a reasonable haul distance was mine waste.

Coal mine refuse was used experimentally as a base for a parking lot constructed in the summer of 1973 at the U.S. Environmental Protection Agency's (EPA) Drainage Control Field Site in Crown, West Virginia. The coal mine refuse was obtained from the Humphrey preparation plant and the fly ash was obtained from the Fort Martin Station of the Monongahela Power Company. The main objective of the project was to monitor any water that might percolate through three coal mine refuse base sections and to evaluate that water for its pollution potential. In addition, moisture-density measurements were made on each of the sections during construction.

After 1 year's service, plate bearing and moisture-density measurements were made on each of the three sections. The results of the plate bearing tests performed on the base and subbase sections indicated that the material was of a low quality granular nature suitable as a subbase but of questionable value as a base course under asphaltic concrete.

### Selection of Representative Mining District

At the start of this study it was established that the refuse utilization feasibility assessment would focus on a study area, or mining district, that would be representative of eastern and midwestern coal regions. Initial criteria for such a mining district were:

1. More than 500,000 tons of coal waste generated annually within approximately a 100 square mile area.

2. Coal waste properties typical of the eastern and midwestern coal fields.

3. Waste deposit is located within 100 miles of at least one community with a wide range of heavy industry.

In addition to the above criteria, which were suggested in the project work scope, the following criteria were felt to be desirable as well:

4. The mining district should be located near an effective means of transportation, either a navigable water course, major highway, or railroad.

5. If a district has more than one coal preparation plant, it is preferable that they be owned and operated by the same company. This will facilitate cooperation between the two plants in developing a refuse use scheme.

6. Other preparation plants should be located in the general vicinity for which the representative district could serve as a model.

Using the 1978 Keystone Coal Industry Manual, preparation plants in the states of Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, and West Virginia that generated large amounts of coal refuse from deep mined coal were identified. On the basis of proximity to an industrialized area and amounts of refuse generated, Monongalia County in West Virginia was chosen as the study site. Two preparation plants in Monongalia County--the Humphrey and Arkwright plants--generated about 2.3 million tons of refuse in 1977. Both plants process coal from the Pittsburgh seam, have adequate transportation facilities and are owned by Consolidation Coal. The Fort Martin power station is located about six miles from the two preparation plants.

### Study Area Characterization

Many site specific factors will play a large part in determining the feasibility of any coal refuse utilization scheme. This is particularly true of plans to use large amounts of refuse in applications where the unit value is low. Such is the case with using the material as a highway base or subbase. Those site specific factors considered to be among the most important are:

1. Location of refuse relative to possible end uses

2. Location of fly ash sources relative to refuse and end uses

3. Transportation paths available for transport of refuse and fly ash

4. Procedures currently used for disposing of refuse and fly ash

5. Availability of competing aggregates and fill materials

Each of the above characteristics can decrease the feasibility of the end-use scheme if they are not favorably fulfilled. Ultimately, the impact can be translated into one of costs relative to competing materials or methods for constructing highway subbase or base courses. The refuse sources in the study area are well-served by highway, railroad and waterway transportation modes, as is the likely fly ash source. The Humphrey and Arkwright refuse is presently disposed of on land in valley-fill disposal operations, while the Fort Martin fly ash is hauled off-site for landfill disposal (some has been sold in the past for $.25/ton plus loading).

The Monongalia County area is relatively free from crushed stone or sand and gravel shortages. However, several adjacent counties all suffer from some degree of aggregate shortage. The availability of natural aggregates can play a major role in the ultimate feasibility of utilizing coal refuse in the construction of a road. If the natural aggregates are located much closer to the construction site than available coal refuse, then there are likely to be few incentives to spur the use of the refuse. However, it has been estimated that coal refuse could be hauled up to a distance of about 40 miles and still be competitive with naturally occurring aggregates in some instances. In areas of aggregate shortage, the distance could conceivably be greater. Thus, although Monongalia County is not itself in an aggregate shortage area, a perimeter of 40 miles extended from the center of the study site includes counties that do have an aggregate shortage.

### Environmental Feasibility

In the past, the principal environmental concerns with respect to using coal refuse in construction applications have been (1) spontaneous combustion of the refuse, and (2) production of acid leachate and runoff. These concerns relate mainly to embankment applications of refuse. For embankment applications, British as well as United States experience has shown that the exclusion of oxygen will eliminate problems of spontaneous combustion and acid drainage. To exclude oxygen in construction uses of coal refuse requires the material to be compacted to its most dense state. Thus, the problem is reduced to the compaction characteristics of refuse materials.

In roadway construction, the wearing surfaces are virtually impermeable so that the formation of acid leachate from a coal refuse subbase or base course is not of real consequence. In fact, the upward migration of groundwater into the roadway base course is a much more critical design consideration (for structural reasons). With proper compaction, and given the addition of alkaline fly ash, which will neutralize any acidity production from pyritic refuse material, it appears that the use of coal refuse and fly ash in roadbase applications is environmentally acceptable. In the EPA field study of leachate production from coal refuse/ fly ash base course material, it was concluded that the leachate from mixtures of refuse and fly ash and of refuse and fly ash plus lime did not constitute an environmental problem.

Economic Feasibility

One of the major reasons for the choice of road base and subbase construction as the utilization technique for coal refuse is the large potential volume of refuse that could conceivably be used. A large number of paving applications exist, all of which can use significant amounts of refuse. These uses include highways, secondary roads, access roads, shopping center parking lots, and airport runways.

Use in roadway construction is expected to be the major market for utilization of refuse; the volumes of aggregate required for airport runways and parking lots is not nearly as great as that required for roadway construction. However, coal refuse banks in close proximity to planned parking lot or runway extension projects could locally be used advantageously. This study concentrated on road base construction as the major potential market for coal refuse.

The economic feasibility of using coal refuse/fly ash mixtures for roadway base and subbase construction in the Monongalia County area was evaluated by examining (1) the potential market for base and subbase material over the next five years, and (2) the economic factors governing the market penetration of the coal refuse/fly ash material. No attempt to evaluate non-economic factors, such as inertia within the roadway construction industry, was made.

Potential Market. In Monongalia County and seven adjacent counties in West Virigina and Pennsylvania, all an average distance of 40 miles or less from the coal refuse sources, proposed roadway construction during the next five years will add less than five percent to existing highway mileage in each county. For all eight counties considered, a total of about 127 miles of new roadways are planned. The maximum extent to which coal refuse/fly ash material could be used for subbase course construction was estimated to be from about 450,000 to 2 million cubic yards. At 85 pounds per cubic foot (compacted), this is equivalent to from 513,000 to 2.3 million tons of coal refuse, assuming a 3 to 1 ratio of coal refuse to fly ash. The ranges of values for maximum utilization of coal refuse were derived by assuming several different road base widths and depths.

Cost Factors. Ultimately, for coal refuse to gain acceptance as a subbase material for road construction, it must perform equally as well as, but at an installed cost less than, conventional aggregates. Unless contractors and highway departments have this economic incentive to use coal refuse, no combination of other factors in its favor will motivate its use. These incentives may be induced by the competitive market, or they could be artificially induced by the direct action of state and federal highway departments, coal companies, or owners of electric utilities, such as subsidies for its use. Incentives that results from natural market forces are the most desirable.

The costs of utilizing coal refuse/fly ash material will have many of the same components as the costs of utilizing conventional materials. Handling and transport costs are dependent on the number of handling stages, the equipment required, and the distance to be transported and are independent of the nature of the material handled. The placing, spreading and grading operations are also independent of the materials involved, which, in this case, are very similar in nature. The limited number of stages where coal refuse/fly ash combinations have the potential for a differential in costs are in: (1) F.O.B. cost of materials; (2) transport distance; (3) handling steps necessary; (4) excavation and loading procedures; and (5) additional mixing costs.

The cost and the availability of conventional subbase materials are intimately connected. Availability implies proximity; proximity implies reasonable price. Because of the large part transportation costs play in the final cost of the delivered aggregate, availability at a certain price is highly dependent upon transportation distance to the construction site. Differences in the price of coal refuse from conventional material can offset the increased costs that will result from the necessity of onsite mixing of the fly ash and coal refuse. Additionally, it may allow the refuse to be transported from a greater distance and still remain economically favorable.

Monongalia County does not suffer from any produced crushed stone or sand and gravel shortages. However, neighboring counties to the south and west have geological shortages of crushed stone. In this analysis it was assumed that, within Monongalia County, aggregate availability (and thus price) was average, and was somewhat below average for the counties identified as aggregate-short to the south and west. Although the extent to which this condition would affect aggregate prices was not determined, it was assumed that the potential for using coal refuse and fly ash combinations for road bases would be enhanced.

The less expensive the coal refuse and fly ash are at the preparation and power plants, the greater the distance that they can be transported and still compete with natural aggregates. Thus, the cooperation of coal companies and utilities to provide their wastes for nominal charges will be a factor in the ultimate success of refuse utilization schemes. In the past, both Consolidation Coal Company and Monongahela Power Company have provided coal refuse and fly ash to various institutions free of charge for experimental purposes. However, the amounts of material provided under these agreements have been relatively small. Larger, regular supplies will almost surely carry some positive price.

Currently, Monongahela Power Company offers its fly ash for sale at $.25/ton for use in projects such as road building and fills and embankments. The Fort Martin power plant pays an independent contractor to dispose of its fly ash and scrubber sludge, so it is in their interest to sell as much fly ash as possible. Monongahela Power estimated that the cost of the fly ash to a contractor at the plant would be approximately $.50/ton, which would include the loading and handling charges at the plant. The costs of transporting the fly ash would be additional.

Consolidation Coal could offer no explicit quote for their refuse. If a contractor or continuing series of contractors were to request large amounts of refuse, Consolidation would most likely initiate a charge for it. Like a utility, a coal company has incentives to sell its refuse, since the company incurs costs in disposing of the refuse. For the Humphrey plant, the marginal cost of disposing of its refuse was estimated at $.54/ton.

Handling and transport can be a significant part of the final delivered cost of refuse and fly ash. Each additional handling step and each additional mile transported increases the delivered cost of the material. The handling and transport stages can be broken down into the following categories, each of which has implicit costs associated with it: (1) excavation and loading; (2) hauling; (3) mixing (of fly ash and refuse); (4) reloading (if mixing was done off site); and (5) unloading, placing and spreading. To approximate these costs, estimates from the 1978 Dodge Guide to Public Works and Heavy Construction Costs were used for both conventional materials as well as fly ash and coal refuse combinations.

The 1978 Dodge Guide estimated the costs of excavation and loading of loam, sand, and loose gravel from between $.15 and $.19 per cubic yard as daily output goes from 2600 to 7600 cubic yards. It was felt that this category of excavation and loading best approximates the conditions under which coal refuse and fly ash might be obtained. This charge is the cost to the contractor and includes only excavation and loading; a typical bid price for the work would be escalated by approximately 40 percent. Thus, excavation and loading will account for between $.21 and $.27 per cubic yard.

Hauling costs of the materials vary with the amounts of refuse and fly ash and the distances they need to be transported. For each particular job there will be two separate sets of haul charges since the fly ash and refuse sources in the study site are in different locations. Since a successful refuse/fly ash mixture will contain a majority of refuse, the proximity of the site to the refuse supply is more important than the proximity to the fly ash source.

The 1978 Dodge Guide gives an average cost of hauling material such as crushed stone or gravel of approximately $.75 for the first cubic yard-mile up to a twenty mile one-way haul. At 20 miles, the cost per cubic yard is quoted at $4.42/cubic yard. Assuming the 40 percent markup, the charges would be $1.05 for the first mile and $.28 per cubic yard-mile up to 20 miles. A 20-mile haul would thus be bid at $6.19 per cubic yard. These charges do not include excavation, loading, or materials charges.

The mixing strategies for refuse and fly ash depend upon distances between the job and materials, the number of handling steps required, and the available mixing techniques. Strategy will be dictated by which method best ensures the proper mixing of the two materials at the least cost. The following options are seen to have the potential for feasibility under certain conditions:

1. Bring the fly ash to the refuse disposal site, mix the two and make the material available for general highway use.

2. Bring the fly ash and refuse to a third location which would act as a central facility for area-wide distribution.

3. Bring both the fly ash and refuse to the construction site in the required quantities and mix on site.

4. Transport refuse to the fly ash disposal site for mixing and make the material available for general distribution.

Regardless of the site at which the two materials are combined, the fly ash must be uniformly dispersed throughout the mixture to ensure structural stability and to adjust the pH of the coal refuse. If this can be ensured, it is likely that the refuse and fly ash will be combined at the construction site. This would eliminate a handling step and an intermediate haul that would be necessary if the two were mixed at some other point. However, if proper mixing equipment is not available at the construction site, another location might be necessary for the proper combining of the refuse and fly ash.

If refuse and fly ash combinations eventually gain acceptance as a road building material, a large-scale central facility could develop to supply refuse and fly ash on a general basis to construction companies in an area. This might be able to provide sufficient economies of scale in the transport of the two materials to make the prospect economical. However, they would have to overcome the environmental problems posed by the interim storage of the two materials. For the near term, it is more likely that fly ash and refuse would be obtained as needed for each particular job.

The 1978 Dodge Guide does not include a category that can be adequately applied to the costs of mixing fly ash and refuse. However, using other available cost factors, the cost per cubic yard of mixing fly ash and coal refuse was estimated at $.91 per cubic yard. Escalated by 40 percent, the bid price is approximately $1.28 per cubic yard. Once the mixing has been done, the placing and spreading costs should be similar to the costs for placing and spreading conventional materials. The 1978 Dodge Guide estimates a cost of $.50 per ton, or a bid price of approximately $.70 per ton.

Summary Table 1 presents the cost estimates for the various stages discussed above. These figures are estimates based on national averages since information specific to the northern West Virginia study area were not available. The estimates show the relative proportions of the total costs that are expected to be included in a representative bid. All costs are based on mid-1978 dollars so that a meaningful comparison between the two alternative methods can be made. The analysis shows the use of coal refuse and fly ash seems to be an advantageous proposition. In fact, a 20-mile haul for refuse and fly ash competes favorably with a 5-mile haul of conventional materials. This advantage is gained because of the difference in the cost of materials. If refuse and fly ash can be obtained for nominal charges,

## SUMMARY TABLE 1

## COST BREAKDOWN ($) FOR CONVENTIONAL AND COAL REFUSE BASE COURSE MATERIALS[a]

| | | CONVENTIONAL MATERIAL | | | | REFUSE/FLY ASH[b] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | HAUL DISTANCE (miles) | | | | HAUL DISTANCE (miles) | | | |
| | | 1 | 5 | 10 | 20 | 1 | 5 | 10 | 20 |
| Material ($/c.y.) | Cost[c] | 4.50 | | | | 0.90[d] | | | |
| | Bid | 6.30 | | | | 1.26 | | | |
| Excavate and Load ($/c.y.) | Cost | 0.15 | | | | 0.15 | | | |
| | Bid | 0.21 | | | | 0.21 | | | |
| Transport ($/c.y.) | Cost | 0.74 | 1.51 | 2.49 | 4.42 | 0.74 | 1.51 | 2.49 | 4.42 |
| | Bid | 1.04 | 2.11 | 3.49 | 6.19 | 1.04 | 2.11 | 3.49 | 6.19 |
| Handling and Mixing ($/c.y.) | Cost | - | - | - | - | 0.91 | | | |
| | Bid | - | - | - | - | 1.28 | | | |
| Placing ($/c.y.) | Cost | 0.64 | | | | 0.61 | | | |
| | Bid | 0.89 | | | | 0.85 | | | |
| Total | Cost | 6.03 | 6.80 | 7.78 | 9.71 | 3.21 | 4.08 | 5.06 | 6.99 |
| | Bid | 8.44 | 9.51 | 10.89 | 13.59 | 4.64 | 5.71 | 7.09 | 9.79 |

[a] 1978 Dodge Guide to Public Works and Heavy Construction; ERCO estimates.

[b] Assumes equal haul distance for fly ash and refuse.

[c] Bid price is cost plus 40 percent.

[d] Based on 3:1 ratio of refuse to fly ash and costs of $1.00 and $.62 per cubic yard respectively.

the savings over conventional materials allow the transport distance to be much greater. Some of the savings are offset by increased charges for handling and mixing; under the assumptions here, refuse/fly ash combinations are still cheaper.

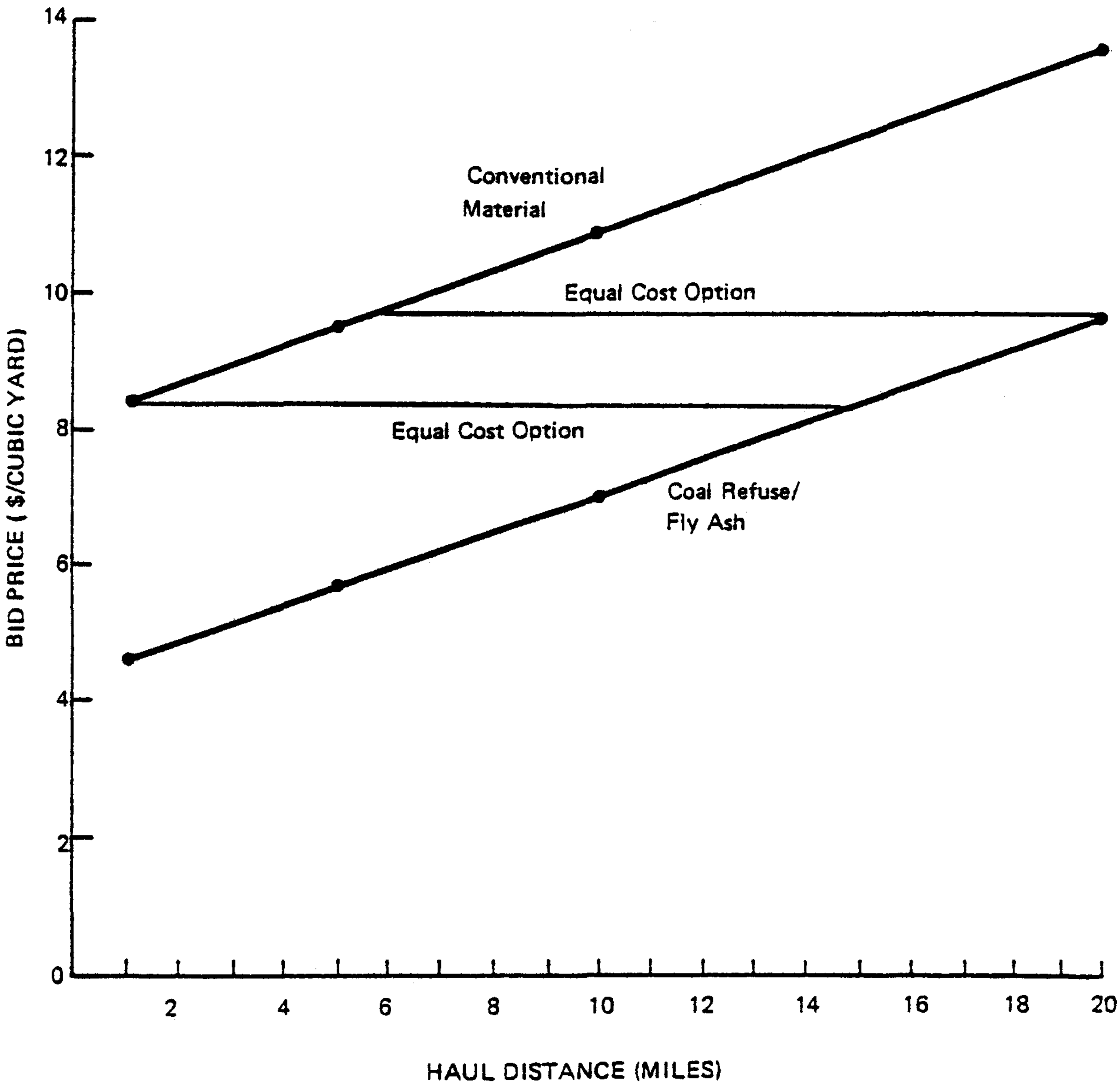
Summary Figure 1 plots the bid prices as a function of haul distance. For a given conventional material use scheme, there exists a coal refuse/fly ash scheme that involves a longer haul for the same overall cost. The extra distance that the refuse/fly ash can be transported is a function of the slopes of the cost to distance plots and the absolute price advantage coal refuse/fly ash combinations command. In the hypothetical situation illustrated, coal refuse/fly ash combinations enjoy a 14-mile haul advantage; that is, they can be transported approximately 14 miles farther than conventional materials and still remain equal in price. Site specific characteristics could change the slopes of both curves and the vertical distances between them. However, for a given amount of material per day, the slopes should be nearly parallel. The two materials are similar enough that differences in necessary equipment should be negligible (aside from the mixing equipment) and transportation charges for similar distances will be similar as well.

## Recommendations for Additional Research

Although there has been considerable research done in relation to coal waste utilization, the fact remains that very few large-volume utilization techniques have been implemented successfully on a sustained basis. The major U.S. successes in this area have been achieved in Pennsylvania, where highway embankments have been built with coal refuse and where old anthracite refuse banks have been reprocessed for fuel recovery. Notable success in refuse bank and pond reprocessing for fuel recovery has also been achieved in a few local projects in West Virginia and Utah.

A review of the history of coal refuse utilization in the United States leads to several observations that provide useful insight into needed research areas:

1. A diversity of technology is now available for application to coal waste utilization, and developing technologies, in particular fluidized-bed combustion and advanced coal preparation processes, offer additional technical alternatives.




Summary Figure 1. Comparison of subbase course delivered prices. (Source: Summary Table 1)

2. Full-scale application of large-volume coal waste utilization methods has been demonstrated in several areas of the country. However, projects undertaken with the support of public funds have been generally more successful than projects undertaken solely by the private sector, with a few exceptions.

3. Laboratory- and pilot-scale research addressing the suitability of specific refuse sources for various utilization methods has been somewhat limited, but results indicate that analytical methods for refuse characterization are available and that refuses can be matched to most appropriate utilization methods.

4. The chemical and physical properties of coal refuse are quite variable, even within a single refuse source. However, for most utilization methods, the critical physical and chemical parameters are known and refuse variability within certain limits can be tolerated. Procedures for dealing with refuse variability have been investigated for some utilization methods.

5. There is no comprehensive coal waste utilization research program in the United States. Research efforts have been sponsored by several federal and state agencies, and by industry, but without benefit of a central administrative body. This "shotgun" approach has produced much useful data and experience, but the fact remains that coal refuse generation rates are far greater than coal refuse utilization rates.

6. The economics of coal waste utilization are determined largely by refuse handling and transportation requirements and by local market conditions for refuse-derived products and materials. Increasingly stringent regulation of refuse disposal practices will likely provide an overall economic incentive for waste utilization, but local economic factors will still prevail.

7. Although many utilization methods are feasible, in the long run it is unlikely that more than 20 to 25 percent of the coal refuse generated can be productively utilized. Thus, research into improved refuse disposal methods and refuse bank and pond reclamation should be vigorously pursued.

The principal recommendation offered here is that the Department of Energy take steps to initiate within the federal government a more coordinated program for increased coal refuse utilization in the United States. Since there are ongoing research efforts and other related programs within DOE and agencies such as the Federal Highway Administration, the Bureau of Mines, the Environmental Protection Agency and the Office of Surface Mining, the establishment of an interagency steering committee on coal waste utilization seems to be in order. Preferably, such a committee would also include representatives from state governments, industry, and universities engaged in coal waste research.

The purpose of the steering committee would be to provide a forum for the exchange of information and ideas that is critical to the design of a meaningful, cost-effective coal waste utilization research program. The future efforts of DOE or any agency with responsibility in this field can hardly be well-managed and conducted without a greater degree of cooperation than has been evident in the past. The historical "shotgun" research approach, as stated previously, has produced a great deal of baseline information on coal waste utilization; however, the overall U.S. program has suffered from the lack of high-level, coordinated program management. The existing Interagency Energy/Environment Research and Development Program has, as one of its many objectives, the demonstration of methods for reusing coal cleaning wastes, but efforts under this program would also benefit from a more focused interagency approach to coal waste utilization.

Within a coordinated interagency framework, the DOE coal waste effort must be more clearly defined in terms of program goals, priority research and development areas, and technology transfer mechanisms. A preliminary outline of the envisioned DOE program is provided below:

1. Participation in interagency steering committee on coal waste utilization

2. Continuation of ongoing DOE research efforts in coal waste and combustion by-product utilization

3. Definition of DOE coal waste utilization research goals and priorities

    - Establish DOE coal waste utilization program with staff and authority

    - Program emphasis on newly-generated coal refuse or on utilization/reclamation of old refuse banks and impoundments (or both)

- Program emphasis on large volume alternatives or on small volume alternatives (or both)

- Identify local refuse utilization opportunities and desires and incorporate into program

- Recognize practical limits on refuse volumes that can be utilized and maintain research efforts geared toward improved disposal and reclamation methods

- Develop baseline information on available coal refuse data and coal refuse utilization programs completed and in progress in the U.S. and abroad

4. Establish DOE coal waste utilization research tasks

   - Technology development--priority on the potential application of fluidized-bed combustion technology to coal refuse for fuel recovery (and possible use of residue for additional utilization methods)

   - Analysis of economic and financial factors affecting coal waste utilization--why have previous attempts at alumina recovery, fuel recovery and brick manufacture failed economically? What government incentives would be needed to improve the economics of certain utilization techniques? What government incentives are appropriate?

   - Institutional studies--how does private sector inertia affect coal waste utilization? How can such inertia be overcome? What legal and reguatory constraints inhibit increased coal refuse utilization?

   - Environmental impacts and costs--what are projected coal waste disposal costs under MESA and EPA regulations? What are the costs and benefits of refuse utilization versus surface disposal?

5. Establish technology transfer mechanisms

6. Initiate DOE coal waste utilization research, development and demonstration programs.

# FEASIBILITY OF ALTERNATIVES FOR SURFACE UTILIZATION OF COAL WASTES

## Introduction

This report contains the results of a study of the "Feasibility of Alternatives for Surface Utilization of Coal Wastes", under U.S. Department of Energy Contract No. ET-78-C-01-3105. The primary objective of the study was to prepare an assessment of the environmental and economic feasibility of a specific coal waste utilization technique in a "representative mining district." The main body of this report presents the desired feasibility assessment.

Secondary objectives of the study were to prepare detailed reviews of the environmental and economic impacts of current surface disposal methods (Task 1), the existing techniques for coal waste utilization (Task 2), and the properties of coal waste materials (Task 3). The principal findings of Tasks 1 through 3 are included herein as Appendices A, B and C, respectively.

This final report is organized as follows. Following this introduction is a brief background section presenting information on coal refuse quantities, general refuse physical and chemical properties, and current refuse disposal practices. Next, the selection of a utilization technique to be the subject of the feasibility assessment is described. The chosen technique involves the use of coarse coal refuse in combination with power plant fly ash to form subbase and base course material for roadway construction. The subsequent section discusses the selection of a specific study area in which the feasibility of refuse/fly ash utilization is assessed. The chosen study area is in northern West Virginia near Morgantown. The next section presents the economic and environmental feasibility evaluation, including a brief comparison of the selected utilization technique to current surface disposal methods. The final section presents recommendations for additional research on coal waste utilization.

## Background

For completeness and to provide continuity among the project task reports, this section of the report presents summary information on coal refuse quantities, properties and disposal methods. More complete background is provided in Appendix A (current disposal methods), Appendix B (coal refuse utilization techniques) and Appendix C (coal refuse quantities and properties).

### Coal Refuse Quantities

The rate at which coal refuse continues to accumulate is a function of several factors including total raw coal production, percentage of raw coal cleaned, prevailing markets for various quality coals, and the specific mining and beneficiation methods used. In 1975, about 107 million tons (dry) of coal refuse was generated in the United States. In general, only slightly more than half of the raw coal produced is cleaned before use. With increasing coal production and more demand for higher quality coal to meet air emission standards, it is likely that annual coal waste generation rates will continue to rise, perhaps reaching 200 million tons per year by 1985.

For further discussion relative to potential future quantities of coal refuse, consider the following analysis of coal refuse generation in the Eastern Interior and Appalachian coal regions. Table 1 presents tonnages of raw coal and coal refuse production of individual states in these regions and for the entire United States. The fourth column of Table 1 lists actual refuse tonnage for 1975. West Virginia leads by far all other states in refuse production, even though it is second to Kentucky in total coal production. The sixth column of Table 1 shows the percent of the raw tonnage cleaned that is refuse and therefore must be reused or disposed. The range for this percentage is from 22 to 38, which substantially agrees with the generally accepted estimates of from 20 to 30 percent.

The last, or seventh, column of Table 1 presents the data in a very interesting and useful way. These values represent the percent of cleaned coal that is accompanied by an equal amount of refuse. The range is from 29 to 62 percent. In other words, for every 100 tons of cleaned coal produced there are 29 to 62 tons of refuse generated. Alabama, at 62 percent, generates the most refuse per ton of cleaned coal, but West Virginia's value of 45 percent helps explain why West Virginia produces so much refuse.

# TABLE 1

## REFUSE AND COAL PRODUCTION (1,000 TONS)

| | 1975 Total Raw Coal Production | Raw Tonnage Cleaned[a] | Percent Cleaned (%) | Cleaned Coal as Percent of Production (%) | 1975 Refuse | Refuse as Percent of Tonnage Cleaned[b] (%) | Refuse as Percent of Cleaned Coal[c] (%) |
|---|---|---|---|---|---|---|---|
| U.S. | 648,438 | 374,094 | 57 | 41 | 107,101 | 29 | 40 |
| Eastern Interior | 141,018 | 110,728 | 79 | 60 | 26,395 | 24 | 31 |
| Appalachian | 385,601 | 243,999 | 63 | 43 | 76,313 | 31 | 46 |
| <u>Eastern Interior</u> | | | | | | | |
| Kentucky (West) | 56,357 | 25,751 | 46 | 35 | 5,938 | 23 | 30 |
| Indiana | 25,124 | 24,906 | 99 | 77 | 5,585 | 22 | 29 |
| Illinois | 59,537 | 59,991 | 100 | 76 | 14,872 | 25 | 33 |
| Iowa | no cleaning | -- | -- | -- | -- | -- | -- |
| Missouri | not reported | -- | -- | -- | -- | -- | -- |
| Kansas | not reported | -- | -- | -- | -- | -- | -- |
| Arkansas | not reported | -- | -- | -- | -- | -- | -- |
| Oklahoma | not reported | -- | -- | -- | -- | -- | -- |
| Texas | no cleaning | -- | -- | -- | -- | -- | -- |
| <u>Appalachian</u> | | | | | | | |
| Kentucky (East) | 87,257 | 33,134 | 38 | 27 | 9,369 | 28 | 39 |
| Pennsylvania | 84,137 | 60,172 | 72 | 51 | 17,600 | 29 | 41 |
| Ohio | 46,770 | 21,850 | 47 | 30 | 7,742 | 35 | 55 |
| West Virginia | 109,238 | 91,398 | 84 | 58 | 28,259 | 31 | 45 |
| Maryland | not reported | -- | -- | -- | -- | -- | -- |
| Virginia | 35,510 | 19,267 | 54 | 36 | 6,393 | 33 | 50 |
| Tennessee | not reported | -- | -- | -- | -- | -- | -- |
| Alabama | 22,644 | 18,178 | 80 | 50 | 6,950 | 38 | 62 |
| Georgia | no cleaning | -- | -- | -- | -- | -- | -- |
| Other states - no cleaning | 49,253 | -- | -- | -- | -- | -- | -- |
| Other states - cleaning | 57,389 | 13,000 | 23 | 17 | 3,522 | 27 | 37 |

[a] Raw tonnage, includes coal and refuse.
[b] Refuse tonnage divided by raw tonnage cleaned.
[c] Refuse tonnage divided by to-nage of cleaned coal resulting from cleaning process.

Estimates of the future tonnages of coal refuse are dependent on assumptions about coal production. Three estimates of coal production are presented in Table 2 covering a wide range of possible production levels. The larger estimates are projections taken from coal industry publications. The estimate of 900 million tons of production was the lowest recent projection found.

The range of estimates for coal production in 1985 can be converted to a range of refuse production by using the percentage factors given in columns four and seven of Table 1. The factors give each state's cleaned coal tonnage in 1975 as a percent of total raw coal production (column four) and each state's refuse generation rate as a percent of clean coal production (column seven). The calculation of 1985 refuse tonnage is as follows:

$$\begin{matrix}\text{1985}\\\text{Refuse}\\\text{Tonnage}\end{matrix} = \begin{pmatrix}\text{1985 Raw}\\\text{Coal}\\\text{Production}\end{pmatrix}\begin{pmatrix}\text{State Clean}\\\text{Coal Percentage}\\\text{Factor}\end{pmatrix}\begin{pmatrix}\text{State Refuse}\\\text{Generation}\\\text{Factor}\end{pmatrix}$$

The estimated 1985 refuse tonnage is presented in Table 3. The estimates range from 148 to 243 million tons. The 1975 refuse levels are included in Table 3 for reference. The levels of refuse in the table appear to be in agreement with coal production values. Under the low growth scenario, only a 6 percent annual increase in coal production is forecast for 1977-1985. The 1985 refuse figures for the low growth scenario reflect this slight increase. The 1985 high growth refuse levels are significantly higher than the 1975 refuse levels.

There does seem to be a minor flaw in the calculations. Some states, particularly Kentucky (east) and West Virginia, may substantially increase the percent of underground coal they clean. The evidence for this is the low present utilization rates of preparation plant capacity in these areas. Utilization could easily double for these states and all of the Appalachian states. Refuse levels then would be about twice the levels found in Table 3.

## Coal Refuse Properties

Two types of waste are generated in coal preparation plants: dry, coarse material and fine particles (smaller than 1 millimeter in size) that are typically handled in a wet slurry. Once coal has been removed from the ground, it is crushed into pieces of 6 inches or less in diameter, and then sized as needed. Much of the material withdrawn with

**TABLE 2**

**1985 COAL PRODUCTION (1,000 TONS)**

| | Low Growth | | National Coal Association | | Keystone | |
|---|---|---|---|---|---|---|
| | Underground | Total | Underground | Total | Underground | Total |
| U.S. | 398,000 | 900,000 | 491,500 | 1,283,000 | 543,000 | 1,480,000 |
| Eastern Interior | 71,300 | 181,000 | 93,220 | 246,700 | 96,170 | 271,100 |
| Appalachian | 267,000 | 458,000 | 349,800 | 548,300 | 350,100 | 559,800 |
| **Eastern Interior** | | | | | | |
| Kentucky (West) | 27,000 | 58,500 | 36,470 | 71,440 | 33,140 | 66,610 |
| Indiana | 600 | 26,800 | 431 | 34,720 | 600 | 34,810 |
| Illinois | 36,100 | 70,600 | 52,270 | 89,340 | 58,450 | 97,740 |
| Iowa | 0 | 530 | 535 | 842 | 0 | 525 |
| Missouri | 0 | 6,630 | 1,800 | 6,167 | 0 | 6,625 |
| Kansas | 0 | 666 | 0 | 576 | 0 | 630 |
| Arkansas | 20 | 570 | 210 | 736 | 20 | 570 |
| Oklahoma | 140 | 5,610 | 1,500 | 5,775 | 1,800 | 7,545 |
| Texas | 0 | 24,600 | 0 | 37,100 | 0 | 69,750 |
| **Appalachian** | | | | | | |
| Kentucky (East) | 46,500 | 98,700 | 56,064 | 113,100 | 63,110 | 128,600 |
| Pennsylvania | 40,100 | 86,500 | 67,380 | 109,100 | 64,640 | 108,500 |
| Ohio | 15,000 | 44,300 | 25,430 | 58,020 | 28,820 | 61,410 |
| W. Virginia | 77,200 | 101,000 | 132,400 | 157,500 | 129,600 | 155,200 |
| Maryland | 480 | 3,090 | 2,175 | 4,695 | 1,975 | 4,495 |
| Virginia | 27,200 | 41,100 | 32,010 | 45,950 | 32,210 | 46,150 |
| Tennessee | 4,720 | 10,400 | 8,918 | 10,610 | 8,108 | 9,802 |
| Alabama | 7,680 | 23,300 | 25,020 | 43,800 | 25,190 | 39,650 |
| Georgia | 0 | 267 | 0 | 200 | 0 | 950 |

TABLE 3

REFUSE PRODUCTION IN 1985
(thousands of tons)

| | 1975 | 1985 LOW GROWTH | 1985 HIGH GROWTH |
|---|---|---|---|
| United States | 107,101 | 148,000 | 243,000 |
| Eastern Interior | 26,395 | 33,700 | 50,400 |
| Appalachia | 76,313 | 90,600 | 111,000 |
| Eastern Interior | | | |
| Kentucky (West) | 5,938 | 6,140 | 6,990 |
| Indiana[a] | 5,585 | 5,980 | 7,770 |
| Illinois | 14,872 | 17,700 | 24,500 |
| Iowa | | | |
| Missouri | | | |
| Kansas | | | |
| Oklahoma | | | |
| Texas | | | |
| Appalachia | | | |
| Kentucky (East) | 9,369 | 10,400 | 13,500 |
| Pennsylvania | 17,600 | 18,100 | 22,700 |
| Ohio | 7,742 | 7,310 | 10,100 |
| West Virginia | 28,260 | 26,400 | 40,500 |
| Maryland | | | |
| Virginia | 6,393 | 7,400 | 8,310 |
| Tennessee | | | |
| Alabama | 6,950 | 7,220 | 12,300 |
| Georgia | | | |
| Other states | 3,522 | | |

[a]Most of Indiana's refuse is from cleaning of surface mined coal.

the coal from the ground is unwanted mineral matter, which is separated, initially by dry separation techniques, to produce the coarse waste product. The coal is then washed with water to remove remaining fine particles of foreign material and dust. This process produces the slurry wastes. The exact characteristics of the two wastes produced depend on the nature of the coal itself and the geology of the formation. Approximately 70 to 80 percent of the total waste generated comprises the coarse fraction; the remaining 20 to 30 percent is comprised of fines (dry weight basis).[1]

Coarse refuse commonly contains coal, rock, carbonaceous shales and pyrites, siltstone, claystone, sandstone, and limestone, in addition to such foreign elements as wood, machine parts, wire and electrical cables, paper, cloth, grease, and oil. Iron, magnesium, potassium, and sodium are all found in coarse refuse. Particles generally range in diameter from 10 to 220 mm.

Slurries produced by water washers contain materials ranging from fine silts and clays to find sands, in suspension in water. Particles are usually less than 80 mm in diameter. Typical fines composition is 60 percent silica ($SiO_2$), 25 percent alumina ($Al_2O_3$), and 7 percent iron oxide ($Fe_2O_3$).

The properties of coal waste vary according to the mineralogical constituents of the waste rock contained in non-coal bands within the coal, the composition of the adjacent strata, the method of mining the coal, the method and efficiency of the cleaning operation, and the quality of the coal and the market for which it is cleaned.

The percent ash in refuse varies from 20 to 78 percent. However, only fine, or slurry refuse shows ash values below 36 percent. Sulfur content appears to be higher in the Midwestern coal fields than the Appalachian field. Western Kentucky refuse contains generally greater than 3 percent sulfur, but eastern Kentucky and West Virginia refuse has less than 2 percent, often less than 1 percent. Sulfur is an important parameter when considering acid runoff from disposal sites because it can be oxidized to produce sulfuric acid.

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[1]Pedco Environmental Inc., Study of Adverse Effects of Solid Wastes from All Mining Activities on the Environment, Draft Report, Cincinnati, Ohio, June 1978.

## Current Disposal Practices

Historical disposal practices for coal refuse have consisted of depositing dry refuse in an embankment suited to local topography and sluicing wet refuse into impoundments created by the embankments. The amount that has accumulated over the years is staggering - the National Academy of Sciences has estimated (conservatively) that active and abandoned waste piles and impoundments in the eastern coal fields alone contain over 3 billion tons of refuse.[1]

These coal refuse piles and impoundments can present serious environmental problems, ranging from severe local air pollution from burning refuse banks to stream and groundwater quality degradation from siltation, acid runoff and leaching of heavy metals. Coal refuse piles have, in the past, often been constructed without adequate planning for safety considerations. Embankment failures have resulted in two major disasters in recent years - in Wales in 1966 and in West Virginia in 1972 - with over 260 deaths recorded.

Surface disposal methods are used to dispose of the vast majority of coal refuse produced in the United States. If the coal is not processed, or is pneumatically cleaned, the refuse is simply transported to refuse piles. Embankments of the following types may then be formed with the coal piles:

1. Valley-fill: where an existing valley is filled with refuse, and the surface leveled and graded on site abandonment.

2. Cross-valley: where the embankment is constructed across an existing valley, but not entirely filling the valley.

3. Sidehill: where wastes are dumped alongside of an existing hill or ridge, so that the original ridge is essentially expanded in a sideways direction.

4. Ridge dump: where an embankment is created by continuously dumping wastes on the pile's ridge,

5. Heaped: where, as the name suggests, the wastes are haphazardly heaped into an amorphous mound.

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[1]National Academy of Sciences, Underground Disposal of Coal Mine Wastes, Washington, D.C., 1975.

If the coal is processed through wet cleaning, suitable refuse disposal is somewhat more complicated and costly. There are three primary choices for refuse disposal from a wet cleaning plant:

1. Mechanically dewater fine refuse at preparation plant, mix the dewatered fines with coarse refuse and transport combined refuse to refuse pile.

2. Pump fine refuse slurry from clarifier into settling ponds, remove sediment with drag line, transport coarse refuse and sediment to disposal area and dump sediment into pits excavated in the coarse refuse.

3. Simultaneously construct a dam with coarse refuse and pump fine refuse slurry behind the coarse refuse dam.

As is the case for the last option described, the embankments formed from the coarse refuse are used to impound the fine refuse slurry. In some cases, the impoundments may contain liners of earth, clay, bentonite, or an artificial material to prevent leaching through the bottom of the pond. Slurries are piped into the ponds, where the fines settle out and, over time, gradually stabilize. Once the lagoon has reached capacity, the excess water can be drained off the surface, and the material covered and revegetated. Alternatively, if temporary lagoons are used, the fines can be excavated and mixed with coarse refuse for disposal in embankments.

Refuse piles may occupy from 1 acre to greater than 100 acres of surface area, and can range from 20 to 300 feet in depth. Most refuse piles are small (less than 500,000 cubic yards). However, most of the refuse is currently contained in a few very large (greater than 1.5 million cubic yards) piles. There are 3,000 to 5,000 active or abandoned refuse piles and ponds in the United States currently, mostly in the eastern coal regions.

## Selection of Coal Refuse Utilization Technique

### Candidate Techniques

Under Task 2 of this study, an exhaustive review of the literature on coal refuse utilization was performed to identify the full range of utilization techniques that have been employed and/or considered in the United States and elsewhere. It was found that coal refuse disposal and utilization has been under study for more than 100 years and that a wide variety of uses have been proposed and, in many cases, implemented. A list of these coal refuse utilization techniques is given in Table 4 (also see Appendix B).

Included in the Task 2 review was consideration of the physical and chemical characteristics of coal refuse, in terms of the properties required for the utilization methods, and the preparation/processing associated with the various utilization methods. Table 5 presents a list of critical physical and chemical parameters for each alternative refuse utilization technique as well as additional information on the technology, economics and experience of each technique.

### Preliminary Screening

In selecting a utilization technique for further study, the information briefly summarized in Table 5 was supplemented and compared with available data on the characteristics of coal refuse being generated in the northern West Virginia study area. The available data on refuse characteristics was quite sparse (as discussed later), but this study was intended to be performed on the basis of data found in the literature and not on new data developed through a refuse sampling and analysis program. Thus, it was necessary to proceed by substituting subjective judgment where the data were not sufficient for precisely comparing refuse characteristics with the specific requirements of all candidate utilization techniques.

The preliminary screening of candidate refuse utilization schemes was carried out to initially remove from consideration those schemes incompatible with either the refuse in the study area or the overall objectives of this study. For initial screening, three primary and three secondary criteria were established as described in Table 6. The primary criteria are considered to be somewhat critical in that if a utilization method does not appear to satisfactorily meet all three criteria, then it is probably very doubtful as a viable, widely applicable coal refuse utilization method. The secondary criteria provide a further indication of the potential of the various techniques.

TABLE 4

TECHNIQUES FOR COAL REFUSE UTILIZATION

Secondary Fuel Recovery

- High grade fuel (low ash, high Btu content)
- Low grade fuel (high ash, low Btu content)

Secondary Mineral Recovery

- Alumina
- Sulfur
- Trace metals

Construction Materials Manufacture

- Lightweight aggregate in Portland cement, bituminous concrete and concrete block
- Coal-crete (low quality concrete)
- Bricks and ceramics
- Mineral wool (insulation)

Construction and Highway Uses

- Landfill
- Embankments
- Base course
- Anti-skid material

Horticultural Uses

- Soilless medium
- Landscape fill and filler material
- Soil nutrient (mixed with manure)

## TABLE 5

## PHYSICAL AND CHEMICAL PARAMETERS CRITICAL TO COAL REFUSE UTILIZATION METHODS

| UTILIZATION METHOD | CRITICAL PHYSICAL AND CHEMICAL PARAMETERS | ADDITIONAL COMMENTS ON TECHNOLOGY, ECONOMICS AND EXPERIENCE |
|---|---|---|
| SECONDARY FUEL RECOVERY | | |
| • High grade fuel<br>• Low grade fuel | Heat value (>3,000 Btu/lb)<br>Ash content (<30%)<br>Sulfur content<br>Volatile content<br>Moisture content (low) | 1. Technology for reprocessing dry refuse banks and wet refuse dredged from impoundments is available. Reprocessed refuse can be mixed with high grade coal to meet boiler specs.<br>2. New heavy-media coal preparation processes allow refuse separation into low (<12%) and medium (<40%) ash combustible fractions.<br>3. Fluidized bed combustion of coal refuse has been investigated in the U.S. and abroad. Bench scale data show ability to burn low-grade refuse, but process is sensitive to heat value and moisture content. No data available on pilot- or demo-scale units. FBC residue may be suitable for bricks and lightweight aggregate.<br>4. Experience with fuel recovery from refuse is extensive in the U.S. and in Europe. |
| SECONDARY MINERAL RECOVERY | | |
| • Alumina | Alumina content (>28%) | 1. Several processes are avaiable to extract alumina ($Al_2O_3$) from coal ash and coal refuse, but to date economics have been unfavorable. |

TABLE 5 (Cont.)

PHYSICAL AND CHEMICAL PARAMETERS CRITICAL TO COAL REFUSE UTILIZATION METHODS

| UTILIZATION METHOD | CRITICAL PHYSICAL AND CHEMICAL PARAMETERS | ADDITIONAL COMMENTS ON TECHNOLOGY, ECONOMICS AND EXPERIENCE |
|---|---|---|
| | | 2. Alumina content in refuse is very variable. Lime sintering process requires >28% alumina while acid processes require > 20% alumina.<br>3. Experience in U.S., Canada, France and Russia has demonstrated technology, but bauxite is still cheaper for aluminum manufacturing. |
| • Sulfur | Sulfur content<br>Trace metal conc. | 1. Sulfur recovery has been demonstrated in laboratory tests, but little interest in full-scale sulfur recovery has been shown. Trace element recovery not widely feasible due to very low, variable trace element concentrations in refuse. |
| CONSTRUCTION MATERIALS MANUFACTURE | | |
| • Lightweight aggregate | Coal content<br>Final density (40-55 pcf)<br>Particle size/shape<br>Moisture absorption (low; dry without deterioration) | 1. Rotary kiln and sinter grate processes are used to make conventional lightweight aggregate (LWA). Although 80% of LWA is made in rotary kilns, the sinter grate process utilizes the heat value of of the coal refuse, thereby reducing external energy inputs.<br>2. Laboratory tests have demonstrated the technical feasibility of using LWA from coal refuse in Portland cement concrete, bituminous concrete, and concrete block. |

TABLE 5 (Cont.)

PHYSICAL AND CHEMICAL PARAMTERRS CRITICAL TO COAL REFUSE UTILIZATION METHODS

| UTILIZATION METHOD | CRITICAL PHYSICAL AND CHEMICAL PARAMETERS | ADDITIONAL COMMENTS ON TECHNOLOGY, ECONOMICS AND EXPERIENCE |
|---|---|---|
| | | 3. Although the availability of natural LWA materials is a major economic disincentive, there have been several commercial LWA-producing operations in the U.S., but none are in business today. In Europe, refuse is used in making cement. |
| • Coal-crete | Sulfur content<br>Carbon content (7-10%)<br>CaO content (high)<br>Grain size (clays important)<br>Pozzolanic reactivity (high) | 1. Coal-crete is concrete made using raw coal refuse as aggregate material. This low quality concrete may be suitable for use underground, where constant temperature and humidity would inhibit acid formation, swelling of shales, and deterioration by weathering. |
| • Bricks and ceramics | Ash (>65%)<br>$Fe_2O_3$ (<8%)<br>CaO content (<0.7%)<br>Normative quartz (12-18%)<br>Grain size (minus 20 sieve)<br>Moisture absorption (low) | 1. Both raw refuse and burnt refuse (red dog) can be used in brick making. Principal requirements are sufficient silicious material for bonding and hardness, and controlled shrinkage after curing.<br>2. Experience in England, Poland and Japan is extensive, but economic feasibility vis-a-vis conventional clay bricks has not been demonstrated in the U.S. |
| • Mineral wool | Alumina (12-14%) | 1. Using coal refuse as raw material in mineral wool manufacturing is technically feasible, but economic incentives for technology development for full-scale operation do not exist. |

TABLE 5 (Cont.)

PHYSICAL AND CHEMICAL PARAMETERS CRITICAL TO COAL REFUSE UTILIZATION METHODS

| UTILIZATION METHOD | CRITICAL PHYSICAL AND CHEMICAL PARAMETERS | ADDITIONAL COMMENTS ON TECHNOLOGY, ECONOMICS AND EXPERIENCE |
|---|---|---|
| CONSTRUCTION AND HIGHWAY USES | | |
| • Landfill and embankments<br>• Base course | Gradation (grain size)<br>Permeability (<$10^{-6}$ cm/sec)<br>Optimum moisture<br>Atterberg limits<br>Specific gravity<br>Specific gravity<br>Density<br>Shear strength<br>Friability<br>Abrasion and fracture resistance | 1. Coal refuse, both raw and burnt, can be used for landfills and embankments long as the engineering properties of the refuse is reliably determined and proper compaction during construction is achieved.<br>2. In the past, objections to this use of refuse have been due to the potential for spontaneous ignition, acid leachate, and uncertain engineering performance in construction. Proper compaction and grading to achieve maximum density along with addition of fine refuse fraction or fly ash have been found to result in an acceptable construction material.<br>3. The economics of coal refuse utilization in construction are site specific in terms of the availability of conventional sand/gravel fill and required hauling distances. Also, more extensive geotechnical engineering analysis is needed for refuse and careful construction practices are essential, although the latter is true for all fill materials.<br>4. There is a long history of coal refuse utilization as landfill and embankment material in the England and the U.S. In recent years, research and full-scale construction projects have advanced the state-of-the-art considerably. |

TABLE 5 (Cont.)

PHYSICAL AND CHEMICAL PARAMETERS CRITICAL TO COAL REFUSE UTILIZATION METHODS

| UTILIZATION METHOD | CRITICAL PHYSICAL AND CHEMICAL PARAMETERS | ADDITIONAL COMMENTS ON TECHNOLOGY, ECONOMICS AND EXPERIENCE |
|---|---|---|
| | | 1. As a subbase course in highway, parking lot, airport and other similar construction projects, the strength, durability and environmental (leaching) characteristics of coal refuse are most important. Recent research results indicate that stabilization of the refuse by adding a cementitious material (e.g., cement, fly ash, lime) is desirable to increase strength and decrease permeability. |
| • Anti-skid material | Grain size<br>Density (35-95 pcf)<br>No long, flat particles | 1. The use of sintered coal refuse as the coarse aggregate in bituminous mixes (asphalt cement, mineral filler, sand, water, and aggregate) has received limited laboratory and field study in recent years. The principal attributes of sintered refuse are its light weight and skid resistance.<br>2. Burnt anthracite refuse has been successfully used as a winter roadway anti-skid material in Pennsylvania. |

TABLE 5 (Concluded)

PHYSICAL AND CHEMICAL PARAMETERS CRITICAL TO COAL REFUSE UTILIZATION METHODS

| UTILIZATION METHOD | CRITICAL PHYSICAL AND CHEMICAL PARAMETERS | ADDITIONAL COMMENTS ON TECHNOLOGY, ECONOMICS AND EXPERIENCE |
|---|---|---|
| **HORTICULTURAL USES** | | |
| • Soilless medium | pH (7.5)<br>Permeability (high)<br>Moisture absorption (high)<br>Nutrient conc. (high in P, I, Ca, Mg, N)<br>Low conc. of toxic elements | 1. Raw refuse is not suitable for horticultural uses, but incinerated refuse has been successfully used in test applications.<br>2. Conventional lightweight aggregate materials (e.g., perlite, vermiculite) have been used in a number of agronomic applications and it is possible that refuse-derived aggregates would be suitable for the same purpoeses. This utilization technique has not been fully explored and would be a small volume, localized technique. |

TABLE 6

SCREENING CRITERIA FOR COAL REFUSE UTILIZATION TECHNIQUES

| CRITERIA | RATIONALE |
|---|---|
| Primary Criteria | |
| 1. Technical feasibility | General comparison of physical/chemical characteristics of coal refuse from the study area with technical requirements of utilization technique. |
| 2. Performance | Expected or demonstrated performance of refuse-based materials or products vis-a-vis that of conventional materials or products. |
| 3. Cost | Expected or estimated cost of refuse-based materials or products relative to cost of conventional materials or products. |
| Secondary Criteria | |
| 1. Market size and potential demand | Estimated percentage of total demand for specific materials or products in study area that could be met with refuse-based materials or products. |
| 2. Consumptive use | Utilization techniques of most interest are those that consume large-volumes of refuse with little remaining for disposal. |
| 3. Experience | Experience in U.S. and abroad with the particular utilization technique for coal refuse |

To rate each utilization technique in terms of the screening criteria, the results of Tasks 2 and 3 were utilized and, where necessary, additional literature was consulted to provide further information. The preliminary evaluation effort was done to identify those use schemes that appear to be incompatible with the study site. Thus, non-quantitative ranking was used to establish the relative degree to which each method met the evaluation criteria and to accomplish the first stage screening. In some cases, such as "technical feasibility," a simple yes/no measure was used. In others, such as "market size," a relative system was used (to relate the market size to the amount of refuse available.) For each use scheme, this qualitative ranking was performed for all criteria. By failing a primary criterion, a utilization technique was immediately disqualified from further consideration. The secondary criteria were used to screen out those methods that might be technically or economically feasible in some cases but were not as attractive as other uses because of small end use markets or because they left significant amounts of the coal waste to be disposed of.

Table 7 illustrates the results of the preliminary screening for the candidate utilization techniques. A negative evaluation indicates that the technique does not adequately meet the criteria. Thus, evaluations of negative in column one, two, or three (the critical criteria) disqualify a technique from further consideration, and negative ratings in columns four through six cause the ranking of the technology to be lowered.

The preliminary screening reveals that three uses show the most promise: use in highway fills and embankments, use in road base construction, and use as an input to the manufacture of lightweight aggregate. All three uses have been demonstrated to be technically feasible, structurally satisfactory, and involve costs of the same order of magnitude compared to conventional materials.

## Selected Technique for Further Study

The coal refuse utilization technique chosen for further consideration in this study involves the use of a combination of coarse coal refuse and power plant fly ash to form subbase and base course material for highway pavements. Related applications of the refuse/fly ash material include airports, parking lots and shopping centers.

# TABLE 7

## RESULTS OF PRELIMINARY SCREENING OF CANDIDATE UTILIZATION TECHNIQUES

| CRITERIA | PRIMARY | | | SECONDARY | | |
|---|---|---|---|---|---|---|
| TECHNIQUES | TECHNICAL FEASIBILITY | PERFORMANCE | COST | MARKET SIZE AND DEMAND | CONSUMPTIVE USE | EXPERIENCE |
| Secondary Fuel Recovery | NEGATIVE Refuse has high ash, low heat value | NEGATIVE Requires reprocessing and mixing to meet boiler specifications | NEGATIVE | NEGATIVE Competing with raw coal | POSITIVE Would reduce waste volumes | POSITIVE Old refuse used in U.S. and Europe |
| Secondary Mineral Recovery | NEGATIVE Low alumina and metal content | NEGATIVE Processing and transport costs favor bauxite-produced aluminum | NEGATIVE | NEGATIVE | NEGATIVE Alumina recovery leaves high waste volume | NEGATIVE Full-scale systems not yet demonstrated |
| Construction Materials Manufacture | | | | | | |
| • Lightweight aggregate | POSITIVE | POSITIVE | POSITIVE | - | POSITIVE | POSITIVE |
| • Coal-crete | POSITIVE | UNCERTAIN | - | - | NEGATIVE | NEGATIVE |
| • Bricks and ceramics | POSITIVE | POSITIVE | - | - | NEGATIVE | POSITIVE |
| • Mineral wool | NEGATIVE | NEGATIVE | - | - | NEGATIVE | NEGATIVE |
| Construction and Highway Uses | | | | | | |
| • Landfill | POSITIVE | POSITIVE | See Note 1 | POSITIVE | POSITIVE | POSITIVE |
| • Embankments | POSITIVE | POSITIVE | See Note 1 | POSITIVE | POSITIVE | POSITIVE |
| • Base course | POSITIVE[2] | POSITIVE | See Note 1 | POSITIVE | NEGATIVE | NEGATIVE |
| • Anti-skid material | POSITIVE | POSITIVE | POSITIVE | POSITIVE | NEGATIVE | POSITIVE |
| Horticultural Uses | NEGATIVE | NEGATIVE | - | NEGATIVE | NEGATIVE | NEGATIVE |

1. The economics associated with refuse utilization in landfills, highway embankments and roadway base courses are very localized, with key factors being (1) refuse handling and transport costs; and (2) the price and availability of conventional competing materials.
2. Recent research sponsored by the U.S. Environmental Protection Agency and the Federal Highway Administration has shown that refuse in combination with fly ash can result in a suitable base course material.

In a flexible pavement structure (bituminous concrete), the layers of the roadway, beginning at the subgrade and following in order upward are typically designated as subbase course, base course, and surface course.

The subbase course is between the subgrade and base course, and usually consists of a compacted layer of granular material, either treated or untreated, or a layer of soil treated with a suitable admixture. Apart from its position in the pavement structure, it is distinguished from the base course material by less stringent specification requirements for strength, aggregate types and gradation. The subbase course is usually used to economically build up the pavement strength above that provided by the subgrade soils. In addition, subbase courses may have secondary functions, such as:

1. Preventing intrusion of fine-grained roadbed soils into base courses (this requires well-graded subbase material).

2. Minimizing the effects of frost action.

3. Preventing accumulation of free water within or below the pavement structure (free-draining subbase material is needed here, along with a water collection system).

4. Providing a working platform for construction equipment.

The base course is located immediately beneath the roadway wearing surface and is constructed directly on the subbase course. It performs its major function as a structural portion of the pavement. The base course usually consists of aggregates such as crushed stone, crushed slag, crushed or uncrushed gravel and sand, or combinations of these materials. The aggregates may be untreated or treated with stabilizing admixtures such as Portland cement, asphalt, lime and fly ash. Generally, specifications for base course materials are considerably more stringent than those for subbase materials in terms of strength, stability, hardness, aggregate type and gradation requirements.

The Federal Highway Administration, Offices of Research and Development has funded a number of recent efforts to investigate proper uses for coal refuse in road construction. These studies have included determining the availability of mining wastes, a users manual for coal refuse in highway embankments, and a study to determine the potential for combining fly ash with coal refuse to form a highway base coarse material.[1] University researchers and highway engineers have been searching for ways to utilize coal refuse and fly ash in road construction for many years; however, most significant developments have occurred in Europe and the United States only recently.

The mining industry has utilized coal wastes materials for roadways for many years, but not without sacrificing performance and environmental quality. The highway industry has typically avoided the use of these materials in favor of conventional soils and aggregate materials, although there has been considerable recent U.S. experience in embankment construction with coal refuse, mostly through projects of the Pennsylvania Department of Transportation.

In view of increasing demand and costs for natural materials, the influences of inflation on material processing and handling costs, and the rising costs of waste disposal, the use of coal-associated wastes in construction is becoming more and more attractive. In certain areas of the country, large supplies of coal refuse and fly ash (coupled with high prices for local conventional materials) could result in cost savings plus environmental benefits if these wastes were utilized in roadway construction.

Technical considerations. The key technical considerations for coal refuse/fly ash utilization as subbase and base course material are related to the compaction characteristics of the materials. In general, what is required to meet highway specifications is a "good recipe for strength and stability." The refuse/fly ash material would typically be used in place of mechanically stabilized material, i.e., material physically processed to consist of primarily crushed stone with 8 to 10 percent fines. Roadway specifications generally limit the maximum size of the aggregate, the percent fines, and the plasticity of the fine fraction.[2]

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[1]DeMillio, A.F., and Besselievre, W.C., "Coal Refuse Utilization in Road Construction," in Proceedings of Fourth Kentucky Coal Refuse Disposal and Utilization Seminar, Lexington, Kentucky, June 1978.

[2]Personal communication, Mr. Al DeMillio, Federal Highway Administration, 14 June 1978.

The design of roadways using refuse/fly ash material requires data on the chemical, physical and engineering properties of the coal refuse and the fly ash. Key chemical properties include composition, loss on ignition, pozzolanic reactivity and pH. Physical characteristics critical to construction uses include gradation, specific gravity, moisture content, Atterberg limits, and moisture absorption. Engineering properties to be determined include moisture-density relationships, friability/durability during compaction, shear strength, permeability, and self-hardening performance.

Considerable testing is indicated to identify optimum blends of refuse and fly ash. In particular, it is necessary to evaluate mixture strength and strength development properties as well as mixture durability and frost susceptibility. For specific refuse and fly ash materials, it may become necessary to examine the further stabilizing effects of adding lime, asphalt or cement to the refuse/fly ash mixture. From an economics standpoint, the most important factor will be materials handling costs, but the amounts and costs of additional stabilizers used could become critical in certain instances.

Experience. European experience in using coal refuse in construction is more extensive than in the United States. Raw coal refuse has been used in England as landfill for a variety of construction purposes. Maneval[1] reports that the National Coal Board (NCB) of Great Britain has developed the art and science of coal refuse utilization as fill material to a fine degree. The following description of British experience is from Maneval:

> Compacted coal refuse has been used successfully for development of aircraft hoverport pads, airports, industrial site fill and fill for housing developments. The British have taken giant strides in "setting right" the enormous coal refuse problem in their country. In the following, the NCB's handing of the refuse problem in Great Britain will be examined as a case history of what can be done if there is a will to do it.

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[1]Maneval, D.R., Recent Foreign and Domestic Experience in Coal Refuse Utilization, Appalachian Regional Commission, Washington, D.C., 1974.

Although there has been some experience in the use of coal refuse for various construction purposes in the United States, most of this type of utilization has been on an ad hoc basis and has not been the result of a thorough inventory of engineering properties under carefully controlled conditions of placement and evaluation. In Great Britain, however, the NCB in recent years has established a section called the "Minestone Executive" whose role it is to develop markets for coal refuse produced by NCB installations. As part of the activities of the NCB, a thorough inventory of the possible outlets for coal refuse was conducted and identification made as to which properties of coal refuse are critical for the intended use of the refuse. Information concerning the mineral content, the size variations, the proper moisture for optimum compaction, the specific gravity, the bulk density, the sulfate content and the frost heave characteristics of each candidate coal refuse pile have been determined by the NCB...The appropriate compaction techniques are then developed. As a result, coal refuse in general has been found to be extremely satisfactory as an earthwork material and can be used with little or no reservations in a wide variety of landfill operations. The Ministry of Transport is currently building extensive road fills using coal refuse as the fill material. Airports, athletic tracks, industrial sites (to raise low lying land above the flood plain), properly constructed earth fill dams, cover for sanitary landfills, and other similar landfill uses have been developed and demonstrated for the use of coal refuse.

The key to utilization of coal refuse in the above applications lies in the proper compaction of the refuse. This compaction reduces air voids to less than 10 percent and thereby attains a permeability of less than $10^{-6}$ cm/sec. This is sufficiently tight to essentially preclude air and water permeation of the pile, thereby attaining a satisfactory fill. In cases where coal refuse is brought into contact with conrete structures a coating of bitumenistic pitch is sometimes uniformly applied to protect the concrete structure against sulfate attack. In the case of a drainage pipe through coal refuse, corrosion resistant pipe such as dense concrete, super-sulfated concrete or terra cotta is used. The NCB has concluded that almost without regard to chemical and physical properties, coal refuse, when properly placed, can be a useful and valuable surface fill material.

The optimum moisture content for maximum compaction of coal refuse has been found to average around 7 percent for German coal refuse and range between 9 and 11 percent for refuse tested in the United Kingdom. Withdrawal from older exposed and weathered piles has advantages over utilization of fresh unweathered refuse because stockpiled refuse is often more homogeneous with drainage characteristics that favor optimum water content (for the best compaction) capability for a variety of uses. Weathering of material on the refuse pile has already produced more fines than would normally be found in raw, fresh refuse. Coal refuse, supplied from an active preparation plant, is subject to interruptions due to weekends, labor problems or other causes. For this reason, construction contractors would rather use refuse from older existing refuse piles of known size and availability.

The use of unburnt coal for highway fill is being pursued by many of the county councils. As a general rule, Proctor moisture determination is now done on all refuse which is considered for highway use as well as testing for spontaneous combustion potentiality. Leaching and swelling indexes, porosity, freeze-thaw tests and wet-dry swelling tests are also done. It was noted that swelling (if any) decreases porosity and this is desirable. The material is sufficiently dense for general construction and there is no possibility of ignition. The Ministry of Transport sets general specifications for use of coal refuse as highway fill throughout the country while local highway officials often set tighter highway specifications for road building programs which are administered on the local level for the Ministry of Transport.

It must be noted that when a road base is made with coal refuse not only is it necessary that there be good compaction but the sides must be covered to a depth of a yard or deeper with top soil. In no case where this procedure has been followed have there been any problems. There are dozens of miles of four-lane, high-speed limited access roads in Great Britain where there is no coal refuse in sight, although one is riding on up to 30 or 50 feet of coal refuse fill. Cement stabilization of the coal refuse highway fill is under consideration for some locations; this will make available a new array of outputs not available by compaction of refuse alone. By using a small amount of cement, coal refuse can be utilized as a cheap concrete, good for external building and for preparing parking lots and similar pads. A mixture of cement (up to 5 percent) plus fly ash plus refuse has been found to be satisfactory or a mixture of 7 to 10 percent cement plus refuse was also found to satisfactory.

The most significant United States experience in coal waste utilization is by the Pennsylvania Department of Transportation program to study the engineering properties of coal waste and to use the material in highway construction whenever it is economically feasible to do so. Coal waste has been selectively used in construction of highways in the Anthracite Region since at least the 1960's, but it has not been a standard practice. It was mostly used for fill and embankment construction in areas where the only material available for construction within a reasonable haul distance was mine waste. Some of the Pennsylvania highway projects where coal waste was recommended and used for construction are:

1. Legislative Route 1005, Section 4-2 (Interstate 81). This section of roadway near Hazleton in Luzerne County had embankments 40 to 50 feet in height constructed of breaker refuse in 5-foot lifts. The outside slopes were covered with ten feet of soil.

2. Township Road 54. Between Mahanoy and Gilberton a section of roadway embankment up to 30 feet in height was constructed mostly of coal refuse. The project was in Schuylkill County.

3. Legislative Route 1005, Section 2-3 Revised Alignment (Interstate 81). Coarse mine rock and breaker refuse within the right-of-way was recommended for use in construction of this roadway south of Hazleton in Luzerne County.

4. Legislative Route 786, Section 3. The removal of 200,000 cubic yards of culm, fine coal and organic silt in the flood plain of Nanticoke Creek was recommended; the material to be replaced with mine waste rock and coarse breaker refuse. This project was located south of Wilkes-Barre in Luzerne County.

5. Legislative Route 786, Section 4. This section of roadway south of Wilkes-Barre in Luzerne County consisted mostly of embankment construction across

an extensively mined area covered with mine waste deposits. The Blue Coal Colliery in Ashley was reworking breaker refuse piles for secondary coal recovery and the processed material was recommended for embankment construction.

6. Legislative Route 1005 (Interstate 81). Coal refuse with bituminous material was used for construction of shoulders near the Dunmore Office of the Pennsylvania Department of Transportation. The office is located near Scranton in Lackawanna County.

In the spring of 1973, a cooperative agreement was worked out in Pennsylvania between the State Departments of Transportation (PennDOT) and Environmental Resources (DER) for the utilization of coal waste in highway construction. As a result of the agreement about 1.5 million cubic yards of coal refuse were used in embankment construction of the Cross Valley Expressway at Forty Fort, Luzerne County, in the Northern Anthracite Coal Field of eastern Pennsylvania. The percentage of unburnt and burnt (red dog) refuse used in embankment construction is estimated to be about equal proportion.

A second project utilizing coal waste proposed for the Northern Anthracite Coal Field is a section of the Lackawanna Valley Expressway between Scranton and Carbondale, Lackawanna County, Pennsylvania. It is estimated anywhere from three to seven million cubic yards of coal waste could be used in construction of the highway.

## An Example of Utilization

Coal mine refuse was used experimentally as a base for a parking lot constructed in the summer of 1973 at the U.S. Environmental Protection Agency's Drainage Control Field Site in West Virginia. The main objective of this project was to assess the water pollution potential of the coal mine refuse when used as a road base material. This aspect of the project is discussed in a paper by Wilmoth and Scott[1] "Use of Coal Mine Refuse and Fly Ash as a Road Base Material". In addition, the paper by Wilmoth and Scott discusses the actual construction of the parking lot, including a breakdown of construction costs.

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[1]Wilmoth, R.C. and R.B. Scott, Use of Coal Mine Refuse and Fly Ash as a Road Base Material, U.S. Environmental Protection Agency Crown Field Site, Rivesville, W.Va., 1974.

A description of the three different coal mine refuse base sections used in the project is given in Table 8. The coal mine refuse was obtained from the Humphrey preparation plant of the Consolidation Coal Company. The fly ash was obtained from the Fort Martin Station of the Monongahela Power Company. Each section was overlain with three inches of West Virginia Department of Highways (WVDOH) Base I asphaltic concrete, followed by one inch of WVDOH Wearing II asphaltic concrete.

The main objective of the project was to monitor any water that might percolate through the various coal mine refuse base sections and to evaluate that water for its pollution potential. In addition, moisture-density measurements were made on each of the sections during construction. After one year's service, plate bearing and moisture-density measurements were made on each of the three sections.

The base in Area 3 was constructed of coal mine refuse alone; i.e., without the addition of lime or fly ash (see Table 8.) This was intended as a control section. Area 1 was constructed with a 75-25 percent blend of coal mine refuse and fly ash, respectively. The intent was to add sufficient fly ash to fill the voids in the coal mine refuse in an attempt to reduce the permeability of the refuse and to provide a buffer for the potential acidity produced by weathering pyrite in the coal mine refuse.

The fly ash and coal mine refuse were blended at the stockpile by using an end loader to repeatedly pick up and dump the fly ash and refuse as it was delivered by truck to the stockpile. This procedure was used for blending the mine refuse - fly ash mixture used in both Area 1 and Area 2. Reasonably uniform mixing was obtained as evidenced by the visual appearance of the material during placing and during the subsequent field testing.

The base section in Area 2 was stabilized with hydrated lime in the upper six inches. It was not practical to bring special mixing equipment to the job site and, therefore, the hydrated lime (5 percent) was merely blended into the upper six inches of the 75-25 coal mine-fly ash blend with a conventional road grader. It was anticipated that the lime would produce pozzolanic action with the fly ash and more effectively seal off the coal mine refuse than would the fly ash alone.

Field moisture-density data taken at the time of construction are given in Table 9. The laboratory densities are consistently lower than those obtained in the field. This may be due to the omission of the plus 3/4 inch material in the laboratory or, more likely, may be due to

## TABLE 8

## PAVEMENT SECTIONS USED AT CROWN PARKING LOT

| AREA 1 | | AREA 2 | | AREA 3 | |
|---|---|---|---|---|---|
| THICKNESS | DESCRIPTION | THICKNESS | DESCRIPTION | THICKNESS | DESCRIPTION |
| 1 in. | WVa DOH Wearing II asphaltic surface course | 1 in. | WVa DOH Wearing II asphaltic surface course | 1 in. | WVa DOH Wearing II asphaltic surface course |
| 3 in. | WVa DOH Base I asphaltic base course | 3 in. | WVa DOH Base I asphaltic base course | 3 in. | WVa DOH Base I asphaltic base course |
| 12 in. | Mixture, 75%-25% coal mine refuse-fly ash | 6 in. | 75%-25% coal mine refuse-fly ash stabilized with with 5% hydrated lime | 15 in. | 100% coal mine refuse |
| - | Compacted subgrade, weathered coal mine refuse | 6 in. | Mixture, 75%-25% coal mine refuse-fly ash | - | Compacted subgrade, weathered coal mine refuse |
| | | - | Compacted subgrade, weathered coal mine refuse | | |

TABLE 9

MOISTURE-DENSITY DATA FROM CROWN PARKING LOT AT TIME OF CONSTRUCTION

| TREATMENT OF REFUSE | TEST CONDITION | DRY DENSITY pcf | MOISTURE, PERCENT |
|---|---|---|---|
| Plain refuse | Laboratory | 96.9 | 5.6 |
| | Field | 69.6 | 10.1 |
| 75% Refuse-25% Fly Ash | Laboratory | 110.4 | 7.0 |
| | Field | 123.4 | 4.4 |
| 75% Refuse-25% Fly Ash with 5% lime, by weight | Laboratory | 102.0 | 4.0 |
| | Field | 107.4 | 4.7 |

the difference in the nature of the field compaction. This point needs to be further researched. The lime treated mixture also gave consistently lower densities. Gradation curves for both the plain refuse and the 75-25 refuse-fly ash blend are given in Figure 1. The change in gradation from the plain refuse to the refuse-fly ash blend is due to the addition of the fly ash. Little degradation of the mine refuse was observed during compaction.

In July of 1974, approximately one year after the initial construction, a ten or twelve inch diameter section of pavement was removed in each area as appropriate. A plate bearing test was run on the surface of each base section as well as on the material directly underlying each base section. Moisture-density determinations were made on the in situ material following each plate bearing test. The results of the moisture-density tests are given in Table 10. The data are in reasonable agreement with the data obtained at the time of construction (Table 9). The discrepancies between the two data sets are attributed to testing variability rather than any significant change in material properties, except for the low densities in Area 3. The coal mine refuse in Area 3 is considered atypical. As sampled during the plate bearing testing, the refuse appeared to be predominately coal with little rock. Scott indicated that the contractor encountered some Humphrey refuse that was exceedingly high in coal content and that the contractor attempted to waste it. This accounts for the anomalous density and appearance of the material in Area 3.

The change in moisture content with depth of the ash-refuse mixture in Area 2 is of particular interest. Just under the asphaltic pavement the base was noticeably drier than at depth. The material directly under the base is old weathered coal mine refuse that is reasonably permeable. This permeability was confirmed by the rapidity with which rain water drained from the test hole after a sudden downpour after the completion of testing. The permeability of the subbase and the moisture gradient in the fly ash refuse mixture indicates a tendency for the fly ash in the mixture to retain water. At 20.5 percent moisture, the fly ash in the base mixture is sufficiently wet such that water can be squeezed from it. In both Area 1 and 3, just below the asphaltic concrete, the base mixture was significantly wetter than when placed, again indicating a tendency for the fly ash to take up and hold moisture.

The physical appearance of the coal mine refuse as it was removed from the test holes during the plate bearing testing was of particular interest. In Areas 1 and 2, the base material was well compacted with excellent particle interlock and could be removed only with considerable

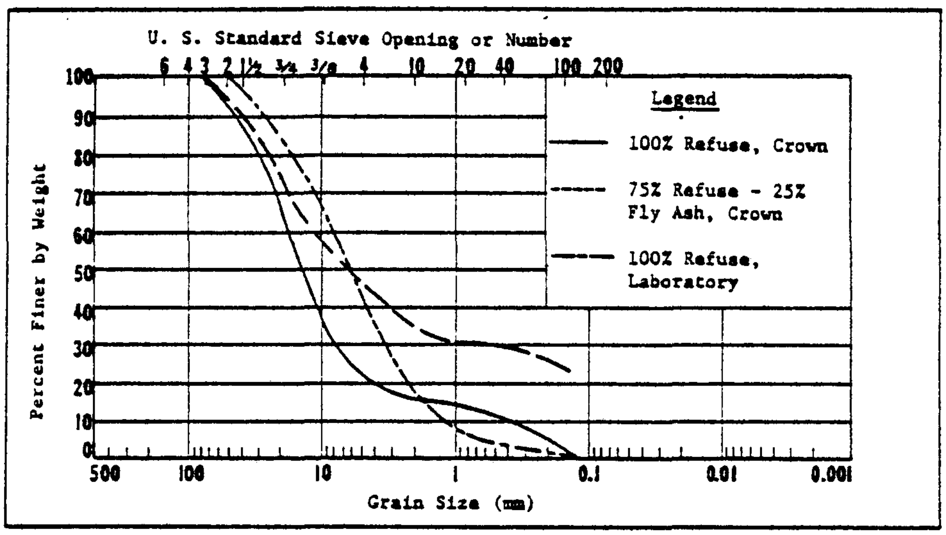


Figure 1. Gradation curves for Humphrey coal mine refuse.

## TABLE 10

## MOISTURE - DENSITY RESULTS ASSOCIATED WITH PLATE BEARING TESTING

| AREA 1 75%-25% REFUSE-FLY ASH | | | AREA 2 75%-25% REFUSE-FLY ASH WITH 5% LIME | | | AREA 3 100% REFUSE | | |
|---|---|---|---|---|---|---|---|---|
| DEPTH,[1] INCHES | MOISTURE, PERCENT | DRY DENSITY, LBS./CU. FT. | DEPTH,[1] INCHES | MOISTURE, PERCENT | DRY DENSITY, LBS./CU. FT. | DEPTH,[1] INCHES | MOISTURE, PERCENT | DRT DENSITY, LBS./CU. FT. |
| 0-6 | 8.1 | 111.0 | 0-1 1/2 | 10.6 | - | 0-6 | 13.5 | 70.7 |
| 10-12 | 11.0 | - | 0-4 | 14.5 | 103.0 | 10-12 | 15.4 | - |
| | | | 1 1/2-3 | 16.2 | - | | | |
| 12-16 | 11.4 | 111.8 | 3-7 | 16.6 | - | - | - | - |
| | | | 10 | 20.5 | - | | | |
| | | | 12-16 | 15.1 | 99.4 | | | |

[1]Measured in base section alone, excluding asphaltic concrete.

chiseling and prying. There was no evidence of slaking or other degradation of the refuse itself. Some very minor staining was observed on three or four of the coarse particles from each test hole. Some of the coarse material that was removed from the hole was allowed to sit overnight in the rain. With subsequent drying the next day many of the large particles had slaked to the point that they easily crumbled when worked between one's fingers.

The material sampled from Area 3 is considered atypical of the Humphrey coal mine refuse. As sampled, it was obviously very low in density and lacking in coarse (plus #4 sieve) rock particles. The major part of the plus #4 material consisted of coal fragments. The material was very open and very permeable. These factors could account for the quality of the water collected from Area 3 as reported by Wilmoth and Scott. Because of its atypical nature the portion of Area 3 that was sampled probably does not represent typical behavior for unstabilized coal mine refuse.

Area 2 was to be stabilized with lime in the upper six inches of the section. As this material was removed from the test hole it was quite apparent that the mixing of the lime was less than adequate. The upper 1 1/2 inches were not cemented at all. The next 4 1/2 inches contained isolated pockets that obviously had not received lime. The effectiveness of the lime was quite dramatic however. It was necesary to use an air chisel to remove the portions of the refuse mixture that contained lime. It is estimated that the unconfined compressive strength of this material was at least 500 psi. There was no evidence of any chemical reaction with pyritic portions of the refuse. The effective layer of lime stabilized material was estimated to be 2-3 inches in the area sampled.

The results of the plate bearing tests that were performed on the base and subbase sections indicated that the material was of a low quality granular nature suitable as a subbase but of questionable value as a base course under asphaltic concrete.

## Description of Study Area

### Selection of Representative Mining District

At the start of this study it was established that the refuse utilization feasibility assessment would focus on a study area, or mining district, that would be representative of eastern and midwestern coal regions. Initial criteria for such a mining district were:

1. More than 500,000 tons of coal waste generated annually within approximately a 100 square mile area.

2. Coal waste properties typical of the eastern and midwestern coal fields.

3. Waste deposit is located within 100 miles of at least one community with a wide range of heavy industry.

In addition to the above criteria, which were suggested in the project work scope, the following criteria were felt to be desirable as well:

4. The mining district should be located near an effective means of transportation, either a navigable water course, major highway, or railroad.

5. If a district has more than one coal preparation plant, it is preferable that they be owned and operated by the same company. This will facilitate the cooperation between the two plants in developing a refuse use scheme.

6. Other preparation plants should be located in the general vicinity for which the representative district could serve as a model.

With the above criteria, the representative site was selected on the basis of an elimination process to narrow the possible choices. The first step was to identify those preparation plants in the states of Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, and West Virginia that generated large amounts of coal refuse from deep mined coal. For this task, the 1978 Keystone Coal Manual was consulted for its "Directory of Mechanical Cleaning Plants". As a preliminary screening method, those plants with a listed daily capacity of 10,000 tons of cleaned coal per day were singled out. From this list, the state by state "Directory of Mines" (which includes figures for production of both mines as well as preparation plants) was consulted to obtain actual preparation plant outputs for 1977.[1]

The data in the Keystone Manual on production of mines and preparation plants is expressed in terms of the output of cleaned coal, i.e., the refuse totals are not explicitly given. To calculate the refuse totals, state-specific values for refuse as a percent of cleaned coal computed in Task 3 of this study were used (see Table 1 above).

In some cases, two or more separate preparation plants within a 100 square mile area generated more than 500,000 tons of refuse between them in 1977. These plants were combined and included in the list of districts with 500,000 tons or more of refuse. If two plants were within a 100 square mile area, yet each generated over 500,000 tons of refuse, they were considered to be separate sites for the preliminary analysis.

It should be noted that in some instances, the Keystone Manual gave a figure for the mine output without giving a total for the production of the preparation plant. When this occurs, the Keystone Manual generally contains the listing--prepared coal: mined at this location. In cases such as this, the amount of coal that was deep mined as assigned to the preparation plant as its output.[2] This agrees with other cases where both the mine and preparation plant production totals are given, and the two totals coincide.

It should also be noted that because of the large number of listings in the Keystone Manual, or because of the missing data, it is possible that there exist certain groups of mines within a 100 square mile are that have total refuse outputs of greater than 500,000 tons. However, these sites are not likely to have as much refuse as the preliminary sites selected and thus are less desirable. In addition, it is felt that the plants selected from screening are sufficient to determine a representative mining district.

Table 11 shows the 20 preparation plants or groups of preparation plants that passed the initial screening for volume of wastes. They are arranged alphabetically by state and are numbered sequentially. It can be seen that Indiana

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[1]Some data were for 1976. Although this was not a strictly accurate estimate of 1977 tons, for the purposes here it was judged to be sufficient.

[2]These plants are duly marked on the accompanying tables.

# TABLE 11

## CANDIDATE MINING DISTRICTS WITH 500,000 TONS PER YEAR OF COAL REFUSE

| | COMPANY | PREPARATION PLANT | ---LOCATION---- CITY | COUNTY | COAL SEAM | AMT. OF COAL 1977 TONS[a] | AMT. OF REFUSE 1977 TONS[b] | LARGE CITY WITHIN 100 MILES[c] |
|---|---|---|---|---|---|---|---|---|
| ILLINOIS | | | | | | | | |
| Refuse = .33 x coal | 1. Monterrey Coal Co. | Monterrey No. 1 Mine | Carlin-ville | Macoupin | Illinois #6 | 2,524,815[p] | 833,189 | St. Louis Peoria |
| | 2. Peabody Coal Co. | Mine No. 10 | Pawnee | Sangamon | Illinois #6 | 2,807,593[m] | 926,506 | St. Louis Peoria |
| KENTUCKY | | | | | | | | |
| Western refuse = .30 x coal | 3. Island Creek Coal Co. | Pevler Mine | Paints-ville | Martin | Stockton, Clarion | 2,188,704[m] | 853,595 | None |
| Eastern refuse = .39 x coal | 4. Martin County Coal Corp. | Martin County Mines (1-C, 1-S (d), 1-S(c), 2-S, 2-C & 5-B) | Inez | Martin | Coalburg; Stockton No. 5; Block; Clarion | 2,127,608[p] | 829,767 | None |
| | 5. National Mines Corp. | Beaver Creek Div. (Stinson Mines) | Wayland | Floyd | Elkhorn #3 | 1,343,571[p] | 523,993 | None |

[p] Prepared at preparation plant
[m] Mined at plant location; amount prepared unspecified

[a] In some cases, data is for 1976
[b] Calculated on the basis of statewide refuse-to-coal ratio
[c] Over 100,000 people (1970 census)

SOURCE: 1978 Keystone Coal Manual, U.S. Bureau of the Census

TABLE 11 (Cont.)

CANDIDATE MINING DISTRICTS WITH 500,000 TONS PER YEAR OF COAL REFUSE

| | COMPANY | PREPARATION PLANT | ---LOCATION---- CITY | COUNTY | COAL SEAM | AMT. OF COAL 1977 TONS[a] | AMT. OF REFUSE 1977 TONS[b] | LARGE CITY WITHIN 100 MILES[c] |
|---|---|---|---|---|---|---|---|---|
| OHIO | | | | | | | | |
| Refuse = .55 x coal | 6. Nacco Mining Co. 614-926-1351 | Powhatan No. 6 | Alledonia | Belmont | Pitts-burgh #8 | 1,099,348[p] | 604,641 | Pittsburgh Akron Youngstown Canton |
| | 7. Quarto Mining Co. | Powhatan No. 4 | Powhatan Point | Monroe | Pitts-burgh #8 | 1,104,856[p] | | Pittsburgh Akron Youngstown Canton |
| | Quarto Mining Co. | Powhatan No. 7 | | | | 282,333[p] 2,387,189 | 1,312,954 | |
| | 8. Southern Ohio Coal Co. | Meigs Mine No. 1 | Athens | Athens | Clarion #4-A | 2,160,000[m] | 1,188,000 | Columbus |
| | Southern Ohio Coal Co. | Racoon Mine No. 3 | | | | | | |
| PENNSYLVANIA | | | | | | | | |
| Refuse = .41 x coal | 9. Greenwich Collieries | North and South Mines | Ebens-burg | Cambria | Lower Freeport | 1,645,891[m,1976] | 674,815 | Pittsburgh |
| | 10. U.S. Steel Corp. | Robena Mine Nos. 1,2,3 | Greens-boro | Greene | Pitts-burgh | 3,375,293[p] | 1,383,870 | Pittsburgh Youngstown |

[p]Prepared at preparation plant
[m]Mined at plant location; amount prepared unspecified

[a]In some cases, data is for 1976
[b]Calculated on the basis of statewide refuse-to-coal ratio
[c]Over 100,000 people (1970 census)

SOURCE: 1978 Keystone Coal Manual, U.S. Bureau of the Census

TABLE 11 (Cont.)

CANDIDATE MINING DISTRICTS WITH 500,000 TONS PER YEAR OF COAL REFUSE

| | COMPANY | PREPARATION PLANT | ---LOCATION---- CITY | COUNTY | COAL SEAM | AMT. OF COAL 1977 TONS[a] | AMT. OF REFUSE 1977 TONS[b] | LARGE CITY WITHIN 100 MILES[c] |
|---|---|---|---|---|---|---|---|---|
| PENNSYLVANIA (Cont'd.) | | | | | | | | |
| | 11. U.S. Steel Corp. | Maple Creek Mine Nos. 1,2 | New Eagle | Washington | Pitts-burgh | 2,043,657[p] | 837,899 | Pittsburgh<br>Akron<br>Youngstown<br>Canton |
| VIRGINIA | | | | | | | | |
| Refuse = .50 x coal | 12. Clinchfield Coal Co. | Moss Preparation Plant | Dante | Russell | Clintwood; Upper Banner; Splash Dam; Upper Boling; Norton | 3,216,290[m] | 1,608,145 | None |
| | 13. Island Creek Coal Co. | Virginia Pocahontas No. 1 | Keen Mtn. | Buchanan | Pocahontas #3 | 688,725[p] | | |
| | | Virginia Pocahontas No. 3 | | | | 706,195[p] | | |
| | | Virginia Pocahontas No. 4 | | | | 144,501[p] | | |
| | | | | | | 1,539,421[p] | 769,710 | None |

[p]Prepared at preparation plant
[m]Mined at plant location; amount prepared unspecified

[a]In some cases, data is for 1976
[b]Calculated on the basis of statewide refuse-to-coal ratio
[c]Over 100,000 people (1970 census)

SOURCE: 1978 Keystone Coal Manual, U.S. Bureau of the Census

TABLE 11 (Cont.)

## CANDIDATE MINING DISTRICTS WITH 500,000 TONS PER YEAR OF COAL REFUSE

| | | COMPANY | PREPARATION PLANT | LOCATION: CITY | LOCATION: COUNTY | COAL SEAM | AMT. OF COAL 1977 TONS[a] | AMT. OF REFUSE 1977 TONS[b] | LARGE CITY WITHIN 100 MILES[c] |
|---|---|---|---|---|---|---|---|---|---|
| WEST VIRGINIA | | | | | | | | | |
| Refuse = .45 x coal | 14. | Consolidation Coal Co. | Arkwright | Osage | Monongalia | Pittsburgh | 2,503,606[p] | 1,126,623 | Pittsburgh |
| | 15. | Consolidation Coal Co. | Humphrey | Osage | Monongalia | Pittsburgh | 2,451,285[p] | 1,103,078 | Pittsburgh |
| | 16. | Consolidation Coal Co. | Mine No. 95 Robinson Run | Shinnston | Harrison | Pittsburgh | 2,098,573[p] | 944,358 | Pittsburgh |
| | 17. | Consolidation Coal Co. | Loveridge Mine No. 22 | Fairview | Marion | Pittsburgh | 1,926,246[p] | | |
| | | Eastern Assoc. Coal Co. | Federal Mine #1 | Granttown | | | 639,835[p] | | |
| | | Eastern Assoc. Coal Co. | Federal Mine #2 | Fairview | | | 1,209,378[p] | | |
| | | | | | | | 3,775,460 | 1,698,957 | Pittsburgh |
| | 18. | Itmann Coal Co. | Itmann Mines | Itmann | Wyoming | Pocahontas #3 | 1,091,449[p] | | |
| | | Eastern Assoc. Coal Co. | Keystone Mine No. 2 | Herndon | | | 411,792[p] | | |
| | | | | | | | 1,503,241 | 676,458 | None |

[p]Prepared at preparation plant
[m]Mined at plant location; amount prepared unspecified

[a]In some cases, data is for 1976
[b]Calculated on the basis of statewide refuse-to-coal ratio
[c]Over 100,000 people (1970 census)

SOURCE: 1978 Keystone Coal Manual, U.S. Bureau of the Census

TABLE 11 (Cont.)

## CANDIDATE MINING DISTRICTS WITH 500,000 TONS PER YEAR OF COAL REFUSE

| | COMPANY | PREPARATION PLANT | ---LOCATION---- CITY | COUNTY | COAL SEAM | AMT. OF COAL 1977 TONS[a] | AMT. OF REFUSE 1977 TONS[b] | LARGE CITY WITHIN 100 MILES[c] |
|---|---|---|---|---|---|---|---|---|
| WEST VIRGINIA (Cont'd.) | | | | | | | | |
| | Eastern Assoc. Coal Corp. | Harris Mine Nos. 1,2 | Bald Knob | Boone | Eagle; Campbell Creek #2 | 986,752 | | |
| 19. | Eastern Assoc. Coal Corp. | Kopperston Mine No. 1 & Cleaning Plant | Koppers-ton | Wyoming | Eagle | 991,681<br>1,978,433 | 890,295 | None |
| 20. | Consolidation Coal Co. | Mine No. 1 | Wana | Monon-galia | Pitts-burgh | 1,418,215 | 638,197 | Pittsburgh |

[p]Prepared at preparation plant
[m]Mined at plant location; amount prepared unspecified

[a]In some cases, data is for 1976
[b]Calculated on the basis of statewide refuse-to-coal ratio
[c]Over 100,000 people (1970 census)

SOURCE: 1978 Keystone Coal Manual, U.S. Bureau of the Census

has no preparation plants with the required minimum qualifications. This is due to the fact that the great majority (over 98% in 1976[1]) of Indiana's coal is strip mined. Since the project is concerned only with wastes from underground mines, any strip mine refuse is not considered here.

Figures 2 through 7 display the location of the 20 plants in Illinois, Kentucky, Ohio, Pennsylvania, Virginia, and West Virginia, respectively. In addition, circles of 100 mile radii centered on cities with populations of 100,000 or more are also plotted.[2] The small circles on the maps in Figures 2 through 7 indicate a 100 square mile area that contains two or more candidate preparation plants. As can be seen, several candidate plants have no cities within 100 miles. None of the three candidate plants in Kentucky, for example, are located within a 100 mile range. In all, only thirteen out of twenty sites do qualify; two in Illinois, three in Ohio, three in Pennsylvania, and five in West Virginia.

Table 12 ranks the thirteen remaining candidate sites by the amount of refuse generated in 1977. The sites are identified by name and by the number assigned to them in Table 11. From this list, the representative site was chosen. As Table 12 is arranged, the combination of three preparation plants in West Viriginia (Site 17--Loveridge No. 22, Federal No. 1, Federal No. 2) generated the most refuse. However, the Loveridge plant is operated by a different coal company than the two Federal mines. The plants with the fifth and sixth most refuse, (#14 Arkwright and #15 Humphrey, respectively) are both located around Osage, West Virginia. Each alone generated over 1,000,000 tons of refuse in 1977 and together they account for over 30 percent more refuse than did site #17. In addition, there is the added advantage of being operated by the same coal company, Consolidation Coal Company. Thus, these two plants were combined into one site at this stage of the selection procedure.

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[1]Keystone Coal Manual, Indiana Directory of Mines.

[2]From the 1970 Census; the figure of 100,000 was chosen as surrogate for industrial development.

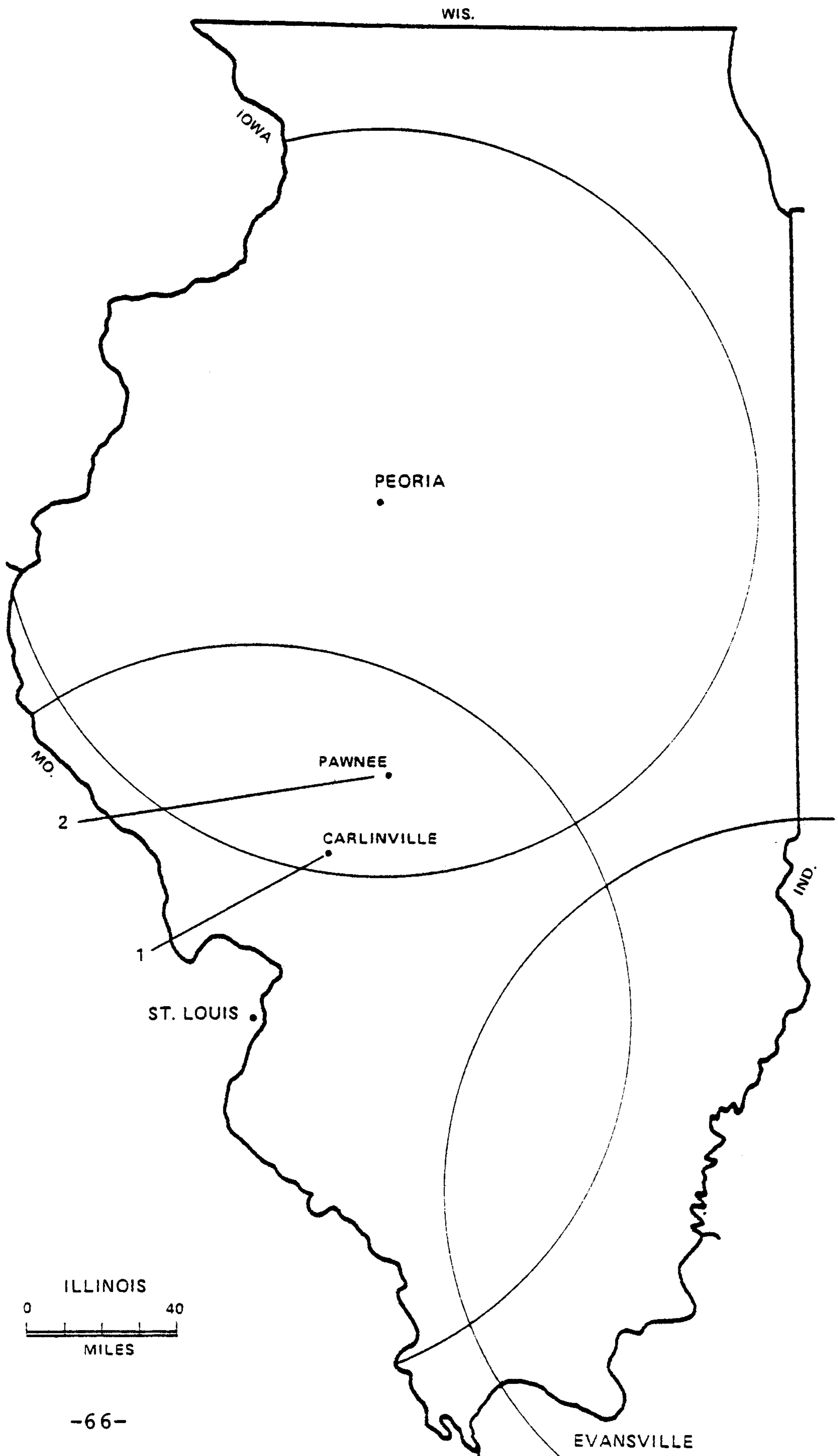

WIS.
IOWA
PEORIA
MO.
PAWNEE
2
CARLINVILLE
1
IND.
ST. LOUIS
ILLINOIS
0
40
MILES
EVANSVILLE



Figure 2.

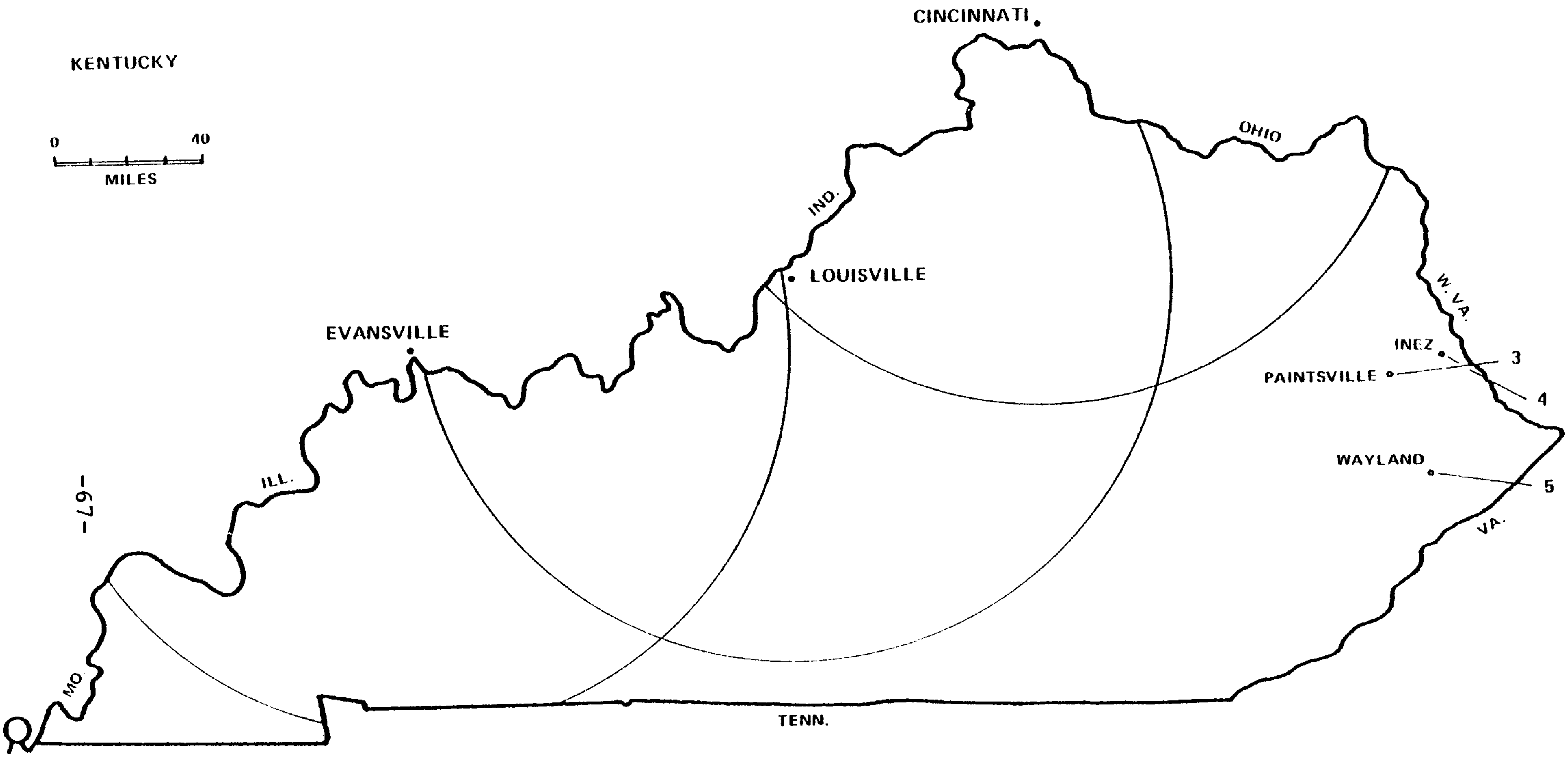
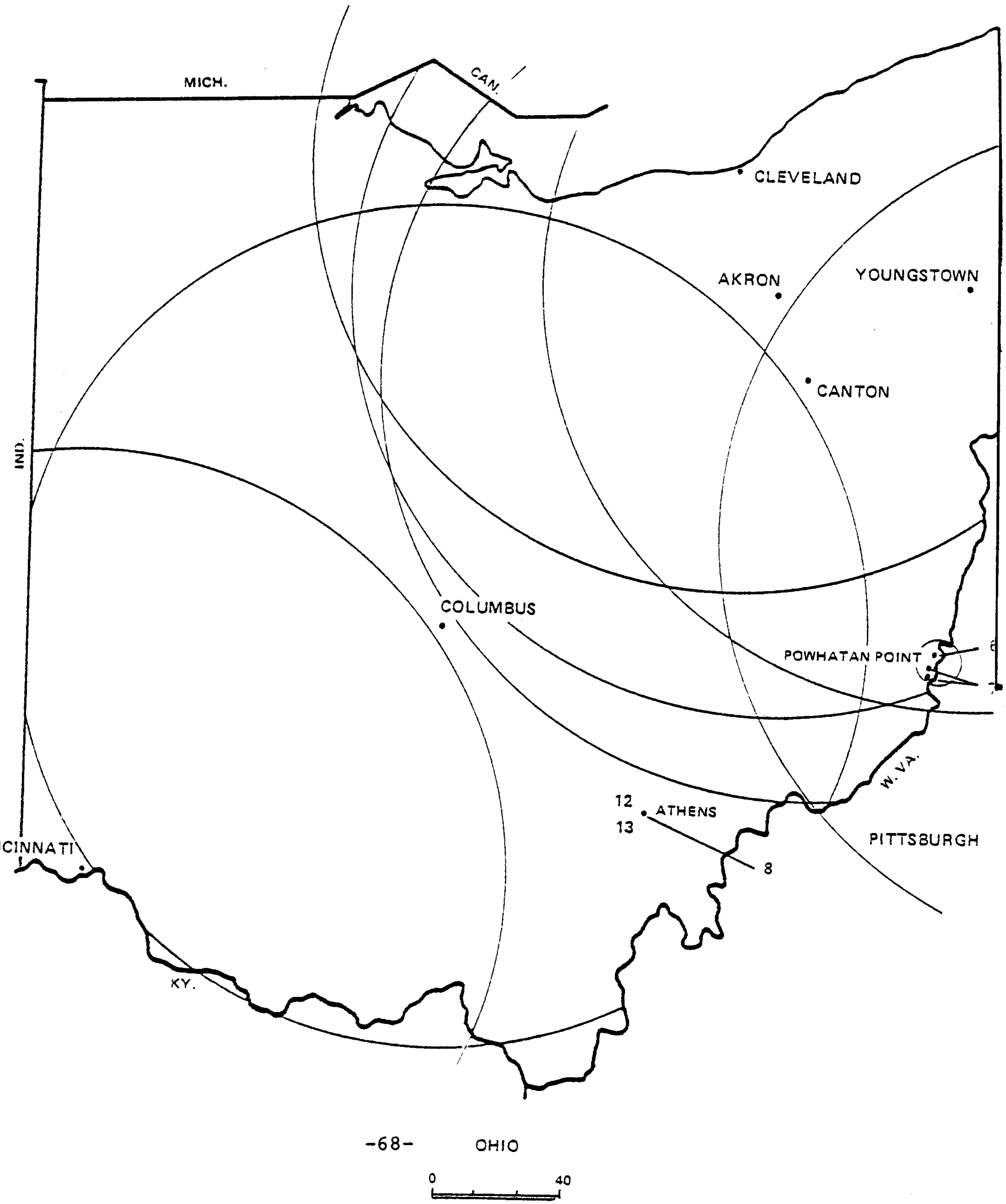

KENTUCKY
0
40
MILES
CINCINNATI
OHIO
IND.
LOUISVILLE
EVANSVILLE
W. VA.
INEZ
3
PAINTSVILLE
4
WAYLAND
5
VA.
ILL.
MO.
TENN.

Figure 3.

Figure 4.


MICH.
CAN.
CLEVELAND
AKRON
YOUNGSTOWN
CANTON
IND.
COLUMBUS
POWHATAN POINT
6
7
W. VA.
12
ATHENS
13
8
PITTSBURGH
CINCINNATI
KY.
OHIO
0
40
MILES

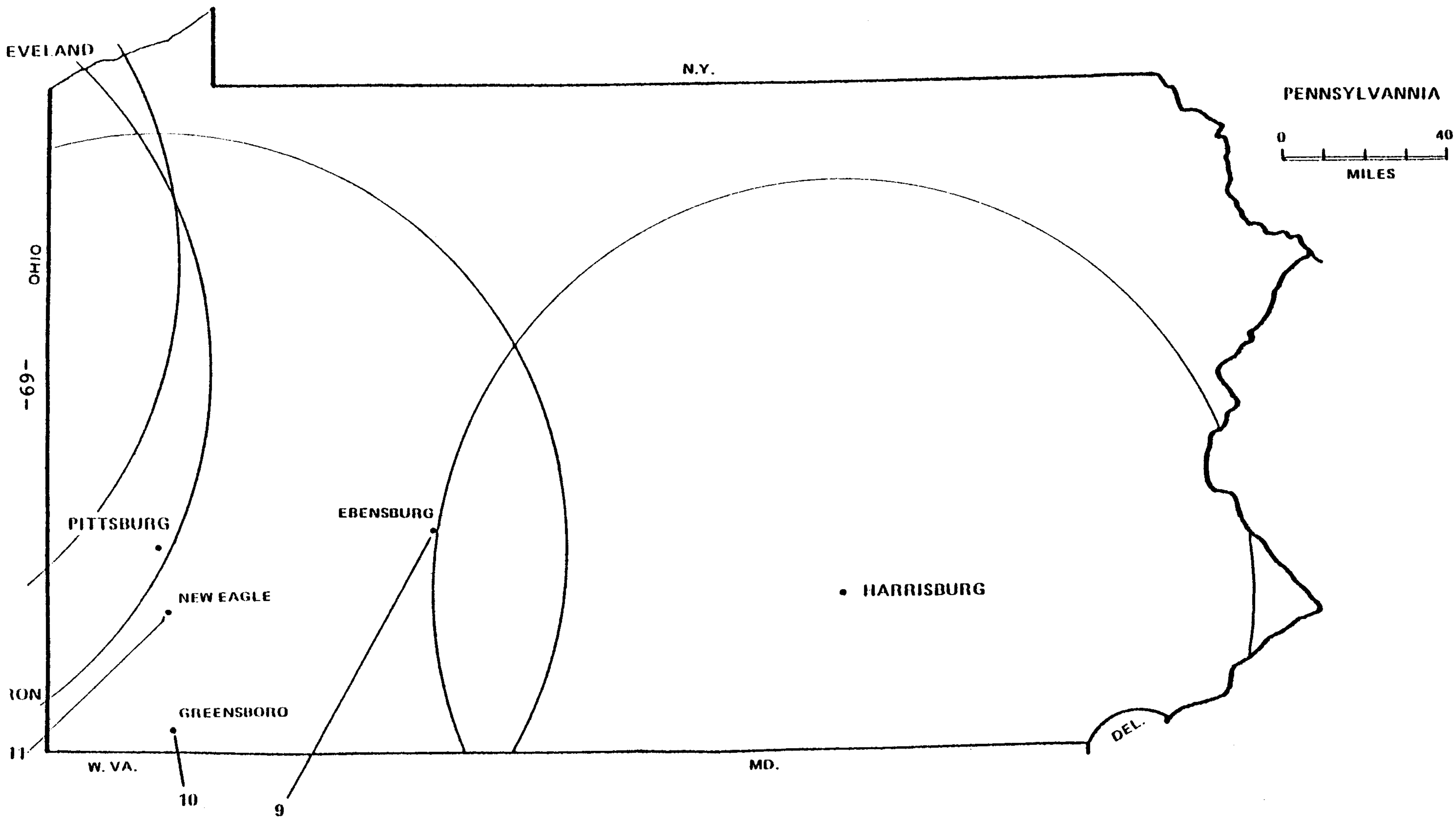

EVELAND
N.Y.
PENNSYLVANNIA
0
40
MILES
OHIO
-69-
PITTSBURG
EBENSBURG
HARRISBURG
NEW EAGLE
RON
GREENSBORO
11
W. VA.
MD.
DEL.
10
9

Figure 5.

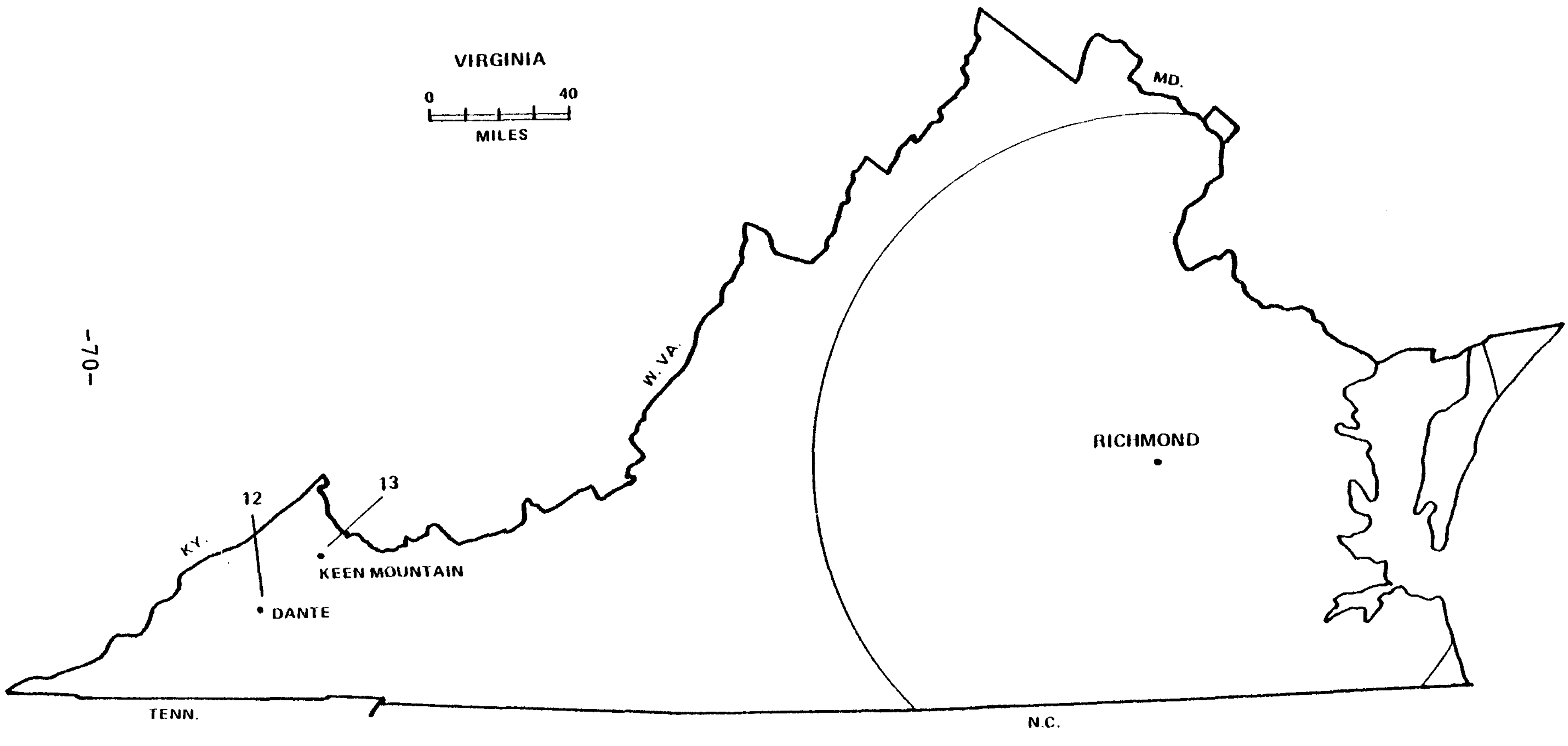

VIRGINIA
0
40
MILES
MD.
W. VA.
KY.
12
13
KEEN MOUNTAIN
DANTE
RICHMOND
TENN.
N.C.

Figure 6.

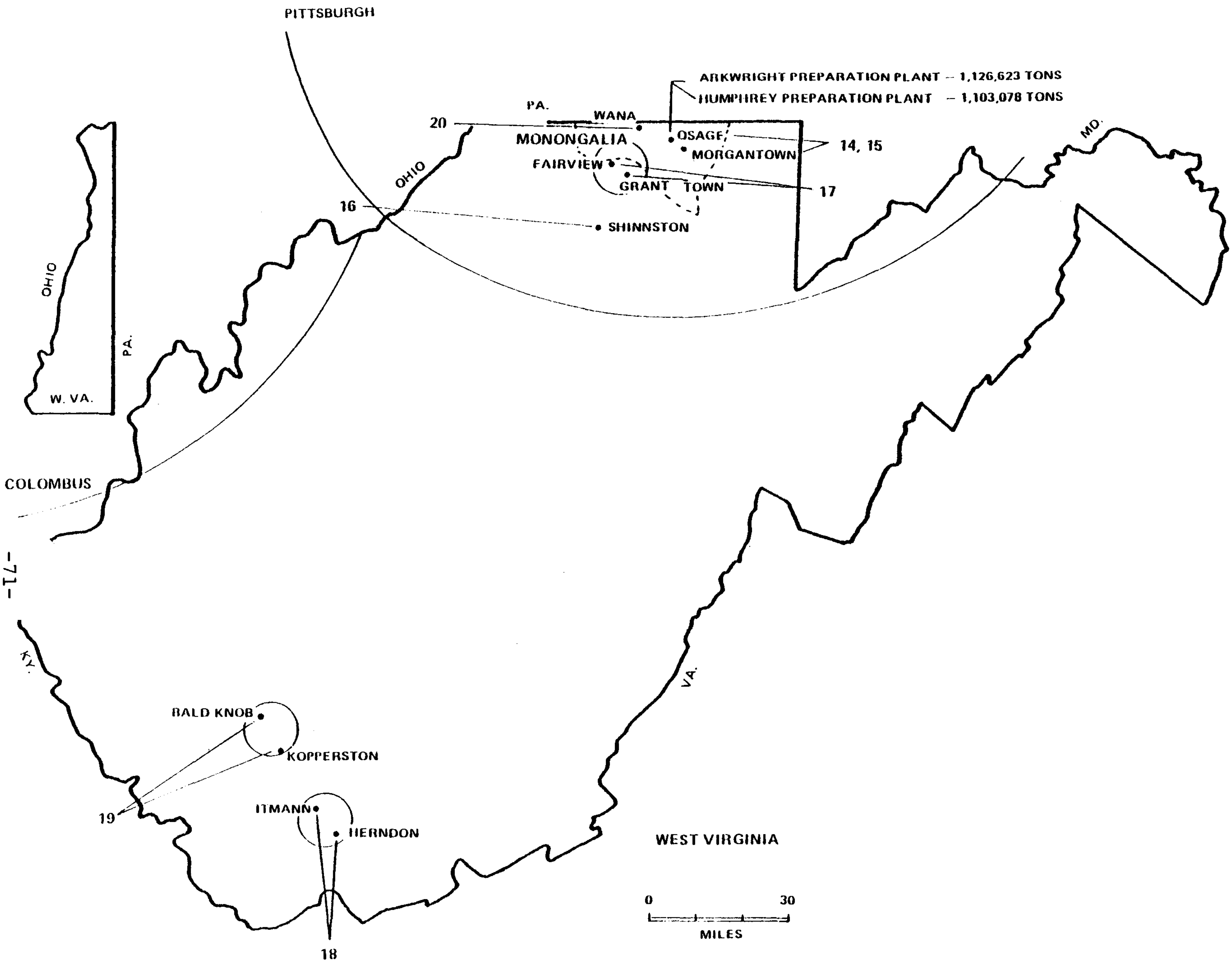



Figure 7. Representative Mining District Selected.

TABLE 12

PREPARATION PLANTS CLOSE TO A LARGE CITY RANKED BY TONS OF REFUSE OUTPUT

| NO. | COMPANY | PREPARATION PLANT | COAL SEAM | TONS OF REFUSE (1977) |
|---|---|---|---|---|
| | Consolidation Coal Co. | Loveridge Mine No. 22 | | |
| 17 | Eastern Association Coal Co. | Federal Mine 1 | Pittsburgh | 1,698,957 |
| | Eastern Association Coal Co. | Federal Mine 2 | | |
| 10 | U.S. Steel Corp. | Robena Mine Nos. 1, 2, 3 | Pittsburgh | 1,383,870 |
| 7 | Quacto Mining Co. | Powhatan No. 4 | Pittsburgh No. 8 | 1,312,954 |
| | Quacto Mining Co. | Powhatan No. 7 | | |
| 8 | Southern Ohio Coal Co. | Meigs Mine No. 1 | Clarion (No. 4-A) | 1,188,000 |
| | Southern Ohio Coal Co. | Raccoon Mine No. 3 | | |
| 14[a] | Consolidation Coal Co. | Arkwright | Pittsburgh | 1,126,623[c] |
| 15[a] | Consolidation Coal Co. | Humphrey | Pittsburgh | 1,103,078[c] |
| 16 | Consolidation Coal Co. | Mine No. 95 Robinson Run | Pittsburgh | 944,358 |
| 2 | Peabody Coal Co. | Pawnee | Illinois No. 6 | 926,506 |
| 11 | U.S. Steel Corp. | Maple Creek Mine Nos. 1 & 2 | Pittsburgh | 837,899 |
| 1 | Monterey Coal Co. | Monterey No. 1 Mine | Illinois No. 6 | 833,189 |
| 9 | Greenwich Collieries | North & South Mines | Lower Freeport | 674,815[b] |
| 20 | Consolidation Coal Co. | Mine No. 1 | Pittsburgh | 638,197 |
| 6 | Nacco Mining Co. | Powhatan No. 6 | Pittsburgh No. 8 | 604,641 |

[a]These preparation plants are within the same town; therefore, their output could be added together to get 2,229,701 tons for the year.

[b]The value here is for 1976.

[c]Chosen for study site.

On the basis of proximity to an industrialized area and the amount of refuse generated, the combined site #14-15 ranks the highest. Other selection criteria exist, however, and these were used to confirm the final selection.

The seam of coal mined at the Arkwright and Humphrey mines is the Pittsburgh seam. According to the 1978 Keystone Manual, over 25 percent of the coal mined in West Virginia in 1970 came from the Pittsburgh seam. As can be seen from Table 12, seven of the thirteen candidate sites also processed Pittsburgh seam coal. Accordingly, the refuse generated from mining this coal can safely be assumed to possess qualities representative of a great deal of the refuse generated in eastern coal fields.

Criteria 4 (above) specifies that the site have access to adequate transportation facilities. Site 14-15 is located on the Monongahela River, which provides water access not only to Pittsburgh, but to the entire Ohio River Valley as well. Interstate Highway 79, which goes to Pittsburgh, is within 3 miles of both preparation plants. Additionally, both plants are served by the same railroad spur.

As mentioned above, both #14 and #15 are owned and operated by Consolidation Coal Company. This satisfies criteria 5 (above). Coordination between the usage of refuse from both plants should be much easier than if there were two or more different owners. In addition, because the Consolidation Group (the controlling interest of Consolidation Coal Co.) is the number two producer of coal in the United States,[1] their refuse amounts are among the largest in the industry. It would seem, then, that a successful method of employing mine refuse in productive uses would be especially advantageous to them.

Figure 7 shows that there are three other candidate sites (with a total of four preparation plants) within 30 miles of Osage. This proximity to other processing plants and mines is seen to be an advantage. Any successful process developed within the representative site is likely to be most applicable to local plants. Thus, the feasibility of a process is seen to be enhanced if similar plants are operating in the area.

In a study now underway for the Federal Highway Administration, GAI Consultants Inc. selected ten "optimum

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[1] 1978 Keystone Coal Industry Manual.

use areas" for coal refuse/fly ash combinations in highway construction.[1] The areas were selected by first determining fifteen parameters that affected the feasibility of such use. Each of the fifteen parameters was given a numerical value that represented an estimated weight in importance as it applied to the feasibility. Each county in Alabama, Illinois, Indiana, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia was evaluated in terms of how well its characteristics satisfied each criteria. They received a numerical value for each parameter in proportion to how well the parameter was satisfied. By adding up all the values for each of the fifteen criteria, a total score was assigned to each county. All in all, twenty-seven counties with the highest scores were grouped into the ten optimum use areas.

Monongalia County (the center of the study site for this project) was the fourth highest rated county of the twenty-seven. Out of a total possible 910 points, it received 654. The three higher rated counties received 662, 672, and 684 points, respectively.

Thus, the GAI ranking method yields a result that supports the choice of the Osage, West Virginia area as the representative district for this study. Although it implies that the study area here may be too well qualified as a use area to adequately "represent" the cross-section of eastern and interior coal provinces, it is felt that the more suitable areas for coal waste utilization should be explored initially in order to minimize initial costs and legitimize the use of coal refuse for construction purposes.

### Study Area Characterization

Many site specific factors will play a large part in determining the feasibility of any coal refuse utilization scheme. This is particularly true of plans to use large amounts of refuse in applications where the unit value is low. Such is the case with using the material as a highway base or subbase. Those site specific factors considered to be among the most important are:

1. Location of refuse relative to possible end uses

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[1] GAI Consultants, Inc., Utilization of Fly Ash and Coal Mine Refuse as a Road Base Material, Preliminary Report to Federal Highway Administration, Washington, D.C., May 1979.

2. Location of fly ash sources relative to refuse and end uses

3. Transportation paths available for transport of refuse and fly ash

4. Procedures currently used for disposing of refuse and fly ash

5. Availability of competing aggregates and fill materials

Each of the above characteristics can decrease the feasibility of the end-use scheme if they are not favorably fulfilled. Ultimately, the impact can be translated into one of costs relative to competing materials or methods for constructing highway subbase or base courses. However, the analysis of relative costs will be reserved for discussion below. This section will outline the basic characteristics of the study area according to the above five factors.

Location of Refuse in the Study Area. Both the Humphrey and Arkwright preparation plants are located on State Route 100, on the far side of the Monongahela River from Morgantown and Star City, West Virginia. (See map, Figure 8.) The Humphrey plant is approximately three miles by road down river from the Arkwright plant. The Monongahela Railroad runs along the river and both plants have railroad loading yards.

Coal transfer from the mine to the preparation plant is accomplished by conveyor belt. Refuse is transported from the plant to a storage hopper from which it is trucked to the disposal site. From the plant, most of the clean coal is loaded on barges, although railway loading is used as well.

At the Humphrey plant, the refuse disposal pile is located over a small hill from the preparation plant. A haul road skirts around the southern base of the hill to the refuse disposal pile, which is a distance of about one-half mile. The pile is a shallow valley-fill that acts as an impoundment for the fine refuse disposal pond to the north. The fine refuse is slurried over the small hill from the preparation plant. No revegetation is currently taking place.

The refuse disposal for the Arkwright preparation plant uses a similar valley fill method. The raw coal is brought in via conveyor belt from the mine, the coal is cleaned, and

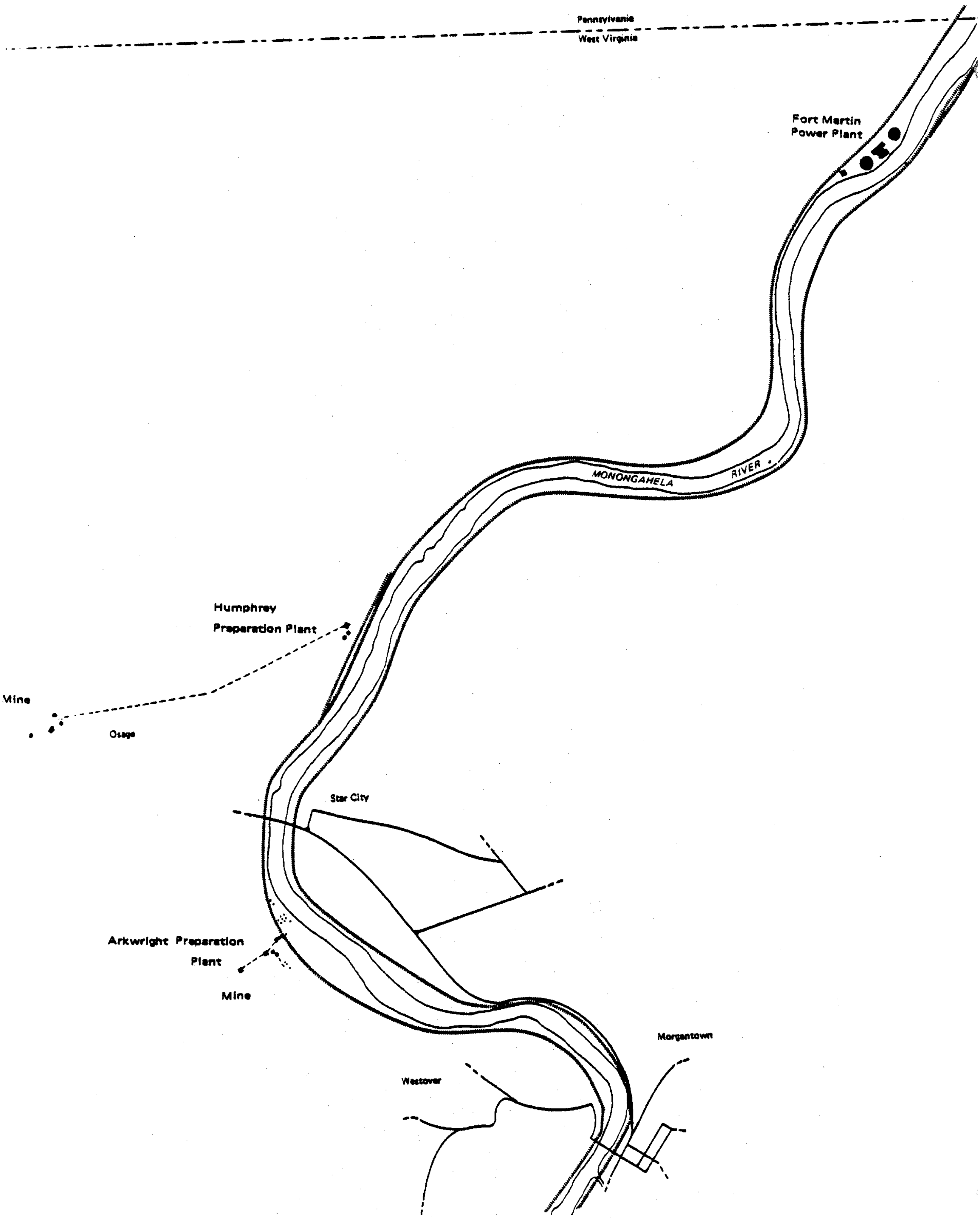
Pennsylvania
West Virginia
Fort Martin
Power Plant
MONONGAHELA RIVER
Humphrey
Preparation Plant
Mine
Osage
Star City
Arkwright Preparation
Plant
Mine
Morgantown
Westover



Figure 8.

the refuse is trucked approximately one quarter mile to the refuse disposal pile. Revegetation is underway for some portions of the refuse disposal pile.

The access from the Morgantown/Star City area by road to both plants is by a medium duty two lane paved road. The Humphrey plant is three miles from the intersection of State Route 7 and U.S. Interstate Highway 79, while the distance from the Arkwright is approximately two miles. Route 7 goes east into Star City and Morgantown and northwest through small West Virginia towns. Interstate 79 travels northward to Pittsburgh (approximately 65 miles) and southward to Charleston, West Virginia.

Location of Fly Ash Sources. A number of power plants exist close to the Arkwright and Humphrey plants. These sources and their approximate distances from the plants are listed in Table 13. Also shown is the capacity of each plant; the 1978 generation of fly ash and bottom ash, and the amount sold in 1975. Figure 9 is a map that shows the locations of each power plant relative to the study area.

As can be seen, the Fort Martin power plant in Maidsville, West Virginia is the most geographically favorable site to obtain the fly ash. It is located 5 miles north by road and only 4 miles downriver from the Humphrey preparation plant. The plant currently offers fly ash for sale at its plant site for $.25/ton plus loading expense. Loading can be done at the fly ash silos as the ash comes from the plant.[1]

The amount of fly ash collected in 1978 was approximately 243,000 tons, while 68,000 tons of bottom ash were collected in the same year.[1] 243,000 tons per year is equivalent to an average of 666 tons of fly ash per day. 1975 collection of both bottom and fly ash was 438,000 tons, about 40 percent more than 1978 levels.[2]

The next two closest plants with fly ash available are the Rivesville and Hatsfield Ferry plants (see Figure 9). The generation of fly ash in 1978 was 86,300 and 406,000 tons, respectively. Bottom ash generation adds 16,900 and

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[1]Personal communication, Mr. Al Babcock, Monongahela Power Co. Personal communication to Steve Fischer, ERCO, 3 May 1979.

[2]Federal Energy Regulatory Commission, Steam Electric Plant Air and Water Quality Control Data, for the year ending December 31, 1975, based on FPC Form No. 67. January 1979.

TABLE 13

POWER PLANT FLY ASH SOURCES[a]

| PLANT AND LOCATION | POWER COMPANY | PLANT CAPACITY (MW) | TOTAL ASH COLLECTED 1975 | TOTAL ASH COLLECTED 1978 FLY | TOTAL ASH COLLECTED 1978 BOTTOM | ASH SOLD (1,000 TONS) | DISTANCE FROM STUDY SITE (MILES) |
|---|---|---|---|---|---|---|---|
| Fort Martin Maidsville, WV | Monongahela Power | 1,152.0 | 437.6 | 242.9 | 67.7 | 10.1 | 5 |
| Rivesville Rivesville, WV | Monongahela Power | 109.8 | 48.7 | 86.3 | 16.9 | 0 | 11 |
| Hatsfield Ferry Masontown, PA | Western Pennsylvania Power | 1,728.0 | 552 | 406 | 78 | 16.3 | 13 |
| Albright Albright, WV | Monongahela Power | 278.3 | 110.8 | 146.6 | 39.9 | 1.6 | 23 |
| Harrison Hanwood, WV | Monongahela Power | 2,052.0 | 720.8 | 503.8 | 98.3 | 26.9 | 25 |

[a]1975 Data are from Steam-Electric Plant and Water Quality Control Data, Summary Report, Federal Energy Regulatory Commission, January 1979. Data for Monongahela Power Plants obtained from Al Babcock, Monongahela Power. Albright Plant data obtained from Robert Sell, Western Pennsylvania Power Co.

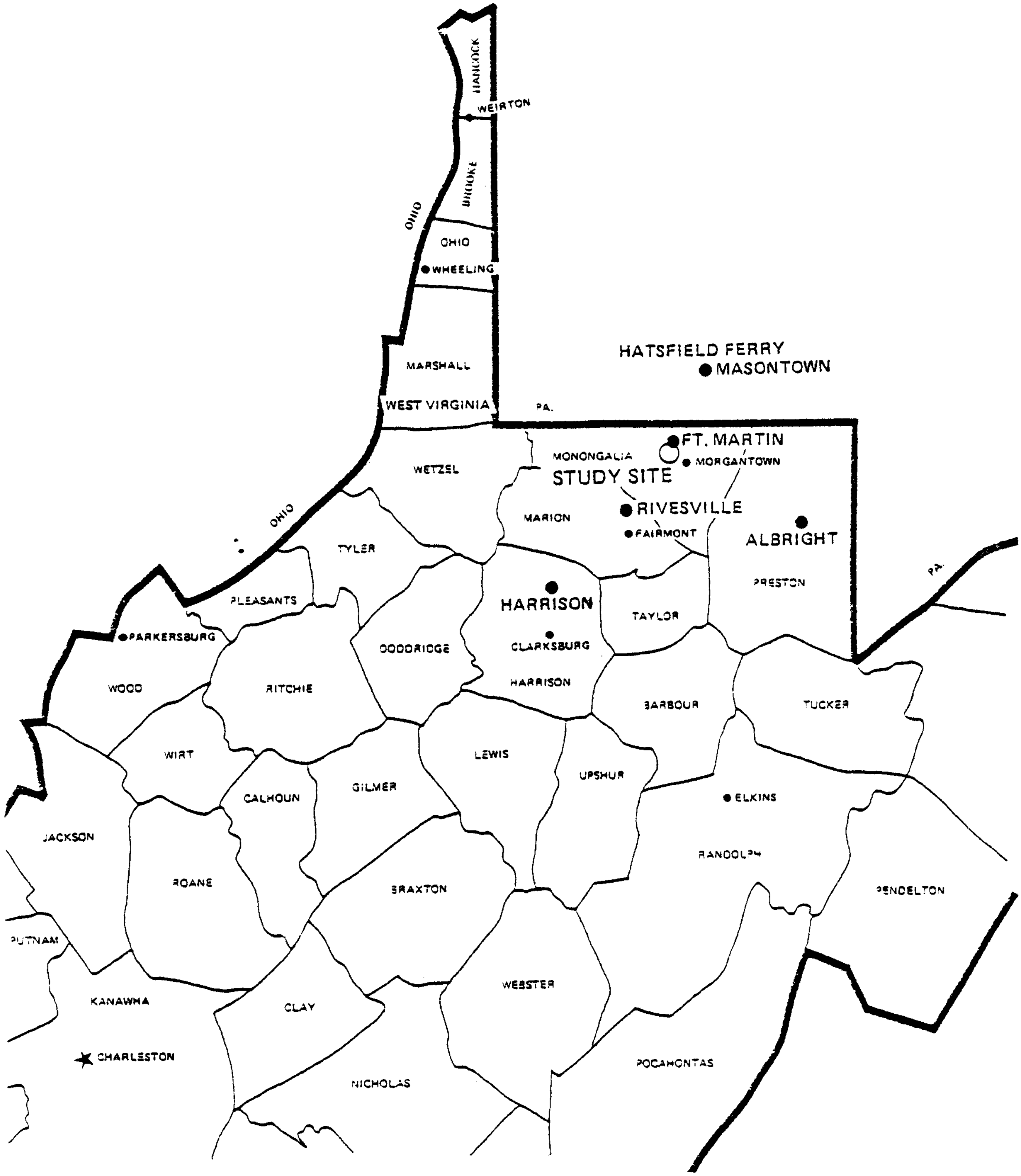


Figure 9. Possible fly ash sources.

78,000 tons to those totals.[1] Should the amount of fly ash from Fort Martin be insufficient to supply the needs of a road building project, the fly ash from these plants could be used as supplementary sources. Rivesville is owned by Monongahela Power Co. and fly ash is available on the same terms as from Fort Martin. Hatsfield Ferry is controlled by Western Pennsylvania Power, which also sells its fly ash on favorable terms.

Aggregate Availability. According to a survey by GAI Consultants, Inc. on aggregate availability in the eastern coal producing regions, Monongalia County is relatively free from crushed stone or sand and gravel shortages.[2] However, adjacent counties to the southwest and east all experience some degree of aggregate shortage. Figures 10 and 11 indicate two measures of aggregate shortage. Figure 10 illustrates geologic shortages of crushed stone and of sand and gravel. Figure 11 indicates those counties that have a shortage of aggregates as reported by the state highway department. As can be seen, Wetzel, Marion, and Preston Counties in West Virginia, which are adjacent to Monongalia, all have crushed stone shortages. Other nearby counties have shortages as well, including Hancock, Brooke, Ohio, Marshall, Harrison, and Taylor Counties.

The degree of availability for natural aggregates in an area can play a major role in the ultimate feasibility of utilizing coal refuse in the construction of a road. If the natural aggregates are located much closer to the construction site than available coal refuse, then there are likely to be few incentives to spur the use of the refuse. However, it has been estimated that coal refuse could be hauled up to a distance of about 40 miles and still be competitive with naturally occurring aggregates in some instances. In areas of aggregate shortage, the distance could conceivably be greater.

Thus, although Monongalia County is not itself in an aggregate shortage area, a perimeter of forty miles extended

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[1]Rivesville data from Al Babcock, Monongahela Power, Hatsfield Ferry data from Robert Sell, Western Pennslyvania Power.

[2]GAI Consultants, Inc., Utilization of Fly Ash and Coal Mine Refuse as a Road Base Material, Preliminary Report to Federal Highway Administration, Washington, D.C., May 1979.

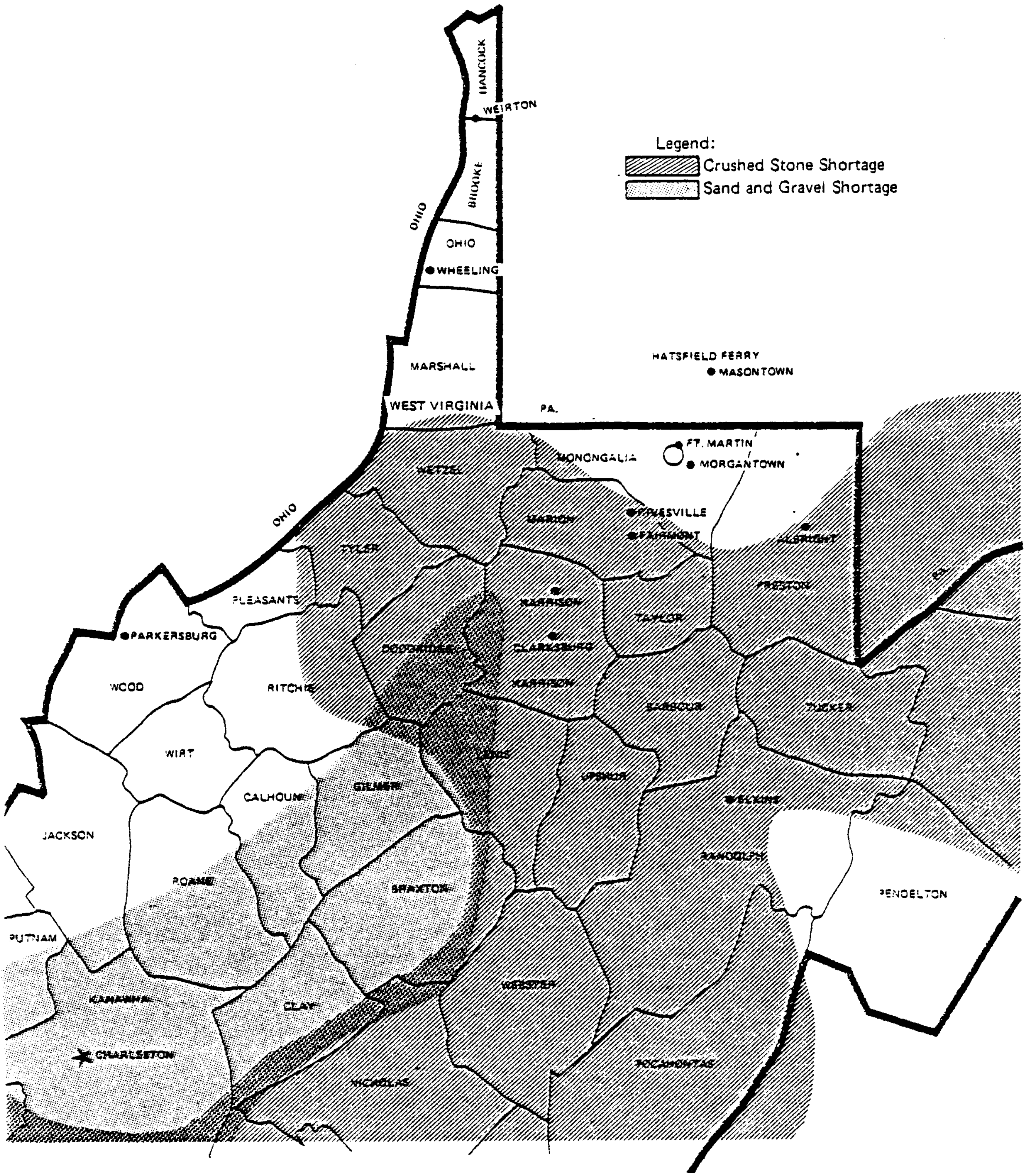


Figure 10. Geologically aggregate short areas.

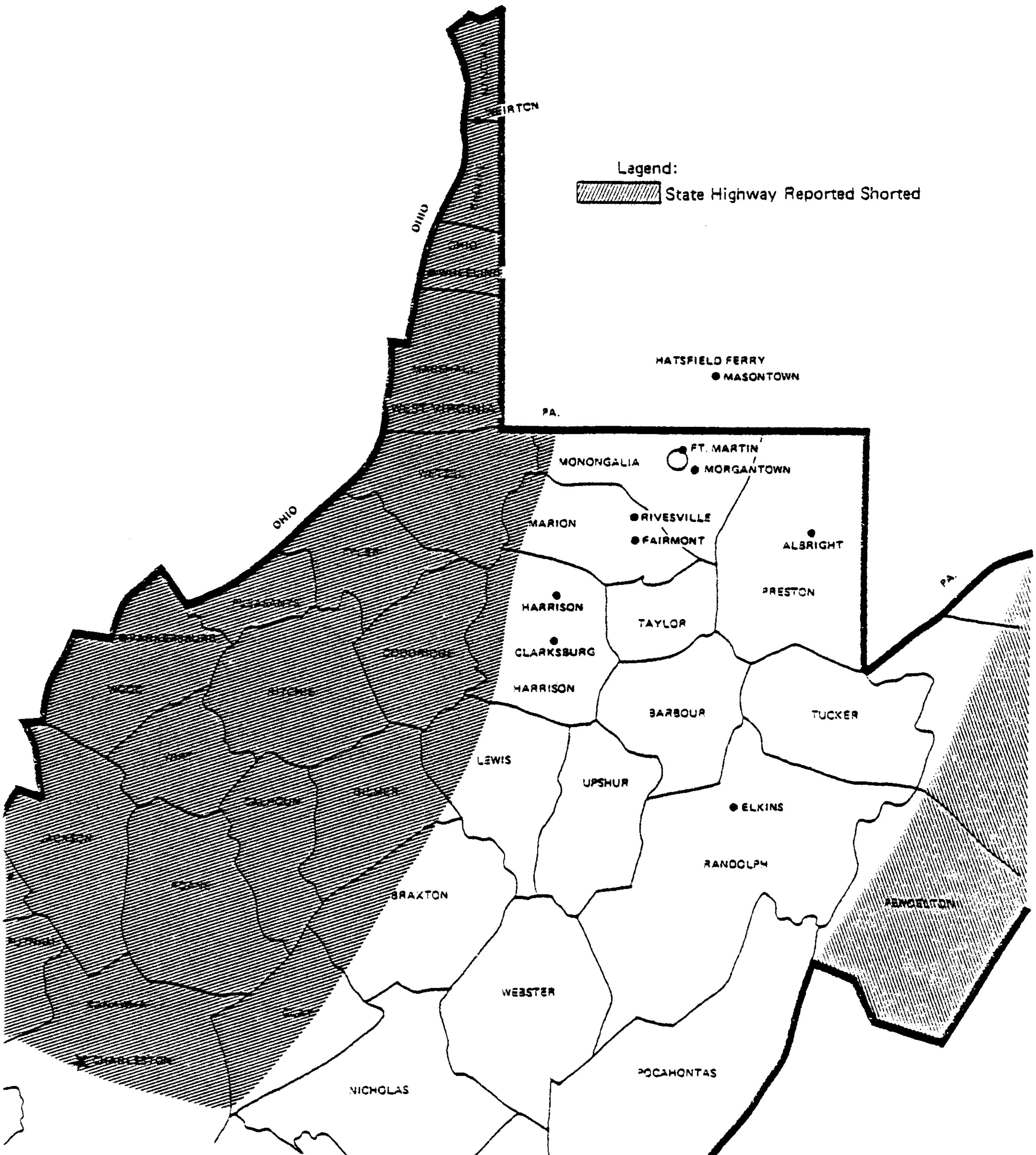


Figure 11. Declared aggregate shortage areas.

from the center of the study site includes counties that do have an aggregate shortage.

Current Refuse Disposal Systems and Costs. The major sources of refuse as identified for this study are the Humphrey and Arkwright preparation plants owned and operated by the Consolidation Coal Company. Between them they generated an estimated 2.2 million tons of refuse in 1977.[1] Since the site selection procedure was done, information from Consolidation Coal Company personnel indicates that current refuse production is somewhat lower due to the smaller coal output and a lower refuse/clean coal ratio. However, refuse production is still around 750,000 tons/year at each plant.[2]

For a number of reasons, the operations at the Humphrey plant will serve as the model for the feasibility analysis here. First, it was felt that there was a need to do a specific analysis from which a more general case for feasibility could be made. By concentrating on only one of the two plants, a more detailed analysis could be done than if it had to incorporate specific characteristics from each plant. Because the plants are located in close proximity to each other, are owned by the same company, mine the same seam of coal, and have similar operating capacities, one plant can be considered to be representative of the other in order to construct a more general case for feasibility. The Humphrey plant was chosen as the representative plant because more data was available from the literature and the Consolidation Coal Company was kind enough to allow a visit to the Humphrey plant. Because of this, the interests of this project were best served by concentrating on the specifics of the Humphrey plant and its refuse.

Coal that has been crushed at two separate mines to 5-inch size is brought to the Humphrey plant by two conveyor belts and enters a surge bin. It is then screened to plus and minus 3/8-inch size. The minus 3/8 inch coal is either shipped directly by conveyor belt to the coal barges or is cleaned on a deister table. The plus 3/8 inch size is cleaned in a chance sand cone.

The deister table product is dewatered on a screen. The fines from the screen are collected by froth flotation

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[1]Based on Keystone Coal Manual reports of clean coal output at each plant and refuse/clean coal rated of .45. Discussions with Humphrey personnel indicate this estimate.

[2]John Stevens, plant superintendent, Humphrey and Arkwright preparation plants.

and dewatered on vacuum disc filters. The large coal sizes are dried in centrifugal driers.

The refuse from the deister tables is dewatered; large material is sent to the rock bin. The fine refuse is pumped to primary thickener along with the refuse from the froth banks. The fines are then flocculated and settled in the thickener and are pumped to the slimes pond. The clarified water from the secondary thickener is reused at the plant so that no discharge occurs to the Monongahela River.

The product from the chance sand cones is dewatered, crushed to 2-inch top size and then shipped by conveyor belt to the river. The fines from dewatering are mostly sand and these are returned to the cones. The refuse from the chance cones is dewatered and run through a heavy media (magnetite) float. The resulting fines, which are mostly sand, are returned to the cones. The product from the heavy media float is dewatered, crushed to a top size of 2 inches and then is sent to the river. The refuse is dewatered and sent to the rock bin. Thus, the eventual output is the clean coal, the large refuse in the rock bin, and the fine refuse in the slimes pond.

The disposal of the refuse is accomplished in two stages. The first stage is the disposal of the large refuse. The overhead rock bin discharges a load of refuse into a back dump or a crawler. The material is transported to the disposal area, a distance of less than one mile, which is located on the other side of a small hill from the preparation plant. It is unloaded at the refuse pile, at which point it is distributed and compacted in eight to ten inch layers by a front end loader. The far end of the disposal pile acts as an embankment that impounds the fine refuse slurry.

The fine refuse is hydraulically pumped from the slimes pond to the impoundment through a six inch pipe that runs directly over the small hill. Approximately 500 gallons per minute of a 30 percent solids slurry is pumped through the system.

The runoff from the pond and refuse pile is treated before being discharged into the Monongahela River. The untreated runoff is highly acidic; twenty tons of lime per week is added to effluent to raise the pH before it is discharged into the river.[1]

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[1]John Stevens, superintendent, Humphrey preparation plant.

Although Consolidated Coal Company could not provide any breakdown of the separate costs for refuse disposal, estimates of refuse disposal costs have been made that are expected to be typical of the Humphrey plant. In 1975, the National Academy of Sciences (NAS) estimated the costs for a surface disposal of coal mine refuse. Their costs are based upon a clean coal output of 2,070,000 tons/year, coarse refuse disposed on a waste pile of 621,000 tons per year and fine refuse disposed of in a slurry impoundment of 69,000 tons per year. The estimates presented by the NAS committee are reproduced here as Table 14. The ultimate figure of $.304 per ton of clean coal is expected to be fairly reasonable. However, the estimates in the table are for 1975, not 1979. The increase in the Engineering News Record Construction Cost Index has been 35 percent in the period from 1975 to June 1, 1979. So total costs should be expected to be higher for the case illustrated here.

The 1975 costs for disposal at the Humphrey plant should be lower than the estimates in Table 14. First, the refuse/ clean coal ratio for the NAS committee estimate was 1:3, while the current ratio at the Humphrey plant is about 1:4. Since the refuse output is similar in both cases, the costs per ton of clean coal should (in 1975 terms) be around 0.23 per ton of clean coal. Secondly, the NAS committee assumed a conveyor belt of 1500 feet was necessary for refuse disposal. The Humphrey plant utilizes a conveyor belt for disposal that is approximately 200 feet long, so the capital charges and operating charges should be reduced accordingly. Conceivably, the 1975 cost could be further reduced by three cents per ton of clean coal, leaving a 1975 cost of .20 per ton. After incorporating the rise in the Engineering Construction Cost Index, the 1979 estimate is $.27 per ton of clean coal. Based on the assumption in the NAS committee estimate and a comparison to the actual characteristics of the Humphrey preparation plant and disposal system, this figure seems to be a reasonable estimate of the costs involved in disposal of the refuse at the Humphrey plant.

To say that Consolidation Coal Company could save $0.27 per ton of refuse they produce if it were to be used for road building is an incorrect assumption. The cost figure quoted above is an average total cost. To determine the amount saved for each ton of refuse used for road construction, one must express the figures in marginal costs. Thus, the first step is to deduct the fixed costs per ton of coal, which account for approximately half of the total costs in the committee estimates. What is left is the average variable costs, which may or may not be a reasonable

## TABLE 14

## ESTIMATE OF COSTS FOR SURFACE DISPOSAL

| OPERATION | TOTAL AMOUNT OR NUMBER | FIXED COSTS | | COSTS RELATED TO COAL PRODUCTION | | COSTS RELATED TO TONS REFUSE HANDLED | | TOTALS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | TOTAL/ YR | COST/TON CLEAN COAL | TOTAL/ YR | COST/TON CLEAN COAL | TOTAL/ YR | COST/TON CLEAN COAL | TOTAL/ YR | COST/TON CLEAN COAL | COST/TON REFUSE |
| Land acquisition | 250,000 | 7,500 | 0.004 | | | | | | | |
| Total | | | | | | | | 7,500 | 0.004 | 0.12 |
| Disposal System | | | | | | | | | | |
| Capital | 708,900 | 183,000 | 0.088 | | | | | | | |
| Labor | 4 man shifts/days | | | 60,700 | 0.029 | | | | | |
| Oper., supply and power | | | | | | 207,000 | 0.100 | | | |
| Total | | | | | | | | 450,700 | 0.217 | 0.651 |
| Reclamation - | | | | | | | | | | |
| Contract charge | | | | | | | | | | |
| Topsoiling | | | | | | 33,500 | 0.016 | | | |
| Revegetation | | | | | | 1,500 | 0.001 | | | |
| Total | | | | | | | | 35,000 | 0.017 | 0.051 |
| Disposal of fines | | | | | | | | | | |
| Capital | 500,000 | 129,000 | 0.062 | | | | | | | |
| Labor | 50 man-days/yr | | | 3,300 | 0.002 | | | | | |
| Oper., supply and power | | | | | | 3,500 | 0.002 | | | |
| Total | | | | | | | | 135,800 | 0.066 | 0.198 |
| Subtotal | | 319,500 | 0.154 | 64,000 | 0.031 | 245,500 | 0.119 | 629,000 | 0.304 | 0.912 |
| Productivity loss (no loss) | | | | | | | | | | |
| Total | | | | | | | | | 0.304 | 0.912 |

[a]Figures based on 2,070,000 tons of clean coal per year; 690,000 tons of refuse produced per eyar; 621,000 tons disposed on a waste pile 69,000 tons disposed in a slurry pond.

Source: National Academy of Sciences, Underground Disposal of Coal Mine Wastes, Report to the National Science Foundation, 1975.

estimate of the marginal costs. If marginal costs are declining (indicating economies of scale) then average variable costs will overestimate marginal costs (or in this case, marginal savings). If marginal costs are going up, the average costs may overstate or understate the costs depending upon where on the cost function the current production lies. If the marginal costs are fairly constant over a large range, the marginal cost will be closely approximated by the average cost. For the purposes of this study, it will be assumed that labor, operation, maintenance, and supplies for disposal are proportional to the amount of refuse handled. Thus, the marginal costs are fairly constant over the relevant range of production, and the average variable cost is a good estimate of the marginal cost of disposal. Thus, marginal costs (savings) for the Humphrey plant will be assumed to be half of the total cost estimate, which is $0.14 per ton of clean coal (or $.54 per ton of refuse).

## Refuse Characterization

The coal refuse produced at the Humphrey preparation plant has been the subject of two refuse characterization studies in the past five years. The results of these two efforts are described in this section. No other data on the Humphrey refuse was available either in the literature or from the plant operators.

### Refuse as an Engineering Material (by Moulton et al.)

Moulton et al.[1] noted in 1974 that for government agencies and the construction industry to routinely accept and utilize coal refuse material, several basic questions must be answered:

1. Do the physical, chemical, and engineering properties of refuse compare favorably with those of conventional construction materials?

2. To what extent can these materials be used in construction and relied upon to produce equal or better performance than achieved with conventional construction materials?

3. Is it necessary that existing material and construction specifications, established for conventional construction materials, be satisfied in order to achieve satisfactory performance?

4. Will the use of refuse materials be in any way hazardous to the public, the environment, or facilities built on or in them?

During the past several years, research conducted in the United States and abroad has addressed the above and related questions. Of particular interest herein was the study conducted by Moulton et al. at West Virginia University to evaluate the potential of coal mine refuse for use as a construction material. The results of that work are summarized below.

Four samples of fresh and weathered coal refuse were subjected to engineering identification, classification, and

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[1]Moulton, L.K., Anderson, D.A., Seals, R.K., and Hussain, S.M., "Coal Mine Refuse: An Engineering Material," in Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal, 1974.

property (performance) tests. The samples of refuse were chosen in order to be representative of the refuses typically produced in the north central and northwestern areas of West Virginia. The four sources of refuse were the Shoemaker Mine, the McElroy mine, the Humphrey Mine, and the Badger Mines. The Humphrey coal refuse is, of course, of principal interest in the present study. However, since data is available on all four West Virginia mines and is considered typical of refuse in the general study area, we will include all four refuse sources in summarizing the Moulton report.

Since coal refuse will weather when exposed to the environment, two different types of samples were obtained from each source: (1) "fresh" refuse, taken directly from the refuse hopper as it came from the preparation plant; and (2) "old" or "aged" refuse that had been exposed to the atmosphere for various periods of time ranging from approximately 18 months to 30 years.

The refuse samples were subjected to a series of identification tests, including grain size distribution, Atterberg limits, specific gravity, and ignition loss. The results, given in Table 15, illustrate the wide range of variability expected in coal refuse. The basic properties of refuse vary greatly not only from source to source, but also from sample to sample from a single source, and with degrees of weathering.

There are a number of significant trends displayed in the data of Table 15 that deserve some consideration. The grain size data imply that in general the weathering of the refuse results in a decrease in the coarsest fraction (gravel sizes) and an increase in the finer fractions, especially in the silt and clay size range. The Atterberg limits indicate that these fines are moderately plastic with a trend toward greater plasticity in the weathered material.

In terms of the Unified Soil Classification System, most of the refuse samples would classify as sandy or silty gravels, although some samples classified as sands. Except for the predominance of the coarse gravel sizes in some samples, the materials look and behave very much like typical residual soils obtained from the weathered zone immediately above rock.

The specific gravity of solids was found to be relatively low as compared to typical soils and rocks in West Virginia. Visual observations indicated that the specific gravity could be related to color with the darker more carbonaceous materials having the lower specific gravity. This observation was confirmed by the results of the ignition tests given in

# TABLE 15

## SUMMARY OF IDENTIFICATION TEST RESULTS

| Identification Test or Property | Units | Identification of Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Philippi | | | Humphrey | | Shoemaker | | McElroy | |
| | | Fresh-Coarse | Fresh-Fine | Old | Fresh | Old | Fresh | Old | Fresh | Old |
| **Grain Size** | | | | | | | | | | |
| Gravel (#4-3") | % | 64.3 | 8.7 | 27.1 | 57.0 | 41.4 | 76.0 | 61.3 | 89.4 | 50.6 |
| Sand | | | | | | | | | | |
| Coarse (#10-#4) | % | 3.0 | 35.0 | 20.2 | 25.4 | 12.6 | 16.3 | 18.4 | 5.2 | 20.4 |
| Medium (#40-#10) | % | 4.9 | 43.3 | 23.7 | 15.8 | 9.6 | 3.3 | 10.6 | 2.9 | 13.8 |
| Fine (#200-#40) | % | 12.2 | 10.5 | 11.6 | 0.7 | 16.6 | 1.2 | 3.5 | 1.7 | 5.6 |
| Silt (0.005 mm-#200) | % | 10.9 | 1.1 | 6.5 | 0.7 | 18.9 | 1.6 | 2.9 | 0.8 | 4.9 |
| Clay (<0.005 mm) | % | 4.7 | 0.4 | 10.6 | 0.4 | 0.9 | 1.6 | 3.3 | - | 4.7 |
| **Atterberg Limits** | | | | | | | | | | |
| Liquid Limit (LL) | % | | | 31.2 | | 36.0 | 30.6 | 34.2 | 28.4 | 36.8 |
| Plasticity index (PI) | - | NP | NP | 5.2 | NP | 11.0 | 10.1 | 15.9 | 8.4 | 13.1 |
| Shrinkage limit (SL) | % | | | 24.8 | | 22.4 | 15.2 | 17.8 | 19.0 | 16.3 |
| Unified Soil Classification | - | GM | SW | SW-SM | GP | SC | GP | GP-GC | GW | GP-GC |
| Specific Gravity of Solids ($G_s$) | gm/cc | 1.68 | 1.98 | 2.0 | 2.22 | 2.41 | 2.52 | 2.63 | 2.45 | 2.61 |
| Ignition Loss[1] | %[2] | 42.6 | - | 49.3 | 29.0 | 27.2 | 17.3 | 15.0 | 16.2 | 18.9 |
| Ash | % | 57.4 | - | 50.7 | 71.0 | 72.8 | 82.7 | 85.0 | 83.8 | 81.1 |

[1] 24 hours at 600 degrees C  [2] Of oven dry weight

Table 15. In fact, it was found that there was a direct relationship between specific gravity and ash content, i.e., the higher the ash content, the higher the specific gravity.

Concerning the engineering properties of the refuse, especially those that relate to the use of the material in construction, laboratory tests included Los Angeles abrasion, degradation on compaction, slaking, relative density, standard Proctor compaction, permeability, shear strength, and stabilization with fly ash.

In general, the results of the Los Angeles abrasion test indicated that fresh refuse might meet ASTM specifications for a variety of uses, but old refuse would not. This was true for the Humphrey refuse sample.

To evaluate the resistance to fracture of the refuse particles, the grain size distribution of the refuse samples was determined both before and after being subjected to standard Proctor compaction. The results of these tests on the Humphrey refuse are given in Table 16, showing very clearly that the refuse will degrade somewhat during compaction. However, the Humphrey refuse exhibited more resistance to fracture than the other three samples.

To evaluate the effects of weathering, particularly alternate exposure to wetting and drying conditions in the presence of air, slaking tests were performed. Coarse (+ 3/8") fractions were obtained and the percent of material in three size ranges (+ #10 sieve, #10-#100 sieves, -#100 seive) was determined for each fraction after each cycle of wetting and drying. The results for the Humphrey refuse (fresh) indicated that the material would degrade during weathering, but the degradation was considerably less than in the other samples from the study area.

The results of tests on abrasion resistance, hardness and durability emphasize the need for more performance-oriented materials specifications and test methods. In terms of the criteria for conventional aggregates, these materials would be deemed unsatisfactory. In fact, based on the rather arbitrary (and possibly very severe) test methods used, it could be concluded that these materials are not particularly abrasion resistant, nor are they very hard or durable. However, none of the test methods gives any real evaluation of how these materials might actually perform with respect to abrasion, hardness and durability under the service conditions that might be encountered in specific applications of the materials. These properties would likely have little bearing on the performance of the materials in a well-constructed highway embankment. On the

TABLE 16

SUMMARY OF DEGRADATION UPON COMPACTION TEST RESULTS FOR HUMPHREY REFUSE

| CONDITIONS | PERCENT OF DRY WEIGHT OF TOTAL SAMPLE | |
|---|---|---|
| | HUMPHREY | |
| | FRESH | OLD |
| Before Compaction: | | |
| Gravel (#4-3") | 37.35 | 34.71 |
| Coarse Sand (#10-#4) | 34.72 | 17.24 |
| Medium Sand (#40-#10) | 23.45 | 27.85 |
| Fine Sand (#200-#40) | 2.45 | 13.15 |
| Silt & Clay (-#200) | 2.03 | 7.05 |
| After Compaction | | |
| Gravel | 34.67 | 27.28 |
| Coarse Sand | 31.83 | 20.60 |
| Medium Sand | 25.99 | 27.93 |
| Fine Sand | 4.41 | 18.86 |
| Silt & Clay | 3.10 | 5.33 |
| Difference:[1] | | |
| Gravel | -2.68 | -7.43 |
| Coarse Sand | -2.89 | 3.86 |
| Medium Sand | 2.54 | 0.08 |
| Fine Sand | 1.96 | 5.71 |
| Silt & Clay | 1.07 | -1.72 |

[1](-) = Loss During Compact

other hand, abrasion resistance, hardness and durability might become relatively more important if the material was to be used in a Portland cement or bituminous stabilized highway base course.

The test results on relative density (Table 17) showed that, in general, the maximum and minimal void ratios are somewhat higher than would normally be expected for natural alluvial materials with similar grain size characteristics. This is perhaps due partly to the angular, plate-like shape of refuse particles. From the standard Proctor compaction tests (Table 18), it appears that the optimum water content for old refuse is significantly higher than for fresh refuse. The relatively low compacted dry densities shown in Tables 17 and 18 are due, in part, to the low specific gravities of the refuse. In additional laboratory tests, greater densities were achieved by impact compaction than by vibration compaction, suggesting that the best compaction might be achieved in the field by means of a heavy vibratory compactor providing both impact and compaction.

The results of the permeability tests demonstrated that the permeability of compacted mine refuse is as variable as the refuse itself, depending greatly upon the age and degree of compaction of the material. The coefficient of permeability varied from about $10^{-5}$ cm/sec to less than $10^{-7}$ cm/sec, with the older more densely compacted materials giving the lower values. These results compare favorably with the range of values (5 X $10^{-2}$ to 5 X $10^{-7}$ cm/sec for coarse discard) reported for British coal mine refuse, although they generally tend toward the less permeable side. This is particularly true when the results are compared with permeability values obtained by field measurement. This suggests that degradation associated with the preparation for permeability test samples by impact compaction might be exerting a disproportionate influence on the laboratory test values. In any event, it is clear that no generalization can be made with respect to the permeability of compacted coal mine refuse, and each individual application of the material must involve careful evaluation wherever the coefficient of permeability becomes an important design parameter.

The shear strength of compacted coal mine refuse was evaluated by means of consolidated-drained (CD) triaxial compression tests. The triaxial specimens were prepared, as nearly as possible, at the standard Proctor optimum water content and maximum dry density. The results of these tests are summarized in Table 19. The data show that the compacted refuse possesses substantial strength. The effective angle of internal friction ranges from 27.0 degrees to 40.8 degrees,

TABLE 17

SUMMARY OF RELATIVE DENSITY TEST RESULTS

| SAMPLE LOCATION | AGE | VOID RATIO | | DRY DENSITY (PCF) | |
|---|---|---|---|---|---|
| | | MAXIMUM | MINIMUM | MAXIMUM | MINIMUM |
| Badger | Fresh (Coarse) | 0.74 | 0.21 | 86.3 | 60.2 |
| | Fresh (Fine) | 0.45 | 0.28 | 96.6 | 85.4 |
| | Old | 0.98 | 0.57 | 79.5 | 63.0 |
| Humphrey | Fresh | 0.93 | 0.66 | 83.7 | 71.6 |
| | Old | 1.38 | 0.83 | 82.4 | 63.1 |
| Shoemaker | Fresh | 0.96 | 0.59 | 98.6 | 80.2 |
| | Old | 1.15 | 0.63 | 100.7 | 76.2 |
| McElroy | Fresh | 0.96 | 0.53 | 100.7 | 78.1 |
| | Old | 1.16 | 0.68 | 97.0 | 75.5 |

TABLE 18

SUMMARY OF STANDARD PROCTOR COMPACTION TEST RESULTS

| SAMPLE LOCATION | AGE | MAXIMUM DRY DENSITY (PCF) | OPTIMUM MOISTURE CONTENT (%) |
|---|---|---|---|
| Badger | Fresh (Coarse) | 93.8 | 7.6 |
| | Fresh (Fine) | 94.6 | 7.4 |
| | Old | 90.8 | 15.4 |
| Humphrey | Fresh | 96.9 | 5.6 |
| | Old | 97.6 | 14.0 |
| Shoemaker | Fresh | 114.7 | 7.0 |
| | Old | 121.2 | 9.2 |
| McElroy | Fresh | 123.8 | 8.0 |
| | Old | 114.5 | 10.8 |

## TABLE 19

## SUMMARY OF TRIAXIAL COMPRESSION TEST RESULTS[1]

| SAMPLE LOCATION | AGE | AVERAGE INITIAL DRY DENSITY (PCF) | AVERAGE INITIAL MOISTURE CONTENT (%) | SHEAR STRENGTH PARAMETERS | |
|---|---|---|---|---|---|
| | | | | C (PSF) | $\phi$ (DEGREES) |
| Badger | Fresh (Coarse) | 94.5 | 10.6 | 0 | 40.8 |
| | Fresh (Fine) | 88.1 | Dry | 288 | 34.6 |
| | Old | 89.7 | 14.0 | 0 | 39.0 |
| Humphrey | Fresh | 80.6 | Dry | 0 | 38.0 |
| | Old | 92.0 | 19.2 | 144 | 30.3 |
| Shoemaker | Fresh | - | - | - | - |
| | Old | 119.3 | 10.9 | 288 | 29.6 |
| McElroy | Fresh | 124.4 | 9.2 | 288 | 31.6 |
| | Old | 112.2 | 13.8 | 432 | 27.0 |

[1]Consolidated - drained (CD) tests.

which compares very favorably with the range of values (25 degrees to 42 degrees) reported for British mine refuse. The data of Table 19 also confirm that the shear strength of the refuse was essentially independent of the initial density.

In the stabilization tests, varying proportions of fly ash, cement, lime or combinations thereof were added to both old and fresh samples of coal mine refuse. The results of these tests are summarized in Table 20. Depending on the sample of mine refuse, the addition of combinations of fly ash-cement and fly ash-lime had significant beneficial effects on the unconfined compressive strengths. The addition of fly ash, cement or lime alone did not produce similarly beneficial effects on strength. This response is thought to be due to excessive moisture absorption, especially in those cases where fly ash alone was added.

The effects of the addition of fly ash on the engineering properties of refuse from the McElroy mine was the subject of a subsequent investigation. Initially, grain size and compaction studies were conducted on the materials, singly and in combination, to establish the "optimum" proportion of fly ash to be added. Unfortunately, all combinations of fly ash and refuse produced grain size distribution curves that were severely gap-graded. Thus, selection of the optimum proportion of fly ash was based primarily on the compaction studies. It was decided to select the proportion of fly ash, expressed as a percent of the total dry weight, that gave the greatest dry density when combined with the mine refuse. The quantity of fly ash that satisfied this criterion was 15 percent. As shown below, however, only a modest increase in the dry density of the mine refuse resulted from the addition of fly ash:

| Percent Fly Ash | Optimum Moisture Content % | Maximum Dry Density (pcf) |
|---|---|---|
| 0 | 8.0 | 124.0 |
| 15 | 9.2 | 126.4 |

With regard to the engineering properties of the refuse-fly ash mixture, several notable observations were made. The average permeability of the mixture (i.e., approximately $4.3 \times 10^{-7}$ cm/sec) was significantly less than that for the mine refuse alone (i.e., approximately $3.6 \times 10^{-5}$ cm/sec). The unconfined compressive strengths of the refuse-fly ash specimens could be classified, according to soil mechanics principles, in a consistency range from stiff to hard. In addition, the specimens prepared from the mixture exhibited increasing strength with time (e.g., 57 psi at 30 days compared to 25 psi at 7 days). On

TABLE 20

SUMMARY OF REFUSE STABILIZATION DATA

| SAMPLE LOCATION | AGE | ADDITIVE FLY ASH (%) | ADDITIVE CEMENT (%) | ADDITIVE LIME (%) | UNCONFINED COMPRESSIVE STRENGTH (PSI) @ 7 DAYS | UNCONFINED COMPRESSIVE STRENGTH (PSI) @ 30 DAYS |
|---|---|---|---|---|---|---|
| Humphrey | Fresh | 25 | 0 | 0 | 13 | 0 |
| | | 20 | 5 | 0 | 439 | 708 |
| | | 20 | 5 | 0 | - | 1119 |
| | | 16 | 4 | 0 | - | 627 |
| | | 20 | 0 | 5 | - | 619 |
| | Old | 0 | 4 | 0 | 44 | 56 |
| | | 0 | 0 | 4 | 22 | 12 |
| Shoemaker | Fresh | 24 | 0 | 0 | 150 | 0 |
| | | 20 | 4 | 0 | 122 | 208 |
| | | 20 | 0 | 4 | - | 119 |
| | Old | 0 | 4 | 0 | 52 | 80 |
| | | 0 | 0 | 4 | 52 | 43 |
| McElroy | Fresh | 14 | 0 | 0 | 12 | 0 |
| | | 20 | 4 | 0 | 219 | 209 |
| | | 10 | 4 | 0 | 127 | 278 |
| | | 10 | 0 | 4 | 14 | 134 |
| | Old | 0 | 4 | 0 | 102 | 0 |
| | | 0 | 0 | 4 | 48 | 0 |

the other hand, the specimens of mine refuse alone displayed initially low strengths that decreased with time. Even though all specimens were wrapped in plastic bags prior to storage in the moist curing room, the untreated mine refuse specimens exhibited swelling tendencies.

The results of the strength tests on the wrapped (protected) refuse-fly ash specimens are in contrast to those observed for the unwrapped (unprotected) specimens utilized in the first study; i.e., the wrapped specimens retained or increased their strengths with time whereas the unwrapped specimens either completely disintegrated or sustained a significant loss in strength. It is quite apparent from these results that the absorption of water is detrimental to the unconfined compressive strength of the refuse-fly ash mixture. Results of consolidated-undrained (CU) triaxial compression tests with back pressure saturation and pore pressure measurement demonstrated that an overall reduction in strength was produced by the addition of fly ash. In general, it was found that the addition of fly ash initially reduced the effective angle of internal friction (ø) and increased the effective cohesion (c). However, at the end of a 60 day protected period the effective strength parameters approached those exhibited by the mine refuse alone.

Geographic Variance of Coal Refuse (by Buttermore et al.)

The West Virginia University Coal Research Bureau Report No. 159[1] presents data on bituminous coal wastes sampled in the nine largest mining districts in the United States. The purpose of the reported work was to determine the composition of bituminous coal wastes and whether significant variance can be expected according to geographical source area. Based upon extensive sampling and analysis, it was concluded that no consistent, significant variance in composition could be specified on the basis of geographical source area. It was further concluded that differences in composition and physical properties of coal wastes are more greatly influenced by mining and preparation methods than by source area.

One of the districts included in the study was District 3, the northern section of West Virginia, not including the northern and eastern panhandle (see Figure 12). The study area is included in District 3. The major coal

[1]Buttermore, W.H., E.J. Simcoe, and M.A. Maloy, Characterization of Coal Refuse, University of West Virginia Coal Research Bureau, Morgantown, West Va., Report No. 159, undated.

# COAL DISTRICT 3 AND SURROUNDING AREA

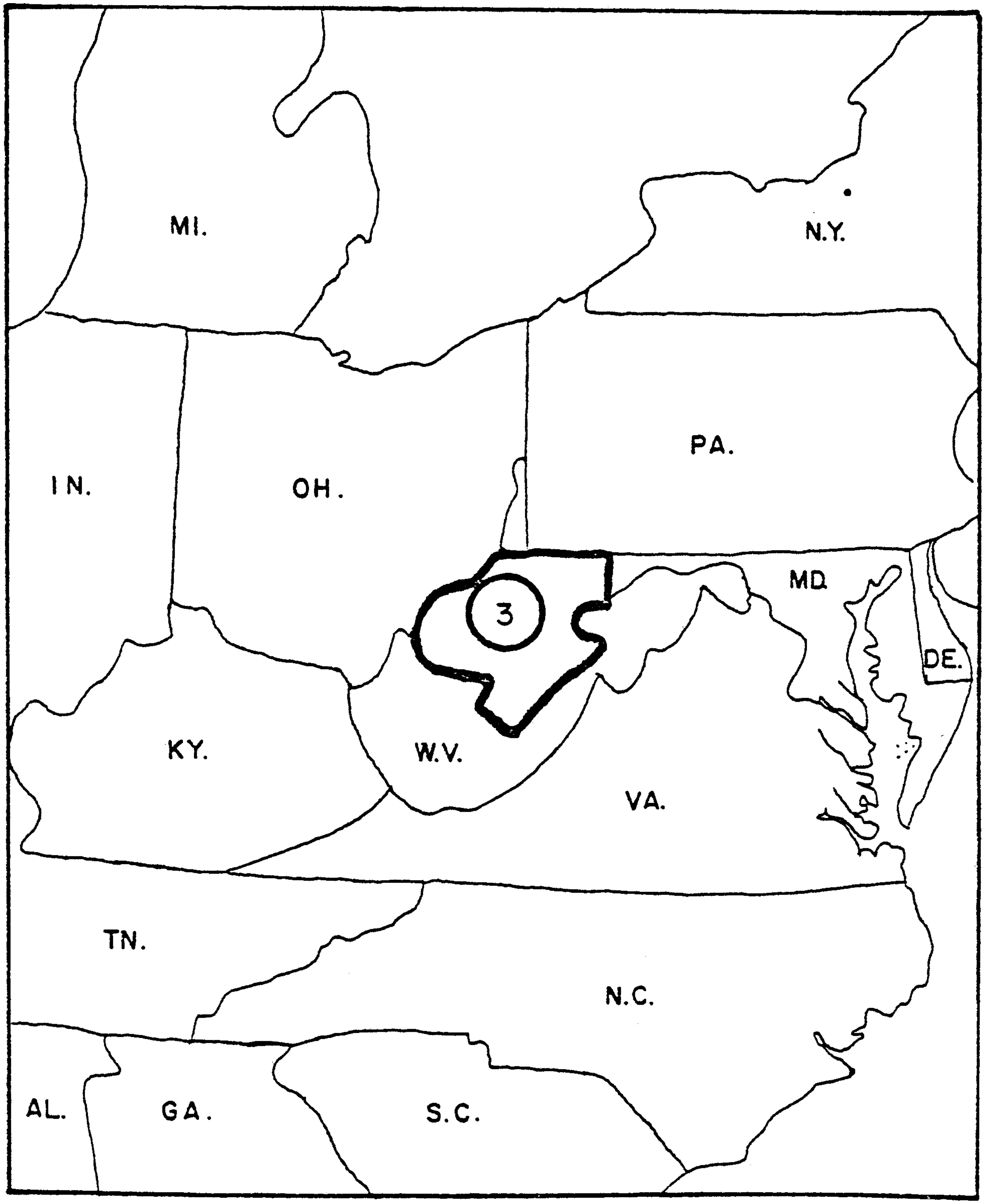



Figure 12.

producing seam in District 3 is the Pittsburgh seam (2 to 20 feet thick; average 7 feet), with coal also produced from the upper and lower Freeport and upper Kittanning seams. Seventy-four percent of the coal produced in District 3 is deep-mined, and common preparation methods include crushers, picking tables, deep washers, chance sand cones, and heavy media separators. The district produces 8.435 million tons of coal waste materials annually, with average analysis as indicated in Table 21.

Of 15 coal waste samples taken in District 3, four samples were of refuse from the Humphrey preparation plant. The results of the chemical and physical analyses of the Humphrey refuse are presented in Table 22 and Figures 13 through 16. By comparing Table 22 (Humphrey refuse) with Table 21 (District 3 refuse) it can be seen that the composition of Humphrey refuse is typical of refuse generated in the entire district. In particular, the coarse refuse, which is of interest for construction uses, is generally high in ash, sulfur, volatile matter and mineral content while being low in heat value. Compacted bulk density values for the Humphrey coarse refuse were from 75 to 90 pcf, which is consistent with data reported previously.

The grain size of the coarse Humphrey refuse (Figures 13, 15 and 16) shows the material to be of a primarily coarse texture, with the coarse portion being relatively uniformly graded in samples 1 and 5. The fine portions of all three samples encompass a wide range of fine grain sizes. Although no data is provided concerning the abrasion resistance, fracture resistance, and durability of the Humphrey refuse, the grading of the refuse suggests that achievement of maximum densities during construction would require breaking down the coarse fraction somewhat to provide a higher percentage of fines and produce an overall better graded material.

TABLE 21

COAL WASTE AVERAGE COMPOSITION
(PERCENT EXCEPT AS NOTED)

| | COARSE REFUSE | FINE REFUSE |
|---|---|---|
| Moisture | 0.87 | 0.90 |
| Carbon | 25.77 | 66.68 |
| Ash | 62.81 | 21.06 |
| Sulfur | 6.22 | 2.59 |
| Vol. Matter | 18.34 | 26.7 |
| Loss on Ignition | 36.79 | 77.87 |
| Btu (per pound) | 4,513 | 11,569 |
| Silicon | 15.01 | 4.73 |
| Aluminum | 6.34 | 2.51 |
| Iron | 6.37 | 3.38 |
| Titanium | 0.33 | 0.12 |
| Calcium | 2.49 | 0.95 |
| Magnesium | 0.43 | 0.90 |
| Sodium | 0.23 | 0.06 |
| Potassium | 0.91 | 0.27 |
| Initial deformation temperature | 1873°F | 1928°F |
| Softening temperature (spherical) | 2414°F | 2512°F |
| Ash softening temperature | 2426°F | 2540°F |
| Fluid temperature | 2468°F | 2560°F |
| Water solubility[1] | 2.41 | 1.65 |
| Compacted bulk density (lbs/ft$^3$) | 84.00 | 61.8 |

[1]Weight percent of sample dissolved in water in one hour.

Source: Buttermore, W.H., E.J. Simcoe, and M.A. Maloy, Characterization of Coal Refuse, University of West Virginia Coal Research Bureau, Morgantown, West Va., Report No. 159, undated.

TABLE 22

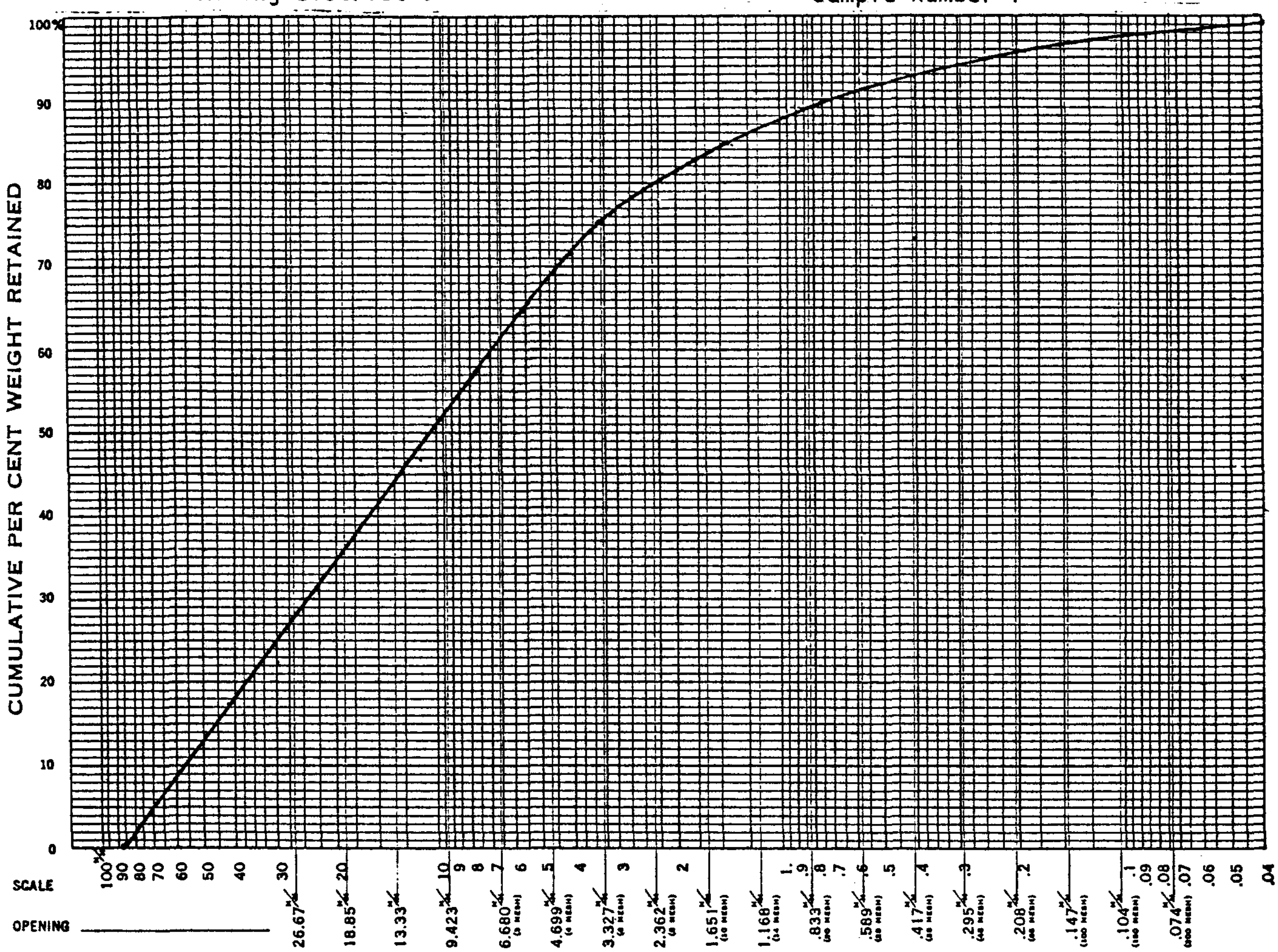
CHARACTERIZATION DATA FOR COAL WASTE SAMPLES FROM THE HUMPHREY PREPARATION PLANT (DISTRICT 3)

| SAMPLE NO.<br>REFUSE TYPE | 1<br>COARSE | 2<br>FINE | 5<br>COARSE | 7<br>COARSE |
|---|---|---|---|---|
| Chemical Analysis | | | | |
| Moisture % | 0.9 | 1.0 | 0.7 | 0.7 |
| Carbon % | 32.31 | 60.43 | 18.44 | 18.16 |
| Ash % | 56.4 | 26.2 | 69.7 | 71.9 |
| Sulfur % | 5.33 | 4.88 | 7.17 | 8.16 |
| Vol. Matter % | 22.1 | 30.2 | 20.3 | 15.7 |
| LOI % | 43.2 | 73.2 | 30.07 | 27.4 |
| Btu (per pound) | 5,740 | 10,690 | 2,760 | 3,030 |
| Si % | 14.29 | 4.28 | 16.8 | 17.37 |
| Al % | 5.49 | 1.77 | 4.5 | 6.46 |
| Fe % | 5.48 | 9.71 | 7.06 | 7.69 |
| Ti % | 0.28 | 0.08 | 0.34 | 0.36 |
| Ca % | 3.13 | 2.77 | 5.38 | 2.89 |
| Mg % | 0.32 | 0.00 | 1.33 | 0.35 |
| Na % | 0.06 | 0.02 | 0.30 | 0.34 |
| K % | 0.92 | 0.24 | 0.76 | 1.93 |
| Ash Fusion Properties | | | | |
| IDT (°F) | 1920 | 1910 | 1870 | 1760 |
| STS (°F) | 2300 | 2160 | 2130 | 2310 |
| AST (°F) | 2320 | 2180 | 2140 | 2330 |
| FT (°F) | 2360 | 2190 | 2160 | 2460 |
| Physical Properties | | | | |
| Water Sol. % | 2.78 | 2.25 | 2.08 | 1.08 |
| Bulk Den. (#/Ft$^3$) | 75.2 | 50.6 | 65.0 | 76.0 |
| Compacted (#/Ft$^3$) | 90.0 | 63.1 | 75.3 | 88.0 |

Source: Buttermore, W.H., E.J. Simcoe, and M.A. Maloy, Characterization of Coal Refuse, University of West Virginia Coal Research Bureau, Morgantown, West Va., Report No. 159, undated.

Figure 13. Cumulative logarithmetic diagram of screen analysis of Humphrey coarse refuse.

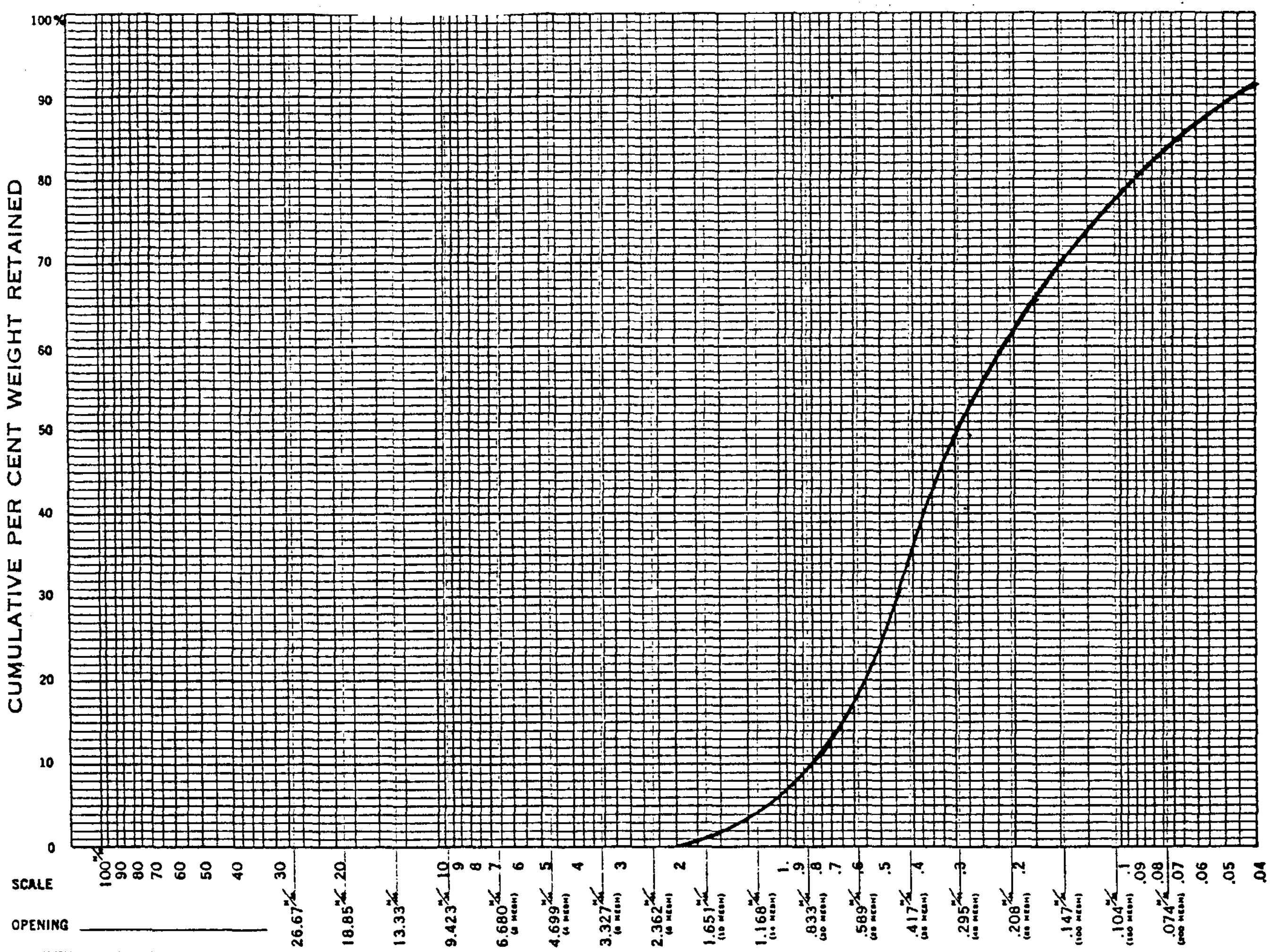
Mining District 3 Sample Number 1




| | SCREEN SCALE RATIO 1.414 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Openings | | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights |
| | Milli-meters | Inches | | | | | | | | | | | |
| | 26.67 | 1.050 | | 3 1/2" | 0 | 0 | 0 | | | | | | |
| | 18.85 | .742 | | 1 3/4" | 527.7 | 17.3 | 17.3 | | | | | | |
| | 13.33 | .525 | | 7/8" | 442.5 | 14.5 | 31.8 | | | | | | |
| | 9.423 | .371 | | 7/16" | 462.6 | 15.1 | 46.9 | | | | | | |
| | 6.680 | .263 | 3 | 3 1/2m | 545.8 | 17.9 | 64.8 | | | | | | |
| | 4.699 | .185 | 4 | 4 | | | | | | | | | |
| | 3.327 | .131 | 6 | 6 | | | | | | | | | |
| | 2.362 | .093 | 8 | 8 | 357.5 | 11.8 | 76.6 | | | | | | |
| | 1.651 | .065 | 10 | 12 | | | | | | | | | |
| | 1.168 | .046 | 14 | 16 | 248.1 | 8.1 | 84.7 | | | | | | |
| | .833 | .0328 | 20 | 20 | 163.4 | 5.4 | 90.1 | | | | | | |
| | .589 | .0232 | 28 | 30 | | | | | | | | | |
| | .417 | .0164 | 35 | 40 | 104.1 | 3.4 | 93.5 | | | | | | |
| | .295 | .0116 | 48 | 50 | | | | | | | | | |
| | .208 | .0082 | 65 | 70 | 69.6 | 2.3 | 95.8 | | | | | | |
| | .147 | .0058 | 100 | 100 | | | | | | | | | |
| | .104 | .0041 | 150 | 140 | 51.9 | 1.7 | 97.5 | | | | | | |
| | .074 | .0029 | 200 | 200 | 36.5 | 1.2 | 98.7 | | | | | | |
| Pass | .074 | .0029 | 200 | 200 | 42.0 | 1.4 | 101.0 | | | | | | |
| | | | | Totals, | 3057.7 | 101.0 | 101.0 | | | | | | |

Figure 14. Cumulative logarithmetic diagram of screen analysis of Humphrey pond fines.

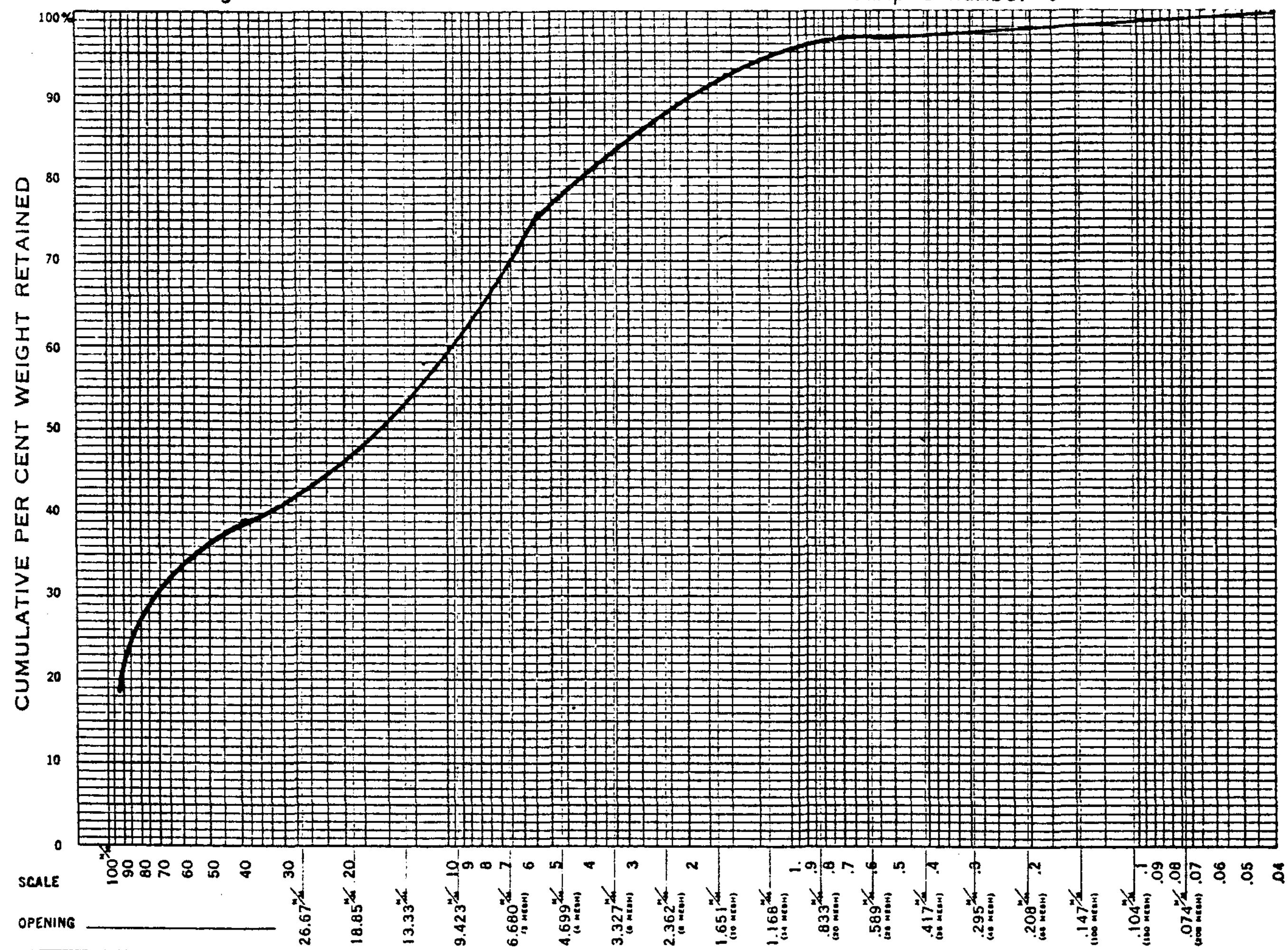
Mining District 3 Sample Number 2




| | SCREEN SCALE RATIO 1.414 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Openings | | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights |
| | Milli-meters | Inches | | | | | | | | | | | |
| | 26.67 | 1.050 | | | | | | | | | | | |
| | 18.85 | .742 | | | | | | | | | | | |
| | 13.33 | .525 | | | | | | | | | | | |
| | 9.423 | .371 | | | | | | | | | | | |
| | 6.680 | .263 | 3 | | | | | | | | | | |
| | 4.699 | .185 | 4 | 4 | | | | | | | | | |
| | 3.327 | .131 | 6 | 6 | | | | | | | | | |
| | 2.362 | .093 | 8 | 8 | | | | | | | | | |
| | 1.651 | .065 | 10 | 12 | 5.0 | 1.3 | 1.3 | | | | | | |
| | 1.168 | .046 | 14 | 16 | 42.6 | 10.7 | 12.0 | | | | | | |
| | .833 | .0328 | 20 | 20 | | | | | | | | | |
| | .589 | .0232 | 28 | 30 | 116.6 | 29.4 | 41.4 | | | | | | |
| | .417 | .0164 | 35 | 40 | | | | | | | | | |
| | .295 | .0116 | 48 | 50 | 94.8 | 23.9 | 65.3 | | | | | | |
| | .208 | .0082 | 65 | 70 | | | | | | | | | |
| | .147 | .0058 | 100 | 100 | 59.1 | 14.9 | 80.2 | | | | | | |
| | .104 | .0041 | 150 | 140 | | | | | | | | | |
| | .074 | .0029 | 200 | 200 | 38.8 | 9.8 | 90.0 | | | | | | |
| Pass | .074 | .0029 | 200 | 200 | 39.4 | 9.9 | 99.9 | | | | | | |
| | | | | Totals, | | | | | | | | | |

Figure 15. Cumulative logarithmetic diagram of screen analysis of Humphrey coarse refuse

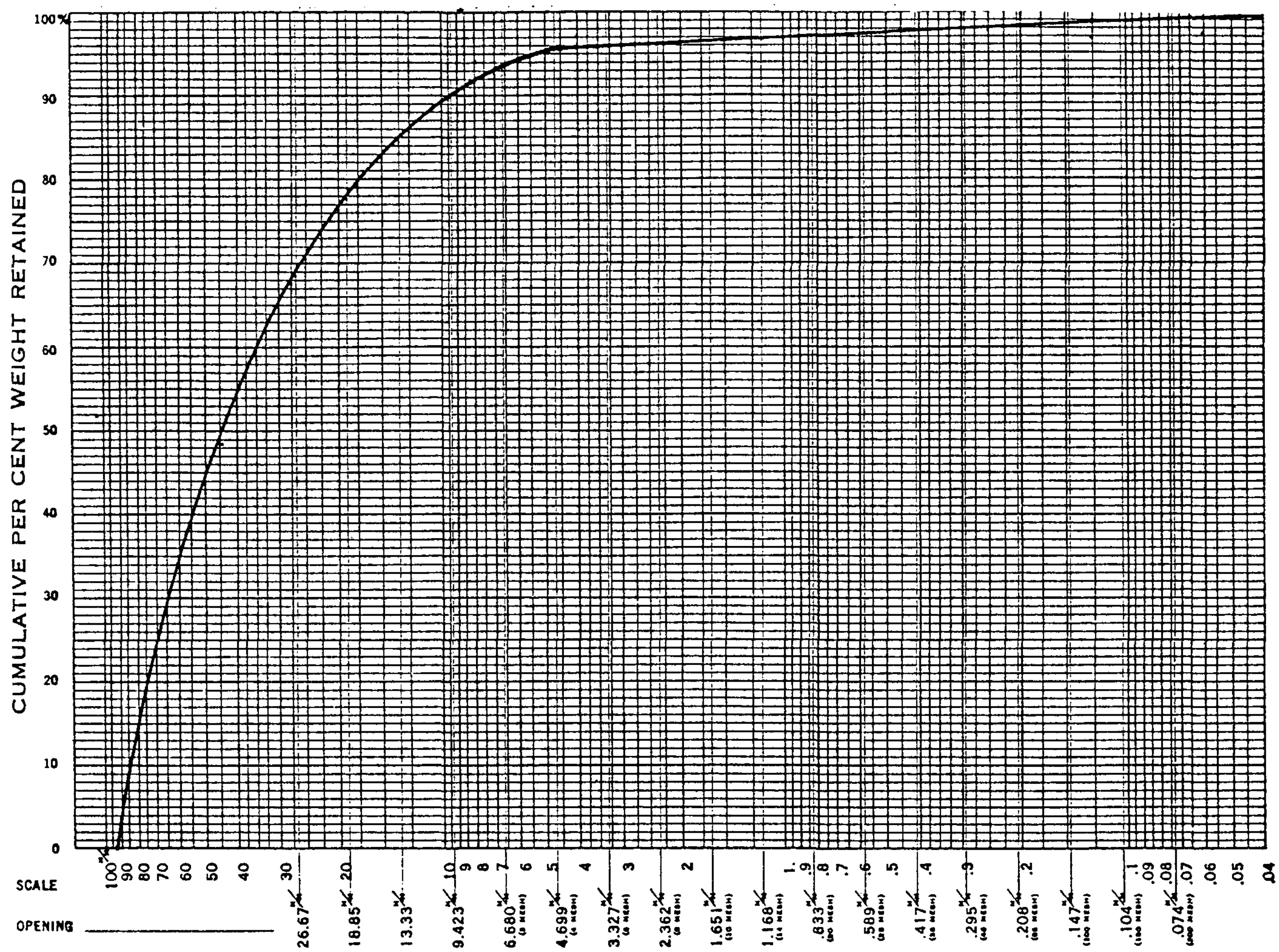
Mining District 3 Sample Number 5




| | SCREEN SCALE RATIO 1.414 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Openings | | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | |
| | Millimeters | Inches | | | | | | | | | | | | |
| | 90.5 | | | 3½" | 692.5 | 18.4 | 18.4 | | | | | | | |
| | 45.3 | | | 1¾" | 466.8 | 12.4 | 30.8 | | | | | | | |
| | 22.6 | | | ⅞" | 437.3 | 11.6 | 42.4 | | | | | | | |
| | 11.2 | | | 7/16" | 579.3 | 15.4 | 57.8 | | | | | | | |
| | 5.66 | | | 3½M | 617.9 | 16.4 | 74.2 | | | | | | | |
| | 2.83 | | | 7M | 422.3 | 11.2 | 85.4 | | | | | | | |
| | 1.41 | | | 14M | 263.8 | 7.0 | 92.4 | | | | | | | |
| | 0.707 | | | 25M | 165.4 | 4.4 | 96.8 | | | | | | | |
| | 0.354 | | | 45M | 39.5 | 1.0 | 97.8 | | | | | | | |
| | 0.177 | | | 80M | 15.3 | 0.4 | 98.2 | | | | | | | |
| | 0.088 | | | 170M | 13.2 | 0.3 | 98.5 | | | | | | | |
| | 0.044 | | | 325M | 12.1 | 0.3 | 98.8 | | | | | | | |
| Pass | 0.044 | | | 325M | 26.5 | 0.7 | 99.5 | | | | | | | |
| | | | | Totals, | 3751.9 | 99.5 | 99.5 | | | | | | | |

Figure 16. Size distribution of Humphrey coarse refuse.

Mining District 3 Sample Number 7




| | SCREEN SCALE RATIO 1.414 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Openings | | Tyler Mesh | U. S. No. | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights | Sample Weights | Per Cent | Per Cent Cumulative Weights |
| | Milli-meters | Inches | | | | | | | | | | | |
| | 90.5 | | | 3½" | 0.0 | 0.0 | 0.0 | | | | | | |
| | 45.3 | | | 1¾" | 1419.4 | 48.0 | 48.0 | | | | | | |
| | 64.00 | | | 2½" | | | | | | | | | |
| | 32.00 | | | 1¼" | | | | | | | | | |
| | 16.00 | | | 5/8" | 825.2 | 28.0 | 76.0 | | | | | | |
| | 8.00 | | | 5/16" | 531.1 | 18.0 | 94.0 | | | | | | |
| | 4.00 | | | 5M | 72.9 | 2.0 | 96.0 | | | | | | |
| | 2.00 | | | 10M | 10.2 | 0.35 | 96.3 | | | | | | |
| | 1.00 | | | 18M | 3.6 | 0.12 | 96.4 | | | | | | |
| | 0.500 | | | 35M | 3.5 | 0.12 | 96.5 | | | | | | |
| | 0.250 | | | 60M | 4.2 | 0.14 | 96.7 | | | | | | |
| | 0.125 | | | 120M | 5.2 | 0.17 | 96.9 | | | | | | |
| | 0.063 | | | 230M | 7.1 | 0.24 | 97.1 | | | | | | |
| Pass | 0.063 | | | 230M | 26.2 | 0.90 | 98.0 | | | | | | |
| | | | | Totals, | 2908.6 | 98.04 | 98.04 | | | | | | |

## Environmental and Economic Feasibility Evaluation

In this section, the feasibility of using coal refuse and fly ash as a roadway subbase or base course material is examined in terms of environmental and economic considerations. A detailed, project-specific feasibility evaluation is beyond the scope of this study, but the discussions below provide an indication of key factors affecting the feasibility of the selected utilization technique.

### Environmental

In the past, the principal environmental concerns with respect to using coal refuse in construction applications have been (1) spontaneous combustion of the refuse, and (2) production of acid leachate and runoff. These concerns relate mainly to embankment applications of refuse. For embankment applications, British as well as PennDOT[1] experience has shown that the exclusion of oxygen will eliminate problems of spontaneous combustion and acid drainage. To exclude oxygen in construction uses of coal refuse requires the material to be compacted to its most dense state. Thus, the problem is reduced to the compaction characteristics of refuse materials.

In roadway construction, the wearing surfaces are virtually impermeable so that the formation of acid leachate from a coal refuse subbase or base course is not of real consequence. In fact, the upward migration of groundwater into the roadway base course is a much more critical design consideration (for structural reasons). With proper compaction, and given the addition of alkaline fly ash, which will neutralize any acidity production from pyritic refuse material, it appears that the use of coal refuse and fly ash in roadbase applications is environmentally acceptable. In their field study of leachate production from coal refuse/fly ash base course material, Wilmoth and Scott[2] concluded that "...the leachate from mixtures of refuse and fly ash and of refuse and fly ash plus lime did not constitute an environmental problem."

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[1]Butler, P.E., Utilization of Coal Mine Refuse in the Construction of Highway Embankments, Pennsylvania Department of Transportation, 1974.

[2]Wilmoth, R.C. and R.B. Scott, Use of Coal Mine Refuse and Fly Ash as a Road Base Material, U.S. Environmental Protection Agency Crown Field Site, Rivesville, W.Va., 1974.

## Economic

As discussed previously, one of the major reasons for the choice of road base and subbase construction as the utilization technique for coal refuse is the large potential volume of refuse that could conceivably be used. A large number of paving applications exist, all of which can use significant amounts of refuse. These uses include:

- Highways
- Secondary roads
- Access roads
- Shopping center parking lots
- Other parking lots
- Airport runways

Use in roadway construction is expected to be the major market for utilization of refuse; the volumes of aggregate required for airport runways and parking lots is not nearly as great as that required for roadway construction. However, coal refuse banks in close proximity to planned parking lot or runway extension projects could locally be used advantageously.

This section, then, concentrates on road base construction as the major potential market for coal refuse. Not only are possible volume needs greater, information on planned roadway expansion is more accessible than data on possible construction of parking lots, runways, etc.

Existing Road Mileage. Table 23 lists Monongalia and seven counties in West Virginia and Pennsylvania that are at an average distance of 40 miles or less from the study site.[1] For each county, existing improved roadway miles, planned roadway construction miles as reported by state highway departments, and the status of aggregate availability (see Figures 10 and 11) are tabulated. As can be seen, proposed roadway construction in the next five years will increase highway miles in each county by less than 5 percent of existing totals. Obtained from state highway departments and reported in a preliminary draft of The Investigation of the Use of Coal Refuse/Fly Ash Compositions as Highway Base Course Materials by GAI Consultants, Inc., these estimates are predicated upon the assumption that state or Federal highway departments will indeed fund the projects. For the purposes here, it can only be assumed that they will.

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[1]Average distance =
$$\frac{\text{closest point in county + farthest point in county}}{2}$$

# TABLE 23

## ADJACENT COUNTY ROADWAY INFORMATION[a]

| | | | | | | AGGREGATE AVAILABILITY | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | GEOLOGIC | |
| COUNTY | STATE | POPULATION 1970 | CURRENT ROADWAY MILES | FIVE YEAR CONSTRUCTION PLANNED (MILES) | AVERAGE DISTANCE FROM STUDY SITE (MILES)[b] | STATE HIGHWAY DECLARED SHORTAGE | SAND | CRUSHED STONE |
| Monongalia | WV | 63,714 | 800 | 4.3 | 7 | No | No | Yes |
| Marion | WV | 61,356 | 706 | 21.4[c] | 18 | No | No | No |
| Greene | PA | 36,090 | 1,532 | 3.8 | 18 | No | No | No |
| Taylor | WV | 13,878 | 379 | 9.7 | 23 | No | No | Yes |
| Preston | WV | 25,455 | 1,235 | 37.1[c] | 25 | No | No | Yes |
| Fayette | PA | 154,667 | 2,076 | 5.7 | 25 | No | No | No |
| Harrison | WV | 73,028 | 816 | 18.5 | 32 | No | No | Yes |
| Wetzel | WV | 20,314 | 608 | 26.6 | 35 | Yes | Yes | Yes |
| | | 428,502 | 8,152 | 127.1 | | | | |

[a]GAI Consultants, Incorporated. Investigation of the Use of Coal Refuse/Fly Ash Compositions as Highway Base Course Materials, preliminary report.

[b]Average distance from study site is calculated as $\frac{\text{Closest Point to Study Site + Farthest Point}}{2}$

[c]Planned construction period for Pennsylvania is twelve years instead of five.

Potential Volume Usage. The potential for the use of refuse for highway base courses depends upon two major factors: (1) highway base course needs; and (2) transportation distance from construction project to coal waste and fly ash sources.

Obviously, the closer the road construction is to the refuse and fly ash sources, the better they will be able to compete with conventional materials. Thus, the planned roadway construction in Marion County represents a more attractive market for the study area refuse than does roadway construction in Harrison County. However, assuming the validity of the assumption that a 40-mile haul distance is the maximum that coal refuse can be transported and still compete with natural aggregates, the maximum possible market would include the total of the proposed road building in the eight counties in Table 23. Table 24 presents a matrix of the possible volumes of coal refuse utilization per mile depending upon the depth of the base and the width of the road, assuming that the ratio of coal refuse to fly ash used in the base course is 3:1.

With 127.1 proposed highway construction miles in the next five years, the range for the maximum amount of refuse utilization as a subbase is 447,000 to 2,013,000 cubic yards of material. At approximately 85 lbs per cubic foot when compacted, this translates to between 513,000 and 2,310,000 tons of Humphrey refuse.[1]

These estimates are, of course, a maximum roadway usage figure over the next five years, and it is not expected that the usage would be as high as this. The extent to which coal refuse could penetrate this market is dependent upon a number of economic, environmental, and institutional factors. The remainder of this section will discuss the factors that affect the cost of utilizing refuse and fly ash, which in turn affect the market penetration potential.

Cost Factors. Ultimately, for coal refuse to gain any acceptance and usage as base and subbase material for road construction, it must perform equally as well at an installed cost less than conventional aggregates. Unless contractors and highway departments have an economic incentive to use refuse, no amount of other factors in its favor will motivate its use. These incentives may be induced by the competitive market, or they could be artifically induced by

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[1]Various values in the literature for the density of Humphrey refuse are 90, 75.3 and 88 lbs/cubic foot (compacted density), 97 and 98 lbs/cubic foot (maximum dry density).

TABLE 24

CUBIC YARDS OF REFUSE REQUIRED PER MILE OF PAVEMENT

| ROAD BASE WIDTH | ROAD SUBBASE DEPTH | | |
|---|---|---|---|
| | 1 ft | 1.25 ft | 1.5 ft |
| 24 ft | 3,520 | 4,400 | 5,280 |
| 36 ft | 5,280 | 6,600 | 7,920 |
| 48 ft | 7,040 | 8,800 | 10,560 |
| 60 ft | 8,800 | 11,000 | 13,200 |
| 72 ft | 10,560 | 13,200 | 15,840 |

the direct action of state and Federal highway departments, coal companies, or owners of electric utilities, such as subsidies for its use. Any incentives that are a result of natural market forces are the most desirable, although there may be cases where additional incentives provided by government or industry would provide net social benefits as well.

The costs of utilizing refuse/fly ash combinations will have many of the same components as the costs of utilizing conventional materials. Handling and transport costs are dependent on the number of handling stages, the equipment required, and the distance to be transported and are relatively unaffected by the nature of the material handled. The placing, spreading and grading operations are likewise relatively unaffected by whether the material is conventional aggregate or a coal refuse/fly ash mixture. Thus, there are only a limited number of stages where coal refuse/fly ash combinations have the potential for a differential in costs. Basically, these points are:

- F.O.B. cost of materials
- Necessary transport distance
- Handling steps necessary
- Excavation and loading procedures
- Additional mixing costs for refuse/fly ash

The potential differences in costs according to the likely procedures for use of refuse/fly ash combinations are examined below.

Cost and Availability of Conventional Subbase Materials. Both the cost and the availability of conventional subbase materials are intimately connected. Availability implies proximity; proximity implies reasonable price. Because of the large part transportation costs play in the final cost of the delivered aggregate, availability at a certain price is highly dependent upon transportation distance to the construction site. Thus, the discussion of the costs of conventional materials and their effect on market penetration can only be in general terms, using hypothetical examples to illustrate particular points.

The 1978 Dodge Guide to Public Works and Heavy Construction Costs estimated mid-1978 costs for coarse aggregate suitable for base course at $4.50/cubic yard.[1] According to Engineering News Record, the average cost of 3/4" X 1/2" aggregate not-in-place in June 1979 was $5.54/ton. June 1979 crushed stone and sand prices were $5.80 and $5.24/ton, respectively.[2] Obviously, like all construction materials, aggregates have seen a sharp increase in price. For consistency, the Dodge Guide price will be used to compare costs of conventional materials and coal-refuse/fly ash combinations (see Table 25), since cost figures are provided for the various construction steps necessary for road construction.

Representative bid prices in the "Unit Prices" feature of Engineering News Record for actual roadway base course aggregates (including hauling, delivery, placing, etc.) in the period from August 1978 through January 1979 range from $6.00 to $25.00 per cubic yard.[3] The variation is introduced because of differences in volume, local availability and markets, and transportation costs.

Differences in the price of coal refuse from conventional materials can offset the increased costs that will result from the necessity of onsite mixing of the fly ash and coal refuse. Additionally, it may allow the refuse to be transported from a greater distance and still remain economically favorable.

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[1]Leonard McMahon, Ed., 1978 Dodge Guide to Public Works and Heavy Construction Costs, (McGraw Hill Information Systems, 1977), p. 93.

[2]Based on prices from 19 metropolitan areas; Engineering News Record, Construction Economics Department. Telephone communication.

[3]Engineering News Record; various issues 1978 and 1979.

As discussed previously, Monongalia County does not suffer from any produced crushed stone or sand and gravel shortages. However, neighboring counties to the south and west have geological shortages of crushed stone. Efforts to systematically identify the existing quarries and sources of crushed stone were unsuccessful, as no cataloging of the sites has been done. Thus, it was assumed that within Monongalia County, aggregate availability (and thus price) was average, and was somewhat below average for the counties identified as aggregate-short to the south and west. Although the extent to which this condition would affect aggregate prices was not determined, it is assumed that the potential for using coal refuse and fly ash combinations for road bases will be enhanced.

Price of Refuse and Price of Fly Ash. The less expensive the refuse and fly ash are at the preparation and power plants, the greater the distance that they can be transported and still compete with natural aggregates. Thus, the cooperation of coal companies and utilities to provide their wastes for nominal charges will be a factor in the ultimate success of refuse utilization schemes. From a profit-maximizing point of view, it may be that a coal company or other utility should charge a relatively high price for their wastes if demand is high. However, public opinion and pressure may dictate that the prices they charge will be kept to a minmuim. Hopefully, utility and coal company cooperation will be obtained.

In the past, both Consolidation Coal Company and Monongahela Power Company have provided refuse and fly ash to various institutions free of charge for experimental purposes. However, the amounts of material provided under these agreements has been relatively small. Larger, regular supplies will almost surely carry some positive price.

Currently, Monongahela Power Company offers its fly ash for sale at $.25/ton for use in projects such as road building and fills and embankments. The Fort Martin power plant currently pays an independent contractor to dispose of its fly ash and scrubber sludge, so it is in their interest to sell as much fly ash as possible. Monongahela Power estimated that the cost of the fly ash to a contractor at the plant would be approximately $.50/ton, which would include the loading and handling charges at the plant. The costs of transporting the fly ash would be additional.[1]

Consolidation Coal could offer no explicit quote for their refuse. Although research and testing programs have obtained Humphrey refuse in the past free of charge, Consolidation Coal Company receives no continuing requests

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[1]Personal communication Mr. Al Babcock, Monongahela Power Co., 3 May 1979.

for the material. On a small scale, the material could be obtained for free. However, if a contractor or continuing series of contractors were to request large amounts of refuse, Consolidation would most likely initiate a charge for it. However, the charge should be minimal. No figures were quoted, since none have been officially developed by the company.[1] Like a utility, a coal company has incentives to sell its refuse, since the company incurs costs in disposing of the refuse. For the Humphrey plant, the marginal cost of disposing of its refuse was estimated at $.54/ton.

Handling and Transport Costs of Refuse and Fly Ash. As mentioned earlier, handling and transport can play a significant part in the final delivered cost of refuse and fly ash. Each additional handling step and each additional mile transported increases the delivered cost of the material. The handling and transport stages can be broken down into the following categories, each of which has implicit costs associated with it:

- Excavation and loading
- Hauling
- Mixing (of fly ash and refuse)
- Reloading (if mixing was done off site)
- Unloading, placing, and spreading

Since each individual road building site will have different characteristics and costs associated with it, there will not be any strict applicability of any explicit costs developed here for the study area. However, reasonable estimates of the relevant cost components can be used as a starting point to gain a first order approximation of the costs involved and the relative importance of each factor in the total costs of the delivered material. To approximate these costs, estimates from the 1978 Dodge Guide to Public Works and Heavy Construction Costs will be used for both conventional materials as well as fly ash and coal refuse combinations.

The excavation and loading of fly ash and refuse could take two forms. The materials can be obtained either directly from the respective silo or loading bin before the materials are disposed of, or they can be obtained from the disposal sites. Upon first examination, one might think that obtaining the refuse or fly ash directly from the

[1]Personal communication, Mr. John Stevens, Consolidation Coal.

loading bins would be the most efficient method. However, if a steady supply is needed, such an approach can be less than optimum if plant shutdowns threaten the output of fly ash or refuse. In addition, the characteristics of the refuse cannot be as easily determined. Using disposal piles for the material ensures a steady supply of a material whose properties can be characterized beforehand and may prove to be cheaper in the long run for large amounts of refuse.

The most feasible method for this is probably a combination of a front end loader and a series of dump trucks into which the refuse or fly ash would be deposited and then transported to the construction site.

The Dodge Guide estimated the costs of excavation and loading of loam, sand, and loose gravel range from between \$.15 and \$.19 per cubic yard as daily output goes from 2600 to 7600 cubic yards.[1] It is felt that this category of excavation and loading best approximates the conditions under which refuse and fly ash might be obtained. This charge is the cost to the contractor and includes only excavation and loading. According to Leonard McMahon, editor of the Dodge Guide, a typical bid price for the work would be escalated by approximately 40 percent. (This figure will be used to escalate the charge for excavation and loading as well as other estimates of contractor costs in the Dodge Guide.) Thus, excavation and loading will account for between \$.21 and \$.27 per cubic yard.

Hauling costs of the materials vary with the amounts of refuse and fly ash and the distances they need to be transported. For each particular job there will be two separate sets of haul charges since the fly ash and refuse sources in the study site are in different locations. Since a successful refuse/fly ash mixture will contain a majority of refuse (a ratio of perhaps 3:1 depending upon the characteristics of both), the proximity of the site to the refuse supply is more important than the proximity to the fly ash source.

The 1978 Dodge Guide gives an average cost of hauling material such as crushed stone or gravel of approximately \$.75 cents for the first cubic yard-mile haul, with an additional \$.20/cubic yard-mile up to a twenty mile one-way haul. At 20 miles, the cost per cubic yard is quoted at \$4.42/cubic yard.[1]

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[1] 1978 Dodge Guide, p. 8.

[2] Leonard McMahon, ed., 1978 Dodge Guide to Public Works and Heavy Construction Costs, p. 10.

Assuming the 40 percent markup, the charges would be $1.05 for the first mile and $.28 per cubic yard-mile up to twenty miles. A twenty mile haul would thus be bid at $6.19 per cubic yard. These charges do not include excavation, loading, or materials charges.

The mixing strategies for refuse and fly ash depend upon distances between the job and materials, the number of handling steps required, and the available mixing techniques. Strategy will be dictated by which method best ensures the proper mixing of the two materials at the least cost. The following options are seen to have the potential for feasibility under certain conditions:

1. Bring the fly ash to the refuse disposal site, mix the two and make the material available for general highway use.
2. Bring the fly ash and refuse to a third location which would act as a central facility for area-wide distribution.
3. Bring both the fly ash and refuse to the construction site in the required quantities and mix on site.
4. Transport refuse to the fly ash disposal site for mixing and make the material availability for general distribution.

Regardless of the site at which the two materials are combined, the fly ash must be uniformly dispersed throughout the mixture to ensure structural stability and to adjust the pH of the coal refuse. If this can be ensured, it is likely that the refuse and fly ash will be combined at the construction site. This would eliminate a handling step and an intermediate haul that would be necessary if the two were mixed at some other point. However, if proper mixing equipment is not available at the construction site, another location might be necessary for the proper combining of the refuse and fly ash.

If refuse and fly ash combinations eventually gain acceptance as a road building material, a large scale central facility could develop to supply refuse and fly ash on a general basis to construction companies in an area. This might be able to provide economies of scale in the transport of the two materials to make the prospect economical. However, they would have to overcome the environmental problems posed by the interim storage of the two materials. For the near term, it is more likely that fly ash and refuse would be obtained as needed for each particular job.

The Dodge Guide does not include a category that can be adequately applied to the costs of mixing fly ash and refuse. However, using cost factors in the guide, an estimate of the cost per cubic yard of mixing fly ash and refuse can be derived. Assuming the operation uses three 2-cubic yard front-end loaders to mix a total of 1000 cubic yards of refuse and fly ash per day, a cost of $.91 per cubic yard is obtained.[1] Escalated by 40 percent, the bid price is approximately $1.28 per cubic yard. This cost should be regarded as fairly high since it may not be necessary to utilize three front end loaders; two may be sufficient.

Once the mixing has been done, the placing and spreading costs should be similar to the costs for placing and spreading conventional materials. The Dodge Guide estimates a cost of $.50 per ton, or a bid price of approximately $.70 per ton, in addition to the cost of the material.[2]

Table 25 summarizes the cost estimates for the various stages discussed above. As mentioned, these figures are estimates based on national averages in the Dodge Guide, since information was unobtainable specifically for the northern West Virginia study area. What the estimates show are the relative proportions of the total costs that are expected to be included in a representative bid. All costs are based on mid-1978 dollars so that a meaningful comparison between the two alternative methods can be made.

Table 25 shows that the use of coal refuse and fly ash seems to be an advantageous proposition. In fact, a twenty mile haul for refuse and fly ash competes favorably with a five mile haul of conventional materials. Obviously, this advantage is gained because of the difference in the cost of materials. If refuse and fly ash can be obtained for nominal charges, the savings over conventional materials allow the transport distance to be much greater. Some of the savings are offset by increased charges for handling and mixing; under the assumptions here, refuse/fly ash combinations are still cheaper.

Figure 17 plots the bid prices presented in Table 25 as a function of haul distance. As can be seen, for a given conventional material use scheme, there exists a coal refuse/fly ash scheme that involves a longer haul for the same

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[1] 1978 Dodge Guide; 3 front end loader operators at $12.85/hr., 3 front end loaders at $170/day, one foreman at $12.00/hr.

[2] 1978 Dodge Guide, p. 93.

TABLE 25

COST BREAKDOWN ($) FOR CONVENTIONAL AND COAL REFUSE BASE COURSE MATERIALS[a]

| | | CONVENTIONAL MATERIAL | | | | REFUSE/FLY ASH[b] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | HAUL DISTANCE (miles) | | | | HAUL DISTANCE (miles) | | | |
| | | 1 | 5 | 10 | 20 | 1 | 5 | 10 | 20 |
| Material ($/c.y.) | Cost[c] | 4.50 | | | | 0.90[d] | | | |
| | Bid | 6.30 | | | | 1.26 | | | |
| Excavate and Load ($/c.y.) | Cost | 0.15 | | | | 0.15 | | | |
| | Bid | 0.21 | | | | 0.21 | | | |
| Transport ($/c.y.) | Cost | 0.74 | 1.51 | 2.49 | 4.42 | 0.74 | 1.51 | 2.49 | 4.42 |
| | Bid | 1.04 | 2.11 | 3.49 | 6.19 | 1.04 | 2.11 | 3.49 | 6.19 |
| Handling and Mixing ($/c.y.) | Cost | - | - | - | - | 0.91 | | | |
| | Bid | - | - | - | - | 1.28 | | | |
| Placing ($/c.y.) | Cost | 0.64 | | | | 0.61 | | | |
| | Bid | 0.89 | | | | 0.85 | | | |
| Total | Cost | 6.03 | 6.80 | 7.78 | 9.71 | 3.21 | 4.08 | 5.06 | 6.99 |
| | Bid | 8.44 | 9.51 | 10.89 | 13.59 | 4.64 | 5.71 | 7.09 | 9.79 |

[a]1978 Dodge Guide to Public Works and Heavy Construction; ERCO estimates.

[b]Assumes equal haul distance for fly ash and refuse.

[c]Bid price is cost plus 40 percent.

[d]Based on 3:1 ratio of refuse to fly ash and costs of $1.00 and $.62 per cubic yard respectively.

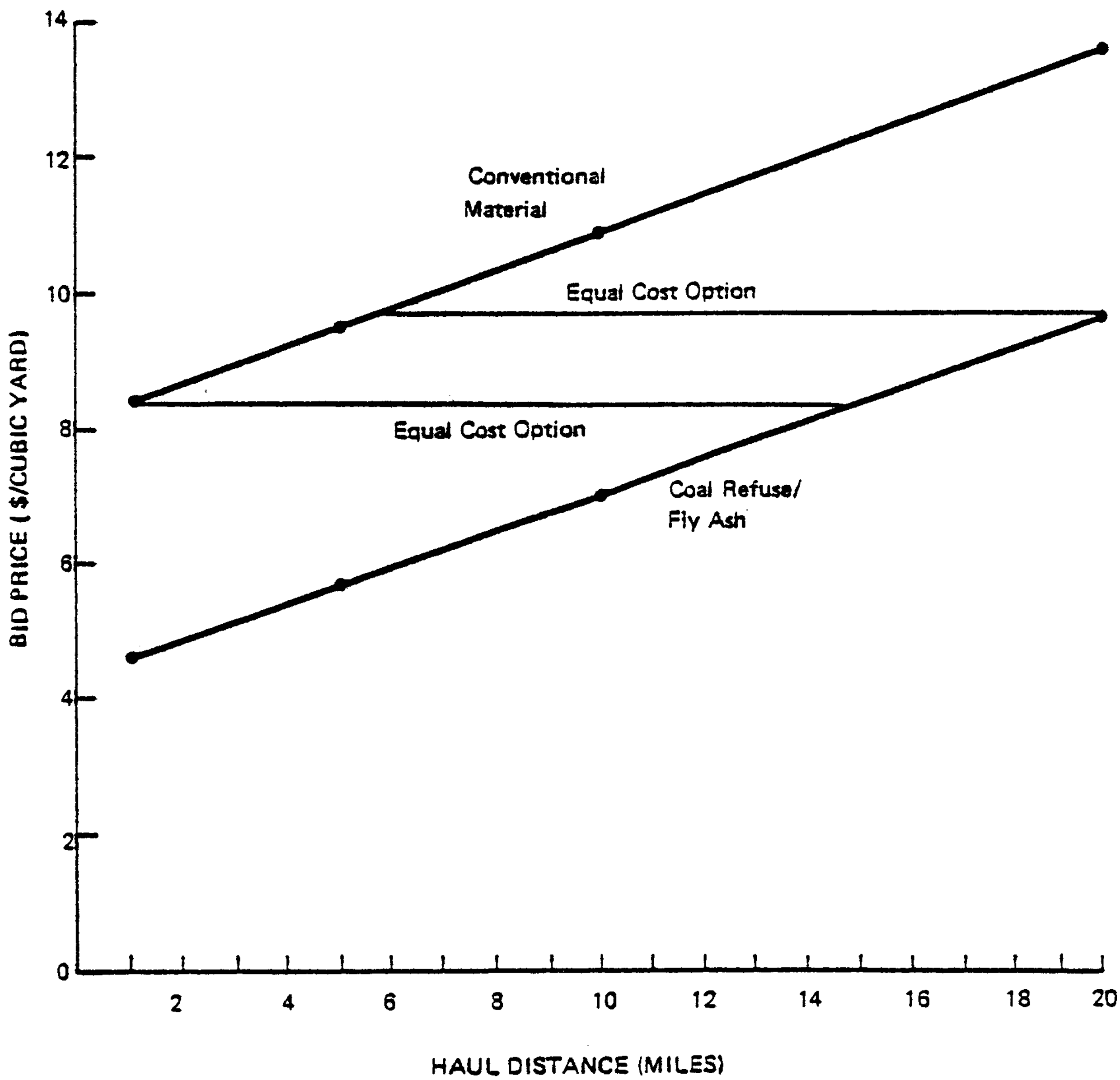


Figure 17. Comparison of subbase course delivered prices. (Source: Table 25)

overall cost. The extra distance that the refuse/fly ash can be transported is a function of the slopes of the cost to distance plots and the absolute price advantage coal refuse/fly ash combinations command. In the hypothetical situation illustrated in Figure 17, coal refuse/fly ash combinations enjoy a fourteen mile haul advantage; that is, they can be transported approximately fourteen miles farther than conventional materials and still remain equal in price.

Of course, site specific characteristics could change the slopes of both curves and the vertical distances between them. However, for a given amount of material per day, the slopes should be nearly parallel. The two materials are similar enough that differences in necessary equipment should be negligible (aside from the mixing equipment) and transportation charges for similar distances will be similar as well.

## Comparison with Current Surface Disposal Methods

The successful utilization of coal refuse as a highway base course presents many advantages over current disposal methods. Careful testing of the refuse from the Humphrey and Arkwright plants and fly ash supplies must be done before the ultimate feasibility can be established. Assuming that a structurally sound mixture and technique can be identified for placing the material in highway subbases and base courses, environmental as well as economic benefits should be accrued for the study area.

### Environmental Comparison

The disposal of the constant stream of refuse emanating from coal mines presents many hurdles to be overcome to prevent environmental damage. The problems of pile runoff, spontaneous combustion, and structural instability have been recounted above. The proper and successful use of coal refuse and fly ash for road base construction should avoid these problems if two basic requirements are met:

- Mixing of the materials must yield a fairly homogeneous substance.
- The material must be properly compacted to reduce void space and permeability.

If these two requirements are met (assuming the coal refuse/fly ash composition and proportions are suitable), the pH of the mixture is raised, the intrusion of water and air is kept to a minimum, the oxidation of pyrites and the swelling of the clays within the refuse is limited, the the possibilities of spontaneous combustion are virtually eliminated. Fortunately, the two requirements above must also be met to ensure the structural stability of the highway base course. Thus, a structurally sound mixture will be environmentally sound as well.

If refuse is properly used for road base construction, then the environmental problems attendant to disposal on the refuse pile will be eliminated for that incremental amount of refuse. The same is true with any fly ash used in the process. If a large amount of refuse is utilized from any one refuse disposal pile, the environmental problems for that pile could be significantly reduced. Unfortunately, localized demand for material from the study area will not significantly alter waste disposal pile volumes; the maximum possible usage of refuse (under the most optimistic assumptions) over a five-year period was estimated at 2.0 million cubic yards, while refuse generation from the Humphrey and Arkwright plants will be an estimated 7.5 million cubic yards during the same period. Thus, environmental improvement relative to present conditions is not expected to be a major factor in the use of refuse/fly ash mixtures.

### Economic Comparison

The proposed utilization scheme would reduce Consolidation Coal Company's expense for disposal of refuse, although the extent to which their bill would be reduced depends upon the degree to which a contractor would obtain the refuse from the refuse bin rather than the disposal pile. As mentioned above, refuse taken directly from the disposal pile may be the more advantageous method of obtaining the refuse, in which case disposal costs are not reduced. If the refuse is sold, overall disposal costs would be reduced by the amount of the charge. The amount sold, however, is not expected to constitute more than a small part of refuse generation. Thus, although it is in the interests of the Consolidation Coal Company to sell refuse or offer the refuse from its refuse bin, the overall effect on its total disposal costs and the delivered price of its coal is not expected to be significant.

The major economic benefits could be expected to be accrued in the construction of roads. With conventional aggregates averaging over $5.00/cubic yard, substantive savings could be realized by using refuse and fly ash supplied at low prices. The price charged by utilities and coal companies will certainly increase if demand for material increases and results in a situation where it is regularly used. However, since any price charged is a net benefit to the utility or coal company, competitive pressures should limit prices when large amounts of refuse are available in an area.

## Recommended Additional Research for Coal Waste Utilization

On the basis of the examination of prior work in the field of coal waste utilization, undertaken as part of this study, several recommendations for additional research can be made. The approach here is not simply to identify coal waste utilization techniques needing further study because there is good reason to conclude that all methods proposed for coal waste utilization can benefit from additional research. Rather, in view of the technology-development orientation of the U.S. Department of Energy (DOE), and in consideration of research now being funded by agencies of Federal and state governments, this section presents a number of recommendations for development of a compehensive coal waste utilization program within DOE.

### Summary Observations on Coal Waste Utilization

Although there has been considerable research done in relation to coal waste utilization, the fact remains that very few large-volume utilization techniques have been implemented successfully on a sustained basis. The major U.S. successes in this area have been achieved in Pennsylvania, where highway embankments have been built with coal refuse and where old anthracite refuse banks have been reprocessed for fuel recovery. Notable success in refuse bank and pond reprocessing for fuel recovery has also been achieved in a few local projects in West Virginia and Utah.

A review of the history of coal refuse utilization in the United States leads to several observations that provide useful insight into needed research areas:

1. A diversity of technology is now available for application to coal waste utilization, and developing technologies, in particular fluidized-bed combustion and advanced coal preparation processes, offer additional technical alternatives.

2. Full-scale application of large-volume coal waste utilization methods has been demonstrated in several areas of the country. However, projects undertaken with the support of public funds have been generally more successful than projects undertaken solely by the private sector, with a few exceptions.

3. Laboratory- and pilot-scale research addressing the suitability of specific refuse sources for various utilization methods has been somewhat limited, but results indicate that analytical methods for refuse

characterization are available and that refuses can be matched to most appropriate utilization methods.

4. The chemical and physical properties of coal refuse are quite variable, even within a single refuse source. However, for most utilization methods, the critical physical and chemical parameters are known and refuse variability within certain limits can be tolerated. Procedures for dealing with refuse variability have been investigated for some utilization methods.

5. There is no comprehensive coal waste utilization research program in the United States. Research efforts have been sponsored by several Federal and state agencies, and by industry, but without benefit of a central administrative body. This "shotgun" approach has produced much useful data and experience (see Table 26), but the fact remains that coal refuse generation rates are far greater than coal refuse utilization rates.

6. The economics of coal waste utilization are determined largely by refuse handling and transportation requirements and by local market conditions for refuse-derived products and materials. Increasingly stringent regulation of refuse disposal practices will likely provide an overall economic incentive for waste utilization, but local economic factors will still prevail.

7. Although many utilization methods are feasible, in the long run it is unlikely that more than 20 to 25 percent of the coal refuse generated can be productively utilized. Thus, research into improved refuse disposal methods and refuse bank and pond reclamation should be vigorously pursued.

With these thoughts in mind, a preliminary outline of an appropriate DOE coal waste utilization research effort has been developed. This outline is described below.

## Research Program Outline

The principal recommendation offered here is that the Department of Energy take steps to initiate within the Federal government a more coordinated program for increased coal refuse utilization in the United States. Since there are ongoing research efforts and other related programs within DOE and agencies such as the Federal Highway Administration

TABLE 26

SUMMARY OF COAL MINE WASTE RESEARCH (1964-1978)[1]

| CATEGORIES OF CITED REPORTS | NUMBER OF CITATIONS |
|---|---|
| Literature reviews | 11 |
| General energy/environmental impact | 19 |
| Conference and symposia proceedings | 6 |
| Surface mine reclamation and refuse bank revegetation | 15 |
| Mining technology and environmental impacts | 18 |
| Acid mine drainage | 12 |
| Coal preparation technology | 5 |
| Coal combustion technology | 4 |
| General feasibility of coal waste utilization | 7 |
| Physical/chemical properties of coal waste | 6 |
| Coal waste disposal and impacts | 19 |
| Coal waste as highway material | 4 (2 foreign) |
| Coal waste for brick production | 1 |
| Coal waste for alumina or sulfur recovery | 2 |

[1]From U.S. Department of Commerce, National Technical Information Service, Coal Mine Waste, A Bibliography with Abstracts, 1964 through January 1978, Springfield, Va., 1978, NTIS/PS-78-0052.

the Bureau of Mines, the Environmnental Protection Agency and the Office of Surface Mining, the establishment of an interagency steering committee on coal waste utilization seems to be in order. Preferably, such a commitee would also include representatives from state governments, industry, and universities engaged in coal waste research.

The purpose of the steering committee would be to provide a forum for the exchange of information and ideas that is critical to the design of a meaningful, cost-effective coal waste utilization research program. The future efforts of DOE or any agency with responsibility in this field can hardly be well-managed and conducted without a greater degree of cooperation than has been evident in the past. The historical "shotgun" research approach, as stated previously, has produced a great deal of baseline information on coal waste utilization; however, the overall U.S. program has suffered from the lack of high-level, coordinated program management. The existing Interagency Energy/Environment Research and Development Program has, as one of its many objectives, the demonstration of methods for reusing coal cleaning wastes, but efforts under this program would also benefit from a more focused interagency approach to coal waste utilization.

Within a coordinated interagency framework, the DOE coal waste effort must be more clearly defined in terms of program goals, priority research and development areas, and technology transfer mechanisms. A preliminary outline of the envisioned DOE program is provided in Table 27. Phase I of the effort would be performed in FY 1980 and would involve complete design of the program, addressing the items listed in Table 27. Phase II would begin in FY 1981, during which priority research, development and demonstration projects would be initiated.

TABLE 27

PRELIMINARY OUTLINE OF DOE COAL WASTE UTILIZATION RESEARCH PROGRAM

Phase I (FY 1980)

1. Participation in interagency steering committee on coal waste utilization. Members to include:
   - Department of Energy
   - Department of Interior
   - Environmental Protection Agency
   - Federal Highway Administration
   - Appalachian Regional Commission
   - State agencies
   - Coal industry
   - Academics
   - Consultants
2. Continuation of ongoing DOE research efforts in coal waste and combustion by-product utilization.
3. Definition of DOE coal waste utilization research goals and priorities.
   - Establish DOE coal waste utilization program with staff and authority
   - Program emphasis on newly-generated coal refuse or on utilization/reclamation of old refuse banks and impoundments (or both)
   - Program emphasis on large volume alternatives or on small volume alternatives (or both)
   - Identify local refuse utilization opportunities and desires and incorporate into program
   - Recognize practical limits on refuse volumes that can be utilized and maintain research efforts geared toward improved disposal and reclamation methods
   - Develop baseline information on available coal refuse data and coal refuse utilization programs completed and in-progress in the U.S. and abroad

TABLE 27 (Cont.)

4. Establish DOE coal waste utilization research tasks

   - Technology development--priority on the potential application of fluidized-bed combustion technology to coal refuse for fuel recovery (and possible use of residue for additional utilization methods)
   - Analysis of economic and financial factors affecting coal waste utilization--why have previous attempts at alumina recovery, fuel recovery and brick manufacture failed economically? What government incentives would be needed to improve the economics of certain utilization techniques? What government incentives are appropriate?
   - Institutional studies--how does private sector inertia affect coal waste utilization? How can such inertia be overcome? What legal and regulatory constraints inhibit increased coal refuse utilization?
   - Environmental impacts and costs--what are projected coal waste disposal costs under MESA and EPA regulations? What are the costs and benefits of refuse utilization versus surface disposal?

5. Establish technology transfer mechanisms

<u>Phase II (Starting FY 1981)</u>

1. Initiate DOE coal waste utilization research, development and demonstration programs.

## ANNOTATED BIBLIOGRAPHY

1. Adams, L.M., Capp, J.P., and Gillmore, D.W. "Coal Mine Spoil and Refuse Bank Reclamation with Powerplant Fly Ash." In Proceedings of the Third Mineral Waste Utilization Symposium. U.S. Bureau of Mines and ITT Research Institute, Chicago, IL, 1972.

Four surface mine spoil banks and three deep mine refuse banks were treated with coal fly ash. The acidity of the refuse was raised by the addition of fly ash. Vegetation was developed and analyzed for metals. High levels of boron are suggested to have caused toxicity symptoms. Leaching apparently accounts for decreased boron uptake and toxicity over the years. Fly ash reclamation costs per acre are provided.

2. Adams, L.M., Capp, J.P., and Eisentrout, E. Reclamation of Acidic Coal-Mine Spoil with Fly Ash. U.S. Bureau of Mines, Report of Investigation 7504, April 1971.

This paper preceded Adams et al., 1972, and investigated only reclamation of surface spoils. The latter paper also reported experiments on deep-mine refuse. Revegetation experiments are reported with some physical and chemical data on the spoils and fly ash.

3. Akers, D.J. Coal Refuse Disposal. Coal Research Bureau Report No. 137, West Virginia University, Morgantown, WV, 1977.

Provides information regarding proper construction of coal refuse piles and slurry impoundments in order to avoid advserve environmental impacts.

4. Akers, D.J., Jr., and Muter, R.B. "Coal Pile Stabilization and Reclamation." In Proceedings of the Fourth Mineral Waste Utilization Symposium. U.S. Bureau of Mines and ITT Research Institute, Chicago, IL, 1974.

Outlines design and operational mechanisms of coal refuse pile construction and maintenance for avoidance of adverse environmental, health and safety impacts.

5. Almes, Richard G. An Overview of Coal Tailings Disposal in the Eastern U.S. D'Appolonia Consulting Engineers, Pittsburgh, PA, undated.

Reviews coal tailings disposal in the eastern United States, identifying major disposal modes, characterizing refuse and summarizing the history of coal refuse disposal practices.

6. Andreuzzi, F.C. A Method for Extinguishing and Removing Burning Coal Refuse Banks. U.S. Bureau of Mines, Information Circular 8484, Washington, DC, 1970.

Describes approach to controlling a mine refuse bank fire by using high pressure water nozzles and spray piping to reduce temperatures, followed by removal of the material.

7. Babcock, A. "Fly Ash Achieving Dramatic Success in Reclaiming Coal Waste Piles." Coal Age, April 1973, pp. 88-89.

Discusses research -- past and ongoing -- regarding use of fly ash as an amendment for improving revegetation and reclamation of coal waste piles.

8. Backer, R.R., Busch, R.A., and Atkins, L.A. Physical Properties of Western Coal Waste Materials. U.S. Bureau of Mines, Report of Investigation 8216, Spokane, WA, 1977.

This paper is a companion paper to the authors' reports on eastern coal refuse. The research was performed at the Spokane Mining Research Center, Spokane, WA. Two western underground mines were studied for physical and chemical parameters. The mines were chosen to be similar to eastern mines so comparisons could be made between the two regions.

9. Bagge, Carl E., President, National Coal Association. Letter to President Carter, dated January 12, 1978.

This letter sets forth the National Coal Association's proposal to meet expanding coal supply demands. A list of new coal-fired steam electric generating plants by state for 1977 through 1986 is enclosed. Also, a state-by-state list of new coal mines and expansion of existing mines planned through 1985 is supplied.

10. Berger, T. "The Sintered Lightweight Aggregate Industry." In Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

The lightweight aggregate industry has experienced dramatic growth in the last 25 years. Coal refuse has been used as a raw material for lightweight aggregate with technical and commercial success. Numerous lightweight aggregate plants have been forced to close because of air pollution regulations, the high cost of ignition fuels, and the economic slowdown of the early 1970's.

11. Bishop, C.S., and Rose, J.G. "Physical and Engineering Characteristics of Coal Preparation Plant Refuse." In Proceedings of the 7th Ohio River Valley Soils Seminar on Shales and Mine Wastes: Geotechnical Properties, Design and Construction, October 1976.

Over 30 engineering and physical parameters of coal wastes were measured at the South-East Coal Company preparation plant in Estill County, Kentucky. Additionally, soil mechanics tests were performed on refuse from 17 eastern Kentucky plants and 6 western Kentucky plants. The significance of parameters on various uses of wastes is discussed.

12. Bishop, C.S., and Simon, N.R. "Selected Soil Mechanics Properties of Kentucky Coal Preparation Plant Refuse." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, September 1976.

This report is reproduced as a subsection of Bishop and Rose (1976). Grain size, plasticity, and California bearing ratios were among the parameters tested.

13. Bland, A.E., Robl, T.L., and Rose, J.G. "Kentucky Coal Preparation Plant Refuse Characterization and Uses." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, September 1976.

This paper is essentially the same as Rose (1976). The tables of normative mineralogy and elemental concentrations of 23 Kentucky coal waste samples are repeated. A section on Coal-Crete is appended to this report. Coal-Crete applications are limited to locations where temperature and humidity are nearly constant, such as underground mines. Cost data are included.

14. Bland, A.E., Robl, T.L., and Rose, J.G. "Evaluation of Interseam and Coal Cleaning Effects on the Chemical Variability of Past and Present Kentucky Coal Refuse." Transactions of the Society of Mining Engineers 262 (December 1977):331-334.

Refuse from 23 Kentucky preparation plants was examined. Both the Appalachian Coal Field (eastern Kentucky) and the Eastern Interior Coal Field (western Kentucky) were studied. Mineral and metal content as well as % ash, % sulfur, and Btu/lb are reported. The Hazard No. 4 seam in eastern Kentucky is noted to have particularly high alumina content (35-38%). Other papers discussing these samples are Bland (1976) and Rose (1976).

15. Breynton, D., and Rose, J. "Utilization of Coal Refuse as a Concrete Aggregate (Coal-Crete)." In Proceedings of the Fifth Mineral Waste Utilization Symposium. Chicago, IL, 1976.

A laboratory study was conducted using coal refuse from three different mine locations as aggregate for producing low-cost, low-quality concrete. The various mixes were evaluated for pillars in coal mines, allowing removal of the otherwise remaining coal pillars.

16. Brown, R.E., Wilson, T.C., and Thomasson, D.L. "Economic Evaluation of Coal Refuse Disposal Systems." In Third Symposium on Coal Preparation. National Coal Association/Bituminous Coal Research, Inc., Louisville, KY, 1977.

Provides cost data for 3 alternative coal refuse disposal systems: 1) mechanical fine refuse dewatering, 2) coarse refuse impoundment, and 3) settling ponds.

17. Brundage, R.S. "Depth of Soil Covering Refuse (Gob) vs. Quality of Vegetation." In First Symposium on Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Evaluated different thicknesses of soil covering over coal mine refuse with regard to effect on vegetation.

18. Busch, R.A., Backer, R.R., and Atkins, L.A. Physical Property Data on Coal Waste Embankment Materials. U.S. Bureau of Mines, Report of Investigation 7964, 1974.

Eight preparation plant sites in West Virginia are examined. In addition to engineering properties, mineral and metal content were measured. Graphs of grain size determinations are included. Emphasis was placed on obtaining accurate shear strength values because of their inmportance to embankment stability. Preparation plant processes for each plant are summarized. This report was funded by the Bureau of Mines in the wake of the 1972 Buffalo Creek disaster where flooding resulting from embankment failure caused 125 deaths.

19. Busch, R.A., Backer, R.R., Atkins, L.A., and Kealy, C.D. Physical Property Data on Fine Coal Refuse. U.S. Bureau of Mines, Spokane Mining Research Center. Report of Investigation 8062, Spokane, WA, 1975.

This sequel to Busch et al., 1974 (RI 7964) discusses the properties and use of fine coal waste.

Its conclusions are very exciting. Coal sludge contains about 30 percent ash and 10,000 Btu/lb. This subbituminous class material is high in alumina. Alcoa privately states that it is more economical to burn coal waste and recover the alumina than to recover alumina from imported bauxite. Computer codes for calculating direct shear strength of the fine wastes are provided.

20. Butler, P. "Utilization of Coal Mine Refuse in Highway Embankment Construction." In Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Since early 1973 the Pennsylvania Department of Transportation (PennDOT) has been actively engaged in the utilization of coal refuse for highway embankments. Laboratory tests of the material's physical characteristics were in good agreement with construction experience. The compaction characteristics of the material are of prime importance. Grain size distribution and moisture-density data demonstrated the importance of refuse degradation in obtaining maximum densities.

21. Buxton, J., Knavel, D., and Yost, G. "Sintered Coal Refuse as a Growing Medium for Plants." In Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

High-quality chrysanthemums and tomato transplants were grown in containers with mixes of peat and up to 75 percent sintered coal refuse. The refuse contains no toxic chemicals, is porous, does not compact, and would be less expensive than materials currently used such as perlite, vermiculite, and coarse sand.

22. Capp, J. P. "Powerplant Fly Ash Utilization to Reclaim Drastically Disturbed Lands in the Eastern United States." In Symposium on Reclamation of Drastically Disturbed Lands. Ohio Agricultural Research and Development Center, Wooster, OH, August 1976.

Fly ash applications to coal refuse piles are studied. The pH, soil character, conductivity, and moisture content of up to twelve untreated spoil banks are reported. Primary emphasis of the report is on plant yields of recovered refuse piles.

23. Capp, J.P., and Gillmore, D.W. "Fly Ash from Coal Burning Power Plants: An Aid in Revegetating Coal Mine Refuse and Spoil Banks." In First Symposium on

Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Describes use of fly ash in reclaiming and revegetating coal mine refuse disposal areas and spoil banks. Includes results of tests of response of various types of vegetation to fly ash treatement.

24. Capp, J.P., Gillmore, D.W., and Simpson, D.G. "Coal Waste Stabilization by Enhanced Vegetation." Mining Congress Journal 61:44-49. Morgantown Energy Research Center, U.S. Bureau of Mines, Morgantown, WV, 1975.

Discusses benefits and problems associated with use of fly ash in mine spoil vegetation. Includes costs.

25. Charmbury, H. "Utilization of Pennsylvania Anthracite Refuse." In Proceedings of the First Kentucky Coal Refuse Disposal and Utilization Seminar. Cumberland, KY, 1975.

This paper discusses some of the research conducted by Pennsylvania State University in the late 1960's and early 1970's regarding the potential uses for anthracite refuse. Recovery of coal is currently the prime mode of utilization. Alumina extraction appears attractive though at the moment uneconomical. "Red dog" has been used successfully as an aggregate in highway bituminous mix and as a soilless medium for crops.

26. Charmbury, H., Chubb, W., and Witkowski, F. The Utilization of Incinerated Anthracite Mine Refuse as an Aggregate in Bituminous Mixes for Surfacing Highways. Pennsylvania State University, Report No. SR-96, University Park, PA, 1973.

Red dog was crushed and sized, and subsequently mixed with 7 to 8 percent asphalt cement and 6 percent filler. Four road tests were conducted by the Pennsylvania Department of Transportation. Monthly inspections revealed no signs of distress over 2-1/2 years. Skid resistance was good.

27. Charmbury, H., and Chubb, W. Operation Anthracite Refuse. Pennsylvania State University, Report No. SR-94, University Park, PA, 1973.

This report provides a summary of a major research effort spanning nearly five years by the Coal Research Section at Pennsylvania State University. The work consisted of three phases: literature survey, laboratory and bench scale testing, and field testing. Three new uses (anti-skid material, soilless growth medium, and aggregate in blacktop surfacing) were developed.

28. Charmbury, H.B., and Maneval, D.R. "The Utilization of Incinerated Anthracite Mine Refuse as Anti-Skid Highway Material." In Proceedings of the Third Mineral Waste Utilization Symposium. U.S. Bureau of Mines and ITT Research Institute, Chicago, IL, 1972.

Burned anthracite refuse from uncontrolled burning embankments is shown to be an effective anti-skid material when properly crushed and sized. Essential properties, such as size, particle shape and foreign materials content, for anti-skid material are listed.

29. Charmbury, H. "Utilization of Coal Mining Wastes." In Proceedings of the First Mineral Waste Utilization Symposium. Chicago, IL, 1968.

The author, Secretary of Mines and Mineral Industries for the State of Pennsylvania, made general comments about past, current and future methods of disposing of and/or utilizing coal refuse.

30. Coalgate, J. A Study of Coal-Associated Wastes Resulting from the Mining, Processing and Utilization of Coal. U.S. Energy Research and Development Administration, Interim Report No. 2, Washington, DC, 1975.

This literature survey of coal-associated wastes (1900-1972) is a bibliography, sometimes briefly annotated, which includes many articles published around the world.

31. Collins, R.J., and Miller, R.H. Availability of Mining Wastes and their Potential for Use as Highway Material. Vol. I: Classification and Technical and Environmental Analysis. U.S. Department of Transportation, Report No. FHWA-RD-76-106, Washington, DC, May 1976.

Coal wastes are one of many mining wastes discussed in this report. Sources and amounts of coal waste are briefly reported. Chemical and mineralogical properties are also reported, especially in regard to coal waste use for highway construction. One hundred and thirty references are included.

32. Condry, L. Recovery of Alumina from Coal Refuse: An Annotated Bibliography. Coal Research Bureau Report No. 130, West Virginia University, Morgantown, WV, 1976.

The report is based on a literature search covering the period 1900 to June 1976. Emphasis is on fly ash rather than coal refuse as a source of alumina.

33. Connell, J.P. "Construction Guidelines for Pollution Control from Coal Refuse Piles and Slurry Ponds." In Third Symposium on Coal Preparation. National Coal Association/Bituminous Coal Research, Inc., Lousiville, KY, 1977.

Presents guidelines for proper construction and operation of refuse disposal piles and slurry ponds.

34. Davidson, W.H. "Reclaiming Refuse Banks from Underground Bituminous Mines in Pennsylvania." In First Symposium on Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Makes recommendations for successful reclamation and revegetation of mine refuse disposal heaps.

35. Dmytriw, S.W., Mazzei, D., and Ke-Kang Wu, K. "Modifying Slopes to Improve Embankment Stability." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

Parameters which affect embankment stability are discussed. A Factor of Safety is calculated based on shearing resistance and shearing force. Three models for slope failure are examined and preventative construction measures are proposed.

36. Donovan, R.P., Felder, R.M., and Rogers, H.H. Vegetative Stabilization of Mineral Waste Heaps. U.S. Environmental Protection Agency, Office of Research and Development, EPA-600/2-76-087, Washington, DC, 1976.

Describes technologies and benefits of vegetating mineral waste heap surfaces.

37. Dorr-Oliver, Inc. Operation Red Dog: A Study of Fluid-Bed Combustion and Potential Uses of Anthracite Culm-Bank Material. U.S. Department of Interior, Office of Coal Research, Washington, DC 20240.

Bench-scale fluid-bed combustion tests were conducted with anthracite refuse to remove carbon and sulfur from the solid residue. The calcined refuse was tested as material for highway construction and brickmaking. A schematic pilot plant was developed, and an economic evaluation of the project was prepared. The combined FBC and brick-fabricating facilities were estimated to have a 10.3 percent return on investment and the capacity to process 735 tons of refuse per day.

38. Doyle, F.J., Bhattand, H.G., and Rapp, J.R. Analysis of Pollution Control Costs. Prepared for Appalachian Regional Commission and Office of Research and Development, U.S. Environmental Protection Agency, EPA-670/2-74-009, 1974.

Report details costs for all aspects of pollution control with respect to mining and other polluting activities in the Monongahela River Basin.

39. Drake, W. "Coal Refuse in Highway Embankments and Aggregates." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

Highway design typically attempts to balance cuts and fills. The local availability of suitable coal refuse may make economical and expedient the recourse of borrowing more and cutting less. Coal refuse aggregate is likely to find little use on Kentucky highways.

40. Drnevich, V.P., Williams, G.P., and Ebelhar, R.J. "Soil Mechanics Tests on Coal Mine Spoils." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

An excellent article which explicitly describes soil mechanics tests and their application to design of spoil banks. Engineering parameters are shown to be related to inexpensively determined index properties. Five methods of building a spoil bank are evaluated.

41. Dunn, J.R., Banino, G.M., and Ernst, W.D. The Physical and Chemical Characteristics of Available Materials for Filling Subsurface Coal Mines. U.S. Bureau of Mines. Final Report, Contract No. J0155182, June 1977.

Several types of material were tested for applicability for filling mines. No chemical tests were done on the coal refuse samples. However, several physical properties are reported for those samples.

42. Falkie, T.V., Gilley, J.E., and Allen, A.S. "Overview of Underground Refuse Disposal." In First Symposium on Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Reviews methods of disposal of coal mining refuse, including surface disposal, underground disposal and utilization.

43. Ford, C.T., and Boyer, J.F. Effect of Coal Cleaning on Fugitive Elements: A Progress Report. Bituminous Coal Research, Inc., Monroeville, PA, September 1978.

This paper reports on an extensive coal washing procedure designed to remove fugitive elements. The resulting coal is less polluting when burned, but the coal mining wastes become more toxic. The investigating team will eventually study twenty coals. Elemental concentrations for two coals are presented along with percent removal in the washing procedures.

44. Ford, C.T., Care, R.R., and Bosshart, R.E. Preliminary Evaluation of the Effect of Coal Cleaning on Trace Element Removal. Bituminous Coal Research Inc., Monroeville, PA, Trace Element Program Report No. 3, July 1976.

Eight coals were washed in a laboratory environment with a concentrating table. The concentrating table process uses gravity separation and a crosscurrent water stream to push clean coal off the top of the heavier refuse. Major and trace element concentrations are reported for the pre- and post-cleaned coal. Concentrations are also listed for two refuse fractions, pyritic and nonpyritic refuse.

45. Freedland, J.W., and Sawyer, S.G. Experience in Field and Laboratory Compaction Testing of Coarse Coal Mine Waste. Mining Enforcement and Safety Administration, Mine Waste Branch, Pittsburgh Technical Support Center, Pittsburgh, PA, undated.

Field densities and laboratory compaction test results are reported for three disposal sites in western Pennsylvania. Wide variations in specific gravity were found at a given disposal site. The refuse samples exhibit the typical moisture content-dry density relationship, i.e., a particular moisture content gives the maximum dry density with values for density dropping off as moisture is either increased or decreased. Compaction rather than moisture content control is suggested to be the superior method to achieve long-term stability.

46. Gleason, V. A Bibliography on Disposal of Refuse from Coal Mines and Coal Cleaning Plants. U.S. Environmental Protection Agency, Cincinnati, OH, 1978.

This comprehensive work contains nearly 500 references to books and articles on coal refuse disposal and utilization, dating from 1893 to 1977. Each entry is annotated. Materials are part of the BCR Library in Monroeville, PA.

47. Glover, H. "The Disposal of Coal Mine Spoil in the United Kingdom." In <u>Environmental Management of Mineral Wastes</u>. Edited by G. Goodman and M. Chadwick. The Netherlands, 1978.

This is a comprehensive, reasonably detailed paper of the coal refuse situation in England, Scotland, and Wales. Both fresh and weathered refuse are characterized chemically and physically. Legislation affecting disposal and reclamation is discussed. Relatively brief mention is made of various utilization techniques.

48. Goodboy, K. "Investigations of a Sinter Process for Extraction of $Al_2O_3$ from Coal Wastes." <u>Metallurgical Transactions</u> B 7B(4), 1976.

The presence of sulfur in coal refuse results in different chemical reactions from those in the conventional lime sinter process. Calcium sulfoaluminate is formed which leaches rapidly, allowing recovery of aluminum oxide. Excess calcium sulfate improves the aluminum oxide extraction, but also accounts for the formation of sodium sulfate.

49. Grube, W.E., Jr., Harris, E.F., and Martin, J.F. <u>Disposal of Coal Mining Industry Byproducts</u>. U.S. Environmental Protection Agency, Cincinnati, OH, 1976.

Land disposal of washing plant wastes, acid mine drainage neutralization sludges, powerplant fly ash and bottom ash, and flue gas desulfurization sludges is discussed. The formation of coal is briefly noted in a discussion of the origin of coal contaminants.

50. Hammond, J. "Lightweight Aggregate as a Construction Material." In <u>Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar</u>. Lexington, KY, 1977.

An overview of the lightweight aggregate industry is presented. The products range from extremely light materials (perlite and vermiculite) for making concrete with good insulating value to heavier materials (clay and shales) for concrete with good structural properties. Annual production in 1976 was 7.5 million cubic yards. Fuel costs and pollution abatement costs are creating premium prices for lightweight aggregates.

51. Hayes, E.T. "Energy Resources Available to the United States, 1985 to 2000." <u>Science</u> 203(4377):233-239 (1979).

Earl Hayes was formerly chief scientist at the U.S. Bureau of Mines. His energy supply outlook is pro-coal.

Data are presented which show that proven reserves of petroleum and natural gas peaked in the early 1970's. Energy growth which has risen 3 to 3-1/2 percent per year since 1940 is estimated to slow to less than 1 percent by the year 2000.

52. Hill, R.D. "Water Pollution from Coal Mines." Paper presented at 45th Annual Conference - Water Pollution Control Association of Pennsylvania. August 9, 1973.

Presents chemistry of acid mine drainage formation, indicates sources of pollution, and suggests methods of treatment and control.

53. Hill, R.D. and Montague, P.E. "The Potential for Using Sewage Sludge and Compost in Mine Reclamation." Presented at the 3rd National Conference on Sludge Management, Disposal and Utilization. Miami, Florida, December 14-16, 1976.

Discusses potential for using sewage sludge and sludge compost for reclamation of strip mined areas and strip mine spoils.

54. Hoffman, D.C., and Snyder, G.A. "Chemical Stability of Fine Coal Refuse with Calcilox™ Additive Stabilization Techniques." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

Refuse production figures are given for the eastern states for 1975: 214 million tons of coal cleaned, resulting in 71 million tons of coarse refuse and 16 million tons of fine refuse. Optimal values of dry density, grain size, and water content are listed for embankment stability. The special problems of fine refuse are discussed.

55. Hudson, L. "Aluminum from Coal Wastes?" In Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

The three major processes for extraction of alumina from ores are described and compared. Both the acid and sintering processes are more capital-intensive and energy-intensive than the Bayer process used with bauxite. Recovery of alumina from coal refuse would require either the acid or sintering process. The relative cost of the ores thus is critical.

56. Humphreys, K., and Lawrence, W. Production of Mineral Wool Insulating Fibers from Coal Ash Slag and Other Coal Derived Waste Materials. Coal Research Bureau

Report No. 53, West Virginia University, Morgantown, WV, 1970.

Coal ash slags and modified fly ash were used successfully to produce mineral wool of commercial quality. Coal mining and washery wastes were not used in this bench-scale test.

57. Jackson, G., and Ware, W. The Feasibility of Utilizing Solid Wastes for Building Materials. U.S. Environmental Protection Agency, Washington, DC, 1977.

A number of solid wastes were identified with potential for matrices, reinforcements, or fillers in building composites. Coal refuse ranked slightly lower than fly ash as a filler in fire-retardant products such as partition walls and fire-door cores, but only on the basis of its narrower range of geographic distribution.

58. Katell, S. The Potential Economics of the Recovery of Trace Elements in Coal Refuse. Coal Research Bureau Report No. 142, West Virginia University, Morgantown, WV, 1977.

The report is based on a cost analysis of a hypothetical plant designed to produce 80,000 tons of alumina and 615,888 tons of cement per year from coal refuse. Return on investment was estimated to be 10.15 percent.

59. Kealy, D., et al. "Those Waste Banks Could Be Sources for Fuel, Alumina." Coal Mining Progress 13(8), 1976.

The article summarizes research performed by the Spokane Mining Research Center: Physical Property Data on Fine Coal Refuse by Busch, Backer, Atkins and Kealy.

60. Keystone Coal Industry Manual. Edited by G.F. Nielson. New York: McGraw-Hill, 1978.

61. Kosowski, Z.V. Control of Mine Drainage from Coal Mine Mineral Wastes. Phase II, Pollution Abatement and Monitoring. Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, DC, EPA/R2-73-230, 1973.

Presents results of a demonstration project studying minimization of pollution due to coal mine refuse piles and slurry lagoons. Focus is on establishment of a vegetative cover.

62. LaRosa, P., and Michaels, H. Study of Sulfur Recovery from Coal Refuse. U.S. Environmental Protection Agency, Cincinnati, OH, 1971.

Laboratory tests were performed in which coal refuse and limestone were ground, pelletized, and introduced into a desulfurizing shaft. The products are a fired ash pellet and $H_2S/SO_2$ offgas, the latter to serve as feedstock for a conventional sulfur recovery plant. Experimental results indicate technical and economic feasibility.

63. Lawrence, W., and Slonaker, J. Gob Aggregate Concrete Products. Coal Research Bureau Report No. 120, West Virginia University, Morgantown, WV, 1976.

Structural concrete products were prepared using raw coal waste as aggregate. The products had favorable compressive strength and withstood simulated mine fires better than commercial products. The major detrimental factor was their poor resistance to weathering.

64. Libicki, J. "Impact of Gob and Power-plant Ash Disposal on Groundwater Quality and Its Control." In Third Symposium on Coal Preparation. National Coal Association/Bituminous Coal Research, Inc., Louisville, KY, 1977.

Discusses potential groundwater contamination problems associated with coal mine refuse disposal. Compares relative effects of a variety of disposal site designs. Makes recommendations regarding site design for groundwater protection.

65. Longwell, C.R., Flint, R.F., and Sanders, J.E. Physical Geology. New York: John Wiley and Sons, 1969.

This introductory geology textbook covers the formation of coal, its distribution, and its composition. A wide range of other geological topics are covered.

66. MacLean, D., Kogelmann, W., and Spicer, T. Investigation of the Haldex (Simdex) Process for Beneficiating Coal Refuse: Hungarian Practice. Pennsylvania State University, Report No. SR-80, 1971.

The Tatabanya Plant in Hungary is reported to separate coal refuse into several marketable streams. The Haldex cyclone allows efficient separation. The waste product is used for bricks, cement manufacture, lightweight aggregate, and for subsurface stowage.

67. Magnuson, M.O., and Cox, R. "Environmental Protection of Surface Areas Near Underground Mining Sites." Coal Age, 1975, 135-138.

Reviews environmental problems associated with underground mining sites (subsidence, acid mine drainage and mine refuse). Indicates projected Bureau of Mines research programs regarding these problems.

68. Maneval, D. "Reprocessing of Coal Refuse for a Second Yield of Steam Coal." In Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

This paper documents recent experience, both in the United States and abroad, with the capture of coal content of old coal refuse banks. Techniques include direct combustion in conventional boilers, mixture with higher grade coals, washing, and fluid-bed combustion.

69. Maneval, D. "Coal Refuse Utilization Prospects: An Update of Recent Work." In Proceedings of the Second Symposium on Coal Preparation. Louisville, KY, 1976.

This paper reviews the most recent developments in coal refuse utilization by both public and private entities. Special attention is given to a number of research activities conducted by the University of Kentucky. These include engineering parameters of the refuse, several utilization experiments, and market research for refuse-produced products.

70. Maneval, D. "Recent European Practice in Coal Refuse Utilization." In Proceedings of the First Kentucky Coal Refuse and Utilization Seminar. Cumberland, KY, 1975.

This paper discusses the occurrence, magnitude, properties and utilization of coal mine refuse. The experience of the British National Coal Board in marketing fresh and weathered refuse is highlighted. Suggestions are presented on how research and demonstration may lead to increased acceptance and usage of coal refuse.

71. Maneval, D. "Utilization of Coal Refuse for Highway Base or Subbase Material." In Proceedings of the Fourth Mineral Waste Utilization Symposium. Chicago, IL, 1974.

The article reviews the experience of the British National Coal Board, particularly with regard to the utilization of coal refuse for highway embankments. The success of these projects, from both engineering and environmental perspectives, has encouraged pilot projects in Pennsylvania and West Virginia.

72. Martin, J.F. "Coal Refuse Disposal in the Eastern United States." News of Environmental Research. Industrial Waste Treatment Research, U.S. Environmental Protection Agency, Cincinnati, OH, December 27, 1974.

Reviews pollution problems associated with coal mine refuse disposal.

73. Martin, J.F. "Quality of Effluents from Coal Refuse Piles." In First Symposium on Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Reviews whole problem of water contamination due to coal mine refuse, including: 1) refuse production, 2) disposal pile construction, and 3) impacts on water quality.

74. Martin, John F. The Impact of Coal Refuse Disposal on Water Quality. U.S. Environmental Protection Agency, Cincinnati, OH, 1976.

Reviews the variety of impacts that leachates, acid drainage and siltation associated with coal refuse disposal may have on water quality.

75. Martin, J.F., Scott, R.B., and Wilmoth, R.C. "Water Quality Aspects of Coal Refuse Utilization." In Proceedings of the First Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1975.

Reviews several approaches to coal refuse utilization, evaluating effect on water quality.

76. Massey, H.F., and Barnhiser, R.I. "Copper, Nickel and Zinc Released from Acid Coal Mine Spoil Materials of Eastern Kentucky." Soil Science 113 (1972):207-212.

Describes experimental results regarding leachate of copper, nickel and zinc from acid coal mine spoils and notes the potential toxicity of these metals to plants.

77. McBride, J.P., Moore, R.E., Witherspoon, J.P., and Blanco, R.E. "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants." Science 202(4372) (December 8, 1978).

The authors list uranium ($\sim$1 ppm) and thorium ($\sim$2 ppm) concentrations in Appalachian and Interior coals. Refuse is not listed separately. Values were taken from the U.S.G.S. Open File Report 76-468 (Swanson et al.). The main thrust of the report is radioactivity doses to man around a coal-fired power plant.

78. McNay, L.M. Coal Refuse Fires: An Environmental Hazard. U.S. Bureau of Mines, Information Circular 8515, Washington, DC, 1971.

Reviews causes and means for preventing and controlling mine refuse bank fires. Discusses environmental impacts of fires and presents data on the number and location of existing fires at the time of writing.

79. Mei, J., Gall, R., and Wilson, J. "Fluidized-Bed Combustion of Anthracite Refuse." In Proceedings of the Twelfth Intersociety Energy Conversion Engineering Conference. 1977.

The Morgantown Energy Research Center of the U.S. Energy Research and Development Administration conducted bench-scale burns of anthracite refuse from five widely differing samples in an 18-inch AFBC. Bed temperatures of 800-900° C were maintained with no supplemental fuels. Combustion efficiency ranged from 70 to 94 percent.

80. Metheny, D. "Thermal Disposal of Fine Refuse in a Fluidized Bed." In Proceedings of the Second Symposium on Coal Preparation. Louisville, KY, 1976.

Slurries (thickener underflows) from coal preparation plants were combusted in an 18-inch diameter fluidized bed. Optimum slurry concentrations appeared to be 38 to 42 percent solids. Operating temperatures of 1400-1700° F were maintained without additional fuel. Ash pellets produced were relatively inert and not subject to degradation by weathering.

81. Meyers, J.F., Pichumani, R., and Kapples, B.S. Fly Ash as a Construction Material for Highways. Department of Transportation, Federal Highway Administration. Report No. FHWA-IP-76-16, Washington, DC, 1976.

Fly ash uses and characteristics are examined to great depth. Worth noting in regard to coal refuse use is the discussion on pozzolanic reactions. A carbon content of 7 to 10 percent is the upper limit for these reactions.

82. Michael Baker, Jr., Inc. Investigation of Mining-Related Pollution Reduction Activities and Economic Incentives in the Monongahela River Basin. Appalachian Regional Commission, Washington, DC, 1975.

This study was performed by the Appalachian Regional Commission to identify feasible economic incentives which would encourage the private sector to undertake environmental improvement activities on abandoned and active coal mining operations in the basin. In addition to reclamation and reduction of acid drainage, a number of productive uses of coal waste are evaluated, based largely on a literature review.

83. Morrison, R., and Kinder, D. "Coal Ash and Coal Refuse: New Potential Resources." In Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

This paper discusses in general terms the resource potential of coal refuse and power plant ash.

84. Moulton, L.K., Anderson, D.A., Seals, R.K., and Hussain, S.M. "Coal Mine Refuse: An Engineering Material." In Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. National Coal Association, Louisville, KY, 1974.

Coal refuse from north central and northwestern West Virginia is identified by physical characteristics and engineering properties. Mines examined include Shoemaker Mine, McElroy Mine, Humphrey Mine, and Badger Mines. Each engineering test is described in detail. Results of a study using coal refuse as a base for a parking lot indicate its potential in this use.

85. Myers, J.W., Pfeiffer, J.J., Murphy, E.M., and Griffith, F.E. Ignition and Control of Burning Coal Mine Refuse. U.S. Bureau of Mines, Report of Investigation 6758, Spokane, WA, 1966.

Discusses parameters affecting spontaneous ignition of mine refuse, including particle size and percent of combustible material. Evaluates methods of ignition and fire control such as capping with fine refuse, applying water as a spray-on by injection.

86. National Academy of Sciences. Underground Disposal of Coal Mine Wastes. Washington, DC, 1975.

Reviews coal mine refuse disposal problem and outlines technical and economical feasibility of underground disposal of the wastes. Also covers legal parameters affecting mine waste disposal.

87. National Coal Association. First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, KY, October 22-24, 1974.

88. National Coal Association. Third Symposium on Coal Preparation. National Coal Association and Bituminous Coal Research, Inc., Louisville, KY, October 18-20, 1977.

89. Nicholson, D.E., and Wayment, W.R. Properties of Hydraulic Backfills and Preliminary Vibratory Compaction Tests. U.S. Bureau of Mines Report of Investigation 6477, Spokane Mining Research Laboratory, Spokane, WA, 1963.

This early report looks at the physical properties of fill from four mines using inplace and laboratory tests. These mines were backfilled with mine tailings after being mines out. A rigorous discussion of the results of the tests, such as triaxial stress and compaction tests, is included.

90. Nielson, G.F. "Keystone Forecasts 765 Million Tons of New Coal Capacity by 1987." Pp. 674-685 in Keystone Coal Industry Manual. New York: McGraw-Hill, 1978.

This article by the Editor-in-Chief of the Keystone Coal Industry Manual predicts new coal capacity by state and by mine. When added to present production, new capacity equals future coal production. However, some new capacity is replacement tonnage for abandoned mines. About 12 to 15 million replacement tons annually are suggested for eastern coal areas.

91. Norman, P. "Combustion of Colliery Shale in a Fluidized Bed." Energy World (18):2-4, July 1975.

Laboratory-scale combustion of coal waste was conducted after drying and crushing the refuse. Bed temperatures of 800-900° C resulted in the combustion of the refuse, but additional fuel (1 to 2 percent propane, or 10 percent coal) was required to maintain combustion.

92. Nunenkamp, D.C. Coal Preparation Environmental Engineering Manual. U.S. Environmental Protection Agency, Office of Research and Development, EPA-500/2-76-138, Washington, DC, 1976.

Discusses coal preparation plants, technologies, wastes produced and means for dealing effectively with those wastes to avoid adverse environmental effects.

93. PAT (Practical Available Technology) Report. "Stabilizing Waste Materials for Landfills." Environmental Science and Technology 11 (May 1977):5.

This paper contains a brief but comprehensive review of water movement in a landfill. Fly ash slurry ponds are the example studied. A commercial stability process, Poz-O-Tec, developed by IU Conversion Systems, is also described.

94. Pedco Environmental, Inc. Study of Adverse Effects of Solid Wastes from All Mining Activities on the Environment. Prepared for the U.S. Environmental Protection Agency, Industrial Extraction Processes Division, Contract No. 58-01-4700, Preliminary Draft, June 1978.

Study reviews the adverse environmental effects of solid wastes generated by the mining industry. Profiles mining industry, waste production and reclamation (disposal), as well as evaluating environmental and health impacts and discussing related laws and regulations.

95. Peluso, R.G. "A Federal View of the Coal Waste Disposal Problem." Mining Congress Journal (January 1974):14-17.

Reviews coal waste problem from federal point of view, discussing related regulatory activity, and outlining the MESA program of dealing with the problem.

96. Peters, J., Spicer, T., and Lovell, H. A Survey of the Location, Magnitude, Characteristics, and Potential Uses of Pennsylvania Refuse. Pennsylvania State University, Report No. SR-67, University Park, PA, 1968.

Over 150 years of coal mining in Pennsylvania has resulted in refuse banks of over 500 million tons. This study shows their location and estimated quantities. Over 170 million tons of recoverable coal is estimated to lie in these banks. Particle size, washability, and chemical data are presented for samples from each of the four major anthracite fields. Quality coals and low-grade fuels could be recovered by washing. Intermediate gravity fractions could be used for lightweight aggregate.

97. Peterson, R. "Engineering Properties of Coal Waste Embankment Material." In Proceedings of the First Symposium on Underground Mining. National Coal Association, Washington, DC, 1975.

This paper briefly defines and illustrates the major soil mechanics, characteristics and tests necessary to understand the performance of coal refuse when utilized for embankments.

98. Ray, S.S., and Parker, F.G. Characterization of Ash from Coal-Fired Power Plants. Office of Energy, Minerals, and Industry, Office of Research and

Development, U.S. Environmental Protection Agency. Report No. EPA-600/7-77-010, Washington, DC, 1977.

Extensive tables of elemental concentrations of Appalachian and Eastern Interior coals are included in this report on fly ash. The information is compiled from numerous sources.

99. Robl, T., and Bland, A. "The Distribution of Aluminum in Shales Associated with the Major Economic Coal Seams of Eastern Kentucky." In Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

Eastern Kentucky coal refuse has potential as an alumina source if an acid extraction process is used since all of the samples contain more than the minimum $Al_2O_3$ required. The deposits do not appear sufficiently rich for alkaline extraction. Western Kentucky does not show promise for alumina recovery.

100. Robl, T., Bland, A., and Rose, J. "Kentucky Coal Refuse: A Geochemical Assessment of Its Potential as a Metals Source." In Proceedings of the Second Symposium on Coal Preparation. National Coal Association, Louisville, KY, 1976.

Coal refuse samples from 23 of the largest preparation plants in Kentucky were analyzed. Total sulfur, Btu, and ash contents were determined. Large differences were found between the eastern and western Kentucky fields. Eastern Kentucky refuse has a higher $Al_2O_3$ content (from 21 to 38 percent), the highest being the Hazard No. 4 seam. An acid process such as the Pechiney $H^+$ is most attractive.

101. Rose, J. "Sintered Coal Refuse Lightweight Masonry Aggregates." In Proceedings of the North American Masonry Conference. 1978 (preprint).

Bituminous coal refuse from five preparation plants in eastern Kentucky was successfully sintered on a traveling grate to produce lightweight aggregate. Standard size concrete blocks were fabricated which met all applicable ASTM standards. The process uses a material already mined, partially crushed, containing 3/4 of the fuel required for sintering. The blocks are 30 percent lighter than conventional blocks, saving in handling and transportation, and are 45 percent better insulators.

102. Rose, J. "Sintered Coal Refuse as a Construction Aggregate." In Proceedings of the Third Kentucky

Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

Coal refuse was quick-fired on a pilot traveling grate machine to produce sintered lightweight aggregate. Its performance in three products was tested: Portland cement concrete, bituminous (or asphalt) mixes for paving, and concrete block. All three products had acceptable performance characteristics.

103. Rose, J.G., Robl, T.L., and Bland, A.E. "Composition and Properties of Refuse from Kentucky Coal Preparation Plants." In Proceedings of the Fifth Mineral Waste Utilization Symposium. Chicago, IL, April 1976.

This is a companion paper to Bland (1976) and Bland (1977). Mineral and metal content of refuse from 23 sites is reported. Slow-fire tests for structural clay product suitability and quick-fire tests for lightweight aggregate were performed. A few samples are reported suitable for lightweight aggregate and ten suitable for clay products. Minimum properties required for clay use are listed.

104. Scott, R., Wilmoth, R., and Light, D. Utilization of Fly Ash and Coal Mine Refuse as a Road Base Material. U.S. Environmental Protection Agency, Cincinnati, OH, 1978.

This paper describes the experience with three test areas of an EPA parking lot constructed using a coal refuse/fly ash base. Leachate was monitored for five years. Core samples were removed and tested for deterioration. Total performance was satisfactory.

105. Smith, R.M., Grube, W.E., Jr. , Akkle, T., Jr., and Sober, A. Mine Spoil Potentials for Soil and Water Quality. National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, 670/2-74-070, Cincinnati, OH, 1974.

Discusses analytical methods applicable to overburden wastes resulting from surface mining operations, and makes recommendations regarding useful testing and classification systems.

106. Snyder, G.A., Zuhl, F.A., and Burch, E.F. "Solidification of Fine Coal Refuse." Mining Congress Journal (December 1977):43-46.

Describes DRAVO process of adding Calcilox™ to fine refuse to produce a solidified mass with dependable engineering properties.

107. Sopper, W.E., Kardos, L.T., and Edgerton, R.B. Using Sewage Effluent and Liquid Digested Sludge to Establish Grasses and Legumes on Bituminous Strip-Mine Spoils. Pennsylvania State University, University Park, PA, 1974.

Reviews properties of sewage sludge and effluent, and assesses their ability to enhance revegetation of strip-mine spoils.

108. Sopper, W.E., Kardos, L.T., and Edgerton, R.B. "Reclamation of A Burned Anthracite Refuse Bank with Municipal Sludge." Compost Science (March/April 1976):12-19.

Describes experimental results of using sewage sludge on a burned anthracite refuse bank to enhance revegetation.

109. Spicer, T. Pennsylvania Anthracite Refuse: A Summary of a Literature Survey on Utilization and Disposal. Pennsylvania State University, Report No. SR-79, University Park, PA, 1971.

This document is a useful, though somewhat dated topic-by-topic bibliography for coal refuse disposal and utilization.

110. Spicer, T.S., and Luckie, P.T. "Operation Anthracite Refuse." In Proceedings of the Second Mineral Waste Utilization Symposium. U.S. Bureau of Mines and ITT Research Institute, Chicago, IL, 1970.

Operation Anthracite Refuse is a program to examine the characteristics, uses, and economics of anthracite refuse. This paper discusses initial investigations, including the history and magnitude of the problem. Major element concentrations, size, and mineralogical composition are reported. Production of anthracite has declined from 100 million tons in the early 20th century to 10 million tons in 1970. Current refuse production is low but one billion tons of refuse are lying above ground today.

111. Stahl, R.W. Survey of Burning Coal-Mine Refuse Banks. U.S. Bureau of Mines, Information Circular 8209, Washington, DC, 1964.

Presents data on the number of burning refuse piles in the United States at the time of writing. Also discusses causes of fires and means of prevention and control.

112. Sullivan, G. "Coal Wastes." In Proceedings of the First Mineral Waste Utilization Symposium. U.S. Bureau of Mines and ITT Research Institute, Chicago, IL, 1968.

The article provides an overview of potential productive uses for coal refuse, including: lightweight aggregate, cinder blocks, soil conditioners, alumina recovery, mineral wool, and sulfur recovery.

113. Sun, S.C., Vasquez-Rosas, H., and Augenstein, D. Pennsylvania Anthracite Refuse: A Literature Survey on Chemical Elements in Coal and Coal Refuse. Pennsylvania State University, Report No. SR-83, University Park, PA, April 1970.

Elemental concentrations in coal, coal ash and coal refuse are presented for foreign and domestic coals. Two hundred forty-five references are summarized in the 29 tables, representing 46 elements in these coals.

114. Szpindler, G., Waters, P., and Young, C. "Fluidized-Bed Combustion as a Solution to the Environmental Problems of Coal Mining Waste." National (Australian) Chemical Engineering Conference. 1974.

The paper discusses the environmental problems of coal waste disposal and indicates how they could be reduced by burning the refuse in fluidized beds. Bench-scale tests were conducted with refuse from five different sources. Coarse wastes with up to 80 percent inerts (70 percent ash, 10 percent moisture) were satisfactorily burned.

115. Szpindler, G., and Waters, P. "Investigations of Potential for Heat and Material Recovery in the Fluidized-Bed Incineration of Coal Washery Rejects and Some Other Industrial Wastes." In Proceedings of the First International Conference on the Conversion of Refuse to Energy. 1975.

Bench-scale tests successfully burned coal refuse in a fluidized bed. Dry wastes performed better than slurries. Wastes with up to 80 percent inerts and with heating values as low as 7000 kJ/kg were successfully used. The objective was to reduce weight and volume of wastes which would subsequently require disposal.

116. Toyabe, Y., Matsumoto, G., and Kishikawa, H. "Manufacturing Ceramic Goods Out of Mining Wastes." In Proceedings of the Fourth Mineral Waste Utilization Symposium. Chicago, IL, 1974.

Shale or clay-based coal refuse was used as a plasticizer for hard pottery stone waste containing FeS as an impurity. Heavyweight floor tiles were produced and are now being tested. The addition of foam producers such as glassy rocks results in a strong material suitable for ornamental and protective tiles.

117. U.S. Department of the Interior, Bureau of Mines. Methods and Costs of Coal Refuse Disposal and Reclamation. Information Circular 8576, 1973.

Presents cost data for mine refuse disposal systems taking into consideration a number of system variables. Also presents case histories of a number of disposal sites.

118. U.S. Department of the Interior, Mining Enforcement and Safety Administration. Coal Refuse Inspection Manual. Washington, DC, 1976.

Provides information about proper construction and operation of mine refuse disposal facilities for prospective inspectors.

119. U.S. Federal Highway Administration. Availability of Mining Wastes and Their Potential for Use as Highway Material. 3 volumes, Washington, DC, 1976.

Coal refuse as well as other mining wastes are covered in this study. The study reports the availability of the materials (quantity, distribution) and potential for utilization in various aspects of highway construction. Both technical and environmental evaluations of the uses are included.

120. Utley, R., Lovell, H., and Spicer, T. The Utilization of Coal Refuse for the Manufacture of Lightweight Aggregate. Pennsylvania State University, Report No. SR-46, University Park, PA, 1964.

Three samples of refuse were washed to obtain a variety of sink-float separations. The sink fractions were flash-fired at different temperatures. Resulting products were tested for specific gravity, percent expansion, and compressive strength. Pyrite appears to yield the gas which causes the bloating. Flash-firing resulted in much unburned carbon, not a problem with a sinter grate.

121. Vogely, W. "The Economic Factors of Mineral Waste Utilization." In Proceedings of the First Mineral Waste Utilization Symposium. U.S. Bureau of Mines and ITT Research Institute, Chicago, IL, 1968.

The author differentiates between wastes which have economic value for their mineral content, and those which have no value but impose social costs. Coal refuse typically has both characteristics. Frequently the market undervalues the potential future value of the material for mineral recovery in contrast to its current value (e.g., as aggregate), destroying that potential.

122. Wachter, R.A. "Water Pollution from Drainage and Runoff from Coal Storage Areas." In *Third Symposium on Coal Preparation*. National Coal Association/Bituminous Coal Research, Inc., Louisville, KY, 1977.

Presents results of experiments regarding runoff and leachate from coal stock piles.

123. Wahler, W.A. "Coal Refuse Regulations, Standards, Criteria, and Guidelines." In *First Symposium on Mine and Preparation Plant Refuse Disposal*. National Coal Association, Louisville, KY, 1974.

Reviews legislation and regulations pertaining to coal mine waste disposal.

124. Wewerka, E.M., Williams, J.M., and Vanderborgh, N.E. "Disposal of Coal Preparation Wastes: Environmental Considerations." Los Alamos Scientific Laboratory, New Mexico. Submitted to *Fourth National Conference on Energy and the Environment*, October 5-7, 1976.

Reviews environmental problems associated with coal preparation wastes disposal and discusses control methods available to alleviate the problems.

125. Wewerka, E.M., Williams, J.M., and Waner, P.L. *Assessment and Control of Environmental Contamination from Trace Elements in Coal Processing Wastes*. U.S. Environmental Protection Agency, Washington, DC, 1976.

Identifies possible adverse environmental impacts of trace elements in coal processing wastes. Reviews EPA's program of research attempting to provide currently unavailable information.

126. Winer, A. "Sources of Canadian Non-Bauxite Alumina." In *Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Symposium*. Lexington, KY, 1977.

The CANMET alumina project is described. Non-bauxite sources of alumina, including coal refuse, are being identified and characterized. Anorthosite, because it is present in large quantities and of reasonable quality, is getting the most attention. This source lends itself to lime sintering whereas coal refuse seems best suited to an acid-leaching process.

APPENDIX A

ENVIRONMENTAL AND ECONOMIC IMPACTS OF CURRENT SURFACE WASTE DISPOSAL METHODS

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In 1975, 20 percent of the coal ore deep-mined in the United States was waste. This amounted to 132 million tons, or five percent of total U.S. mining wastes. With the current emphasis on coal development, it is anticipated that coal and waste production will increase dramatically, with an estimated 1.1 billion tons of coal and 200 million tons of waste produced annually by 1985.[1]

These wastes, comprised of coarse, dry materials resulting from mechanical coal separation processes, and slurries of fine particles generated during washing operations, must either be utilized or disposed of safely. Between 1930 and 1971, 197,900 acres of land were used for disposal purposes in the United States, with only 26,480 acres of this area having been reclaimed. A number of serious adverse environmental, health, and safety effects of current disposal methods have prompted a review of these widely used techniques, in order to assess the full magnitude of the impacts and to develop means of minimizing or avoiding them. A review of the available literature suggests that it is quite possible, with careful planning, design and operation, to reduce the adverse effects of current disposal techniques to an acceptable level.

The purpose of this paper is to review currently used methods for surface disposal of coal mine refuse, and to evaluate the environmental and economic impacts of these disposal methods on the mining industry and the affected communities. The paper is written in six parts, as follows:

- Waste Characterization
- Current Surface Disposal Methods
- Environmental, Health, Safety, and Economic Effects of Current Disposal Methods
- Recommended Pollution Control and Safety Measures
- Costs of Disposal Systems
- Legislation and Regulations

Topics are covered in more or less detail, as appropriate to the overall purpose of the paper.

## A.1 Waste Characterization

Two types of coal wastes are produced during deep mining operations: coarse, dry materials, and wet slurries of fine particles. Once coal has been removed from the ground, it is crushed into pieces of 6 inches or less in diameter, and, most often, sized. Much of the material withdrawn with the coal from the ground is unwanted mineral matter, and is separated, initially by dry separation techniques, to produce the coarse waste product. The coal is then washed with water to remove remaining fine particles of foreign material and dust. This process produces the slurry wastes. The exact characteristics of the two wastes produced depend on the nature of the coal itself and the geology of the formation. Approximately 70 to 80 percent of the total waste generated comprises the coarse fraction; the remaining 20 to 30 percent is comprised of fines (dry weight basis) in the general case.[2]

Coarse refuse commonly contains coal, rock, carbonaceous shales and pyrites, siltstone, claystone, sandstone, and limestone, in addition to such foreign elements as wood, machine parts, wire and electrical cables, paper, cloth, grease, and oil.[3,4] Iron, magnesium, potassium, and sodium are all found in coarse refuse.[2] Particles generally range in diameter from 10 to 200 mm.[5]

Slurries produced by water washers contain materials ranging from fine silts and clays to fine sands, in suspension in water. Particles are usually less than 80 mm in diameter.[5] Typical fines composition is 60 percent silica ($SiO_2$), 25 percent alumina ($Al_2O_3$), and 7 percent iron oxide ($Fe_2O_3$).[2]

## A.2 Current Disposal Methods

Coarse and fine refuse can either be disposed of separately or in combination. Coarse wastes are generally disposed of in one of a variety of types of embankments. Fine slurries can either be placed in impoundments, often created by coarse refuse embankments, or be dewatered, and the product mixed with the coarse refuse for simultaneous disposal. In some cases chemicals, such as Calcilox, are added to the slurries to enhance solidification and stabilization of the fine particles.[6,7]

Nonimpounding embankments include:[4]

1. Valley-fill: where an existing valley is filled with refuse, and the surface leveled and graded on site abandonment.

2. Cross-valley: where the embankment is constructed across an existing valley, but not entirely filling the valley.

3. Sidehill: where wastes are dumped alongside of an existing hill or ridge, so that the original ridge is essentially expanded in a sideways direction.

4. Ridge dump: where an embankment is created by continuously dumping wastes on the pile's ridge, thus extending the existing pile.

5. Heaped: where, as the name suggests, the wastes are haphazardly heaped into an amorphous mound.

Impoundments can be created behind cross-valley and sidehill embankments. They can also be built independently as diked ponds, or can be incised out of the surface of a coarse waste embankment. Such impoundments may contain liners of earth, clay, bentonite, or an artificial material, to prevent leaching through the bottom of the pond.[2] Slurries are piped into the ponds, where the fines settle out and, over time, gradually stabilize. Once the lagoon has reached capacity, the excess water can be drained off the surface, and the material covered and revegetated. Alternatively, if temporary lagoons are used, the fines can be excavated and mixed with coarse refuse for disposal in embankments.

Refuse piles generally occupy from 1 acre to greater than 100 acres of surface area, and can range from 20 to 300 feet in depth. Most refuse piles are small (less than 500,000 cubic yards). However, most of the refuse is currently contained in a few very large (greater than 1.5 million cubic yards) piles. There are 3,000 to 5,000 active or abandoned refuse piles in the United States currently, mostly in the eastern coal regions. A 1968 Department of the Interior study of 961 piles indicated that greater than 50 percent of them posed health or safety hazards.[8]

## A.3 Environmental, Health, Safety, and Economic Effects

The four areas in which current disposal techniques create adverse effects are:

1. Air pollution
2. Water pollution
3. Physical instability
4. Economic/industrial development.

As pointed out by Akers:[9]

> These problems may be difficult to control in an existing, poorly designed refuse pile; however, they can be largely avoided in a new pile through careful planning.

The problems, as they do exist, are discussed below.

### A.3.1 Air Pollution

During the history of surface disposal of coal mine refuse, fires in waste embankments have been frequent occurrences. A survey of existing piles in 1964 showed at least 495 piles in some state of uncontrolled combustion.[10] A later survey, taken during 1968 and 1969, found 292 burning banks in 13 of 21 coal producing states, including Alabama, Colorado, Illinois, Kentucky, Maryland, Minnesota, Ohio, Oklahoma, Pennsylvania, Utah, Virginia, Washington, and West Virginia.[11]

Combustion of coal refuse piles is initiated by one of the following:

1. <u>Spontaneous ignition</u>, for which sufficient air must enter the pile to oxidize coal and combustible materials and produce heat, but air flow must not be large enough to carry away the heat necessary for combustion.
2. <u>Careless burning of trash</u>.
3. <u>Forest fires</u>.
4. <u>Campfires left burning</u>.
5. <u>Intentional ignition to produce "red dog</u>."

Air, essential for combustion, penetrates crevices between lumps of refuse, is heated by the oxidation of combustible materials, and rises through the pile. Substantial air flows can develop as a result of this mechanism, providing adequate oxygen to support combustion for long periods of time. Refuse piles have been known to burn for several decades. Burning is generally most evident on the sides and bottoms of slopes where larger lumps of refuse have accumulated during dumping.[3]

Pollutants released to the atmosphere by burning embankments include smoke, minute dust particles, poisonous and noxious gases such as carbon monoxide, hydrogen sulfide, sulfur and nitrogen oxides, and ammonia.[11] From 1971 to 1973, coal refuse fires were the largest U.S. source of airborne benzo(a)pyrene, a suspected carcinogen.[2] Approximately 310 tons of benzo(a)pyrene per year, or 34.7 percent of the total atmospheric input, was due to these fires. This contribution has more recently dropped to less than 50 tons/year due to improved fire prevention and control. According to Wewerka,[12] one percent of the total anthropogenic input of carbon, sulfur, and nitrogen oxide to the atmosphere resulted from refuse fires at the time of the study.

The pollutants introduced by burning refuse banks can have adverse effects of the health of nearby residents, increase rates of corrosion on zinc and steel surfaces, cause plant damage and defoliation, and diminish sunlight and visibility. During temperature inversions, the concentration of pollutants in the vicinity of refuse fires can reach levels dangerous to human health. During periods of precipitation, smogs often form near burning refuse heaps, hampering traffic flow and causing accidents. A number of deaths have been caused by refuse fires.[11] Although the economic costs of most of these adverse effects cannot be quantified, it is clear that the impacts are undesirable, and require appropriate remedial action. Measures for the prevention and control of the fires are discussed below in Section 4.

The only other air pollution problem associated with mine waste disposal is the emission of fugitive dusts as a result of the movements and activities of trucks and bulldozers. This is generally more of a problem in arid areas, and is not of any major importance in Eastern coal-producing regions.

### A.3.2 Water Pollution

One of the most widely recognized environmental problems associated with coal mine refuse disposal in surface embankments is the pollution of nearby streams by metal-containing acid runoff and by silt carried with the runoff. Approximately 10,000 miles of streams in Appalachia have been contaminated by acid runoff, both from mines themselves and from refuse piles. The contribution of the refuse piles is thought to be from 7 to 30 percent of the total.[12,13] A 1972 study in Pennsylvania showed that out of 135 active piles, 61 contributed to acid pollution of streams, and 60 contributed to silt pollution.[13] The nature and magnitude of the acid drainage problem depends on location, coal seam mined, embankment compaction, cover material, etc. The Eastern coal regions, eastern Kentucky, Indiana, and Illinois are characterized by formation of the worst acid runoff.[14]

Acid drainage is formed when iron sulfides in the mine refuse are exposed to air and water. Oxidation of the pyrite or marcasite materials produces sulfuric acid ($H_2SO_4$) and iron sulfate ($FeSO_4$) according to the following reactions:

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$$

(Pyrite) (Ferrous Sulfate) (Sulfuric Acid)

$$FeS_2 + 14Fe^{+++} + 8H_2O = 15Fe^{++} + 2SO_4^{=} + 16H^+$$

(Pyrite) (Ferric Iron) (Ferrous Iron) (Sulfate) (Acid)

These reaction products can react further to:

$$4FeSO_4 + O_2 + 2H_2SO_4 = 2Fe_2(SO_4)_3 + 2H_2O$$

$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4$$

From 1.5 to 2 pounds per acre per day of acid and 0.5 to 0.7 pounds per acre per day of soluble iron can be produced by this process.[8]

As the acid water percolates through the pile it leaches minerals out of the wastes. Metals, in particular the heavy metals of environmental concern, are known to have increased mobility in acid environments. Thus a number of metals, including iron, aluminum, calcium, and magnesium, as well as sulfate, can leach out into the water, reaching levels detrimental to soils and destructive to aquatic life and plants. Table A-1 presents chemical characteristics of runoff from an Illinois refuse pile.

As the acid runoff and leachate flows into streams, several environmental insults can occur. Ordinarily, receiving waters have a certain capacity to buffer themselves due to the presence of calcareous materials and carbonates.[2] However, this capacity can be overwhelmed. Often the acid content of mine refuse drainage is sufficient to substantially lower the pH of receiving waters, with resultant detrimental effects on aquatic life. As the stream water becomes more acid, microorganism populations are altered, leaving acidophilic bacteria, fungi, and yeasts. Trace metals brought in with the drainage waters can accumulate in sediments, plants, and organisms. A lake polluted with acid mine drainage showed a lack of vegetation, lowered pH, increased sulfate content, decreased fish populations, and decreased abundance and diversity of planktonic rotifers when compared with an unpolluted lake.[2] The acid brought in with the drainage waters is also directly toxic to fish.

Often, when refuse drainage waters are released into streams, a ferric hydroxide precipitate, known as "yellow boy," forms and

TABLE A-1

CHARACTERISTICS OF RUNOFF FROM COAL MINE WASTES IN THE SHAWNEE NATIONAL FOREST, SOUTHERN ILLINOIS[a]

| Parameters | Average Value in Palzo Tract (ppm) |
|---|---|
| Acidity (as $CaCO_3$) | 20,000 |
| pH | 2.3 |
| Total iron | 4,000 |
| Aluminum | 2,000 |
| Total manganese | 320 |
| Magnesium | 890 |
| Copper | 5.0 |
| Zinc | 20.0 |
| Calcium | 490 |
| Chromium ($Cr^{+6}$) | 2.00 |
| Total lead | 0.25 |
| Total cadmium | 0.81 |
| Sulfate | 23,700 |

[a]Williams, R.E. Waste production and disposal in mining, milling, and metallurgical industries.

SOURCE: Reference 2, Appendix A.

is deposited on the stream bottoms, smothering life and destroying breeding areas.[8] Mechanisms for restoring injured streams are not well understood, and in many cases the damage appears irreversible.

Mine refuse drainage waters often contain high concentrations of silt, comprising fines of coal, minerals, and soils.[8] If the water is discharged into a stream, the silt will tend to settle out, and, like "yellow boy," will smother life forms on the stream bottom and restrict breeding areas. Sediments and silts can mechanically interfere with fish respiration, and can contribute toxic metals to the food chain. They also cause increased turbidity, which in turn leads to decreased photosynthetic activity, and, as a result, a lowered dissolved oxygen content in the affected water. In many cases, siltation is a much greater pollution problem than acid drainage. The extent to which siltation is a problem is dependent on slope steepness, compaction, drainage control structures, and cover material.

### A.3.3 Physical Instability

Coal mine refuse piles have, in the past, often been built without adequate forethought and planning. Sites have been chosen for convenience, and not for safety. Dumps have been built carelessly on hillsides, valleys, swamps, and settling basins.[12] Such haphazard design and construction can lead to physical instabilities and structural failures, with attendant damage to property and loss of life. Two disasters, one in Aberfan, Wales, and the other in Buffalo Creek, West Virginia, focussed attention on design inadequacies, and induced a movement towards more responsible planning and construction.

In 1966, 140,000 cubic yards of refuse from a waste pile in Aberfan, South Wales broke loose and slid over a part of the town, taking 144 lives and destroying much property. The refuse heap had been constructed over a water spring.[2,13] Then in 1972, an impoundment in Buffalo Creek, West Virginia gave way, and 650,000 cubic yards of water containing 220,000 cubic yards of waste rushed downstream, obliterating obstacles in its path. One hundred and twenty-five people were killed, and hundreds of homes were destroyed.[2,13] This failure occurred following a storm which dropped 3.7 inches of rain in 72 hours--a 2- to 3-year frequency storm. Both of these accidents were due to pile saturation by water, which reduced pile strength, enabling the material to flow as a liquid. In both instances, proper attention to engineering details could have prevented the accidents. (Note, see Supplement 1 to Appendix A for detailed accounts of these two disasters.)

In 1973, five Pennsylvania impoundments gave way after Hurricane Agnes had passed through. Over 33 percent of the impoundments surveyed after the Buffalo Creek disaster were judged to present potential hazards.[13]

Obviously the carelessness that has in the past led to accidents such as the ones described above can no longer be tolerated. Again, the dollar cost of these accidents cannot be tabulated, nor can the loss of life be put into a cost-benefit equation. However, this clear safety hazard can and should be dealt with.

#### A.3.4 Economic/Industrial Development

The cost of current disposal methods in terms of the hindrance of economic development in coal mining and waste disposal regions cannot be clearly determined. It is certain, however, that many disposal sites are not only environmentally unsound, but are also aesthetically displeasing, and present an obstacle to industrial or residential development in the surrounding area. Refuse piles, incorrectly constructed and operated, are visually repugnant. Burning banks produce hazardous gases, odors, dust, and smoke. Unreclaimed refuse banks present a real safety hazard to children or adults trespassing on the sites. These and similar factors militate against the development of new living or working facilities near disposal areas. This problem has inhibited economic growth in a number of the Eastern coal producing states, most notably West Virginia and Pennsylvania.

## A.4 Recommended Pollution Control and Safety Measures

Most of the problems mentioned above are difficult if not impossible to solve with regard to existing refuse embankments. For example, extinguishing or controlling an existing bank fire has proven to be exceedingly difficult. Methods such as flooding or spraying with water, injecting limestone slurries, blanketing with an impermeable medium, and isolating the burning part have been tried, with relatively little success.[10] A pile that has been incorrectly constructed, and shows signs of failure, can generally not be corrected without dismantling and reconstruction--an expensive and time-consuming undertaking. Similarly, once a pattern of leachate formation and discharge to a stream has become established in a poorly constructed pile, it is costly and technically difficult to correct the deficiency.

However, proper design and construction of the disposal facility at the outset can, without excessive expense, avoid all of the adverse effects of current disposal practices. The several factors that require consideration in the design of a refuse disposal system are siting, pile construction and shape, drainage, and revegetation or reclamation. Each of these factors will be discussed in this section.

### A.4.1 Siting

Correct siting of a disposal facility is essential. Subsurface and surface geology and hydrology need be given consideration. Water is the most likely cause of pile instability.[9] As water infiltrates a pile, pore pressure increases, resulting in a decrease in shear strength within the material, which in turn increases the likelihood of structural failure. Hence, embankments should be sited where they will not be subject to constant infiltration by water--either spring water or surface runoff. As mentioned earlier, the failure of the Aberfan embankment occurred because the pile had been placed over a water spring.

Foundation stability is also a critical consideration in ensuring the safety of a refuse pile. Placement of a pile on a soft or swampy foundation, or over an unsupported surface (such as the area above underground mines) would simply be foolish, although such has been known to occur. Exercise of basic engineering judgment in facility siting can easily overcome problems of this elementary nature.

### A.4.2 Pile Construction

Proper pile construction has three aims--effective disposal of wastes, development of a safe pile structure, and prevention of air or water infiltration of the pile. The measures necessary to accomplish these objectives are complementary, and straightforward.

In an analysis of the physical properties of coarse coal mine wastes, Busch et al.[15] determined that shear strength, permeability, and grain size distribution are "quite uniform," and that average values for these parameters can be obtained and used reliably in design. According to their findings:

> A concerted effort of density control in the field could produce a waste pile that would have uniform high density, corresponding improved stability, and low permeability.[15]

Furthermore, strength was not affected by moisture content, except in the extreme, where the stability of saturated materials was found to be affected by sudden changes in load. It is therefore clear that the waste material itself is suitable for the construction of structurally sound, relatively impermeable embankments.

In order for a fire to occur in a refuse pile, it is necessary for oxygen to infiltrate the material. Similarly, acid drainage cannot form unless both oxygen and water can penetrate and percolate through the wastes. Thus, the two problems of fires and acid drainage can be eliminated by reducing the ability of air and water to penetrate the pile. This is relatively easily accomplished by applying the wastes in layers, compacting the layers, and sandwiching clay in between the layers, covering at a minimum the edges of the pile.[9]

Characteristically, wastes have been dumped on pile slopes, with the result that larger chunks would roll down to the bottoms of the slopes, leaving the finer material on top. As a consequence of this particle size segregation, air could find an easy entry into the pile through the spaces between the large chunks. Hence oxidation, acid formation, and fires could result. Proper placement of wastes to avoid this segregation, and adequate compaction, would eliminate this problem.[16]

Two other measures that reduce the probability of pile ignition can also be adopted. Winds frequently enter piles through very sleep slopes. This air penetration of the pile sides can be avoided by keeping slopes less than 33 percent.[16] Pile stability would also be enhanced by this practice. Wastes can also be allowed to weather partially prior to final placement in the disposal pile. Heat generated during this initial oxidation would then simply be dissipated to the atmosphere, rather than building up within the pile. This approach would tend to prevent the development of sufficient internal pile temperatures to initiate combustion.[3]

### A.4.3 Drainage

Installation of adequate drainage facilities at a refuse disposal site can prevent infiltration of rainwater through the pile, reduce erosion of pile sides, and enhance long-term stability. Ditches around and subdrains under refuse piles are recommended by Connell.[17] Impoundment ponds should be drained by decant towers, siphons, or pumps. Peak runoff should be adequately handled by provision of ample freeboard or good diversion structure.[2] Adoption of simple measures such as these, consistent with standard engineering practice, would greatly alleviate problems thus far commonly associated with refuse banks.

### A.4.4 Revegetation or Reclamation

Revegetation of abandoned dumpsites accomplishes several objectives. First, it seals the surface of the piles, inhibiting entry of air and water. Second, it provides an additional degree of stability, and enhances resistance to erosion. Third, it facilitates site maintenance. Finally, it makes the land available for use in forestry, agriculture, industry, and recreation.[18] Since the total acreage of abandoned coal mine refuse areas in the eastern United States is several thousand acres, this reclamation of useless land could produce substantial benefits.[19]

A currently recommended reclamation practice is described as follows:[19]

1. Grade and/or shape the pile so that no water will pool on the surface, slopes will be able to hold vegetation, and erosion will be minimized.

2. Cover with a 12- to 18-inch layer of minesoil or topsoil.

3. Seed as soon as possible with grasses and legumes.

4. Use low-growing fibrous root system species of trees and shrubs to eliminate windthrow.

Experiments have been conducted to determine the appropriate thickness of soil to place over a refuse site. The results have indicated that a 9-inch layer is sufficient to promote vegetation, and that thicker layers (1, 2, 3, and 4 feet) produce no additional benefit.[20] The recommendation above of 12 to 18 inches makes allowance for the fact that it is difficult to spread a 9-inch layer of soil evenly over the slopes of a refuse pile.

The use of soil amendments to enhance revegetation has been recommended by a number of investigators. Power plant fly ash has been found to partially neutralize acidic soils, improve soil texture, enable rapid establishment of a grass and legume cover, and consume substantial quantities of an erstwhile waste.[21] Likewise, sewage sludge and sludge compost has been found useful for the same application.[22] According to Sopper:

> Treated municipal sludge effluent and liquid digested sludge are a valuable means of amending harsh conditions which make spoil banks so unsuitable for establishment and growth of vegetation. In particular, the effluent and sludge have considerable nutrient value and soil building potential, and can aid in the reduction of toxic concentrations of metals in the spoil leachate.

It becomes clear, after reviewing the problems with current disposal techniques and the solutions to those problems, that the adverse impacts characteristically associated with coal mine refuse embankments have been due largely to negligence and/or lack of forethought. The techniques suitable for reducing or eliminating the problems are standard engineering practices, and do not require new, sophisticated, or unusual technology. In fact, since public attention was focussed on refuse disposal by the disasters in Aberfan and Buffalo Creek, disposal practices have improved considerably. This is in part due to increased regulatory activity, which will be discussed below. It is also the simple result of an expanded awareness on the part of mine owners and operators of the consequences of improper disposal, and a recognition that those consequences are no longer acceptable.

## A.5 Costs of Disposal Systems

A number of studies have been performed to determine the cost of typical coal mine refuse disposal systems.[23,24,25] The Bureau of Mines studied disposal costs in Pennsylvania in 1973. Spreading and compacting of refuse at the dump site ranged from 3 to 20 cents per ton of waste. Costs of covering with soil and planting ranged from $750 to $1,646 per acre. Total costs of reclamation projects were $1,800 to $15,000 per acre. Refuse preparation costs were $772 to $5,550 per acre, while soil covering and planting costs were $1,083 to $5,086 per acre.[23]

Brown et al.[24] developed cost estimates for three types of disposal systems. The model systems were designed to handle 1.06 million tons of coarse refuse and 0.10 million tons of fine refuse per year. The Mechanical Fine Refuse Dewatering System first dewaters the slurries of fines. The dewatered product is mixed with coarse refuse, and disposed of in the refuse pile. Costs for this disposal system were determined to be $1.73 per ton of refuse and $0.74 per ton of coal produced. The second system consisted of temporary storage and settling of the fines in settling ponds, with subsequent removal of the partially dewatered material and deposition in excavations in the coarse refuse at the dump site. Costs for this operation were $1.92 per ton of refuse and $0.83 per ton of coal produced. The third system analyzed involved the simultaneous construction of a dam with coarse refuse and impoundment of the fine refuse slurry behind the impoundment. Costs for this system were $1.54 per ton of the refuse and $0.66 per ton of coal produced. Detailed cost figures from this study are contained in Supplement 2 to Appendix A.

## A.6 Legislation and Regulations

Disposal of coal mine refuse has only recently come under the close scrutiny of the law. In 1971, regulations were developed under authority of the 1969 Coal Mine Health and Safety Act prescribing minimum requirements for water or silt retaining coal waste structures. As part of these regulations, design plans for refuse facilities would require approval of MESA, the Mining Enforcement and Safety Administration[26].

More recently, under the Surface Mining Control and Reclamation Act of 1977 (SMCRA), the U.S. Department of Interior, Office of Surface Mining (OSM) has established a regulatory program for coal mining and refuse disposal operations. The intent of SMCRA is to minimize the adverse effects of surface and underground coal mining. Final regulations establishing the OSM regulatory program were published in the Federal Register on March 13, 1979.

At the present time, under the Resource Conservation and Recovery Act of 1976 (RCRA), the U.S. Environmental Protection Agency is developing proposed regulations covering the RCRA "special wastes" category, which includes coal mining wastes. It is unclear whether or not coal wastes will be designated as hazardous, be subject to testing on a case-by-case basis to determine if they are hazardous, or be exempted from hazardous waste guidelines due to the tremendous waste volume and the very high costs of disposal under hazardous disposal facility guidelines. Proposed regulations should be made public by the fall of 1979.

## SUPPLEMENT 1 TO APPENDIX A

## DISASTERS OF PHYSICAL INSTABILITY

### Aberfan, South Wales, October 21, 1966

At about 9:15 a.m. on Friday, October 21, 1966, many thousands of tons of colliery rubbish swept swiftly and with a jet-like roar down the side of the Merthyr Mountain which forms the western flank of the coal-mining village of Aberfan. This massive breakaway from a vast tip (pile) overwhelmed in its course the two Hafod-Tanglwys-Uchaf farm cottages on the mountainside and killed three occupants. It crossed the disused canal and surmounted the railway embankment. It engulfed and destroyed a school and eighteen houses and damaged another school and other dwellings in the village before its onward flow substantially ceased. . . . Despite desperate and heroically sustained efforts of (the many people of) all ages and occupations who rushed to Aberfan from far and wide, after 11 a.m. on that fateful day nobody buried by the slide was rescued alive. In the disaster no less than 144 men, women, and children were killed. Most of them were between the ages of 7 and 10, 109 of them perishing inside the Pantglas Junior School. Of the 28 adults who died, 5 were teachers in the school. In addition, 29 children and 6 adults were injured, some of them seriously. Sixteen houses were damaged by sludge, 60 houses had to be evacuated, others were unavoidably damaged in the course of the rescue operations, and a number of motor cars were crushed by the initial fall. According to Professor Bishop, in the final slip some 140,000 cubic yards of rubbish were deposited on the lower slopes of the mountainside and in the village of Aberfan. (From Report of the Tribunal appointed to inquire into the Disaster at Aberfan, 1967, p. 26.)

### Buffalo Creek, West Virginia, February 26, 1972

Approximately 21 million cubic feet of water was released from the coal-refuse dams on Middle Fork (Saunders, Logan County, West Virginia) beginning at about 8:00 a.m. on February 26. . . . The previously impounded water then began its wild 17-mile plunge down Buffalo Creek falling more than 700 feet in its race from Saunders to Man. . . . All homes and structures at Saunders were totally destroyed. . . . The flood wave traveled from Saunders to Pardee in about 10 minutes at an average velocity of 19 feet per second. . . . The flood waters arrived at Lorado at about 8:15 a.m. The flood flow was 6 to 8 feet deep on the flood plain and almost completely destroyed the town. A few well-constructed buildings survived, but nearly all homes of wooden construction erected on a slab foundation were demolished. . . . Flood damage downstream from Amherstadale, although still serious, was far less extensive.

The flooding resulted in the confirmed deaths of 116 persons as of the date of this report (March 12, 1972), total destruction of 502 permanent home structures and 44 mobile homes, and minor damage to 270 additional homes along Buffalo Creek from Saunders to Man, West Virginia, a distance of about 17 miles. It was estimated that about 4,000 persons were left homeless. Numerous homes in the Buffalo Creek area that were located above the flood plain escaped damage.

The flooding also destroyed about 1,000 automobiles and trucks, several highway and railway bridges, sections of raildoad tracks and highway, public utility power cables and poles, telephone lines and poles, and other installations. Mine refuse, silt and debris were scattered for miles along Buffalo Creek. About 30 persons who resided in the Buffalo Creek area remained in the missing list. (From U.S. Department of the Interior, 1972, pp. 17-22.)

SUPPLEMENT 2 TO APPENDIX A

# ECONOMIC EVALUATION OF COAL REFUSE DISPOSAL SYSTEMS

by

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from

Third Symposium on Coal Preparation

Louisville, KY

October 1977



| ITEM | RAW COAL INPUT | CLEAN COAL OUTPUT | COARSE REFUSE | | FINE REFUSE SOLIDS |
|---|---|---|---|---|---|
| | | | COMPACT | LOOSE | |
| Tons per hour | 1,000 | 700 | 275 | | 25 |
| Millions of Tons per Year | 3.84 | 2.69 | 1.06 | | 0.10 |
| Cubic Yards per Hour | – | – | 194 | 226 | 34 |
| Millions of Cubic Yards per Year | – | – | 0.74 | 0.87 | 0.13 |
| Millions of Cubic Yards in 20 Years | – | – | 14.9 | 17.4 | 2.6 |

FIGURE 1. PREPARATION PLANT QUANTITIES

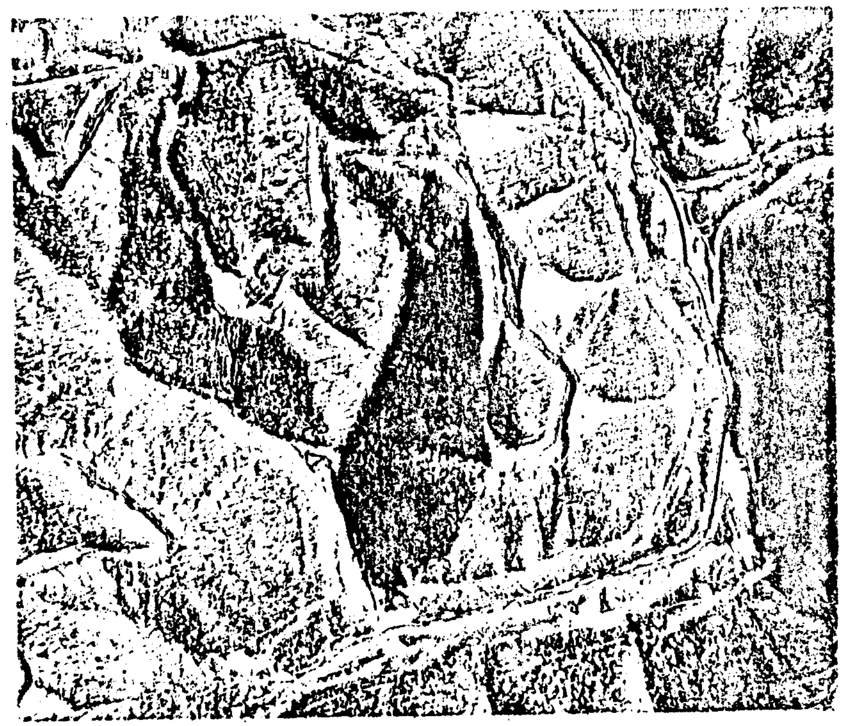

FIGURE 2. REFUSE DISPOSAL AND PLANT SITES

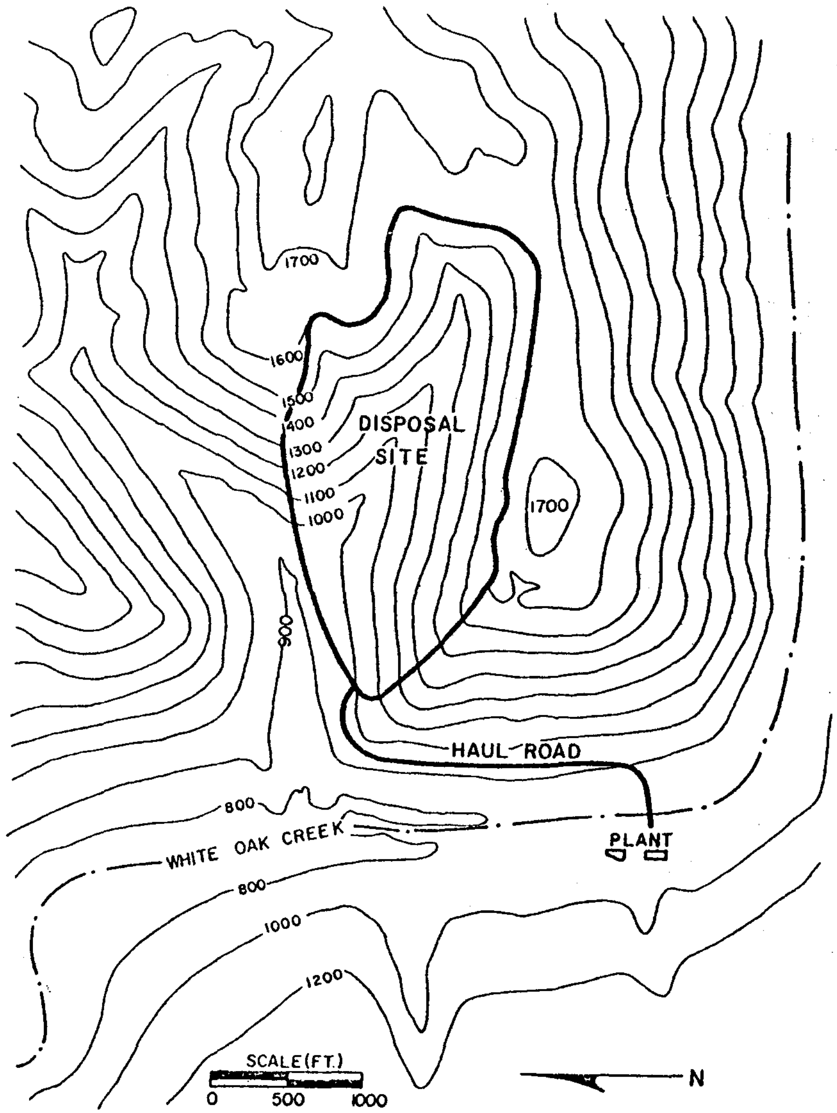


FIGURE 3. REFUSE DISPOSAL PLAN

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| | | | |
|---|---|---|---|
| A. | SITE DEVELOPMENT (5.6%) | | |
| 1. | Land purchase 40 acres x $500/acre | $ 20,000 | |
| 2. | Disposal facility design | $ 40,000 | |
| 3. | Initial site preparation | $ 900,000 | |
| | 20 Year Cost | $ 960,000 | |
| | Annual Cost = $960,000 x (CRF = .11746) | | $ 112,762 |
| B. | COMBINED REFUSE HANDLING (65.5%) | | |
| 1. | Equipment | | |
| | 3 Cat. 773 (50 ton) trucks w/t gate | $ 760,872 | |
| | 1 Cat. D6C LGP dozer | $ 118,135 | |
| | 1 Cat. D8K dozer | $ 162,046 | |
| | 1 Cat. 988B front end loader | $ 201,182 | |
| | 2 Light plants | $ 18,207 | |
| | 3 Year Cost | $ 1,260,442 | |
| | Annual Cost = $1,260,442 x (CRF = .40211) | | $ 506,836 |
| 2. | Labor | | |
| | 13 Operators x $100/day x 240 days/yr | $ 312,000 | |
| | 1 Foreman x $125/day x 240 days/yr | $ 30,000 | |
| | Annual Cost | $ 342,000 | $ 342,000 |
| 3. | Operating | | |
| | 2 Trucks x $36.09/hr x 3,840 hrs | $ 277,171 | |
| | 1 D6C LGP dozer x $13.49/hr x 3,840 hrs | $ 51,802 | |
| | 1 D8K dozer x $20.16/hr x 3,840 hrs | $ 77,414 | |
| | 1 Front end loader x $27.16/hr x 1,920 hrs | $ 52,147 | |
| | 2 Light plants x $1.00/hr x 1,920 hrs | $ 3,840 | |
| | Annual Cost | $ 462,374 | $ 462,374 |
| C. | FINE REFUSE DEWATERING (23.5%) | | |
| 1. | Equipment | | |
| | Filter equipment | $ 400,000 | |
| | 2 500-hp vacuum pumps & motors x $20,000 | $ 40,000 | |
| | Equipment installation | $ 350,000 | |
| | 20 Year Cost | $ 790,000 | |
| | Annual Cost = $790,000 x (CRF = .11746) | | $ 92,793 |
| 2. | Operating and Labor Costs | | |
| | 450 kw/hr x 3,840 hr/yr x $0.0275/kwh | $ 47,520 | |
| | $0.0041/gal. slurry x $21,000 gal./hr x 3,840 hr/yr | $ 330,624 | |
| | Annual Cost | $ 378,144 | $ 378,144 |
| D. | MISCELLANEOUS ITEMS (5.4%) | | |
| 1. | 300 ft/yr underdrains x $20/ft | $ 6,000 | |
| 2. | 700 ft/yr new roads x $30/ft | $ 21,000 | |
| 3. | 250 ft/yr diversion ditches x $5/ft | $ 1,250 | |
| 4. | Clear 2 acres/yr x $2,000/acre | $ 4,000 | |
| 5. | Reclaim 3 acres/yr x $1,500/yr | $ 4,500 | |
| 6. | Engineering, reports, testing, surveying | $ 40,000 | |
| 7. | Equip. insurance, taxes, licenses $1,260,442 x 0.025 | $ 31,511 | |
| | Annual Cost | $ 108,261 | $ 108,261 |
| E. | TOTAL ANNUAL COST | | $ 2,003,170 |
| | Cost/ton refuse = $ 1.73 | | |
| | Cost/ton clean coal = $ 0.74 | | |

FIGURE 4. COST OF COMBINED REFUSE DISPOSAL

| | | | |
|---|---|---|---|
| A. | SITE DEVELOPMENT (9.9%) | | |
| | 1. Land purchase 40 acres x $500/acre | $ 20,000 | |
| | 2. Disposal facility design | $ 150,000 | |
| | 3. Initial site preparation | $ 1,125,000 | |
| | 4. 60,000 cy starter dike x $3.50/cy | $ 210,000 | |
| | 20 Year Cost | $ 1,505,000 | |
| | Annual Cost = $1,505,000 x (CRF =.11746) | | $ 176,777 |
| B. | COARSE REFUSE HANDLING (77.1%) | | |
| | 1. Equipment | | |
| | 3 Cat. 773 (50 ton) trucks w/t gate | $ 760,872 | |
| | 2 Cat. D8K dozers with compactor | $ 374,092 | |
| | 1 Cat. 988B front end loader | $ 201,182 | |
| | 2 Light plants | $ 18,207 | |
| | 3 Year Cost | $ 1,354,353 | |
| | Annual Cost = $1,354,353 x (CRF = .40211) | | $ 544,599 |
| | 2. Labor | | |
| | 13 Operators x $100/day x 240 days/yr | $ 312,000 | |
| | 1 Foreman x $125/day x 240 days/yr | $ 30,000 | |
| | Annual Cost | $ 342,000 | $ 342,000 |
| | 3. Operating | | |
| | 2 trucks x $36.09/hr x 3,840 hrs | $ 277,171 | |
| | 2 D8K dozer x $20.16/hr x 3,840 hrs | $ 154,828 | |
| | 1 Front end loader x $27.16/hr x 1,920 hrs | $ 52,147 | |
| | 2 Light plants x $1.00/hr x 1,920 hrs | $ 3,840 | |
| | Annual Cost | $ 487,986 | $ 487,986 |
| C. | FINE REFUSE HANDLING (5.8%) | | |
| | 1. Equipment | | |
| | 7,000 ft pipe x $11.00/ft x (CRF = .26380) | $ 20,313 | |
| | 6 Pumps & accessories x $10,000 x (CRF =.18744) | $ 11,246 | |
| | 400 ft decant x $130/ft x (CRF = .11746) | $ 6,108 | |
| | 2,600 ft culvert x $20/ft x (CRF = .11746) | $ 6,108 | |
| | Annual Cost | $ 43,776 | $ 43,775 |
| | 2. Operating | | |
| | Pump maintenance & parts | $ 15,000 | |
| | Pump power 1,650,000 kwh/yr x $0.0275/kwh | $ 45,375 | |
| | Annual Cost | $ 60,375 | $ 60,375 |
| D. | MISCELLANEOUS ITEMS (7.1%) | | |
| | 1. 1,000 cy/yr drainage blankets x $15/cy | $ 15,000 | |
| | 2. 700 ft/yr new roads x $30/ft | $ 21,000 | |
| | 3. 200 ft/yr diversion ditches x $5/ft | $ 1,000 | |
| | 4. Clear 2 acres/yr x $2,000/acre | $ 4,000 | |
| | 5. Reclaim 3 acres/yr x $1,500/yr | $ 4,500 | |
| | 6. Engineering reports, testing, surveying | $ 47,000 | |
| | 7. Equip. insurance, taxes, licenses $1,354,353 x 0.025 | $ 33,859 | |
| | Annual Cost | $ 126,359 | $ 126,359 |
| E. | TOTAL ANNUAL COST | | $ 1,781,871 |

Cost/ton refuse = $ 1.54
Cost/ton clean coal = $ 0.66

FIGURE 5. COST OF COARSE REFUSE IMPOUNDMENT

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| | | | |
|---|---|---|---|
| A. | SITE DEVELOPMENT (5.4%) | | |
| | 1. Land purchase 40 acres x $500/acre | $ 20,000 | |
| | 2. Disposal facility design | $ 40,000 | |
| | 3. Initial site preparation | $ 900,000 | |
| | 4. 20,000 cy pond construction x $3.50/cy | $ 70,000 | |
| | 20 Year Cost | $ 1,030,000 | |
| | Annual Cost = $1,030,000 x (CRF = .11746) | | $ 120,984 |
| B. | COARSE REFUSE HANDLING (64.4%) | | |
| | 1. Equipment | | |
| | 3 Cat. 773 (50 ton) trucks w/t gate | $ 760,872 | |
| | 2 Cat. D8K dozers | $ 324,092 | |
| | 1 Cat. 988B front end loader | $ 201,182 | |
| | 3 Light plants | $ 27,310 | |
| | 3 Year Cost | $ 1,313,456 | |
| | Annual Cost = $1,313,456 x (CRF = .40211) | | $ 528,154 |
| | 2. Labor | | |
| | 14 Operators x $100/day x 240 days/yr | $ 336,000 | |
| | 1 Foreman x $125/day x 240 days/yr | $ 30,000 | |
| | Annual Cost | $ 366,000 | $ 366,000 |
| | 3. Operating | | |
| | 2 50-ton trucks x $36.09/hr x 3,840 hrs | $ 277,171 | |
| | 2 D8K dozer x $20.16/hr x 3,840 hrs | $ 154,828 | |
| | 1 Front end loader x $27.16/hr x 3,840 hrs | $ 104,294 | |
| | 3 Light plants x $1.00/hr x 1,920 hrs | $ 5,760 | |
| | Annual Cost | $ 542,053 | $ 542,053 |
| C. | FINE REFUSE HANDLING (24.9%) | | |
| | 1. Equipment | | |
| | 1,500 ft pipe x $11.00/ft x (CRF = .26380) | $ 4,353 | |
| | 2 Pumps & accessories x $10,000 x (CRF = .18744) | $ 3,749 | |
| | 3 20-ton dump trucks x $50,000 x (CRF = .40211) | $ 60,317 | |
| | 1 40-ton crawler crane, $180,000 x (CRF = .18744) | $ 33,739 | |
| | Annual Cost | $ 102,158 | $ 102,158 |
| | 2. Labor | | |
| | 9 Operators x $100/day x 240 days/yr | $ 216,000 | |
| | 1 Foreman x $125/day x 240 days/yr | $ 30,000 | |
| | Annual Cost | $ 246,000 | $ 246,000 |
| | 3. Operating | | |
| | Pump maintenance, parts & power | $ 20,000 | |
| | 3 trucks x $10.53/hr x 3,840 hrs | $ 121,306 | |
| | 1 crane x $17.30/hr x 3,840 hrs | $ 66,432 | |
| | Annual Cost | $ 207,738 | $ 207,738 |
| D. | MISCELLANEOUS ITEMS (5.3%) | | |
| | 1. 300 ft/yr underdrains x $20/ft | $ 6,000 | |
| | 2. 700 ft/yr new roads x $30/ft | $ 21,000 | |
| | 3. 250 ft/yr diversion ditches x $5/ft | $ 1,250 | |
| | 4. Clear 2 acres/yr x $2,000/acre | $ 4,000 | |
| | 5. Reclaim 3 acres/yr x $1,500/yr | $ 4,500 | |
| | 6. Engineering, reports, testing, surveying | $ 40,000 | |
| | 7. Equip. insurance, taxes, licenses $1,643,456 x 0.025 | $ 41,086 | |
| | Annual Cost | $ 117,836 | $ 117,836 |
| E. | TOTAL ANNUAL COST | | $ 2,230,923 |

Cost/ton refuse = $ 1.92
Cost/ton clean coal = $ 0.83

FIGURE 6. COST OF SETTLING POND DISPOSAL SYSTEM

## REFERENCES FOR APPENDIX A


1. Falkie, T.V., Gilley, J.E., and Allen, A.S. Overview of Underground Refuse Disposal. Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. Lousville, KY: National Coal Association, 1974.

2. Pedco Environmental, Inc. Study of the Adverse Effects of Solid Wastes from All Mining Activities on the Environment. For the U.S. Environmental Protection Agency. Contract No. 58-01-4700, June 1978 (preliminary draft).

3. Myers, J.W., Pfeiffer, J.J., Murphy, E.M., and Griffith, F.E. Ignition and Control of Burning Coal Mine Refuse. U.S. Bureau of Mines Report of Investigation 6758, Spokane, WA, 1966.

4. U.S. Department of Interior. Mining Enforcement and Safety Administration. Coal Refuse Inspection Manual. Washington, D.C., 1976.

5. Libicki, J. Impact of Gob and Power Plant Ash Disposal on Groundwater Quality and Its Control. Proceedings of the Third Symposium on Coal Preparation. Louisville, KY: National Coal Association/Bituminous Coal Research, Inc., 1977.

6. Hoffman, D.C. Calcilox Additive Stabilization of Fine Coal Refuse - A Cost Approach. Proceedings of the Third Symposium on Coal Preparation. Louisville, KY: National Coal Association/Bituminous Coal Research, Inc., 1977.

7. Snyder, G.A., Zuhl, F.A., and Burch, E.F. "Solidification of Fine Coal Refuse." Mining Congress Journal, 43-46, December 1977.

8. Wewerka, E.M., Williams, J.M., and Waner, P.L. Assessment and Control of Environmental Contamination from Trace Elements in Coal Processing Wastes. For the U.S. Environmental Protection Agency. Cincinnati, OH, 1976.

9. Akers, D.J. Coal Refuse Disposal. Coal Research Bureau Report No. 137. Morgantown, WV: West Virginia University, 1977.

10. Stahl, R.W. Survey of Burning Coal Mine Refuse Banks. U.S. Bureau of Mines Information Circular 8209. Pittsburgh, PA, 1964.

11. McNay, L.M. Coal Refuse Fires: An Environmental Hazard. U.S. Bureau of Mines Information Circular 8515. Washington, D.C., 1971.

12. Wewerka, E.M., Williams, J.M., and Vanderborgh, N.E. Disposal of Coal Preparation Wastes: Environmental Considerations. Submitted to the Fourth National Conference on Energy and the Environment. Los Alamos, NM, October 1976.

13. National Academy of Sciences. Underground Disposal of Coal Mine Wastes. Washington, D.C., 1975.

14. Martin, J.F. "Coal Refuse Disposal in the Eastern United States." News of Environmental Research. Cincinnati, OH: Industrial Waste Treatment Research, December 1974.

15. Busch, R.A., Backer, R.R., and Atkins, L.A. Physical Property Data on Coal Waste Embankment Materials. U.S. Bureau of Mines Report of Investigation 7964. Spokane, WA, 1974.

16. Hill, R.D. Water Pollution from Coal Mines. Paper presented to the 45th Annual Conference - Water Pollution Control Association of Pennsylvania. University Park, PA, August 1973.

17. Connell, J.P. Construction Guidelines for Pollution Control from Coal Refuse Piles and Slurry Ponds. Proceedings of the Third Symposium on Coal Preparation. Louisville, KY: National Coal Association/Bituminous Coal Research, Inc., 1977.

18. Akers, D.J., Jr., and Muter, R.B. Coal Pile Stabilization and Reclamation. Proceedings of the Fourth Mineral Waste Utilization Symposium. Chicago, IL: U.S. Bureau of Mines and ITT Research Institute, March 1974.

19. Brundage, R.S. Depth of Soil Covering Refuse (Gob) vs. Quality of Vegetation. Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, KY: National Coal Association, 1974.

20. Kosowski, Z.V. Control of Mine Drainage from Coal Mine Mineral Wastes - Pollution Abatement and Monitoring (EPA/R2-73-230). For the U.S. Environmental Protection Agency. Washington, D.C., 1973.

21. Adams, L.M., Capp, J.P., and Gillmore, D.W. Coal Mine Spoil and Refuse Bank Reclamation with Powerplant Fly Ash. Proceedings of the Third Mineral Waste Utilization Symposium. Chicago, IL: U.S. Bureau of Mines and ITT Research Institute, March 1972.

22. Hill, R.D., and Montague, P.E. The Potential for Using Sewage Sludge and Compost in Mine Reclamation. Presented to the Third National Conference on Sludge Management, Disposal, and Utilization. Miami, FL, December 1976.

23. U.S. Department of Interior. Bureau of Mines. Methods and Costs of Coal Refuse Disposal and Reclamation. Information Circular 8576. Pittsburgh, PA, 1973.

24. Brown, R.E., Wilson, T.C., and Thomasson, D.L. Economic Evaluation of Coal Refuse Disposal Systems. Proceedings of the Third Symposium on Coal Preparation. Lousville, KY: National Coal Association/Bituminous Coal Research, Inc., 1977.

25. Doyle, F.J., Bhattand, H.G., and Rapp, J.R. Analysis of Pollution Control Costs (EPA-670/2-74-009). Washington, D.C.: Appalachian Regional Commission and U.S. Environmental Protection Agency, 1974.

26. Peluso, R.G. "A Federal View of the Coal Waste Disposal Problem." Mining Congress Journal, 14-17, January 1974.

APPENDIX B

# EXISTING TECHNIQUES FOR COAL WASTE UTILIZATION

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APPENDIX B

## EXISTING TECHNIQUES FOR COAL WASTE UTILIZATION

Attempts to find productive uses for coal refuse are not a recent phenomenon. Through the latter half of the nineteenth century, coal refuse disposal and utilization stimulated a great deal of study and experimentation. In 1889, the Commonwealth of Pennsylvania appointed a commission to investigate coal refuse production and the potential for its utilization. The Commission's report included 134 references to reports, journals and books published between 1884 and 1892 discussing the productive use of coal waste, 82 patents for utilizing or burning fine coal sizes and coal waste, and 89 patents for manufacturing artificial fuels by combining coal fines and waste with other materials.[1]

Although much of the early work focused on ways to use fine coal sizes, other modes of utilization were also being investigated. With this long history of efforts to productively utilize coal waste, it should come as no surprise that a wide variety of uses have been proposed and, in some cases, put into action.

Set forth in the following pages are the uses which have received any significant attention in the literature. In each instance, the properties essential to the final product will be described. Additionally, the physical and chemical characteristics of the waste required for a given use will be identified. Preparation and processing requirements for each use will be described, accompanied, where available, by processing cost data.

## B.1 Secondary Fuel Recovery

As coal burning technology has evolved over the years, the reprocessing of coal refuse banks has proved to be economically desirable in a large number of cases. As early as the 1880's, culm banks in Pennsylvania's anthracite fields were reprocessed for a second yield of marketable coal. In the 1930's and again following WWII, technical and economic factors led to considerable activity in reprocessing anthracite refuse.[2]

A combination of technical and economic factors has made secondary fuel recovery attractive in the 1970's. To illustrate the level of activity, in 1974 Pennsylvania alone had issued permits to reprocess 17 bituminous refuse disposal sites and 35 anthracite refuse disposal sites.[1]

The processing of these banks almost always results in the creation of a secondary bank although the volume and possibly the area occupied by the bank is reduced. Charmbury has noted that since reprocessing for secondary fuel recovery is the most important method at the present time for the utilization of Pennsylvania anthracite refuse, owners of existing banks are reluctant to let the refuse go for other uses until they are certain that the bank has no fuel value.[3] The marketplace thereby favors those modes of utilization which take advantage of the fuel value of the refuse, and works against those in which capture of the fuel value is precluded. The foregoing, of course, applies only if the material has, or is perceived by the owner to have, some significant fuel value.

The U.S. Environmental Protection Agency (EPA) in January, 1975, amended Section 60.44 of its "Standards of Performance for New Stationary Sources" to exempt steam generating units burning at least 25 percent coal refuse from the nitrogen oxides ($NO_x$) standards of performance. Such exemption does not, however, apply to sulfur oxides ($SO_x$) or particulate matter.

According to EPA, the exemption was expected to affect only one planned source and was never intended to have wide applicability. Presumably at the time the standard was proposed in 1971, EPA was unaware of the possibility of burning coal refuse in combination with other fossil fuels.[1]

### B.1.1 High Grade Fuel Recovery

To date, most reprocessing efforts in the United States have concentrated on the recovery of a high grade marketable coal (high Btu, low ash). This is being done in a number of ways, but most involve either rewashing or mixing the refuse with a higher grade coal to meet conventional boiler operating specifications.

Slurry settling ponds are one attractive source of refuse. Many operators are using a small two-man dredge to remove slurry deposits. Peabody Coal Company anticipates recovery of nearly a million tons of coal from a slurry settling pond at its Bee-Veer mine in Macon, Missouri. The dredged material is pumped to the preparation plant, equipped with new processing machinery, where it is washed, dried, sorted and shipped to a steam generating plant. Peabody estimates its total possible recovery from its slurry ponds at close to 20 million tons.[1] In other instances culm banks are being mined with small earth-moving equipment. The refuse is either cleaned, or if sufficiently high in Btu content, it may be mixed directly with a higher grade coal without further preparation.

Most coal burning power plants operate with coal having fuel values ranging between 10,000 and 12,000 Btu per pound and with ash as high as 30 percent. Thus, the refuse from most banks can be directly mixed with coal provided that the heating value and the ash content of the mixed product meet the design requirements of the boiler for which the fuel is intended.[2]

Improvements in coal preparation technology have also been a factor in encouraging the reprocessing of coal refuse for high grade coal. Heavy-media processes using magnetite or fine sizes of the refuse itself as the specific gravity controlling media allow the separation of refuse into clean coal (12 percent ash maximum), low grade fuel (20-40 percent ash), and a noncombustible residue.[4]

One heavy-media process which has been used successfully in Hungary, Poland, and Great Britain is the Haldex (Simdex) process. The key to the process is the Haldex Cyclone which uses a medium of refuse fines. It has been very successful in recovering fuel and a variety of other marketable products (bricks, cement, lightweight aggregate, etc.).[5]

Recco Coals, Inc. started operation of their pilot Renkol Coal Classifier in West Virginia in 1972. This mobile unit appears both efficient and versatile, handling 230 tons/hour of refuse and producing 70 tons/hour of coal consistently at or above 12,500 Btu.[1]

B.1.2 Low Grade Fuel Recovery

The recovery of low grade (low Btu/high ash) coal has been of minimal interest in the United States to date with the exception of mixing that coal with a high grade coal sufficient to make the mixture suitable for conventional boilers.

In Europe, however, there has been considerable experience with the burning of low grade coal processed from culm banks. The direct burning of coal waste banks has been practiced in Europe since World War II. France has used up its anthracite banks as a source of fuel in the last 25 years. Power plants have been constructed in Great Britain designed to burn coal waste.[1] Coal with as little as 5000 Btu/lb heating value can be burned in specially designed, conventional boilers provided the waste is friable enough to permit economical grinding to a fine size.[6]

Recent interest in fluidized-bed combustion (FBC) technology for burning coal has stimulated investigation and experimentation, mostly bench scale, of applying the technology to coal wastes. There are two related but different areas of interest: using the FBC for volumetric reduction of the refuse, or for the generation of process heat.

The British National Coal Board (NCB) has found that tailings and slurries, produced at the rate of five million tons/year in the United Kingdom, can be dried and burned in a fluidized bed, possibly without the need for extra fuel.[7] The liquid content of the slurries was not specified, but is likely to have been as high as 60 percent. Pilot tests were made in a 1 $m^2$ combustor, but a larger reactor is being built in Derbyshire.[7]

A similar approach has been tested by Heyl & Patterson, Inc. with the slurries from preparation plants in Pennsylvania, Virginia and Kentucky. Typically, this material is simply pumped into slurry ponds or behind dams built up of coarse refuse. As an alternative, Heyl & Patterson propose combusting the thickener underflow, usually from 20 to 40 percent solids of which 35 to 65 percent is ash. Experimenting with an 18 inch diameter FBC demonstrated that combustion was self-sustaining so long as the solids content did not fall below 38 percent. Below that, it was usually necessary to supply additional heat, either by running the start-up burner or by adding coal fines to the slurry. For the system to be autogenous, the heating value of the solids needs only to be 6,000 to 8,000 Btu/lb. of dry solids. The quantity of material requiring disposal was reduced by approximately 80 percent. This material, a lightweight ash pellet, appears to be relatively inert and minimally degraded by weathering. Some experimental evidence suggests that by operating the bed at a higher temperature, a lightweight aggregate would be formed.[8]

From the standpoint of utilization, FBC's appear to represent an effective way of secondary fuel recovery from coal refuse. Numerous bench scale experiments with the material have been conducted, both in the United States and abroad. The general findings are summarized below.

Self-sustaining combustion typically was achieved with as little as 2,500 to 3,500 Btu/lb. Ash content as high as 65 to 75 percent was acceptable. Typical moisture content of the refuse was 7 to 10 percent. Bed temperatures normally were maintained in the range of 800 to 900°C.

Industrial scale FBC's could be fired by coal refuse to produce process steam or generate electricity. Because FBC's typically recover heat both in the bed where combustion is occurring and in the freeboard above the bed, it may be possible to extract up to 50 percent of the heat generated.[9] Morgantown Energy Research Center of the U.S. Energy Research and Development Administration (ERDA) found the heat release rate to be at least twice as high as for a conventional boiler (47,000 to 90,000 Btu/hr/ft$^3$ for the FBC; 20,000 Btu/hr/ft$^3$ for a conventional boiler), but only 45 percent of the heat obtained in burning high grade coal rather than refuse in an FBC (200,000 Btu/hr/ft$^3$).[10]

Dorr-Oliver, Inc., in the late 1960's, experimented with the recovery of coal from refuse in an FBC. In its study for the Office of Coal Research, Dorr-Oliver concluded that combustion of anthracite refuse in an FBC may be economically feasible in the future under more favorable economic conditions than those prevailing at the time. This study, termed Operation Red Dog because of its concurrent focus on modes of utilizing the incinerated refuse (i.e., "red dog"), found the manufacture of brick to be the most feasible product for the calcined refuse. Although superior grade brick was produced, an economic evaluation of the FBC/brick fabricating facility was not sufficiently favorable (a return of 10.3 percent on a capital investment of $4,535,000) to proceed with construction and operation of a pilot plant.[11] Escalating fuel costs in the last nine years may have favorably altered the outlook for this mode of utilization.

Preparation requirements for FBC utilization are crushing the reactor feed. The optimal size is not agreed upon. ERDA crushed the refuse to pass a 1/4 inch screen; Dorr-Oliver used 4 mesh as the maximum; and a British experiment found 12 to 44 mesh to be preferable.[10,11,12] In all cases, the researchers attempted to minimize the creation of dust-size particles during crushing because of their tendency to be carried out of the bed uncombusted in the stack gases.

Potential uses for the calcined refuse will be dealt with in subsequent sections of this chapter. These may include lightweight aggregate, bricks, and secondary mineral recovery.

## B.2 Secondary Mineral Recovery

### B.2.1 Alumina

Because there is a significant amount of alumina coal wastes, it is technologically feasible to recover it from fly and bottom ash or from preparation plant washings. There are several known chemical processes for extracting alumina ($Al_2O_3$) from the various ores in which it is found, including coal wastes. The barrier to the extraction of alumina has been and continues to be an economic one.

Bauxite has been the traditional ore of choice for the manufacture of aluminum. It is plentiful; known deposits are estimated to be sufficient to fulfill the world demand for a century. Yet of the total known deposits, very little lies within the U.S. Domestic bauxite mined in Arkansas supplies less than 10 percent of the nation's aluminum demand.[13]

Many of the world's bauxite producers formed a cartel-like organization a few years ago known as the International Bauxite Association. Although the IBA markedly increased the severance tax on bauxite, it has not had unlimited power over the market for several reasons. Most notably are the facts that some large producers are not members of the IBA, cartels in general are difficult to maintain, and all producers are aware that a ceiling exists above which alternate sources of alumina will be economical to extract. These reasons make a bauxite embargo unlikely.[13]

Beyond its abundance, bauxite has other prominent advantages. It is rich, frequently containing more than 50 percent alumina. It is easily processed, because little raw material preparation is required; it uses an alkaline process so that all process equipment can be made of mild steel; and the process itself is simple. All these factors combine to make the cost of processing bauxite much lower than the cost of extracting alumina from other sources such as clays or coal wastes. The alternative processes will be competitive only if the raw material is very cheap in comparison to bauxite.

Bauxite and coal refuse are not the only domestic sources of alumina. Many alternative materials have been considered: anorthite (20-36 percent $Al_2O_3$), nepheline (32 percent), leucite (23 percent), kyanite (63 percent), kaolinite (39.5 percent), illite (20 percent), shales (15-25 percent), and fly ash (20-40 percent). Nepheline is currently being used in Russia.[14] Anorthite is being seriously investigated in Canada and fly ash is[15] being used in Hungary and Poland, primarily for its usefulness in manufacturing cement, but alumina is extracted as a by-product.[11]

The alumina content in coal refuse varies widely from coal field to coal field. Robl et al. from the University of Kentucky sampled coal refuse from 23 of the largest preparation plants in Kentucky. The alumina concentration in the Eastern Kentucky fields averaged 26 percent in contrast to 18 percent in the Western Kentucky fields.[14] Alcoa sampled these fields as well, but found Western Pennsylvania's refuse to be richer in alumina than the Kentucky wastes.[13]

Interestingly, Robl found that refuse from the Hazard No. 4 seam is anomalous, producing a refuse significantly higher in $Al_2O_3$, averaging 35 percent. Moreover, Hazard No. 4 has a wide geographic distribution, being present in Kentucky, Virginia, West Virginia, and Tennessee. The high alumina content is attributed to a brown flint clay splint which divides the Hazard No. 4 seam into two parts. The use of automated mining techniques results in the mining of the entire seam, with the clay splint being removed at the preparation plants. The splint results in a large amount of refuse, up to one ton of refuse for two tons of coal. Because of the seam's low sulfur content, many operators plan to increase production two or threefold from 1976 to 1979.[17]

Two types of processes are available for extracting alumina from coal refuse. One of these, lime sintering, has been used in Poland and Hungary at a commercial scale. It involves sintering the crushed refuse and limestone at temperatures ranging from 1100 to 1400° C, just below the mixture's fusion point. The sintered material is then leached to remove either calcium aluminate or sodium aluminate.[17]

For the lime sintering process to be feasible, the alumina content of the refuse should be greater than 28 percent.[17] . The process also requires large quantities of limestone—10 to 12 tons for one ton of alumina produced ——so that the presence of limestone in the immediate vicinity is very important. Alcoa has developed a modification of this lime sintering process which uses the fuel content of the coal waste to supply energy for the kilns. Waste with approximately 4,000 Btu/lb would be satisfactory.[13] .

The second type of extraction is the acid process. Here the refuse is crushed, roasted at 750° C, and leached with an acid. The leachate is then purified of solids, crystalized, and calcined.[13] . One of the more promising variants of the acid process is the Pechiney $H^+$, a two-stage process using sulfuric acid to attack the ore, and hydrochloric acid to produce aluminum chloride which is then calcined to alumina. This two-stage process has the advantages of not requiring the roasting of the raw refuse, and of allowing the easy separation of iron compounds from the leachate.[17] .

The acid process may also lend itself to fluidized-bed combustion. Combustion of the refuse in a bed of about 750° C would provide the roasting necessary to prepare the material for the acid leaching, but Alcoa feels the process would leach too many other undesirable salts which could lead to a pollution problem.[13] .

The alumina content necessary for the acid processes is lower than for the lime sintering processes. The threshold for the acid processes is 20 percent in leachable form (approximately 22 percent total) in contrast to the 28 percent for sintering.[14] . Robl has noted several other characteristics which affect the feasibility of the acid processes. Calcium content should be low, presumably less than 1 percent. Relatively high Btu content provides a portion of the energy for the process. Sulfur content in Eastern Kentucky refuse sampled by Robl ranged from 0.2 to 3.66 percent in the form of sulfides. This may be a partial source for the sulfuric acid used in the Pechiney $H^+$ process.[14]

A few recent experiences with ventures to extract alumina from non-bauxite sources, especially coal refuse, are worthy of mention. North American Coal Corporation produced a high grade aluminum sulfate from coal refuse containing 20 to 25 percent alumina at a pilot plant in Ohio in 1962-1963. The company gave serious consideration to a commercial scale venture to extract alumina from its refuse piles, but the product could not compete in the market with bauxite-produced alumina.[6,11]

In the early 1970's, Alcoa conducted serious experimentation with the modified lime sintering process described by Goodboy.[18] . Refuse in the Pennsylvania anthracite fields was most attractive due to an alumina content of 22 to 30 percent, Btu content ranging from 3,700 to 10,000, ash ranging from 46 to 68 percent, and local availability of limestone.[3] . Plans were made and equipment was purchased to build a demonstration plant which would process 10 tons of coal per day. Soaring energy costs suddenly made coal wastes, which had been assumed to have a negative economic value, worth $4 to $8 per ton. Alcoa also concluded it would be extremely difficult to bring limestone out of the same mine with the coal, even though they are found in close proximity, thus adding substantial transportation costs to the venture. The project was abandoned.[13] .

A French firm, Perchura, is believed to have operated a large pilot plant using clays of 20 percent alumina and less.[11] Canada is aggressively experimenting with recovery of alumina from non-bauxite sources, especially anorthite.[15] And the Soviet Union appears to have extracted alumina from coal washing refuse and coal ash.[19]

### B.2.2 Trace and Transition Metals

Some 46 elements are known to occur in coal ash and refuse. Many are found in only very small quantities, being generally rare in occurrence. Various studies have been conducted to determine if any of these metals could be economically recovered from coal refuse.[4,11,14,20] No one has yet answered that question in the affirmative.

Robl et al. at the University of Kentucky are working on the possibility of recovering one or more metals as a secondary product in the recovery of alumina.[14] Barium cobalt, copper, nickel, rubidium, strontium, yttrium, zinc, zirconium, uranium, and thorium are being sought. The only trace element found in sufficient quantity to be of interest was zinc. Concentrations of zinc much higher than in Kentucky refuse are found in Illinois.

Although not a trace element, titanium is found in concentrations of two to ten percent in Eastern Kentucky refuse, particularly in the Hazard No. 4 seam, noted above for its unusually high alumina content.

### B.2.3 Sulfur

Very little attention has been given to the recovery of sulfur from coal refuse with the exception of a study for EPA in 1971.[21] Laboratory tests were performed in which coal refuse and limestone were ground, pelletized, and introduced into a desulfurizing shaft. Off gases would serve as feedstock to a conventional sulfur recovery plant. The experimental results indicated both technical and economic feasibility.[21] Subsequent lack of interest may reflect changes in the world market for sulfur.

Sulfuric acid is manufactured in Britain as a by-product of cement manufacture from coal refuse.[7]

## B.3 Construction Materials

### B.3.1 Lightweight Aggregate

Lightweight aggregate is used primarily as a substitute for limestone in cement and cement products. It is adaptable to being poured in place, precast, prestressed, and to being fabricated into concrete blocks. Because of its versatility, high compressive strength, light weight, chemical stability, and insulating properties, it has wide applicability in concrete construction. Some well-known structures using lightweight aggregate are the World Trade Center in New York City, the TWA terminal at John F. Kennedy International Airport, and the San Francisco/Oakland bridge.[22]

Some lightweight aggregates, e.g., vermiculite and perlite, make concrete with high insulating but poor load-bearing characteristics. In order to obtain good load-bearing characteristics, lightweight aggregates such as expanded shales, clays, slates, or slags are used.

In order to qualify as a lightweight aggregate, a material must have a dry-loose weight of less than 65 $lb/ft^3$.[23] Concrete produced with expended shales, clays, slates, or coal refuse typically averages 90 to 120 $lbs/ft^3$ whereas conventional aggregates make concrete averaging from 135 to 150 $lbs/ft^3$.[22]

There are two basic processes for manufacturing lightweight aggregates: the rotary kiln and the sintering grate processes. Both involve heating the raw material (shale, clays, slates, or coal refuse) to the point of incipient fusion where either bloating or agglomeration takes place.

Almost 80 percent of the expanded lightweight aggregate is produced by the rotary kiln method. The pre-sized material is introduced to the kiln, and as it approaches the burning zone it becomes semi-molten. The material expands (bloats) because gases are formed but are trapped beneath a glassy surface layer.

In sintering, the material is crushed, mixed with water (and coal, if the material is other than coal refuse), and pelletized. It then travels along a continuous grate where it is fired. In contrast to the bloating of the rotary kiln process, sintering obtains its lightweight characteristics more by the creation of voids by carbon burn-out and the agglomeration of particles as they near fusion.[24]

Although the rotary kiln method has been favored for expanding material other than coal refuse, the method has an inherent disadvantage, viz. its energy requirements. Rotary kilns were typically fired by gas or oil. Gas shortages have forced conversion to oil or coal. Regardless of the fuel used, however, increasing fuel costs are reflected in the price of the aggregate.

The sintering grate process, on the other hand, takes advantage of the Btu content of the coal refuse. Jerry Rose at the University of Kentucky has determined that approximately three-fourths of the fuel requirements for sintering is provided by the solid fuel in the raw feed.[23] The process which Rose describes is a sealed sintering facility with a multi-pass recycled draft. This modification permits total coal burn-out, an important requirement, and the control of emissions, particularly of sulfur oxides ($SO_x$), a problem which has forced the closing of numerous rotary kilns and sintering grates.[23,25]

There is some uncertainty as to whether lightweight aggregates can be produced in a fluidized bed. Dorr-Oliver noted that the refuse it sampled failed to bloat at normal bed temperatures (1400 to 1800° F). On one or two occasions the temperatures rose rapidly to an excessive level, bloating the refuse, but in so doing caused defluidization of the bed.[11] ERDA researchers, on the other hand, reported that the production of lightweight aggregate in an FBC was supported by at least some experimental evidence.[8]

The required refuse characteristics have been estimated by Rose. Coal content should be about 6 percent or less so that carbon burn-out is achieved. Low sulfur refuse is desirable in order to minimize $SO_x$. Refuse preparation required crushing so that 90 percent was smaller than 3/8 in.[23]

Rose found that masonry blocks made from sintered coal refuse aggregate met or exceeded all of the appropriate ASTM standards. ASTM C 90 specifies a minimum compressive strength of 1000 psi for general use, moisture controlled blocks. All the sintered blocks exceeded this (1,210 to 1,520 psi), but they were inherently weaker than blocks made with conventional (limestone and sand) aggregate which averaged 1,650 psi. This somewhat reduced load-bearing capability is typical for lightweight aggregates.[23]

Significantly, the blocks weighed 30 percent less than limestone blocks, thus reducing transportation costs and expanding the potential market area. Heat transfer through the blocks was also a notable 45 percent less than through conventional blocks.[23]

Lightweight aggregate has uses other than in concrete, though they are as yet minor. Most notably these are as an anti-skid aggregate in bituminous highway surfaces, and a variety of horticultural uses. These will be dealt with below.

There has been significant operational experience with manufacturers of lightweight aggregate from coal refuse. Since 1959, the Clinchfield Coal Company in Virginia produced 200,000 tons a year of rotary kiln fired lightweight aggregate product called "Clinch-Lite." This material was made from crushed bituminous coal shale refuse. Unfavorable market and cost conditions forced closure of the plant in 1975.[6]

Bituminous coal refuse from the Truax-Traer Coal Company in West Virginia was also processed into a lightweight aggregate product beginning in 1955. The refuse was crushed to passing 1/4 inch size, pelletized and burned on a chain grate stoker. The sintered product met the requirements of ASTM Designation C-130 for lightweight aggregate, but production was discontinued around 1960.[6]

Anthracite coal refuse also has been used as a source of lightweight aggregate. The By-Lite Corporation in Pennsylvania manufactured a lightweight travelling grate product called "By-Lite." This product was used primarily in block manufacture with some additional use in lightweight concrete.[6] The operation was recently shut down for economic reasons.

### B.3.2 Cement

Cement has been manufactured successfully in Europe from coal refuse. Either raw coal refuse or preburned refuse is used as the raw material, replacing the clay fraction of the usual cement kiln feed composition. The refuse provides both the silica and the alumina required for the proper Portland cement clinker.[26]

A report of the Polish Tatabanya coal refuse utilization project notes that 75 to 80 percent of the coal content of the raw refuse can be utilized in the clinker burning, thus reducing conventional fuel requirements. This operation utilizes about half a million tons of coal waste per year.[5] As described in Section 2.2.1, alumina also is recovered in this process. Cost estimates for a combined cement/alumina facility in the U.S. show a less than satisfactory rate of return of 10.15 percent.[16]

In Great Britain, Glover reports that 130,000 tons/yr of unburned spoil is used in the manufacture of cement by both the conventional clay/limestone process and the combined cement/sulfuric acid process.[7]

### B.3.3 Coal-Crete

Raw coal refuse has been tested for its suitability as an aggregate in low quality concrete mixes.[7,27,28] The major shortcoming is that the concrete products weather poorly. The concrete not only is stained by the pyrite present in the aggregate, but it also slowly disintegrates. The disintegration may be caused by the shales present swelling slightly and then breaking down and/or by the formation of sulfuric acid which reacts with the cementitious bonding material.[28]

Breynton and Rose prepared coal-crete from a variety of refuse samples. Substantial amounts of fines or clay material were detrimental to the strength and durability of the product. Since it is not sufficiently durable to withstand weathering, coal-crete might be used in underground mines where temperature and humidity are nearly constant all year. Coal-crete pillars could be poured for roof supports, allowing coal pillars to be mined. Such a proposal was not, however, found to be economically feasible.[27]

### B.3.4 Mineral Wool

The production of mineral wool from coal refuse was proposed as early as 1940. Since 1966, West Virginia University has been investigating the possibility of producing mineral wool from coal ash slags and fly ash.[29]

Preliminary tests were made by a mineral wool producer using current anthracite refuse as the raw material. The resulting wool was an undesirable brown color, but more importantly, the cupola couldn't be operated in its normal temperature range without freezing. The need for a higher temperature was assigned to the alumina ($Al_2O_3$) content of the refuse. The material normally used by this manufacturer of mineral wool contains 12 to 13 percent alumina while the refuse contained 24 to 28 percent. The cupola would either have to be redesigned for operating at a higher temperature to use the higher alumina material, or other materials would have to be added.[30] What effect the increased price of insulation has on the economic feasibility of this process is not clear.

### B.3.5 Bricks and Ceramics

Bricks, through typically made from clay, have been made from most silicious materials, including coal refuse and fly ash. Glover observed that the use of coal mine spoils for brick manufacture is probably nearly as old as the coal mining industry. Even today, some of the carboniferous fireclays are mined specifically for the purpose of making refractory bricks. At present, some 500,000 tons of coal mine spoil in Great Britain is used directly in the manufacture of building bricks.[7]

There are two basic forms in which coal refuse can be utilized in brick manufacture: raw and burnt. Bland et al. at the University of Kentucky examined 66 samples of coal refuse taken from 23 preparation plants representing both the Eastern and Western Kentucky fields. Of the 66 raw refuse samples, only nine were judged satisfactory and one marginal for brickmaking. The major fault was a lack of sufficient clay binder to hold the mass together and provide the necessary degree of hardness. Those characteristics deemed most restrictive for brick manufacture were:

- ash content of 65 percent or greater,
- $Fe_2 0_3$ content of 8 percent or less,
- Ca0 content of 0.7 percent or less, and
- normative quartz content between 12 and 18 percent.

All of the suitable samples were of a coarse or medium size fraction, and were from the Eastern Kentucky coal basin.[24]

In Poland, the coal refuse by itself (or mixed with clay) produces a building material reputedly of superior strength to products obtained by conventional technology. It permits an average increase of 30 percent of the burning equipment capacity and reduces the bulk density of the products. The process allows a 75 to 90 percent reduction in fuel cost in the ceramic industry by eliminating the use of commercial coal. As a result, waste coal cleaned by the Haldex process in Hungary and Poland was utilized to the extent of one million metric tons/year in 1971.[5]

Dorr-Oliver, in its experiments with the fluidized bed combustion of coal refuse, found the manufacture of brick to be the most feasible utilization of the burnt refuse. ASTM superior-grade brick was made from the anthractite refuse using 72 percent coarse (minus 10 mesh) crushed fluid bed underflow product, 25 percent fine fluid bed cyclone product and three percent sodium silicate in solution. To this mix, 11 percent water was added, allowing the material to be shaped into bricks for firing. Other samples of refuse required different mix formulations. In spite of this, Dorr-Oliver concluded that the optimum brick fabrication requirements appeared robust enough to warrant confidence that the findings could be successfully applied to calcined "red dog" of highly variable quality.

Despite the technological feasibility, Dorr-Oliver concluded that the estimated rate of return of 10.3 percent on fluid bed/brick fabricated facility was inadequate to justify a pilot plant.[11] However, alternate refuse disposal costs were not factored into the economic evaluation.

Coal refuse has had minimal usage in other ceramics. In Japan, some experimental work was conducted to produce heavyweight floor tiles by combining shale or clay-based coal mine washing debris with hard pottery stone wastes containing FeS as an impurity. In other studies, Japanese scientists had found that the coal refuse, when burned with about 10 percent iron powder, produces a dense mass suitable for pottery.[31]

## B.4 Landfill and Embankments

Coarse coal refuse has been used for landfill and embankments over the years with varying degrees of success. Today it is widely understood that successful utilization of the refuse for fill depends on the results of laboratory analyses of the engineering properties of the specific refuse in question, and on proper compaction during construction.

Other than small amounts of fill for commercial or industrial construction, most uses of refuse have been either embankments for disposal of preparation plant slurries or highway embankments. Since slurry pond embankments are a disposal mode rather than a productive use, this section will address the suitability of coal refuse for highway embankments.

In the past, the principal objections to the use of coal refuse in highway embankments have been its tendency toward ignition by spontaneous combustion, and its production of acidic leachate. Although burnt refuse had long been acceptable as a fill material in Great Britain, it was only after the Aberfan disaster that serious research and experimentation was done which demonstrated that raw refuse, if properly compacted, became a satisfactory engineering soil for embankments and fills.[32]

Under the dual research and promotional efforts of Minestone Executive, the National Coal Board has developed coal refuse utilization as a fill material to a fine degree. Compacted coal refuse has been used successfully for development of airports, helicopter landing pads, industrial site fill, fill for housing developments, and for highway embankments totalling in excess of 20 km.[6,7,26,32,33]

Efforts to use coal refuse for landfill or highway embankments in the U.S. has lagged considerably behind Great Britain. Recently, however this has begun to change. Major steps have been made by the Pennsylvania Department of Transportation (PENNDOT), both in the laboratory and in the field.

PENNDOT considers the nonfuel utilization of refuse banks containing marketable coal to be a misuse of the resource. Loss on Ignition (LOI) tests should therefore be performed to ensure that the coal content of the refuse is less than 15 percent.[34]

Butler of PENNDOT has reported the importance of grain-size distribution, moisture-density relationship, and shear strength in determining the suitability of a given refuse for fill. In brief, he found the compaction characteristics to be the major consideration. Grain-size distribution and moisture-density data demonstrated the occurrence and importance of material degradation in obtaining maximum densities during construction. The measure of the degree or amount of degradation under impact loading, from either moisture - density testing or construction compaction, requires continual grain-size distribution analyses to evaluate the densities achieved. Where continued degradation is evident, maximum densities are most likely not being achieved.[34]

Work under Moulton et al. at West Virginia University tended to confirm the results of British experience in using coal refuse as an engineering material.[35] Peterson, of the U.S. Mining Enforcement and Safety Administration, has also found refuse suitable for embankment construction, but only after refuse-specific laboratory testing.[36] Testing at the University of Kentucky further verified that there are no adverse engineering properties associated with coal refuse which would prevent its use as a construction material. Permeability of the compacted material is very low, a factor which minimizes leachate formation.[32]

The use of coal mine refuse as embankment fill in highway construction in Kentucky was investigated. Although the material was determined to be satisfactory, transportation costs limit its use to the immediate location of the refuse pile, i.e. within ¼ mile.[32] The Kentucky Department of Transportation is not averse to using coal wastes for embankments, but it has made clear its unwillingness to absorb any increased construction costs in the process.[37]

Field experience in the U.S. is not extensive. The most comprehensive reporting of this usage was compiled for the U.S. Federal Highway Administration in 1976:

> In Illinois coal mining wastes have been used to a limited extent. A portion of Interstate Route 57 in Franklin County was constructed on an embankment of coal refuse.

Several refuse piles were located within the corridor of the Interstate and the material was used as fill rather than being removed and stockpiled at another site. Present evaluation of this section of Interstate Route 57 indicates that there has been no direct problems resulting from the use of coal refuse for embankment.

In eastern Ohio, coal refuse has been accepted for use in embankments for years, provided the materials conform to weight, compaction, and other requirements of the specifications. Coal refuse is considered as random material in the state specification.

More than 1.5 million cubic yards (1.4 million cubic meters) of anthracite coal refuse were used in the construction of a highway embankment for the Cross Valley Expressway in northeast, Pennsylvania near Wilkes-Barre. This embankment forms part of the western approach to a bridge which crosses the Susquehanna River between Forty Fort and Kingston. The material from the refuse bank was first cleaned to remove its residual coal content and then placed in layers and thoroughly compacted to eliminate the possibility of spontaneous combustion and acid mine drainage. Instrumentation was installed during the construction of the embankment in order to monitor foundation response and ambient temperatures at various locations within the embankment.

Anthracite coal refuse was also used to construct embankments 40 to 50 feet (12 to 15 meters) high for two sections of Interstate Route 81 near Hazleton in Luzerne County. The refuse was placed and compacted in five foot (1.5 meter) lifts and the outside slopes were covered with ten feet (3 meters) of soil.

Based on the success of these installations, the Pennsylvania department of Transportation is planning to utilize coal refuse in future highway projects. Several projects in the western portion of the state will incorporate processed bituminous coal refuse into construction as embankment material.[6]

This report for FHWA, entitled Availability of Mining Wastes and Their Potential for Use as Highway Material, also identifies design and construction techniques which overcome the problems which engineers have feared in using coal refuse, viz. spontaneous combustion and acid leachate. Most important is the need to properly compact the refuse in relatively thin layers (8 inches or 203.2 mm maximum) to at least 97 percent of its maximum dry density to decrease the void ratio, thus reducing the internal circulation of air and the permeability of the material. This eliminates, for all practical purposes, the threat of spontaneous combustion, oxidation of pyrites, and acidic leachate. At the same time the shear strength of the material is improved. A cover of several feet of natural soil is also recommended over the slopes of coal refuse embankments.[6]

Mixing of the refuse with fly ash has been proposed for several reasons. First, it is presumed that it would allow for greater densities and higher shear strength because of its ability to fill the voids between refuse particles. Second, the acidic nature of coal refuse can be effectively neutralized by the fly ash. Third, it has been reported that fly ash will eliminate the problem of delayed plant toxicity caused by toxic elements in the refuse. Until that is established, however, a sealing blanket of soil thick enough for sustaining vegetation should be used.[1]

## B.5 Highway Uses

Several highway uses other than embankment construction have been suggested for coal refuse. "Red dog" has been used for years for tertiary roads in mining country, but its use has not been wholly satisfactory due to dust and acid runoff problems. Researchers more recently have focused their attention on using coal refuse as the aggregate component for bituminous mix ("black top"), as a road base or sub-base material, and as an anti-skid substance.

### B.5.1 Bituminous Mix

Incinerated refuse has been tested for its suitability as an aggregate in bituminous mixes for highway paving. The most extensive testing was done by Pennsylvania State University and PENNDOT using crushed incinerated anthracite refuse. Laboratory tests on material screened between 9/16 and 3/32 of an inch had good stability, met the void criteria, and could be mixed properly with asphalt cement. PENNDOT approved four experimental projects in Luzerne County: (1) a two-lane secondary road with relatively light automobile traffic, (2) a two-lane secondary road with heavy truck traffic, (3) a four-lane primary highway with high-speed traffic, and (4) a two-lane city road. For this mix, 1,400 tons of refuse material were used, covering 30,000 square yards in thicknesses of one to two inches.

No difficulties were encountered during paving. Monthly inspections over two and a half years did not reveal any signs of distress. Several series of skid resistance tests were made by the Department of Transportation with excellent results.[30] Recent reports, however, have indicated that the experimental sections did not wear sufficiently well under traffic. PENNDOT has made no further use of the material for this purpose.[6]

Rose, in his work with sintered refuse as a lightweight aggregate, has conducted some tests with this material in bituminous mixes. The main attribute of this material in bituminous mixes is its skid-resistance, and to some extent, its lightweight characteristics. Also tested was an "open-graded" mix. These type mixes have a high void content, allowing water to drain through the surfaces, thereby decreasing water build-up under vehicle tires, a major factor in skidding on wet pavement. Laboratory tests indicated the sintered aggregate performed as well as the skid-resistant granites used in Georgia.[34]

B.5.2 Road Base and Subbase Material

Raw coal refuse is seldom suitable for applications requiring strong aggregates. Glover has reported on the upgrading of refuse by stabilizing it with either lime or cement, giving it sufficient compressive strength to be suitable as highway subbase. The cost of adding as much as 10 percent cement may be justified in some cases.[7]

Good results were obtained in using raw coal refuse, particularly when mixed with 25 percent fly ash, as a road base material for the parking lot at an EPA facility in West Virginia.[35,39] Field compaction of the base materials was satisfactory, and the density of the in-place materials exceeded the laboratory design values. After five years of service the wearing course of the asphalt was structurally sound. Core samples showed no signs of degradation. Leachate monitoring revealed very little leachate formation.[38]

B.5.3 Anti-Skid Applications

Charmbury reported in 1972 that PENNDOT has successfully experimented with the spreading of crushed incinerated anthracite refuse on roads and highways during the winter as an anti-skid material. PENNDOT was using approximately 1.5 million tons of anti-skid material annually. Such materials as cinders, crushed stone, sand, and boiler slag are tradionally used. The burned refuse was crushed and then passed through a double-deck vibrating screen. The screening was found to be necessary to remove extreme fines, especially clay, which clogged the spreaders on the trucks. Optimal conditions were achieved by using material which passed through the 9/16 screen but remained on top of the 3/32" screen. The product is capable of being mixed with melting agents such as calcium chloride. It is easy to handle, flows freely, and has excellent skid-resistance characteristics.[39] PENNDOT has since specified this incinerated anthra cite refuse for anti-shed material.[30]

## B.6 Horticultural Uses

Lightweight aggregate has been used extensively as a soilless growth medium by horticulturists. Most widely used are the naturally occurring aggregates, vermiculite and perlite. Manufactured aggregates are now also being used for this purpose. The Lightweight Aggregate Producers Association estimates that five percent of its annual production currently goes to horticultural uses, and it expects this market to grow substantially.

Experiments at Pennsylvania State University made use of a variety of coal wastes including burned anthracite refuse and a lightweight aggregate produced from coal wastes (Lelite). Incinerated refuse was selected for most of the experiments because of its low cost and wide availability. The material was used successfully to grow carnations, roses, azalsas, African violets, and many other plants. Preparation involved crushing, sizing, and mixing with peat moss.[30]

Buxton et al. at the University of Kentucky have successfully grown chrysanthemums and tomato transplants in mixes of peat and up to 75 percent sintered coal refuse.

Unlike raw refuse, the sintered material is physically and chemically inert. Thus, there is no problem with chemicals which otherwise would be toxic to the plants. It is porous, thereby providing a good water-holding capacity, and is relatively lightweight. Buxton estimates the material would be less expensive than the materials currently used.[40]

Other horticultural uses for sintered aggregate include a variety of landscaping uses, a field long neglected by the lightweight aggregate industry. Both the Lightweight Aggregate Producers Association and the Expanded Shale, Clay, and Slate Institute are actively investigating a variety of ways of using both raw and burned aggregate for landscaping.

One additional horticultural use for coal refuse is the possibility of manufacturing clay pots, using either raw or burned refuse as the raw material.

## REFERENCES FOR APPENDIX B


1. Michael Baker, Jr., Inc. Investigation of Mining-Related Pollution Reduction Activities and Economic Incentives in the Monongahela River Basin. For the Appalachian Regional Commission. Washington, D.C., 1975.

2. Maneval, David R. Reprocessing of Coal Refuse for a Second Yield of Steam Coal. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

3. Charmbury, H. Utilization of Pennsylvania Anthracite Refuse. Proceedings of the First Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1975.

4. Spicer, T. Pennsylvania Anthracite Refuse: A Summary of a Literature Survey on Utilization and Disposal. Report No. SR-79. University Park, PA: Pennsylvania State University, 1971.

5. MacLean, D., Kogelman, W., and Spicer, T. Investigation of the Haldex (Simdex) Process for Beneficiating Coal Refuse: Hungarian Practice. Report No. SR-80. University Park, PA: Pennsylvania State University, 1971.

6. U.S. Federal Highway Administration. Availability of Mining Wastes and Their Potential for Use as Highway Material (three volumes). Washington, D.C., 1976.

7. Glover, H., "The Disposal of Coal Mine Spoil in the United Kingdom." In Goodman and Chadwick, eds., Environmental Management of Mineral Wastes. The Netherlands, 1978.

8. Methany, D. Thermal Disposal of Fine Refuse in a Fluidized Bed. Proceedings of the Second Symposium on Coal Preparation. Washington, D.C.: National Coal Association, 1976.

9. Szpindler, G., and Waters, P. Investigation of Potential for Heat and Material Recovery in the Fluidized-Bed Incineration of Coal Washery Rejects and Some Other Industrial Wastes. Proceedings of the First International Conference on the Conversion of Refuse to Energy. 1975.

10. Mei, J., Gall, R., and Wilson, J. Fluidized-Bed Combustion of Anthracite Refuse. Proceedings of the Twelfth Intersociety Energy Conversion Engineering Conference. 1977.

11. Dorr-Oliver, Inc. Operation Red Dog: A Study of Fluid-Bed Combustion and Potential Uses of Anthracite Culm-Bank Material. For the U.S. Department of Interior, Office of Coal Research. Washington, D.C., 1969.

12. Norman, P. "Combustion of Colliery Shale in a Fluidized Bed." Energy World (18):2-4, July 1975.

13. Hudson, L. Aluminum from Coal Wastes? Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

14. Robl, T., Bland, A., and Rose, J. Kentucky Coal Refuse: A Geochemical Assessment of Its Potential as a Metals Source. Proceedings of the Second Symposium on Coal Preparation. Washington, D.C.: National Coal Association, 1976.

15. Winer, A. Sources of Canadian Non-Bauxite Alumina. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

16. Katell, S. The Potential Economics of the Recovery of Trace Elements in Coal Refuse. Coal Research Bureau Report No. 142. Morgantown, WV: West Virginia University, 1977.

17. Robl, T., and Bland, A. The Distribution of Alumina in Shales Associated with the Major Economic Coal Seams of Eastern Kentucky. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

18. Goodboy, K. "Investigations of a Sinter Process for Extraction of $Al_2O_3$ from Coal Wastes." Metallurgical Transactions B 7B(4), 1976.

19. Condry, L. Recovery of Alumina from Coal Refuse: An Annotated Bibliography. Coal Research Bureau Report No. 130. Morgantown, WV: West Virginia University, 1976.

20. Spicer, T., and Luckie, P. Operation Anthracite Refuse. Proceedings of the Second Mineral Waste Utilization Symposium. Chicago, IL: U.S. Bureau of Mines and ITT Research Institute, 1970.

21. LaRosa, P., and Michaels, H. Study of Sulfur Recovery from Coal Refuse. For the U.S. Environmental Protection Agency. Washington, D.C., 1971.

22. Hammond, J. Lightweight Aggregate as a Construction Material. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

23. Rose, J. Sintered Coal Refuse Lightweight Masonry Aggregates. Proceedings of the North American Masonry Conference. 1978 (preprint).

24. Bland, A., Robl, T., and Rose, J. Kentucky Coal Preparation Plant Refuse Characterization and Uses. Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

25. Berger, T. The Sintered Lightweight Aggregate Industry. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

26. Maneval, D. Recent European Practice in Coal Refuse Utilization. Proceedings of the First Kentucky Coal Refuse Disposal and Utilization Seminar. Cumberland, KY, 1975.

27. Breynton, D., and Rose, J. Utilization of Coal Refuse as a Concrete Aggregate (Coal-Crete). Proceedings of the Fifth Mineral Waste Utilization Symposium. Chicago, IL, 1976.

28. Laurence, W., and Slonaker, J. Gob Aggregate Concrete Products. Coal Research Bureau Report No. 120. Morgantown, WV: West Virginia University, 1976.

29. Humphreys, K., and Laurence, J. Production of Mineral Wood Insulating Fibers from Coal Ash Slag and Other Coal-Derived Waste Materials. Coal Research Bureau Report No. 53. Morgantown, WV: West Virginia University,1970.

30. Charmbury, H., and Chubb, W. Operation Anthracite Refuse. Report No. SR-94. University Park, PA: Pennsylvania State University, 1973.

31. Toyabe, Y., Matsumoto, G., and Kishikawa, H. Manufacturing Ceramic Goods Out of Mining Wastes. Proceedings of the Fourth Mineral Waste Utilization Symposium. Chicago, IL, 1974.

32. Maneval, D. Utilization of Coal Refuse for Highway Base or Subbase Material. Proceedings of the Fourth Mineral Waste Utilization Symposium. Chicago, IL, 1974.

33. Maneval, D. Coal Refuse Utilization Prospects: An Update of Recent Work. Proceedings of the Second Symposium on Coal Preparation. Washington, D.C.: National Coal Association, 1976.

34. Butler, P. Utilization of Coal Mine Refuse in Highway Embankment Construction. Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, KY: National Coal Association, 1974.

35. Moulton, L, Anderson, D., Hussain, S., and Seals, R. Coal Mine Refuse: An Engineering Material. Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, KY: National Coal Association, 1974.

36. Peterson, R. Engineering Properties of Coal Waste Embankment Material. Proceedings of the First Symposium on Underground Mining. Louisville, KY: National Coal Association, 1975.

37. Drake, W. Coal Refuse in Highway Embankments and Aggregates. Proceedings ofthe Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

38. Scott, R., Wilmoth, R., and Light, D. Utilization of Fly Ash and coal Mine Refuse as a Road Base Material. For the U.S. Environmental Protection Agency. Cincinnati, OH, 1978.

39. Charmbury, H., and Maneval, D. The Utilization of Incinerated Anthracite Mine Refuse as Anti-Skid Highway Material. Proceedings of the Third Mineral Waste Utilization Symposium. Chicago, IL, 1972.

40. Buxton, J., Knavel, D., and Yost, G. Sintered Coal Refuse as a Growing Medium for Plants. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

41. Morrison, R., and Kinder, D. Coal Ash and Coal Refuse: New Potential Resources. Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

## ADDITIONAL (UNREFERENCED) SOURCES


1. Charmbury, H. Utilization of Coal Mining Wastes. Proceedings of the First Mineral Waste Utilization Symposium. Chicago, IL, 1968.

2. Charmbury, H., Chubb, W., and Witkowski, F. The Utilization of Incinerated Anthracite Mine Refuse as an Aggregate in Bituminous Mixes for Surfacing Highways. Report No. SR-96. University Park, PA: Pennsylvania State University, 1973.

3. Coalgate, J. A Study of Coal-Associated Wastes Resulting From the Mining, Processing, and Utilization of Coal. Washington, D.C.: U.S. Energy Research and Development Administration, 1975.

4. Gleason, V. A Bibliography on Disposal of Refuse from Coal Mines and Coal Cleaning Plants. For the U.S. Environmental Protection Agency, Washington, D.C., 1978.

5. Jackson, G., and Ware, W. The Feasibility of Utilizing Solid Wastes for Building Materials. For the U.S. Environmental Protection Agency, Washington, D.C., 1977.

6. Kealy, D., et al. "Those Waste Banks Could Be Sources for Fuel, Alumina." Coal Mining Process 13(8), 1976.

7. Peters, J., Spicer, T., and Lovell, H. A Survey of the Location, Magnitude, Characteristics, and Potential Uses of Pennsylvania Refuse. Report No. SR-67. University Park, PA: Pennsylvania State University, 1968.

8. Rose, J. Sintered Coal Refuse as a Constructed Aggregate. Proceedings of the Third Kentucky Coal Refuse Disposal and Utilization Seminar. Lexington, KY, 1977.

9. Sullivan, G. Coal Wastes. Proceedings of the First Mineral Waste Utilization Symposium. Chicago, IL, 1968.

10. Szpindler, G., Waters, P., and Young, C. Fluidized-Bed Combustion as a Solution to the Environmental Problems of Coal Mining Waste. National (Australian) Chemical Engineering Conference. 1974.

11. Utley, R., Lovell, H., and Spicer, T. The Utilization of Coal Refuse for the Manufacture of Lightweight Aggregate. Report No. SR-46. University Park, PA: Pennsylvania State University, 1964.

12. Vogely, W. The Economic Factors of Mineral Waste Utilization. Proceedings of the First Mineral Waste Utilization Symposium. Chicago, IL, 1968.

# APPENDIX C

## COAL WASTE TONNAGES, DISTRIBUTION AND PROPERTIES

# COAL WASTE TONNAGES, DISTRIBUTION AND PROPERTIES

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APPENDIX C

## COAL WASTE TONNAGES, DISTRIBUTION AND PROPERTIES

The Appalachian and Interior coal provinces are and will remain the major coal producing areas in the United States. Among individual states, Kentucky will remain the number one producer until 1982, when it should be surpassed by Wyoming. From now through 1985 more coal will be mined in the east than in the west.[1] Of the eastern coal, more than 50 percent will come from underground mines. The refuse generated in cleaning this coal is a major raw material source for which economically viable utilization schemes can and should be developed.

This Appendix was prepared under Task 3 of this study and, as designed, is based upon data available in the coal refuse literature. No attempt was made to generate new data on coal refuse properties. The tonnages and distribution of this coal refuse are examined first in this Appendix, followed by a look at the chemical and physical properties of the refuse material. The relationship between refuse properties and potential end uses are briefly discussed. Tables of data with extensive notes are included in each section.

## C.1 Refuse Production

Present coal refuse production is derived from the U.S. Bureau of Mines Minerals Handbook. Future production must be estimated from projected coal production and preparation plant capacity. Additional evidence for refuse production levels can come from estimates of new coal-fired electric utilities.

Tonnage of coal and refuse are listed for the Eastern Interior and Appalachian Coal Fields and individual states in those regions in Table C-1. Total U.S. levels are included for reference. The fourth (boxed) column of Table C-1 lists actual refuse tonnage for 1975. West Virginia leads by far all other states in refuse production, even though it is second to Kentucky in total production. The fifth column shows what percent of material coming out of the ground and destined for cleaning will be refuse and therefore must be reused or disposed. The range for this percentage is 22 to 38, which substantially agrees with the generally accepted range of 20 to 30 percent.

The last, or sixth, column presents the data in a very interesting and useful way. These values represent what percent of cleaned coal is accompanied by an equal amount of refuse. The range is 29 to 62 percent. In other words, for every 100 tons of cleaned coal to burn there are 29 to 62 tons of refuse available for reuse. Alabama, at 62, has the highest percent of refuse per ton of cleaned coal, but West Virginia's value of 45 helps explain why West Virginia produces so much refuse. Great Britain has similar values[2]. Thirty to 50 percent of material brought to the surface there is unwanted minerals.

## TABLE C-1

## REFUSE AND COAL PRODUCTION

| | 1975 Total Coal Production (Thousands of Tons) | Tonnage Cleaned[a] (Thousands of Tons) | Percent of Coal Cleaned[b] | Refuse Thou. Tons | Refuse Percent of Raw Tonnage Cleaned[c] | Refuse Percent of Cleaned Coal[d] |
|---|---|---|---|---|---|---|
| U.S. | 648,438 | 374,094 | 41 | 107,101 | 29 | 40 |
| Eastern Interior | ~141,018 | 110,728 | 60 | 26,395 | 24 | 31 |
| Appalachian | ~385,601 | 243,999 | 43 | 76,313 | 31 | 46 |
| Eastern Interior | | | | | | |
| Kentucky (West) | 56,357 | 25,751 | 35 | 5,938 | 23 | 30 |
| Indiana | 25,124 | 24,986 | 77 | 5,585 | 22 | 29 |
| Illinois | 59,537 | 59,991 | 76 | 14,872 | 25 | 33 |
| Iowa | no cleaning | | | | | |
| Missouri | not reported | | | | | |
| Kansas | not reported | | | | | |
| Arkansas | not reported | | | | | |
| Oklahoma | not reported | | | | | |
| Texas | no cleaning | | | | | |
| Appalachian | | | | | | |
| Kentucky (East) | 87,257 | 33,134 | 27 | 9,369 | 28 | 39 |
| Pennsylvania | 84,137 | 60,172 | 51 | 17,600 | 29 | 41 |
| Ohio | 46,770 | 21,850 | 30 | 7,742 | 35 | 55 |
| West Virginia | 109,238 | 91,398 | 58 | 28,259 | 31 | 45 |
| Maryland | not reported | | | | | |
| Virginia | 35,510 | 19,267 | 36 | 6,393 | 33 | 50 |
| Tennessee | not reported | | | | | |
| Alabama | 22,644 | 18,178 | 50 | 6,950 | 38 | 62 |
| Georgia | no cleaning | | | | | |
| Other states - no cleaning | 49,253 | | | | | |
| Other states - cleaning | 57,389 | 13,008 | 17 | 3,522 | 27 | 37 |

[a]Raw tonnage, includes coal and refuse.

[b]Refuse subtracted from tonnage cleaned and then divided by total production.

[c]Refuse tonnage divided by raw tonnage cleaned.

[d]Refuse tonnage divided by tonnage of coal resulting from cleaning process.

To pick a site for in-depth evaluation for Task 4, more local information is required. Refuse tonnage is not reported by preparation plant. However, the annual coal capacity of each preparation plant in a state is known. That state's refuse percent of cleaned coal is also known. By combining this information with operating efficiencies, the amount of refuse from each plant can be estimated. The caveat here is that each preparation plant has its own characteristic percent refuse value which can only be approximated by the statewide average.

The cleaning capacities by state and region are listed in Table C-2. Information for individual preparation plants can be found in the Keystone Coal Industry manual.[3] The first and second columns of Table C-2 list tonnage per day and per year. The third column lists the percent of time a state's plants would have to operate to produce the tonnage for 1977 for that state. The values are rough estimates but do indicate a significant trend. There is excess cleaning capacity in the Appalachian Coal Field. The low use rates may in part be due to labor strikes in 1976 and 1977. However, they are partly due to new capacity coming on line to handle the higher production forecasts for Kentucky, Pennslylvania, Ohio and West Virginia for the years 1978-1985. In the Eastern Interior fields, Texas and Illinois have a forecast of large production increases, but this coal will be strip-mined and not cleaned. Production values for 1977 to 1985 will be listed later in this section.

Estimates of future tonnage of coal and refuse are tenuous at best. The changing energy picture causes almost constant reevaluations of what can be produced, what should be produced, and what will be produced. For example, six forecasts for 1985 total U.S. production are presented in Table C-3. The predictions

# TABLE C-2

## COAL CLEANING PLANT CAPACITY[a]

| | THOUSAND TONS/DAY | THOUSAND TONS/YEAR[b] | OPERATING EFFICIENCY(%)[c] |
|---|---|---|---|
| Eastern Interior | 294. | 107,222 | 92 |
| Appalachian | 1395 | 509,230 | 37 |
| Eastern Interior<br>Kentucky (West) | 72:8 | 26,572 | 75 |
| Indiana | 44.5 | 16,242 | 118 |
| Illinois | 160.05 | 58,418 | 85 |
| Iowa | not listed | | |
| Missouri | 10.0 | 3,650 | |
| Kansas | 3.8 | 1,387 | |
| Arkansas | not reported | | |
| Oklahoma | 2.6 | 949 | |
| Texas | not listed | | |
| Appalachian<br>Kentucky (East) | 214.36 | 78,241 | 32 |
| Pennsylvania | 294.76 | 107,587 | 39 |
| Ohio | 96.75 | 35,313 | 36 |
| West Virginia | 533.08 | 194,572 | 28 |
| Maryland | not reported | | |
| Virginia | 171..3 | 62,525 | 23 |
| Tennessee | 9.72 | 3,548 | |
| Alabama | 59.2 | 21,606 | 49 |
| Georgia | not listed | | |
| Pennsylvania<br>Anthracite | 16.15 | 5,895 | |

[a] 1978 Keystone Coal Industry Manual

[b] Calculated for 365 day year from daily rate.

[c] Operating efficiency, or percent of capacity used, was determined by taking 1977 total production and multiplying by the percent of coal cleaned in 1975 (Table 3-1). The resulting tonnage was divided by 1977 capacity to get operating efficiency. The percent values from 1975 were used because this was the last year for which cleaning and refuse tonnage data were available.

TABLE C-3
(Reference 4 )

COAL PRODUCTION FORECASTS
(millions of tons)

| | 1985 | 1990 | 2000 |
|---|---|---|---|
| Project Interdependence[a] | 940 | 1225 | |
| National Energy Plan[b] | 1050 | 1250 | |
| Department of Commerce[c] | 890 | | 1860 |
| CONAES[d] | 995 | 1250 | 1700 |
| Project Independence[e] | 1100 | 1300 | |
| Earl T. Hayes[f] | 900 | | |
| Keystone Coal Industry Manual[g] | 1480 | | |

[a]Project Interdependence, "U.S. and World Energy Outlook through 1990" (Gov. Printing Office, Wash. D.C., 1977).

[b]Executive Office of the President, Office of Energy Policy and Planning, "The National Energy Plan," (Gov. Printing Office, Wash. D.C., 1977).

[c]Dept. of Commerce, Domestic and International Business Administration, "Forecast of Likely U.S. Energy Supply/Demand Balances for 1985 and 2000 and Implications for U.S. Energy Policy," (NTIS PB 266 240, National Technical Information Service, Springfield, VA, 1977).

[d]Report of the National Research Council Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences (in review, June 1978).

[e]Federal Energy Administration, "Project Independence Blueprint," Government Printing Office, Wash. D.C., 1974).

[f]Prediction in June 1978, Reference 22.

[g]Keystone Coal Industry Manual, 1978. Production from 1976 added to planned new capacity up to 1985. New capacity utilization: 100%.

range from 900 million tons to 1.5 billion tons. Similarly 1976 Keystone predicted 535 million tons new capacity by the end of 1985. In 1978 Keystone predicted 800 million new tons by the end of 1985.

Electric utility coal consumption is another way of predicting 1985 coal production. The new coal requirements for utilities can be estimated by converting megawatts to tons of coal. Table C-4 lists new megawatts by state and region and the concomitant coal required to generate those megawatts. The leading states are Texas, Indiana, Oklahoma and Alabama. Most of the coal will come from within the state because of lower transportation costs. When these coal requirements are compared to Keystone Coal Industry Manual forecasts of coal production, it is seen that the Appalachian states will meet their needs with new underground coal. The interior states, with the exception of Kentucky (West) and Illinois, must use strip-mined coal to meet their needs.

New underground capacity by state for each year from 1977 to 1985 is listed in Table C-5. These figures illustrate the point raised before that most new underground capacity will occur in the Appalachian Coal Field. The figures are 150 million tons annual for Appalachia versus less than 50 million tons for the Eastern Interior. West Virginia has the highest forecast of over 50 million tons in one state! The new capacity forecasts will be added to 1976 underground production to get a prediction of future underground production. Then the percent refuse values which were created in Table C-1 can be applied to arrive at a prediction of refuse generation through 1985. Later the state's refuse can be allotted to its individual preparation plants (based on plant capacity) in order to help pick the Task 4 site.

TABLE C-4

COAL REQUIREMENTS FOR NEW ELECTRIC UTILITIES IN 1985
(Reference 5)

| | MEGAWATTS | THOUS. TONS COAL REQUIRED PER YEAR[a] |
|---|---|---|
| U.S. | 130,249 | 334,300 |
| Eastern Interior | 54,254 | 139,200 |
| Appalachia | 25,205 | 64,690 |
| Eastern Interior | | |
| Kentucky (West) | 3,545[b] | 9,098 |
| Indiana | 7,007 | 17,980 |
| Illinois | 5,291 | 13,580 |
| Iowa | 2,322 | 5,959 |
| Missouri | 3,440 | 8,829 |
| Kansas | 4,025 | 10,330 |
| Arkansas | 3,320 | 8,521 |
| Oklahoma | 6,450 | 16,550 |
| Texas | 18,854 | 48,390 |
| Appalachia | | |
| Kentucky (East) | 3,545[b] | 9,098 |
| Pennsylvania | 3,100 | 7,956 |
| Ohio | 3,440 | 8,829 |
| West Virginia | 4,442 | 11,400 |
| Maryland | 800 | 2,053 |
| Virginia | 0 | 0 |
| Tennessee | 0 | 0 |
| Alabama | 5,478 | 14,060 |
| Georgia | 4,400 | 11,290 |

[a] Tonnage per megawatt calculated on the basis of:

$$\frac{\text{lbs of coal}}{\text{megawatt}} = \frac{\text{3413 Btu/hr}}{\text{thermal kilowatt}} \times \frac{1}{\text{thermal to elec. conversion}} \times \text{operating efficiency} \times \frac{1}{\text{heat value in Btu/lb}}$$

where: thermal to electric conversion is 34%, operating efficiency is 70%, heat value of eastern coal is 12,000 Btu/lb.

[b] Total Kentucky divided evenly between Eastern and Western Kentucky.

## TABLE C-5

### NEW UNDERGROUND CAPACITY BY YEAR[a]

(thousands of tons)

| | pre-1977 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | TOTAL END OF 1986 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| U.S | | 41,650 | 49,010 | 37,290 | 32,590 | 21,700 | 19,090 | 15,200 | 13,300 | 17,930 | 283,910 |
| Eastern Interior | | 6,800 | 6,800 | 6,150 | 4,050 | 3,850 | 4,600 | 3,800 | 3,300 | 1,300 | 47,550 |
| Appalachia | | 25,900 | 31,310 | 24,190 | 13,740 | 8,420 | 6,030 | 4,720 | 2,350 | 2,950 | 150,260 |
| Eastern Interior | | | | | | | | | | | |
| Kentucky (West) | 2,750 | 2,200 | 850 | 750 | 250 | 500 | 1,000 | 1,500 | 1,600 | 600 | 12,000 |
| Indiana | 300 | 200 | | | | | | | | | 500 |
| Illinois | 4,100 | 4,400 | 5,900 | 4,900 | 3,400 | 3,150 | 3,400 | 2,000 | 1,600 | 600 | 33,750 |
| Iowa | | | | | | | | | | | |
| Missouri | | | | | | | | | | | |
| Kansas | | | | | | | | | | | |
| Arkansas | | | | | | | | | | | |
| Oklahoma | | | | 500 | 400 | 200 | 200 | 300 | 100 | 100 | 1,800 |
| Texas | | | | | | | | | | | |
| Appalachia | | | | | | | | | | | |
| Kentucky (East) | 1,200 | 3,630 | 5,420 | 2,650 | 2,350 | 1,550 | 1,500 | 1,550 | 1,550 | 2,550 | 35,500 |
| Pennsylvania (Bituminous) | 3,750 | 5,350 | 4,950 | 3,200 | 2,750 | 1,700 | 1,210 | 1,120 | 30 | | 23,960 |
| Ohio | | 2,880 | 3,500 | 3,100 | 300 | 800 | 600 | 600 | 300 | 100 | 16,200 |
| West Virginia | 8,100 | 10,470 | 12,440 | 9,090 | 4,190 | 2,370 | 2,240 | 200 | | | 50,700 |
| Maryland | | 200 | 500 | 800 | 300 | | | | | | 1,800 |
| Virginia | | 750 | 1,150 | 1,000 | 750 | 1,300 | 180 | 950 | 70 | | 6,150 |
| Tennessee | | 800 | | | | | | | | | 800 |
| Alabama | 1,250 | 1,900 | 3,350 | 4,350 | 2,300 | 700 | 300 | 300 | 400 | 300 | 15,150 |
| Georgia | | | | | | | | | | | |
| Pennsylvania (Anthracite) | | | | | | | | | | | |

[a] Keystone Coal Industry Manual, 1978. New mines and expansion of old mines, reported at end of year levels.

The results of Table C-5 (New Underground Capacity) are added to present production so that total underground production for the years 1977-1985 can be estimated in Table C-6.

West Virginia at 130 million tons in 1985 has the highest underground production, followed by Pennsylvania, eastern Kentucky, and western Kentucky. This relationship holds for every year in the period 1977-1985. These estimates are the high end of the predicted range, partly because new capacity is added in at 100 percent utilization, partly because of the natural bias of the estimator (Keystone), and partly because of the energy outlook at the time of estimation. For comparison, the National Coal Association (NCA) estimate and a low growth scenario estimate for underground and total coal production for 1985 are presented in Table C-7. The NCA values are intermediate compared to the Keystone Coal Industry Manual estimates (included in Table C-7 for reference). The low growth estimates were derived from Table C-3, Coal Production Forecasts. The lowest forecast in that table, 900 million tons of coal in 1985, represents an 18 percent increase over 1977 production. This 18 percent increase was prorated to eastern U.S. and western U.S. on the basis of Keystone forecast for total (underground and strip) new capacity in 1985. Such calculations reveal that 33 percent of new capacity will be developed in the east. Thirty-three percent of 18 percent results in a 6 percent increase in eastern coal production in 1985 under a low growth scenario. For Table C-7, this 6 percent increase was prorated among the states again on the basis of total new capacity estimates. For example, of the fifteen eastern states having new capacity in 1985, West Virginia would contribute 17 percent of that capacity, according to Keystone. So, West Virginia gets 17 percent of the 6 percent low growth forecast for eastern U.S. states.

## TABLE C-6

### UNDERGROUND COAL PRODUCTION (thousands of tons/year)[a]
(Reference 1)

| | 1977[b] | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|---|---|---|---|---|
| U.S. | 336,938 | 385,948 | 423,238 | 455,828 | 477,528 | 496,618 | 511,818 | 525,118 | 543,048 |
| Eastern Interior | 62,317 | 69,117 | 75,267 | 79,317 | 83,167 | 87,767 | 91,567 | 94,867 | 96,167 |
| Appalachia | 256,438 | 287,748 | 311,938 | 325,678 | 334,098 | 340,128 | 344,848 | 347,198 | 350,148 |
| Eastern Interior | | | | | | | | | |
| Kentucky (West) | 26,088 | 26,938 | 27,688 | 27,938 | 28,438 | 29,438 | 30,938 | 32,538 | 33,138 |
| Indiana | 631 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Illinois | 33,453 | 39,403 | 44,303 | 47,703 | 50,853 | 54,253 | 56,253 | 57,853 | 58,453 |
| Iowa | | | | | | | | | |
| Missouri | | | | | | | | | |
| Kansas | | | | | | | | | |
| Arkansas | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Oklahoma | | | 500 | 900 | 1,100 | 1,300 | 1,600 | 1,700 | 1,800 |
| Texas | | | | | | | | | |
| Appalachia | | | | | | | | | |
| Kentucky (East) | 43,989 | 49,409 | 52,059 | 54,409 | 55,959 | 57,459 | 59,009 | 60,559 | 63,109 |
| Pennsylvania | 38,365[c] | 54,627[d] | 57,827 | 60,577 | 62,277 | 63,487 | 64,607 | 64,637 | 64,637 |
| Ohio | 13,925[c] | 23,015[d] | 26,115 | 26,415 | 27,215 | 27,315 | 28,415 | 28,715 | 28,815 |
| West Virginia | 74,030[c] | 110,703[d] | 119,793 | 124,783 | 127,153 | 129,393 | 129,593 | 129,593 | 129,593 |
| Maryland | 375 | 875 | 1,675 | 1,975 | 1,975 | 1,975 | 1,975 | 1,975 | 1,975 |
| Virginia | 26,805 | 27,956 | 28,956 | 29,706 | 31,006 | 31,186 | 32,136 | 32,206 | 32,206 |
| Tennessee | 4,675[c] | 8,108[d] | 8,108 | 8,108 | 8,108 | 8,108 | 8,108 | 8,108 | 8,108 |
| Alabama | 6,580[c] | 12,538[d] | 16,888 | 19,188 | 19,888 | 20,188 | 20,488 | 20,888 | 21,188 |
| Georgia | | | | | | | | | |

[a]Results for coal production assume 100% use of new capacity. Some new capacity is replacement tonnage for expired mines. Blanks indicate no underground production. Estimates place this replacement tonnage at 12-15 million tons for total (underground plus strip) eastern U.S. production.

[b]1977 estimated new underground capacity added to 1976 production (actual).

[c]1977 estimated underground production.

[d]1977 and 1978 estimated new underground capacity added to 1976 production (actual).

TABLE C-7

1985 COAL PRODUCTION[a]
(thousands of tons)

| | Low Growth | | National Coal Association | | Keystone | |
|---|---|---|---|---|---|---|
| | Underground | Total | Underground | Total | Underground | Total |
| U.S. | 398,000 | 900,000 | 491,500 | 1,283,000 | 543,000 | 1,480,000 |
| Eastern Interior | 71,300 | 181,000 | 93,220 | 246,700 | 96,170 | 271,100 |
| Appalachian | 267,000 | 458,000 | 349,800 | 548,300 | 350,100 | 559,800 |
| **Eastern Interior** | | | | | | |
| Kentucky (West) | 27,000 | 58,500 | 36,470 | 71,440 | 33,140 | 66,610 |
| Indiana | 600 | 26,800 | 431 | 34,720 | 600 | 34,810 |
| Illinois | 36,100 | 70,600 | 52,270 | 89,340 | 58,450 | 97,740 |
| Iowa | 0 | 530 | 535 | 842 | 0 | 525 |
| Missouri | 0 | 6,630 | 1,800 | 6,167 | 0 | 6,625 |
| Kansas | 0 | 666 | 0 | 576 | 0 | 630 |
| Arkansas | 20 | 570 | 210 | 736 | 20 | 570 |
| Oklahoma | 140 | 5,610 | 1,500 | 5,775 | 1,800 | 7,545 |
| Texas | 0 | 24,600 | 0 | 37,100 | 0 | 69,750 |
| **Appalachian** | | | | | | |
| Kentucky (East) | 46,500 | 98,700 | 56,064 | 113,100 | 63,110 | 128,600 |
| Pennsylvania | 40,100 | 86,500 | 67,380 | 109,100 | 64,640 | 108,500 |
| Ohio | 15,000 | 44,300 | 25,430 | 58,020 | 28,820 | 61,410 |
| W. Virginia | 77,200 | 101,000 | 132,400 | 157,500 | 129,600 | 155,200 |
| Maryland | 480 | 3,090 | 2,175 | 4,695 | 1,975 | 4,495 |
| Virginia | 27,200 | 41,100 | 32,010 | 45,950 | 32,210 | 46,150 |
| Tennessee | 4,720 | 10,400 | 8,918 | 10,610 | 8,108 | 9,802 |
| Alabama | 7,680 | 23,300 | 25,020 | 43,800 | 25,190 | 39,650 |
| Georgia | 0 | 267 | 0 | 200 | 0 | 950 |

[a] National Coal Association figures from reference 5 and Keystone figures from reference 1.

The results of these calculations appear in the first and second columns of Table C-7.

The low growth scenario shows West Virginia to remain comfortably in the first place for underground and total production with 77 million tons of underground coal and 101 million tons total. Pennsylvania slips from second to third place with eastern Kentucky replacing it. The eastern Kentucky values are 47 million underground and 99 million total. However, if eastern and western Kentucky tonnages are added together, the underground production approaches West Virginia, and the total at 157 million exceeds the West Virginia amount by 50 percent.

The range of estimates for coal production in 1985 can be converted to a range of refuse production with the conversion factors in columns three and six of Table C-1. These factors represent how much refuse is generated per ton of cleaned coal and how much of a state's underground production goes to cleaning before being burned. The calculation of refuse tonnage is as follows: The 1985 underground tonnage will be multiplied by a state's cleaning percentage then multiplied by its refuse per ton of cleaned coal factor. Since the percent of coal cleaned in each state may increase due to tighter environmental restraints, the refuse numbers may be a bit low. However, the wide range of predicted coal tonnage is ample to insure the amount of refuse actually produced will fall within the predicted range.

The refuse results for 1985 are listed in Table C-8. The 1975 levels from Table C-1 are included for reference. The levels of refuse in Table C-7 appear to be in good agreement with coal production values. Under the low growth scenario only a 6 percent increase in coal is forecast for 1977-1985. The 1985 refuse figures reflect this slight increase.

The 1985 high growth refuse levels are significantly higher than the 1975 reports.

There does seem to be a minor flaw in the calculations. Some states, particularly Kentucky (east) and West Virginia, may substantially increase the percent of underground coal they clean. The evidence for this is the low present utilization rates of preparation plant capacity as listed in Table C-2. Utilization could easily double for these states and all of the Appalachian states. Refuse levels then would be twice the levels found in Table C-8. Other investigations reporting 1975 refuse levels are in agreement, given the uncertainties, with the data in Table C-8. For example, Hoffman and Snyder[6] report 87 million tons of refuse in 1975, which is reasonably close to the 107 million tons of the table. Bishop and Rose[7] report 20 million tons in Kentucky for the same year, while the table lists 15 million tons.

The majority of coal refuse is coarse material (plus 28 mesh). Hoffman and Snyder[6] estimate about 80 percent as coarse. The remaining 20 percent represents a very significant amount of fine refuse which may have very different utilization schemes than the coarse refuse. Any successful reuse program must address both these types of material.

TABLE C-8

REFUSE PRODUCTION IN 1985
(thousands of tons)

| | 1975 | 1985 | |
|---|---|---|---|
| | | Low Growth | High Growth |
| U.S. | 107,101 | 148,000 | 243,000 |
| Eastern Interior | 26,395 | 33,700 | 50,400 |
| Appalachia | 76,313 | 90,600 | 111,000 |
| Eastern Interior | | | |
| Kentucky (West) | 5,938 | 6,140 | 6,990 |
| Indiana | 5,585 | 5,980[a] | 7,770[a] |
| Illinois | 14,872 | 17,700 | 24,500 |
| Iowa | | | |
| Missouri | | | |
| Kansas | | | |
| Oklahoma | | | |
| Texas | | | |
| Appalachia | | | |
| Kentucky (East) | 9,369 | 10,400 | 13,500 |
| Pennsylvania | 17,600 | 18,100 | 22,700 |
| Ohio | 7,742 | 7,310 | 10,100 |
| West Virginia | 28,260 | 26,400 | 40,500 |
| Maryland | | | |
| Virginia | 6,393 | 7,400 | 8,310 |
| Tennessee | | | |
| Alabama | 6,950 | 7,220 | 12,300 |
| Georgia | | | |
| Other states | 3,522 | | |

[a] Most of Indiana's refuse is from cleaning of surface mined coal.

## C.2 Chemical and Physical Properties

Individual mine and state values for physical and chemical properties appear at the back of this section in Tables C-15, C-16, and C-17. The notes accompanying the tables explicitly explain the parameters measured.

New Mexico and Utah are included in the physical property and major constituent tables for comparison of eastern and western refuses. The ranges of property values are summarized in Tables C-9, C-10 and C-11.

### C.2.1 Physical Properties

Grain size values for refuse indicate a soil-like material. However, refuse is not always well graded, which does cause problems for embankment construction. Fines should be a maximum of 40 percent (passing 200 mesh) for safe construction.[6] Grain size is very important when refuse is used on an anti-skid material on winter roads. Material should be less than 9/16" but not less than 3/32". The material also should not contain injurious material such as glass or sharp flat shale and should blend with an ice-melting agent such as $CaCl_2$.[8]

Refuse specific gravity, as low as 1.6, does not approach coal at 1.4 but the high end of the range, 2.7, is within the specific gravity range for soil. Specific gravity along with density is an important parameter in construction. Density has a wide range from 68-124 pcf. Most refuse levels fall within a narrower range centered around 90 pcf. A range of 35-92 pcf is acceptable for use as highway anti-skid material.[8] The density of a refuse can be increased up to 40 percent

## TABLE C-9

## RANGE OF PHYSICAL PROPERTIES FOR EASTERN AND MIDWESTERN COAL WASTE

| | |
|---|---|
| Grain Size[a]: | |
| Median $D_{50}$ (mm) | 0.02 - 18 |
| Effective $D_{10}$ (mm) | 0.0004 - 2 |
| Coefficient of Uniformity | 3 - 2300 |
| Range (mm) | 0.0004 - 50 |
| Specific Gravity[b] | 1.6 - 2.7 |
| Density (maximum dry, pcf)[c] | 68 - 124 |
| Optimum Moisture (%)[d] | 5 - 23 |
| Permeability (fpm)[e] | $2x10^{-8}$ - $1x10^{-2}$ |
| Shear Strength[f] | |
| Shear Angle (degrees)[g] | 20 - 41 |
| Strength ($\bar{c}$, psi)[h] | 0 - 13 |
| California Bearing Ratio[i] | |
| Soaked | 2 - 15 |
| Unsoaked | 3 - 44 |
| Los Angeles Abrasion Test[j] | 34 - 57 |
| Atterberg Limits[k] | |
| Liquid Limit[l] | 20 - 51 |
| Plastic Limit[m] | 15 - 26 |
| Plastic Index | 0 - 16 |
| Activity[n] | 0.17 - 0.70 |
| Soil Classification[o] | |
| Unified[p] | GW to SC |
| AASHTO | A-2 to A-4 |
| Textural | Sand to Silt Loam |

## NOTES FOR TABLE C-9

a. Grain size using U.S. Standard sieves. $D_{50}$ is median diameter. $D_{10}$ is largest diameter of smallest 10 percent of particles. Coefficient of uniformity is the $D_{60}$ divided by the $D_{10}$ and indicates range of particle size. A low value indicates uniform size and a narrow range, a high value indicates a wide range which may or may not be uniform. For comparison beach sand has a value of 2-6 and sand gravel soils are 200-300, but sometimes as high as 1000.

b. Soil specific gravity ranges from 2.6-2.8 and bituminous coal is around 1.4.

c. Density as measured by Proctor Compaction Test, ASTM D698-66T. Impact of 5.5 lb rammer is used to achieve compaction. The standard Proctor Compaction Test uses a compaction force of 12,400 ft.-lb/ft$^3$. A Modified Proctor Test uses a 56,000 ft-lb/ft$^3$ force.

An impact compaction is used to test fine-grained (minus 200 mesh material constituting less than 12% by weight) or cohesive materials. When the material to be tested is coarse-grained or cohesionless a vibratory compaction is used. This latter method yields a relative density value. Relative density is expressed as a percent of the range of the loosest and densest states the material can achieve. In some cases these minimum and maximum dry densities are also reported.

d. Moisture content of refuse at which Proctor maximum density is reached.

e. "fpm" is feet per minute. Refuse values are smaller than soils of similar classifications. Soils: $5x10^{-5}$ to $5x10^{-7}$ fpm.

f. The Triaxial compression test is an often used measure of shear strength. In the test the sample is enclosed in a flexible membrane in the shape of a cylinder. A confining pressure is applied to the side walls of the membrane and an axial load is applied to one end. The load is applied until rupture of the confining membrane. The sample is usually compacted to its maximum dry density and optimum moisture content. The stresses which are applied are measured along with pore water pressure to determine

f. (cont'd)
effective stress. Effective stress is only the stress carried by the sample particles. The stress carried by pore water is disregarded since this carrying capacity does not contribute to shearing resistance, or embankment stability.

The Triaxial test may be carried out in several modes. The sample can be consolidated or unconsolidated and it can be drained or undrained. Consolidation of a sample means that after water is added to the sample (to obtain optimum moisture) and the confining stress applied, some water is allowed to drain out. This relieves the water pressure created in the soil voids. If no more water is allowed to drain during the test the sample is said to be tested in an undrained mode. The sample can be allowed to drain during the application of the axial force, which would be the drained mode.

g. Shear angle is sometimes referred to as the friction angle. Soils of the same classification as coal refuse have effective stress angles of 28-34.

h. Strength or cohesion, $\bar{c}$, is measured in pounds per square inch. Soils can have strengths of 1.6 to 3.0 psi.

i. The California Bearing Ratio (CBR) is a measure of shearing resistance. It tests the penetration of a piston into the material relative to the penetration of the same piston into a standard sample of crushed stone. It is used to evaluate the suitability of fill for bases and subbases for highways. Soils of similar classification to coal refuse have CBR values from 5 to 40. The soaked test is one in which the material is compacted then saturated with water. The unsoaked test is a dry compacted test.

j. Los Angeles Abrasion Test: ASTM C131-69. To pass test a material must have a value greater than 40 to 50 (exact value depends upon expected use of material). For example, if a coal refuse failed to meet specifications for a stabilized highway base course, it might still be used as a highway embankment.

k. The Atterberg Limits relate moisture content to physical behavior and are useful in determining embankment stability. The liquid limit (LL) is the moisture content when the material passes from a plastic to a liquid state. The plastic limit (PL) is the moisture content when the material goes from a semisolid to a plastic state. The plastic index (PI) is the difference between these two limits. A large PI is good for embankment stability.

k. (con't.d)

A small PI means the material could pass from a semisolid state to a liquid state and an embankment failure would result. Sandy soils can have LL equal to 20 or less, while clays have LL from 40 to 60.

The applicability of Atterberg Limits to coal refuse is somewhat in doubt. Coal refuse contains volatile materials which may interfere with accurate determination of water content. Since water content is determined by heating the material both water and other volatiles may be driven off during the test.

l. ASTM D423.

m. ASTM D424.

n. Activity is defined as the plastic index divided by the percentage 0.002 mm clay content. The values reported for eastern Kentucky coal place it in the illite clay mineral type.

o. Three soil classification schemes are presented: the Unified Soil Classification System, the American Association of State Highway and Transportation Officials (AASHTO) System, and the U.S. Department of Agriculture Textural Classification System. Coal refuse may be unsuitable for classification because of unnatural size gradations, low specific gravity, and contaminating materials.

p. Unified classification scheme is reproduced in Supplement 1 to Appendix C.

TABLE C-10

RANGE OF MAJOR CONSTITUENTS OF COAL WASTE FOR EASTERN AND MIDWESTERN COAL

| | |
|---|---|
| % Ash | 20 - 78 |
| % Sulfur | 0.25 - 3.5 |
| Heat Value (Btu/lb) | 1,400 - 11,900 |
| pH | 3.5 - 8.1 |
| C.E.C. (26) | 4.3 - 12 |
| Major Elements (%) [a] | |
| $Al_2O_3$ | 2.9 - 37 |
| CaO | 0.01 - 24 |
| $Fe_2O_3$ | 1.1 - 43 |
| $K_2O$ | 0.06 - 4.3 |
| MgO | 0.08 - 1.9 |
| MnO | 0.01 - 0.16 |
| $Na_2O$ | 0.02 - 0.91 |
| $P_2O_5$ | 0.08 - 0.86 |
| $SiO_2$ | 9.7 - 69 |
| $TiO_2$ | 0.7 - 1.7 |
| Mineralogic Content (%) [a] | |
| Apatite | 0.21 - 2.4 |
| Calcite | 0 - 16 |
| Hematite | 0 - 7.3 |
| Illite | 15 - 47 |
| Kaolinite | 2.4 - 74 |
| Magnesite | 0.24 - 1.3 |
| Pyrite | 1 - 12 |
| Quartz | 1 - 26 |

[a] Element and mineral content are concentrations in ashed refuse. Refuse is usually ashed in a laboratory muffle furnace at around 750° C.

TABLE C-11

RANGE OF MINOR AND TRACE ELEMENTS IN EASTERN AND MIDWESTERN COAL REFUSE

| | ppm |
|---|---|
| Ag | 1 - 10 |
| As | 17 - 960 |
| Ba | 18 - 1100 |
| Be | 0.62 - 10 |
| Cd | 0.34 - 1 |
| Co | 7 - 86 |
| Cr | 18 - 86 |
| Cu | 17 - 103 |
| F | 82 - 130 |
| Ga | 10 - 100 |
| Hg | 0.3 - 4.2 |
| Ni | 39 - 110 |
| Pb | 20 - 821 |
| Rb | 68 - 200 |
| Se | 4.7 - 19 |
| Sr | 110 - 230 |
| V | 12 - 142 |
| Y | 18 - 38 |
| Zn | 30 - 280 |
| Zr | 73 - 1060 |

by adding the fine refuse (minus 200 mesh) to the coarse.[6] Density may be measured by compacting the material with vibrations or with impactions. Impaction is the better test for all but the coarsest refuse. It gives higher values which more accurately reflect construction conditions. Table C-12 shows the effect of impaction on density measurements. The higher values for impacted refuse are probably due to the friability of refuse. Friability is the ability to be crushed to a powder.[6] The fine material produced partially fills the void spaces and increases density and strength. Friability is not commonly measured but does appear to be a critical parameter for any construction use.

Weathering also affects grain size and density. Moulton et al. performed a slaking test on West Virginia refuse.[6] The test alternately exposed the material to wetting and drying. The results showed degradation occurring, with the coarse fraction suffering the most degradation.

The optimum moisture content of refuse (where greatest density is reached) varied from 5 - 23 percent. Water content is important to embankment construction. Too much or too little water and the density falls off.

The permeability of refuse material is an important parameter. It varies widely from $10^{-2}$ to $10^{-8}$ fpm. Very low permeable material can be used to cap landfills to prevent leaching or surface water contamination. It can be used to cover earthen dams. On the other hand, high permeability is required for vegetation. Permeability is also important in construction. Factors affecting this quality are void ratio, grain size and distribution, degree of cementation, and the degree of saturation. Compaction can also affect permeability. One researcher found permeability decreasing 1000 fold when density was increased 25 percent.[6]

TABLE C-12

COMPARISON OF COMPACTION METHODS FOR WEST VIRGINIA MINE REFUSE

(Reference 9)

| Mine | Age of Refuse | Dry Density (pcf) | |
|---|---|---|---|
| | | Vibration | Impaction |
| Philippi | new coarse | 86 | 94 |
| | new fine | 97 | 95 |
| | old | 80 | 91 |
| Humphrey | new | 84 | 97 |
| | old | 82 | 98 |
| Shoemaker | new | 99 | 115 |
| | old | 101 | 121 |
| McElroy | new | 100 | 124 |
| | old | 97 | 115 |

Shear strength is the classical measure of suitability for embankment or foundation uses. Most refuse had a shear angle around 30 degrees though the range was from 20 to 41. The strength was 0 to 13 psi, centered around 2 psi. These values put refuse in the same class as many soils which are suitable for embankments and for highway subbases.[9] Preparation of the refuse can drastically affect its strength. In one experiment refuse was found to have no cohesion, but after an impact test is became cohesive.[10] Another test of strength is the California Bearing Ratio, which tests strength at saturated and dry moisture conditions. The saturated or soaked test indicates how the material will perform in a wet environment. The refuse values for this test ranged from 2 - 15. Soils can range from 5 - 40.

The Los Angeles Abrasion Test is used to test soil material for a number of uses. The refuse range from 34 to 57 indicates the material suitable for some uses but unsuitable for others. This test was not widely used by researchers so sparse data is available. The Atterberg parameters are another set of soil property tests. Their usefulness to refuse has not been fully documented because of the difficulty in accurately determining moisture content of refuse. (See Note k to Table C-9.) Some refuses test within soil ranges but others are non-plastic and so have a plastic index of zero. This means the material could suddenly pass from a solid to a liquid state, resulting in a construction failure.

Three soil classification schemes are presented in the tables. The most discriminating, and therefore useful, appears to be the Unified System. The Unified scheme is presented as Supplement 1 to Appendix C.

The physical properties of refuse guide the user to various construction designs, but do not point out other potential uses of this material. A look at the constituents and chemical properties will help in this regard.

### C.2.2 Major Constituents

Major constituent summaries are found in Table C-10, previously listed. The percent ash of refuse varies from 20 to 78 percent. However, only fine, or slurry, refuse had values below 36. High ash content is a problem for furnaces regardless of Btu value. New furnaces can burn material of up to 30 percent ash, but new designs may soon lead to furnaces able to burn 50 percent ash.[11] Any combustion use of refuse, though, leads to a new disposal or reuse problem of from 20 to 50 percent of the original material.

Sulfur content appears to be higher in the midwestern coalfields than the Appalachian field. Western Kentucky refuse is generally greater than 3 percent sulfur, but eastern Kentucky and West Virginia less than 2 percent, often less than 1 percent. Sulfur is an important parameter when considering acid runoff from disposal sites because it can be oxidized to produce sulfuric acid.

The heat value of refuse varies widely but the fine refuse is significantly higher than coarse refuse. Eastern fine refuse with values from 6,000 - 12,000 Btu/lb often has higher values than western coal at 8,500 Btu/lb.[10] These figures may even classify certain fine refuses as coal. Coal is defined as having less than 40 percent inorganic matter and between 15 - 50 percent volatiles.[12] The highest coarse refuse value was 5,900 Btu/lb in West Virginia, though Bland et al. report unspecified refuses with levels as high as

7,000 Btu/lb.[10] The deeper coal cleaning in the future may put more of these Btu's in the coal and less in the refuse. Nevertheless, many refuses have a significant heat value.

The pH and cation exchange capacity (C.E.C.) were not widely reported. Both acidic and basic refuses were found. Those refuses with pH at the low end of the scale, around 3.5, would be unsuitable for vegetation. The material would have to be amended to a pH of greater than 5 to support plant growth.

The major cationic elements in refuse are silicon, aluminum and iron. Alumina content ($Al_2O_3$) is generally around 20 percent though it can be as low as 2.9 percent and as high as 37 percent. The production of aluminum from alumina ores (kaolinite, for one) is an essential and potentially profitable venture. The profitability level seems to be above 35 percent alumina content. Refuse from the Hazard No. 4 seam in eastern Kentucky and from some Pennsylvania anthracite meets this requirement. After the recovery of alumina, the high silicon content ash may make a stable road base material. However, at present prices and demand for alumina, most refuses would not be suitable for recovery. Other disposal or reuse costs or new technology or local market conditions could quickly change this picture.

Iron content as $Fe_2O_3$ ranges from 1.1 to 43 percent. Most refuses have values below 10 percent. Calcium content as CaO ranges from 0.01 to 24 percent but most eastern refuse values are below 10 percent. Kansas and Oklahoma at 22 - 24 percent are the exceptions. Western refuse at 5 - 9 percent is generally higher in calcium than eastern refuse with the exception noted above. Calcium is a plant nutrient but is also critical to construction use.[13] Refuse is classified as a pozzolanic material if it becomes cementious when wetted and lime added. If CaO content is high enough refuse may be more easily used in concrete constructions. Carbon content, though not often reported, is another parameter crucial to the pozzolanic reaction. If it is greater than 7 - 10 percent, the reaction is prevented.[14]

Other elements and mineralogic contents are listed in Table C-10 and the more complete tables at the back of this section. Mineralogic classifications reflect the relationships between elemental concentrations.

### C.2.3 Minor and Trace Elements

Ranges for minor and trace elements are listed in Table C-11. No data on re-mining the refuse for these elements was found. Minor elemental concentrations may be important in landfill or vegetation uses of refuse, either from a regulatory standpoint or a toxic standpoint. Boron, though not reported in refuse, was found to be toxic to plants at concentrations greater than 100 ppm.[15] Appalachian coal values for boron are 25 ppm and Eastern Interior values are 96 ppm.[16] For comparison to refuse values, element concentrations in Appalachian and Eastern Interior coals are listed in Table C-13. Weathering releases the elements to the surrounding environment as shown in Table C-14.

All the physical and chemical properties of coal refuse may be important to at least one re-use scheme. The critical step is to pick a site where re-use markets exist jointly with refuse suitable for the uses that the market supports. Values for chemical and physical properties of individual sites are listed in Tables C-15 to C-17. Task 4 will explore markets and uses at a particular site in the Appalachian or Eastern Interior coal fields.

TABLE C-13

AVERAGE CONTENT OF MINOR ELEMENTS IN APPALACHIAN AND EASTERN INTERIOR COALS (NOT REFUSE)

(Reference 16)

| | EASTERN INTERIOR 47 Bed Samples ppm | APPALACHIAN 65 Bed Samples ppm |
|---|---|---|
| Be | 2.5 | 2.5 |
| B | 96 | 25 |
| Ti | 450 | 340 |
| V | 35 | 21 |
| Cr | 20 | 13 |
| Co | 3.8 | 5.1 |
| Ni | 15 | 14 |
| Cu | 11 | 15 |
| Zn | 44 | 7.6 |
| Ga | 4.1 | 4.9 |
| Ge | 13 | 5.8 |
| Mo | 4.3 | 3.5 |
| Sn | 1.5 | 0.4 |
| Y | 7.7 | 14 |
| La | 5.1 | 9.4 |

TABLE C-14

EFFECT OF WEATHERING ON MINOR ELEMENT COMPOSITION

(Reference 17)

| | Co (ppm) | Cu (ppm) | Ni (ppm) | Zn (ppm) |
|---|---|---|---|---|
| Eastern Kentucky | | | | |
| 50% Winifred and 50% Hazard No. 7 | | | | |
| Present Production | 26 | 61 | 64 | 124 |
| 5-Year Old Refuse | 18 | 35 | 41 | 83 |
| Western Kentucky | | | | |
| No. 11 | | | | |
| Present Production | 88 | 76 | 88 | 223 |
| 3-Year Old Refuse | 33 | 25 | 31 | 58 |
| 10-Year Old Refuse | 28 | 18 | 31 | 40 |
| No. 9 | | | | |
| Present Production | 78 | 92 | 113 | 313 |
| 2-Year Old Refuse | 101 | 100 | 87 | 151 |
| 5-Year Old Refuse | 39 | 30 | 23 | 38 |

## TABLE C-15

## PHYSICAL PROPERTIES OF EASTERN AND MIDWESTERN COAL REFUSE

| | KENTUCKY 23 Plants in Eastern & Western Kentucky | KENTUCKY (EAST) Estill County South-East Coal Co. | KENTUCKY (EAST) Prevler No. 1 Seam | KENTUCKY (EAST) Blend 1 | KENTUCKY (EAST) Blend 2 | KENTUCKY (EAST) Blend 3 | KENTUCKY (EAST) Blend 4 | KENTUCKY (WEST) (Southern Section) Ohio No. 11 Seam |
|---|---|---|---|---|---|---|---|---|
| (References) | (7) | (7) | (10) | (18) | (18) | (18) | (18) | (17) |
| Grain Size[a]: | | | | | | | | |
| Median $D_{50}$ (mm) | 0.24-18[q] | 0.023-1.0 | | | | | | |
| Effective $D_{10}$ (mm) | 0.0012-2 | 0.001-0.002 | | 0.007-0.02 | 0.007-0.02 | 0.007-0.02 | 0.007-0.02 | |
| Coefficient of uniformity | 3-1500 | 170-2300 | | | | | | |
| Range (mm) | 0.001-50 | 0.001-19 | | | | | | |
| Specific Gravity[b] | 1.6-2.7[r] | 1.8-2.6[u] | 1.9 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 |
| Density (maximum dry, pcf)[c] | 85-115 | 81-115 | | | | | | |
| Optimum Moisture (%)[d] | 8-23 | 9-14 | | | | | | |
| Permeability (fpm)[e] | | $2x10^{-6}$-$8x10^{-8}$ | | $6x10^{-6}$[w] | $2x10^{-6}$ | $5x10^{-6}$ | $1x10^{-6}$ | |
| Shear Strength[f] | | | | | | | | |
| Shear Angle (degrees)[g] | | 29-34 | | 31[x] | 32 | 31 | 29 | |
| Strength ($\bar{c}$, psi)[h] | | 0.0 | | 2.8 | 2.5 | 1.3 | 2.9 | |
| California Bearing Ratio[i] | | | | | | | | |
| Soaked | 2-15[s] | 6-15 | | | | | | |
| Unsoaked | 3-44 | 13-40 | | | | | | |
| Los Angeles Abrasion Test[j] | | | | | | | | |
| Atterberg Limits[k] | | | | | | | | |
| Liquid Limit[l] | 26-40 | 25-35 | | | | | | |
| Plastic Limit[m] | 18-26 | 15-26 | | | | | | |
| Plastic Index | 5-13[t] | 2-13 | | | | | | |
| Activity[n] | | 0.17-0.70 | | | | | | |
| Soil Classification[o] | | | | | | | | |
| Unified[p] | GP to SC | SC[v] | | | | | | |
| AASHTO | A-2 | A-4, A-2-4 | | | | | | |
| Textural | Sand to Clay Loam | Clay Loam | | | | | | |

# TABLE C-15 (page 2)

| (References) | PENNSYLVANIA Pittsburgh and Thick Freeport Seams (19) | PENNSYLVANIA Pittsburgh Seam Fine Refuse (6) | PENNSYLVANIA New Kensington East (20) | WEST VIRGINIA (NORTHERN SECTION) Surface Mine Spoil (11) | WEST VIRGINIA Fine Refuse (21) | WEST VIRGINIA Bunker Mine (15) | WEST VIRGINIA Cassville Mine (15) | WEST VIRGINIA Shannopin Mine (15) |
|---|---|---|---|---|---|---|---|---|
| Grain Size[a]: | | | | | | | | |
| Median $D_{50}$ (mm) | 5 | 0.1[aa] | | | | | | |
| Effective $D_{10}$ (mm) | 0.09 | 0.002 | | | .0004-.09 | | | |
| Coefficient of Uniformity | 78 | | | | 6-58 | | | |
| Range (mm) | | 0.001-#20 U.S. Sieve | | | | | | |
| Specific Gravity[b] | | 1.6 | 2.3 | | 1.5-2.1 | | | |
| Density (maximum dry, pcf)[c] | 105[y] | | | 86[cc] | 68[dd] | | | |
| Optimum Moisture (%)[d] | | | | | 23 | | | |
| Permeability (fpm)[e] | | $10^{-7}$ | | | $7 \times 10^{-3}$-$1 \times 10^{-6}$ | | | |
| Shear Strength[f] | | | | | | | | |
| Shear Angle (degrees)[g] | | 36[bb] | | | 20-35[ee] | | | |
| Strength ($\bar{c}$, psi)[h] | | 0 | | | 0.4-5 | | | |
| California Bearing Ratio[i] | | | | | | | | |
| Soaked | | | | | | | | |
| Unsoaked | | | | | | | | |
| Los Angeles Abrasion Test[j] | | | | | | | | |
| Atterberg Limits[k] | | | | | | | | |
| Liquid Limit[l] | 20 | | | | 34-51 | | | |
| Plastic Limit[m] | N.P.[z] | | | | | | | |
| Plastic Index | | | | | 0-13 | | | |
| Activity[n] | | | | | | | | |
| Soil Classification[o] | | | | | | | | |
| Unified[p] | GW, GP | | GP | | | | | |
| AASHTO | | | | | | | | |
| Textural | | | | Silt loam, loam | | | | |

## TABLE C-15 (page 3)

| | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) Humphrey Mine New Production | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) Humphrey Mine Old Production | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) McElroy Mine New Production | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) McElroy Mine Old Production | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) Philippi Mine New Production Coarse | WEST VIRGINIA (NORTH CENTRAL-NORTHWEST) Philippi Mine New Production Fine | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) Philippi Mine Old Production | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) Shoemaker Mine New Production | WEST VIRGINIA (NORTH CENTRAL-NORTH WEST) Shoemaker Mine Old Production |
|---|---|---|---|---|---|---|---|---|---|
| (References) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) |
| Grain Size[ff]: | | | | | | | | | |
| % Gravel | 57 | 41 | 89 | 51 | 64 | 8.7 | 27 | 76 | 61 |
| % Sand | 42 | 39 | 10 | 39 | 20 | 90 | 56 | 21 | 33 |
| % Silt and Clay | 1.1 | 20 | 0.8 | 9.6 | 16 | 1.5 | 17 | 3.2 | 6.2 |
| Specific Gravity[b] | 2.2 | 2.4 | 2.5 | 2.6 | 1.7 | 2.0 | 2.0 | 2.5 | 2.6 |
| Density (maximum dry, pcf)[c] | 97 | 98 | 124 | 115 | 94 | 95 | 91 | 115 | 121 |
| Optimum Moisture (%)[d] | 5.6 | 14 | 8 | 11 | 7.6 | 7.4 | 15 | 7 | 9.2 |
| Permeability (fpm)[e] | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ | $10^{-5}$ to $10^{-7}$ |
| Shear Strength[f] | | | | | | | | | |
| Shear Angle (degrees)[g] | 38 | 30 | 32 | 27 | 41[99] | 35 | 39 | | 30 |
| Strength ($\bar{c}$, psi)[h] | 0 | 1.0 | 2.0 | 3.0 | 0 | 2.0 | 0 | | 2.0 |
| California Bearing Ratio[i] | | | | | | | | | |
| Soaked | | | | | | | | | |
| Unsoaked | | | | | | | | | |
| Los Angeles Abrasion Test[j] | 37 | 57 | 37 | 52 | 46 | 34 | 35 | 36 | 40 |
| Atterberg Limits[k] | | | | | | | | | |
| Liquid Limit[l] | | 36 | 28 | 37 | | | 31 | 31 | 34 |
| Plastic Limit[m] | | | | | | | | | |
| Plastic Index | | 11 | 8.4 | 13 | | | 5.2 | 10 | 16 |
| Activity[n] | | | | | | | | | |
| Soil Classification[o] | | | | | | | | | |
| Unified[p] | GP | SC | GW | GP-GC | GM | SW | SW-SM | GP | GP-GC |
| AASHTO | | | | | | | | | |
| Textural | | | | | | | | | |

TABLE C-15 (page 4)

| | WEST VIRGINIA (SOUTHERN SECTION) Algoma Seam | WEST VIRGINIA (SOUTHERN SECTION) Cemetery Branch Hollow Seam | WEST VIRGINIA (SOUTHERN SECTION) Gauley Eagle No. 4 Seam | WEST VIRGINIA (SOUTHERN SECTION) Guyan No. 5 Seam | WEST VIRGINIA (SOUTHERN SECTION) Hampton No. 3 Seam | WEST VIRGINIA (SOUTHERN SECTION) Hampton No. 4 Seam |
|---|---|---|---|---|---|---|
| (References) | (22) | (22) | (22) | (22) | (22) | (22) |
| Grain Size [ff]: | | | | | | |
| % Gravel | | | | | | |
| % Sand | 0.52 | 0.03 | 0.03 | 0.11 | 0.5 | 0.09 |
| % Silt and Clay | 18 | 250 | 213 | 64 | 14 | 63 |
| Specific Gravity [b] | 1.7-2.2 | 1.7-2.3 | 1.8-2.2 | 1.7-2.1 | 1.6-2.7 | 1.7-1.8 |
| Density (maximum dry, pcf) [c] | 108 | 101 | 101 | 94 | 97 | 89 |
| Optimum Moisture (%) [d] | | | | | | |
| Permeability (fpm) [e] | $5x10^{-4}$ | $2x10^{-8}$ | $2x10^{-8}$ | $6x10^{-5}$ | $5x10^{-4}$ | $1x10^{-6}$ |
| Shear Strength [f] | | | | | | |
| Shear Angle (degrees) [g] | 36 [hh] | 37 [ii] | | 32 [ii] | 31 [ii] | 35 [jj] |
| Strength (C, psi) [h] | 2.4 | 0.2 | | 11 | 8.3 | 0 |
| California Bearing Ratio [i] | | | | | | |
| Soaked | | | | | | |
| Unsoaked | | | | | | |
| Los Angeles Abrasion Test [j] | | | | | | |
| Atterberg Limits [k] | | | | | | |
| Liquid Limit [l] | | | | | | |
| Plastic Limit [m] | | | | | | |
| Plastic Index | | | | | | |
| Activity [n] | | | | | | |
| Soil Classification [o] | | | | | | |
| Unified [p] | | | | | | |
| AASHTO | | | | | | |
| Textural | | | | | | |

| | WEST VIRGINIA (SOUTHERN SECTION) Jenkin Jones Seam | NEW MEXICO (NORTHEAST SECTION) One Mine Coarse Refuse | NEW MEXICO (NORTHEAST SECTION) One Mine Fine Refuse | UTAH (CENTRAL SECTION) One Mine Coarse Refuse | UTAH (CENTRAL SECTION) One Mine Fine Refuse |
|---|---|---|---|---|---|
| (References) | (22) | (23) | | | |
| Grain Size [ff]: | | | | | |
| % Gravel | | | | | |
| % Sand | 0.27 | 0.22 | .001-.06 | 0.44 | .0035-.05 |
| % Silt and Clay | 22 | 29 | 6-72 | 24 | 6-38 |
| Specific Gravity [b] | 1.6-2.3 | 2.0 | 1.6-2.6 | 1.8 | 1.3-1.8 |
| Density (maximum dry, pcf) [c] | 106 | 100 [kk] | 30 | 87 [kk] | 54 |
| Optimum Moisture (%) [d] | | | | | |
| Permeability (fpm) [e] | $7x10^{-4}$ | $8x10^{-6}$ | $0-1x10^{-3}$ [ll] | $3x10^{-2}$ | $0-1x10^{-2}$ [ll] |
| Shear Strength [f] | | | | | |
| Shear Angle (degrees) [g] | 33 [ii] | 22 | 21-33 | 27 | 13-28 |
| Strength (C, psi) [h] | 13 | 3.3 | 0-4.5 | 7.9 | 0-11 |
| California Bearing Ratio [i] | | | | | |
| Soaked | | | | | |
| Unsoaked | | | | | |
| Los Angeles Abrasion Test [j] | | | | | |
| Atterberg Limits [k] | | | | | |
| Liquid Limit [l] | | | | | |
| Plastic Limit [m] | | | | | |
| Plastic Index | | | | | |
| Activity [n] | | | | | |
| Soil Classification [o] | | | | | |
| Unified [p] | | | | | |
| AASHTO | | | | | |
| Textural | | | | | |

## NOTES FOR TABLE C-15

a. Grain size using U.S. Standard sieves. $D_{50}$ is median diameter. $D_{10}$ is largest diameter of smallest 10 percent of particles. Coefficient of uniformity is the $D_{60}$ divided by the $D_{10}$ and indicates range of particle size. A low value indicates uniform size and a narrow range, a high value indicates a wide range which may or may not be uniform. For comparison beach sand has a value of 2-6 and sand gravel soils are 200-300, but sometimes as high as 1000.

b. Soil specific gravity ranges from 2.6-2.8 and bituminous coal is around 1.4.

c. Density as measured by Proctor Compaction Test, ASTM D698-66T. Impact of 5.5 lb rammer is used to achieve compaction. The standard Proctor Compaction Test uses a compaction force of 12,400 ft.-lb/ft$^3$. A Modified Proctor Test uses a 56,000 ft-lb/ft$^3$ force.

An impact compaction is used to test fine-grained (minus 200 mesh material constituting less than 12% by weight) or cohesive materials. When the material to be tested is coarse-grained or cohesionless a vibratory compaction is used. This latter method yields a relative density value. Relative density is expressed as a percent of the range of the loosest and densest states the material can achieve. In some cases these minimum and maximum dry densities are also reported.

d. Moisture content of refuse at which Proctor maximum density is reached.

e. "fpm" is feet per minute. Refuse values are smaller than soils of similar classifications. Soils: $5 \times 10^{-5}$ to $5 \times 10^{-7}$ fpm.

f. The Triaxial compression test is an often used measure of shear strength. In the test the sample is enclosed in a flexible membrane in the shape of a cylinder. A confining pressure is applied to the side walls of the membrane and an axial load is applied to one end. The load is applied until rupture of the confining membrane. The sample is usually compacted to its maximum dry density and optimum moisture content. The stresses which are applied are measured along with pore water pressure to determine

f. (cont'd)
effective stress. Effective stress is only the stress carried by the sample particles. The stress carried by pore water is disregarded since this carrying capacity does not contribute to shearing resistance, or embankment stability.

The Triaxial test may be carried out in several modes. The sample can be consolidated or unconsolidated and it can be drained or undrained. Consolidation of a sample means that after water is added to the sample (to obtain optimum moisture) and the confining stress applied, some water is allowed to drain out. This relieves the water pressure created in the soil voids. If no more water is allowed to drain during the test the sample is said to be tested in an undrained mode. The sample can be allowed to drain during the application of the axial force, which would be the drained mode.

g. Shear angle is sometimes referred to as the friction angle Soils of the same classification as coal refuse have effective stress angles of 28-34.

h. Strength or cohesion, $\bar{c}$, is measured in pounds per square inch. Soils can have strengths of 1.6 to 3.0 psi.

i. The California Bearing Ratio (CBR) is a measure of shearing resistance. It tests the penetration of a piston into the material relative to the penetration of the same piston into a standard sample of crushed stone. It is used to evaluate the suitability of fill for bases and subbases for highways. Soils of similar classification to coal refuse have CBR values from 5 to 40. The soaked test is one in which the material is compacted then saturated with water. The unsoaked test is a dry compacted test.

j. Los Angeles Abrasion Test: ASTM C131-69. To pass test a material must have a value greater than 40 to 50 (exact value depends upon expected use of material). For example, if a coal refuse failed to meet specifications for a stabilized highway base course, it might still be used as a highway embankment.

k. The Atterberg Limits relate moisture content to physical behavior and are useful in determining embankment stability. The liquid limit (LL) is the moisture content when the material passes from a plastic to a liquid state. The plastic limit (PL) is the moisture content when the material goes from a semisolid to a plastic state. The plastic index (PI) is the difference between these two limits. A large PI is good for embankment stability.

k. (Cont'd.)

A small PI means the material could pass from a semisolid state to a liquid state and an embankment failure would result. Sandy soils can have LL equal to 20 or less, while clays have LL from 40 to 60.

The applicability of Atterberg Limits to coal refuse is somewhat in doubt. Coal refuse contains volatile materials which may interfere with accurate determination of water content. Since water content is determined by heating the material both water and other volatiles may be driven off during the test.

l. ASTM D423.

m. ASTM D424.

n. Activity is defined as the plastic index divided by the percentage 0.002 mm clay content. The values reported for eastern Kentucky coal place it in the illite clay mineral type.

o. Three soil classification schemes are presented: the Unified Soil Classification System, the American Association of State Highway and Transportation Officials (AASHTO) System, and the U.S. Department of Agriculture Textural Classification System. Coal refuse may be unsuitable for classification because of unnatural size gradations, low specific gravity, and contaminating materials.

p. Unified classification scheme is reproduced in Supplement 1.

q. Most preparation plants in western Kentucky clean only the coarse fraction of coal. Therefore, the refuse from these samples has a larger median diameter than eastern Kentucky coal.

r. The wide range of particle sizes and poorly graded nature of the refuse caused a lack of reproducibility for specific gravity, even on multiple tests of the same sample.

s. The range of reductions in CBR values from unsoaked to soaked conditions was 5 to 84 percent, with an average of 46 percent. Some coal refuses may be used for highway subgrades according to the CBR values.

t. Five of eighteen samples were non-plastic.

u. ASTM D854.

v. These classifications represent embankment material. Lagoon deposits tended to have a wider range from clay to sandy clay loam.

w. Permeability as compacted for eastern Kentucky blends.

x. Triaxial compression test performed in consolidated undrained mode for four eastern Kentucky blends (1-4).

y. Density can be determined a number of ways either in field conditions or laboratory conditions. The value of 105 pcf for western Pennsylvania refuse is the optimum dry density determined by a Standard Procter Compaction in a 6" mold. When a Modified Procter compaction is used on a 6" mold the value is 114 pcf. The Standard Procter uses a compaction force of 12,400 ft-lb/ft$^3$, while the modified uses a 56,000 ft-lb/ft$^3$ force.

Relative density tests (using vibration rather than impaction to compact) for western Pennsylvania refuse gave a minimum density of 84 pcf and a maximum of 108 pcf. Relative density test: ASTM 2049-69.

z. These coal seams were found to have non-plastic refuse.

aa. % Gravel: 0
% Sand: 50
% Silt & Clay: 50

bb. Triaxial shear test performed in consolidated and undrained mode. This mode was selected to represent slurry pond conditions.

cc. Uncompacted bulk density.

dd. Density was also determined on the undisturbed Shelby tube samples in a drained direct shear test. The values ranged from 47-64 pcf. When the samples were allowed to consolidate the density increased to 51-75 pcf.

ee. The shear angle strength values were determined by a direct shear test. The moisture range for testing the strength of these fine refuse samples is 22-66 percent. Most samples were tested at around 50 percent moisture which is, or is close to, the saturation value.

An undrained, unconsolidated triaxial shear test showed no shear strength. This resulted because the high degree of saturation allowed the pore pressure to equal the confining, or lateral, pressure.

ff.

| | |
|---|---|
| Gravel size: | #4 mesh to 3" |
| Sand size: | #200 mesh to #4 mesh |
| Silt size: | 0.005 mm to #200 mesh |
| Clay size: | <0.005 mm |

gg. Triaxial shear test performed in consolidated and drained mode for northern West Virginia sites: Philippi, Humphrey, Shoemaker, and McElroy.

hh. This test was a direct shear test and not a triaxial compression test. The apparatus was a field testing device which was modified for laboratory use by the Spokane Mining Research Center.

This sample had a consolidated density of 101 pcf and a degree of saturation (moisture content) of 87 percent.

ii. The triaxial shear test was performed on an unconsolidated and undrained sample. The amount of moisture present varied for each sample. This can be expressed as percent of saturation. For the West Virginia mines the values are:

| | |
|---|---|
| Hampton No. 3 | 40% |
| Jenkins Jones | 37% |
| Guyan No. 5 | 45% |
| Cemetery Branch Hollow | 37% |

jj. Test performed was a direct shear test (see Note hh). Consolidated density: 84 pcf. Degree of saturation: 69 percent.

kk. Maximum density was determined by a relative density procedure, i.e., vibration rather than impaction force used for compaction. The in-situ relative density for coarse refuse was 79 percent for the New Mexico mine and 70 percent for the Utah mine.

11. Zero value indicates an impervious layer.

TABLE C-16

## MAJOR CONSTITUENTS OF EASTERN AND MIDWESTERN COAL REFUSE

| | ALABAMA[a] Walker Co. Clements Seam | KANSAS[a] Crawford Co. Baxter Seam | KENTUCKY (EAST) 17 Prep. Plants Coarse Refuse | KENTUCKY (EAST) 17 Prep. Plants Fine Refuse | KENTUCKY (EAST) 17 Prep. Plants Slurry | KENTUCKY (EAST) Estill County South-East Coal Co. | KENTUCKY (EAST) Lower Elkhorn Seam | KENTUCKY (EAST) Elkhorn No. 3 Seam | KENTUCKY (EAST) Hazard No. 4 Seam | KENTUCKY (EAST) Hazard No. 5 Seam | KENTUCKY (EAST) Hazard No. 7 Seam | KENTUCKY (EAST) Pevler No. 1 Seam |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (References | (24) | (24) | (10) | (10) | (10) | (7) | (10,17) | (10,17) | (10,17) | (10,17) | (10) | (10) |
| % Ash | 81 | 61 | 72 | 46 | 41 | 65 | 67/20[e] | 78/53[e,f] | | | | 58 |
| % Sulfur | 3.5 | 17 | 0.9 | 1.9 | 0.6 | 1.4 | 0.35 | 1.7 | 0.25 | 0.62 | | 0.29 |
| Heat Value (Btu/lb) | 1400 | 3500 | 3100 | 6440 | 8230 | 4500 | 4300/11,900[e] | 2200/6000[e,f] | | | | 4920 |
| % Carbon | | | | | | | | | | | | |
| pH | | | | | | | | | | | | |
| C.E.C. (mg/100g)[b] | | | | | | | | | | | | |
| Major Elements[c] | | | | | | | | | | | | |
| $Al_2O_3$ (%) | 25 | 4.8 | 26 | 26 | 25 | 27 | 25 | 23 | 35 | 26 | 26 | |
| CaO | 0.53 | 24 | 0.32 | 1.1 | 1.4 | 0.53 | 0.39 | 0.31 | 0.30 | 0.29 | 0.09 | |
| $Fe_2O_3$ | 5.8 | 21 | 6.5 | 9.0 | 8.0 | 7.4 | 5.6 | 11 | 2.9 | 7.7 | 3.8 | |
| $K_2O$ | | | 3.9 | 4.0 | 3.9 | 3.9 | 4.5 | 4.2 | 1.5 | 4.2 | 4.6 | |
| MgO | | | 1.5 | 1.6 | 1.8 | 1.6 | 1.7 | 1.7 | 0.61 | 1.6 | 1.4 | |
| MnO | 0.0008 | 0.15 | 0.04 | 0.03 | 0.04 | 0.04 | 0.03 | 0.05 | 0.02 | 0.09 | 0.02 | |
| $Na_2O$ | | | 0.36 | 0.38 | 0.42 | 0.39 | 0.36 | 0.49 | 0.15 | 0.25 | 0.24 | |
| $P_2O_5$ | | | 0.10 | 0.10 | 0.14 | 0.10 | 0.11 | 0.09 | 0.08 | 0.08 | 0.09 | |
| $SiO_2$ | 45 | 9.7 | 56 | 53 | 54 | 55 | 57 | 55 | 52 | 56 | 5[illegible] | |
| $TiO_2$ | | | 1.4 | 1.3 | 1.3 | 1.3 | 1.4 | 1.2 | 1.7 | 1.3 | 1.3 | |
| Mineralogical Content (%)[c] | | | | | | | | | | | | |
| Apatite | | | 0.29 | 0.30 | 0.38 | 0.28 | 0.32 | 0.25 | 0.21 | 0.22 | 0.26 | |
| Calcite | | | 0.34 | 1.2 | 2.1 | 0.73 | 0.43 | 0.35 | 0.33 | 0.33 | 0 | |
| Hematite | | | 1.2 | 0.91 | 2.0 | 0.01 | 1.4 | 2.9 | 0.70 | 3.1 | 0.71 | |
| Illite | | | 41 | 40 | 40 | 40 | 47 | 44 | 15 | 43 | 47 | |
| Kaolinite | | | 38 | 39 | 35 | 40 | 31 | 29 | 74 | 35 | 34 | |
| Magnesite | | | 0.69 | 0.82 | 1.3 | 0.95[d] | 0.79 | 1.0 | 0.38 | 0.80 | 0.26 | |
| Pyrite | | | 2.3 | 3.3 | 2.7 | 3.4 | 1.2 | 4.5 | 0.95 | 1.6 | 0.47 | |
| Quartz | | | 15 | 12 | 14 | 13 | 16 | 17 | 6.9 | 14 | 16 | |

TABLE C-16 (page 2)

| | KENTUCKY (WEST) 6 Prep. Plants Coarse Refuse | KENTUCKY (WEST) 6 Prep. Plants Fine Refuse | KENTUCKY (WEST) 6 Prep. Plants Slurry | KENTUCKY[a] (WEST) Bulter Co. No. 6 Seam | KENTUCKY (WEST) No. 9 Seam | KENTUCKY (WEST) No. 11 Seam | KENTUCKY (WEST) Ohio No.11 Seam |
|---|---|---|---|---|---|---|---|
| (References) | (10) | (10) | (10) | (24) | (10,17) | (10,17) | (10,17) |
| % Ash | 68 | 36 | 40 | 61 | | 73/36[e] | 62 |
| % Sulfur | 2.9 | 3.2 | 2.9 | 35[g] | 2.4 | 3.4 | 3.5 |
| Heat Value (Btu/lb) | 3500 | 8500 | 8000 | 4100 | | 2500/8500[e] | 4200 |
| % Carbon | | | | | | | |
| pH | | | | | | | |
| C.E.C. (mg/100g)[b] | | | | | | | |
| Major Elements[c] | | | | | | | |
| $Al_2O_3$ (%) | 19 | 15 | 19 | 2.9 | 17 | 20 | |
| CaO | 2.5 | 10 | 3.0 | 0.26 | 2.5 | 2.2 | |
| $Fe_2O_3$ | 19 | 17 | 14 | 43 | 21 | 19 | |
| $K_2O$ | 2.8 | 1.9 | 2.7 | | 3.3 | 2.3 | |
| MgO | 1.0 | 0.71 | 0.98 | | 1.3 | 0.75 | |
| MnO | 0.04 | 0.04 | 0.06 | 0.02 | 0.06 | 0.02 | |
| $Na_2O$ | 0.56 | 0.23 | 0.33 | | 0.91 | 0.57 | |
| $P_2O_5$ | 0.48 | 0.44 | 0.31 | | 0.18 | 0.86 | |
| $SiO_2$ | 52 | 48 | 55 | 13 | 51 | 51 | |
| $TiO_2$ | 0.97 | 0.78 | 1.0 | | 0.90 | 1.1 | |
| Mineralogical Content (%)[c] | | | | | | | |
| Apatite | 1.4 | 2.3 | 0.86 | | 0.52 | 2.4 | |
| Calcite | 3.4 | 16 | 4.5 | | 4.1 | 2.0 | |
| Hematite | 7.2 | 0 | 0 | | 7.2 | 7.3 | |
| Illite | 30 | 20 | 28 | | 35 | 23 | |
| Kaolinite | 26 | 2.4 | 27 | | 19 | 33 | |
| Magnesite | 0.46 | 0.32 | 0.44 | | 0.82 | 0.24 | |
| Pyrite | 7.7 | 12 | 9.3 | | 7.2 | 7.6 | |
| Quartz | 23 | 25 | 26 | | 23 | 22 | |

## TABLE C-16 (page 3)

| | OHIO Powhatan Point | OKLAHOMA[a] Rogers Co. Ft. Scott Seam | PENNSYLVANIA Butler Co. Lower Freeport Seam | PENNSYLVANIA[a] Indiana Co. Lower Freeport Seam | PENNSYLVANIA[a] Westmoreland Company Lower Kittanning Seam | PENNSYLVANIA Pittsburgh Seam Fine Refuse | PENNSYLVANIA Anthracite Refuse | PENNSYLVANIA Anthracite Refuse |
|---|---|---|---|---|---|---|---|---|
| (References) | (25) | (24) | (24) | (24) | (24) | (6) | (14) | (16) |
| % Ash | | 69 | 59 | 77 | 77 | 29 | 65 | |
| % Sulfur | | 11 | 31 | 6.1 | 9.1[g] | 1.4 | | 0-2.5[g] |
| Heat Value (Btu/lb) | | 2200 | 4200 | 2500 | 2200 | | | |
| % Carbon | | | | | | | | |
| pH | | | | | | | | |
| C.E.C. (mg/100g)[b] | | | | | | | | |
| **Major Elements[c]** | | | | | | | | |
| $Al_2O_3$ (%) | 26 | 4.5 | 6.7 | 18 | 19 | 24 | 30-37 | 30-37 |
| CaO | 0.1 | 22 | 0.20 | 0.38 | 0.34 | 1.3 | 1-2 | 1-2 |
| $Fe_2O_3$ | 3.3 | 12 | 39 | 9.3 | 13 | 8.7 | 3-10 | 3-10 |
| $K_2O$ | 0.59[h] | | | | | | 1-3[h] | |
| MgO | 0.8 | | | | | 0.9 | 0-1 | 0-1 |
| MnO | | 0.08 | 0.01 | 0.01 | 0.02 | | | |
| $Na_2O$ | | | | | | | | |
| $P_2O_5$ | | | | | | | | |
| $SiO_2$ | 60 | 24 | 12 | 44 | 41 | 55 | 50-57 | 50-57 |
| $TiO_2$ | 1.2 | | | | | | 1-2 | 1-2 |
| **Mineralogical Content (%)[c]** | | | | | | | | |
| Apatite | | | | | | | | |
| Calcite | | | | | | | 1-10 | |
| Hematite | | | | | | | | |
| Illite | | | | | | | 1-10 | |
| Kaolinite | | | | | | | 70 | |
| Magnesite | | | | | | | | |
| Pyrite | | | | | | | 1-10 | |
| Quartz | | | | | | | 1-10 | |

TABLE C -16 (page 4)

| (References) | WEST VIRGINIA (NORTHERN SECTION) Surface Mine Spoil (11) | WEST VIRGINIA Coarse Refuse[i] (21) | WEST VIRGINIA Red Dog[j] (21) | WEST VIRGINIA Site WHD Fine Refuse (21) | WEST VIRGINIA Site BHD Fine Refuse (21) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Bunker Mine (15) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Cassville Mine (15) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Shannopin Mine (15) |
|---|---|---|---|---|---|---|---|---|
| % Ash | | 55 | 90 | 32 | 26 | | | |
| % Sulfur | 0.3 | 1.1 | 1.5 | 0.5 | 0.8 | | | |
| Heat Value (Btu/lb) | | 5900 | 600 | 9600 | 10700 | | | |
| % Carbon | | | | | | | | |
| pH | 3.5 | | | | | 2.3-3.0 | 3.0-3.8 | <4->8 |
| C.E.C. (mg/100g)[b] | 12 | | | | | | | |
| <u>Major Elements</u>[c] | | | | | | | | |
| $Al_2O_3$ (%) | 18 | 23 | 23 | 27 | 25 | | | |
| CaO | 0.2 | 2.2 | 0.6 | 3.2 | 1.4 | | | |
| $Fe_2O_3$ | 7.9 | 7.2 | 8.1 | 5.4 | 7.9 | | | |
| $K_2O$ | 2.4 | 4.0 | 3.7 | 4.3 | 3.7 | | | |
| MgO | 0.2 | 1.3 | 1.0 | 1.9 | 1.3 | | | |
| MnO | | | 0.01-0.1 | 0.01-0.1 | 0.01-0.1 | | | |
| $Na_2O$ | 0.7 | 0.4 | 0.3 | 0.5 | 0.2 | | | |
| $P_2O_5$ | 0.1 | | | | | | | |
| $SiO_2$ | 69 | 59 | 61 | 53 | 57 | | | |
| $TiO_2$ | 0.7 | 1.2 | 1.3 | 1.0 | 1.2 | | | |
| <u>Mineralogical Content (%)</u>[c] | | | | | | | | |
| Apatite | | | | | | | | |
| Calcite | | trace | n.d.[k] | trace | n.d.[k] | | | |
| Hematite | | | | | | | | |
| Illite | | minor | n.d. | trace | minor | | | |
| Kaolinite | | minor | n.d. | minor | minor | | | |
| Magnesite | | | | | | | | |
| Pyrite | | | | | | | | |
| Quartz | | major | major | major | major | | | |

TABLE C-16 (page 5)

| (References) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Humphrey Mine New Production (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Humphrey Mine Old Production (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) McElroy Mine New Production (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) McElroy Mine Old Production (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Philippi Mine New Production Coarse Refuse (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Philippi Mine New Production Fine Refuse (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Philippi Mine Old Production (9) | WEST VIRGINIA (NORTH WEST-NORTH CENTRAL) Shoemaker Mine New Production (9) | WEST VIRGI (NORTH WEST NORTH CENT Shoemaker Old Product (9) |
|---|---|---|---|---|---|---|---|---|---|
| % Ash | 71 | 73 | 84 | 81 | 57 | | 51 | 83 | 85 |
| % Sulfur | | | | | | | | | |
| Heat Value (Btu/lb) | | | | | | | | | |
| % Carbon | | | | | | | | | |
| pH | | | | | | | | | |
| C.E.C. (mg/100g) [b] | | | | | | | | | |
| Major Elements [c] | | | | | | | | | |
| $Al_2O_3$ (%) | | | | | | | | | |
| CaO | | | | | | | | | |
| $Fe_2O_3$ | | | | | | | | | |
| $K_2O$ | | | | | | | | | |
| MgO | | | | | | | | | |
| MnO | | | | | | | | | |
| $Na_2O$ | | | | | | | | | |
| $P_2O_5$ | | | | | | | | | |
| $SiO_2$ | | | | | | | | | |
| $TiO_2$ | | | | | | | | | |
| Mineralogical Content (%) [c] | | | | | | | | | |
| Apatite | | | | | | | | | |
| Calcite | | | | | | | | | |
| Hematite | | | | | | | | | |
| Illite | | | | | | | | | |
| Kaolinite | | | | | | | | | |
| Magnesite | | | | | | | | | |
| Pyrite | | | | | | | | | |
| Quartz | | | | | | | | | |

TABLE C-16 (page 6)

| | WEST VIRGINIA (SOUTHERN SECTION Algoma Seam | WEST VIRGINIA (SOUTHERN SECTION Cemetery Branch Hollow Seam | WEST VIRGINIA (SOUTHERN SECTION Gauley Eagle No. 4 Seam | WEST VIRGINIA (SOUTHERN SECTION Guyan No. 5 Seam | WEST VIRGINIA (SOUTHERN SECTION Hampton No. 3 Seam | WEST VIRGINIA (SOUTHERN SECTION Hampton No. 4 Seam | WEST VIRGINIA (SOUTHERN SECTION Jenkin Jones Seam | WEST VIRGINIA[a] Grant Co. Bakerstown Seam | NEW MEXICO (NORTHEAST SECTION) (One Mine) | UTAH (CENTRAL SECTION) (One Mine) |
|---|---|---|---|---|---|---|---|---|---|---|
| (References) | (22) | (22) | (22) | (22) | (22) | (22) | (22) | (24) | (23) | (23) |
| % Ash | | | 60 | | | | | 69 | 39-74 | 26-49 |
| % Sulfur | | | 0.39 | | | | | 18[g] | 0.2-0.6 | 0.9-4.4 |
| Heat Value (Btu/lb) | | | 5250 | | | | | 3400 | 2700-8100 | 6600-10,000 |
| % Carbon | | | | | | | | | 10-32 | 28-42 |
| pH | 5.1 | 8.1 | 6.1 | 3.6 | 7.1 | 7.0 | 7.5 | | | |
| C.E.C. (mg/100g)[b] | 8.8 | 4.3 | 7.0 | 4.6 | 5.5 | 5.9 | 4.8 | | | |
| Major Elements[c] | | | | | | | | | | |
| $Al_2O_3$ (%) | | | | | | | | 11 | 22 | 18 |
| CaO | 0.01 | 0.26 | 0.01 | 0.01 | 0.01 | 0.03. | 0.02 | 0.85 | 8.7 | 5.3 |
| $Fe_2O_3$ | 5.9 | 1.4 | 1.1 | 2.3 | 2.0 | 1.4 | 1.4 | 27 | 4.9 | 8.6 |
| $K_2O$ | 0.14 | 0.11 | 0.06 | 0.11 | 0.12 | 0.11 | 0.12 | | 2.1 | 3.2 |
| MgO | 0.37 | 0.29 | 0.08 | 0.17 | 0.25 | 0.29 | 0.37 | | 1.6 | 1.1 |
| MnO | 0.16 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.02 | 0.02 | | |
| $Na_2O$ | 0.04 | 0.05 | 0.02 | 0.03 | 0.05 | 0.04 | 0.03 | | 1.2 | 0.6 |
| $P_2O_5$ | | | | | | | | | | |
| $SiO_2$ | | | | | | | | 28 | 57 | 60 |
| $TiO_2$ | | | | | | | | | 0.7 | 0.8 |
| Mineralogical Content (%)[c] | | | | | | | | | | |
| Apatite | | | | | | | | | | |
| Calcite | | | | | | | | | | |
| Hematite | | | <1 | | | | | | | |
| Illite | | | | | | | | | | |
| Kaolinite | | | | | | | | | | |
| Magnesite | | | | | | | | | | |
| Pyrite | ~5 | | | ~5 | | | | | | |
| Quartz | ~5-10 | | ~1 | | ~20 | ~1 | >20 | | | |

## NOTES FOR TABLE C-16

a. These coals were subject to deep cleaning to study trace element removal from coal by cleaning procedures. The refuse produced may be typical of future coal refuses, which may have to be deep cleaned to meet stringent air and water pollution standards upon burning.

The reference lists major and minor constituents for five zones of the coal cleaning apparatus plus feed coal values. The next-to-last zone contains non-pyritic refuse and the last zone contains pyritic refuse. The values for these two zones will be averaged and reported in the tables.

b. Cation exchange capacity, milliequivalents/100 g.

c. Element and mineral content are concentrations in ashed refuse. The refuse is usually ashed in a laboratory muffle furnace at around 750° C.

d. Expressed as magnesium carbonate.

e. Coarse refuse value followed by slurry value.

f. 86 percent Elkhorn No. 3 plus 14 percent Elkhorn No. 2.

g. Sulfur expressed as percent of ash rather than as percent of refuse.

h. Alkali oxides total: $Na_2O$ and $K_2O$.

i. Composite sample of 8 West Virginia preparation plants.

j. Red dog is burned coal waste. Formation of red dog may be accidental (from spontaneous combustion of refuse banks) or on purpose (from an incineration process).

k. "n.d." is "not detected". "Major" means the mineral form predominates. Minor means the mineral is present in significant amounts and "trace" indicates it is just detectable.

TABLE C-17

## MINOR AND TRACE ELEMENTS IN EASTERN AND MIDWESTERN COAL REFUSE
(ppm)

| | ALABAMA Walker Co. Clements Seam | KANSAS Crawford Co. Baxter Seam | KENTUCKY (EAST) Lower Elkhorn Seam | KENTUCKY (EAST) Elkhorn No. 3 Seam | KENTUCKY (EAST) Hazard No. 4 Seam | KENTUCKY (EAST) Hazard No. 5A Seam | KENTUCKY (WEST) Butler Co. No. 6 Seam | KENTUCKY (WEST) No. 9 Seam | KENTUCKY (WEST) No. 11 Seam | OKLAHOMA Rogers Co. Ft. Scott Seam | PENNSYLVANIA Indiana Co. Lower Freeport Seam | PENNSYLVANIA Butler Co. Lower Freeport Seam | PENNSYLVANIA Westmoreland Company Lower Kittanning Seam |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (References) | (24) | (24) | (10,17) | (10,17) | (10,17) | (10,17) | (24) | (10,17) | (10,17) | (24) | (24) | (24) | (24) |
| Ag | | | | | | | | | | | | | |
| As | 220 | 20 | | | | | 30 | | | 17 | 260 | 960 | 56 |
| Ba | | | 750 | 700 | 490 | 660 | | 1100 | 380 | | | | |
| Be | 5.0 | 0.62 | | | | | 0.82 | | | 1.3 | 2.5 | 1.4 | 2.7 |
| Cd | | | | | | | 3.4 | | | | | | |
| Co | | | 21 | 43 | 7 | 32 | | 79 | 86 | | | | |
| Cr | 81 | 22 | | | | | 18 | | | 39 | 75 | 27 | 86 |
| Cu | 103 | 61 | 51 | 62 | 19 | 61 | 17 | 94 | 75 | 46 | 55 | 82 | 70 |
| F | 125 | 82 | | | | | 31 | | | 239 | 140 | 86 | 73 |
| Ga | | | | | | | | | | | | | |
| Hg | 0.6 | 0.4 | | | | | 1.2 | | | 0.3 | 2.9 | 2.6 | 1.6 |
| Ni | 63 | 40 | 51 | 55 | 26 | 63 | 39 | 110 | 89 | 44 | 65 | 98 | 67 |
| Pb | 47 | 821 | | | | | 52 | | | 97 | 56 | 143 | 76 |
| Rb | | | 190 | 170 | 68 | 170 | | 200 | 120 | | | | |
| Se | 16 | 4.7 | | | | | 6.3 | | | 7.2 | 19 | 10 | 13 |
| Sr | | | 210 | 230 | 190 | 210 | | 110 | 130 | | | | |
| V | 131 | 32 | | | | | 12 | | | 52 | 128 | 29 | 142 |
| Y | | | 32 | 30 | 34 | 38 | | 18 | 30 | | | | |
| Zn | | | 93 | 120 | 47 | 120 | | 280 | 240 | | | | |
| Zr | 100 | 320 | 230 | 200 | 430 | 210 | 1060 | 140 | 160 | 130 | 130 | 735 | 73 |

## TABLE C-17 (page 2)

| | WEST VIRGINIA Fine Refuse Site BDH | WEST VIRGINIA Fine Refuse Site WDH | WEST VIRGINIA[a] (SOUTHERN SECTION) Algoma Seam | WEST VIRGINIA[a] (SOUTHERN SECTION) Cemetery Branch Hollow Seam | WEST VIRGINIA[a] (SOUTHERN SECTION) Gauley Eagle No. 4 Seam | WEST VIRGINIA Grant Co. Bakerstown Seam | WEST VIRGINIA[a] (SOUTHERN SECTION) Guyan No. 5 Seam | WEST VIRGINIA[a] (SOUTHERN SECTION) Hampton No. 3 Seam | WEST VIRGINIA[a] (SOUTHERN SECTION) Hampton No. 4 Seam | WEST VIRGINIA[a] (SOUTHERN SECTION) Jenkin Jones Seam |
|---|---|---|---|---|---|---|---|---|---|---|
| (References) | (21) | (21) | (22) | (22) | (22) | (24) | (22) | (22) | (22) | (22) |
| Ag | 1-10 | | | | | | | | | |
| As | | | | | | 340 | | | | |
| Ba (ppm) | | | 50 | 25 | 18 | | 18 | 25 | 30 | 35 |
| Be | 1-10 | 1-10 | | | | 1.9 | | | | |
| Cd | | | 1.00 | 0.75 | 0.65 | | 0.75 | 0.65 | 0.50 | 0.75 |
| Co | 10-100 | 10-100 | | | | | | | | |
| Cr | 10-100 | 10-100 | | | | 64 | | | | |
| Cu | | | | | | 70 | | | | |
| F | | | | | | 130 | | | | |
| Ga | 10-100 | 10-100 | | | | | | | | |
| Hg | | | | | | 4.2 | | | | |
| Ni | 100-1000 | 100-1000 | | | | 74 | | | | |
| Pb | 100-1000 | 100-1000 | 150 | 60 | 20 | 86 | 30 | 35 | 35 | 100 |
| Rb | | | | | | | | | | |
| Se | 10-100 | 10-100 | | | | 47 | | | | |
| Sr | | | | | | | | | | |
| V | 100-1000 | 100-1000 | | | | 76 | | | | |
| Y | 10-100 | 10-100 | | | | | | | | |
| Zn | | | 85 | 60 | 30 | | 30 | 60 | 40 | 65 |
| Zr | 10-100 | 10-100 | | | | 96 | | | | |

[a]Concentrations determined by Atomic Absorption Analysis. Two grams of minus 200 mesh, add 25 ml concentrated $HNO_3$, evaporate, dilute to 50 ml with 10% $HNO_3$ solution. (Elements determined for seven West Virginia mines: Ca, Cd, Cu, Fe, K, Mg, Mn, Na, Pb, Zn at Gauley Eagle No. 4, Algoma, Jenkin Jones, Guyan No. 5, Hampton No. 4, Cemetery Branch Hollow.)

## Supplement 1 to Appendix C

| MAJOR DIVISIONS | | | GROUP SYMBOLS | TYPICAL NAMES |
|---|---|---|---|---|
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | GRAVELS 50% or more of coarse fraction retained on No. 4 sieve | CLEAN GRAVELS | GW | Well-graded gravels and gravel-sand mixtures, little or no fines |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | GRAVELS 50% or more of coarse fraction retained on No. 4 sieve | CLEAN GRAVELS | GP | Poorly graded gravels and gravel-sand mixtures, little or no fines |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | GRAVELS 50% or more of coarse fraction retained on No. 4 sieve | GRAVELS WITH FINES | GM | Silty gravels, gravel-sand-silt mixtures |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | GRAVELS 50% or more of coarse fraction retained on No. 4 sieve | GRAVELS WITH FINES | GC | Clayey gravels, gravel-sand-clay mixtures |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | SANDS More than 50% of coarse fraction passes No. 4 sieve | CLEAN SANDS | SW | Well-graded sands and gravelly sands, little or no fines |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | SANDS More than 50% of coarse fraction passes No. 4 sieve | CLEAN SANDS | SP | Poorly graded sands and gravelly sands, little or no fines |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | SANDS More than 50% of coarse fraction passes No. 4 sieve | SANDS WITH FINES | SM | Silty sands, sand-silt mixtures |
| COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve* | SANDS More than 50% of coarse fraction passes No. 4 sieve | SANDS WITH FINES | SC | Clayey sands, sand-clay mixtures |
| FINE-GRAINED SOILS 50% or more passes No. 200 sieve* | SILTS AND CLAYS Liquid limit 50% or less | | ML | Inorganic silts, very fine sands, rock flour, silty or clayey fine sands |
| FINE-GRAINED SOILS 50% or more passes No. 200 sieve* | SILTS AND CLAYS Liquid limit 50% or less | | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays |
| FINE-GRAINED SOILS 50% or more passes No. 200 sieve* | SILTS AND CLAYS Liquid limit 50% or less | | OL | Organic silts and organic silty clays of low plasticity |
| FINE-GRAINED SOILS 50% or more passes No. 200 sieve* | SILTS AND CLAYS Liquid limit greater than 50% | | MH | Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts |
| FINE-GRAINED SOILS 50% or more passes No. 200 sieve* | SILTS AND CLAYS Liquid limit greater than 50% | | CH | Inorganic clays of high plasticity, fat clays |
| FINE-GRAINED SOILS 50% or more passes No. 200 sieve* | SILTS AND CLAYS Liquid limit greater than 50% | | OH | Organic clays of medium to high plasticity |
| Highly Organic Soils | | | PT | Peat, muck and other highly organic soils |

* Based on the material passing the 3-in. (75-mm) sieve.

## REFERENCES FOR APPENDIX C


1. Nielson, G.F. "Keystone Forecasts 765 Million Tons of New Coal Capacity by 1987." Keystone Coal Industry Manual. New York: McGraw-Hill, 1978, 674-685.

2. Glover, H.G. "The Disposal of Coal Mine Spoil in the United Kingdom." In Goodman, G.T., and Chadwick, M.J., Environmental Management of Mineral Wastes. The Netherlands: Sijthoff & Noordhoff, 1978.

3. Nielson, G.F., ed. Keystone Coal Industry Manual. New York: McGraw-Hill, 1978.

4. Hayes, E.T. "Energy Resources Available to the United States, 1985 to 2000." Science 203(4377):233-239, 1979.

5. Bagge, C.E., President, National Coal Association. Letter to President Jimmy Carter, dated 12 January 1978.

6. Hoffman, D.C., and Snyder, G.A. Chemical Stability of Fine Coal Refuse with Calcilox[R] Additive Stabilization Techniques. Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

7. Bishop, C.S. and Rose, J.G. Physical and Engineering Characteristics of Coal Preparation Plant Refuse. Proceedings of the Seventh Ohio River Valley Soils Seminar on Shales and Mine Wastes: Geotechnical Properties, Design, and Construction. October 1976.

8. Charmbury, H.B., and Maneval, D.R. The Utilization of Incinerated Anthracite Mine Refuse as Anti-Skid Highway Material. Proceedings of the Third Mineral Waste Utilization Symposium. Chicago, IL: U.S. Bureau of Mines and ITT Research Institute, 1972.

9. Moulton, L.K., Anderson, D.A., Seals, R.K., and Hussain, S.M. Coal Mine Refuse: An Engineering Material. Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, KY: National Coal Association, 1974.

10. Bland, A.E., Robl, T.L., and Rose, J.G. Kentucky Coal Preparation Plant Refuse Characterization and Uses. Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, September 1976.

11. Adams, L.M., Capp, J.P., and Eisentrout, E. Reclamation of Acidic Coal Mine Spoil with Fly Ash. U.S. Bureau of Mines Report of Investigation 7504. April 1971.

12. Longwell, C.R., Flint, R.F., and Sanders, J.E. Physical Geology. New York: John Wiley and Sons, 1969.

13. Meyers, J.F., Pichumani, R, and Kapples, B.S. Fly Ash As a Construction Material for Highways. Report No. FHWA-IP-76-16. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, June 1976.

14. Spicer, T.S., and Luckie, P.T. Operation Anthracite Refuse. Proceedings of the Second Mineral Waste Utilization Symposium. Chicago, IL: U.S. Bureau of Mines and ITT Research Institute, March 1970.

15. Adams, L.M., Capp, J.P., and Gillmore, D.W. Coal Mine Spoil and Refuse Bank Reclamation with Power Plant Fly Ash. Proceedings of the Third Mineral Waste Utilization Symposium. Chicago, IL: U.S. Bureau of Mines and ITT Research Institute, 1972.

16. Sun, S.C., Vasquez-Rosas, H., and Angerstein, D. Pennsylvania Anthracite Refuse: A Literature Survey on Chemical Elements in Coal and Coal Refuse. Report No. SR-83. University Park, PA: Pennsylvania State University, April 1970.

17. Bland, A.E., Robl, T.L., and Rose, J.G. "Evaluation of Interseam and Coal Cleaning Effects on the Chemical Variability of Past and Present Kentucky Coal Refuse." Transactions of the Society of Mining Engineers 262: 331-334, December 1971.

18. Drnevich, U.P., Williams, G.P., and Ebelhar, R.J. Soil Mechanics Tests on Coal Mine Spoils. Proceedings of the Second Kentucky Coal Refuse Disposal and Utilization Seminar. Pineville, KY, 1976.

19. Freedland, J.W. and Sawyer, S.G. Experience in Field and Laboratory Compaction Testing of Coarse Coal Mine Waste. For the U.S. Department of Interior, Mining Enforcement and Safety Administration. Pittsburgh, PA, 1976.

20. Dunn, J.R., Banino, G.M., and Ernst, W.D. The Physical and Chemical Characteristics of Available Materials for Filling Subsurface Coal Mines (Contract No. J0155182). For the U.S. Bureau of Mines. Washington, D.C., June 1977.

21. Busch, R.A., Backer, R.R., Atkins, L.A., and Kealy, C.D. Physical Property Data on Fine Coal Refuse. U.S. Bureau of Mines Report of Investigation 8062. Spokane, WA, 1975.

22. Busch, R.A., Backer, R.R., and Atkins, L.A. Physical Property Data on Coal Waste Embankment Materials. U.S. Bureau of Mines Report of Investigation 7964. Spokane, WA, 1974.

23. Backer, R.R., Busch, R.A., and Atkins, L.A. Physical Properties of Western Coal Waste Materials. U.S. Bureau of Mines Report of Investigation 8216. Spokane, WA, 1977.

24. Ford, C.T., Care, R.R., and Bosshart, R.E. Preliminary Evaluation of the Effect of Coal Cleaning on Trace Element Removal. Monroeville, PA: Bituminous Coal Research, Inc., 1976.

25. Collins, R.J., and Miller, R.H. Availability of Mining Wastes and Their Potential for Use as Highway Material, Volume I: Classification and Technical and Environmental Analysis. U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-RD-76-106. Washington, D.C., May 1976.