Materials Characterization Paper
In Support of the
Advanced Notice of Proposed Rulemaking –
Identification of Nonhazardous Materials That Are Solid Waste

Coal Refuse

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1. Definition of Coal Refuse

This paper focuses on coal refuse that is a by-product of coal mining (mining rejects). Coal refuse is generally defined by a minimum ash content combined with a maximum heating value, measured on a dry basis. (ARIPPA, p. 1 and EPA 2002, p. 2-2). Coal refuse mining rejects are a low BTU-value material generated by the coal mining process. The material consists primarily of non-combustible rock, with some attached carbon material that cannot be effectively separated. Large volumes of these materials were accumulated at mining sites from the time mining first began in the Appalachians through the late 1970s. Beginning in the late 1970s, laws were enacted that, for the first time, required stabilization and reclamation of mining sites, including coal refuse disposal piles and fills (ARIPPA, p.1). Current mining operations continue to generate the material. Mining rejects are referred to by various names, including: "gob" (garbage of bituminous) or "boney" in the bituminous coal mining regions of western Pennsylvania, West Virginia and elsewhere; and "culm" in the eastern Pennsylvania anthracite region. Coal refuse piles also may be referred to as slate dumps (Energy Justice 2007, p.1; WPCAMR 2001, p.2; NRC 2006, p.16).

2. Annual Quantities of Coal Refuse Generated and Used

(1) **Sectors That Generate Coal Refuse:**

- Coal Mining Rejects are generated by NAICS industry sector 212111 - Bituminous Coal and Lignite Surface Mining, 212112 - Bituminous Coal Underground Mining, and 212113 - Anthracite Mining. The U.S. Department of Energy categorizes the locations of these industries into three regions:
    - Appalachian Region, which includes the states of Alabama, Kentucky (eastern), Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia;
    - Interior Region, which includes the states of Arkansas, Illinois, Indiana, Kansas, Kentucky (western), Louisiana, Mississippi, Missouri, Oklahoma, and Texas; and
    - Western Region, which includes the states of Alaska, Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming (USDOE 2007b, p.14).

(2) **Quantities and Prices of Coal Refuse Generated:**

Comprehensive national data concerning current generation rates of mining rejects were not identified in the course of this review. In 2007, however, the amount of coal produced at U.S. coal mines reached an all-time high of 1,145.0 million short tons; this production data includes quantities extracted from surface and underground mines, and normally *excludes* secondary materials removed at mines or associated preparation plants (USDOE 2007a).[1] Thus, the amount of raw mining product is higher than this 1,145.0 million short ton total. The amount of mining reject resulting from this production is uncertain, but up to 50 percent of the raw mined product may end up as refuse depending on the rock and impurities in the coal (VCE 1996). Considering this 50 percent generation estimate with the 2007 coal production number, results in an estimate that up to 1,145 million tons of coal reject may have been generated in 2007 (i.e., 50 percent of raw mined product is saleable product, while 50 percent is rejects). As an example of specific data from one state, fifteen million tons of mining reject are generated annually in Virginia (VCE 1996).

Information on the price of coal refuse is limited, but can be expected to compare favorably with “virgin” energy sources in the applications where it is used.

(3) **Trends in Generation of Coal Refuse:**

Generation of coal refuse correlates with the production and use of coal. According to the DOE’s *Annual Energy Outlook 2007 with Projections to 2030*, coal production is projected to increase in coming decades, particularly in the Powder River Basin of Wyoming. From 2005 to 2030, production in the Powder River Basin is projected to grow by 289 million tons. The Rocky Mountain, Central West, and East North Central regions are projected to show the largest increases in coal demand, by about 100 million tons each, from 2005 to 2030. Increasing coal use for electricity generation at existing plants and construction of a few new coal-fired plants lead to forecasted annual production increases that average 1.1 percent per year from 2005 to 2015. The forecasted growth in coal production is stronger from 2015 to 2030, averaging 1.8 percent per year, as new coal-fired generating capacity is added and several coal-to-liquids (CTL) plants are brought on line (USDOE 2007b). Overall, the generation of coal refuse will likely increase as the demand for coal-based energy grows; however, it is unclear how this increase will affect recapturing of existing coal refuse from stockpiles.

3. Uses of Coal Refuse

(1) **Combustion Uses of Coal Refuse:**

- There are 18 coal refuse plants (Fossil fuel electric power generation - NAICS 221112), and 13 more that use it as a secondary fuel, with bituminous coal as their

[1] This amount does not include the recovery of coal refuse, which was 0.8 million short tons in 2007.

primary fuel. Fourteen of the 18 coal refuse plants are in Pennsylvania, three are in West Virginia, and one is in Utah. Seventeen more plants have been proposed in Pennsylvania, West Virginia, Kentucky, Indiana, Illinois, Colorado, and Virginia (Energy Justice 2007, p.1).

- According to the Anthracite Region Independent Power Producers Association (ARIPPA), from 1988 to the end of 2003, coal refuse plants in Pennsylvania used 88.5 million tons of coal refuse, mostly from "legacy" refuse piles. ARIPPA's records show that the plants in the Commonwealth burn an average of about 7.5 million tons of coal refuse per year as fuel, mostly from "legacy" coal refuse piles (PADEP 2004a, p.2).
- The type of process used for the combustion of mining rejects is circulating fluidized bed (CFB) combustion (also known as fluidized bed combustor (FBC) boiler technology) (Energy Justice 2007, p.1). CFB is an integrated technology for reducing sulfur dioxide (SO_2) and NO_x emissions during the combustion of coal. For the CFBs currently in use in all sectors, coal is the primary fuel source, followed by biomass and coal refuse. The heat input capacities of all industrial, commercial, and institutional (ICI) CFB units generally range from 1.4 to 1,075 MMBtu/hr. (EPA 2004, p.2-7).

(2) **Non-Combustion Uses of Coal Refuse**

- ***Granular Base:*** Coarse coal refuse can be used as aggregate in granular base applications. Burnt coal refuse (red dog) is also a suitable granular base material. Proper compaction of coarse coal refuse to its maximum dry density is necessary to achieve stability within a pavement structure. Fine coal refuse slurry has little or no load carrying capability and is, therefore, unsuitable for use as a construction material (TFHRC post-1994, p.1).

  Coal refuse has been successfully used in cement stabilized base applications in Europe.[2] The success of this material for use in this application is reportedly dependent on proper compaction. There has been occasional use of coal refuse in Alabama, Kentucky, Virginia, and West Virginia as an alternative material for bases and subbases (TFHRC post-1994, pp.1-2).[3]

- ***Mine Reclamation Projects:*** Ash leftover from combustion in a CFB boiler is alkaline and used for mine reclamation projects. The ash is often hauled back to the same gob pile site, where it can be mixed with soils impacted by acid mine drainage around abandoned mines to neutralize acidity and immobilize heavy metals. The Commonwealth of Pennsylvania has certified CFB ash for beneficial use in mining reclamation projects, and the Department of Environmental

[2] For example, the Ministry of Transport in the United Kingdom permits the use of incinerated coal refuse (well-burnt, nonplastic shale) as a granular subbase material in Ministry controlled road work (TFHRC, post-1994, p.2).

[3] The Pennsylvania Department of Transportation has rejected anthracite refuse usage as aggregate for base and subbase courses because of high percent dissolution losses in the sodium sulfate (soundness test). West Virginia is evaluating the use of coal refuse as subbase material (TFHRC, post-1994, p.2).

Protection regulates and routinely tests it (WPCAMR post-2001, p.2). Following combustion of gob in the CFB boiler, the solids that remain are called ash.[4]

(3) **Quantities of Coal Refuse Stockpiled/Stored**[5]
All mining rejects are stockpiled. Comprehensive national data concerning the volume of legacy mining rejects was not identified during the course of this review. In Pennsylvania, however, historically, (i.e., from the early 1800s to the 1970s) mine rejects were placed in piles in the state's coal regions until laws were enacted in the late 1970s that required the coal companies to reclaim the sites that they mined. According to one source, upwards of 2.4 billion tons of coal refuse had been dealt with in this manner in Pennsylvania by that time (Energy Justice 2007, p.1). Another source indicates that Pennsylvania had an estimated 8,529 acres of "legacy" coal refuse piles throughout the state as of 2003. These piles include at least 258 million tons of coal refuse (PADEP 2004a). In addition, according to ARIPPA, from 1988 to the end of 2003, coal refuse plants in Pennsylvania consumed 88.5 million tons of the material, mostly from "legacy" refuse piles. ARIPPA's records show that the plants in the Commonwealth burn an average of about 7.5 million tons of coal refuse per year, mostly from "legacy" coal refuse piles (PADEP 2004a, p.2).

4. Management and Combustion Processes

(1) **Types of Combustion Units:**
Circulating fluidized bed combustion units and pulverized coal power plants are the only units that use any coal refuse.

(2) **Sourcing information:**
Sources of mining rejects include coal refuse or "gob/culm piles".[6]

(3) **Processing Information:**
In general, the material is hauled from mining areas (i.e., gob and culm piles) to coal-fired power plants, crushed to a top size of approximately five millimeters, and then burned in circulating fluidized beds for energy. Along with the fuel, crushed limestone is injected into the bottom of the combustion chamber where the calcium carbonate in the limestone is converted into calcium oxide. The calcium oxide then reacts with the sulfur in the coal refuse, thereby reducing the sulfur oxide emissions. The heavier fuel and limestone particles that cannot be retained in the circulating

[4] CFB Ash can be used for other kinds of reclamation projects. For example, one project will use CFB ash injected into the partially flooded underground voids of an abandoned mine to mitigate acid mine drainage that currently breaks out on the surface (WPCAMR).

[5] See the CCP Materials Characterization Paper for further information on CCP landfill volumes.

[6] Based on the sources consulted in the development of this document, brokers or traders do not appear to be involved in sourcing the waste products to the power plants. It appears the utilities/power plants are supplying themselves with the waste pile materials.

fluidized bed drop to the bottom of the chamber. This burned fuel, known as bottom ash, is removed from the combustion chamber. (PADEP 2004b, Ch 1, pp. 3-4). Ash leftover from CFBs may be hauled back to the same gob/culm pile site, where it can be mixed with soils around abandoned mines to neutralize acidity and immobilize heavy metals (WPCAMR post-2001, p.2).

(4) **Changes in Technology to Improve Use of Coal Refuse in Combustion:**
As noted, the advent of circulated fluidized bed (CFB) combustion boilers, along with higher fuel costs, has facilitated the combustion uses of coal refuse. In addition, certain technology advancements are in use or development that may serve to further improve the application of coal refuse in combustion:

- CSIRO-Liquatech hybrid coal and gas turbine system, developed in Australia, harnesses existing technologies in a 1.2 megawatt hybrid coal and gas turbine system that burns coal refuse and methane gas to generate electricity. The electricity can either be used to power a mine's operations or be returned to the grid for general consumption (CSIRO 2002, p.1).
- Radar Acquisitions Corp. is in the process of developing an engineered solid fuel (Re-Fuel™) for utilities. The primary component of Re-Fuel™ is coal refuse (gob piles and coal slurry pond material); the secondary component is biomass (i.e. agricultural material or sawdust). The goal of the RPS Fuels™ technology is to convert these two materials into a product that looks and acts like coal, but burns more efficiently and with reduced stack emissions. (Radar, p.1).

(5) **State Status of Combustion as Beneficial Use:**
There are currently three states that have power plants that burn coal refuse as fuel (Pennsylvania, West Virginia, and Utah). There are currently five additional states that are proposing to build power plants that will burn coal refuse: Kentucky, Indiana, Illinois, Colorado, and Virginia.[7]

5. Coal Refuse Composition and Impacts

(1) **Composition of Coal Refuse**
The Btu value for this material is 6,000 to 9,500 Btu per pound (NRC, 2006). Nationally, this material has an average of 60 percent of the BTU value of normal coals (Energy Justice 2007, p.1). The ash contents of coal refuse is high: according to an ARIPPA-sponsored study, twelve Pennsylvania plants using coal refuse as a key ingredient of their fuel, burned over 8 million tons/year of refuse coal and generated in the process approximately 5 million tons of ash (Earthtech 2000, Vol. 1, p. iv).

Mining rejects have a higher concentration of mercury than normal coals. In West Virginia and nationally, gob has 4 times more mercury than bituminous coal. In Pennsylvania, gob has 3.5 times more mercury than bituminous coal. Culm has 19

[7] Note that this information represents the results of preliminary research; we have not performed an exhaustive investigation of state activities and regulations for all states concerning coal refuse.

percent more mercury than anthracite coal. Bituminous rejects also have higher levels of sulfur. Data on other metals in the material is sparse, but single metals tests on Pennsylvania culm and gob show both to have about four times more chromium and three times more lead (Energy Justice 2007, p.1)), and the content of arsenic is relatively elevated as well (Coleman and Bragg, 1990, in Earthtech, 2000, Vol. 1, pp. 15-16).

(2) **Impact Information**

As noted, the typical process used for the combustion of mining rejects is circulating fluidized bed (CFB) combustion (Energy Justice 2007, p.1). CFB is an integrated technology for reducing sulfur dioxide (SO_2) and NO_x emissions during the combustion of coal. In a typical CFB boiler, crushed coal and inert material (sand, silica, alumina, or ash) and/or a sorbent (limestone) are maintained in a highly turbulent suspended state by the upward flow of primary air from the windbox located directly below the combustion floor. This fluidized state provides a large amount of surface contact between the air and solid particles, which promotes uniform and efficient combustion at lower furnace temperatures than conventional coal-fired boilers. Once the hot gases leave the combustion chamber, they pass through the convective sections of the boiler, which are similar or identical to components used in conventional boilers. For the CFBs currently in use in all sectors, coal is the primary fuel source, followed in descending order by biomass, coal refuse, and municipal waste. The heat input capacities of all ICI CFB units generally range from 1.4 to 1,075 MMBtu/hr (EPA 2004, pp.2-7).

Concerning impacts related to emissions from this combustion process, the Pennsylvania Department of Environmental Protection (PADEP) required the owners of a Pennsylvania bituminous coal refuse fired facility to conduct extensive air toxics emissions stack testing to support its request to burn a 10 percent mixture of coal tar contaminated soil in combination with normal coal refuse. The coal refuse facility shows lower emissions for all of the toxic pollutants compared to a typical pulverized coal combustor. The dioxin levels were approximately 4 times lower, while most metals were about half, with the exception of mercury, which was 10 times lower per gigawatt-hour generated (PADEP post-2004, p.2). Based on stack testing of two CFB combustion plants, 99.7% to 99.8% of the mercury was captured in the ash (Earthtech, 2000, Vol. 1, p. vi). According to the same source (Earthtech, 2000, Vol.1, p. 1), there are several reasons for the general low emission levels of trace metals such as As, Cd, Cr, Hg, Pb, Ni and Se in the fluidized bed combustion process. Those include the significantly lower combustion temperatures (800-950 ^{0}C) as compared to pulverized coal combustion boilers (1200-1540 ^{0}C), resulting in much longer circulation of the ash particles in the boiler, and allowing for more effective fixation of these metals; capture of ash in a baghouse rather than by electrostatic precipitator; and the addition of limestone which enhances metal fixation unto the ash.

The culm (reject anthracite coal) combusting facilities represent the majority of the coal refuse facilities in Pennsylvania and the data submitted to the Department shows that these facilities have been achieving a NOx emissions level of 0.15 lbs/MMBtu. In comparison, a typical pulverized coal facility without add-on selective catalytic reduction (SCR) controls, which is presently the majority of pulverized units, would emit NOx in the 0.3 to 0.5 lb/MMBtu range. This continuous emissions monitoring (CEM) data also shows that some of the coal refuse facilities have been achieving an SO_2 emissions rate of 0.20 to 0.25 lbs/MMBtu range using limestone injection. The pulverized coal-fired boilers typically emit in the range of 2 to 3 lbs. of SO_2 per MMBtu. The six Pennsylvania pulverized coal-fired units with SO_2 scrubbing operate in the 0.1 to 0.4 lbs. of SO_2 per MMBtu range (PADEP post-2004, p.2).

Pennsylvania coal refuse burning facilities are lower emitters of both NOx and SOx than the typical coal-fired utilities. However, it should also be noted that an SO_2 emission rate of 0.1 lbs/MMBtu is achievable for a newly built pulverized coal-fired unit that would be required to install an SO_2 scrubber under an SO_2 Best Available Control Technology (BACT) determination. Therefore, newly constructed electric generating combustors of either coal refuse or coal would emit at very comparable levels, because both would be employing very similar BACT for all pollutants. (PADEP post-2004, p.2).

Impacts related to the use of coal refuse are discussed qualitatively below. Note that a further discussion of the uses of coal combustion products (CCPs) as ingredients is provided in the CCP Materials Characterization Paper.

- ***Other Impacts Related to Mining Rejects:***
  The potential benefits of returning suitable FBC ash to abandoned or active mine lands for use in reclamation include:
  - The alkaline nature and encapsulating ability of the material make it useful for some mine reclamation applications. In particular, reclaiming coal refuse piles without the benefit of adding FBC ash does less to address the often-severe water quality problems that emanate from some of the piles.
  - The reclamation of abandoned mine land (AML) with FBC ash is often privately funded, freeing up state and federal government AML resources for other applications.
  - The ash from FBC plants has chemical and physical properties that limit the potential for the ash itself to become a source of environmental contamination (Earthtech, 2000, Vol 1, pp. v-vi; PADEP 2004b, Ch. 1, pp.6-7).
  - Reclaiming AML with ash serves to eliminate the safety hazard of abandoned mine highwalls and cropfalls.

- ***Additional Avoided Impacts:***
  Use of coal refuse as a replacement for traditional primary fuels eliminates the environmental impacts associated with extraction and processing of the traditional fuels. Exhibit 1 lists the quantities of emissions for mining reject combustion as reported by the Pennsylvania DEP and the quantities of cradle-to-gate emissions and combustion emissions for coal as reported by typical industrial boilers in the late 1990s. Note that there may be impacts associated with the previously

described processing of coal refuse in preparation for combustion not considered here, and there may be alternative uses (e.g., aggregate, mine reclamation) that are environmentally preferable to combustion.

Furthermore, use of coal refuse as a fuel serves the important benefit of removing the piles of gob and culm. The piles can be a fire hazard and a source of surface and ground-water pollution.

Exhibit 1: Emissions from Combustion of Coal Refuse and Extraction and Combustion of Traditional Coal

Pollutant	Coal Refuse	Coal	
	Combustion	Combustion	Combustion plus Upstream
	---------- *Lb./MMBtu* ----------		
Criteria Pollutants			
PM2.5	-	-	-
PM10	-	0.054	0.054
PM, unspecified	-	-	0.246
NOx	0.15	0.482	0.504
VOCs	-	0.006	0.014
SOx	0.20 - 0.25	1.446	1.469
CO	-	0.068	0.085
Pb	-	8.93×10^{-6}	9.19×10^{-6}
Hg	-	2.05×10^{-6}	2.14×10^{-6}

Sources:
PADEP post-2004, p.2; Franklin Associates 1998.
Note:
"-" signifies data not available; may equal zero.

The emission information presented in this table is derived from Life Cycle Inventory (LCI) data, as compiled by Franklin Associates. LCI data identifies and quantifies resource inputs, energy requirements, and releases to the air, water, and land for each step in the manufacture of a product or process, from the extraction of the raw materials to ultimate disposal. The LCI can be used to identify those system components or life cycle steps that are the main contributors to environmental burdens such as energy use, solid waste, and atmospheric and waterborne emissions. Uncertainty in an LCI is due to the cumulative effects of input uncertainties and data variability.

There are several life cycle inventory databases available in the U.S. and Europe. For this paper, we applied the most readily available LCI database that was most consistent with the materials and uses examined. These LCI data rely on system boundaries as defined by Franklin Associates, as described in the documentation for this database, available at: http://www.pre.nl/download/manuals/DatabaseManualFranklinUS98.pdf.

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