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"MULLED COAL - A BENEFICIATED COAL FORM
FOR USE AS A FUEL OR FUEL INTERMEDIATE"

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Phase III: Final Report

Prepared By:

ENERGY INTERNATIONAL CORPORATION
135 William Pitt Way
Pittsburgh, PA 15238

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Prepared For:

PETC Project Manager: Anthony E. Mayne
Pittsburgh Energy Technology Center
U.S. Department of Energy
P. O. Box 10940
Pittsburgh, PA 15236

MULLED COAL - PHASE III - FINAL REPORT

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EXECUTIVE SUMMARY

Energy International Corporation (EI) was awarded a contract by the Department of Energy, Pittsburgh Energy Technology Center (DOE-PETC) to evaluate a new concept for utilization of the fine coal wetcake produced by many of the physical beneficiation processes now under development.

EI proposed development of a stabilized wetcake with properties that would facilitate storage, handling, transport, and subsequent conversion of the material into Coal-Water Fuel (CWF) at the point of use. The effort was performed in three phases.

Phase I established the technical feasibility of stabilizing the fine coal "wetcake" in a form that can be readily handled and converted into a desired fuel form at the combustion site.

The preferred form of stabilized "wetcake" was a granular free flowing material with the moisture encapsulated with the fine coal particles. The product was termed Mulled Coal. Phase I results indicated that the Mulled Coal was not only suitable as a CWF intermediate, but also had potential as a solid fuel. Based upon these findings, an application for patent was filed. Notification was received from the Patent Office in January of 1993 with final issuance of patent in August 1993.

Phase II demonstrated the utilization of the Mulled Coal process to store and move fine coal products as a stable "wetcake". Tasks in this phase tested components of the various systems required for storage, handling and combustion of the fine coals and subsequently demonstrated operation of an integrated system for storing, handling, and atomizing the highly beneficiated fine coal products.

Phase III expanded the technology by:

1. Evaluating Mulled Coal from representative coals from all producing regions in the U.S., including low rank coals and anthracite.
2. Development of bench-scale tests to compare handling properties of experimental mulls.
3. Design, construction, and operation of a 1 ton/hr continuous processing unit for conversion of wetcakes into granular mull.
4. Evaluation of the effects of beneficiation on mull formulations.
5. Developing an estimate of capital and operating costs for commercial units installed at an existing cleaning facility for production capacities of 50, 250, and 1000 tons/hr.

The key findings of this program were:

1. Development of a stable form for fine coal wetcakes generated by cleaning coal processes. This fuel can be handled in conventional equipment and is applicable to coals from anthracite to subbituminous.
2. It appears that Appalachian coals generally are amenable to both mulling to the granular mull form and to the subsequent conversion to coal-water fuels. The lower rank coals can be converted into acceptable quality granular mulls, but are not well suited to conversion to coal-water fuels.
3. Demonstration of an in-line process for conversion of the solid fuel form to high quality liquid fuel at the time of combustion.
4. Development of a design and cost estimate for a commercial facility to convert coal wetcake into the granular free-flowing Mulled Coal.
5. Potential of the technology for coal fines generated in conventional coal operations and slurry pond recovery operations.
6. The production of Mulled Coal has been estimated to cost \$3 to \$5 per wet ton for conversion of the fines into a usable granular Mulled Coal product. For 65% solids wet fine coal fed into the mulling circuit, this corresponds to a cost range of about \$5 to \$8/ton dry coal or 15 to 30 cents per million Btu.
7. When the Mulled Coal product from fines production in a coal preparation plant is recombined with the coarse cleaned coal, the low cost of reclaiming the waste fines will reduce substantially the cost per ton of coal delivered from the preparation plant.
8. The cost of coal-water fuel (CWF) delivered to a typical boiler fuel user and prepared from Mulled Coal has been estimated to be \$1.00 to \$1.10 per million Btu in addition to the cost of the coal feed. This includes production of Mulled Coal, transportation to the user site, and conversion to CWF.

1.0 INTRODUCTION

1.1 Technical Problem Addressed

Under the auspices of the Department of Energy and private industry, considerable progress has been made in:

- a. preparation of coal-water fuels
- b. combustion of low-ash coal based fuel forms
- c. processes to provide deeply-cleaned coal

These technology advances are compatible with national objectives to increase the environmentally responsive use of readily available and abundant coal resources, and to reduce oil and gas fuel consumption.

As these technical developments move toward commercial application, the need for coordinated efforts and integrated requirements have become increasingly apparent. Systems are vitally needed to integrate energy delivery systems from the raw resource through processing to application and use. Problems have been encountered in the preparation of conventional coal-water fuels that mutually satisfy the requirements for storage stability, handling, preparation, atomization, combustion, and economics. Experience has been slow in evolving generic technologies or products and coal-specific requirements and specifications continue to dominate the development. Thus, prospects for commercialization remain highly specific to the coal, the processor, and the end use.

Developments in advanced beneficiation of coal to meet stringent requirements for low ash and low sulfur can be anticipated to further complicate the problem areas. This is attributable to the beneficiated coal being produced in very fine particles with high surface areas, modified surface characteristics, reduced particle size distribution range, and high inherent moisture. Experience in the storage, handling, and transport of highly beneficiated coal has been limited. This is understandable, as quantities of such product are only now becoming available in meaningful quantities.

Much of the existing work and experience with advanced coal-based fuels such as CWF has been built on the premise that the fuel should and will be compatible with use in the existing storage, handling, and transport equipment as a "one-to-one" replacement for conventional oil fuels. Expensive additives, additional processing, equipment, and system modifications will be needed to provide effective and versatile fuel delivery systems. This will be even more significant for fine particle highly beneficiated coal fuels.

The conventional approach for formulation of CWF would be to develop a single formulation that meets the requirements of the total fuel system. At best, the resultant material will have specifications that represent a compromise.

1.2 Technical Approach

Energy International is developing a technology that will use staged formulations to create opportunities to make use of fine coal wetcakes. These wetcakes are currently difficult or nearly impossible to store, handle, or transport in their existing form to either further process operations or to users. These wetcakes or wet fines are produced in the fine coal portions of coal preparation plant circuits or as products of advanced fine coal cleaning technologies. The technical approach offered by Energy International to address these problems of wet fines and wetcakes has two major components:

- o Conversion of the wet fines or wetcakes to a stabilized fuel form capable of removal from the current plant operations and being stored, handled, and transported as an intermediate, called Mulled Coal.
- o Preparation of a Mulled Coal with characteristics suitable for user applications either as a precursor to a coal-water slurry fuel, blending with other coarser coal products, or direct use as the Mulled Coal fuel form.

This concept is an alternative to the expensive and energy intensive thermal drying processing of fine coal wetcakes. The material is suitable for both direct feed use in conventional and fluid bed combustors as well as on-site conversion to combustible slurries. Just prior to combustion, the Mulled Coal would be modified to provide the properties needed for proper atomization. By maintaining the coal form relatively close to the feed wetcake, only minor processing with low additive levels and low energy blending is needed at the point of production. Its conversion to slurry or other use-feed form is made near the time of use and thus the requirements for stability, climatic control, and other storage, transport, and handling requirements are much less severe.

The technical approach used in the development of the Mulled Coal concept in this project is comprised of a series of tasks organized into three phases. These were designed to produce formulations and system designs suitable to convert fine coal "wetcakes" into a material that can be stored, handled, and transported to a site where it can be utilized as a fuel in existing and developing combustion devices. The project was divided into three phases:

Phase I provided the technology base and established the technical feasibility of the concept. The information developed during Phase I provided a basis for design and implementation of a demonstration program (Phase II).

Phase II demonstrated the ability to utilize the Mulled Coal to improve the ability to store and move fine coal products as a stable "wetcake" and to convert the wetcake into a Coal Water Fuel.

Phase III expanded the technology to a wider range of coals including existing coal preparation plant fine particle process streams and refuse recovery operations in addition to coal ranks from subbituminous to anthracite.

EI proposed development of a stabilized wetcake with properties that would facilitate storage, handling, transport, and subsequent conversion of the material into Coal-Water Fuel (CWF) at the point of use. The initial effort was directed toward the identification and evaluation of additives and formulations that would transform the wet cake into the stabilized intermediate fuel form. That form was originally envisioned to be a paste-like material. During the investigations, it was found that a granular form could be produced and this particular form had greater versatility and broader applications. Without any change in scope of the work, the emphasis was shifted and broadened to adapt to this granular form. Thus, the technical approach used in this project provided the flexibility to accommodate the new developments found in the investigations and specific objectives and test criteria were modified accordingly.

Phase I established the technical feasibility of stabilizing the fine coal "wetcake" in a form that can be readily handled and converted into a desired fuel form at the combustion site.

The preferred form of stabilized "wetcake" was a granular free flowing material with the moisture encapsulated with the fine coal particles. The product was termed Mulled Coal. Phase I results indicated that the Mulled Coal was not only suitable as a CWF intermediate, but also had potential as a solid fuel.

Separate individual reports have been prepared and issued for the Phase I and Phase II activities. These two reports are available to the public through the National Technical Information Service of the U. S. Department of Commerce, Springfield, Virginia (703)-487-4650. They are available to DOE and DOE contractors from the Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, TN 37831 or by phone at (615) 576-8401. The report numbers for acquisition purposes are provided below. These two reports have the same title and contract number identification as this report with the following additional identification:

Project Title: "MULLED COAL - A BENEFICIATED COAL FORM FOR USE AS A FUEL OR FUEL INTERMEDIATE"

Contract Number: DE-AC22-90PC90167

Phase I: Feasibility Studies October 1991 NTIS Number: DE92004847/XAB
Report Number: DOE/PC/90167-T4

Phase II: System Demonstration May 1992 NTIS Number: DE92018456/XAB
Report Number: DOE/PC/90167-T5

The key results and developments of Phase I and Phase II are summarized in the immediately following Sections 1.3 and 1.4. The Phase III activities are reported in the main body of this report.

1.3 Summary of Phase I Results

Phase I provided the technology base and established the technical feasibility of the concept. The information developed during Phase I provided a basis for design and implementation of a full scale test (Phase II).

Phase I results included:

- o Identification of additives that would produce a stabilized wetcake. Stabilized wetcakes were produced in varying types ranging from highly thixotropic gels to free-flowing/granular powders. All stabilized wetcakes retained the original moisture levels (20 to 50%) of the wetcake.
- o Selection of the granular form of the Milled Coal as the preferred form.
- o Preparation of granular mulls from a wide range of bituminous coals with particle sizes from 10 microns to >100 microns.
- o Indications that the granular mulls will lose moisture on standing or heating with little change in handling characteristics or appearance.
- o Indication that the granular mulls would resist rewetting.
- o Indications that freeze-thaw cycles or high ambient temperatures (<120 degrees F) had little effect on handling properties.
- o Indications that the granular mull could be readily converted into a Coal Water Fuel with conventional CWF additives.

The granular mull was the preferred form for the following reasons:

1. Consistency of handling characteristics over a range of moisture levels, coal particle sizes, and coals.
2. Lower reagent costs.
3. Potentially simpler storage, handling, and transportation system.

Also based on the results of Phase I activities, conceptual schemes for the handling, transportation and use of the granular mull were developed.

1.4 Summary of Phase II Results

The Phase II activities were to determine if the granular form of the mull would improve the ability to store and transport fine wet coal in barrel quantities and subsequently be used to prepare a usable fuel for combustion. They included:

1. Testing and evaluation of mixing and feeding equipment for the preparation of the mull and subsequent conversion of the mull into CWF.
2. Determination of the bulk flow properties of the mulls as a function of additive level, particle size, and moisture content on freshly prepared samples stored under different conditions.

3. A "full system" test in which barrel quantities of mull were prepared from a wetcake (derived from an advanced physical fine coal cleaning process) in a continuous process.

During the Phase II System Demonstration tasks, the results have confirmed the observations of Phase I, i.e.,

- o The granular Mulled Coal has handling characteristics compatible with existing solids handling equipment.
- o Open storage does not materially affect handling properties.
- o Aged samples will lose surface moisture and will not rewet upon subsequent exposure to rain.
- o Mulled Coal can be pneumatically transported and injected into the boiler with heated air without agglomeration.
- o Mulled Coal can be converted into CWF with an in-line processor.
- o CWF prepared from Mulled Coal in an in-line processor can be readily pumped and atomized.

2.0 PHASE III ACTIVITIES

2.1 Overview

Phase III expanded the technology base by identifying applications relating to a wider range of coals and existing coal streams from active coal wash plants and slurry pond recovery operations. The Phase III results included:

- o Development of bench procedures for evaluating handling properties of fine coal solids.
- o Establishing evaluation criteria of mulls prepared from various ranks of coal from conventional wash plants and slurry recovery operations.
- o Estimation of runoff/leaching characteristics of mulls in open storage.
- o Development of equipment circuitry for continuous processing of mulls on a commercial basis.
- o Preparation of capital and operating cost estimates for commercial operations.

2.2 Laboratory Protocol for Evaluation of Mulled Coal Products

In order to evaluate the effectiveness of the mulling process and formulation options, it was appropriate to develop tests for evaluation of the handling and storage properties of the Mulled Coal products. The various testing procedures and equipment that are used for assessing bulk solids and fine particulates were reviewed, and experimental procedures were set up for this purpose. Tests to measure the following parameters were established:

1. Equilibrium moisture
2. Angle of incipient repose
3. Angle of fall
4. Angle of slide
5. Dispersibility
6. Compactability
7. Uniformity

This testing and evaluation protocol was used to evaluate the various Mulled Coal products.

These tests were adopted in order to quantify the physical properties of "good" and "poor" mulls, in order to facilitate selection of mulling agents and to establish optimum concentrations.

2.2.1 Equilibrium Moisture

Objective: The rate of loss of moisture and the stabilized moisture levels for coal and coal mulls under passive conditions are important to estimate the storage characteristics and the need or the ability to dry the wet mulls.

Principle: The weighed sample is stored in a draft-free area at room temperature and weighed periodically until the weight is essentially constant.

Procedure: A sample of the material to be tested is poured into a tared 100 cm diameter Petri dish so as to overfill the dish. The excess material is screened off with a spatula to be even with the sides of the dish. The filled dish is then weighed to obtain the initial weight of the sample. The dish is stored in a draft-free area (not a hood). The sample and dish are weighed at time intervals of 2, 6, 24 and 48 hours and each 24 hour period thereafter until consecutive weighings agree within 0.2 gm (final sample weight) or a weight gain is observed. The sample should then be placed in an oven at 105°C for one hour, cooled in a dessicator and weighed to determine the total moisture. The moisture loss, the equilibrium moisture and the total moisture are calculated from the weight measurements.

$$\% \text{ Moisture Loss at Time, } t = \frac{(\text{Original Wt.} - \text{Wt. @ } t) \times 100}{\text{Original Sample Wt.}}$$

$$\% \text{ Total Moisture} = \frac{(\text{Original Sample Wt.} - \text{Oven Dried Wt.}) \times 100}{\text{Original Sample Wt.}}$$

$$\% \text{ Equilibrium Moisture} = \frac{(\text{Final Sample Wt.} - \text{Oven Dried Wt.}) \times 100}{\text{Final Sample Wt.}}$$

2.2.2 Angle of Repose

Objective: The angle of repose for solids is a direct indication of the flowability of materials and therefore an indicator of the internal friction and ease of transport of solid materials.

Principle: The angle of repose is the angle between the horizontal and the slope of a heap of material dropped from some elevation. For most purposes it can be defined as the constant angle to the horizontal assumed by a cone-like pile of the material.

Procedure: Approximately 150 grams of the material to be tested is poured from a 250 ml beaker from a height of seven inches onto a flat stainless steel tray. The angle as defined above is measured with the aid of a protractor and recorded. The measured value is reported as the angle in degrees.

2.2.3 Angle of Fall

Objective: The angle of fall is another, but more sensitive, indication of the flowability of the material. It is a measure of the response to a small impact force applied to a pile of the material.

Principle: A small jarring force is applied to the pile of material used for the angle of repose measurements and a new angle measured. No change in the angle of repose indicates high internal friction and lower flowability. The greater the difference between the angle of repose and the angle of fall the greater flowability the material has.

Procedure: After the angle of repose measurement is made an 111 gram weight is dropped from the top of the rod (7"), attached to the pan to jar the pile of material. The angle of repose is measured again and recorded. This angle is called the angle of fall. The smaller the angle of fall the more flowable is the material. The measured value is reported as the angle in degrees.

2.2.4 Angle of Slide

Objective: Angle of slide provides an indication of the material's flowability and is particularly useful in hopper and chute design.

Principle: The angle of slide is the angle at which a material will slide down a flat surface due to its own weight.

Procedure: Approximately 150 grams of the material is poured upon the flat surface of the stainless steel pan until a constant angle of repose is obtained. The pan is held rigid by the ring stand clamp until the required amount of material is on the pan. The clamp holding the pan is then loosened and the pan tilted slowly until the pile just moves. The pan is again clamped and the angle from the horizontal is measured with a protractor and recorded as the angle of incipient slide. The pan is again loosened and

the tilting of the pan is continued until the material gently slides from the pan. The pan is then clamped and the angle again measured. This angle is recorded as the angle of slide. The smaller the angle of slide the more flowable the material. The measured value is reported as the angle in degrees.

2.2.5 Dispersibility

Objective: The dispersibility measurement gives an indication of the flowability and/or floodability of the solid bulk material.

Principle: The dispersibility is determined estimating the amount weight loss of material that and falls outside of a given area when a weighed sample of the material is dropped from a given height to impact on a horizontal plate.

Procedure: To determine the dispersibility a simple apparatus is used. This consists of a 4-inch diameter plastic cylinder 13 inches long, supported vertically from a ring stand 4 inches above a 4-inch diameter watch glass. A 10 gram sample of the material is dropped "en masse" through the cylinder from a height of 24 inches above the watch glass. Material remaining on the watch glass is weighed. The difference is calculated as weight percent and dispersibility is reported as a percentage.

2.2.6 Compactability

Objective: Compactability is also another measure of flowability and is important for determining the storage and packing characteristics of materials.

Principle: The compactability is expressed as a percent difference between the loose and packed density of the material. The more compactable a material is, the less flowable it will be. Generally the borderline between free flowing and non free flowing material is a compactability of about 20%.

Procedure: First the material is poured through a 3/8" mesh screen, 8 inches in diameter into a tared bottom pan (also 8 inches in diameter) until it overflows. The screen is removed and the excess material screened off to be level with the weight of the material recorded. This is the loose weight of the material. The screen is replaced and additional material added until it overflows the screen. The screen lid is then put on and the assembly placed in a Tyler Ro-Tap testing sieve shaker for five minutes. The lid and screen are removed and, as before, the excess material screened off. The pan and contents are then weighed and the weight of the packed material recorded. The percent compactability is calculated from the measured weights of packed and loose material. The measurement is reported as a percentage.

2.3 Mulling of U.S. Coals

2.3.1 Coals Selected for Evaluation

Most of the work done in developing the Mulled Coal concept and formulation through the early activities of this project was done using the Upper Elkhorn #3 type of standard reference coal. It was important to determine the effectiveness of mulling on a representative set of U.S. coals. The coal resources of the U.S. were carefully reviewed and coals were selected to enable the evaluation of mulling on each of the major regions and types of coal available. Table 1 provides a listing of the coals selected and evaluated. Coal analyses for each of these coals are provided in Table 2, which includes proximate analysis, analysis for sulfur and heat content. The table also includes some key moisture and particle sizing data for the wet-cakes used to prepare the Mulled Coal samples for testing.

In earlier laboratory testing during the formulation evaluations of this contract several different coals were acceptably mulled and converted to coal-water fuels. From this evidence, it was clear that a wide range of coals could be mulled and slurried when the starting coal material was a deeply-cleaned and very fine particle coal (-325 mesh). Since the potential applications and interests in the Mulled Coal had broadened since that earlier work, it was decided that the evaluation of alternative coals should be more broadly based with regard to the particle sizing and ash level of the coal. Therefore, the initial testing in this task was done with particle sizes up to 28 mesh top size and mean diameter as large as 110 microns. After evaluation of the initial set of tests, some of the test results were inconsistent and the preparation of mulls was repeated using less mulling agent, smaller particles and added samples of coal.

The selected coals for initial evaluation were crushed and ground to a standardized size of -28 mesh (mean sizes ranging from about 50 to 110 microns) and wetted to provide a wetcake. The wetcake samples were then mulled in a pug mill in batch mode with the mulling agent added at a standard formulation amount of 2%. In some cases, moisture in the wet cake, the particle sizing or the amount of mulling agent was varied to improve the visible quality of the mulled product. Samples of the Mulled Coal products were then evaluated with the laboratory testing as described in Section 3.1.

Based on the results of the initial series of tests, additional test samples were prepared and evaluated. In concurrent work done under corporate sponsorship outside the scope of this contract, it had been noted that particle size and mineral matter content of the coal could significantly alter the quality of the mulled product. Therefore, the repeat tests in some cases used a smaller particle sizing of -100 mesh. The Pittsburgh #8 coal sample was compared with several other samples of Pittsburgh #8 and similar Upper Freeport coals from the northern Appalachian coal region. Where additional tests were performed, results in Table 3 are for the later samples.

2.3.2 Test Results

The first assessment of the mulling characteristics of a particular type of coal and the quality of the resulting mull was subjectively observed as the mull was prepared and the product collected. In the judgement of the

Table 1

ALTERNATIVE COALS

<u>Region/Type of Coal</u>	<u>Coal Name/Seam/Source</u>
Western Bituminous	Sunnyside seam and mine Utah
Western Subbituminous	Sarpy Creek - Rosebud-McKay Seam Absaloka Mine Westmoreland Resources Montana
Mid-Continent Basin	Washed Lower Block Miller Creek Mine Black Beauty Coal Co. Indiana
Anthracite	Lehigh Valley
Northern Appalachian	Pittsburgh #8
Central Appalachian/ High Volatile	Taggart blend 5-6% ash Wentz Mine and Preparation Plant Westmoreland Coal Company Virginia
Central Appalachian/ Low Volatile	Pocahontas/Sewell Virginia Crews Coal Company West Virginia

Table 2

COAL ANALYSIS FOR ALTERNATIVE COALS

Coal Type: State:	Bituminous				Subbitum Montana	Anthracite Pa
	VA	WVA	PA	Indiana	Utah	
PROXIMATE ANALYSIS						
As Received:						
% Moisture	2.35	0.38	N/A	6.75	1.60	2.99
% Ash	5.51	3.74	N/A	5.52	4.94	9.16
% Volatile	34.63	19.28	N/A	34.82	37.82	3.64
% Fixed Carbon	57.52	76.60	N/A	52.91	55.64	84.21
Dry Basis:						
% Ash	5.64	3.75	6.18	5.92	5.02	9.44
% Volatile	35.46	19.35	37.99	37.34	38.43	3.75
% Fixed Carbon	58.90	76.90	55.83	56.74	56.55	86.81
% Sulfur:						
As Received	0.61	0.68	N/A	0.78	0.49	0.60
Dry Basis	0.79	0.68	1.23	0.84	0.50	0.62
Heat Content (Btu/lb):						
As Received	14,238	15,022	N/A	12,916	13,948	12,921
Dry Basis	14,581	15,079	14,125	13,851	14,175	13,319
Moisture Ash Free	15,453	15,666	15,055	14,723	14,924	14,707

PHYSICAL PARAMETERS FOR MULLED COAL PREPARATION

PARTICLE SIZE DISTRIBUTION						
Top Size (microns)	124	740	124	249	124	352
MV diameter (microns)	22	48	21	31	24	112
WET CAKE MOISTURE LEVEL						
	31	21	25	37	29	25

Table 3

LABORATORY HANDLEABILITY CHARACTERISTIC TEST RESULTS
ALTERNATIVE COALS

Coal Type:	Bituminous					Subbitum			Anthracite
	VA	WVA	PA-1	PA-2	PA-3	Indiana	Utah	Montana	
State:									Pa
Angle of Repose *	43	37	39	32	41	43	37	43	39
Angle of Fall *	27	25	28	28	28	36	27	34	33
Incipient Slide *	22	23	19	31	20	17	20	30	14
Angle of Slide *	40	46	40	44	43	46	38	53	24
Dispersability **	11	9	7	3	8	11	3	40	9
Compactability **	20	39	31	49	23	19	21	10	(***)
Uniformity **	9	3	6	3	2	23	7	85	(***)
+ 6M	15	5	19	6	14	42	14	15	(***)
6x14M	10	7	18	29	14	30	15	0	(***)
14x30M	66	84	57	62	70	5	63	0	(***)
-30M									
Percent Ash	6	4	6	8	N/A	6	5	10	9
Percent Moisture	31	21	25	25	31	37	29	34	25
Top Size (microns)	124	740	124	704	88	249	124	249	352
Mean Size (microns)	22	48	21	179	16	31	24	36	112

PA-1 = Pittsburgh #8, Consolidation Coal, Bailey Mine

PA-2 = Pittsburgh #8, Eastern Coal, Federal Mine #2

PA-3 = Upper Freeport, Penelec, Homer City

(*) The angles of repose, fall, incipient slide and slide are reported in degrees.
 (**) Dispersability, compactability, and uniformity are reported as percentages.
 (***) Data not available for anthracite - insufficient sample size

technical staff, all of the tested coals were capable of being mulled to an acceptable quality level. Some differences were noted in that the mulls prepared from the lower rank coals were not of the same quality as those prepared from the higher rank coals. In particular, the subbituminous coal was noted to be very difficult to convert into an acceptable mull at the larger particle size. It appeared to be wet and clumpy, but the measured characteristics showed a considerable improvement in handling properties. The further testing done with reduced particle size produced a far better mulled coal product and those data are shown in Table 3. Further, the Illinois Basin (Indiana) and Pittsburgh seam coals both exhibited a tendency to create little gummy balls in the Mulled Coal form for the larger particle sizes. While the mulling process converted these wetcake samples into materials that are readily handleable in bulk equipment, they did not exhibit the uniformity measurements and fine granular-like characteristics of the other coals. These samples were repeat tested with reduced particle sizes. In addition, the northern Appalachian coals are of particularly wide interest and variation in coal properties, so other samples of the type were tested and reported in Table 3. The one sample was a commercially cleaned product with lower ash and sulfur contents. Another was taken from a plant fine coal waste stream.

Each of the mulls that was prepared in the lab for the various coals was tested and the results are reported in Table 3. The initial test sample of the subbituminous coal from the Absaloka Mine (with a larger particle size) had slightly lower values for the angles of repose, fall, slide, incipient slide and a higher dispersibility. All of these are indications that this particular coal did not handle as well as the others even after the mulling process. Initially, uniformity test data could not be measured for the subbituminous coal sample as the wet, clumpy or gummy nature of the mulled version clogged the test equipment. The improved results found when the reduced particle sizing was used are shown in Table 3.

The initial samples of the Illinois Basin coal (the Lower Block coal from Indiana), western bituminous coal (Sunnyside from Utah), and anthracite coal (Lehigh Valley) all exhibited some of the same tendencies in the measured test results as noted above for the subbituminous coal, but to a lesser extent. The results indicate that all of these coals can be mulled to effectively improve the handling characteristics. The measured test results for the uniformity test for the Pittsburgh seam and Lower Block (Indiana) coals showed notably different size distributions than was typical of the better quality mulls. The uniformity data showed that 98% of the Mulled Coal for the initial samples of Pittsburgh and Lower Block coals was greater than 14 mesh in size, while other coals generally had in excess of 90 weight % of the sample less than 14 mesh. Again, the 100 mesh particle size significantly improved the measured handling characteristic test results that are presented in Table 3. These results show at least 75% of the sample less than 14 mesh for the northern Appalachian type coals (Pittsburgh and Upper Freeport) and 35% less than 14 mesh for the Lower Block (Indiana) coal.

2.4 Effect of Beneficiation on Mulling

2.4.1 Coals Selected for Evaluation

One of the major potential application areas for the Mulled Coal technology is the treatment of the wet fine coal product derived from advanced deep cleaning processes. To attain the deep cleaning reduction of sulfur or ash, the coal is typically ground to a very fine size (e.g., less than 325 mesh) to release the pyrite and other mineral matter and enable the separation from the coal through a water based wet processing method such as flotation or agglomeration. These wet fine coal products can vary considerably in ash content, particle sizing, and retained moisture depending on the level of deep cleaning that is desired and designed for the process. This part of the effort was intended to determine if there would be any noticeable effects of the cleaning process on the effectiveness of the mulling of the coal when considering the particle sizing, ash content and moisture levels.

EI had previous experience with deep-cleaning two of the candidate coals. This background afforded a basis for providing cleaned wetcake products for mulling evaluations. The Upper Elkhorn #3 and Lower Block coals had been cleaned at Virginia Tech in their microbubble column flotation system and the release curves (ash reduction vs. yield) had been characterized. Most of the work in earlier phases of this contract was done with Upper Elkhorn #3 coal that had been cleaned to 1.5 to 2% ash by heavy media separation processing at CQ, Inc. as well as at Virginia Tech. For this task, it was decided to use the commercial specification Upper Elkhorn #3 type of coal produced at the Wentz Preparation Plant source previously used for the other cleaning samples. This Upper Elkhorn #3 coal had an ash level of less than 6%. This enabled the evaluation of the original parent source coal, two cleaned products at coarse and fine grinds, and the fine product refuse. The increase in ash level in the refuse product is not excessive. It still could be converted into a useable product by mulling. Evaluating the mulling characteristics would also provide experience with mulling a product with higher levels of ash. Therefore, the Upper Elkhorn #3 and Lower Block coals were selected for testing the effects of coal cleaning.

2.4.2 Test Procedures

Several drums of these two coals were obtained from the Wentz Preparation Plant and the Miller Creek Mine. The coals were sent to Virginia Tech for cleaning. Each of the coals were ground to two different sizings (a coarse grind and a fine grind) and then were cleaned in the microbubble column flotation cell. The dilute coal products in a water stream were then processed in a centrifuge to concentrate the solid clean coal particles to approximately 50% solids and 50% water for delivery to EI's facilities. A portion of the refuse fines from the cleaning process was collected and retained during the cleaning of the Upper Elkhorn #3 coal.

The coarse and fine grind clean coal products from Virginia Tech and the refuse fines were all produced as dilute coal-in-water streams and were concentrated in the centrifuge to produce a wetcake. These wetcakes were very difficult to handle and tended to pack in the drums during the transportation to EI, with a layer of water accumulating at the top surface of the coal. Mulled coals were made at EI from these wetcakes for all of the

clean and refuse samples. The parent coals were ground to the appropriate size and water was added to simulate wetcake. The mulls were then made from the wetcakes.

The Upper Elkhorn #3 and Lower Block parent coals, the two cleaned coals at coarse and fine sizes, and the Upper Elkhorn #3 refuse products were analyzed and evaluated in EI's lab facilities. Each of the samples were mulled using the standard mulling formulation and processing conditions. The handling characteristics were then determined. The coal analysis and particle size information for each of these samples are provided in Table 4 and the measured handling properties are in Table 5.

2.4.3 Results

The test results in Table 5 show that all of the samples could be mulled to produce readily handleable materials. The differences in the measured properties are relatively small. The dispersibility of the cleaned products was in each case less than the parent coal sample. The uniformity of Lower Block (Indiana) coal showed a high percentage (98%) over 14 mesh for the parent coal. This had also been noted in the section evaluating the alternative coal types. However, when the Lower Block coal was cleaned, the measured uniformity results were consistent with the other good quality mulls. The results in Table 5 are, to some extent, related to the particle size of the coal sample. This can be particularly seen in the uniformity data where the percent of less than 30 mesh material decreases as the mean particle size decreases. That tendency is less notable for the Lower Block coal, but nevertheless the finer cleaned coal is comprised of size fractions that are similar to the Upper Elkhorn coal. The major difference is in the starting parent coals which have significantly different size uniformity characteristics.

Table 4

COAL ANALYSIS FOR PARENT AND DEEP-CLEANED COALS

Coal Name:	Parent	Upper Elkhorn #3	Fine Refuse	Parent	Lower Block	Fine
Level of Cleaning:	Coarse Cleaned	Fine Cleaned		Coarse Cleaned	Coarse Cleaned	Cleaned
PROXIMATE ANALYSIS						
As Received:						
% Moisture	24.20	25.50	46.39	34.33	43.40	52.35
% Ash	4.28	2.51	1.14	3.89	1.06	0.83
% Volatile	26.88	27.33	20.82	24.52	21.16	18.88
% Fixed Carbon	44.65	44.66	31.66	37.26	34.38	27.93
Dry Basis:						
% Ash	5.64	3.37	2.12	5.92	1.88	1.75
% Volatile	35.46	36.68	38.83	37.34	37.38	39.63
% Fixed Carbon	58.90	59.95	59.05	56.74	60.74	58.62
% Sulfur:						
As Received	0.61	0.59	0.40	0.78	0.50	0.51
Dry Basis	0.79	0.79	0.75	0.84	0.51	0.52
Heat Content (Btu/lb):						
As Received	11,052	10,948	7,859	12,916	14,085	14,136
Dry Basis	14,581	14,695	14,660	13,851	14,256	14,300
Moisture Ash Free	15,453	15,207	14,978	14,723	14,529	14,555
PARTICLE SIZE DISTRIBUTION						
Top Size (microns)	352	352	31	704	249	88
MV diameter (microns)	61	48	9	109	27	13

NOTE: As Received Analysis is reported for wetcake used for Milled Coal preparation

Table 5

LABORATORY HANDLEABILITY CHARACTERISTIC TEST RESULTS
DEEPLY-CLEANED COALS

Coal Name: Level of Cleaning:	Parent Coal		Upper Elkhorn #3		Fine Refuse		Parent Coal		Lower Block	
	Coarse Cleaned	Fine Cleaned	Coarse Cleaned	Fine Cleaned	Coarse Cleaned	Fine Cleaned	Coarse Cleaned	Fine Cleaned	Coarse Cleaned	Fine Cleaned
Angle of Repose *	39	40	40	40	38	33	33	30	42	42
Angle of Fall *	30	30	29	21	23	26	21	22	27	27
Incipient Slide *	23	22	27	23	45	49	43	44	23	23
Angle of Slide *	49	40	51	32	17	17	9	6	35	35
Dispersability **	12	3	7	23	48	48	17	17	6	6
Compactability **	49	48	29	23	57	57	2	2	0	0
Uniformity **	0	3	7	3	9	41	11	11	10	10
+ 6M	2	8	16	9	14	1	13	13	14	14
6x14M	9	8	12	72	72	0	72	72	74	74
14x30M	88	79	63							
-30M										

(*) The angles of repose, fall, incipient slide and slide are reported in degrees.
 (**) Dispersability, compactability, and uniformity are reported as percentages.

2.5 Leaching Studies

2.5.1 Background

When coal fines are stored in open piles and exposed to rain, several effects can be anticipated.

1. When rain hits the dry surface, plumes of coal dust will rise and be carried off in the wind resulting in particulate emissions in the air. This will continue until the coal surface is saturated. This is a special problem for storage of fines by themselves or in high concentrations.
2. As the rain water flows through the storage pile, coal fines will be carried with the water away from the pile creating a groundwater suspended solids problem. The very fine dust will be found as a scum on the surface of the water with the problem continuing as additional coal fines are generated during storage and handling due to attrition of the coarser fractions.
3. The wet coal pile will retain an inventory of surface moisture which is in intimate contact with the coal and mineral matter resulting in leaching of the slightly soluble components found in the pile and generated during exposure to oxygen and moisture. This is the mechanics for acid runoff of high sulfur coals during storage.

Since the mulling agent is organic in nature, and classified as a criteria pollutant, organic carbon, it is important to estimate the effect of open storage on groundwater contamination.

2.5.2 Test Procedures

A slanted board apparatus with run-off collection drains was set up in the laboratory to conduct these run-off leaching studies. Two separate drainage boards were used to accommodate two coal samples for testing at the same time. One coal sample was the Mulled Coal product and the other was the dried wet filter cake parent of the particular Mulled Coal. The coal used was the Upper Elkhorn #3 coal that had been cleaned in the microbubble flotation column at Virginia Tech. The wet filter cake was mulled to provide the one sample. The other sample of wet filter cake was dried to a moisture level of 10% to represent the coal fines that might be found in a commercial coal pile after having been thermally dried and then included with the commercial product of the preparation plant. The samples had a particle size distribution with a top size of 352 microns and a mean size of 61 microns prior to mulling.

A five gallon bucket sample of each test material was up-ended onto the slanted board device to create a pile that was approximately 1.5 feet in diameter. The piles were then sprayed with water for a period of five minutes. The water collected during the period of spraying was then removed and the collection vessel was then replaced. The continuing drainage run-off was then collected for a period of five minutes following the completion of the spraying. The wetted coal piles were then left dormant for a period of two days and then the test procedure was repeated. This procedure was then

repeated for a second dormant period of two days, so that the total test period was five days with a total of three test sprays.

The retained samples were then tested to determine both the total quantity of coal fines collected and the weight percentage of coal fines in the collected sample. The samples were filtered and dried to determine the dry weight of the coal collected in these run-off samples. The liquid filtrate was then analyzed for total organic carbon content (TOC) of the sample as a measure of the hydrocarbon material removed during the drainage period. The data collected from the leaching study tests are shown in Table 6.

2.5.3 Results

The results of these tests display impressive advantages of the Mulled Coal over the dried filter cake material. The results consist of both subjective observations and the data reported in Table 6. When the tests were conducted, two observations were immediately noted. First, there was a significant plume of fine coal particles that rose from the dried filter cake material as soon as the water spray hit the pile. The particulate plume from the Mulled Coal was barely visible. After the spraying was completed, the Mulled Coal pile retained its original shape and appearance and did not appear to be wetted. In contrast, the dried coal pile was distorted in shape, losing all semblance of a conical pile, pitted and cratered, and a wet mess.

The above test data indicates the following:

- o In all test data sets, the Mulled Coal lost less fine coal by washing than did the parent, by a factor of 10 to 20.
- o The TOC content of the Mulled Coal filtrate was no more, and, in most cases, less than for the parent coal.
- o The TOC content of the filtrate samples generally decreased over the life of the test.

The results are consistent with the hypothesis that the Mulled Coal agglomeration binds the ultra fine coal particles together preventing their loss by drainage. Further, the mulling agent does not seem to be susceptible to leaching by the water. The eluded TOC seen in the untreated coal could be due largely to colloidal coal particles drained from the untreated coal.

Table 6

LEACHING AND COALPILE RUN-OFF STUDIES

	<u>Mulled Coal</u>		<u>Dry Pulverized Coal</u>	
	<u>Wt. % Coal</u>	<u>TOC</u>	<u>Wt. % Coal</u>	<u>TOC</u>
<u>TEST #1</u>				
A--While Spraying	0.51	3.2	12.89	3.2
B--After Spraying	0.28	2.9	8.19	6.4
<u>TEST #2</u>				
A--While Spraying	1.61	2.2	20.56	2.1
B--After Spraying	0.21	1.8	4.70	3.6
<u>TEST #3</u>				
A--While Spraying	1.72	1.3	14.49	1.3
B--After Spraying	0.20	1.7	6.54	2.2

2.6 Equipment Circuitry

2.6.1 Background

Converting wetcake to Mulled Coal is accomplished with a circuit which consists of a reagent delivery system, low energy mixing equipment and a control device which is used to meter reagent into the circuit in a precise ratio to the amount of dry coal contained in the feed. Component design and costs are determined by capacity requirements, the nature of the wetcake feed and targeted handling characteristics of the end product. System and installation costs are influenced by whether the circuit represents only a simple addition to an existing plant circuit or whether it is to be a stand alone project with structure and coal handling facilities designed specifically for the Mulled Coal circuit.

Figure 1 is a schematic diagram showing the general arrangement of major components of the Mulled Coal circuit. The following pages describe design considerations and projected costs for various capacities and applications of the circuit.

2.6.2 Volumetric Screw Feeder

Wetcake is collected and fed to the circuit from a surge hopper/volumetric screw feeder. This piece of equipment may or may not be required depending upon how wetcake is mechanically dewatered ahead of the Mulled Coal circuit. If wetcake is mechanically dewatered in filters or other equipment with intermittent cake discharge cycles, then a screw feeder and hopper are required to level out feed to the circuit. Descriptive information for a typical feeder design is provided in Figure 2.

The surge feeder presents a design challenge because it must mechanically overcome all of the negative handling characteristics which the circuit eventually eliminates. The surge hopper is designed to hold one minute of rated system capacity which would adequately span the intermittent range of any cake discharge cycle. All valley angles within the feeder exceed 75°. The bottom of the surge hopper is equipped with a specially designed large diameter intermediate auger which prevents bridging and provides an induced positive flow to the final feed device, which is an open auger operating in a close-tolerance tube. The feed augers are provided with infinitely variable DC drives, and feed rates are available from 0 to 125% of rated capacity.

2.6.3 Mixing Machine

The primary process component is a double paddle mixer. The machine has a lined horizontal mixing chamber which has a working capacity of between 1.0 and 1.5 cu ft for each ton per hour fed to the circuit. Running the length of the mixing chamber are two parallel, counter rotating stainless steel shafts which are provided with a set of overlapping and adjustable stainless steel mixing paddles. The double paddle mixer design and dimensions are shown in Figure 3.

Untreated wetcake is dropped by gravity into the feed end of the mixing chamber. Reagent, which is pumped to the circuit under pressure, is applied to the wetcake in the first quarter of the chamber through a series

Figure 1

MULLED COAL PROCESS CIRCUIT
Schematic Diagram

Figure 2

SURGE HOPPER/VOLUMETRIC FEEDER

Rated Capacity (TPH)	50	75	100
Surge Capacity (Tons)	3	5	8
Feed Rate Available (TPH)	75	100	125
Overall Length (L)	10'-0"	12'-0"	12'-0"
Overall Height (H)	4'-0"	5'-0"	7'-0"
Hopper Size (AxBxC - Cubic Feet)	128	192	320
Horsepower Rating (HP)	20	30	40

Figure 3

DOUBLE PADDLE MIXER

Rated Capacity (TPH)	50	75	100
Mixing Chamber			
Length (L-Feet)	10	10	10
Width (W-Inches)	44	56	66
Height (H-Inches)	32	38	42
Drive End (X-Inches)	48	54	60
Discharge End (Y-Inches)	18	24	28
Overall Height (Z-Inches)	54	56	58
Horsepower (HP)	50	75	100

of two or three fan spray nozzles. As the wetcake moves down the mixing chamber it is gently, but thoroughly, blended with and coated by the reagent. By the time the material has reached the fourth quarter of the chamber, it has undergone a change of consistency into free flowing Mulled Coal. At the down stream end of the chamber, Mulled Coal flows over an adjustable weir and is discharged by gravity through a chute.

Depending on the nature of the wetcake and targeted Mulled Coal handling characteristics, retention time in the mixing chamber is between 1.5 and 2.25 minutes. Retention time and mixing action are adjusted by changing shaft speed, saddle angles and the weir opening.

2.6.4 Reagent Delivery System

The reagent storage and delivery system (shown in Figure 4) consists of a main, outside storage tank which should hold a minimum of one week of projected reagent usage at full production rates, a surge tank with storage capacity for about one shift running time, a pump to periodically charge the surge tank, and a metering pump capable of delivering reagent to the circuit at demand volume and pressure. The process works best when reagent is applied in fine droplets under moderate pressure.

2.6.5 Control Circuit

Circuit controls are designed to meter a preset volume of reagent to the circuit based upon the amount of dry coal and free moisture in the wet cake feed. Desired Mulled Coal handling characteristics can be achieved and continuously maintained with a minimum dosage of reagent, in spite of the relatively wide variations in volume and surface moisture which are typical in some fine coal preparation circuits.

A typical control circuit diagram is shown in Figure 5. The principal components of the control circuit are:

- Variable speed controls on the surge feeder auger
- Continuous belt scale
- On line moisture analyzer
- Variable speed controls on positive displacement reagent pump
- On line reagent flow meter
- Variable speed controls on paddle mixer shafts
- PLC

Output signals from the belt scale and moisture probe provide rate data to the PLC which controls feed auger speed, reagent flow and paddle mixer speed. The reagent flow meter provides a positive indication that reagent is entering the circuit in desired amounts, and keeps a running inventory of reagent in storage. Integrating paddle mixer speed controls in the circuit ensures that the varying wetcake feeds are exposed to an optimum retention time in the mixing chamber.

The control circuit can be installed with proven reliable electronics which have been used successfully in coal preparation plant environments for a number of years. The circuit is sophisticated and expensive, and it is designed primarily to closely control reagent costs under varying feed conditions. Reagent costs normally account for over 80% of the total cost of operating a Mulled Coal circuit.

Where wetcake feed conditions vary, and target Mulled Coal characteristics are critical, the control circuit is essential for efficient operation. However, where feed conditions are not expected to vary, and where Mulled Coal characteristics are less critical, the control circuit as described represents "overkill", and a much simpler and less expensive system can be used.

Figure 4

REAGENT DELIVERY SYSTEM

Rated Capacity (TPH)	50	75	100
Main Storage Tank (Gal.)	18,000	27,000	36,000
Surge Tank (Gal.)	1,200	1,800	2,400
Charge Pump (GPH)	40	60	80
Metering Pump (GPN)	1-6	2-8	3-11

Figure 5

CONTROL CIRCUIT DIAGRAM

2.7 Cost Estimates

2.7.1 Background for Costing

In order to facilitate comparisons of various intermediate fuel forms, DOE has offered guidelines for estimating capital and operating costs for systems which begin with the acceptance of beneficiated coal at the preparation plant and end after the conversion to a CWF at an end user facility.

Suggested guidelines include:

1. Process facilities with capacities of 50, 250 and 1000 tons per day should be considered.
2. End users are located an average distance of 50 miles from the 50 and 250 tons per day plants and 100 miles from the 1000 tons per day plant.
3. Capital costs should include equipment needed by both the producer and end user.
4. Standard multipliers are furnished for estimating capital and operating costs.

The following pages contain capital and operating costs which have been estimated in accordance with DOE guidelines. Several exceptions to the guidelines have been taken to be suitable for the specific nature of Milled Coal and those exceptions are noted in the discussions and tables.

The primary reason for conversion to Milled Coal is to avert the storage and handling problems of the fine particle wetcake and therefore the mulling circuit will most reasonably be directly inserted and integrated into the existing preparation plant circuit. This can be done either by (1) a separately housed Milled Coal circuit immediately adjacent to the existing facility and integrally connected, or (2) insertion of the Milled Coal circuit into the existing facility so that it is not a stand-alone circuit. In either case, the circuit and equipment will be designed, installed, and costed as a package unit and will utilize existing infrastructure and operating labor.

The primary influence on the capital cost for installing a Milled Coal circuit is not the capacity of the equipment. As with most coal preparation circuits, especially retrofitted circuits, capital cost is most heavily influenced by the specific application for the circuit and the extent of auxiliary facilities needed to support the circuit.

When a Milled Coal circuit is to be retrofitted to an existing preparation plant, and its intended use is to condition the dewatered product of a 100M x 0 recovery circuit, it can usually be fitted into the existing plant structure.

There will be isolated cases where there is not enough room for the circuit in an existing plant building. In such cases, a small addition must be constructed to house all or part of the components of the Muddled Coal circuit.

A distinctly different case arises when the Muddled Coal circuit will stand alone (not part of an integrated preparation plant) on a new project. The intended application of the circuit might be to condition material recovered from a slurry pond for feed to a boiler. In this case, coal handling facilities and a plant building must be constructed solely for the purpose of supporting the Muddled Coal circuit.

The Muddled Coal intermediate fuel product will be shipped in conventional hauling equipment from the preparation plant site directly to the site of the end user. Such haulage would typically be by trucks for small quantities and rail cars for very large users. An intermediate central conversion site for multiple users is not as suitable for a Muddled Coal based system as it might be for a conventional coal-water fuel. It is anticipated that conversion to CWF will be accomplished at the existing user facility and it will share the infrastructure and operating labor.

2.7.2 Capital Costs

Following the DOE guidelines, the capital costs for intermediate fuel production plants are calculated as if these facilities are entirely separated from coal preparation plants, and have their own plant buildings, coal handling and support facilities. This may be an appropriate method of comparing costs, but in practice, intermediate fuel production circuits would most likely be included within the preparation plant building, and capital costs would be significantly less than costs calculated within these guidelines. This is especially true with respect to the Muddled Coal circuit since it has only three small process components which can be configured in a relatively small space. For our estimates, the Muddled Coal preparation facility has been costed as if it is a wholly separated facility immediately adjacent and interconnected with the existing preparation plant.

Capital costs for end user coal storage and CWF conversion facilities have been calculated with the guideline multipliers. However, the Muddled Coal storage and slurrying facilities are very simple and would cost less since the multipliers are more appropriate for integrated plants with extensive support facilities. The capital cost estimates for various sized Muddled Coal plants are shown in Table 7.

2.7.3 Operating Costs

In accordance with the guidelines, labor costs are to be calculated as if Muddled Coal is produced at a separate plant with a separate labor force dedicated only to the Muddled Coal circuit. This would yield a grossly distorted operating cost for the 50 tons per day and 250 tons per day plants. It requires only one man per shift working at partial work load to operate Muddled Coal circuits up to 200 TPH of capacity. Since most of the operating cost multipliers are a function of operating labor, operating costs are distorted at low capacities where labor is not fully utilized.

Table 7

CAPITAL COSTS
MULLED COAL PROCESSING PLANTS

Daily Plant Capacity (Tons)*	50	250	1000
Circuit Capacity (Tons per Hour)	4	20	75
Operating Hours per Day	16	16	16
Operating Hours per Year	200	200	200
Annual Production (Tons)	10,000	50,000	200,000
 Purchased Equipment Costs			
Double Paddle Mixer	\$ 30,000	\$ 40,000	\$ 60,000
Surge Feeder	12,000	15,000	20,000
Weighbelt	8,000	12,000	15,000
Reagent Tanks	5,000	10,000	20,000
	<u>55,000</u>	<u>77,000</u>	<u>115,000</u>
 Direct Cost Items			
Equipment Inst. @ 30% of PE	16,500	23,100	34,500
Inst. & Controls @ 13% of PE	7,150	10,010	14,950
Piping @ 31% of PE	17,050	23,870	35,650
Electrical @ 10% of PE	5,500	7,700	11,500
Building @ 29% of PE	15,950	22,330	33,350
Yard & Imp. @ 10% of PE	5,500	7,700	11,500
Service Facilities @ 35% of PE	19,250	26,950	40,250
	<u>86,900</u>	<u>121,660</u>	<u>181,700</u>
 Indirect Cost Items			
Engr. & Super. @ 32% of PE	17,600	24,640	36,800
Construction Exp. @ 34% of PE	18,700	26,180	39,100
	<u>36,300</u>	<u>50,820</u>	<u>75,900</u>
 Other			
Contractors Fees @ 5% of D+ID	6,160	8,624	12,880
Contingencies @ 10% of D+ID	12,320	17,248	25,760
Working Capital @ 74% of PE	40,700	56,980	85,100
Startup Cost @ 50% of PE	27,500	38,500	57,500
	<u>86,680</u>	<u>121,352</u>	<u>181,240</u>
 Total Fixed Capital Investment	\$264,880	\$370,832	\$553,840

*Tons of wet coal

There is a significant difference in operating labor costs for an integrated circuit versus a stand alone circuit. In the integrated plant, there is usually an operator working in the vicinity of fine coal dewatering equipment who would have time to periodically check the operation of the Mulled Coal Circuit and perform routine maintenance. In a two shift operation, it is estimated that an equivalent of one person at 50% work load rate would be required to operate and maintain the Mulled Coal circuit. This provides the basis for our labor cost estimates for the large scale plant (1000 TPD). We have used lesser work loading rates for the smaller plants (25% and 35%) on a similar basis. To the contrary, however, in a stand alone circuit, at least two men must work full time for each shift of plant operation (one man to feed wetcake into the plant and operate stockpile facilities, and one man to operate the plant).

In practice, these intermediate fuel production circuits would be manned by preparation plant personnel with other duties, and the costs assigned to the circuit would be far less than one man per shift - even in the case of the 1000 TPD capacity.

In our cost estimates, we have taken exception with the DOE guidelines and chosen to assign staffing at partial work load rates of 25%, 35%, and 50% for the three different sized plants. This moderates the distortion in labor based costing that would otherwise be expected when estimating by these guidelines.

The operating cost estimates for production of Mulled Coal are shown in Table 8 for the assumption of 35% wetcake feed material. Mulled Coal can be produced from the wetcake for \$3 to \$5 per ton on a wet coal basis in plants in the commercial size range of 250 to 1000 tons per day. This corresponds to cost levels of \$5 to \$8 per dry ton of coal or \$0.15 to \$0.30 per million Btu as shown in the summary costs in Table 11.

In this estimate, it can be seen that the cost of the reagent for mulling constitutes a major component of the total cost in the larger sized operations. In the smaller size plants, the direct labor costs and the labor based items determined through multipliers tend to dominate the cost structure. However, at the larger sizes where economy of scale and effective labor utilization are achieved, the labor based component of cost is reduced to less than 20% and the reagent cost represents around 70% of the total costs. For these estimates, a reagent addition level of 1% has been assumed for costing purposes. In earlier phases of this project, it was found that the required reagent level can vary from 0.5 to 3%. We have found that the reagent level of 1% is typical for the better quality mulls prepared in continuous, well mixed processing units, so we have used this as a costing basis.

2.7.4 CWF Conversion Plant Costs

CWF conversion plants will not necessarily operate at the same daily capacity as the Mulled Coal production plant. There are not significant economies of scale in operating the CWF conversion plant, because over 75% of the cost of operating the plant is additive (dispersant) cost.

TABLE 8
MULLED COAL PROCESSING PLANTS
(Operating Costs)

	50	250	1000
DAILY PLANT CAPACITY (Tons of Wet Coal)	50	250	1000
CIRCUIT CAPACITY (Tons of Wet Coal/Hr.)	4	20	75
OPERATING HOURS PER DAY	16	16	16
OPERATING DAYS PER YEAR	200	200	200
ANNUAL OPERATING COSTS:			
Additive Cost (@ 1% Dosage)	21604	108020	432081
Utilities (Power)	6000	7000	14000
	27604	115020	446081
Labor			
Operating @ \$30.00/Hr.	24000	33600	48000
Maintenance @ 3% OF FCI	7946	11125	16615
Supervision @ 15% Operating	3600	5040	7200
	35546	49765	71815
Materials			
Operating Supplies @ 15% Operating Labor	3600	5040	7200
Maintenance Supplies @ 4% of FCI	10595	14833	22154
Laboratory Services @ 15% Operating Labor	3600	5040	7200
	17795	24913	36554
Plant Overhead @ 60% of labor	21328	29859	43089
Local Taxes & Insurance @ 1.5% of FCI	3973	5562	8308
Depreciation @ 8% of FCI	21190	29667	44307
TOTAL COST	127437	254786	650154
	12.74	5.10	3.25

- Notes: 1. Assumed moisture percent in wet cake and Mulled Coal = 35
2. Assumed percentage of operating labor time needed for Mulled Coal plant operation
50 tpd plant	=	25
250 tpd plant	=	35
1000 tpd plant	=	50

Table 9

CAPITAL COSTS
MULLED COAL CONVERSION TO CWF

Daily Plant Capacity (Tons of CWF)	50	250
Circuit Capacity (Tons per Hour)	3	16
Operating Hours per Day	16	16
Operating Days per Year	250	250
Annual Production (Tons of CWF)	12,500	62,500
Purchased Equipment Costs	\$40,000	\$110,000
Direct Cost Items		
Included in Packaged Unit Purchase Equipment		
Indirect Cost Items		
Engr. & Supervision @ 30% of PE	12,800	35,200
Construction Exp. @ 34% of PE	<u>13,600</u>	<u>37,400</u>
	\$26,400	\$72,600
Other Costs		
Contractors Fees @ 5% of PE+ID	3,320	9,130
Contingencies @ 10% of PE+ID	<u>6,640</u>	<u>18,260</u>
	\$ 9,960	\$27,390
Total Fixed Capital Investment	\$ 76,360	\$209,990

Estimating Basis:

1. 50 TPD plant -- 1 mulling unit at \$30,000 + \$10,000 other
2. 250 TPD plant -- 3 mulling units at \$30,000 each + \$20,000

For our estimates of the capital costs of the Milled Coal-to-CWF conversion circuit, we have chosen to include the direct cost items as a part of the purchased equipment package with the expectation that such direct items will be either directly a part of the package or will be modifications to the existing systems. Therefore, the cost multipliers for direct costs are not appropriate for the Milled-to-CWF conversion plant. Our estimates of the capital costs required for the Milled-to-CWF conversion plant are shown in Table 9.

CWF conversion costs are calculated only on the basis of 50 and 250 tons per day. We assume that a 50 ton per day Milled Coal plant would be installed only to feed a CWF conversion plant of similar capacity. The larger Milled Coal plants (250 and 1000 TPD) would more likely deliver product to several individual user facilities of the 50 to 250 TPD size range. These costs are added to the 50, 250 and 1000 TPD Milled Coal production costs.

The estimates of operating costs for conversion of the Milled Coal to CWF of 65% solids loadings are shown in Table 10. The major component of the costs is the reagent additives to prepare the CWF (dispersant). Preparing the CWF at the user facility immediately prior to consumption saves the costs associated with stabilizing chemicals and mixing requirements during storage.

2.7.5 Transportation Costs

DOE guidelines indicate transportation distances of 10, 50, 100 and 300 miles. Transportation costs for a distance of 100 miles was selected for comparisons. Truck haulage is the selected mode of transportation because the small tonnages could not be shipped conveniently by rail, with the possible exception of shipments for a very large user, such as a 1000 ton per day.

Truck transportation costs are based on a standard loading charge of \$0.75 per ton and a mileage charge of \$0.07 per ton mile.

2.7.6 Delivered Product Costs

Estimates of the delivered Milled Coal and converted CWF fuel product costs are presented in Table 11. The cost estimates for conversion of wet fines to a mull and transportation to a user facility are shown in the top portion of the table. It is evident that the transportation costs for the product significantly exceed the production costs for preparation of the Milled Coal for the larger sized processing facilities. The reverse is true in the smallest sized production plants. In turn, both of these cost elements are considerably less than the cost of tonnage quantities of coal available through conventional sources which typically can be in the range of \$20 to \$40 per ton. The cost estimates have not explicitly included the cost of the coal feed to the Milled Coal circuit, as that can vary considerably depending on whether the feed material is a deeply cleaned fine coal product of an advanced coal cleaning process or whether the feed material is obtained as an otherwise wasted refuse stream of coal fines from a conventional plant. The important point to note is that the incremental costs of preparing Milled Coal is likely to be only a few dollars per ton of neat Milled Coal product (100% Milled Coal). This incremental cost will be offset by combining the fines with the full product stream and by the rest of the other costs of mining, coal preparation and transportation.

The costs estimated for conversion of the Mulled Coal to a coal-water fuel (CWF) are exhibited on the lower part of Table 11 and are shown to be competitive with production costs for other methods of CWF preparation. In summary, conversion of coal fines in wetcake form to a Mulled Coal product can enable these fines to be a usable fuel product in the following three forms at the incremental cost ranges shown below:

Neat Mulled Coal	\$3 to \$5 per wet ton \$5 to \$8 per dry ton
Blended Mulled Coal at 25% or less with coarse coal	\$0.75 to \$1.25 per ton
Mulled Coal delivered and converted to coal-water fuel on site	\$1.00 to \$1.10 per mmBtu

Table 10

OPERATING COSTS
MULLED COAL CONVERSION TO CWF
 (65% solids CWF)

Daily Plant Capacity (Tons)	250	
Circuit Capacity (Tons per Hour)	16	
Operating Hours per Day	16	
Operating Days per Year	250	
Annual CWF Production (Tons)	62,500	
Annual Operating Cost	<u>Cost</u>	<u>\$/MM Btu</u>
Additives (Dispersant @ 0.75% Dosage)	304,688	0.259
Utilities	2,000	0.002
Labor		
Operating @ \$30/hour & 35% of operator	42,000	0.036
Maintenance @ 3% of FCI	6,300	0.005
Supervision @ 15% Operating	<u>6,300</u>	<u>0.005</u>
	54,600	0.046
Materials		
Operating Supplies @ 15% Oper. Labor	6,300	0.005
Maintenance @ 40% of FCI	83,996	0.071
Laboratory Charges @ 15% of Oper. Labor	<u>6,300</u>	<u>0.005</u>
	96,596	0.082
Plant Overhead @ 60% of Labor	32,760	0.028
Local Taxes & Ins. @ 1.5% of FCI	3,150	0.003
Depreciation @ 8% of FCI	16,799	0.014
	-----	-----
Total Operating Cost	\$ 510,592	\$ 0.433

Table 11

MULLED COAL/CWF
SYSTEM COST SUMMARY

Capacity (TPD of Wet Coal)			
- Mulled Coal	50	250	1000
- CWF Conversion	50	50	250
<u>Mulled Coal Production Plant</u>			
Annual CWF Production (Tons of Wet Coal)			
- Mulled Coal	10,000	50,000	200,000
Capital Costs			
Mulled Coal Plant	\$264,880	\$370,832	\$553,840
Operating Costs (\$/Ton of Dry Coal)			
Mulled Coal Production	\$19.61	\$ 7.84	\$ 5.00
Trucking	<u>11.92</u>	<u>11.92</u>	<u>11.92</u>
Total Delivered Cost	\$31.53	\$19.76	\$16.92
Operating Costs (\$/mm Btu)			
Mulled Coal Production	\$ 0.68	\$ 0.27	\$ 0.17
Trucking	<u>0.41</u>	<u>0.41</u>	<u>0.41</u>
Total Delivered Cost	\$ 1.09	\$ 0.68	\$ 0.58
<u>CWF Conversion at User Site</u>			
Annual CWF Conversion (Tons of CWF)			
- CWF @ 65% solids	10,000	10,000	50,000
Capital Costs	\$76,360	\$76,360	\$209,990
Operating Costs (\$/Dry Ton in CWF)	\$ 12.57	\$ 12.57	\$ 12.57
(\$/mm Btu)	\$ 0.43	\$ 0.43	\$ 0.43
<u>Total Operating Costs for Mulling & Conversion</u>			
(\$/Ton of Dry Coal)	\$ 44.10	\$ 32.33	\$ 29.49
(\$/mmBtu)	\$ 1.52	\$ 1.11	\$ 1.02

Note: Costs do not include the clean coal feed to the Mulled Coal circuit

3.0 CONCLUSIONS

The feasibility studies of the Mulled Coal Contract (Phase I) resulted in the production of two distinct types of mulls, the "gel" form and the "granular" form.

The "gel" form is of the type anticipated in the original proposal, (i.e., a highly viscous liquid with consistency ranging from that of bread dough to a heavy oil). The formulations are similar to those for coal-water fuels (CWF). Conversion to CWF can be achieved by shearing the mull at high shear rates ($>200/\text{sec}$) without using additional chemicals or by mixing with water.

The "granular" form of the mull has the consistency of dry powder with a particle size several times larger than the feed coal while still retaining the moisture content of the original filter cake. The formulation utilizes a reagent readily available at costs of 10% of the gel type. The granular mull can be converted to CWF utilizing conventional CWF reagents in a low shear system. The preparation of the granular mulls seems insensitive to moisture levels, feed particle size, or variations in coal processing. Initial studies suggest that loss of moisture during storage has little effect on the handling characteristics. This form is now identified as Mulled Coal.

The granular form of the Mulled Coal was the formulation of choice because of the:

- o Consistency of handling characteristics over a range of moisture levels, coal particle sizes, and coals.
- o Lower reagent costs.
- o Potentially simpler storage, handling and transportation systems.
- o Easy conversion to coal-water fuels.

Subsequent studies (Phase II) confirmed that:

- o The Mulled Coal has handling characteristics compatible with existing solids handling equipment.
- o Open storage does not materially affect handling properties.
- o Aged samples will lose moisture and will not rewet upon subsequent exposure to rain.
- o Mulled Coal can be converted into CWF with an in-line processor.
- o CWF prepared from Mulled Coal in an in-line processor can be readily pumped and atomized.

Finally, it was demonstrated that the Mulled Coal technology:

- o Is applicable to coals ranging in rank from subbituminous to anthracite.
- o It appears that the Appalachian coals generally are amenable to mulling and to subsequent conversion to CWF.
- o The Mid-Continent and Western Bituminous samples were mulled successfully, although the handling properties were not the same high quality obtained with the Central Appalachian coals. While suitable for storage, transportation and direct use as fuels, these mulls cannot be recommended for conversion to CWFs on the basis of tests in this project.
- o Anthracite yielded a mull having properties similar to the Mid-Continent mull: suitable for direct use, but not for slurry.
- o The testing of Western Subbituminous mulled coal gave results indicating substantially inferior handling properties, particularly at large particle sizes. With smaller particles, the indications are that an acceptable mull with improved handling characteristics will result, but the conversion to a decent quality CWF has not been demonstrated.
- o Can be useful on existing streams from conventional coal facilities and refuse recovery operations.
- o Has no adverse environmental impacts during storage, handling and combustion.
- o Can be produced in readily available equipment at 100 tons/hour.
- o Can replace thermally dried steam coal at \$0.50-\$1.00/ton.
- o Can convert cleaned wet coal fines to a usable product with acceptable characteristics at an added cost in the range of about \$3.00 to \$5.00 per ton of wet coal for commercial plant sizes of 250 to 1000 tons per day, or about 15 to 30 cents per million Btu.
- o When the Mulled Coal product from fines production in a coal preparation plant is recombined and blended with the coarse cleaned coal, the low cost of reclaiming the waste fines will reduce substantially the cost per ton of coal delivered from the preparation plant.
- o The cost of coal-water fuel (CWF) delivered to a typical boiler fuel user and prepared from Mulled Coal has been estimated to be \$1.00 to \$1.10 per million Btu in addition to the cost of the coal feed. This includes production of Mulled Coal, transportation to the user site, and conversion to CWF.

The project has fully met its objectives by developing a technology to improve the storage, handling and transport of deeply cleaned premium coals. The resulting technology is considered by many to be a major

breakthrough in handling these materials both as a solid fuel and as a precursor to Coal Water Fuels. However, the Mulled Coal process may find more immediate applications for coal fines streams from existing operations, and in facilitating processing of coal fines from blackwater pond recovery operations.

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