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FINAL

**IMPROVEMENT OF STORAGE, HANDLING,
AND TRANSPORTABILITY OF FINE COAL**

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QUARTERLY TECHNICAL PROGRESS REPORT NO. 4

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1.0 PROJECT SUMMARY

1.1 Background and Objectives

Fine coal production is on the rise in the U.S., and it will continue to increase as underground mining companies invest in more productive equipment. Fine coal cleaning technologies have been developed which can efficiently and economically separate coal from clay and other mineral matter in the fine size fractions, but they have not gained universal acceptance in the coal industry because the product is considered too wet by most coal users.

Historically, coal producers take one of two approaches in dealing with fine coal production. On the one hand, they may wash it and recover it as a wet cake which must be thermally dried prior to shipment. On the other hand, many operators make to attempt to recover fine coal, and dispose of it as a wet cake or slurry in refuse piles, slurry impoundments and abandoned deep mines. There are environmental problems related to both of these practices.

The Mulled Coal process was developed as a means of overcoming the adverse handling characteristics of wet fine coal without thermal drying. The process involves the addition of a low cost, harmless reagent to wet fine coal using off-the-shelf mixing equipment. Based on laboratory- and bench-scale testing, Mulled Coal can be stored, shipped, and burned without causing any of the plugging, pasting, carryback and freezing problems normally associated with wet coal. On the other hand, Mulled Coal does not cause the fugitive and airborne dust problems normally associated with thermally dried coal.

The objectives of this project are to demonstrate that:

- The Mulled Coal process, which has been proven to work on a wide range of wet fine coals at bench scale, will work equally well on a continuous basis, producing consistent quality at a convincing rate of production in a commercial coal preparation plant.
- The wet product from a fine coal cleaning circuit can be converted to a solid fuel form for ease of handling and cost savings in storage and rail car transportation.
- A wet fine coal product thus converted to a solid fuel form, can be stored, shipped, and burned with conventional fuel handling, transportation, and combustion systems.

1.2 Project Overview

It is useful to describe the project in groups of activities in order to fully understand the interactions between activities and to better understand the information flow and decisions of the project. The project is organized around two major demonstrations: (1) the production of Mulled Coal in a commercial operating setting, and (2) the delivery of the Mulled Coal product through existing commercial storage, transport, and handling systems.

The initial project activities were performed largely at the EI facilities and were conducted to produce the formulations, test procedures, and design packages required to procure and install the Mulled Coal circuit at the Drummond Company, Inc., Chetopa Preparation Plant in Graysville, Alabama. The installed circuit will be used for the demonstration of Mulled Coal production. The second set of demonstrations will be the shipment and handling of Mulled Coal in existing coal transportation systems. Data collected from all phases of production and delivery will then be analyzed, evaluated, and reported.

The Mulled Coal circuit will be installed in the operating preparation plant located at the Chetopa Mine site. The Chetopa Plant processes 360 to 450 tonnes/hr (400 to 500 tons/hr) of raw coal to produce 250 to 320 tonnes/hr (275 to 350 tons/hr) of clean coal for shipment to the steam coal market. Approximately 45 to 55 tonnes/hr (50 to 60 tons/hr) of fine coal is cleaned in froth cells to produce 40 to 45 tonnes/hr (45 to 50 tons/hr) of a fine clean coal that is 10-14 percent ash. Froth concentrate reports to a vacuum filter where a 24-27 percent moisture filter cake is discharged to a collecting belt. In current operations, the wet filter cake is combined with the coarser size fractions of clean coal for storage and delivery to market. The wet filter cake comprises about 15 to 18 percent of the total clean coal product from the plant.

The proof-of-concept (or POC) circuit will process a 2.7 tonnes/hr (3 tons/hr) slipstream of froth concentrate from the existing froth cells in the Chetopa Plant as feed to the Mulled Coal circuit. The froth concentrate will be dewatered in a centrifuge to prepare a wet fine coal feed material for conversion into a free-flowing granular material. The Mulled Coal product will be directed to a 450 tonne (500 ton) open storage pile. The POC unit will be of a design that can be scaled up to 135 tonnes/hr (150 tons/hr). Figure 1 shows the key components of the Chetopa Plant cleaning circuit and the Mulled Coal circuit that will be installed.

The Mulled Coal circuit will be installed in an empty bay at the Chetopa Plant. This area is convenient to the discharge location from the froth cells and at a lower elevation. The use of gravity feeds will minimize field fabrication. Equipment will be installed to divert a 2.7 tonnes/hr (3 tons/hr) slipstream of the froth concentrate to a dewatering centrifuge. The concentrated wet coal fines from the centrifuge will be dropped through a chute directly into a surge hopper and feed system for the Mulled Coal circuit. The Mulled Coal product will be gravity discharged from the circuit to a truck or product discharge area from which it will be hauled to a stockpile which will be located at the edge of the active clean coal stockpile area.

During the 3-month operating period, the facility should produce 910 tonnes (1000 tons) of the Mulled Coal for evaluation in various storage, handling, and transportation equipment and operations.

Figure 1

ENERGY INTERNATIONAL

POC PROJECT
SCHEMATIC FLOW DIAGRAM

DATE: JULY 5, 1994

2.0 PROJECT TECHNICAL WORK PLANS

2.1 Technical Approach and Work Plan Overview

This project focuses on achieving two demonstrations of the Mulled Coal technology: (1) Production in a commercial operating environment, and (2) Delivery of product in existing storage, transportation, and handling systems. To successfully complete these demonstrations, the project has been organized into a series of task activities which lead to the demonstrations, support the engineering and management needs of the project, and assess and report the activities and results. The development of the design basis and assessment of Mulled Coal technology application are direct parallels to activities that would be needed in any specific individual commercial application.

The technical approach is comprised of the following:

1. Prepare work plans at the beginning of the project with mechanisms for adding detail and updating the plans as new information is generated.
2. Collect and evaluate information specific to the coal and plant operations at the host site that is needed to complete the circuit design, equipment selections, installation plans, and production scheduling and plans.
3. Use the evaluation results to complete the design, equipment selection, and production planning.
4. Procure, install, and start-up the Mulled Coal circuit at the host site.
5. Conduct the demonstration of production operations.
6. Select delivery destinations and develop specific plans for monitoring dumping, fuel handling, etc. at each unique destination. Final decisions and detailed plans will be made when coal deliveries are ready to be scheduled, which in commercial practice is several months from the expected availability of product for shipment.
7. Conduct the demonstration of Mulled Coal technology in existing storage, transportation, and handling operations.
8. Prepare technical and economic assessment of the technology based on the data generated in the demonstration operations.

2.2 Work Plan Assumptions

Developing the work plans has required making key assumptions, which are:

1. The fine wet clean coal produced at the Chetopa Plant can be mulled using the experience base of reagent formulations and dosage rates.

2. The dilute froth concentrate will be a suitable alternative feedstock should the vacuum filter cake not be suitable.
3. The slipstream from the froth cell discharge can be taken without disruption of the existing plant operations.
4. The storage, transportation, handling, and stability characteristics of Mulled Coal will be similar to those properties as evaluated in the bench-scale engineering evaluations and testing.

3.0 TECHNICAL PROGRESS

3.1 Overview

During this reporting period, technical progress was made in four activity areas. Those activity areas are: completion of the bench-scale and pilot-plant pugmill test evaluations, process design engineering and equipment selection, detailed engineering, and procurement. Work in these activity areas will be described in the following sections.

The approach used during this period of technical activities was to continue and complete the collection of sufficient information in bench-scale mulling tests and pilot-plant pugmill tests to enable the selection of the equipment, and design of the components and project circuit schematic flow diagram. Additional samples of froth concentrate were collected from the Drummond preparation plant to enable the completion of these tests.

During the previous activities, the technical decision was made to design the circuit with the froth concentrate as the project feedstock. Based on that decision, a project schematic flow diagram for the Mulled Coal circuit as it is to be installed at Drummond was developed and is shown in Figure 1. The initial concept as shown in this figure allows for the diversion of a slipstream of the froth concentrate from the discharge stream from the flotation cells. It will most likely be taken from the feed end of the flotation cell launder, which will enable a high and consistent quality of the project feed and will have a minimal disruption to the plant process flow stream. The detailed design and location of the slipstream take-off has been reviewed with Drummond for approval. Also, during the previous quarter, initial design of specific major equipment had been initiated in order to begin the procurement process in a timely manner. During this period, equipment and circuit design was continued and completed.

With the selection of froth concentrate as the project feedstock, it is necessary to include a screen bowl centrifuge to concentrate the solids content and produce a wet cake of acceptable moisture content for the mulling circuit. This centrifuge will be supplied to the project by Decanter Machine at no cost to the project for the demonstration activities. The discharge from the centrifuge will then be fed through a surge feeder and moisture probe to the pugmill for mulling.

The development of the preliminary project schematic flow diagram and conceptual design basis provided sufficient information to begin selection and design of major equipment. Long lead time procurement actions were initiated as quickly as specifications and bid packages were prepared. Along with that, additional testing in the bench-scale and pugmill tests provided the more detailed database needed for the final design and operating plans.

3.2 Evaluate the Application of the Mulled Coal Process

3.2.1 Pilot Plant Testing

Under the best of circumstances, 1000 g laboratory tests determine mullability characteristics in only relative terms. In order to study the Mulled Coal process under more realistic conditions, EI

has set up a pilot plant circuit capable of continuously processing wet fine coal at a rate of 150 kg to 250 kg per hour. The major components of the pilot plant are actual scale models of equipment we planned to use for the proof-of-concept circuit.

The pilot plant is a simple circuit which consists of (Figure 2):

Surge Feeder

A volumetric steel feeder with a manually charged 50 kg hopper capable of precisely and continuously feeding even the most problematic wet cakes at a rate of 0-750 kg per hour. The machine is equipped with an open spiral type feed auger which discharges wet cake through a close tolerance tube. There is also a larger diameter intramitter auger running concentric with the metering auger which keeps the material in the feed hopper "live", and prevents the bridging and plugging normally associated with moving wet fine coal through a hopper.

Pug Mill

A twin counter rotating shaft type with a total capacity of 0.5 m³, a working capacity of 0.3 m³ and a wet cake processing capacity of about 600 kg per hour. All wetted parts are stainless steel, and the counter rotating shafts are equipped with adjustable paddle blades which mix and move the material through the mixing chamber. Shaft speed and paddle angle are varied to change retention time and mixing conditions.

Reagent Delivery System

The system includes a small (1 liter) reagent tank, a positive displacement metering pump and the required hoses, valves, etc. to deliver 30 to 90 ml/minute to two cone spray nozzles located at the feed end of the pug mill. Reagent is delivered in such small quantities, that compressed air is used to atomize the reagent droplets.

Prior to starting a test run, the surge feeder is preset to meter a steady flow of wet cake into the circuit (usually about 160 kg/hour). Pug mill speed and paddle configuration are preset to a certain mixing procedure and retention time. The reagent delivery system is calibrated and set to deliver reagent to the circuit on the basis of a set percentage of the dry weight of coal being fed into the circuit.

When testing, the circuit is operated manually. Wet cake can be charged to the surge feeder hopper by transferring sample to 5 gallon buckets and dumping them in, or by dumping directly from 55 gallon sample drums. As much as 50 kg of wet cake can be added in a few seconds, but the feeder will continue to discharge at the preset rate. The surge feeder, pug mill, and reagent pump are started manually, and the tests usually run continuously for between 15 and 45 minutes. Milled Coal is collected in 20 kg wash tubs as it is discharged from the pug mill. Feed rate, retention time and reagent dose can be changed while operating. Charging wet cake and collecting the finished product is also done while operating. The only circuit adjustment requiring a circuit shut down is a change to the pug mill paddle angles.

Figure 2

MULLED COAL PILOT PLANT

We used the pilot plant to run mullability tests, but we also used it to study capacities and power requirements for the feeder and pug mill so that we could make the necessary calculations to scale the system up to 3.6 tonnes/hour. Mullability test results will be reported here. Capacity and load tests will be discussed in a later section.

Due to the aging problem with bulk samples, only one valid mullability test was run with the pilot plant circuit. Feed coal was a froth concentrate sample which was fresh, and the test was conducted within two days of first opening the sample drums. In the case of all other bulk samples, initial test work was limited to size distribution analysis and laboratory scale mulling tests. By the time we were ready to conduct continuous testing, the mullability of the bulk samples had deteriorated to the point where no useful information could be learned from a continuous pilot plant test.

The feed characteristics, the circuit setup, and the test results for the one valid pilot plant test were as follows:

Feed Characteristics:

Source	Filtered Froth Concentrate
Ash	12.10%
Moisture	24.00%
Size	As Received (nominal 28M x 0)
pH of Water	7.5

System Settings:

Reagent Dose	2% by dry weight of coal (48.5 ml/min)
Feed Rate	159 kg/hr
Feeder Setting	(10% capacity)
Pug Mill RPM	125
Elapsed Time	25 minutes

Totals:

Reagent Used	1.70 liter
Mulled Coal Produced	93 kg

Uniformity Test Results:

Time	+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
1st 10 minutes	2.64	25.66	51.51	20.19	75.70
2nd 10 minutes	3.14	36.97	47.69	12.20	59.89
3rd 10 minutes	4.63	34.45	51.11	9.81	60.92
Average	3.47	32.36	50.10	14.07	65.50
Marker Test *96-54	7.51	26.09	48.02	18.38	66.40

*Immediately prior to the pilot plant test, we ran a lab scale K.A. mulling test on the same sample to see how uniformity test results would compare from the lab scale test to the pilot plant test.

The system setup, the feed rate, and the reagent dose for this test are considered standard starting points for pilot plant testing. The Mulled Coal produced in this test was considered to be very good quality. Unfortunately there was not enough unoxidized sample to continue pilot plant testing with adjusted system settings to see if we could improve quality or reduce reagent dosage.

The pilot plant test did give us renewed confidence that the Mulled Coal circuit was going to work well on Chetopa fine coal. As it turned out, the full scale demonstration circuit worked far better than any of our lab scale or pilot plant testing would have indicated. Even if we had available additional unoxidized sample, more pilot plant tests would not have been of much help in establishing system settings for the production phase of the project.

3.2.2 Stability Tests

A series of stability tests was conducted on the Mulled Coal produced in the pilot plant test. The objective was to predict how Mulled Coal might behave in the normal commercial coal storage, transportation and combustion environment. Certain marker characteristics of Mulled Coal were compared to those same characteristics of untreated wet cake and bone dry coal. All of the testing methods and procedures used for this series of stability tests was based on industry and ASTM standard tests. Each was modified to accommodate the nature of Mulled Coal, the sample sizes available in this project and the need to be able to perform the tests within the available laboratory facilities.

3.2.2.1 Resistance to Freezing

Three 50 g samples each of Mulled Coal and untreated wet cake (before mulling) were loaded in identical sample pans and placed in a freezer at 5°F for 24 hours. Each "frozen" sample was removed from the freezer and evaluated with a simple drop shatter test. The "frozen" sample pan was raised to a height of 1M and dropped into a 100 cm x 200 cm x 300 cm stainless steel pan. When the sample struck the pan it shattered. Frozen material tended to shatter into large pieces. Unfrozen or loosely frozen material retained its approximate original size distribution. The extent of shatter was evaluated by hand screening the material in a three screen stack with 6M, 14M, and 28M openings. Results of the tests were averaged and are presented in Figures 3 and 4.

Mulled Coal does not present any problems when exposed to freezing temperatures. It appears not to be frozen at all, but moisture encapsulated within individual agglomerates may actually freeze, however, the reagent coating prevents individual ice crystals from bonding. On the other hand, the unmulled wet cake forms a solid block of ice when exposed to freezing temperatures.

3.2.2.2 Bulk Density

Good quality Mulled Coal always has a lower bulk density than the same coal as measured before mulling. Mulled Coal is down in the 36-39 lb/ft³ range and untreated wet cake is up in the 44-

Figure 3

FREEZE RESISTANCE DROP SHATTER TEST

Figure 4

UNIFORMITY TEST RESULTS
Mulled Coal Before & After Freezing

50 lb/ft³ range. Samples in the 44-50 lb/ft³ range generally have a Handleability Index of under 10, and Mulled Coal samples in the 36-39 lb/ft³ range generally have a Handleability Index of over 60. Results of bulk density testing are as follows:

Mulled Coal	Time	Bulk Density (lb/ft ³)
	1st 10 minutes	38.57
	2nd 10 minutes	38.74
	3rd 10 minutes	39.62
Mulled Coal	Average	38.98
Untreated Wet Cake		45.94

ASTM procedures for bulk density tests for coal require a sample size of exactly 1 ft³. There was not enough material available in this phase of the project to run ASTM bulk density tests. The bulk density tests reported above are based on a sample size of 0.35 ft³.

3.2.2.3 Propensity to Slide

The slide characteristics of the Mulled Coal produced in the pilot plant test were compared to those same properties of unmulled coal and dry coal from the same bulk sample.

The test series included angle of repose, angle of fall, angle of incipient slide and angle of slide. This series of tests in general is used universally to evaluate flow properties of bulk materials. Laboratory procedures and equipment used for the tests were designed specifically to do before and after testing on Mulled Coal, so absolute results cannot be used to design slide angles in fuel handling systems, and the test results for Mulled Coal cannot be compared to tests of other bulk materials done at other laboratories. However, relative results are a good indication of the improvement which takes place as a result of the Mulled Coal process, and they are a good way to compare one Mulled Coal to another.

A brief description of each test is as follows:

- a. Angle of Repose - This is a universally accepted indicator of the flowability of a bulk solid. It is a measurement of the included angle between the slope of a cone shaped pile and the horizontal. As the angle of repose decreases, the material is deemed to be more flowable. The angle of repose for dry coal is generally expressed as 37°.

We use about 200g of sample and pour it gradually on to a stainless steel plate from a height of about 15 cm. Results of Angle of Repose tests are reported in Table I.

- b. Angle of Fall - This test uses the same conical pile used for the angle of repose measurement. The pile is jarred by dropping a weight onto the base plate somewhere near but not at the base of the slope. The pile will fall creating a new and shallower angle between the slope and horizontal. The difference between the two angles is considered a measurement of flowability. The way the pile falls is also of special

interest. If particles fall and spread out along the base of the pile, only a degree of flowability is indicated. If the entire pile collapses, it is a sign that the material contained entrained air, and the material could be prone to flood flow. Results of Angle of Fall tests are reported in Table I.

- c. Angle of Incipient Slide and Angle of Slide - The angle of slide is the angle at which material will completely slide down a flat surface due to its own weight. The angle of incipient slide is the angle at which the material first begins to move.

About 50 g of material is placed in a stainless steel pan measuring about 10 cm x 18 cm with shallow lips on three sides. At the beginning of the test the pan is set exactly horizontal. The pan is gradually rotated with a geared-down motor. The lab technician closely observes the procedure and stops the rotation at the appropriate spots to take angle measurements. This is a subjective test, and we rely on the same lab technician to produce repeatable results.

Absolute results are not used to design chute slopes or bin bottom valley angles, but relative results are a good indication of the improved handling characteristics which can be achieved through the use of the Mulled Coal process. Results of propensity to slide tests are reported in Table I.

- d. Dispersability - Dispersability is the measurement of the "dustiness" of a fine coal sample. The apparatus used for this test includes a 10 cm ID tube which is about 33 cm long. The tube is supported vertically with a ring stand; with the bottom of the tube located about 10 cm above the lab table. Directly beneath the tube is a 10 cm watch glass resting on the lab table. A 50 g sample is dumped through the tube "en masse" from a point about 61 cm above the lab table or 18 cm above the top of the tube. Material remaining in the watch glass is weighed, and the remaining material is considered to have been dispersed. Results are expressed in terms of the percentage of material which was dispersed.

As would be expected, very little of an unmulled 24% moisture wet cake will be dispersed. The interesting comparison in this test is how Mulled Coal will measure up against dry coal. What we look for is a Mulled Coal which has handling characteristics close to dry coal, but is not as dusty as dry coal. Results of dispersability tests are reported in Table I.

3.3 Process Design Engineering

This phase of the project included designing the Mulled Coal circuit and adapting it to prevailing conditions at the Chetopa plant. The primary objective was to design and locate circuit equipment and controls in such a way that we could meet project objectives, and at the same time cause a minimum of interference with Drummond's normal operations.

Table I

Propensity To Slide & Dispersability Test Results

Test / Material Tested	Unmulled Coal	Mulled Coal	Dry Coal
Propensity To Slide			
Angle Of Insipient Slide (Deg.)	29	23	18
Angle Of Slide (Deg.)	49	42	32
Angle Of Repose (Deg.)	44	36	36
Angle Of Fall (Deg.)	40	28	21
Dispersability (%)	2.31	1.66	7.17

3.3.1 Site Survey

The Chetopa plant was built in 1966 by Alabama By-Products Corporation. In the mid-1980's Alabama By-Products was purchased by Drummond. The plant began as a fairly standard heavy media washer/concentrating table operation. Over the years there have been a number of plant additions to increase capacity and modernize the washing circuit. The latest addition (1987) included a heavy media cyclone circuit for 1/2" x 28M coal, and it doubled the capacity of the flotation circuit and vacuum filter. There are detailed structural steel, machinery plan and elevation drawings for recent plant additions, but original structural steel drawings and elevation and plan drawings for areas not involved in recent additions or currently in use are limited.

On our first visit to the site with Drummond personnel, we identified an empty machinery bay in a corner of the plant at a lower elevation which was completely isolated from the current plant operation (Figure 5). It was decided that, if at all possible, the Mulled Coal circuit would be located in that bay.

The empty bay measured 5-1/2M x 6M with a ceiling height of 2.5M. It contained no unused equipment or old piping. It was located close to and below the fine coal circuit, and it was situated in a place where it would be easy to get the Mulled Coal production out of the plant.

The proposed project bay would be very tight quarters for the project equipment and controls, and structural steel floor supports for the bay immediately above the project bay were very complicated. It would require a very precise layout to fit in the project equipment, chutes, etc. without disturbing the plant structure.

We gathered available drawings from the Drummond engineering department, and then we went in independently and located column lines, structural floor and wall supports, machinery, pipe lines, chute work, etc. in all areas which might be affected by project equipment and activities (Figures 6 and 7).

After making a few preliminary layouts, it was clear that the project would fit in the proposed location. While there were a few access problems, the empty bay represented the best possible location for the project. Drummond gave us permission to proceed with that location, and we began adapting the circuit to fit the space.

3.3.2 Interface Design

The interface with the Chetopa plant, or the points where we took material out of or put it back into the normal plant circuit, was the critical part of the design work. It had to be designed so that, from an operational standpoint:

1. We would cut out a representative cross section of the full stream of froth concentrate.

Figure 5

Figure 6

PERSONNEL ENTRANCE

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CHETOPA PREPARATION PLANT
COLUMN LINES

SCALE: 1" = 16'

2. We would have complete control over the amount of froth concentrate which we were removing from the full stream.
3. When we were broken down or shut down, froth concentrate would completely bypass the Mulled Coal circuit.
4. Slurry pipes and valves would not plug up.
5. We had ready and quick access to all valves and pipes in case of an emergency.

From the standpoint of interfering with normal Chetopa operations:

1. There would be sufficient back-up and redundancy in the control circuit so that no kind of emergency or mechanical problem with the Mulled Coal circuit could result in shutting down the entire preparation plant.
2. We took coal and water out of the circuit and returned effluents back into the circuit in such a way that we would not cause any solids or hydraulic imbalance in the plant circuit.
3. The handling, trucking, weighing and storage of Mulled Coal would not interfere with normal Chetopa stockpiling and shipping operations.

From laboratory testing, it had been determined that the feed source must be concentrate from the Denver flotation cells. It must be taken after the concentrate from all four Denver cells is combined in one pipe, and it must be taken out ahead of the point where concentrate from the Wemco cells joins concentrate from the Denver cells. This narrowed the available sites for the take off point to an 11M section of 25 cm diameter pipe running from the Denver cells to the vacuum filter.

Decanter Machine, the manufacturer of the centrifuge, advised that, for the best possible slurry flow conditions, the slipstream should come off the main pipe at a 45° angle, and the take off point should be as close as possible to the centrifuge.

The position of the centrifuge could not be changed without altering major structural floor supports, so the initial criteria established for the take off point narrowed the location to a specific point on the 25 cm line running from the Denver cells to the vacuum filter. As it turned out, the target point was an ideal location for the pipe tap, valves, reducers, fittings, etc. which were required to direct a slipstream from the 25 cm line to the centrifuge.

When the Chetopa plant was built, rail cars were loaded directly beneath the plant. The side track ran between column lines (1) and (2), and the side track area was open from ground elevation (438'-6") up to elevation 458'6", which was the floor elevation for the main bay for the Mulled Coal circuit (Figures 5 and 8). The side track is still there, but it is not currently in use. In order to make smooth roadways for rubber tired equipment, the tracks have been covered up, making a perfect haul road directly beneath the project bay. Getting Mulled Coal out of the plant was simply a matter of

Figure 8

CHETOPA PREPARATION PLANT GENERAL ARRANGEMENT

cutting a hole in the floor and dropping Mulled Coal from the pug mill directly into a chute which discharged into a small (6.5 tonne) dump truck. The dump truck was leased by the project, and was used exclusively to haul Mulled Coal from the plant, across the Chetopa scales, and then to the Mulled Coal stockpile area. The round trip was less than one mile.

The Chetopa stockpile area is quite large (over 100,000 tons capacity), but there was never more than 5,000 to 20,000 tons of clean coal on the ground during the life of the project. There was plenty of space available, and the Mulled Coal stockpile was located on a corner of the main stockpile area which was well clear of any Chetopa traffic.

3.3.3 Pug Mill Design

For several years EI had used a Patterson Pump Company model 10 pug mill in a 275 kg/hr Mulled Coal pilot plant. The machine is equipped with a stainless steel mixing chamber measuring 25 cm wide by 1M long by 25 cm deep. The machine is rated at 1.6 ft³ total capacity and 0.9 ft³ working capacity. Mixing is provided by a set of stainless steel shafts which are mounted parallel, are counter rotating, and are equipped with a set of overlapping and adjustable stainless steel paddles.

Over the years, several other types of mixers had been used at low capacities including pin type, ribbon type, and lobe type mixers. After extensive experimentation, it was determined that the counter rotating shaft pug mill with a "half figure 8" mixing chamber configuration represented the best alternative for producing good quality Mulled Coal at an affordable price. This type of mixer is in common use in a wide variety of minerals processing applications, and it would be a rather straightforward matter to scale up from the pilot plant, to the proof-of-concept and then on to the commercial size.

The nominal feed rate for the project was established at 3 tons per hour of dry coal or 4 tons per hour of 25% moisture wet cake. We wanted the circuit to be capable of handling 150% surges, so the capacity design point for the pug mill was set at 6 tons per hour. A capacity of 6 tons per hour does not simply mean the amount of material which can be moved through the mixing chamber. It means the amount of material which can be moved through the mixing chamber under ideal mixing conditions which are generally "mid point" settings for retention time, RPM and paddle angle.

We normally operated the pilot plant at a wet cake feed rate of 160 kg/hr, but the feed rate was not controlled by the capacity of the pug mill. Pilot plant feed rate was limited by the capacity to deliver reagent and the capacity of a single lab technician to manually charge buckets of wet cake and remove tubs of Mulled Coal. In a series of capacity tests run in June of 1995, it was determined that the pilot plant pug mill had a processing capacity of about 600 kg/hr.

Based on a target capacity of 6 tons per hour, we needed a machine with about 10 times the capacity of the pilot plant pug mill. The capacities and dimensions for this type of pug mill as offered by Patterson Pump Company are shown in Figure 9. The pilot plant pug mill is a Model 10. The Model 18 machine is about 10 times the capacity of the Model 10, so the Model 18 was the design used for the project. The design of mixing chamber, paddles, etc. from the 5.5 tons/hr machine clear up to the 60 tons/hr machine is exactly the same, so we expected equal or better mixing efficiencies as we moved up in capacity.

Figure 9
Pug Mill

Model	A	B	C	D	E	Total Capacity Cu. Ft.	Max. Working Capacity Cu. Ft.
10	10"	Per Application	3'-0"	Per Application	9½"	1.6	0.9
14	14"		7'-6"		12"	7.5	5
18	18"		10'-0"		15"	17	10
25	2'-1"		10'-0"		19"	30	20
33	2'-9"		10'-0"		2'-0"	50	35
39	3'-3"		10'-0"		2'-4"	70	50
44½	3'-8½"		10'-0"		2'-8"	88	65
56½	4'-8½"		10'-0"		3'-2"	130	100
66½	5'-6½"		10'-0"		3'-6"	185	150

3.3.4 Surge Feeder Design

From whatever type of device which is used to mechanically dewater fine coal (vacuum filters, filter presses, centrifuges, etc.) wet cake discharges are generally subject to short term surges and bursts in material flow. The surge feeder is included in the Mulled Coal circuit to level out feed rate spikes, and deliver wet cake to the feed end of the pug mill at a smooth even flow rate. A smooth feed rate is especially important at this point because this is where reagent is added to the wet cake, and since the reagent dose is only a small fraction of the total feed (less than 2%), even application is critical.

The surge feeder design presented a challenge because the machine must mechanically overcome all of the bridging, plugging and fouling problems normally associated with wet fine coal -- the very problems which the Mulled Coal process was designed to eliminate. Early in the development of the process, we experimented with various types of vibrating, reciprocating and solid screw feeders. None of them proved satisfactory. It was finally determined that wet cakes could best be conveyed or fed with an open spiral auger working in a close tolerance tube. However, the open auger by itself would not feed wet cake from a hopper bottom because the material is notorious for bridging over in a hopper or bin bottom configuration.

We decided to look at open auger type feeders which were equipped with some type of larger diameter rotating mechanism which was designed to prevent bridging. We sent typical wet cake samples to a number of manufacturers who made such a machine. They all responded that their machine would not handle wet cake, and they advised against using a surge feeder in our process.

Conventional wisdom was telling us that it could not be done, but we finally located a manufacturer's representative who was willing to give us a short term lease on an auger-type feeder to see if we could modify it in some way that could handle wet fine coal. Before setting up the feeder, we ordered a standard part which slightly modified the large diameter rotating device. When the part arrived, we installed it and tested the machine on a particularly sticky wet cake (50% moisture and <325 mesh). The feeder began immediately to do an excellent job of feeding even the most problematic wet cakes, and the bridging problem was completely eliminated.

That particular feeder, an Acrison Model 105Z with a slightly modified intruder auger (larger diameter concentric auger) is now part of the EI Mulled Coal pilot plant. The machine is rated by Acrison at 200 ft³/hr. In capacity test work conducted in June of 1995 it was determined that the 105Z feeder would feed wet fine coal at the rate of 1590 kg/hr operating at 100% and 1200 kg/hr operating at 75%. This translates to about 95 ft³/hr and 70 ft³/hr respectively. We elected to specify a feeder which would deliver 6 tons per hour while operating at 75% capacity. Based on Acrison figures, we were looking for a feeder with 4.6 times the capacity of the Model 105Z or a capacity of 920 ft³/hr. We selected a 900 ft³/hr model with almost exactly the same design features as the pilot plant feeder.

3.3.5 Reagent Delivery System Design

The reagent delivery system was one of the most important considerations in the design phase of the project. In most cases, reagent cost will exceed 80% of the total cost of owning and operating a Mulled Coal circuit, and the precisely controlled and even application of the proper reagent dose is the key factor in maintaining Mulled Coal quality. Design considerations included reagent dose, major component design (pump, flow meters, valves, nozzles, etc., the integrated delivery system and system controls).

3.3.5.1 Reagent Dose

We expected to use the results of a series of parametric K. A. mulling tests to predict the required reagent dose at various levels of feed ash, feed moisture, and feed size distribution. Due to the oxidation problem with bulk samples from Chetopa we were unable to use K. A. muller test results to make precise reagent dose predictions. However, we learned a number of things which were useful in designing the reagent delivery system:

1. We could expect a very narrow range of feed ash (11%-13%), and the ash range did not have a significant effect on mullability or required reagent dose. Therefore, it would not be necessary to continuously monitor feed ash in order to make adjustments to reagent dose.
2. We could expect a very narrow range of feed size distribution, and the range would have no significant effect on mullability or required reagent dose.
3. As would be expected, changes in moisture had the most profound effect on mullability, but the effect of moisture could be offset by raising and lowering the reagent dose. We would need to make changes to dose based on changes in moisture, and we would need to offset reagent flow based on TPH changes in feed rate.
4. We expected to run the demonstration circuit over a moisture range of 20% to 26%. There is not a linear relationship between moisture and mullability throughout the full 6% moisture range. Increases in moisture at levels above 23% require larger increases in reagent dose than increases in moisture down in the 20%-23% range.
5. From previous Mulled Coal research, it was determined that a reagent dose of about 2% of the weight of dry coal in the wet cake generally produced a good quality mull. That rule of thumb appeared to hold true with Chetopa coal only at the 23% moisture coal. Combining the valid data from the K. A. muller tests on Chetopa coal with previous Mulled Coal research, we calculated the required reagent dose at different levels of production and moisture (Figure 10). These calculations were programmed into the system control circuit. However, due to the inconsistency of Chetopa sample results and the experimental nature of the project, we also provided for a wide variety of automatic and manual adjustments which would virtually permit the circuit operator to apply any desired reagent dose at any time.

Figure 10

REAGENT USAGE

As it turned out the calculations made from Chetopa data and previous research work were not valid. The process is much more efficient at 3-5 tons per hour than it is in laboratory tests, and the reagent use was only about one-half of what was originally predicted.

3.3.5.2 Major Reagent System Component Design

1. **Reagent Pump** - The system required an extremely reliable positive displacement-type pump capable of producing reagent flow over the full calculated range, and at nozzle pressures sufficient to properly atomize the reagent. The calculated flow range was 3-33 GPH, and we knew from laboratory testing that optimum dynamic pressure for proper atomization over the full flow range was 18-35 PSI.

We wanted to control reagent dose within $\pm 0.1\%$ of the dry weight of coal in the wet cake feed. This translates to controlling pump speed within 50 RPM.

The wide flow range at the anticipated pressures, coupled with control requirements, established a fairly difficult duty for the pump.

For reliability we wanted a magnetically coupled pump. To eliminate pulse flow we wanted a gear pump. For control purposes, we wanted an electrically commutated (brushless DC) pump drive.

2. **Flow Meter** - The relatively low flow rate, the wide flow range, and the viscosity of the reagent suggested a gear type positive displacement flow meter. The precise control target suggested that we use equipment manufactured by Max Machinery, a leading manufacturer of precision low flow meters and totalizers.

3.3.5.3 The Integrated Delivery System

Figure 11 shows sketches of the general arrangement of the reagent delivery system and the reagent spray manifold which was used on the feed end of the pug mill.

Due to the experimental nature of the project, we decided to provide an option to use compressed air assisted "fog" nozzles to atomize the reagent as it was applied to the wet cake. We assembled the reagent delivery system in our Pittsburgh laboratory to test it before going into the field, and we were fairly certain that fog nozzles would not be required. However, we had compressed air available so we designed the system so that we could use either an unassisted fan spray or an air assisted fog nozzle. As it turned out, the unassisted, wide angle fan sprays produced ideal atomization at about 25 PSI, so we never used compressed air in the delivery system.

In Figure 12, all components from 3 through 14 were located in the circuit control room. This was done to keep manual valve controls and pressure gauges in full view of the circuit operator. Items 3 through 6 and 12 through 14 were located in a steel cabinet, and the valves and pressure gauges (7 through 11) were mounted on a manifold against the wall of the control room.

1. SHUT OFF VALVE
2. QUICK DISCONNECT
3. SUCTION FILTER
4. PUMP
5. SYSTEM RELIEF VALVE
6. FLOW METER
7. SYSTEM PRESSURE GAUGE
8. BRANCH CIRCUIT SHUT OFF VALVES
9. LIQUID LINE PRESSURE REGULATORS
10. AIR LINE PRESSURE REGULATORS
11. AIR LINE SYSTEM PRESSURE GAUGE
12. AIR LINE FILTER
13. AIR LINE SOLENOID VALVE
14. AIR LINE SHUT OFF VALVE
15. PLANT AIR LINE
16. AIR ATOMIZING SPRAY NOZZLES
17. REAGENT DRUM

Figure 11

REAGENT DELIVERY SYSTEM

Figure 12

ELEV 458'-6
MACHINERY PLAN
STEPS LOCATION

REVISED 11/03/94

Reagent usage was less than one drum per shift, although original calculations indicated that we would use just under two drums per shift. Just prior to the start of a run in testing, we moved about 18 full drums of reagent up to the project bay. The original plan was to remove empties and bring in full drums about every two weeks. The balance of the reagent inventory was stored on pallets in an outside supply yard located within a few hundred meters of the plant. As it turned out, we only replenished the reagent inventory twice during the life of the project; we brought in about 13 drums the first time and 9 drums the second time.

The reagent drum in use was cradled in a drum dolly which was spotted just outside one of the back walls of the control room (Figure 12). We had two sets of dollies, shut off valves, drum vents and quick disconnects, so the next full drum in line was set up and spotted immediately adjacent to the active drum. When the active drum was within a few gallons of being empty (we knew the exact amount of remaining reagent at any given time because of an automatic totalizer which could be set to zero at each drum change), the drums would be changed "on the fly". Changing drums was simply a matter of moving a quick disconnect hose from one drum to another. The procedure took only a few seconds. The remaining reagent in the drum which was changed out was transferred to a scavenger drum which was put back into the cycle when it was completely filled.

For inspection purposes, the pug mill mixing chamber was originally provided with three hinged top covers; with each cover spanning about 1/3 the length of the mixing chamber. We removed the hinged cover from the feed end of the machine and replaced it with the reagent spray manifold and covers shown in Figures 13 and 14. The fan spray nozzles produced a flat spray pattern with about a 100 degree included angle. The reason that the manifold and covers were raised above the level of the top of the pug mill was to insure that the spray pattern would cover the entire width of the mixing chamber.

3.3.5.4 Reagent Control System

The reagent pump RPM (reagent flow rate) was controlled with a 4-20 MA signal from the PLC. An output device transmitted reagent flow rates directly to a flow meter/totalizer mounted in the face of the control panel, and it also transmitted to a computer screen through the PLC. The control loop was set up so that changes in moisture, as interpreted by an on-line microwave moisture monitor, would result in automatic adjustments to reagent dose in accordance with the calculations shown in Figure 29. To adjust for changes in feed rate, there were offsets which could be made by clicking on buttons on the main computer screen. Finally, reagent dose was infinitely controllable with a manual switch located on the face of the control panel.

3.3.6 Slipstream Take-Off Design

Figure 15 shows the design of the slipstream take off point or the layout of the pipe taps, valves and piping to direct 3-5.5 tons per hour from the Chetopa fine coal stream to the Mulled Coal circuit.

Figure 13
REAGENT SPRAY MANIFOLD

FEED END PUG MILL COVER

Figure 13

SLIP STREAM TAKE OFF POINT

1. 4" Weld On Pipe Tap With Floating Flange
2. 4" Ball Valve - Manually Operated
3. 4" Knife Gate Valve - V Port, Air Operated
4. 4" To 3" Reducer - Flanged Ends, SDR
5. 3" SDR Pipe - Plain Ends
6. 1" Saddle Type Pipe Tap
7. 3" SDR 45° Ell - Flanged Ends
8. 3" Centrifuge Flange - Steel
9. 3" SDR 90° Ell - Flanged Ends
10. 3" Victaulic Couplings (2)
11. Knife Gate Valve Positioning Device
12. 1" Weld On Pipe Tap

Overall design criteria included:

1. On the advice of Decanter Machine, the main pipe tap should come off the 25 cm concentrate line at a 45 degree angle, and the tap should be as close as possible to the centrifuge. There was no pressure in the 25 cm line from the Denver flotation cell to the vacuum filter, but the rotation of the centrifuge would create a positive suction. The shortest distance between the pipe tap and centrifuge would result in the most positive and controllable flow for the slipstream.
2. The percent solids in the froth concentrate could run as high as 35% which is a high solids content for a low pressure line. The distance from the main pipe tap to the manual ball valve was held as short as possible, because we knew that solids would settle out and plug that area during periods when the Mulled Coal circuit was shut down. A 1" pipe tap was welded into the main pipe tap (item 12 in Figure 15). It was connected to a high pressure fresh water line. Whenever the Mulled Coal circuit was to be started up after more than a 30 minute shutdown, high pressure water would be used to flush out the main pipe tap area before starting up. To provide for smooth, low friction flow from the valves to the centrifuge, we used fabricated sweep elbows and low friction high density polyethylene pipe. Victaulic couplings were used to splice in a short piece of 3" pipe so that we could quickly open up the pipe line to clear a blockage (item 10 in Figure 15). We got into the line at that point on occasion to gather feed samples, but the line never plugged up during operation.
3. The inlet flange on the centrifuge was 3" diameter, but we used a 4" pipe tap, 4" valves and a 4" to 3" reducer (items 1 through 4 in Figure 15). The reason for this is that 3" diameter is not a standard size for the type of knife gate valve used in the project, and the decision to go with 4" equipment was based on price and availability.
4. The air activated gate valve (item 3 in Figure 15) is the principal component of the slipstream take-off system. The valve was in total control of feed rate to the Mulled Coal circuit. The valve ahead of it, the manual ball valve (item 2 in Figure 15), was always set either fully open or fully closed.

All welded parts in the knife gate valve were stainless steel. From the standpoint of wear resistance, this was overkill for a short duration project, but we were concerned that corrosion in the valve body could exacerbate plugging problems.

For precise flow control the valve was provided with a V-port. It was also provided with an automatic positioning device and automatic position feed back unit, so percent opening from 0-100% always appeared on the computer screen, and precise adjustments (within +/- 1%) could be made quickly by simply clicking on buttons on the computer screen.

The automatic positioning unit consumed about 0.5 ft³/min at 80 PSI. In order to insure a clean, uninterrupted air supply, a small piston type air compressor was

installed and made captive to the slipstream take-off system. (It should be noted that this same compressor would have supplied air for atomizing reagent spray nozzles should it have been required.)

Finally, there was a back up compressed nitrogen system (tank, regulator, hoses, etc.) which was available to operate the valve in the case of a loss of compressed air. The back up system was designed to operate only in emergencies or for a short duration (less than one shift). Midway in the project there was an air compressor failure, and the back up system was used to complete the production shift.

5. The manual ball valve (item 2 in Figure 15) was the last line of defense in insuring that no kind of failure in the Mulled Coal circuit could result in shutting down the entire Chetopa plant. The valve was run either fully closed or fully open. In case the knife gate valve ever got stuck in the open position (which actually happened when the air compressor failed), the ball valve could be closed to direct flow away from the Mulled Coal circuit. Closing the ball valve also allowed us to completely remove the knife gate valve or any other section of the slipstream take-off system for repairs (this was never necessary in the life of the project).
6. Item 6 in Figure 15 is a 1" pipe tap which was also connected to a high pressure fresh water line. The plan was to use this line to flush out the centrifuge should it become necessary, and to add dilution water to the feed in an attempt to control feed solids or product moisture. In actual practice, the line was useful for flushing out the centrifuge, but we were never able to effectively control moisture or feed solids from that point.

3.3.7 Chute Design

The design, arrangement and installation of chutes was a key consideration in designing the Mulled Coal circuit. The centrifuge product chute and the chute from the centrifuge to the surge feeder were to carry wet cake with wide swings in moisture content, the material which historically causes plugging problems in chutes. We established three principal criteria which were to be included in chute design.

1. The wet cake chutes should be absolutely vertical.
2. The materials of construction had to have a low efficiency of friction.
3. The wet cake chutes were to be installed in such a way that they could easily be cleaned out if they were plugged.

The Mulled Coal product truck loading chute was less of a design problem. The chute was to be lined with a low coefficient of friction material. It was to be installed at a slope angle of 40 degrees or less, because we always wanted to produce a Mulled Coal product which would slide freely at 40 degrees. If the chute began to back up or plug off, it would be an indication that we were producing an off standard product.

Figure 16 is a sketch of the general arrangement of the principal chutes in the circuit. Item 1 is the centrifuge product chute which is actually part of the centrifuge. Item 2 is the chute from the centrifuge to the feeder, and item 3 is the Mulled Coal truck loading chute.

The centrifuge chute is actually part of the centrifuge, but Decanter Machine generally used this centrifuge for short-run trial demonstrations, and the chute was lined with corroded steel and some pieces of rubber belting. We wanted a better chute liner for this project, so we removed the steel and rubber and lined the chute with UHMW PVC.

We left a gap of 30 CM between the centrifuge chute and long chute to the feeder. The gap was left so that, without having to move or dismantle any structure, we could clean out the centrifuge chute from the bottom, and we could get at the top of the long chute if either one of them ever plugged up. To keep water and other foreign material out of the Mulled Coal circuit, we hung a transition skirt between the two chutes. The skirt was cut from a heavy, but flexible plastic brattice cloth which is commonly used in deep mine operations. Grommets were installed in the brattice cloth so that it would not rip when it was bolted to the chute frames.

The long chute from the centrifuge to the surge feeder and the Mulled Coal truck loading chute were both fabricated from the same 6 meter long piece of 46 cm diameter heavy wall, high density polyethylene pipe. Since the bottom of the rectangular centrifuge chute was about 60 cm wide and the pipe was only 46 cm in diameter, a high density polyethylene funnel shaped piece was fabricated and butt welded to the first section of pipe. There was not enough room to fit the long chute through the hole in the floor at elevation 476", so two flanged pipe joints were provided so that short pieces could be put in place and bolted together. It was also felt that it might be necessary to unbolt and separate the short pieces if the chute ever plugged up tight.

The long chute was terminated about 12" above the surge feeder hopper and a transition skirt was provided in the same fashion as the skirt under the centrifuge chute. Finally, the surge feeder was set on a heavy duty machinery table which was mounted on wheels. If we ever needed to get at the bottom of the long chute, we could simply wheel the surge feeder out of the way.

The attention to details in the chute designed paid off. At various times in the project we processed some very high moisture wet cake, and at other times there were some operator errors which resulted in plugged chutes. Most of the precautionary design measures were ultimately used, but there was never much production time lost in unplugging chutes.

A sketch of the type of design used for the Mulled Coal truck loading chute is shown in Figure 17. A piece of the polyethylene pipe was cut in half and bolted to a light angle and flat bar stock frame. We made one small field alteration. Due to high wind conditions during the time of the production phase of the project, and due to the fact that the empty side-track bay under the plant acted like a wind tunnel, it was necessary to cover the top of the chute with sheet metal. At the discharge end of the chute we hung another brattice cloth skirt to reduce wind losses in the area where the Mulled Coal dropped into the haul truck.

Figure 16
CHUTE ARRANGEMENT

Figure 17

MULLED COAL CHUTE

There was one other small rectangular UHMW PVC chute used in the circuit. It simply surrounded the Mulled Coal stream where it dropped from the pug mill, through the floor and onto the truck loading chute. One side of the chute was removable so that we could reach into the coal stream from the project bay to take Mulled Coal quality control samples.

3.3.8 Access Design

Project equipment was to be located in four different bays which were stacked one on top of the other. The screen bowl centrifuge was to be located in the top bay at elevation 476'-0. This bay also contained concentrate lines and one end of the vacuum filter used to dewater Chetopa fine coal. The centrifuge effluent drains and sampling ports for the project were located in the next bay down at elevation 467'-0. This bay also contained the filter cake collecting belt and the vacuum filter drain line. The main bay at elevation 458'-6 contained the reagent system, the surge feeder, the pug mill and the control room. There was no Chetopa equipment in the main bay. The project haul truck traveled in the open bay immediately beneath the main project bay. There was no other equipment of any kind in this bay - it was an open roadway under the plant which was once used to load rail cars.

The successful operation of the project demanded quick and ready access between all of the bays with project equipment. The demonstration circuit operator and EI technicians would routinely be on the move between all of the project bays - especially between the control room and the outside to check on the status of the truck loading. (The truck was not manned during loading, but it would be necessary to advance the truck a few feet on three or four occasions during each loading.)

Prior to the start of the project, there was no quick way to get from the main project bay to the two bays immediately above, and there was no way to get from the main bay outside to monitor truck loading. In addition, the main personnel entrance to the Chetopa plant was over 100' from the main bay, and since that bay was in a remote, unused corner of the plant, getting from the plant entrance to the project bay required going up and down quite a few flights of stairs (Figure 18).

In order to provide fast access to all project equipment, we decided to incorporate two new sets of steps into the Mulled Coal circuit. One set was a new outside personnel entrance from ground elevation up to the control room, and the other connected the main bay to the one immediately above (Figures 19 and 20). The steps, along with a new door into the plant, would make it possible for our operators to travel from the slipstream take-off point to the haul truck in a matter of seconds.

There was no way to get the large pieces of project equipment (centrifuge, pug mill, surge feeder, reagent drums and control panel) into the plant without cutting holes in the plant siding. At the conclusion of the project, the equipment would have to be removed through the same openings. Also, there would be a need from time to time to hoist additional drums of reagent up into the main project bay. In order to get this equipment in and out, it would be necessary to open up the plant siding at elevations 458'-6" and 476'-0".

Drummond felt that they would also be able to use the same openings to move their own equipment and supplies in and out of the plant. It was decided that we would install permanent hoist doors at the appropriate locations, and that the hoist beam would be located at the highest possible plant elevation which was in line with the new hoist doors (Figure 19).

Figure 18

CHETOPA PREPARATION PLANT GENERAL ARRANGEMENT

Figure 9

ACCESS STEPS & HOIST DOORS

Figure 20
ACCESS STEPS

3.3.9 Circuit Control Design

The Mulled Coal circuit would rarely be used on a stand-alone basis. It would most commonly be used as a final product conditioning step in a standard or advanced fine coal cleaning circuit, so we wanted to demonstrate a control circuit which used equipment and strategies similar to the systems used in modern coal preparation plants.

The design of the control circuit was based on the following considerations:

1. The Mulled Coal circuit control was to be completely independent of the control circuit for the overall Chetopa plant. In commercial practice, the two control circuits would have been integrated, but because of the experimental nature of the demonstration, we wanted to try out some fairly sophisticated controls and data acquisition and management which would not be used for normal commercial installations. We also wanted to be in complete control of the system at all times.

We did not want any interruptions in the demonstration circuit to affect the overall Chetopa plant in any way, and we did not want any interruptions in the Chetopa plant (emergency shutdowns, etc.) to affect the operation of the Mulled Coal circuit in any way.

Other than the slipstream take-off point, the only physical connection between the two circuits was that the main power line to the Mulled Coal circuit originated in the overall plant motor control center. Therefore, if the overall plant lost power, the Mulled Coal circuit would lose power.

2. In order to be consistent with the type of equipment used to control modern coal preparation plants, the Mulled Coal circuit would be provided with a standard motor control center which could be operated in a manual mode. However, under normal circumstances, the circuit would be controlled with a programmable logic controller which was interfaced with a captive PC which was used for data entry, data acquisition and data storage. The PLC/PC system could be operated in either a full automatic or semi-automatic mode. This system would allow for three separate methods of operation. It was highly unlikely that any malfunction in the control system would result in lost production, and the system gave us the option of experimenting with a number of different methods of operation.
3. The PLC/PC system was to be provided with an off-the-shelf industrial automation software package which would operate in a Windows environment, and would give us the following capabilities.
 - (a) Data Acquisition - Communicate with I/O devices in the PLC and gather real time data on motor loads, valve settings, reagent flow and moisture readings.

- (b) Data Presentation - Provide a series of simple and clear graphic display screens which would allow us to start, stop, and adjust the circuit, monitor the circuit in real and historical time, and adjust control logic.
 - (c) Data Control - Automatically apply algorithms that maintain process values within pre-determined limits.
 - (d) Alarming - Recognize and interpret exceptional events (overloads, circuit imbalance, etc.) and provide the operator with visual and audible alarms that the circuit or individual components were not performing within acceptable limits.
 - (e) Data Archiving - Store acquired data points in such a way that they could be retrieved from files at a later date and used to create trend displays of historical data.
4. Process Control Design - Since feed moisture had the most profound effect on Mulled Coal quality, we decided to control the process with a loop which would automatically adjust reagent dose based on feed moisture.

Moisture data was to be provided to the loop with an on line moisture analyzer which was guaranteed to continuously monitor feed moisture with an accuracy of 0.5% (at the nominal set point of 23% moisture). Moisture data was interpreted by the computer, and reagent flow was automatically adjusted with an algorithm which produced the flow rates shown in Table II. This part of the loop controlled the process at a level feed rate.

Reagent dose also had to be adjusted because of changes in feed rate. Due to the short duration of the project and some space limitations, it was not economically feasible to install equipment specifically designed to monitor feed rate (weight belts, o/o solids monitors, etc.). However, each truck load of Mulled Coal would be timed and weighed, and historical data would be available to show precise valve settings and motor loads throughout each loading cycle.

It was felt that, after some operating experience, we would be able to determine a predictable relationship between valve settings, motor loads and wet cake feed rate with enough accuracy to automatically adjust reagent dose. To begin the demonstration, we programmed in reagent dose offsets at 0.5 TPH increments which could be executed simply by clicking on a button on the computer screen.

5. Operating Voltages - The control circuit was somewhat complicated by the fact that the small size of some of the equipment prohibited the exclusive use of 480VAC, 3 phase motors which is a fairly standard utilization voltage in modern preparation plants. We were forced to provide circuits and control

Table II

REAGENT USAGE AT VARIOUS FEED RATES & MOISTURES								
% Moisture	20.00	20.20	20.40	20.60	20.80	21.00	21.20	21.40
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	9.87	9.96	10.05	10.13	10.22	10.31	10.39	10.48
6000	11.85	11.95	12.06	12.16	12.27	12.37	12.47	12.57
7000	13.82	13.95	14.07	14.19	14.31	14.43	14.55	14.67
8000	15.80	15.94	16.08	16.22	16.35	16.49	16.63	16.76
9000	17.77	17.93	18.09	18.24	18.40	18.55	18.71	18.86
% Moisture	21.60	21.80	22.00	22.20	22.40	22.60	22.80	23.00
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	10.56	10.64	10.73	10.81	10.89	10.92	10.89	10.86
6000	12.67	12.77	12.87	12.97	13.07	13.10	13.07	13.03
7000	14.78	14.90	15.02	15.13	15.25	15.28	15.24	15.20
8000	16.90	17.03	17.16	17.29	17.42	17.47	17.42	17.38
9000	19.01	19.16	19.31	19.46	19.60	19.65	19.60	19.55
% Moisture	23.20	23.40	23.60	23.80	24.00	24.20	24.40	24.60
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	11.37	11.88	12.39	12.90	13.40	13.90	14.39	14.89
6000	13.65	14.26	14.87	15.48	16.08	16.68	17.27	17.87
7000	15.92	16.64	17.35	18.06	18.76	19.46	20.15	20.84
8000	18.20	19.01	19.83	20.64	21.44	22.24	23.03	23.82
9000	20.47	21.39	22.31	23.21	24.12	25.02	25.91	26.80
% Moisture	24.80	25.00	25.20	25.40	25.60	25.80	26.00	
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	15.38	15.87	16.35	16.83	17.31	17.79	18.27	
6000	18.46	19.04	19.62	20.20	20.78	21.35	21.92	
7000	21.53	22.21	22.89	23.57	24.24	24.91	25.57	
8000	24.61	25.39	26.16	26.94	27.70	28.47	29.22	
9000	27.68	28.56	29.43	30.30	31.17	32.02	32.88	

equipment for 480VAC 3-phase, 220 VAC 3-phase, 220 VAC 1- phase, 110 AC 1 phase, 250 VDC and 5 VDC.

6. Contractor - The design of the control circuit was to be fairly complicated, and we did not want communications between contractors to become a problem, so we decided that we would seek a single contractor with the capability to design, build, test, install and start-up the control circuit.

3.3.10 Control Room Layout

Figures 21 and 22 show the layout of the control room and the way it fit into the main project bay at elevation 458'-6. The control room was tight for space, but it was necessary to maintain adequate walkways around the equipment in the main project bay, and the control room was designated to be the maximum size for the space remaining. There was adequate room for an operator in the area of the motor control center and computer, along with another person conducting laboratory test work at the work bench.

The control room was to be semi water and dust tight. The project was too short in duration to go to the expense of installing a completely tight and atmosphere controlled room. Our intention was to design a structure which would prevent water and dust from damaging the computer and lab equipment.

Maintaining the ceiling in a semi water tight condition was a challenge. Under normal circumstances, it would not have been much of a problem, but the Chetopa plant followed a clean-up procedure which resulted in a great deal of wash water flowing through the floor above the main project bay and onto the ceiling of the control room. In the plant, all spills and routine clean-up were handled with high pressure/high flow fire hoses. The coal washed away in this manner would work its way down through the floors of the plant until it ran through the bottom floor and outside; where it could eventually be picked up and moved with a front end loader. This was a good clean-up system, but unfortunately, the control room ceiling was directly in the path of all of the wash down water from the fine coal side of the plant -- which is most vulnerable to overflow and conveyor belt spills.

The wash down water did not bother us out in the project machinery bays. If water and coal fines were washed down on the equipment from above, we simply cleaned out our own bays with a fire hose. All of the project equipment had good paint jobs or was of plastic or stainless steel construction, and all electrical enclosures (junction boxes, E stops, disconnect switches, etc.) were of NEMA 4 design, so we could wash them down with high pressure hoses.

The control room walls and ceiling were fabricated with galvanized sheeting which was framed in with light angle and bar stock. All seams were welded and sealed from inside and outside. The galvanized sheet ceiling was provided with a heavy plastic vapor barrier which was installed like a bonnet. Above the bonnet was an oversized sheet of corrugated steel which was completely sealed on the outside.

Figure 21

Layout of Control Room

Figure 22

ELEV 458'-6
MACHINERY PLAN
STEPS LOCATION

REVISED 11/03/94

The corrugated sheet went in after we experienced some ceiling leaks during the run-in phase of the project. After that, we never had another problem, and we never had a dust problem, but we had to clean up the control room at least two times each operating shift.

3.3.11 Preliminary Sketches

The final design engineering task was to prepare a series of preliminary sketches of structural additions and the general arrangement of equipment which was to be installed in the various machinery bays. The sketches were to be presented to Drummond for approval, and they were to be used to solicit bids for detailed engineering, electrical contracting, and actual erection and installation of the equipment. They were also used to prepare a detailed bill of materials for the project.

Although some of these sketches appear elsewhere in this report, they are shown here again as part of the series. The series includes:

Figure 23	Schematic Flow Diagram
Figure 24	Machinery Plan at Elevation 476'
Figure 25	Machinery Plan at Elevation 467'
Figure 26	Machinery Plan at Elevation 458'
Figure 27	Machinery Elevations between Columns 1&2

3.4 Detailed Engineering

As a result of laboratory testing and the various design engineering tasks, we were able to identify specifications and sources for major equipment, and we were able to prepare preliminary bills of material for pipe parts, fabricated parts, structural steel and electrical parts. The preliminary bills of material along with the series of sketches of the project bays were used to solicit quotations from engineering, electrical, mechanical, and erection contractors.

3.4.1 Major Equipment Components

Screen Bowl Centrifuge

Manufacturer	Decanter Machine, Inc.
Model	18" x 42" Test Machine
Drive	50 HP, 460 Vac-3P, Turbo Clutch

Pug Mill

Manufacturer	Patterson Pump Company
Model	No. 18 Pug Mill Mixer
Drive	7-1/2 HP, 230/460 Vac-3P, Variable Frequency

Figure 23

POC PROJECT
SCHEMATIC FLOW DIAGRAM

DATE: JULY 5, 1994

REVISED
11/04/94

Figure 24
ELEV 476'-0
MACHINERY PLAN

Figure 25

ELEV 467'-0
MACHINERY PLAN

REVISED 11/4/94

Figure 26

ELEV 458'-6
MACHINERY PLAN
STEPS LOCATION

REVISED 11/03/94

Figure 27

MACHINERY ELEVATIONS **Between Columns 1 & 2**

Surge Feeder

Manufacturer	Acrison, Inc.
Model	140-R
Drive	Variable Speed DC

On-Line Moisture Monitor

Manufacturer	Berthold Systems, Inc.
Model	Mono-Moist 5800

Knife Gate Valve

Manufacturer	Orbe Valve
Size	4", V-Port
Actuation	Air
Accessories	Auto Position & Position Feedback

Compressor

Manufacturer	Ingersoll-Rand
Model	T10220P
Drive	2 HP, 110/220 Vac-1P

Reagent Pump

Manufacturer	Micropump Corporation
Model	HG 132

Reagent Flow Meter

Manufacturer	Max Machinery, Inc.
Model	221

Programmable Logic Controller

Manufacturer	Omron Electronics, Inc.
Model	C200H

Computer

Manufacturer	Gateway 2000
Model	486 DX2-66

Automation Software

Manufacturer
Model

Intellution, Inc.
FIX DMACS

3.4.2 Bills of Material

Tables III through VII show the preliminary bills of material for the project. These initial documents were not 100% complete and not all specifications were exact. They were based on design engineering considerations and were only intended to be a starting point. Initially they were used to clarify bid requests from engineering, electrical and mechanical contractors. As the project progressed they were revised and expanded, and they were used internally to track cost and delivery.

3.4.3 Detailed Engineering

The series of project sketches in Figures 18 through 27, the bills of material in Tables III through VII and a narrative description of the scope of work were sent to several engineering firms for bids. DeBardeleben and Associates, a local construction and erection engineering firm was selected to do the work.

The scope of work included:

1. Examine the structural steel in all bays housing project equipment and make recommendations for additions or improvements.
2. Verify measurements and equipment locations shown on EI sketches and drawings.
3. Design structural steel additions, steps, the control room, hoist doors and access doors.
4. Prepare a set of detailed construction and erection drawings.

Slipstream Take-Off Point

For several months we were considering alternative locations for the slipstream take-off point. Originally it was to be located directly beneath the flotation cell launder. From that point the slipstream would be piped a distance of about 30' to the centrifuge. We were concerned about solids settling out (when the demonstration circuit was not operating), and plugging off the first ball valve. From the original location we would have been able to flush out the first ball valve with a fire hose directed from the open top of the launder.

We ultimately decided to locate the take-off point as close as possible to the centrifuge, and provide dedicated flush water lines to clear up any plugging problems. There were distinct advantages to being close to the centrifuge, and, in practice, we never experienced any plugging problems which could not be cleaned up with the flush water lines.

Table III

PRELIMINARY BILL OF MATERIALS						
Pipe & Plumbing Supplies						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Slip Stream Take-Off						
4" Steel Pipe Tap By 12" Long	1	Sch 40	X			
1" Weld On Pipe Tap	1		X			
150 lb. Floating Flange - 4"	1		X			
4" Stainless Steel Ball Valve	1	Flanged Ends	X			
4" x 3" SDR11 Tapered Reducer	1	Flanged Ends	X			
3" SDR Flange Adapter	2		X			
3" SDR Pipe by 36" Long, Plain Ends	1		X			
1" Saddle Type Pipe Tap For 3" Pipe	1		X			
3" Victaulic Couplings	2		X			
3" SDR 45° Ell, Fabricated, Flanged En	1		X			
3" SDR 90° Ell, Fabricated, Flanged En	1		X			
1" High Pressure Hose By 40' Long	1		X			
Connect Lines To Fresh Water System	Lot	1" Ball Valves, Fittings, etc.	X			
Centrifuge Push Water Line						
20' 3/8" Hose, Fittings, etc.	Lot		X			
Centrifuge Effluent Sampling Ports						
6" Flexible Hose By 3' Long	2		X			
6" To 4" Tapered PVC Reducer	2	Sch 40	X			
4" To 2" Tapered PVC Reducer	2	Sch 40	X			
2" x 2" x 2" PVC Tees	2	Sch 40	X			
2" x 2" x 1" PVC Tee	1	Sch 40	X			
2" PVC Ball Valves	3	Sch 40	X			
1" PVC Ball Valve	1	Sch 40	X			
2" PVC Pipe By 5' Long	1	Sch 40	X			
1" Hose & Fittings By 2' Long	1	Sch 40	X			
Fittings, Adapters, Glue, etc.	Lot		X			
2" Steel, Sch 40, Weld On Pipe Tap	1	Sch 40	X			

Table III
(Continued)

PRELIMINARY BILL OF MATERIALS						
Pipe & Plumbing Supplies						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Compressor To Knife Gate Valve						
30' 3/8" High Press Hose	Lot	Push Lock Pipe Fittings	X			
Airline Filter	1		X			
Nitrogen Cylinder To Knife Gate Valve						
Nitrogen Air Regulator Valves	1		X			
20' 1/4" High Press Hose & Fittings	Lot		X			
Control Room To Reagent Sprays						
3/8" 200 PSI Hose	120'		X			
3/8" & 1/4" Push Lock Fittings	Lot		X			
Reagent Delivery System						
Drum Vents	2		X			
3/4 " Drum Taps	2		X			
Suction Filter	1		X			
0 - 150 PSI Relief Valve	1		X			
0 - 100 PSI Pressure Gauges	2		X			
1/4" Ball Valves	6		X			
1/4" Pressure Regulators	6		X			
5 GPH, 120°, Fan Spray Nozzles	3		X			
5 GPH Fog Nozzles	3		X			
Misc. Fittings & Tubing	Lot		X			

PRELIMINARY BILL OF MATERIALS					
Fabricated Parts					
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost
Outside Steps					
48" Steps, Landings & Handrails	Lot	Elev. 438' -6 to 458' -6	X		
Structural Steel Supports For Above	Lot		X		
Inside Steps					
36" Steps & Handrails	Lot	Elev. 458' -6 To 467'	X		
Hoist Doors					
4" Rectangular Tubing	80'	Framing	X		
12" Channel	40'	Framing	X		
Industrial Hinges	8		X		
Steel Pipe & Angle	Lot	Personnel Guards	X		
Mono-Moist Mounting Brackets					
2" Angle & Bar Stock	Lot	Field Fabricated	X		
Machined Mounting Plates	Lot	Scin. Detector & Source	X		
Centrifuge Chute					
1/4" UHMW/PVC Sheet	2	24" x 24"	X		
1/4" UHMW/PVC Sheet	2	24" x 6"	X		
Chute From Centrifuge To Feeder					
24" to 18" Tapered Funnel, Flanged En	1	High Density Polyethylene	X		
18" SDR Pipe Section, Flanged Ends	2	High Density Polyethylene	X		
Milled Coal Chute					
Rectangular PVC Transition Piece	1		X		
Half Round 18" Dia. Liner x 60"	1	High Density Polyethylene	X		
Light Angle & Steel Framing	Lot		X		

Table IV
(Continued)

PRELIMINARY BILL OF MATERIALS						
Fabricated Parts						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Surge Feeder Tube Extension						
UHMW PVC, Machined Per Drawing	1		X			
Reagent Spray Manifold						
(2) Pieces Sheet Metal	Lot	Bent & Punched Per Dwg.	X			
Reagent Pump & Flow Meter Cabinet						
Sheet Metal Cabinet	Lot	Fabricated Per Drawing	X			
Doors						
Outside Access Door	Lot	Per Drawing	X			
Control Room Door	Lot	Per Drawing	X			
Control Room						
1/8" Galvanized Steel Sheeting	10	4' x 8'	X			
30" x 40" Plexiglass "Window"	1		X			
Light Angle & Steel Framing	Lot		X			
12' x 12' Heavy Plastic Bonnet			X			
10' x 10' Corrugated Sheeting			X			
Surge Feeder Hopper						
3/32" Sheeting, Bent Per Drawing			X			
Water Barrier Where Chute Intersects Floor						
20" x 36" Tapered Sheet Metal Cone		Field Fabricated	X			
Machinery Guards						
Centrifuge	2	Per Drawing	X			
Pug Mill	1	Per Drawing	X			

PRELIMINARY BILL OF MATERIALS

Application/Description

Qty

Specs

Furnished By

EI Cont

Vendor

Cost

Status

Centrifuge Supports

12" WF26 x 10' Long

2

X

8" Channel x 8' Long

1

Floor Supports

X

Hoist Beam

12" WF26 x 14' Long

X

Flooring

4' x 8' 1/4" Checkered Floor Plate

2

Replace Bad Flooring

X

Outside Steps

Beam & Knee Braces

Lot

Per Drawing

X

Floor Supports

8" Channel x 40'

Xtra Supports

X

Table VI

PRELIMINARY BILL OF MATERIALS						
Electrical Equipment						
Application/Description	Qty	Specs	Furnished By EI Cont	Vendor	Cost	Status
Chetopa MCC To Project MCC						
150 Amp, 480 Volt AC Circuit Breaker	1		X			
2" Conduit & Fittings	120'		X			
Phase Wires & Ground Wire	480'		X			
Project MCC						
Control Cabinet	1	60" x 48" x 16"	X			
150 Amp Main Circuit Breakers	1		X			
Starters & Circuit Breakers For Equip.	Lot		X			
Distribution Transformer		480-120/240 Volt AC	X			
Current Trans. With 4-20 ma Output	Lot		X			
Constant Voltage Regulator			X			
Push Buttons & Selector Switches	Lot		X			
Misc Relays & Switches	Lot		X			
DC Power Supply	1		X			
Mushroom E Stop	1		X			
Programable Logic Controller	1		X			
Backplane	1		X			
I/O Modules	Lot		X			
I/O Module Computer Interface	Lot		X			
UPS	1		X			
Control Panel Wiring, Fuses etc.	Lot		X			
Wiring Diagrams	Lot		X			
Motor & Instrument Leads						
3/4" Conduit & Fittings	400'		X			
Motor Leads	600'		X			
Control Wire	1500'		X			

PRELIMINARY BILL OF MATERIALS

Electrical Equipment

Application/Description	Qty	Specs	Furnished By EI Cont	Vendor	Cost	Status
Misc. Electrical Equipment						
Machinery E Stops	3		X			
Machinery Fused Disconnects	3		X			
Insulating Floor Mats	5		X			
Drum Heaters	2		X			
110 Volt Outlets	7					
Overhead Lights	3		X			
Electric Heater	1		X			

Table VII

PRELIMINARY BILL OF MATERIALS						
Misc. Equipment						
Application/Description	Qty	Specs	Furnished By EI Cont	Vendor	Cost	Status
Machinery Cart	1	36" x 72" 36" High	X			
Lab Bench	1	60" x 20"	X			
Drum Cradels	2		X			
Moisture Balance	1		X			
3000 Gram Electronic Balance	1		X			
K A Muller	1		X			
Electric Clock	1		X			
RO-TAP Vibrating Screen	1		X			
Hand Tools & Power Tools	Lot		X			
Tool Cabinet	1		X			
Computer Desk 48" x 30"	1		X			
Dot Matrix Printer	1			X		
Fire Extinguishers	3		X			
First Aid Kit	1		X			

Moisture Monitor Mounting Brackets

The original design of the mounting plate and brackets for the components of the on-line moisture monitor severely restricted access at the key intersection where the surge feeder discharged into the pug mill. The mounting plate was to be structurally attached to the machine table for the surge feeder.

We ultimately decided to attach the mounting brackets to the base of the pug mill and eliminate the large mounting plate. Space was very limited in this area, so we decided that the changes would be fabricated by EI technicians in the field. The final design greatly increased access at this critical intersection.

3.4.4 Electrical Controls

The design considerations outlined in 3.3.9, the electrical bill of materials in Table VI and a narrative description of the scope of work were presented to several contractors for competitive bidding. The scope of work was to include the detailed design of the control circuit and all of its components, furnishing all control circuit materials (including the PLC, the PC and programming services), building and wiring the motor control center and computer interface, testing each component at the point of manufacture, installing the circuit at the Chetopa plant (including all motor leads and control wires) and technical assistance with start up and system adjustments.

A contract was awarded to Hy-Tech Sales, Inc., with a subcontract to Elcon Technologies and drawings of the circuit (as designed and built by the contractor) are shown in Figures 28 through 31.

3.5 Procurement

For purposes of erecting and installing the Mulled Coal circuit at the Chetopa plant, EI acted as the general contractor. In its role as general contractor, EI was responsible for the procurement of all equipment and supplies, except for the structural steel, heavy fabrications, and electrical components identified as subcontractor furnished items in Tables III through VII.

Major equipment components were procured well in advance with deliveries scheduled as they were needed. For all other materials such as pipe and electrical supplies, chute liners and light machining, local vendors were identified who could furnish whatever was needed on short notice. Space in the project bays was limited, so equipment and materials were brought to the job site only a few days before they were to be installed.

Due to the short duration of the project (only 6 months) we decided to lease major equipment components wherever possible. We were very fortunate in that Decanter Machine decided to donate the use of the screen bowl centrifuge - the single most expensive component of the circuit. We were able to lease the surge feeder, the on-line moisture monitor and the pug mill. All other equipment, supplies and services were purchased outright.

Figure 28

ELECTRICAL CONTROL CIRCUIT-1

ELECTRICAL CONTROL CIRCUIT-2

[illegible]

ELECTRICAL CONTROL CIRCUIT-3

4.0 SUMMARY

During this fourth quarter of the contract period, activities were underway under Tasks 2 and 3. Sufficient characterization of the bench-scale testing and pilot-plant testing results enabled the design and procurement activities to move forward. On that basis, activities in the areas of design and procurement that had been initiated during the previous quarter were conducted and completed.