QUARTERLY TECHNICAL PROGRESS REPORT NO. 26

For

ENGINEERING DEVELOPMENT OF ADVANCED PHYSICAL FINE COAL CLEANING TECHNOLOGIES – FROTH FLOTATION

Prepared for
U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
Pittsburgh, Pennsylvania

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With
Ohio Coal Development Office
Babcock & Wilcox
Consolidation Coal Company
Center for Research on Sulfur in Coal
EIMCO Process Equipment Company
Illinois State Geologic Survey
Kentucky Energy Cabinet Laboratory
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## TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Scope of this Document
1.2 Overall Project Scope
1.3 Work Executed at Different Locations

2.0 TASK 2 PRELIMINARY CONCEPTUAL DESIGN

2.1 Overview and Scope
2.2 Review of Work Completed This Quarter

3.0 TASK 3 CRITICAL AREA DETERMINATION

3.1 Overview and Scope
3.2 Review of Work Completed This Quarter

4.0 TASK 4 TEST PLAN FORMULATION

4.1 Overview and Scope
4.2 Review of Work Completed This Quarter

5.0 TASK 5 BENCH-SCALE PROCESS TESTING

5.1 Overview and Scope
5.2 Review of Work Completed This Quarter

6.0 COMPONENT AND UNIT OPERATIONS DEVELOPMENT

6.1 Overview and Scope
6.2 Review of Work Completed this Quarter

7.0 EVALUATION OF BENCH-SCALE AND COMPONENT TEST RESULTS

7.1 Overview and Scope
7.2 Work Complete this Quarter

8.0 REVISED CONCEPTUAL DESIGN OF SEMI-WORKS PLANT

8.1 Overview and Scope
8.2 Review of Work Completed this Quarter

9.0 POC MODULE DESIGN

9.1 Overview and Scope
9.2 Review of Work Completed this Quarter

10.0 POC MODULE FABRICATION

10.1 Overview and Scope
10.2 Review of Work Completed this Quarter
# Table of Contents

(continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.0 POC Installation and Start-Up</td>
<td>14</td>
</tr>
<tr>
<td>11.1 Overview and Scope</td>
<td>14</td>
</tr>
<tr>
<td>11.2 Review of Work Completed this Quarter</td>
<td>14</td>
</tr>
<tr>
<td>12.0 POC Test Plan Formulation</td>
<td>15</td>
</tr>
<tr>
<td>12.1 Overview and Scope</td>
<td>15</td>
</tr>
<tr>
<td>12.2 Review of Work Completed this Quarter</td>
<td>15</td>
</tr>
<tr>
<td>13.0 POC Operation</td>
<td>16</td>
</tr>
<tr>
<td>13.1 Overview and Scope</td>
<td>16</td>
</tr>
<tr>
<td>13.2 Review of Work Completed this Quarter</td>
<td>16</td>
</tr>
<tr>
<td>14.0 POC Operations Analysis</td>
<td>17</td>
</tr>
<tr>
<td>14.1 Overview and Scope</td>
<td>17</td>
</tr>
<tr>
<td>14.2 Review of Work Completed this Quarter</td>
<td>17</td>
</tr>
<tr>
<td>15.0 Final Semi-Works Conceptual Design</td>
<td>18</td>
</tr>
<tr>
<td>15.1 Overview and Scope</td>
<td>18</td>
</tr>
<tr>
<td>15.2 Review of Work Completed This Quarter</td>
<td>18</td>
</tr>
<tr>
<td>16.0 POC Module Removal</td>
<td>35</td>
</tr>
<tr>
<td>16.1 Overview and Scope</td>
<td>35</td>
</tr>
<tr>
<td>16.2 Review of Work Complete This Quarter</td>
<td>35</td>
</tr>
<tr>
<td>FIGURE</td>
<td>TITLE</td>
</tr>
<tr>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>1.1</td>
<td>Project Organization Chart</td>
</tr>
<tr>
<td>1.01</td>
<td>Simplified Block Diagram of the POC Process</td>
</tr>
<tr>
<td>1.02</td>
<td>Pittsburgh No. 8 Seam Coal, Box-Beihnenken Matrix Results</td>
</tr>
<tr>
<td>1.03</td>
<td>Upper Freeport Seam Coal, Box-Beihkenen Matrix Results</td>
</tr>
<tr>
<td>1.04</td>
<td>Illinois No. 6 Seam Coal, Box Beihnenken Matrix Results</td>
</tr>
<tr>
<td>1.05</td>
<td>Pittsburgh No. 8 Seam Coal Average Performance During 24-Hour Demonstration Run</td>
</tr>
<tr>
<td>1.06</td>
<td>Upper Freeport Seam Coal Average Performance During 24-Hour Demonstration Run</td>
</tr>
<tr>
<td>1.07</td>
<td>Illinois No. 6 Seam Coal Average Performance During 24-Hour Demonstration Run</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Task and the Responsible Team Member</td>
</tr>
<tr>
<td>1.01</td>
<td>Head Analysis for Washability Samples</td>
</tr>
<tr>
<td>1.02</td>
<td>Contributions to Energy Loss and Pyritic Sulfur Removal During 24-Hour Demonstration Runs</td>
</tr>
<tr>
<td>1.03</td>
<td>Capital Requirements and First Year Operating and Maintenance Costs for a 200 TPH Advanced Froth Flotation Plant (7560 Hours)</td>
</tr>
<tr>
<td>1.04</td>
<td>Advanced Froth Flotation Economics (Annualized Basis)</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

A study conducted by Pittsburgh Energy Technology Center of sulfur emissions from about 1,300 United States coal-fired utility boilers indicated that half of the emissions were the result of burning coals having greater than 1.2 pounds of \( \text{SO}_2 \) per million BTU. This was mainly attributed to the high pyritic sulfur content of the boiler fuel. A significant reduction in \( \text{SO}_2 \) emissions could be accomplished by removing the pyrite from the coals by advanced physical fine coal cleaning.

An engineering development project was prepared to build upon the basic research effort conducted under a solicitation for research into Fine Coal Surface Control. The engineering development project is intended to use general plant design knowledge and conceptualize a plant to utilize advanced froth flotation technology to process coal and produce a product having maximum practical pyritic sulfur reduction consistent with maximum practical BTU recovery.

1.1 Scope of this Document

The Department of Energy (DOE) awarded a contract entitled "Engineering Development of Advanced Physical Fine Coal Cleaning Technology - Froth Flotation", to ICF Kaiser Engineers with the following team members, Ohio Coal Development Office, Babcock and Wilcox, Consolidation Coal Company, Eimco Process Equipment Company, Illinois State Geological Survey, Virginia Polytechnic Institute and State University, Process Technology, Inc. The organizational chart for this project is presented in Figure 1.1.

This document a quarterly report prepared in accordance with the project reporting requirements covering the period from January 1, 1995 to March 31, 1995. This report provides a summary of the technical work undertaken during this period, highlighting the major results. A brief description of the work done prior to this quarter is provided in this report under the task headings.

1.2 Overall Project Scope

The overall project scope of the engineering development project is to conceptually develop a commercial flowsheet to maximize pyritic sulfur reduction at practical energy recovery values. This is being accomplished by utilizing the basic research data on the surface properties of coal, mineral matter and pyrite obtained from the Coal Surface Control for Advanced Fine Coal Flotation Project, to develop this conceptual flowsheet. The conceptual flowsheet must be examined to identify critical areas that need additional design data. This data will then be developed using batch and semi-continuous bench scale testing. In addition to actual bench scale testing, other unit operations from other industries processing fine material will be reviewed for potential application and incorporated into the design if appropriate.

The conceptual flowsheet will be revised based on the results of the bench scale testing and areas will be identified that need further larger scale design data verification, to prove out the design. The
Figure 1-1

Project Organization Chart

Department of Energy

ICF Kaiser Engineers (ICF KE)
Project Manager

Project Advisory Committee

Consolidation Coal
Team Members
Technical Support

Process Technology
Process Design Evaluation

Babcock & Wilcox
Process Design Evaluation

ICF KE
Project Design Engineering
Project Procurement
Construction Mgmt.

VPI
Column Cell Optimization

EIMCO
Dewatering Clarification

Process Developers
Advanced Flotation Machine
proof-of-concept will be accomplished by designing, constructing, operating and testing a 2-3 ton per hour proof-of-concept plant. This plant will be designed for continuous operation and will include two consecutive 5 days, 24 hour per day runs on each of the three test coals to demonstrate process performance on a commercial basis.

The data from the basic research on coal surfaces, bench scale testing and proof-of-concept scale testing will be utilized to design a final conceptual flowsheet.

The economics of the flowsheet will be determined to enable industry to assess the feasibility of incorporating the advanced fine coal cleaning technology into the production of clean coal for generating electricity. This concept should provide an ability to reduce sulfur oxide emissions more economically than FGD systems when compared on a dollar per ton of sulfur removed basis.

1.3 Work Executed at Different Locations

The project team consists of research and engineering groups at ICF Kaiser Engineers, Babcock and Wilcox, Consolidation Coal Company, Eimco Process Equipment Company, Illinois State Geological Survey, Virginia Polytechnic Institute and State University, Process Technology, Inc. and Michigan Technological University Institute of Materials Processing with ICF Kaiser Engineers as the prime contractor with DOE. The work being conducted by different organizations is based upon their area of expertise and this has been incorporated into the project Work Plan. The work undertaken by the different organizations is identified in Table 1.1. This report is prepared in an integrated manner combining work done by each organization by task. This is considered to be a more effective way of presenting the technical data developed by each organization.

Table 1.1
Task and the Responsible Team Member

<table>
<thead>
<tr>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
<th>Task 5</th>
<th>Task 6</th>
<th>Task 7</th>
<th>Task 8</th>
<th>Task 9</th>
<th>Task 10</th>
<th>Task 11</th>
<th>Task 12</th>
<th>Task 13</th>
<th>Task 14</th>
<th>Task 15</th>
<th>Task 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Planning</td>
<td>Preliminary Conceptual Design</td>
<td>Determination of Critical Areas</td>
<td>Test Plan Formulation</td>
<td>Bench Scale Testing</td>
<td>Component Development</td>
<td>Analysis of Test Results</td>
<td>Revised Conceptual Design</td>
<td>POC Module Design</td>
<td>POC Procurement and Fabrication</td>
<td>POC Installation and Startup</td>
<td>POC Test Plan Formulation</td>
<td>POC Testing and Operation</td>
<td>Analysis of POC Test Results</td>
<td>Final Conceptual Design</td>
<td>POC Module Removal</td>
</tr>
</tbody>
</table>
2.0 TASK 2 PRELIMINARY CONCEPTUAL DESIGN

2.1 Overview and Scope

The previous completion of this task resulted in the preliminary conceptual design of a 20TPH semi-works advanced froth flotation facility. The non-site-specific plant was designed using the best available information and technology to achieve continuous, steady-state process operation with 90% availability. The process plant is a fully instrumented, integrated, stand-alone facility. A greenfield site was assumed for the plant.

Throughout the project, the work was organized along a task/sub-task basis with each sub-task logically assigned to provide necessary information for the next sub-task, ultimately resulting in completion of the conceptual design. For Task 2, the first sub-task determined the design criteria needed to meet or exceed the advanced froth flotation process specifications. At completion, work under this sub-task provided information to design the flowsheet of the process, and provided an energy and material balance of all process streams. A list of all major process equipment was prepared and used as a basis for a factored estimate for the capital, operating and maintenance costs of the semi-works process and plant.

ICF Kaiser Engineers, assisted by the project sub-contractors and Technical Support Group, was responsible for the performance and completion of this task. This conceptual design is the basis for Tasks 3, 4, 5, and 6 and will be revised in Task 8 for use as a basis for the 2-3TPH POC module design in Task 9.

2.2 Review of Work Completed This Quarter

On August 15, 1989, DOE approved Task 1.2 as submitted. With this as a basis, ICF KE and the team members proceeded with the remainder of the project. No additional work was planned nor completed during this quarter.
3.0 TASK 3 CRITICAL AREA DETERMINATION

3.1 Overview and Scope

Work performed during the conceptual design of Task 2 identified areas where uncertainties exist in the design of the unit operations for the advanced froth flotation process. Some of these problem areas could not be solved based on currently available information or technology. The objective of this task was to determine those critical areas where more information would be necessary and outline the work needed to obtain the design information.

A design deficiency list was generated, and the project team determined the parameters needed for final design of the unit operation - either by further engineering analysis or by experimental data obtained from bench-scale tests. Other solids processing industries, such as phosphate and clay beneficiation, were examined to assess the means by which they effectively process ultra fine particles.

Each identified design deficiency was then ranked according to its relative importance to the successful continuous operation of the advanced froth flotation process. Both a technical and economic analyses of the consequences of not being able to gather the required design information for each deficiency was evaluated.

ICF Kaiser Engineers, Consolidation Coal and the other members of the Technical Support Team (B&W, VPI and EIMCO) have contributed to this task. The process deficiencies identified in this task will be addressed in Tasks 4, 5, and 6 through additional engineering computation and analysis and experimental techniques.

3.2 Review of Work Completed This Quarter

The final report of this task has been submitted to DOE. No additional work was planned nor completed during this quarter.
4.0 TASK 4 TEST PLAN FORMULATION

4.1 Overview and Scope

Work completed in this task produced the criteria for additional engineering analysis, computation and detailed experimental bench-scale testing for areas of uncertainty identified in Task 3. The engineering analysis, computation, bench-scale testing and component development was formulated to produce necessary design information to define a commercially operating system.

In order to produce the required information by means of bench-scale testing and component development, a uniform coal sample was procured. After agreement with DOE, a selected sample of coal from those previously listed was secured.

The test plan was developed in two parts. The first part listed procedures for engineering and computational analyses of those deficiencies previously identified that could be solved without bench scale testing. Likewise, the second part prepared procedures for bench-scale testing and component development for those deficiencies previously identified in Task 3.

The first part, engineering analysis and computation, provided for means of employing presently known theory from other industries to address deficiencies. This included examinations of literature and contacting proven experts and operating personnel in fields related to this deficiency. From the information gathered, engineering calculations will be utilized to resolve this type of deficiency.

The second part, bench-scale testing and component development, became necessary when the part one information was unavailable or when the theory had never been commercially applied. Justification for the test work was provided to show that technical data and process needs could only be obtained by test work and that the test work results would produce necessary information to define a commercially operating system.

The test work planned was based upon non-continuous and/or semi-continuous bench-scale units of general laboratory design and would include only those unit operations identified as deficiencies in Task 3.

The detailed, quantified tests addressed obtaining data necessary for solving problems uncovered in the deficiency review. Each identified deficiency had a plan developed to address the reason for the testing, the means for the test matrix to obtain results and the expected results. Each test plan established procedures, adhering as much as possible, to known and industry-acceptable procedures for sampling and data collection. Raw data collection would be reduced to minimize expenses and to better be able to compare results and obtain meaningful information, especially scale-up factors.
The Development Test Plan for both parts one and two contained schedules, manpower requirements, and resources necessary to obtain information to define a commercially available system.

The plan for use of the team members was developed to comply with the results of the DOE uniform coal sample procurement and storage procedures. The quantity of coal necessary for each testing program was calculated. A sample of all three of the referenced coals was to be obtained, preferably from the same source as the Surface Control contractor. This coal would be stored and handled as outlined in the coal procurement and storage plan. These procedures, when properly followed, should minimize physical and chemical changes to the raw coal.

4.2 Review of Work Completed This Quarter

The Task 4 Report was submitted to DOE as a final report. No additional work was planned nor completed during this quarter.
5.0 TASK 5 BENCH-SCALE PROCESS TESTING

5.1 Overview and Scope

The overall goal of Task 5, "Bench-Scale Process Testing" is to develop the necessary unit operation design and process performance data required to 1) reduce or eliminate the technical and engineering uncertainties of the preliminary 20TPH advanced location semi-works plant and 2) design, build and operate a 2-3 TPH advanced flotation POC module.

The unit operation performance and process design information required to support development of the advanced flotation process is being examined in a multi-tier program at B&W and Process Technology, Inc. Laboratory scale studies are being conducted in several key process areas - conventional precleaning of the raw coal, microgrinding of the pre-cleaned coal, advanced froth flotation of the fine coal and dewatering of the product streams. The results of these studies are then being used to guide small, semi-continuous and continuous testing of the key unit operations at approximately 100 lb/hr.

The bench-scale and semi-continuous process design evaluation test programs will provide detailed information for developing process material and energy balances. The material balance data will be used to correctly design and size the equipment for the POC module. The energy balance information will allow for estimation the cost effectiveness of the design.

The bench-scale test programs will also identify the optimum conditions for microgrinding the coal for maximum pyritic sulfur rejection in advanced flotation and the most promising advanced flotation technique which will then be integrated into the overall processing scheme. The 100 lb/hr test program will provide verification of the laboratory tests results and demonstration that these results can be scaled-up for application in the 20TPH semi-works plant design.

Both the bench-scale, semi-continuous and continuous process design evaluation tests will serve as critical reviews of the preliminary process flowsheet. Process deficiencies and limitations discovered in these programs will require modification of the original conceptual flowsheet. This information will aid in identifying solutions to the successful implementation of advanced flotation technology.

The bench-scale and process testing consists of eleven major subtasks performed over a period of 12 months.

5.2 Review of Work Completed This Quarter

This task has been completed and the results of this task are reported in the Task 7 report. No additional work was planned nor completed during this quarter.
6.0 COMPONENT AND UNIT OPERATIONS DEVELOPMENT

6.1 Overview and Scope

The Task 6 effort involves three main elements including column cell development, flotation circuit testing and flotation cell modeling. The work outlined is to research column designs and operation parameters in developing an optimized column flotation cell (OCFC) to meet the overall program objectives. The test results obtained through this effort will be evaluated against the results obtained from the round-robin test program in Task 5. Any design parameters or operating conditions that are unique with the round-robin test winner that were not evaluated as part of the optimized column development work will be reviewed and tested so as to incorporate all possible scenarios in presenting DOE with the best available flotation process for use in the 2 to 3 ton per hour POC.

Following development of the OCFC, various flotation circuit configurations will be evaluated to determine the "best" circuit design for the 2 to 3 ton per hour POC. Single and multiple stage flotation, grab and run, rougher/scavenger/cleaner, etc., test circuits will be tested as part of this effort. Upon completion of this test work, the "best" possible flotation cell will have been tested in a number of possible flotation circuit designs to possibly provide the "best" flotation approach in meeting the design criteria.

In conjunction with the flotation test effort, model development work will be conducted to provide a tool in evaluating the various flotation circuit configurations and in predicting flotation performance. The model will be useful in selecting operating conditions in the POC and in evaluating the performance of the POC.

6.2 Review of Work Completed this Quarter

This task has been completed and the results of this task are reported in the Task 7 Report. No additional work was planned or completed during this quarter.
7.0 EVALUATION OF BENCH-SCALE AND COMPONENT TEST RESULTS

7.1 Overview and Scope

A bench-scale and component testing report was prepared and submitted to DOE after completing Task 5 and Task 6.

The report included the preparation, presentation and analysis of all the experimental data obtained in the bench-scale and component unit operations, development and testing. A comparison of the results obtained with the expected limitations and deficiencies that occurred from bench-scale testing was compiled.

Following the evaluation of the bench-scale and component testing results, a residual needs analysis was prepared. This was prepared after comparing results learned in Tasks 5 and 6 with the original residual needs analysis.

Finally, a bench-scale testing summary was prepared. It specifically addressed the results of the bench-scale component testing in respect to the information necessary to define a commercially operating system. This included equipment selection, sizing, evaluation and operation to achieve both coal cleaning as well as the cost of system operation.

7.2 Review of Work Completed this Quarter

This task has been completed and the Task 7 Report submitted to DOE in its final version. No additional work was planned or completed during this quarter.
8.0 REVISED CONCEPTUAL DESIGN OF SEMI-WORKS PLANT

8.1 Overview and Scope

Following DOE authorization to proceed with this task, the preliminary conceptual design of a 20TPH semi-works plant (Task 2) was redesigned from all information available at this point in the project. This update of the conceptual design incorporated information derived about fine grinding, advanced froth flotation, and dewatering in Tasks 5 and 6. The summary report produced in Task 7 describing bench-scale test results and component development was used as a basis.

This task complied with all of the design requirements discussed in Task 2. The process flowsheet was updated with complete energy and material balances for all process flowstreams. The equipment list was updated and supplied the base for a recalculation of the factored estimate of the capital, operating and maintenance costs. In addition, differences between the designs in Task 8 and Task 2 were highlighted and their effects on process and plant design credibility, efficiency, maintenance, operation, complexity, control, performance, and economics were discussed.

ICF Kaiser Engineers, with assistance from its sub-contractors and the Technical Support Group, were responsible for the completion of this task. This design will serve as a basis for the POC design in Task 9 and the final semi-works design in Task 15.

8.2 Review of Work Completed this Quarter

This task has been completed and a final report submitted to DOE. No additional work was planned or completed during this quarter.
9.0 POC MODULE DESIGN

9.1 Overview and Scope

In order to develop additional confidence in the conceptual design of the advanced froth flotation circuit, a 2-3 TPH Proof-of-Concept (POC) facility was necessary. During operation of this facility, the ICF KE team will demonstrate the ability of the conceptual flowsheets to meet the program goals of maximum pyritic sulfur reduction coupled with maximum energy recovery on three DOE specified coals. The POC circuit was designed to be integrated into the Ohio Coal Development's facility near Beverly, Ohio.

OCDO's facility will provide the precleaning unit operations and ICF KE will add the advanced froth flotation circuitry. The work in this task will include the POC conceptual design, flowsheet development, equipment list, fabrication and construction drawings, procurement specifications and bid packages and a facilities estimate at the completion of design. After DOE approval, the design was finalized for the next task.

9.2 Review of Work Completed this Quarter

This task has been completed and the Task 9 report submitted to DOE. No additional work was planned or completed during this quarter.
10.0 POC MODULE FABRICATION

10.1 Overview and Scope

The overall objective of this task is to obtain the equipment, materials and shop labor to fabricate and assemble each of the individual modules which constitute the POC Module. The ICF KE procurement team will solicit bids, place orders, and expedite all vendors, materialmen and fabricators. Procurement will utilize the drawings and specifications produced in Task 1.9 as the basis for these activities. At the completion of the assembly procedure, an ICF KE representative will inspect and perform a functional check of each module before it leaves the shop.

Several sub-tasks have been identified for their importance in the successful completion of this task. Work will include placing purchase orders, procurement of the equipment and materials, fabrication of the modules, functionally checking the modules, shipping the modules to the jobsite and preparing the installation and maintenance manuals.

10.2 Review of Work Completed this Quarter

This task has been completed. No additional work was planned or completed during this quarter.
11.0 POC INSTALLATION AND START-UP

11.1 Overview and Scope

This task covers the functions necessary to install and successfully start-up the POC module at the jobsite. The installation was carried out by an installation subcontractor with construction management provided by ICF KE. The start-up was supervised by ICF KE and conducted using process engineers from the entire team and craft labor supplied by the installation subcontractor.

This task includes several major subtasks which was carried out to assure a successful, on-schedule installation and start-up. ICF KE will conduct work on installation and interconnection of the modules, preparation of start-up plans and procedures, the start-up functions and the finalization of the operations manual.

DOE's TPO was kept informed of construction progress and has access to the site for inspection of the work. ICF KE's construction manager was assigned prior to the start of construction activities and maintained the job progress through on-site assessment of the work and was using the construction schedule produced in Task 9 for control.

11.2 Review of Work Completed this Quarter

All construction has been completed. No additional work was planned or completed during this quarter.
12.0 POC TEST PLAN FORMULATION

12.1 Overview and Scope

The project team will coordinate its expertise and develop a testing plan that will provide performance data, quality data, scale-up data and operating data. The plan was submitted to DOE for approval after completion of Tasks 9 and 10.

This plan, after approval/revisions, will become the final test plan. The test plan will include long term testing, steady-state operation and effects of recycle operation. The testing program will demonstrate 90% onstream capability, evaluate process control instrumentation, develop information for scale-up, demonstrate compliance with regulatory requirements, evaluate materials of construction, and determine process economics. Ancillary information such as quality of waste stream materials was gathered.

The finalized plan will include a budget and schedule to complete all required tests and to produce batches of material for testing of beneficiated coal.

12.2 Review of Work Completed this Quarter

This Task has been completed. No additional work was planned or completed during this quarter.
13.0 POC OPERATION

13.1 Overview and Scope

This task is the actual demonstration of the advanced froth flotation technology. All previous work has led to this task. ICF KE technicians and process engineers from the team will operate the plant over a 10 month period to demonstrate the capability of the technology to remove 85% of the pyritic sulfur from three different test coals while covering at least 85% of the as-mined coal's energy content.

Six major subtasks have been included to better define the overall work scope for this task. The ICF KE team will test the Pittsburgh #8 seam, the Illinois #6 seam and the Upper Freeport seam; the team will operate the circuit in a continuous run; the team will analyze all samples generated in those runs and will develop a plan to store and dispose of the coal and refuse products.

All laboratory data generated will be accessible to all team members and the DOE. The TPO will be notified of all run days in advance for the purpose of planning his trips to the site. Sufficient time will be allowed in the test plan, developed in Task 12, to permit quick analysis of data generated from a completed test before continuing to the next test.

13.2 Review of Work Completed This Quarter

This Task has been completed. No additional work was planned or completed during this quarter.
14.0 TASK 14 POC OPERATIONS ANALYSIS

14.1 Overview and Scope

The completion of this task will result in a complete analysis of the results from all the test runs on all of the coals cleaned in the POC module. The work will include, in an organized and readily accessible manner, all available laboratory data and operating results from the Advanced Flotation technology. The information will be utilized to generate results that will be compared to the batch and semi-continuous results with respect to quality and equipment design parameters. This information will then be used for the Final Conceptual Design of the 20 TPH semi-works facility. The results will be contained in a formal POC Testing Summary Report.

14.2 Review of Work Completed This Quarter

This Task has been completed. No additional work was planned or completed during this quarter.
15.0 TASK 15 FINAL SEMI-WORKS CONCEPTUAL DESIGN

15.1 Overview and Scope

At the completion of this task, a conceptual design for a 20 TPH semi-works facility will be available. The design will be based on all knowledge gained previously in Tasks 5, 6, and 13. The work in this task will be primarily concerned with updating the conceptual design that was available in Task 8 with results of the POC scale-up operations from Task 13. Further, the team will project the design to a 200 TPH commercial facility and provide a conceptual estimate of the capital and operating costs for that facility.

The task will include several deliverables - the final report, design drawings for the semi-works plant, a detailed capital cost estimate of the semi-works plant and a preliminary conceptual estimate for the commercial plant.

15.2 Review of Work Completed This Quarter

The following is the executive summary of the Final Report. For additional information, please see the Final Report.

Bench-Scale Test Results

Bench-scale testing was conducted in order to reduce the technical and engineering related design deficiencies of the proposed advanced froth flotation process. For bench-scale testing, the coarse fraction (1/4 in. x 48 mesh) of the Pittsburgh No. 8 seam coal was precleaned in a water-only cyclone while the Upper Freeport and Illinois No. 6 coals were precleaned in a heavy-media cyclone. The heavy-media cyclone achieved energy recoveries of 95 percent or greater while the water-only cyclone performance was poor, with an energy recovery of only 85 percent.

The clean coal from the coarse gravity-based cleaning circuit was then crushed to 48 mesh x zero and, in the case of heavy-media cyclone cleaning, combined with the natural 48 mesh x zero size fractions of the raw coal. The coarse water-only cyclone clean coal already contained the 48 mesh x zero material. The resulting 48 mesh x zero streams for all three coals were then cleaned in a water-only cyclone. For each coal, water-only cyclone energy recoveries were greater than 95 percent. Pyrite rejections were 28 percent and 31 percent for the Pittsburgh No. 8 and Upper Freeport coal seams, but only 13 percent for the Illinois No. 6 coal seam.

The clean coal from the water-only cyclone operation was classified into 48 mesh x 200 mesh and 200 mesh x zero size fractions for conventional froth flotation testing. Investigators evaluated "grab-and-run" flotation in an effort to produce a clean coal from the flotation "grab" stage of six percent ash or less for all three coals. The Upper Freeport "grab" product met the clean coal ash target while the Illinois No. 6 seam coal "grab" product clearly did not meet the six percent ash criteria. No firm conclusions were
reached regarding the "grab" product for the Pittsburgh No. 8 seam coal as the "grab" product ash slightly exceeded six percent.

Grinding circuit evaluations conducted for this project included the comparison of the cleaning performance potential at two different coal grinds, 200 mesh and 325 mesh, using the Pittsburgh No. 8 seam coal. Each of these samples were then cleaned in a 2-inch diameter column flotation cell in order to compare the separation characteristics of the two coal grinds. The results from the column tests indicated that the 325 mesh x zero size fraction liberates significantly more pyrite than the 200 mesh x zero grind. At roughly identical energy recoveries of nearly 96 percent, 36 percent of the pyrite was rejected with the 325 mesh grind while only 25 percent was rejected with the 200 mesh grind.

Column flotation testing at the bench-scale level included extensive testing in a laboratory size column flotation unit followed by 100 pounds-per-hour testing in larger units. At the laboratory level, investigators evaluated whether multiple-stage column flotation could significantly outperform single-stage column flotation. In addition, a 54-point test matrix was developed using a composite Box-Behnken design and conducted on single-stage column flotation. All data obtained during the single versus multiple-stage flotation testing form a relatively narrow band of potential grade-versus-recovery results. Therefore, investigators ruled out a multiple-stage approach for POC operations. The data from the 54 point test matrix indicate that the best results between energy recovery and pyrite rejection occurred between 55 and 63 percent pyrite rejection with energy recoveries of up to 92 percent.

Using the best results from the 100 pounds-per-hour testing of each unit operation and Bilmat, a computer-based material balance program, investigators next developed overall cleaning circuit performance projections in order to assess the potential for meeting the major coal cleaning performance goals. For the Pittsburgh No. 8 seam coal, neither the energy recovery nor the pyritic-sulfur-rejection target of 85 percent was achieved, primarily due to the poor coarse water-only cyclone performance. The Illinois No. 6 seam coal projection indicated a 91 percent pyritic sulfur rejection with a nearly 81 percent energy recovery. For the Upper Freeport seam coal, the projections indicated 78 percent pyrite rejection and 91 percent energy recovery were possible.

Clean coal and refuse slurries were subjected to dewatering tests using pressure filtration, vacuum filtration, and belt filter press techniques. The target moisture for the clean coal was 30 percent while the refuse moisture target was 35 percent. The bench-scale dewatering test results indicated that the clean-coal-moisture goal could be achieved with the Pittsburgh No. 8 and Upper Freeport seam coals using pressure filtration techniques. The Illinois No. 6 seam coal could only be dewatered to 38 percent moisture. Neither the vacuum filtration techniques nor the belt filter press could produce 30 percent clean coal moistures for any of the three coals.
Tests on the refuse samples of each coal indicated that the fine Upper Freeport seam refuse could be dewatered to less than 35 percent moisture using vacuum filtration, pressure filtration, or the belt filter press. Only vacuum filtration could meet the 35 percent target on the Illinois No. 6 refuse, and only pressure filtration was successful on the Pittsburgh No. 8 seam refuse. Despite the lack of success of the belt filter press on these two coals, the belt filter press was recommended for dewatering the refuse stream for all three coals, primarily due to the superior handleability of the belt press refuse cake.

Based on the bench-scale and 100 pounds-per-hour test results, the following conclusions were drawn for the Semi-Works flowsheet:

- The coarse water-only cyclone (1/4 inch x 48 mesh) continued to be included in the plant design. However, a heavy-media cyclone would be used in the POC and, if successful, be considered for the final Semi-Works plant design.

- The fine (48 mesh x zero) water-only cyclone circuit was maintained in the Semi-Works plant design.

- Conventional froth flotation should be applied separately on the 48 mesh by 200 mesh and the 200 mesh x zero size fractions.

- The raw coal crusher, the precleaned or middlings coal crusher, and ball-mill were to be sized by the equipment manufacturers based on the maximum particle size, the Hardgrove grindability of the feed, the top size requirements for the crushed products, and the throughput tonnage.

- A multiple-stage column flotation circuit was not warranted due to the relatively slight improvement in grade-versus-recovery results when compared to single-stage column flotation results.

- A clean-coal thickener would need to be included in the design to concentrate the advanced froth flotation concentrate.

- A batch-type recessed plate pressure filter would achieve the lowest clean-coal-product moisture. However, a final decision regarding the dewatering of clean coal for the Semi-Works plant design will occur after POC testing is completed on a hyperbaric disk filter.

- Dewatering of the refuse thickener underflow will be accomplished using a belt-filter press.

Proof-Of-Concept (POC) Scale Test Results

Figure 1.01 presents a simplified block diagram of the POC flowsheet.
Figure 1.01 Simplified Block Diagram of the POC Process
As can be seen from Figure 1.01, the 1/4 inch x 48 mesh was cleaned using a heavy-media cyclone with the objectives of recovering 97 percent of the feed coal's energy. The heavy-media-cyclone clean coal was crushed to 48 mesh by zero using a cagepactor crusher, combined with the raw 48 mesh by zero and fed to a water-only cyclone. The water-only cyclone was maximized to recover 97 percent of its feed energy. The water-only cyclone clean coal reported to the ball-mill where it was crushed to 200 mesh by zero and fed to the column flotation cell for final cleaning. Primary performance goals of the POC flowsheet were to achieve 85 percent energy recovery with 85 percent pyritic sulfur removal when compared to the raw coal feed of the plant.

The Pittsburgh No. 8 seam coal from Brooke County, West Virginia; the Upper Freeport seam coal from Somerset County, Pennsylvania; and the Illinois No. 6 seam coal from Saline County, Illinois were the three coals tested. Table 1.01 contains the washability head analyses on a dry basis for the three coals.

<table>
<thead>
<tr>
<th>Coal Seam</th>
<th>% Ash</th>
<th>% Sulfur</th>
<th>% Pyritic Sulfur</th>
<th>Btu/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pittsburgh No. 8</td>
<td>40.38</td>
<td>3.14</td>
<td>2.16</td>
<td>8,292</td>
</tr>
<tr>
<td>Upper Freeport</td>
<td>18.12</td>
<td>3.99</td>
<td>2.81</td>
<td>11,975</td>
</tr>
<tr>
<td>Illinois No. 6</td>
<td>36.23</td>
<td>4.11</td>
<td>2.75</td>
<td>8,866</td>
</tr>
</tbody>
</table>

Once the heavy-media cyclone, water-only cyclone, and grinding circuits were maximized, testing began to determine the best conditions at which to operate the advanced column flotation cell. The critical operating variables that were evaluated for the column cell included feed rate, aeration rate, frother rate, wash-water rate, frother type, and collector rate. A 16 point, resolution IV fractional factorial experiment was conducted on the Pittsburgh No. 8 seam coal to determine the best conditions for aeration rate, wash-water rate and frother type for the column cell. Results from the fractional matrix testing concluded that the following parameters should remain constant for the column cell throughout the remainder of the POC operations.

- MIBC reagent should be used as the frothing agent.
- An aeration rate of 140 SCFM should be maintained.
- A wash-water rate of 100 gallons per minute should be maintained.

With the heavy-media cyclone and water-only cyclone maximized, and with the best conditions for aeration rate, wash-water rate, and frother type determined for the column flotation cell, investigators conducted a Box-Behnken test matrix on each of the three coals. Figures 1.02, 1.03, and 1.04 show the energy recoveries as a
function of ash rejection, pyritic sulfur rejection, and total sulfur rejection for the overall POC circuit while conducting the Box-Behnken test matrices for the Pittsburgh No. 8, Upper Freeport, and Illinois No. 6 coal seams.

![Graph](image)

**Figure 1.02 Pittsburgh No. 8 Seam Coal, Box-Behnken Matrix Results**

After completing the Box-Behnken matrix for each of the three coals, all equipment was configured and all variables were set at the maximum values to conduct the 24-hour demonstration tests. The Pittsburgh No. 8 seam was processed for four days during the first and second week of the demonstration run. Both the Upper Freeport and Illinois No. 6 seams were processed for five days during both the first and second week of the demonstration runs. During the 24-hour demonstration runs, a complete set of samples were collected every eight hours for all the pertinent circuits in operation. Figure 1.05, 1.06, and 1.07 present the Bilmat-adjusted data for the average of all eight-hour sampling periods for the Pittsburgh No. 8, Upper Freeport, and Illinois No. 6 coal seams.

For the Pittsburgh No. 8 Seam, the POC recovered 89.5 percent of the raw coal's energy while removing 73.6 percent of the coal's pyritic sulfur. Performance evaluations for the Upper Freeport Seam indicated an overall energy recovery of 87.5 percent, while 76.2 percent of the raw coal’s pyritic sulfur was removed. For the Upper Freeport Seam, the POC recovered 85.8 percent of the energy and removed 79.4 percent of the pyritic sulfur in the raw coal.

Table 1.02 presents the contributions of each coal-cleaning circuit to total energy loss and pyritic-sulfur removal for each of the
three coals. These values are based on the average results obtained during the 24-hour demonstration runs. The heavy-media cyclone circuit for each coal removed the bulk of the pyritic sulfur while losing relatively low amounts of energy. Depending on the coal, the heavy-media cyclone circuit removed 60 to 70 percent of the total amount of pyrite that was removed. Meanwhile, the energy content in the heavy-media cyclone circuit refuse was only 32 to 36 percent of the total energy losses.

Since large amounts of pyrite have been removed prior to the water-only cyclone and the advanced froth flotation circuit, the ratio of pyrite rejection to energy loss is significantly lower for these circuits. For the Upper Freeport Seam, for example, the advanced froth flotation removed 25 percent of the total amount of pyrite that was rejected, and the energy content in the flotation tailings accounted for 71 percent of the total energy losses. Contributing to the lower ratios is the more-difficult-to-clean nature of fine- and ultrafine-particle streams.
Figure 1.04 Illinois No. 6 Seam Coal, Box-Behnken Test Matrix Results

Table 1.02
Contributions to Energy Loss and Pyritic Sulfur Removal* During 24-Hour Demonstration Runs

<table>
<thead>
<tr>
<th>Circuit (Size Cleaned)</th>
<th>Pittsburgh No. 8 Coal</th>
<th>Upper Freeport Coal</th>
<th>Illinois No. 6 Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy-Media Cyclone Circuit (+48 mesh)</td>
<td>3.8</td>
<td>44.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Water-Only Cyclone Circuit (48 mesh x 0)</td>
<td>4.0</td>
<td>16.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Advanced Froth Flotation Circuit (200 mesh x 0)</td>
<td>2.7</td>
<td>12.7</td>
<td>8.9</td>
</tr>
</tbody>
</table>

* Values represent the percentages of the raw coal energy content and pyritic sulfur content found in the refuse stream of each circuit.

Cumulative plant availability during 24-hour demonstration runs for the three coals was 94.9 percent. Individually, plant availabilities for the Pittsburgh No. 8, the Upper Freeport and the Illinois No. 6 coals were 98.0, 97.4, and 89.9 percent, respectively. No downtime encountered during the demonstration runs was attributed to the advanced process equipment.
Figure 1.05
Pittsburgh No. 8 Seam Coal
Average Performance
During 24-Hour Demonstration Run

<table>
<thead>
<tr>
<th>Plant Feed</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash %</td>
<td>46.05</td>
</tr>
<tr>
<td>Total Sulfur %</td>
<td>2.90</td>
</tr>
<tr>
<td>Pyritic Sulfur %</td>
<td>2.04</td>
</tr>
<tr>
<td>BTU Per Pound</td>
<td>7,329</td>
</tr>
</tbody>
</table>

Coarse Circuit Performance
- 96.2% Energy Recovery
- 44.3% Pyrite Rejection

<table>
<thead>
<tr>
<th>Coarse Refuse</th>
<th>% of Raw Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>31.1</td>
</tr>
<tr>
<td>Energy</td>
<td>3.8</td>
</tr>
<tr>
<td>Pyrite</td>
<td>44.3</td>
</tr>
</tbody>
</table>

1/4" x 48M

Fine Circuit Performance
- 95.9% Energy Recovery
- 29.8% Pyrite Rejection

<table>
<thead>
<tr>
<th>Fine Refuse</th>
<th>% of Raw Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>4.5</td>
</tr>
<tr>
<td>Energy</td>
<td>4.0</td>
</tr>
<tr>
<td>Pyrite</td>
<td>16.6</td>
</tr>
</tbody>
</table>

48M x 0

Mill Product
- 85.4% Passing 200M Mesh
- 38.4 Micron Average Particle Size
- 23.4 Micron D50

Advanced Flotation Performance
- 97.1% Energy Recovery
- 32.4% Pyrite Rejection

<table>
<thead>
<tr>
<th>Plant Clean Coal</th>
<th>% of Raw Coal</th>
<th>Ash %</th>
<th>Weight</th>
<th>Total Sulfur %</th>
<th>Energy</th>
<th>Pyrite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>48.2</td>
<td>2.50</td>
<td>89.5</td>
<td>26.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plant Refuse</td>
<td>% of Raw Coal</td>
<td>Ash %</td>
<td>Weight</td>
<td>Total Sulfur %</td>
<td>Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% of Raw Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>% of Raw Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Plant Clean Coal
- Plant Refuse

- BTU Per Pound: 13,618
- BTU Per Pound: 1,479

Ultrafine Refuse
- % of Raw Coal: 16.2
- % of Raw Coal: 7.65
- Energy: 2.7
- Energy: 2.0
- Pyrite: 12.7
- Pyrite: 2.7

Weight % of Raw Coal
- 51.8
- 10.5
- Pyrite: 73.6

Total Sulfur % of Raw Coal
- 3.27
- 2.90

Energy
- 2.7
- 2.0

Pyrite
- 16.2
- 7.65
**Figure 1.06**

**Upper Freeport Seam Coal**

**Average Performance During 24-Hour Demonstration Run**

<table>
<thead>
<tr>
<th>Plant Feed</th>
<th>%</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash %</td>
<td>24.18</td>
<td></td>
</tr>
<tr>
<td>Total Sulfur %</td>
<td>4.41</td>
<td></td>
</tr>
<tr>
<td>Pyritic Sulfur %</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td>BTU Per Pound</td>
<td>11,848</td>
<td></td>
</tr>
</tbody>
</table>

---

**Coarse Circuit Performance**

97.3% Energy Recovery

49.4% Pyrite Rejection

---

**Plant Clean Coal**

<table>
<thead>
<tr>
<th>% of Raw Coal</th>
<th>Ash %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>77.9</td>
<td>2.30</td>
</tr>
<tr>
<td>Energy</td>
<td>87.5</td>
<td>1.06</td>
</tr>
<tr>
<td>Pyrite</td>
<td>23.8</td>
<td>13,456</td>
</tr>
</tbody>
</table>

**Plant Refuse**

<table>
<thead>
<tr>
<th>% of Raw Coal</th>
<th>Ash %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>28.1</td>
<td>9.80</td>
</tr>
<tr>
<td>Energy</td>
<td>12.5</td>
<td>8.66</td>
</tr>
<tr>
<td>Pyrite</td>
<td>76.2</td>
<td>4,902</td>
</tr>
</tbody>
</table>

---

**Coarse Refuse % of Raw Coal**

| Weight | 9.1   |
| Energy | 2.7   |
| Pyrite | 49.4  |

---

**Fine Refuse % of Raw Coal**

| Weight | 1.6 |
| Energy | 0.9 |
| Pyrite | 7.9 |

---

**Mill Product**

% Passing 200M

82.6% Passing Mesh

44.5 Micron Average Particle Size

30.8 Micron D50

---

**Advanced Flotation Performance**

90.8% Energy Recovery

44.3% Pyrite Rejection

---

**Ultrafine Refuse % of Raw Coal**

| Weight | 17.5 |
| Energy | 8.9  |
| Pyrite | 18.9 |
Figure 1.07
Illinois No. 6 Seam Coal
Average Performance
During 24-Hour Demonstration Run

Plant Feed
<table>
<thead>
<tr>
<th>Ash %</th>
<th>34.49</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sulfur %</td>
<td>4.27</td>
</tr>
<tr>
<td>Pyritic Sulfur %</td>
<td>2.41</td>
</tr>
<tr>
<td>BTU Per Pound</td>
<td>9,162</td>
</tr>
</tbody>
</table>

Coarse Circuit Performance
95.5% Energy Recovery
55.4% Pyrite Rejection

1/4" x 48M

Coarse Refuse
% of Raw Coal
| Weight | 20.3 |
| Energy | 4.5  |
| Pyrite | 55.4 |

48M x 0

Fine Refuse
% of Raw Coal
| Weight | 3.3  |
| Energy | 2.2  |
| Pyrite | 10.4 |

Mill Product
% Passing 200M
83.9% Passing Mesh
42.3 Micron Average Particle Size
28.3 Micron D50

Advanced Flotation Performance
92% Energy Recovery
39.6% Pyrite Rejection

Ultrafine Refuse
% of Raw Coal
| Weight | 18.5 |
| Energy | 7.5  |
| Pyrite | 13.6 |

Plant Clean Coal

<table>
<thead>
<tr>
<th>% of Raw Coal</th>
<th>Ash %</th>
<th>Weight</th>
<th>Total Sulfur %</th>
<th>Energy</th>
<th>Pyrite</th>
<th>BTU Per Pound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.20</td>
<td>57.9</td>
<td>3.00</td>
<td>85.8</td>
<td>20.6</td>
<td>13,574</td>
</tr>
</tbody>
</table>

Plant Refuse

<table>
<thead>
<tr>
<th>% of Raw Coal</th>
<th>Ash %</th>
<th>Weight</th>
<th>Total Sulfur %</th>
<th>Energy</th>
<th>Pyrite</th>
<th>BTU Per Pound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>72.08</td>
<td>42.1</td>
<td>6.02</td>
<td>4.55</td>
<td>3,084</td>
<td></td>
</tr>
</tbody>
</table>
Conceptual Design for 20 TPH Semi-Works Plant

The bench-scale and POC-scale test plans were designed to provide investigators with the information necessary to design and engineer a 20 tons-per-hour Semi-Works Facility that incorporates the proposed advanced froth flotation technology and achieves the objectives established for the process. The coal cleaning philosophy that was applied to the project was twofold: first, to remove sulfur and mineral matter at the coarsest size consistent with low subsequent energy losses; and to utilize multiple coal comminution stages to liberate mineral matter and impurities from the desirable coal portion of the raw coal feed stream.

To accomplish this and to meet project goals, the Semi-Works facility includes three stages of coal crushing and grinding operations each followed by a cleaning operation designed to remove the liberated impurities generated by the comminution efforts. Raw coal received at the facility will be crushed to 1/2 inch by zero. The crushed product is separated into two sizes and the 1/2 inch by 48 mesh size fraction is efficiently cleaned in a heavy-media cyclone circuit. The heavy-media cyclone will be configured to effect a high (1.85 to 1.90 S.G.) specific gravity of separation on the coal feed so that little energy is lost.

The heavy-media cyclone clean coal is crushed, in closed circuit, to 48 mesh by zero, combined with the raw 48 mesh by zero size fraction and cleaned in a water-only cyclone circuit to remove impurities liberated by the crushing stage or present in the raw fraction. Again, the water-only cyclone circuit is configured to minimize energy losses, yet remove both pyritic sulfur and mineral matter prior to fine grinding.

The heavy-media- and water-only-cyclone circuits represent commercially proven and available technologies that are practical and effective for their intended use in the process. Significant pyritic sulfur rejections at low energy loss can be expected at this point in the process. The material removed from these operations would be, for many coals, the hardest materials and the most expensive to grind on a per-pound basis.

The water-only cyclone clean coal is introduced into a closed, wet-grinding circuit utilizing classification ahead of a horizontal ball mill to prepare a proper ball-mill feed and improve circuit effectiveness. The mill circuit will produce a product of approximately 83 to 85 percent passing 200 mesh that will finally be cleaned in the advanced froth flotation circuit. Thickening, dewatering, and recovery techniques for all circuit products will use commercially available technologies.

The Semi-Works facility will be a fully automated continuous process. State-of-the-art instrumentations and control technologies are included in the proposed design. Five samplers will be provided in order to monitor the plant products as well as internal process streams.
The Semi-Works capital cost estimate of the plant proper is approximately $10,915,000. Another $750,000 will be required for the purchase of land, start-up modifications, and working capital.

200 TPH Commercial Plant Economic Analysis

Based on the capital cost of the Semi-Works plant, the cost for 200 and 500 tons-per-hour facilities were extrapolated. In addition, fixed and variable, first-year operating-and-maintenance costs were estimated for these commercial plants. Table 1.03 presents a summary of these costs for a 200 tons-per-hour (TPH) facility operating 7560 hours per year.

<table>
<thead>
<tr>
<th>Table 1.03</th>
<th>Capital Requirements and 1st Year Operating and Maintenance Costs for a 200 TPH Advanced Froth Flotation Plant (7560 Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Capital Requirement</td>
<td>$59,624,735</td>
</tr>
<tr>
<td>Working Capital Requirement</td>
<td>$467,723</td>
</tr>
<tr>
<td>Fixed Operating and Maintenance Costs</td>
<td>$5,892,451</td>
</tr>
<tr>
<td>Variable Operating and Maintenance Costs</td>
<td>12,080,238</td>
</tr>
</tbody>
</table>

In order to compare these values to those of existing facilities and to evaluate them on an investment basis, these values were input into an economic model developed by Eos Technologies, Inc. for the U.S. Department of Energy. Based on the above costs and a set of economic assumptions, the model generates the clean coal price required for the investment to generate a user-established, after-tax rate of return. Also, the cost to remove sulfur, on a dollars per ton of SO₂ equivalent, is determined. Table 1.04 presents these values for 200 and 500 TPH commercial facilities as well as the economic assumptions on which the estimates are based.
## Table 1.04
Advanced Froth Flotation Economics (Annualized Basis)

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Pittsburgh No. 8</th>
<th>Upper Freeport</th>
<th>Illinois No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Coal Price ($/MMBtu)</td>
<td>1.49</td>
<td>1.50</td>
<td>1.55</td>
</tr>
<tr>
<td>Clean Coal Price ($/Ton)</td>
<td>40.65</td>
<td>40.27</td>
<td>41.96</td>
</tr>
<tr>
<td>Annual Desulfurization Cost*</td>
<td>$326.82</td>
<td>$305.42</td>
<td>$304.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Pittsburgh No. 8</th>
<th>Upper Freeport</th>
<th>Illinois No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Coal Price ($/MMBtu)</td>
<td>1.81</td>
<td>1.81</td>
<td>1.87</td>
</tr>
<tr>
<td>Clean Coal Price ($/Ton)</td>
<td>49.32</td>
<td>48.68</td>
<td>50.63</td>
</tr>
<tr>
<td>Annual Desulfurization Cost*</td>
<td>$477.08</td>
<td>$442.49</td>
<td>$435.09</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Pittsburgh No. 8</th>
<th>Upper Freeport</th>
<th>Illinois No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Coal Price ($/MMBtu)</td>
<td>1.38</td>
<td>1.39</td>
<td>1.44</td>
</tr>
<tr>
<td>Clean Coal Price ($/Ton)</td>
<td>37.68</td>
<td>37.30</td>
<td>38.99</td>
</tr>
<tr>
<td>Annual Desulfurization Cost</td>
<td>$275.27</td>
<td>$256.95</td>
<td>$259.84</td>
</tr>
</tbody>
</table>

### ECONOMIC ASSUMPTIONS

- **Plant Life**: 20 Years
- **Inflation Rate**: 4.0%
- **Royalties**: None
- **Corporate Tax Rate**: 30.0%
- **Financing**: 100% Equity
- **Rate of Return**: 10.0%
- **Annual Desulfurization Costs are per ton of SO₂ equivalent.**

As the table indicates, plant size and operating schedule both significantly affect the costs of coal production and thus, the desulfurization costs. For the Pittsburgh No. 8 coal, for example, desulfurization costs for a 200 TPH (product) plant operating 7,560 hours per year are estimated at $327 per ton of SO₂ equivalent. For a 500 TPH plant with the same operating schedule, desulfurization costs drop to $275 per ton. On an average, desulfurization costs decrease by 15 percent for the 500 TPH plants.

Due to the large capital requirements for these advanced plants, operating schedule affects costs to a greater extent than plant size. A typical coal preparation facility operates five days per week, two shifts per day. Maintenance is conducted on the third shift. This operating schedule results in 3456 hours of operation per year and, as the cost estimates reveal, a gross under utilization of facilities. For the Illinois No. 6 coal, a 200 TPH plant operating 7560 hours per year can remove sulfur for about $305 per ton of SO₂ equivalent. When the same size plant operates, only 3456 hours per year, the desulfurization cost climbs to $435 per ton.

### Conclusions
Based on the findings of this project, the following conclusions may be drawn.

- **The proposed process technology is ready for commercialization.** However, the product from the process may require reconstitution in order to be marketable.

- The proposed technology can recover 85 percent of the energy in each of the raw coals while removing 75 to 80 percent of the raw coals’ pyritic sulfur.

- Clean coal ash values of 7.2 to 10.3 percent, on a dry basis, were achieved with the proposed technology.

- Grinding to levels finer than 85 percent passing 200 mesh will be required to remove 85 percent of the raw coal's pyrite while maintaining 85 percent energy recovery.

- Based on raw coal costs of $0.80 per million Btu, clean coal prices of $1.50 per million Btu will be required for investments in the proposed technology to earn a 10 percent after-tax rate of return.

- Desulfurization costs, on a dollars per ton of SO₂ equivalent, of $255 to $275 are estimated for a 500 tons-per-hour commercial facility incorporating the proposed advanced froth flotation process.

The overall objective of the Kelsey centrifugal jig and Carpco MGS test program was to verify the amount of additional pyritic sulfur that could be rejected by subjecting the column flotation concentrate to gravity separation processes. Additional pyritic sulfur rejections of approximately 30% are achievable with a Btu loss of only a few percent.

A review of the washability analyses of the column flotation products indicates that a fair amount of sink 2.0 material of very-high-pyritic-sulfur content was in the column cell concentrate. This is due to the fact that flotation is dependent on surface chemical properties and is not a gravity separation process. Since pyrite is hydrophobic, it tends to float with the coal product. The microcell™ column flotation cell was an improvement over conventional flotation cells since it used a deep froth bed and wash water which helped to reject pyritic material. Additionally, much of the pyritic material that floated was due to the fact that the grinding process did not achieve total liberation, and a lot of the pyrite was still locked within the coal matrix. Review of the data indicates that the column product contains about 3% sink 2.0 at approximately 20% pyritic sulfur. At best, based on the test results, gravity separation of the column flotation product using devices such as the Kelsey jig or Carpco MGS rejected around 50% of this material.

The fact that so much high-pyrite containing sink material was recovered by the Kelsey Jig and MGS was due to the very fine
particle size consist being treated. However, this was not the only factor. The percent solids in the gravity separation device feed was also important, and in the case of the Carpco MGS played a major role. Apparently, the percent solids in Carpco MGS feed was too dilute and caused a flushing effect with most of the solids, including the high density solids, flowing with the water and reporting to product. Actual Carpco MGS test results had inadequate pyritic sulfur rejection and exceptionally high Btu recoveries due to this fact.

The Kelsey jig performance was not as significantly impacted by the dilute nature of the feed material, but its performance could be improved with better control of feed solids content. The feed percent solids in the gravity separation device ranged from 7 to 14%. In retrospect, the feed percent solids should have been included as a test parameter.

Since so little reject material was produced by both gravity separators, there was insufficient reject material to submit for washability analysis. In one case there was actually insufficient material to do a pyritic-sulfur determination. As such, samples of the gravity device feed and product were submitted for washability. This is the major factor why a "shotgun" scattering of performance values was produced.

Based on the data collected, an attempt was made to determine the probable error distribution factors for both of the gravity devices. The probable error values were then applied to the washability analysis for the column flotation concentrate and the quality of the Kelsey jig and MGS were then calculated based on the ash rejection, total sulfur rejection, pyrite sulfur rejection, and Btu recovery.

The following is a summary of the calculations. One must recognize that these are calculated values and are only representative of the results possible in combining column flotation and gravity-based separation unit operations.

By combining separation operations, pyritic sulfur rejection can be increased 7 to 9% for the Kelsey jig while sustaining a 2 to 3% additional Btu loss. Likewise, pyritic sulfur rejection can be increased 6 to 8% for the MGS while sustaining an additional Btu loss of only 0.5 to 1.5%.

The goal of the advanced flotation project was to achieve 85% pyritic sulfur rejection and 85% Btu recovery. The data indicates that this goal was attainable for the Illinois No. 6 coal and possible for the Pittsburgh No. 8 and Upper Freeport. If the gravity separating devices could operate at a lower separating gravity reducing the Btu recovery and increasing the pyritic sulfur rejection. Thus, the results possible with the combined advanced flotation/gravity separation machine were very close to the stated project goals.
Important findings resulted from the testing of the Kelsey Jig and Carpco MGS. Following are the conclusions derived from the test work and evaluation.

- No exact quantitative conclusions can be determined because of the scatter in the performance curve data.
- Substantial high pyritic sulfur remains in the microcel™ column flotation concentrate product.
- Although the microcel™ flotation column is effective in rejecting well-liberated mineral matter such as ultrafine clay slimes, other novel gravity separation-based devices are more efficient in removing composite particles containing a high specific gravity component such as pyrite.
- Combining synergistically surface-based and gravity-based separation technology can substantially improve rejection of ash and pyritic sulfur contaminants than either separation device can alone.
- The improved rejection of ash and sulfur contaminants can be accomplished with acceptable Btu losses.
- Since the combined microcel™ flotation column/gravity separation circuit is effective in removing composite particles still containing unliberated pyrite, very fine grinding may be unnecessary.
- The feed solids concentration to advanced fine particle gravity-based separation equipment must be regulated to obtain optimum performance. At too low feed solids concentrations, hydraulic problems preclude making a good gravity separation.
- Commercial sizes of the Kelsey jig can process in excess of 10 TPH for the size material in the test program.
- Commercial sizes of the Multi-Gravity separator can process in excess of 5 TPH for the size material in this program.
16.0 TASK 16 POC MODULE REMOVAL

16.1 Overview and Scope

This task involves removing the POC module from the host facility, restoring the site, and protecting and shipping all Contractor-procured government property to PETC.

In decommissioning the process equipment, strict adherence to removing process reagents and contaminants and to capping and blanking all openings on the POC module and OCDO host facility interfaces. All government property will be protected from environmental damage prior to and during shipment to PETC. All DOE and OCDO host facility property will be restored to its condition prior to the start of Task 11.

16.2 Review of Work Completed This Quarter

The DOE/PETC and OCDO reached a Personal Property Loan Agreement concerning the DOE equipment. This equipment will be used by OCDO in conducting future additional coal preparation research at the test site.

No additional work was planned or completed during this quarter.