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THE DEVELOPMENT OF COAL-BASED TECHNOLOGIES FOR DEPARTMENT OF DEFENSE FACILITIES

Semiannual Technical Progress Report for the Period 09/28/1996 to 03/27/1997

By

Bruce G. Miller, Sharon Falcone Miller, Joel L. Morrison, Sarma V. Pisupati, and Alan W. Scaroni
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Fuel Science Program;
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Mineral Processing Section;
Adam Rose, Timothy J. Considine, Richard L. Gordon, Ahmet E. Kocagil, Jeffrey Lazo, and Katherine McClain,
Department of Mineral Economics; and
Norman Chigier and Adel Mansour,
Carnegie Mellon University

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For
U.S. Department of Energy
Federal Energy Technology Center
P.O. Box 10940
Pittsburgh, Pennsylvania 15236

By
The Consortium for Coal-Water Slurry Fuel Technology
The Pennsylvania State University
C211 Coal Utilization Laboratory
University Park, Pennsylvania 16802

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June 19, 1997

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Pittsburgh, Pennsylvania 15236

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EXECUTIVE SUMMARY

The U.S. Department of Defense (DOD), through an Interagency Agreement with the U.S. Department of Energy (DOE), has initiated a three-phase program with the Consortium for Coal-Water Slurry Fuel Technology, with the aim of developing technologies which can potentially decrease DOD's reliance on imported oil by increasing its use of coal. The program is being conducted as a cooperative agreement between the Consortium and DOE.

Activities this reporting period are summarized by phase.

PHASE I

Phase I was completed on November 1, 1995.

PHASE II

Work in Phase II focused on emissions reductions, coal beneficiation/preparation studies, and economic analyses of coal use.

Emissions reductions investigations included the installation of a ceramic filtering device on the demonstration boiler. Also, a sodium bicarbonate duct injection system was received for installation on the demonstration boiler.

Work related to coal preparation and utilization, and the economic analysis was primarily focused on preparing the final report.

PHASE III

Work in Phase III focused on coal preparation studies, pilot-scale NO_x reduction studies, economic analyses of coal use, and evaluation of deeply-cleaned coal as boiler fuel.

Coal preparation studies were focused on continuing activities on particle size control, physical separations, surface-based separation processes, and dry processing.

Preliminary pilot-scale NO_x reduction catalyst tests were conducted when firing natural gas in Penn State's down-fired combustor. This is the first step in the scale-up of bench-scale results obtained in Phase II to the demonstration boiler scale when firing coal.

The economic study focused on community sensitivity to coal usage, regional/ national economic impacts of new coal utilization technologies, and constructing a national energy portfolio.

The evaluation of deeply-cleaned coal as boiler fuel included installing a ribbon mixer into Penn State's micronized coal-water mixture circuit for reentraining filter cake. In addition, three cleaned coals were received from CQ Inc. and three cleaned coals were received from Cyprus-Amax.

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1.0 INTRODUCTION

The U.S. Department of Defense (DOD), through an Interagency Agreement with the U.S. Department of Energy (DOE), has initiated a three-phase program with the Consortium for Coal-Water Slurry Fuel Technology, with the aim of decreasing DOD's reliance on imported oil by increasing its use of coal. The program is being conducted as a cooperative agreement between the Consortium and DOE. The first phase was completed; work is underway in the other two phases.

To achieve the objectives of the program, a team of researchers was assembled from Penn State (The Energy Institute, Mineral Processing Section, Department of Mineral Economics, Fuel Science Program, and Polymer Science Program), Energy and Environmental Research Corporation (EER), AMAX Research and Development Center, ABB Combustion Engineering, Inc., CeraMem Separations, Inc., Comprehensive Design Architects and Engineers, and Raytheon Constructors & Engineers.

Phase I activities were focused on developing clean, coal-based combustion technologies for the utilization of both micronized coal-water mixtures (MCWMs) and dry, micronized coal (DMC) in fuel oil-designed industrial boilers. Phase II research and development continued to focus on industrial boiler retrofit technologies by addressing emissions control strategies for providing ultra-low emissions when firing coal-based fuels in industrial-scale boilers. Phase III activities expands upon emissions reduction strategies through the use of deeply-cleaned coals as a means for reducing air toxics Each phase includes an engineering cost analysis and technology assessment. The activities and status of the phases are described below.

The objective in Phase I was to deliver fully engineered retrofit options for a fuel oil-designed watertube boiler located on a DOD installation to fire either MCWM or DMC. This was achieved through a program consisting of the following five tasks: 1) Coal Beneficiation and Preparation; 2) Combustion Performance Evaluation; 3) Engineering Design; 4) Engineering and Economic Analysis; and 5) Final Report/Submission of Design Package. Following is an outline of the project tasks that comprised Phase I:

Task 1: Coal Beneficiation/Preparation

Subtask 1.1	Identify/Procure Coals
Subtask 1.2	Determine Liberation Potential
Subtask 1.3	Produce Laboratory-Scale Quantities of Micronized Coal-Water Mixtures (MCWMs)
Subtask 1.4	Develop Dry Coal Cleaning Technique
Subtask 1.5	Produce MCWMs and Dry, Micronized Coal (DMC) From Dry Clean Coal
Subtask 1.6	Produce MCWM and DMC for the Demonstration Boiler
Subtask 1.7	Project Management and Support

- Task 2: Combustion Performance Evaluation
  - Subtask 2.1 Boiler Retrofit
  - Subtask 2.2 Fuel Evaluation in the Research Boiler
  - Subtask 2.3 Performance Evaluation of the MCWM and DMC in the Demonstration Boiler
  - Subtask 2.4 Evaluate Emissions Reductions Strategies
  - Subtask 2.5 Project Management and Support
- Task 3: Engineering Design
  - Subtask 3.1 MCWM/DMC Preparation Facilities
  - Subtask 3.2 Fuel Handling
  - Subtask 3.3 Burner System
  - Subtask 3.4 Ash Removal, Handling, and Disposal
  - Subtask 3.5 Air Pollution Control
  - Subtask 3.6 Integrate Engineering Design
  - Subtask 3.7 Project Management and Support
- Task 4: Engineering and Economic Analysis
  - Subtask 4.1 Survey Boiler Population/Identify Boilers for Conversion
  - Subtask 4.2 Identify Appropriate Cost-Estimating Methodologies
  - Subtask 4.3 Estimate Basic Costs of New Technologies
  - Subtask 4.4 Process Analysis of MCWM and DMC
  - Subtask 4.5 Analyze/Identify Transportation Cost of Commercial Sources of MCWM and Cleaned Coal for DMC Production
  - Subtask 4.6 Determine Community Spillovers
  - Subtask 4.7 Regional Market Considerations and Impacts
  - Subtask 4.8 Integrate the Analysis
  - Subtask 4.9 Project Management and Support
- Task 5: Final Report/Submission of Design Package

The Phase I activities included:

Task 1: The coal beneficiation and preparation effort was conducted by Penn State's Mineral Processing Section with assistance from Penn State's Polymer Science Program and AMAX Research and Development Center. This task involved identifying and procuring six coals that could be cleaned to <1.0 wt.% sulfur and <5.0 wt.% ash which have been, or possess the characteristics to enable them to be. made into MCWMs. The coals were subjected to detailed characterization and used to produce laboratory-scale quantities of MCWM. A fundamental study of MCWM stabilization was conducted. Additional activities included developing a dry coal cleaning technique and producing MCWMs and DMC from the resulting cleaned coal.

Task 2: Penn State's The Energy Institute conducted the combustion performance evaluation with assistance from EER and Penn State's Fuel Science Program. The technical aspects of converting a fuel oil-designed boiler at a DOD facility were identified in this task. All appropriate components were evaluated, including the fuel, the fuel storage, handling and delivery equipment, the burner, the boiler, the ash handling and disposal equipment, the emissions control system, and the boiler control system. Combustion performance as indicated by flame stability, completeness of combustion, and related issues such as system derating, changes in system maintenance, the occurrence of slagging, fouling, corrosion and erosion, and air pollutant emissions were determined. As part of this task, MCWM and DMC were evaluated in The Energy Institute's 15,000 lb steam/h watertube boiler. EER provided a coal-designed burner for retrofitting Penn State's boiler. In addition, EER designed the burner for the DOD boiler identified for retrofitting.

Task 3: An engineering study was performed for a complete retrofit of a DOD boiler facility to fire either MCWM or DMC. The designs were performed by EER with input from the other project participants. The designs included the coal preparation, the fuel handling, the burner, the ash removal, handling, and disposal, and the air pollution control systems. The two designs were for the DOD boiler identified in Task 4. The retrofits were designed for community/societal acceptability. The deliverables for this task were a detailed design that could be used for soliciting bids from engineering/construction firms to retrofit the candidate DOD boiler.

Task 4: An engineering cost analysis and a technology assessment of MCWM and DMC combustion were performed by Penn State's Department of Mineral Economics and The Energy Institute with assistance from the industrial participants. The effort involved surveying the DOD boiler population, identifying boilers for conversion, identifying appropriate cost-estimating methodologies, estimating basic costs for new technologies, developing a process model, analyzing and identifying transportation costs for commercial sources of MCWM and cleaned coal, determining community spillovers, and determining regional market considerations and impacts.

Task 5: The results from each of the tasks were summarized in a final report. In addition, the design packages for the boiler retrofits were submitted. These included the engineering design and economic analysis.

The original objectives of Phase II were to: (a) extend the Phase I boiler retrofit options by including designs to achieve further reductions in gaseous and particulate emissions, (b) prepare and characterize fuels compatible with coal precombustors, and (c) investigate precombustion as a means of using high ash, high sulfur coals. Upon investigating precombustion options for installing a system on either the demonstration boiler (15,000 lb steam/h) or research boiler (1,000 lb steam/h), it became apparent that there were limited viable options and that the complexity of the systems would likely preclude their use on small-scale, industrial boilers. A similar conclusion was presented by the U.S. Corps of Engineers regarding the use of slagging combustors in the Army (Davidson et al., 1991). Consequently, the Phase II work was revised by eliminating the precombustion fundamental, pilot-scale, and demonstration-scale studies and focusing on fundamental, pilot-scale, and demonstration-scale emissions reduction strategies. An economic analysis of precombustion strategies was conducted, as originally planned, in order to compare precombustion strategies with (low ash) MCWM and DMC combustion retrofits. The revised Phase II consists of four tasks as outlined below:

- Task 1. Emissions Reduction
    - Subtask 1.1 Evaluation of Emissions Reduction Strategies
    - Subtask 1.2 Installation of an Emissions Reduction System on the Demonstration Boiler
    - Subtask 1.3 Evaluation of an Emissions Reduction System
    - Subtask 1.4 Conduct NO_x Emissions Study
    - Subtask 1.5 Conduct VOC Study
    - Subtask 1.6 Conduct Trace Element Study
    - Subtask 1.7 Conduct Nitrogen Occurrence Study
- Task 2. Coal Preparation/Utilization
    - Subtask 2.1 Optimization of Particle Size Consist for CWM Formulation
    - Subtask 2.2 Fine Grinding/Classification/Liberation
    - Subtask 2.3 Fine Gravity Concentration
    - Subtask 2.4 Agglomeration/Flotation Studies
    - Subtask 2.5 Fundamental Studies of Surface-Based Processes
    - Subtask 2.6 Column Flotation
    - Subtask 2.7 Dry Cleaning of Fine Coal
    - Subtask 2.8 CWM Density Control
    - Subtask 2.9 Stabilization of CWM
    - Subtask 2.10 Atomizer Testing
- Task 3. Engineering Design and Cost; and Economic Analysis
    - Subtask 3.1 Determination of Basic Cost Estimation of Boiler Retrofits
    - Subtask 3.2 Determination of Process Analysis
    - Subtask 3.3 Determination of Environmental and Regulatory Impacts
    - Subtask 3.4 Determination of Transportation Cost Analysis
    - Subtask 3.5 Determination of Technology Adoption
    - Subtask 3.6 Determination of Regional Economic Impacts
    - Subtask 3.7 Determination of Public Perception of Benefits and Costs
    - Subtask 3.8 Determination of Social Benefits
    - Subtask 3.9 Determination of Coal Market Analysis
    - Subtask 3.10 Engineering Design
    - Subtask 3.11 Integration of Analyses
- Task 4. Final Report/Submission of Design Package

Portions of Phase II have been completed. The Phase II activities include:

<u>Task 1:</u> Task 1 activities are ongoing. In Task 1, strategies are being developed to provide for ultra-low emissions when firing coal-based fuels in industrial-scale boilers. Emissions being addressed are SO_2, NO_x, fine particulate matter (<10 µm), and air toxics (volatile organic compounds and trace metals). Post-combustion and during-combustion technologies to reduce SO_2 and NO_x emissions from coal-fired industrial boilers were

surveyed. Novel technologies that are under development but are not commercially available were also surveyed as well as proven technologies such as limestone/lime injection, selective catalytic reduction, and nonselective catalytic reduction. Options for removing the submicron particulate were investigated. In addition, methods to remove air toxics from the flue gas, such as scrubbing, were investigated.

Task 2: Task 2 activities have been completed except for Subtask 2.10, which is an atomization study being conducted by Carnegie Mellon University, which was recently added to the program. Emphasis in Task 2 was on the refinement and optimization of coal grinding and CWM preparation procedures, and on the development of advanced processes for beneficiating high ash, high sulfur coals. CWM formulation is still an art and there was a clear need for scientifically-based guidelines for slurry design. This involved determining the optimum particle size distribution, how and why the optimum particle size distribution varies from coal to coal, and the specific roles of chemical dispersing and stabilizing agents. Extensive, physical pre-cleaning of coal is especially important in small-boiler applications. The research effort built on work conducted in Phase I.

Task 3: Task 3 economic analysis activities are nearly complete and focus on determining the basic cost estimation of boiler retrofits, evaluating environmental, regulatory, and regional economic impacts, and analyzing the coal market.

Task 4: The results from each of the tasks will be summarized in a final report.

The original objectives of Phase III were to: (a) develop coal-based fuel/waste cofiring technologies, and (b) assist DOD in improving the combustion performance and reducing emissions from existing stoker-fired boilers. Since the initial development of the program's statements of work (Phases I through III), there has been a change in military boiler plant operating philosophy. This, coupled with recent developments in cofiring technologies and DOE coal preparation programs, necessitates the revision of the Phase III statement of work. Consequently, the Phase III work has been revised by eliminating coal-based fuel/waste cofiring and stoker combustion performance analysis and evaluation, and focusing these efforts toward evaluating deeply-cleaned coals as industrial boiler fuels, and investigating fundamental, pilot-scale, and demonstration-scale emissions reduction strategies. The revised Phase III consists of five tasks as outlined below:

Task 1. Coal Preparation/Utilization

Subtask 1.1	Particle Size Control
Subtask 1.2	Physical Separations
Subtask 1.3	Surface-Based Separation Process
Subtask 1.4	Dry Processing
Subtask 1.5	Stabilization of Coal-Water Mixtures

Task 2. Emissions Reduction
  - Subtask 2.1 SO_2 Reduction
  - Subtask 2.2 NO_x Reduction
  - Subtask 2.3 Study of VOC and Trace Element Production, Reduction, and Capture

Task 3. Economic Evaluation
  - Subtask 3.1 Cost and Market Penetration of Coal-Based Fuel Technologies
  - Subtask 3.2 Selection of Incentives for Commercialization of the Coal-Using Technology
  - Subtask 3.3 Community Sensitivity to Coal Fuel Usage
  - Subtask 3.4 Regional Economic Impacts of New Coal Utilization Technologies
  - Subtask 3.5 Economic Analysis of the Defense Department's Fuel Mix
  - Subtask 3.6 Constructing a National Energy Portfolio which Minimizes Energy Price Shock Effects
  - Subtask 3.7 Proposed Research on the Coal Markets and their Impact on Coal-Based Fuel Technologies
  - Subtask 3.8 Integrate the Analysis

Task 4. Evaluation of Deeply-Cleaned Coal as Boiler Fuels
  - Subtask 4.1 Modify MCWM Preparation Circuit
  - Subtask 4.2 Fuels Characterization
  - Subtask 4.3 Pilot-Scale Combustion Tests
  - Subtask 4.4 Demonstration-Scale Combustion Tests

Task 5. Final Report

The Phase III activities include:

Task 1: Research conducted under Phase I and Phase II of this project has revealed a number of specific areas where continued and/or more focused effort is required in order to develop more effective and more reliable coal processing systems. Specific objectives of Task 1 are centered around:

- focused investigations into specific coal-cleaning options and their associated ancillary operations; and
- integration of processing/cleaning operations for overall system optimization.

As in the previous phases, emphasis is on fine-coal processing for the production of high-quality, micronized coal for dry coal and coal-water mixture (CWM) applications.

Task 2: Task 2 is a continuation of the emissions reduction work started in Phase II, and involves fundamental studies, pilot-scale investigations, and full-scale demonstrations. The low-temperature NO_x reduction catalyst identified in Phase II will be tested at the pilot and demonstration scale. The effect of coal cleaning, particulate removal devices, and boiler operating conditions on air toxics emissions from coal-fired industrial boilers will also be investigated.

Task 3: The activities in Task 3 focus on determining cost and market penetration, selection of incentives, and regional economic impacts of coal-based fuel technologies. In addition, DOD's fuel mix is being determined and a national energy portfolio constructed.

Task 4: The results from each of the tasks will be summarized in a final report.

The status of Phase I is presented in Section 2.0. The accomplishments and status of Phase II, Tasks 1, 2, 3, and 4 are presented in Sections 3.0, 4.0, 5.0, and 6.0, respectively. The accomplishments and status of Phase III, Tasks 1, 2, 3,4, and 5 are presented in Sections 7.0, 8.0, 9.0, 10.0, and 11.0, respectively. Section 12.0 discusses miscellaneous activities that were conducted. Activities planned for the next semiannual period are listed in Section 13.0. References and acknowledgments are contained in Sections 14.0 and 15.0, respectively. The project schedule for Phases II and III is given in Figures 1-1 and 1-2, respectively, with a description of the milestones contained in Tables 1-1 and 1-2, respectively.

2.0 PHASE I, TASK 5: FINAL REPORT/SUBMISSION OF DESIGN PACKAGE

The draft final report for Phase I was completed on November 1, 1995. DOE's comments were received in December 1996 and the final report was submitted on January 31, 1997.

3.0 PHASE II, TASK 1: EMISSIONS REDUCTION

The objective of this task is to develop strategies to provide for ultra-low emissions when firing coal-based fuels in industrial-scale boilers. Emissions being addressed are SO_2, NO_x, fine particulate matter ($<10\ \mu m$), and air toxics (volatile organic compounds and trace metals).

3.1 Subtask 1.1 Evaluation of Emissions Reduction Strategies

Subtask 1.1 was previously completed.

3.2 Subtask 1.2 Install System on the Demonstration Boiler

Activity is underway to install an SO_2 reduction system and a ceramic filter on the demonstration boiler to reduce SO_2 emissions, and remove ultrafine particulate and increase the particulate collection efficiency, respectively. The SO_2 reduction system and a ceramic filter are discussed in Sections 2.2.1 and 2.2.2, respectively.

3.2.1 SO_2 Reduction System

A sodium duct injection system was received during this reporting period. The system, shown schematically in Figure 3-1, consists of a bag (sodium bicarbonate) unloading station, hopper with weigh cells, eductor, and piping to a port located in the ducting upstream of the baghouse and ceramic filter. The system will be installed during

Task 1. Emissions Reductions

- Subtask 1.1 - Evaluate Emissions Reductions Strategies
- Subtask 1.2 - Install System on Demonstration Boiler
- Subtask 1.3 - Evaluate Emissions Reduction System
- Subtask 1.4 - Conduct NO_X Emissions Study
- Subtask 1.5 - Conduct VOC Study
- Subtask 1.6 - Conduct Trace Element Study
- Subtask 1.7 - Conduct Nitrogen Occurrence Study

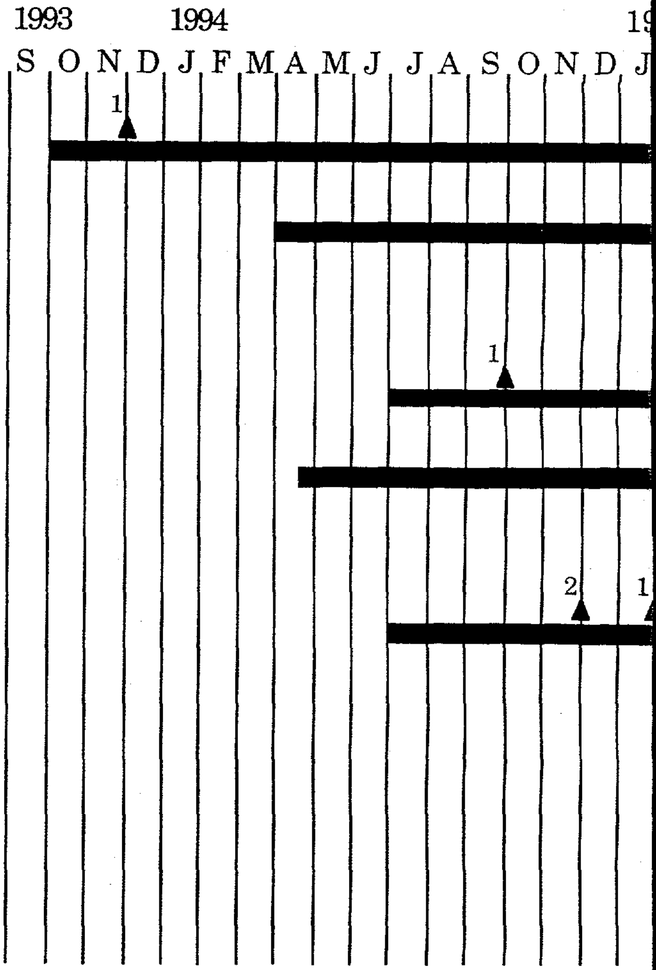
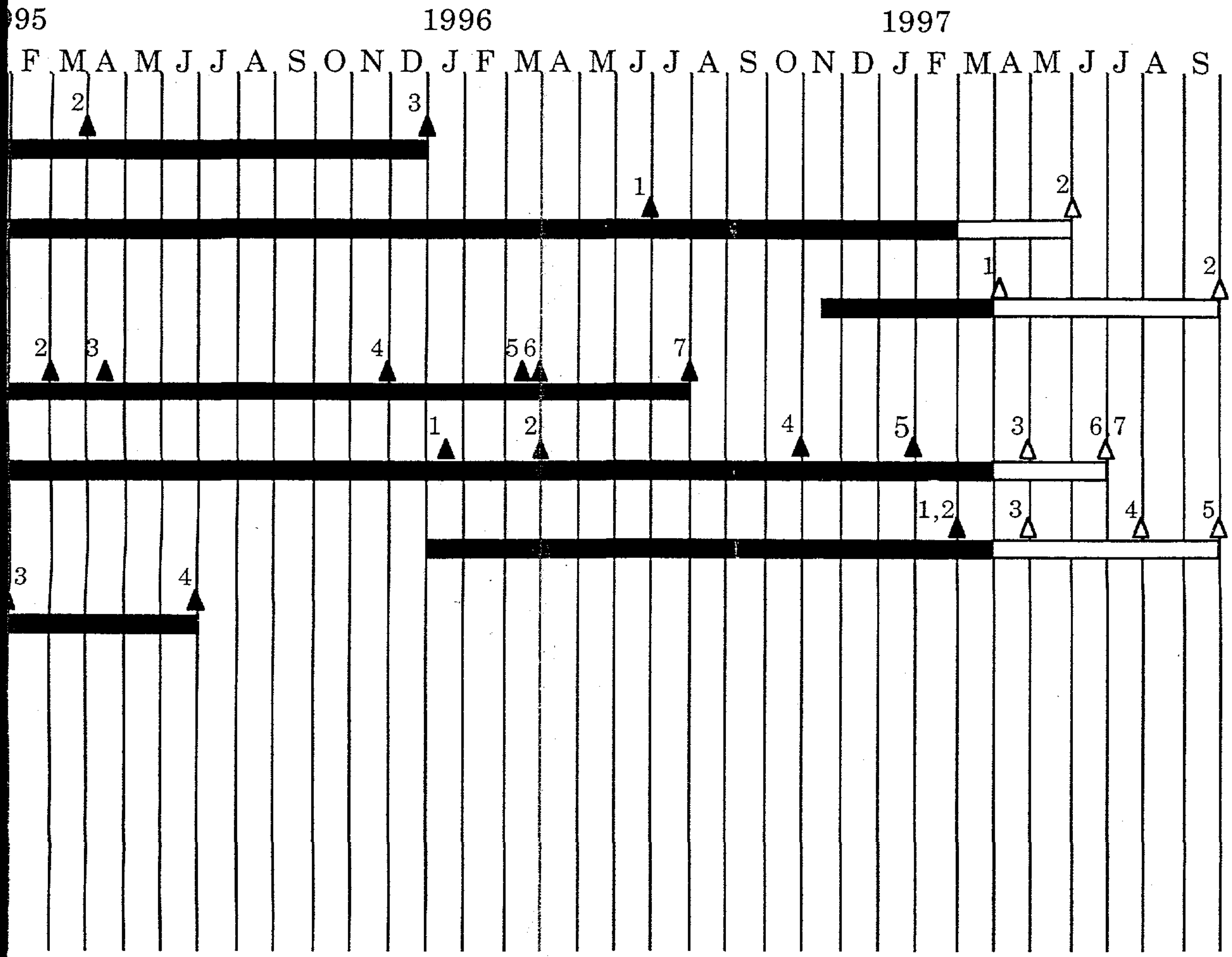


Figure 1-1. DOD PHASE II M



ILESTONE SCHEDULE

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Task 2. Coal Preparation / Utilization

Subtask 2.1 - Optimization of Particle Size Consist for Slurry Formulation

Subtask 2.2 - Fine Grinding / Classification / Liberation

Subtask 2.3 - Fine Gravity Concentration

Subtask 2.4 - Agglomeration / Flotation Studies

Subtask 2.5 - Fundamental Studies of Surface-Based Processes

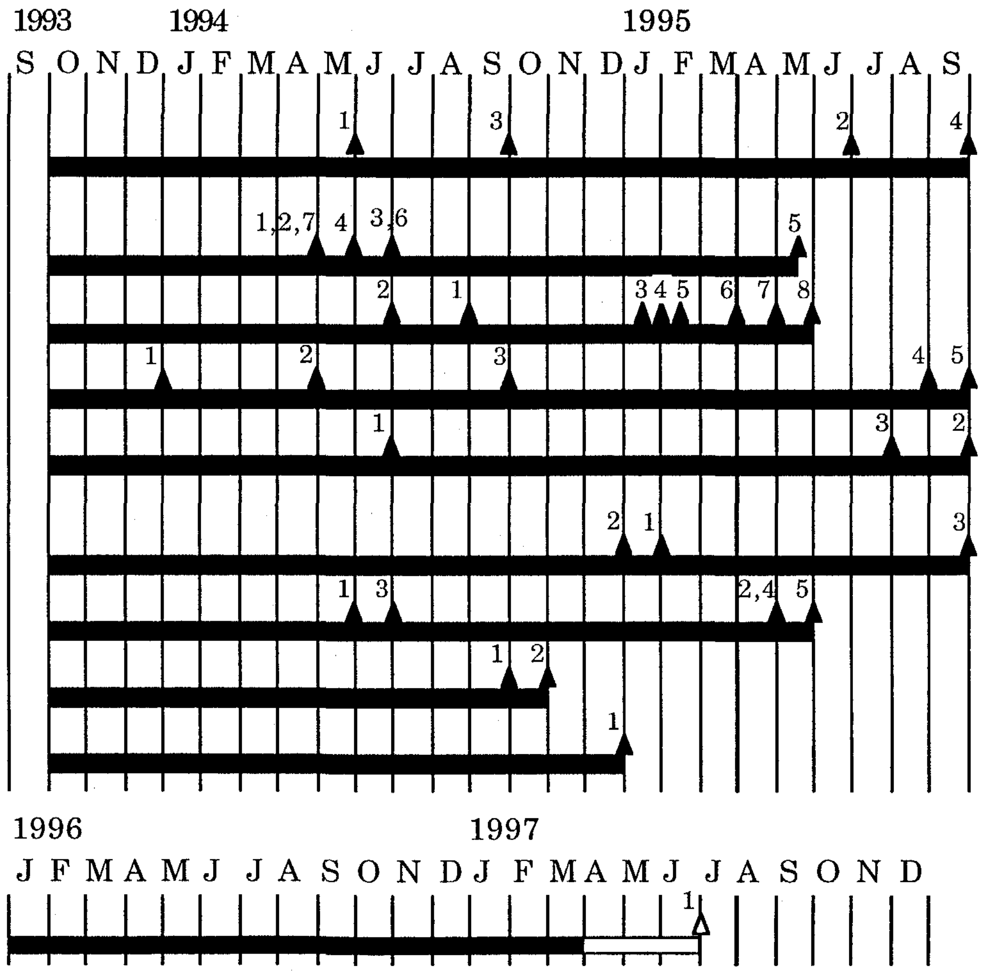
Subtask 2.6 - Column Flotation

Subtask 2.7 - Dry Cleaning of Fine Coal

Subtask 2.8 - Slurry Density Control

Subtask 2.9 - Stabilization of CWSF

Subtask 2.10 - Atomizer Testing



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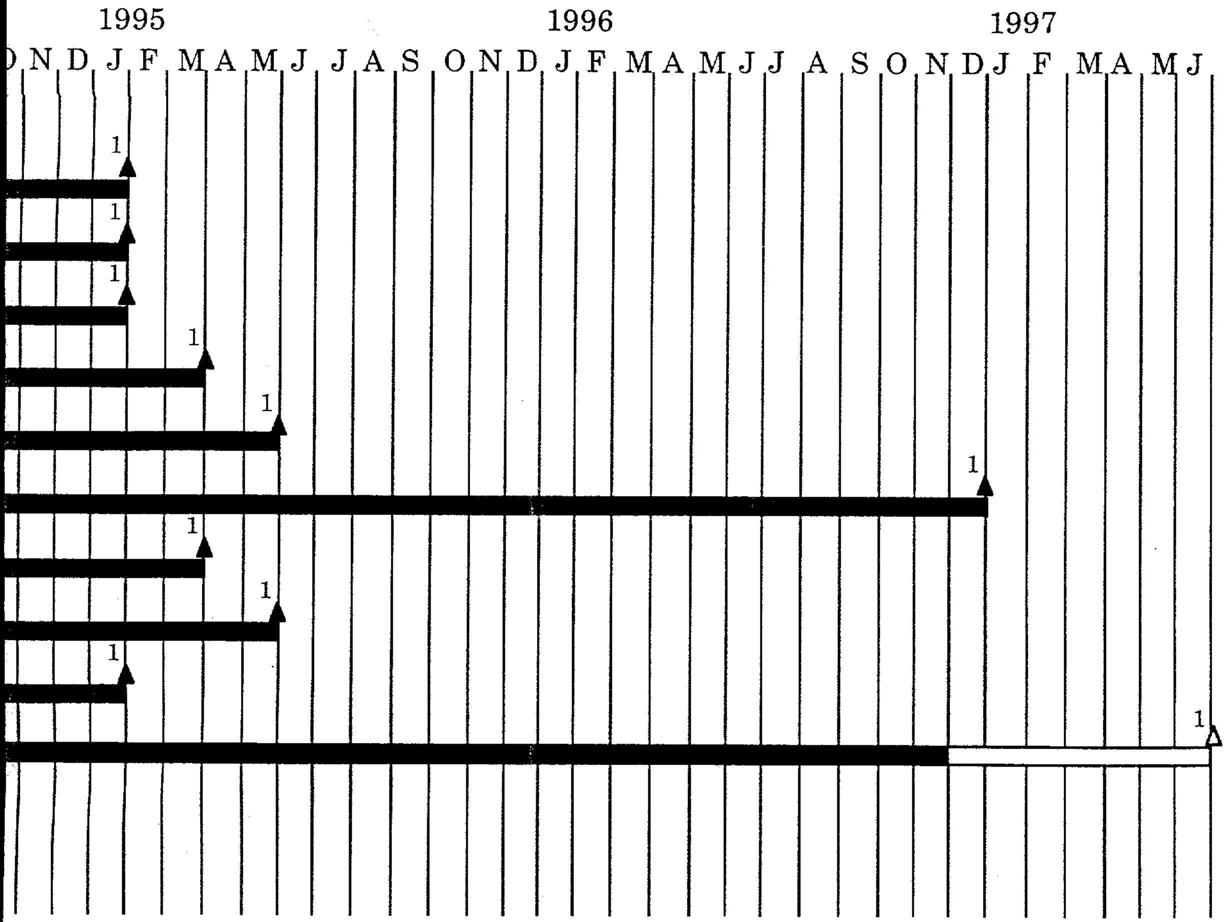
Task 3. Engineering Design and Cost and Economic Analysis													
Subtask 3.1 - Basic Cost Estimation of Boiler Retrofits		■	■	■	■	■	■	■	■	■	■	■	■
Subtask 3.2 - Process Analysis		■	■	■	■	■	■	■	■	■	■	■	■
Subtask 3.3 - Environmental and Regulatory Impacts					■	■	■	■	■	■	■	■	■
Subtask 3.4 - Transportation Cost Analysis		■	■	■	■	■	■	■	■	■	■	■	■
Subtask 3.5 - Technology Adoption			■	■	■	■	■	■	■	■	■	■	■
Subtask 3.6 - Regional Economic Impacts		■	■	■	■	■	■	■	■	■	■	■	■
Subtask 3.7 - Public Perception of Benefits and Costs		■	■	■	■	■	■	■	■	■	■	■	■
Subtask 3.8 - Social Benefits			■	■	■	■	■	■	■	■	■	■	■
Subtask 3.9 - Coal Market Analysis		■	■	■	■	■	■	■	■	■	■	■	■
Subtask 3.10 - Integration of Analyses		■	■	■	■	■	■	■	■	■	■	■	■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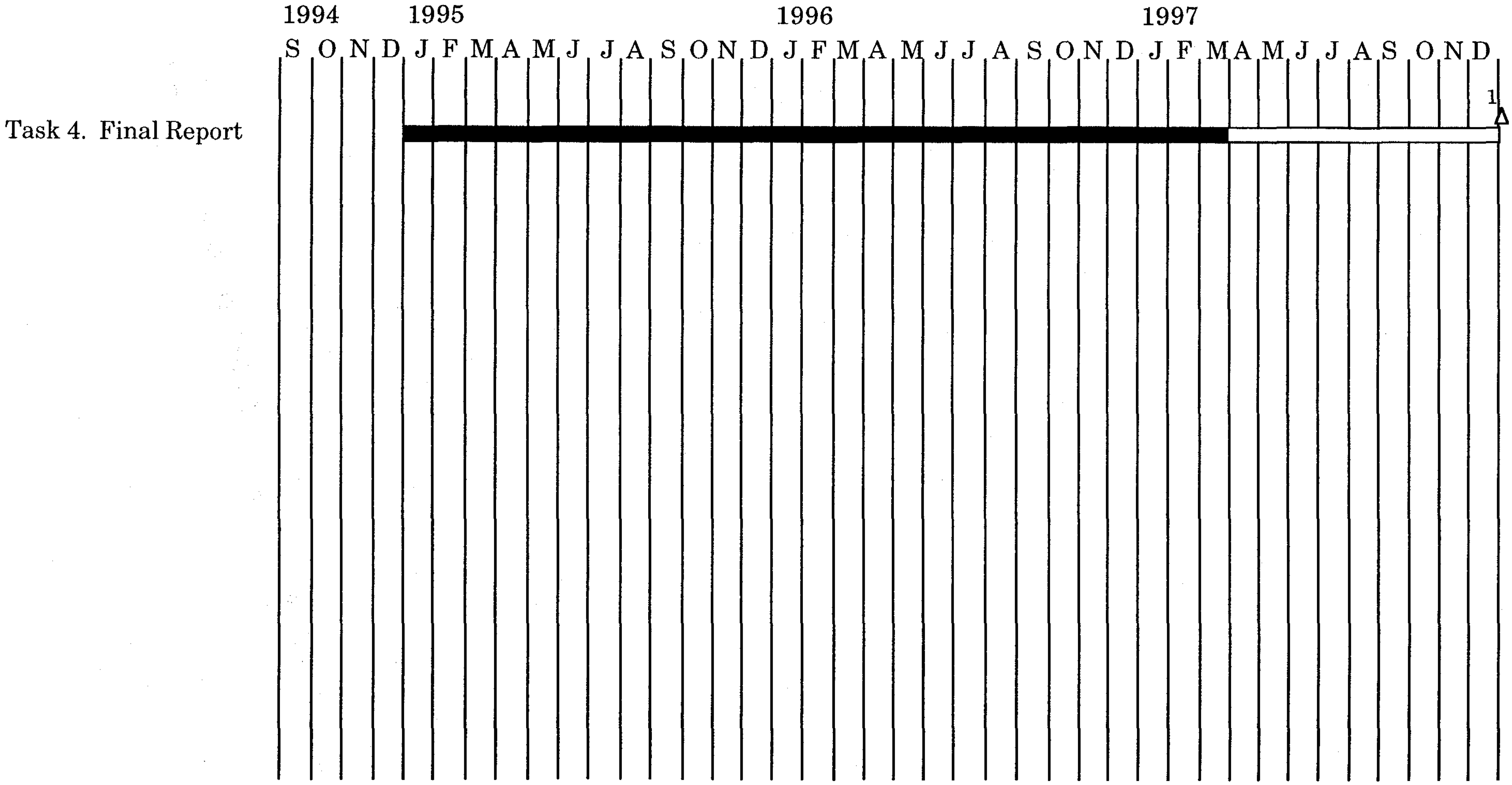
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Task 4. Final Report
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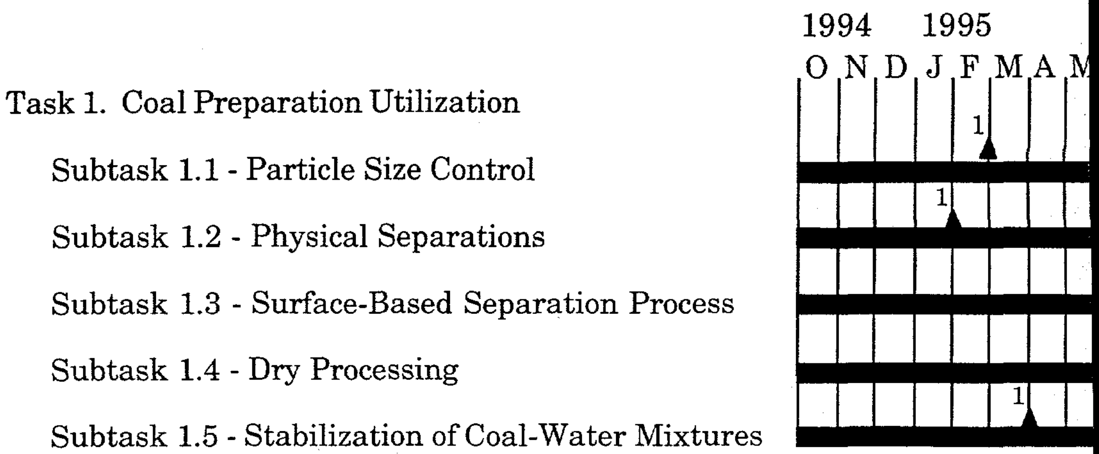
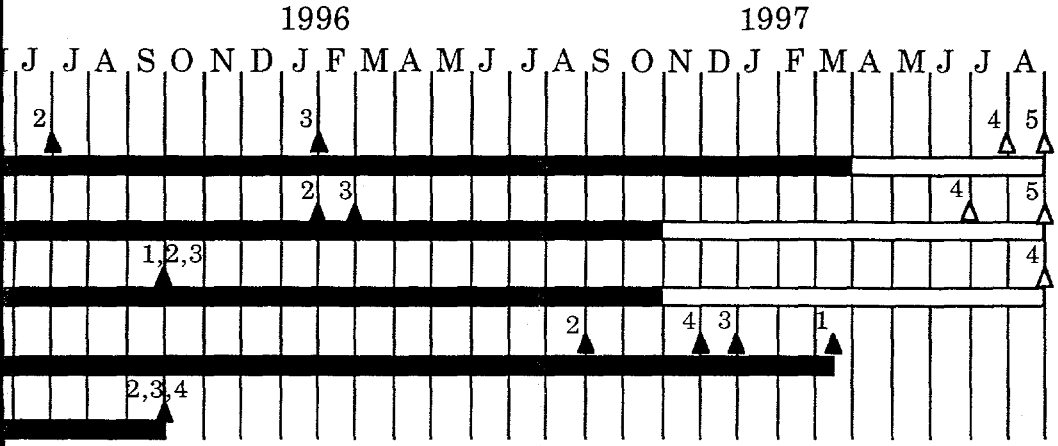
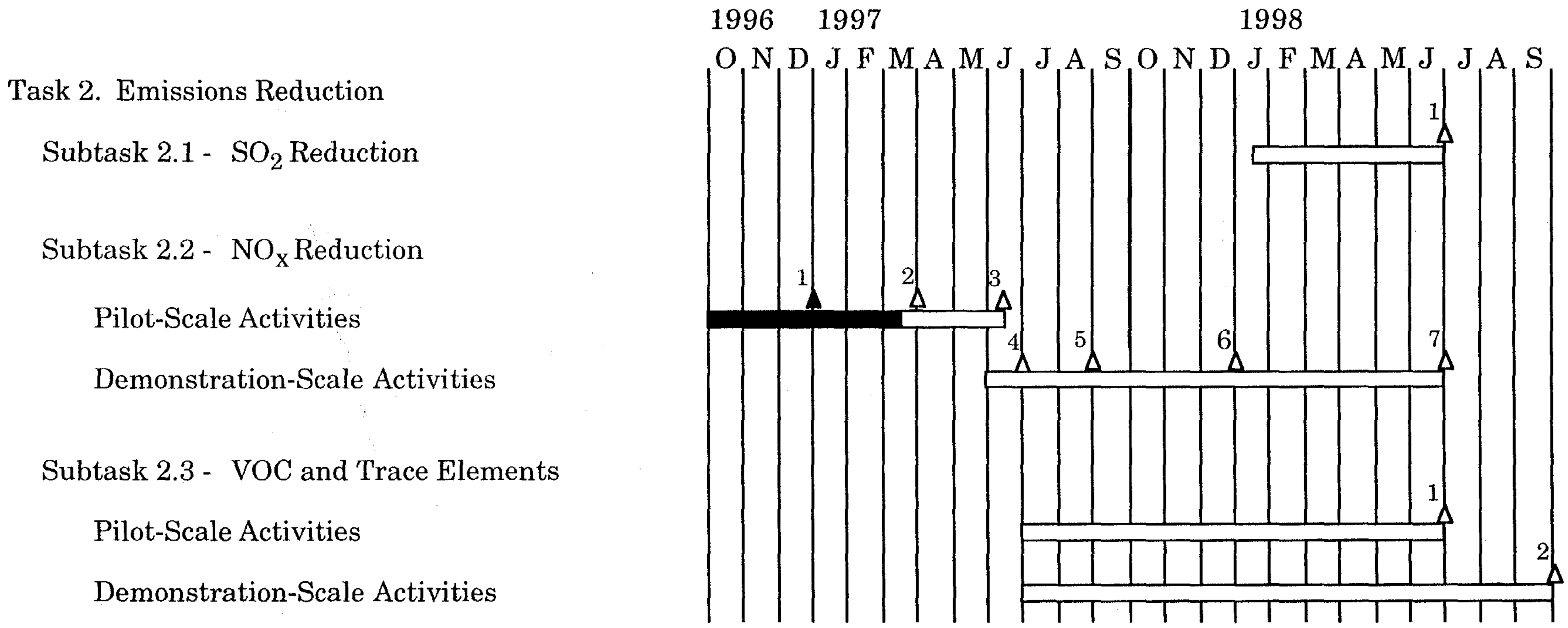


Figure 1-2. DOD PHASE II



MILESTONE SCHEDULE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Task 2. Emissions Reduction
Subtask 2.1 - SO2 Reduction
Subtask 2.2 - NOx Reduction
Pilot-Scale Activities
Demonstration-Scale Activities
Subtask 2.3 - VOC and Trace Elements
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Demonstration-Scale Activities
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Task 3. Economic Evaluation

Subtask 3.1 - Cost and Market Penetration of Coal-Based Fuel Technologies

Subtask 3.2 - Selection of Incentives for Commercialization of the Coal Using Technology

Subtask 3.3 - Community Sensitivity of Coal Fuel Usage

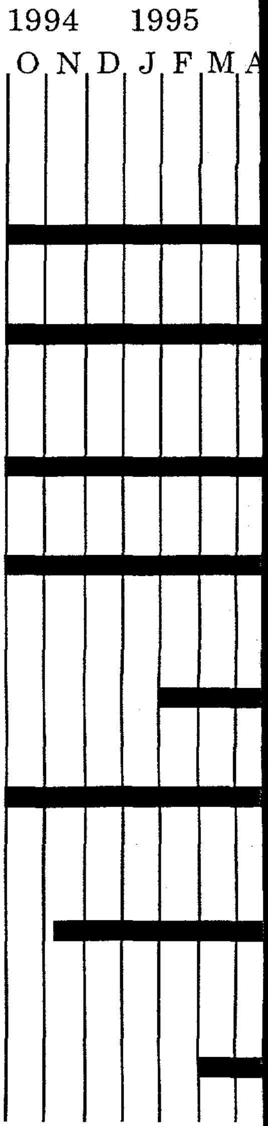
Subtask 3.4 - Regional-National Economic Impacts of New Coal Utilization Technologies

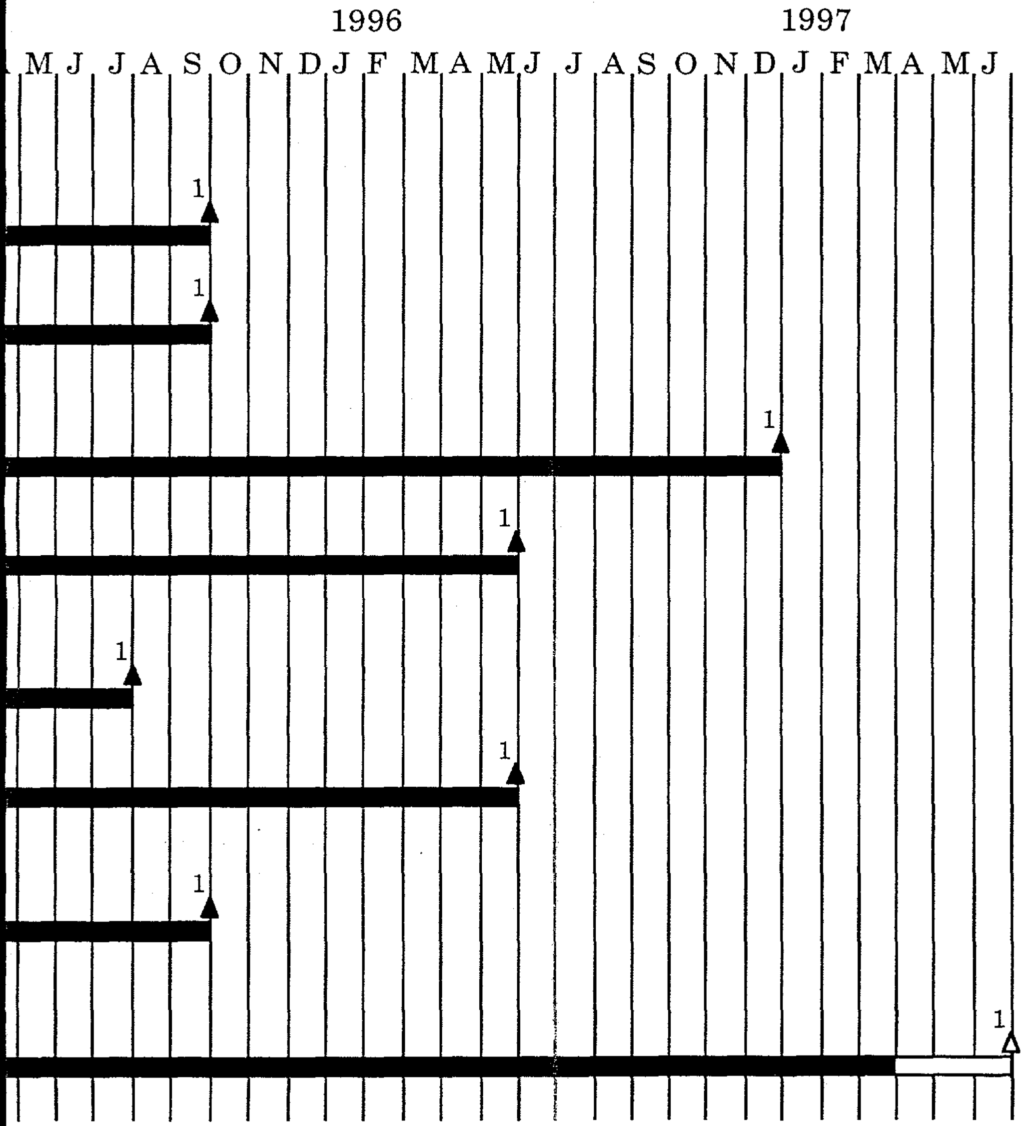
Subtask 3.5 - Economic Analysis of the Defense Department's Fuel Mix

Subtask 3.6 - Constructing a National Energy Portfolio which Minimizes Energy Price Shock Effects

Subtask 3.7 - Proposed Research on the Coal Markets and their Impact on Coal-Based Fuel Technologies

Subtask 3.8 - Integration of Economic Analysis

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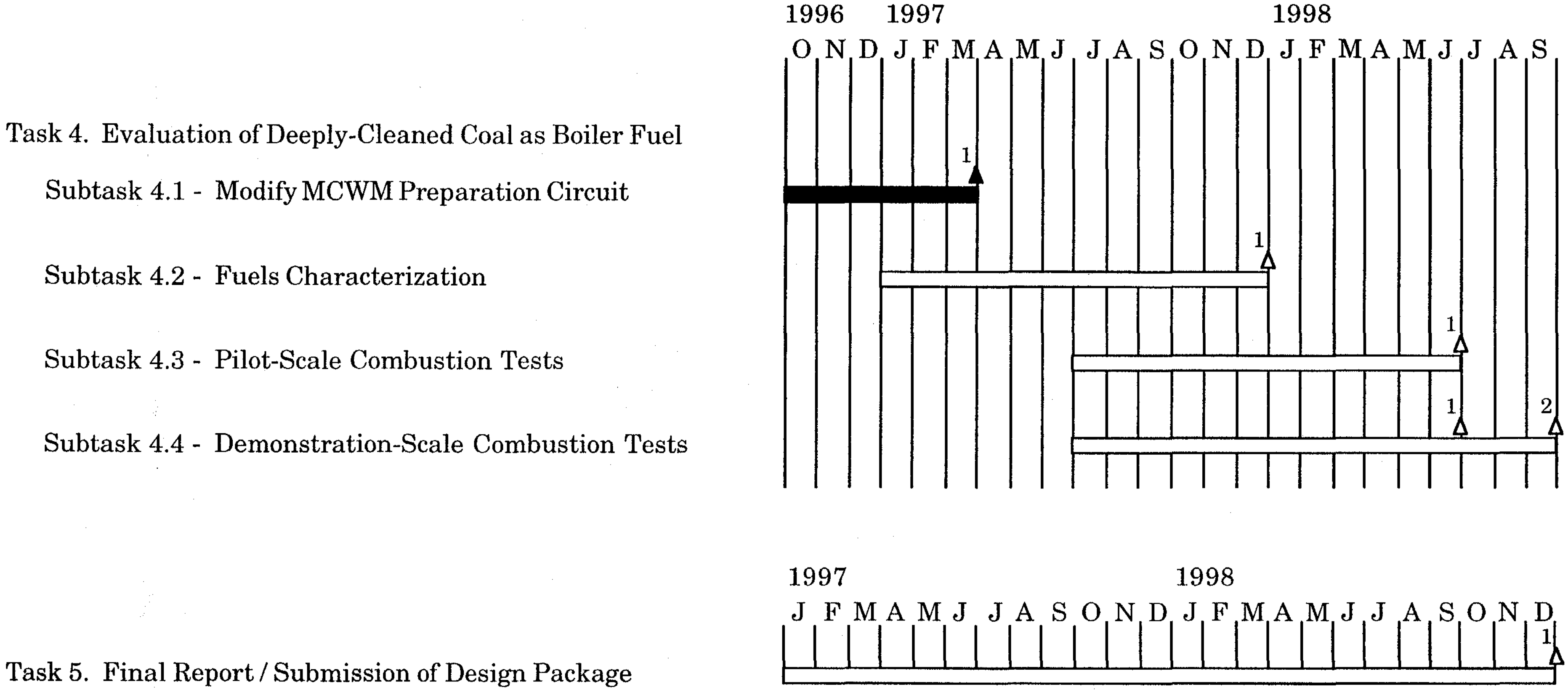
Task 4. Evaluation of Deeply-Cleaned Coal as Boiler Fuel
Subtask 4.1 - Modify MCWM Preparation Circuit
Subtask 4.2 - Fuels Characterization
Subtask 4.3 - Pilot-Scale Combustion Tests
Subtask 4.4 - Demonstration-Scale Combustion Tests
Task 5. Final Report / Submission of Design Package
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Table 1-1. Phase II. Milestone Description

Milestone	Description	Planned Completion Date	Actual Completion Date
Task 1. Emissions Reduction			
Subtask 1.1. Evaluation of Emissions Reduction Strategies			
Subtask 1.1, No. 1	Receive proposals for pollution control system	12/01/93	12/01/93
Subtask 1.1, No. 2	Complete summary report of pollution control technologies	03/31/95	03/31/95
Subtask 1.1, No. 3	Select pollution control system	12/31/95	12/31/95
Subtask 1.2. Install System on Demonstration Boiler			
Subtask 1.2, No. 1	Design pollution control system	05/01/96	07/01/96
Subtask 1.2, No. 2	Complete installation of system	06/01/97	
Subtask 1.3. Evaluate Emissions Reduction System			
Subtask 1.3, No. 1	Shakedown system	03/31/97	
Subtask 1.3, No. 2	Complete system evaluation	09/30/97	
Subtask 1.4. Conduct NO_x Emissions Study			
Subtask 1.4, No. 1	Review state-of-the art in NO_x catalysts	10/01/94	10/01/94
Subtask 1.4, No. 2	Design bench-scale flow reactor	02/01/95	03/01/95
Subtask 1.4, No. 3	Design FTIR gas analysis system for the flow reactor	04/01/95	04/18/95
Subtask 1.4, No. 4	Construct flow reactor and data acquisition system	10/01/95	12/15/95
Subtask 1.4, No. 5	Shake down system and calibrate FTIR spectrometer	03/01/96	03/15/96
Subtask 1.4, No. 6	Select and acquire catalysts for testing	04/01/96	04/01/96
Subtask 1.4, No. 7	Develop catalyst characterization database	06/15/96	08/01/96
Subtask 1.5. Conduct VOC Study			
Subtask 1.5, No. 1	Modify research boiler	12/31/95	01/15/96
Subtask 1.5, No. 2	Literature survey on trace organic emissions and analytical procedures	03/31/96	04/01/96
Subtask 1.5, No. 3	Evaluate the GC/MS equipment and upgradation	04/30/97	
Subtask 1.5, No. 4	Procurement of Method 5 apparatus and auxiliaries	10/31/96	10/31/96
Subtask 1.5, No. 5	Shakedown of the sampling procedures	01/31/97	01/31/97
Subtask 1.5, No. 6	Conduct test program and analyze samples	06/30/97	
Subtask 1.5, No. 7	Analysis of the results	06/30/97	
Subtask 1.6. Conduct Trace Element Study			
Subtask 1.6, No. 1	Conduct literature survey on trace element emissions and analysis techniques	11/30/96	03/01/97
Subtask 1.6, No. 2	Procure sampling equipment	02/28/97	02/28/97
Subtask 1.6, No. 3	Shake down sampling procedure	04/30/97	
Subtask 1.6, No. 4	Characterize emissions from industrial boiler	07/31/97	
Subtask 1.6, No. 5	Analysis of results	09/30/97	
Subtask 1.7. Conduct Nitrogen Occurrence Study			
Subtask 1.7, No. 1	Optimization of sample preparation for ^{15}N NMR on coals and chars	01/31/95	01/31/95
Subtask 1.7, No. 2	First solid-state ^{15}N NMR spectra at natural ^{15}N abundance of coals obtained	11/30/94	11/30/94
Subtask 1.7, No. 3	First solid-state ^{15}N NMR spectra at natural ^{15}N abundance of chars obtained	01/31/95	01/31/95

Milestone	Description	Planned Completion Date	Actual Completion Date
Subtask 1.7, No. 4	Examination of the N-functionality in vitrinite coals as a function of maturation degree by means of ^{15}N and ^{13}C NMR spectroscopy	06/30/95	06/30/95
Task 2. Coal Preparation/Utilization			
Subtask 2.1. Optimization of Particle Size Consist for Slurry Formulation			
Subtask 2.1, No. 1	Samples of fine and coarse slurry components prepared	04/30/94	05/30/94
Subtask 2.1, No. 2	Rheological characterization of components completed	04/30/95	06/30/95
Subtask 2.1, No. 3	Models for rheology of binary mixtures developed	09/30/94	09/30/94
Subtask 2.1, No. 4	Optimization studies complete	06/30/95	09/30/95
Subtask 2.2. Fine Grinding/Classification Liberation			
Subtask 2.2, No. 1	Grinding kinetics data for wet ball milling obtained	04/30/94	04/30/94
Subtask 2.2, No. 2	Wet classifier performance evaluated	04/30/95	04/30/95
Subtask 2.2, No. 3	Dry classifier performance evaluated	04/30/94	06/30/94
Subtask 2.2, No. 4	Grinding kinetics data for stirred media milling obtained	05/31/94	05/31/94
Subtask 2.2, No. 5	Closed-circuit jet-milling data obtained	05/15/95	05/15/95
Subtask 2.2, No. 6	Slurry production simulations initiated	06/30/94	06/30/94
Subtask 2.2, No. 7	Liberation data on Type III coal obtained	04/30/94	04/30/94
Subtask 2.3. Fine Gravity Concentration			
Subtask 2.3, No. 1	Initiate magnetic fluid separation of Type III coal	07/31/94	08/15/94
Subtask 2.3, No. 2	Complete batch centrifuge testing	04/30/94	06/30/94
Subtask 2.3, No. 3	Continuous centrifuge test rig set-up	09/30/94	01/15/95
Subtask 2.3, No. 4	Initiate magnetite classification studies	10/15/94	01/31/95
Subtask 2.3, No. 5	Initiate separations of Type III coals	02/28/95	02/28/95
Subtask 2.3, No. 6	Initiate micronized coal classification studies	04/30/95	03/31/95
Subtask 2.3, No. 7	Evaluate dense-medium separation data	04/30/95	04/30/95
Subtask 2.3, No. 8	Evaluate size classification data	05/31/95	05/31/95
Subtask 2.4. Agglomeration/Flotation Studies			
Subtask 2.4, No. 1	Set-up device to size separate flotation products of micronized coal	12/31/93	12/31/93
Subtask 2.4, No. 2	Set-up equipment for larger scale tests using 2.2 cu.ft. flotation cells	04/30/94	04/30/94
Subtask 2.4, No. 3	Conduct agglomeration-flotation tests for micronized Type III coal	09/30/94	09/30/94
Subtask 2.4, No. 4	Conduct agglomeration-flotation tests in larger cells	03/31/95	08/31/95
Subtask 2.4, No. 5	Determine parameters for scale-up	06/30/95	09/30/95
Subtask 2.5. Fundamental Studies of Surface-Based Processes			
Subtask 2.5, No. 1	Conduct interface characterization studies to determine flotation reagent-coal interactions	06/30/94	06/30/94
Subtask 2.5, No. 2	Measure contact angles in the coal-oil-surfactant-water system	06/30/95	09/30/95
Subtask 2.5, No. 3	Determine effect of surfactants on slurry stability	05/31/95	07/31/95
Subtask 2.6. Column Flotation			
Subtask 2.6, No. 1	Test work on Type II coals	11/30/94	01/31/95
Subtask 2.6, No. 2	Test work on Type III coals	09/30/94	12/31/94
Subtask 2.6, No. 3	Determine scale-up parameters	05/31/95	09/30/95
Subtask 2.7. Dry Cleaning of Fine Coal			
Subtask 2.7, No. 1	Complete evaluation of Type III coal in batch separator	04/30/94	05/31/94

Milestone	Description	Planned Completion Date	Actual Completion Date
Subtask 2.7, No. 2	Integration of closed dry grinding circuit with TES	04/30/95	04/30/95
Subtask 2.7, No. 3	Initiate investigation of continuous TES	04/01/94	06/30/94
Subtask 2.7, No. 4	Complete charge measurements on Type II coal	04/30/95	04/30/95
Subtask 2.7, No. 5	Complete charge measurements on Type III	05/31/95	05/31/95
Subtask 2.8. Slurry Density Control			
Subtask 2.8, No. 1	Evaluate procedures for reversible flocculation of fine coal	09/30/94	09/30/94
Subtask 2.8, No. 2	Establish process engineering for thickening of fine-coal slurries	10/31/94	10/31/94
Subtask 2.9. Stabilization of CWSF			
Subtask 2.9, No. 1	Complete stabilization study	12/31/94	12/31/94
Subtask 2.10. Atomizer Testing			
Subtask 2.10, No. 1	Complete atomization study	06/30/97	
Task 3. Engineering Design and Cost; and Economic Analysis			
Subtask 3.1. Determine Basic Cost Estimation of Boiler Retrofits		02/01/95	02/01/95
Subtask 3.2. Determine Process Analysis		02/01/95	02/01/95
Subtask 3.3. Determine Environmental and Regulatory Impacts		02/01/95	02/01/95
Subtask 3.4. Determine Transportation Cost Analysis		04/01/95	04/01/95
Subtask 3.5. Determine Technology Adoption		06/01/95	06/01/95
Subtask 3.6. Determine Regional Economic Impacts		12/31/96	12/31/96
Subtask 3.7. Determine Public Perception of Benefits and Costs		04/01/95	04/01/95
Subtask 3.8. Determine Social Benefits		06/01/95	06/01/95
Subtask 3.9. Determine Coal Market Analysis		02/01/95	02/01/95
Subtask 3.10. Complete Integration of Analyses		06/30/97	
Task 4. Final Report		12/31/97	

Table 1-2. Phase III. Milestone Description

Milestone	**Description**	**Planned Completion Date**	**Actual Completion Date**
Task 1. Coal Preparation/Utilization			
Subtask 1.1. Particle Size Control			
Subtask 1.1, No. 1	Evaluate conventional ball milling circuit	02/28/95	02/28/95
Subtask 1.1, No. 2	Evaluate stirred-media milling circuit	06/30/95	06/30/95
Subtask 1.1, No. 3	Complete baseline testing of attrition milling for the production of broad size distributions	01/31/96	01/31/96
Subtask 1.1, No. 4	Complete preliminary evaluation of dry grinding/ classifier circuit	07/31/97	
Subtask 1.1, No. 5	Initiate investigation of an integrated grinding/cleaning circuit	08/31/97	
Subtask 1.2. Physical Separations			
Subtask 1.2, No. 1	Complete preliminary investigation of magnetic fluid-based separation for fine coal cleaning	01/31/95	01/31/95
Subtask 1.2, No. 2	Complete baseline testing of dense-medium separation using the continuous, solid-bowl centrifuge	01/31/96	01/31/96
Subtask 1.2, No. 3	Initiate investigation of magnetic fluid cyclone separations	02/29/96	02/29/96
Subtask 1.2, No. 4	Complete baseline testing of solid-bowl centrifuge for micronized coal classification	06/30/97	
Subtask 1.2, No. 5	Initiate testing of integrated centrifugal/flotation system	08/31/97	
Subtask 1.3. Surface-Based Separation Processes			
Subtask 1.3, No. 1	Set up and evaluate continuous flotation circuit	05/31/95	09/30/95
Subtask 1.3, No. 2	Evaluate effectiveness of alternative bubble generators in flotation column	06/30/95	09/30/95
Subtask 1.3, No. 3	Baseline testing on selected coal	08/31/95	09/30/95
Subtask 1.3, No. 4	Evaluate flotation system performance	08/31/97	
Subtask 1.4 Dry Processing			
Subtask 1.4, No. 1	Complete deagglomeration testing using the batch triboelectrostatic separator	01/31/97	03/15/97
Subtask 1.4, No. 2	Complete baseline testing of continuous triboelectrostatic separator unit	05/31/96	08/31/96
Subtask 1.4, No. 3	Initiate investigation of alternative approaches to charging/deagglomeration	12/31/96	12/31/96
Subtask 1.4, No. 4	Complete preliminary testing of integrated grinding and triboelectrostatic separator unit	11/30/96	11/30/96

Milestone	Description	Planned Completion Date	Actual Completion Date
Subtask 1.5 Stabilization of Coal-Water Mixtures			
Subtask 1.5, No. 1	Complete PSD model extension	04/01/95	04/01/95
Subtask 1.5, No. 2	Complete construction of computer program	09/27/95	09/27/95
Subtask 1.5, No. 3	Complete PSD model comparison to experimental results	09/27/95	09/27/95
Subtask 1.5, No. 4	Complete coal oxidation study	09/27/95	09/27/95
Task 2. Emissions Reduction			
Subtask 2.1. SO_2 Reduction			
Subtask 2.1, No. 1	Evaluate SO_2 reduction system in coordination with NO_x reduction system	07/01/98	
Subtask 2.2. NO_x Reduction			
Subtask 2.2, No. 1	Complete preliminary pilot-scale testing firing natural gas	12/31/96	12/31/96
Subtask 2.2, No. 2	Design pilot-scale tests for NO_x reduction system	04/01/97	
Subtask 2.2, No. 3	Perform pilot-scale tests of NO_x reduction system	06/15/97	
Subtask 2.2, No. 4	Design selective catalytic NO_x reduction system	06/30/97	
Subtask 2.2, No. 5	Design demonstration boiler modifications for NO_x reduction system	09/01/97	
Subtask 2.2, No. 6	Modify demonstration boiler system for NOx reduction system	12/31/97	
Subtask 2.2, No. 7	Complete testing of NOx reduction system	07/01/98	
Subtask 2.3. Study VOC and Trace Element Production, Reduction, and Capture			
Subtask 2.3, No. 1	Complete pilot-scale testing of deeply-cleaned coals	07/01/98	
Subtask 2.3, No. 2	Complete demonstration-scale testing of deeply-cleaned coals	10/01/98	
Task 3. Economic Evaluation			
Subtask 3.1. Cost and Market Penetration of Coal-Based Fuel Technologies			
Subtask 3.1, No. 1	Complete study of cost and market penetration of coal-based fuel technologies	06/01/95	09/27/95
Subtask 3.2. Selection of Incentives for Commercialization of the Coal Using Technology			
Subtask 3.2, No. 1	Complete selection of incentives for commercialization of the coal-using technology	09/27/95	09/27/95
Subtask 3.3. Community Sensitivity to Coal Fuel Usage			

Milestone	Description	Planned Completion Date	Actual Completion Date
Subtask 3.3, No. 1	Complete evaluation of community sensitivity to coal fuel usage	12/31/96	
Subtask 3.4 Regional Economic Impacts of New Coal Utilization Technologies			
Subtask 3.4, No. 1	Complete study of regional economic impacts of new coal utilization technologies	06/01/96	06/01/96
Subtask 3.5 Economic Analysis of the Defense Department's Fuel Mix			
Subtask 3.5, No. 1	Complete economic analysis of the defense department's fuel mix	09/27/95	06/30/95
Subtask 3.6 Constructing a National Energy Portfolio which Minimizes Energy Price Shock Effects			
Subtask 3.6, No. 1	Complete construction of a national energy portfolio which minimizes energy price shock effects	06/01/96	06/01/96
Subtask 3.7 Proposed Research on the Coal Markets and their Impact on Coal-Based Fuel Technologies			
Subtask 3.7, No. 1	Complete research on the coal markets and their impact on coal-based fuel technologies	09/27/95	09/27/95
Subtask 3.8 Integrate the Analysis			
Subtask 3.8, No.1	Complete integration of the analysis	06/30/97	
Task 4. Evaluation of Deeply-Cleaned Coals as Boiler Fuels			
Subtask 4.1 Modify MCWM Preparation Circuit			
Subtask 4.1, No. 1	Complete modifications to MCWM preparation circuit	04/01/97	03/01/97
Subtask 4.2 Fuels Characterization			
Subtask 4.2, No. 1	Complete fuels characterization	01/01/98	
Subtask 4.3 Pilot-Scale Combustion Tests			
Subtask 4.3, No. 1	Complete pilot-scale testing of deeply-cleaned coals	07/01/98	
Subtask 4.4 Demonstration-Scale Combustion Tests			
Subtask 4.4, No. 1	Complete demonstration-scale testing of deeply-cleaned coals	10/01/98	

Milestone	Description	Planned Completion Date	Actual Completion Date
Task 5.	**Final Report/Submission of Design Package**	12/27/98	

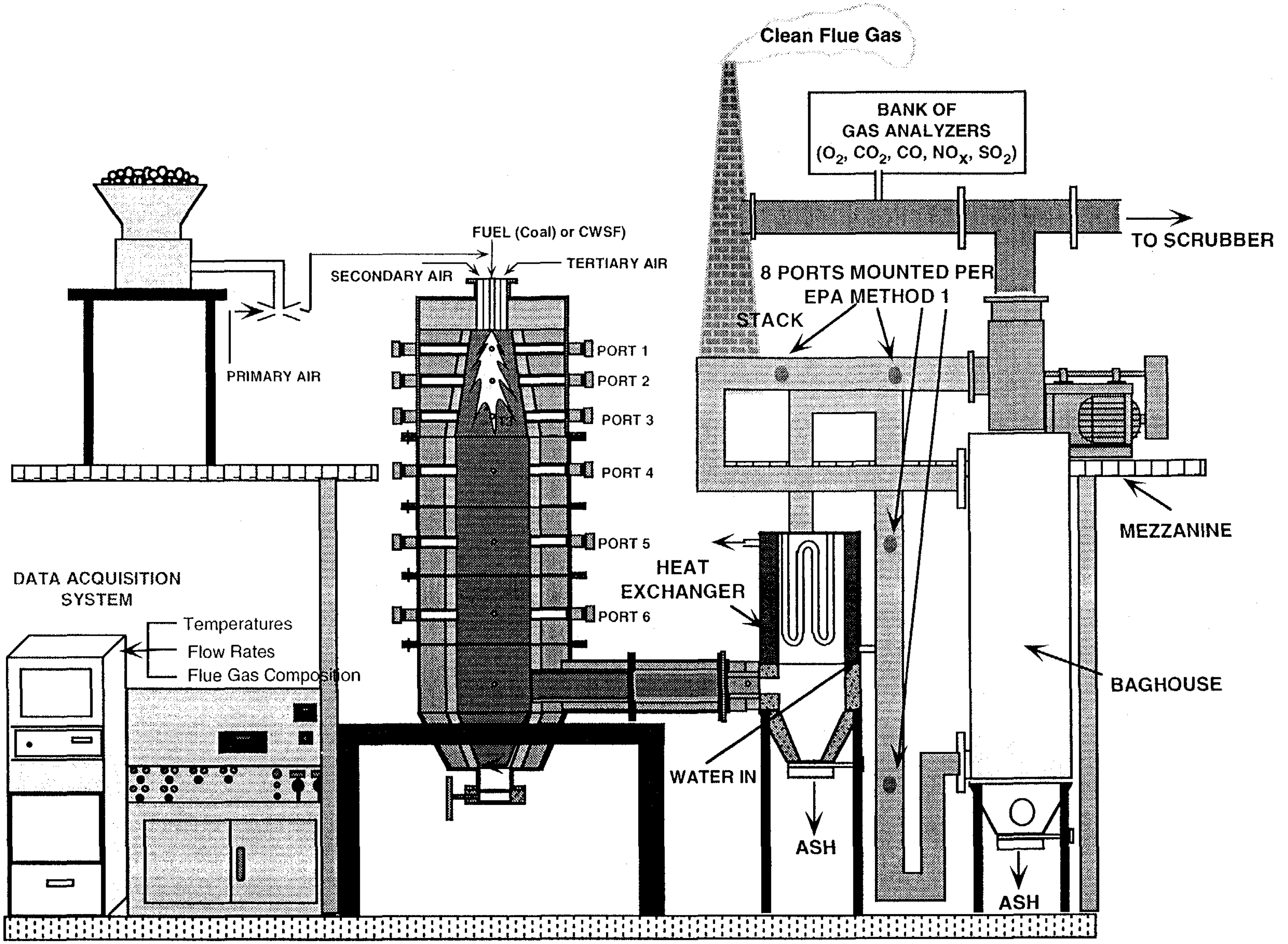


Figure 3-1. SCHEMATIC DIAGRAM OF THE DOWN-FIRED COMBUSTION TEST FACILITY
(NOT TO SCALE)

the next reporting period after approval from Penn State's Office of Physical Plant and the Pennsylvania Department of Environmental Protection.

3.2.2 Ceramic Filter

Construction of the ceramic filter was completed during this reporting period. Shakedown of the system is currently underway. The ceramic filter was installed adjacent to the existing baghouse and will be capable of filtering the entire flue gas stream. The system has been engineered such that the flue gas stream can be passed either through the baghouse or ceramic filter. Schematic diagrams of the new system and details of the ceramic filter chamber were given in previous semiannual reports (Miller et al., 1996a,b).

3.3 Subtask 1.3 Evaluate Emissions Reduction System

No work was conducted on this subtask.

3.4 Subtask 1.4 Conduct NO_x Emissions Study

Subtask 1.4 is completed.

3.5 Subtask 1.5 Conduct VOC Study

During this reporting period, preparations were made prior to beginning the VOC testing. The ducting on the down-fired combustor (DFC) was modified to accept sampling probes and Pitot tubes as specified in EPA Method 1. The ducting was modified both prior to the baghouse inlet and downstream of the baghouse outlet (see Figure 3-1.). The ducting and baghouse were insulated to help minimize condensation prior to the stack. Duct heaters have been purchased to maintain the stack gas temperatures.

Gas velocities through the ducts were measured according to EPA Method 2 procedures. Appropriately sized probes were procured. Stack gas compositions, wet and dry molecular weights of the stack gas, and flue gas moisture values were determined as specified in EPA Methods 3 and 4. Isokinetic sampling equipment having performance characteristics described in EPA Method 5 was procured.

Shakedown of the sampling train has been performed utilizing the post-baghouse sampling ports. EPA Method 8 has been employed for this shakedown. Isokinetic sampling rates between 90 and 110% were routinely achieved. SO_2 concentrations as determined by EPA Method 8 routinely agreed within ±5% of the values determined using an on-line SO_2 analyzer. The sampling port for the on-line SO_2 analyzer is located approximately 6 feet downstream of the isokinetic sampling port.

The ducting on the research boiler was also modified to meet EPA Method 1 specifications. Isokinetic sampling from the boiler using EPA Method 5 is now possible. The new sampling ports on the research boiler, like the DFC, are located prior to the baghouse inlet and downstream of the baghouse outlet (see Figure 3-2.).

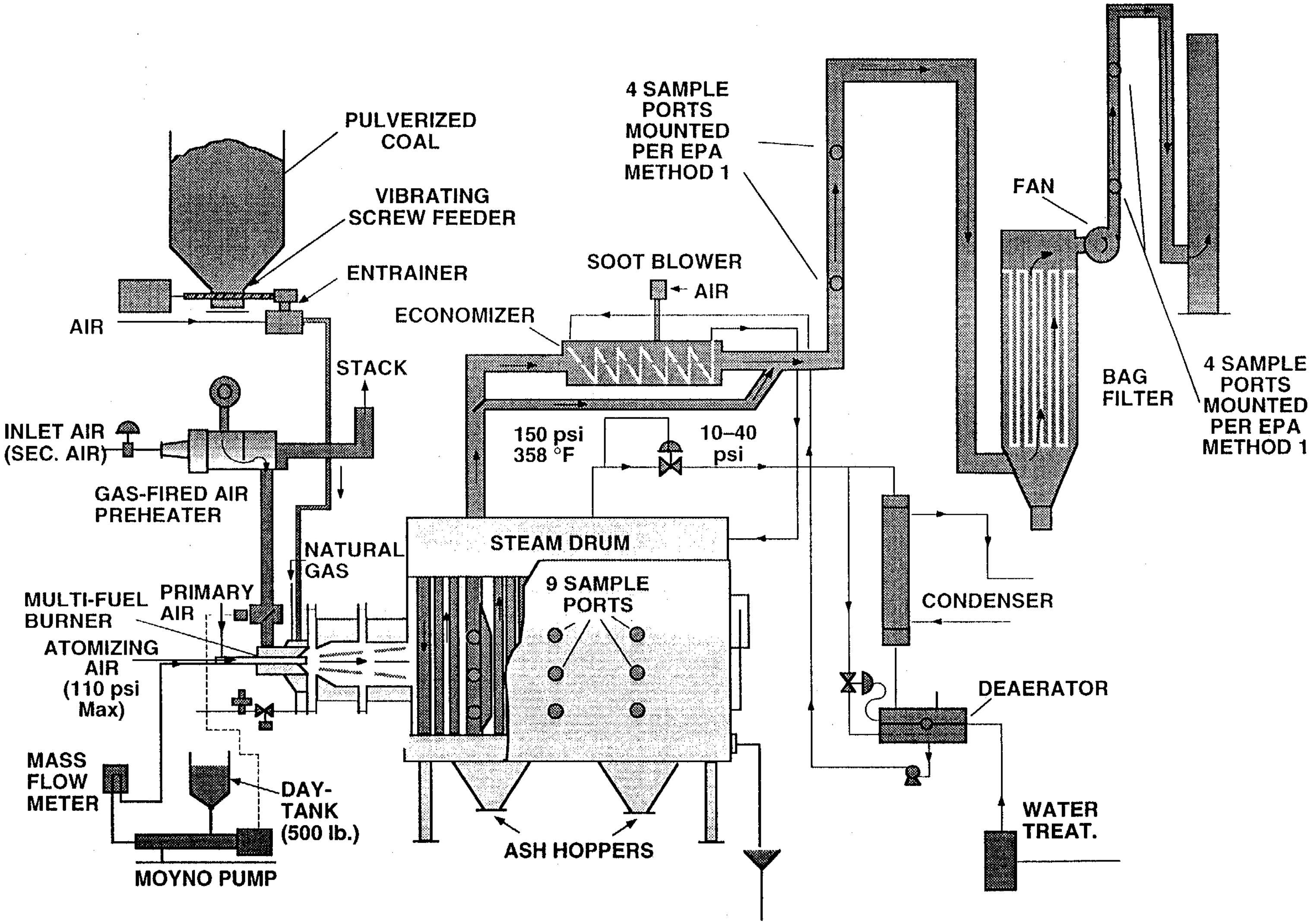


Figure 3-2. SCHEMATIC DIAGRAM OF THE RESEARCH BOILER (1,000 lb/h Steam)
(NOT TO SCALE)

Appropriate quantities and purities of water and other chemicals necessary for initial polycyclic aromatic hydrocarbon (PAH) determinations have been obtained. All ancillary glassware, filters, etc. have been obtained. A high resolution GC/MS has been reserved for the PAH determinations. Calibration of the GC/MS for PAH determinations will occur just prior to the PAH sampling.

3.6 Subtask 1.6 Conduct Trace Element Study

The objective of Subtask 1.6 is to characterize trace element emissions from coal-fired industrial boilers. Activities that were conducted during this reporting period included completing a literature search on trace element emissions from coal-fired boilers, specifically from utility-scale boilers. In addition, the necessary sampling equipment was received.

During the next reporting period, pilot-scale tests will be conducted firing pulverized coal and coal-water mixtures (CWMs) in Penn State's down-fired combustor (300,000 Btu/h) and research boiler (1.5 million Btu/h) while sampling the flue gas for trace element emissions. During this testing, partitioning (solid vs. gas) of the trace elements in the flue gas will be determined. Preliminary results will be obtained that address the effect of fuel form (pulverized coal or CWM) on trace element emissions. In addition, baghouse penetration and scale up (down-fired combustor vs. research boiler) will be studied.

3.7 Subtask 1.7 Conduct Nitrogen Occurrence Study

Subtask 1.7 has been completed and the results are being prepared for the Phase II final report. A summary of the results is contained in this section.

The conclusion to be drawn from this preliminary study is that a breakdown of the less stable pyrrolic-N and a relative enrichment of carbazolic-N occurs during combustion. The latter might be selectively enriched due to the loss of other more labile N-compounds or newly formed during combustion. Although it was shown for the first time that ^{15}N NMR spectroscopy can help in understanding and examining chemical processes during combustion, a more detailed and expanded investigation of such processes is necessary.

4.0 PHASE II, TASK 2: COAL PREPARATION/UTILIZATION

Activities in Phase II, Task 2 primarily focused on preparing the final report and initiating a study with Carnegie Mellon University to study the fundamental behavior of atomization. Results of the study are presented in Section 4.1.

4.1 Subtask 2.10 Conduct Atomization Study

The objective of this subtask is to determine the effect of MCWM stability additives (e.g., Flocon 4800 C) on the MCWM rheology, atomization characteristics, and combustion behavior. The activities in this subtask are being conducted by Carnegie Mellon University (CMU) and Penn State.

4.1.1 Measurement of the Extensional Viscosity of Coal-Water Mixtures

Penn State provided six samples of coal-water mixtures (CWMs) to CMU. Table 4-1 shows the solids loading, stabilizer concentrations, and shear viscosity of the samples. The stabilizer concentrations used were 0, 400 ppm, which is typically the concentration used by Penn State, and 800 ppm. All samples were subjected to screening to determine if the extensional viscosity plays an important role in atomization. An attempt has been made to measure the extensional viscosity of the CWMs using the falling droplet technique. The samples' solids loadings ranged from 50.0 to 54.6% of coal by mass. The shear viscosity at a shear rate of 100/s ranged from 109 to 714 cp. The attempt failed however because the CWMs did not generate a trailing filament (see Figure 4-1). All samples were observed in the drip mode of breakup. The samples were placed in a capillary tube with an inner diameter of 1.1 mm. As the droplets fell from the end of the capillary tube, digital images were obtained with the Greenfield Digital Spray Analyzer. The images from the CCD camera of the Greenfield analyzer were stored in a computer and translated into a common personal computer image for presentation. The filament life was less than 20 ms indicating that elastic behavior is not dominant. Typically only viscoelastic liquids and liquids which show predominant elastic behavior generate a trailing filament. This indicates that for the samples provided, the extensional viscosity did not play any significant role. Possibly the stabilizer concentration was too low to affect the breakup of the CWMs.

4.1.2 Characterization of the Delavan Nozzle

Penn State provided a Delavan atomizer to CMU for characterization under quiescent conditions (no secondary or tertiary air flow) using the laser Diffraction particle sizer. A spray chamber was constructed for characterizing the Delavan nozzle. During the next reporting period, the six CWMs will be tested with the Delavan nozzle and the near and far fields of the atomizer will be studied. The CWM and atomizing air flow rates will be varied and the effects of these parameters on breakup on the CWMs will be studied. The following tasks will be performed:

- Measure the CWM spray characteristics, i.e., the particle size distributions using the laser diffraction particle analyzer.
- Study the effects of additives (particularly stabilizers) typically used in CWMs for their influence on rheological properties and atomization. Determine the influence of shear viscosity on atomization.

Table 4-1. Solids Loading, Stabilizer Concentration, and Apparent Viscosity of the Carnegie Mellon Test Coal-Water Mixtures

Sample Id	**Solids Loading (wt.%)**	**Stabilizer Concentration (wt. % active solids, dry coal)**	**Apparent Viscosity (cp, @ 100 sec^{-1})**
CMU-54-0	54.6	0	322
CMU-54-400	54.6	0.04	651
CMU-54-800	54.5	0.08	714
CMU-50-0	50.0	0	109
CMU-50-400	50.2	0.04	181
CMU-50-800	50.3	0.08	200

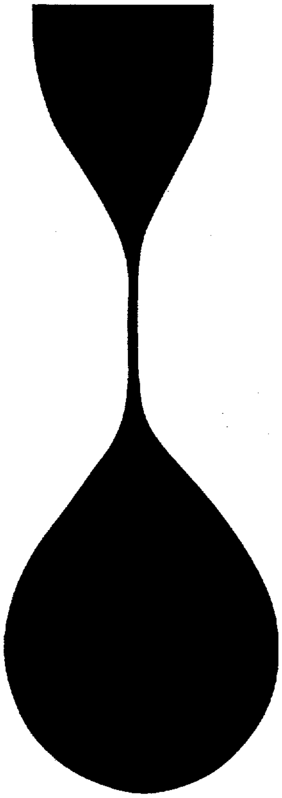


Figure 4-1. BREAKUP OF COAL-WATER MIXTURE SAMPLE IN THE DRIP MODE (CMU-50-800)

- Study the fundamental mechanisms of atomization of CWMs. Develop models for the breakup of CWMs using air-blast atomizers.
- Use the Malvern laser diffraction instrument for measurement of droplet size in the spray field produced by the triple concentric air assist atomizer.
- Vary flow rates of liquid and atomizing air. Measure drop size distribution. Determine quality of atomization from microphotography. Establish the relationships between rheological properties of solutions at high shear rates and atomization quality.

5.0 PHASE II, TASK 3 ENGINEERING DESIGN AND COST; AND ECONOMIC ANALYSIS

Phase II, Task 3 has been completed except for Subtask 3.10, integration of analysis. Activities during this reporting focused on working on a discussion of regional economic benefits of decreased dependence on imported oil was prepared for Subtask 3.10.

5.1 Subtask 3.10 Integration of Analyses

5.1.1 Introduction

Many policymakers have extolled the benefits of decreased reliance on imported oil. The gains would stem from lowering expected losses from potential embargoes and other political actions that cause shortages or price spikes. In addition, there would be gains from the positive economic stimulus of increased domestic production of energy resources. These would include not only direct output and employment impacts in domestic energy industries, but also general equilibrium effects by way of the stimulus to other sectors. Of course, the gains would be relatively greater in those regions providing the domestic energy substitutes.

In place of foreign oil, there are several domestic alternatives. For example, the U.S. has more energy in coal than the Middle East has in oil reserves. Moreover, recent advances in technology hold the promise of burning coal more efficiently, thereby lowering its cost and pollution emissions (e.g., Miller et al., 1997). In addition, there are a range of renewable resource options whose technological development is progressing as well.

Estimates of the value of the "security premium" on imported oil have dropped in recent years (see, e.g., Bohi and Toman, 1993). The adjustments are based on revisions of estimates of the actual macroeconomic shocks associated with the Arab oil embargo and Iranian revolution. Also noted is the fact that while the U.S. is now importing as large a percentage of oil as before the embargo about (45%), most of these imports are from countries considered friendly to the U.S. or that are at least politically stable.

Even if the security issue wanes, however, the economic stimulus from increased domestic energy production remains an attractive benefit of increased coal utilization. But just how significant is it? 1.0% of GNP, 0.1%, of GNP or some infinitesimal amount. Even the 0.1% figure represents $7 billion of GNP and nearly 150,000 jobs.

The purpose of this section is to measure the economic stimulus effect of replacing foreign oil with domestic energy resources. Specifically, a computable general equilibrium model developed by Li (1994) was employed to examine the widespread adoption of coal-fired industrial boilers in Pennsylvania as determined by Schaal (1995). Although the impacts in the state of Pennsylvania are likely to be higher than most other parts of the U.S., and therefore represent an upward bound for generalization purposes, they are indicative of the extent of potential benefits from oil imports substitution policies.

Ordinarily, if it is assumed that an economy is already in equilibrium, the existing pattern of international trade in energy would be optimal, and any import substitution policy would imply a decrease in economic activity. However, the factor that makes the opposite outcome possible is the development of a new technology that lowers the effective price of coal vis-a-vis imported oil.

5.1.2 Analysis

The computable general equilibrium (CGE) model of the Pennsylvania economy constructed as part of Task 4.7 of the Phase II Report (see also Li, 1994; Li and Rose, 1995) was utilized to determine the regional impacts of industrial boiler conversion. Computable general equilibrium refers to: a model of the entire economy based on decisions by individual producers and consumers in response to price signals, within limits of available capital, labor, natural resources. These models are the most advanced tools of regional economic analysis in use today.

The model was applied to an assessment of industrial boiler conversion potential undertaken by Schaal as part of Task 4.1 of the Phase II Report and Task 5.1 of the Phase III Report (see also Schaal, 1995). A major modification was, however, introduced in the analysis below. Schaal's previous work on conversion of oil-fired industrial boilers to coal involves several rather pessimistic assumptions, and he found the potential to be a maximum direct increase of industrial coal demand of 4.6% for the entire State. Relaxing some of the restrictive assumptions resulted in a "Mid-Range" estimate of 17.5%. Moreover, an optimistic scenario at the level of 35% is also granted.

Conversion in five major sectors was simulated: Plastics, Glass, Stone and Clay, Nonferrous Metals, and Other Manufacturing. For lack of more detailed information, it was assumed that the same target conversion for each sector in terms of increased coal consumption (see the second row of each partition of Table 5-1). This, however, results in differing percentages of petroleum replacement among sectors (see the last row of each

Table 5-1. Calculation of Coal Substitution for Petroleum in Boiler Retrofit Sectors

Pessimistic Scenario (4.6%)	Nonferrous Metals	Plastic	Glass	Stone	Other Manufac
Base Coal consumption ($)	2137	1190	334	20045	76564
Increased coal consumption (%Δ)	4.60	4.60	4.60	4.60	4.60
Increased coal consumption ($)	98	55	15	922	3522
Increased coal consumption (ton)	3	2	1	31	117
Increased coal consumption (mmBtu)	86	48	13	804	3071
Replaced petroleum consumption (mmBtu)	86	48	13	804	3071
Replaced petroleum consumption (bbl)	14	8	2	134	512
Replaced petroleum consumption ($)	312	174	49	2927	11179
Base petroleum consumption ($)	24870	20846	10730	11201	417309
Replaced petroleum consumption (%Δ)	1.25	0.83	0.45	26.13	2.68

Mid-Range Scenario (17.5%)	Nonferrous Metals	Plastic	Glass	Stone	Other Manufac
Base coal consumption ($)	2137	1190	334	20045	76564
Increased coal consumption (%Δ)	17.50	17.50	17.50	17.50	17.50
Increased coal consumption ($)	374	208	58	3508	13399
Increased coal consumption (ton)	12	7	2	117	447
Increased coal consumption (mmBtu)	326	182	51	3059	11684
Replaced petroleum consumption (mmBtu)	326	182	51	3059	11684
Replaced petroleum consumption (bbl)	54	30	8	510	1947
Replaced petroleum consumption ($)	1187	661	186	11134	42529
Base petroleum consumption ($)	24870	20846	10730	11201	417309
Replaced petroleum consumption (%Δ)	4.77	3.17	1.73	99.40	10.19

Optimistic Scenario (35.0%)	Nonferrous Metals	Plastic	Glass	Stone[a]	Other Manufac
Base coal consumption ($)	2137	1190	334	20045	76564
Increased coal consumption (%Δ)	35.00	35.00	35.00	17.50	35.00
Increased coal consumption ($)	748	417	117	3508	26797
Increased coal consumption (ton)	25	14	4	117	893
Increased coal consumption (mmBtu)	652	363	102	3059	23367
Replaced petroleum consumption (mmBtu)	652	363	102	3059	23367
Replaced petroleum consumption (bbl)	109	61	17	510	3895
Replaced petroleum consumption ($)	2374	1322	371	11134	85057
Base petroleum consumption ($)	24870	20846	10730	11201	417309
Replaced petroleum consumption (%Δ)	9.55	6.34	3.46	99.40	20.38

Price of coal is $30/ton; price of refined petroleum is $21.84/bbl.
Heat content of coal is 26.16 million Btu/ton; heat content of refined petroleum is 6 million Btu/bbl.

[a] Figures are the same as Mid-Range Scenario so as not to exceed 100% substitution.

partition in Table 5-1), with the Stone and Clay product sector being the locus of the greatest percentage displacement of oil.

5.1.3 Results

The results of the simulations are presented in Tables 5-2 and 5-3 under varying conditions relating to CGE model "closure" and import conditions. Briefly, the closure rule refers to whether a full employment economy (classical closure rule) is assumed or underemployment equilibrium (Keynesian) is allowed. Also, simulations were run that allow for some of the increased coal use to be imported from other states versus insisting it all be Pennsylvania coal.

The results of the various cases (in effect, sensitivity analyses) are relatively similar in qualitative terms. For example, in the Pessimistic Scenario, coal boiler conversion has a definite positive impact on the Pennsylvania economy, but only in the range of a 0.003% to 0.043% increase Gross Regional Product (GRP). It also results in upward pressure on prices, though only to a minuscule extent. The Optimistic Scenario calls for GRP increases ranging from 0.014% to 0.169%. The fact that the GRP effects increase by a factor of 4 when the conversion target increases by a factor of 8 indicates the nonlinearities inherent in the model.

Just how significant are these numbers? The Pennsylvania GRP is about $200 billion annually, so a 0.1% increase is $200 million. A 0.1% increase in employment is 6,000 jobs, which is a profoundly significant impact.

The impacts on selected sectors are presented in Table 5-3 for the Mid-Range Scenario (17.5% substitution). For example, coal industry output is projected to increase by 0.7% to 1.6%. There is also a slight increase in coal prices, but the results in Table 5-2 indicate that this has no overall injurious effect on the State's economy.

The impact on the State's Oil and Gas sector is much smaller in percentage terms than the increase in coal output, for the main part, because the majority of the feedstock for oil-fired boilers is imported from other states. Moreover, the decrease in the price of oil and gas as a result of lower demand following conversion is a positive stimulus to the State's economy.

The results for the Nonferrous Metals industry indicate a very slight price increase and a small decrease in output. The model to provide more insight into why these take place is currently being examined.

5.1.4 Future Work

The study will be completed during the next reporting period. This will include more in-depth analysis of sectoral results. Also, the simulations thus far have been limited to the stimulus off of the State's economy by coal substitution and the displacement of

Table 5-2. Macroeconomic Impacts of Industrial Boiler Retrofit Using MCWM Technology - All Scenarios (percentage change)

Variable	Case I	Case II	Case III	Case IV
Pessimistic Scenario (4.6%)				
Real GRP	0.010	0.043	0.003	0.021
Price Index	0.002	0.004	0.003	0.004
Total industry output	0.001	0.036	-0.014	0.000
Total employment	—	0.044	—	0.029
Total regional exports	-0.022	-0.004	-0.046	-0.048
Total regional imports	0.044	0.093	0.031	0.057
Total foreign exports	-0.060	-0.020	-0.083	-0.070
Total foreign imports	-0.048	-0.014	-0.068	-0.057
Mid-Range Scenario (17.5%)				
Real GRP	0.026	0.107	0.009	0.051
Price Index	0.011	0.014	0.012	0.014
Total industry output	0.001	0.087	-0.038	-0.005
Total employment	—	0.108	—	0.068
Total regional exports	-0.049	-0.006	-0.113	-0.118
Total regional imports	0.119	0.239	0.081	0.141
Total foreign exports	-0.145	-0.046	-0.206	-0.175
Total foreign imports	-0.117	-0.033	-0.169	-0.143
Optimistic Scenario (35.0%)				
Real GRP	0.041	0.169	0.014	0.079
Price Index	0.018	0.023	0.020	0.024
Total industry output	0.001	0.136	-0.063	-0.011
Total employment	—	0.170	—	0.105
Total regional exports	-0.075	-0.008	-0.180	-0.187
Total regional imports	0.194	0.384	0.129	0.222
Total foreign export s	-0.240	-0.083	-0.338	-0.291
Total foreign imports	-0.193	-0.061	-0.277	-0.238

Case I: No restrictions on regional coal imports, classical closure rule.
Case II: No restrictions on regional coal imports, Keynesian closure rule.
Case III: Fixed regional coal imports, classical closure rule.
Case IV: Fixed regional coal imports, Keynesian closure rule.

Table 5-3. Microeconomic Impacts of Industrial Boiler Retrofit Using MCWM Technology - Mid-Range Scenario for Key Sectors (percentage change)

Sector/ Variable	Case I	Case II	Case III	Case IV
Coal				
Price	0.027	0.023	0.053	0.047
Industry output	0.700	0.794	1.544	1.612
Employment	0.686	0.806	1.538	1.625
Regional exports	0.669	0.766	1.508	1.579
Regional imports	0.894	0.958	—	—
Foreign exports	0.536	0.673	1.383	1.482
Foreign imports	—	—	—	—
Oil & natural gas				
Price	-0.086	-0.060	-0.080	-0.062
Industry outputs	0.020	-0.044	0.010	-0.039
Employment	0.023	-0.012	0.022	-0.007
Regional exports	0.024	-0.042	0.029	-0.024
Regional imports	-0.488	-0.380	-0.481	-0.421
Foreign exports	-0.122	-0.145	-0.135	-0.151
Foreign imports	-0.344	-0.279	-0.351	-0.321
Nonferrous metals				
Price	0.029	0.032	0.030	0.033
Industry output	-0.205	-0.068	-0.428	-0.444
Employment	-0.214	-0.056	-0.430	-0.432
Regional exports	-0.237	-0.112	-0.463	-0.490
Regional imports	0.107	0.255	-0.106	-0.115
Foreign exports	-0.412	-0.236	-0.627	-0.616
Foreign imports	0.459	0.503	0.224	0.139

Case I: No restrictions on regional coal imports, classical closure rule.
Case II: No restrictions on regional coal imports, Keynesian closure rule.
Case III: Fixed regional coal imports, classical closure rule.
Case IV: Fixed regional coal imports, Keynesian closure rule.

foreign oil. The stimulating or dampening influence of boiler conversion costs themselves will also be examined.

6.0 PHASE II, TASK 4 FINAL REPORT/SUBMISSION OF DESIGN PACKAGE

Work in preparing the final report continued. Tasks 2 (except for Subtask 2.10) and 3 (except for Subtask 3.10) have been completed.

7.0 PHASE III, TASK 1 COAL PREPARATION/UTILIZATION

7.1 Subtask 1.1 Particle Size Control

7.1.1 Attrition Milling

Test results and data analysis described in previous reports (Miller et al., 1996a,b) are being re-evaluated. In recent studies in a related project, the distribution of individual particle weights for sizes close to the original (media) feed size have been determined. These results suggest that the use of simple, abrasive-wear models for media attrition does not adequately describe the process. More realistically, it appears that depletion of media-size material occurs through two mechanisms:

- fracture (or large-scale chipping) of a fraction f of the feed material, and
- slow abrasion of the remaining portion.

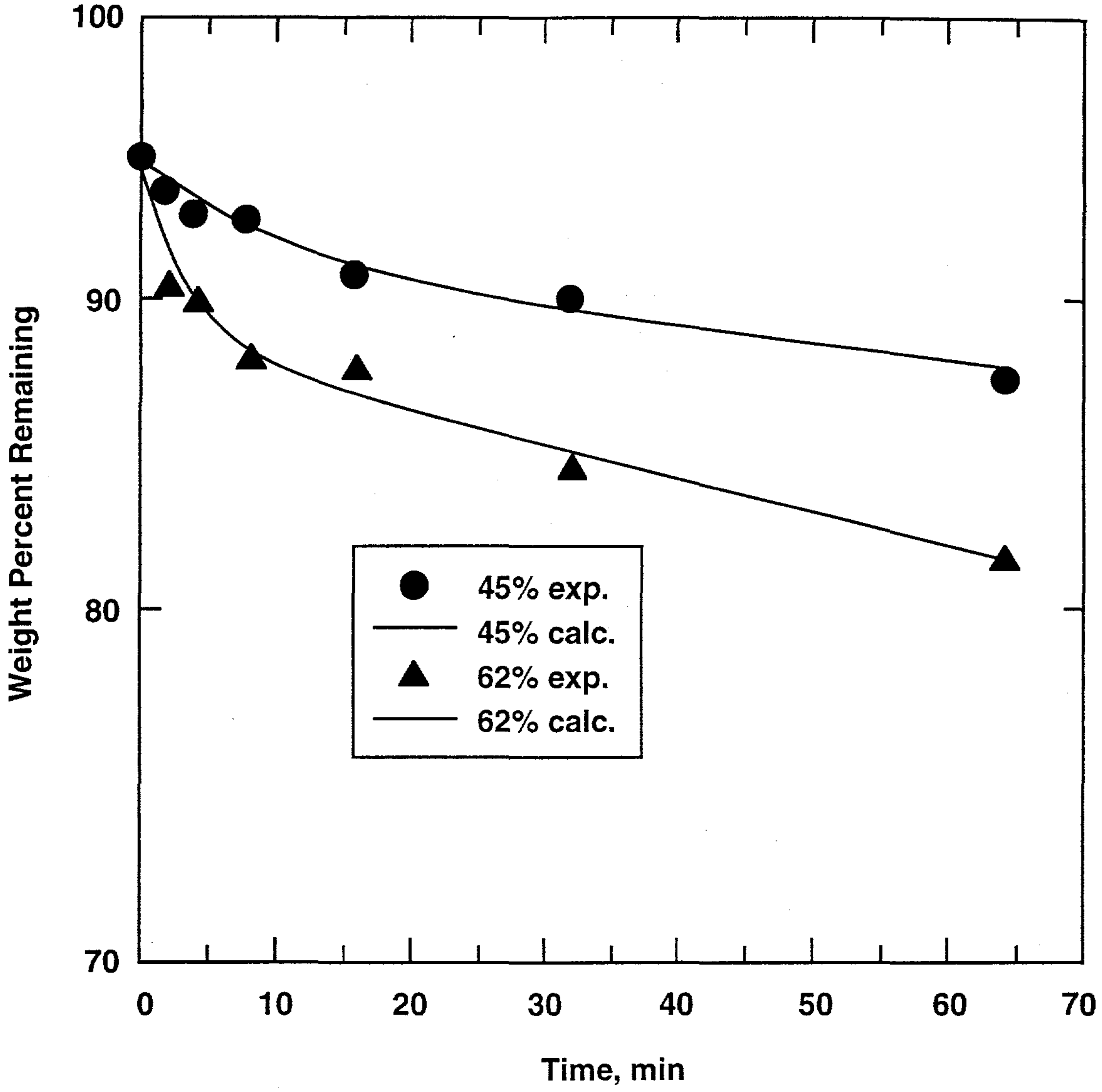
The material subject to fracture presumably includes highly irregular and/or friable particles. All particles in the mill are expected to be subject to abrasion.

A model for the combined fracture/abrasion process can be developed by assuming that the fracture process is approximately first-order, leading to an exponential decay in the mass of these "breakable" particles, while the abrasion processes involves a slow reduction in the mass of a fixed <u>number</u> of "non-breakable" particles. For an abrasion process which follows the Davis wear law described previously (Davis 1919, Miller et al., 1996a), but with a rate constant that decreases linearly with the extent of abrasion, formulation of the combined model leads to the following expression for the mass of material remaining in the coarse, "media" size after time t:

$$W(t) = [1-f(1-e^{-St})][1-R(1+kt)] / (1+kt)^3 (1-R) \qquad (7\text{-}1)$$

where f is the fraction of "breakable" material, S is the associated specific rate of breakage k is the abrasion rate constant and R is the ratio of the upper and lower boundaries of the original size interval. In this formulation, it is assumed that the initial distribution of sizes in the original interval was uniform (rectangular).

The application of the model to media-size disappearance in the attrition milling of 16x20 U.S. mesh Taggart Seam coal is illustrated in Figure 7-1. It is clear that the model



Model Parameter values used are:

Concentration	f	S(min^{-1})	k(min^{-1})	W_o
45	0.04	0.1	1.1×10^{-4}	0.95
62	0.07	0.3	2.3×10^{-4}	0.95

Figure 7-1. APPLICATION OF FRACTURE / ABRASION MODEL TO ATTRITION OF NOMINAL 16x20 MESH TAGGART SEAM COAL AT DIFFERENT SOLIDS CONCENTRATIONS

can describe such data well. In this case, it appears that increasing the solids loading in the mill increases the fraction susceptible to the fracture process, possibly by eliminating liquid films between particles which could provide a lubricating (or damping) action. Both the abrasion rate and the breakage rate increase with solids loading.

Since the fracture process produces particles in intermediate sizes close to the feed size, analysis of product size distribution from the combined process is more complex than was the case for simple abrasion (Miller et al., 1996a). In particular, it is necessary to consider fracture as well as abrasion for the intermediate size material and to make estimates of the fraction of "breakable" material in the fragments produced by breakage of larger particles. Extension of the model to the prediction of complete product size distributions is in progress, as part of a separately funded research project.

7.2 Subtask 1.2 Physical Separations

7.2.1 Fine Coal Classification

Additional fine-coal classification tests were carried out with the continuous, solid-bowl centrifuge using a new weir setting. This resulted in the formation of a slightly deeper pool than used in the previous tests. As with the previous tests, -100 mesh Upper Freeport seam coal was used. A slurry feed rate of 11.4 L/m (3 gpm) and a solids concentration of 10% coal (by weight) were also used for all tests. The test variables included centrifuge bowl and scroll speeds. Table 7-1 summarizes the operating conditions for this series of tests.

The weir overflow (fine product) and scroll discharge (coarse product) were sampled and analyzed using a Microtrac X-100 particle size analyzer. Figure 7-2 shows the reconstituted (calculated) feed size distribution and product size distribution curves for centrifuge Tests 1 and 2. As can be seen, the product size distribution of the weir discharge stream for test 2 was finer than that of Test 1, while the scroll discharge was coarser. For example, 98.6% of the material in the fine stream was less than 11 μm for Test 2 compared to 87.5% for Test 1. The corresponding amounts less than 11 μm in the coarse stream were 8.6% and 13.6%, respectively. This shows that varying the scroll speed will change the size distributions of the product streams.

As described in the previous report, the size distribution data were used to determine the circulation ratio (T/Q) for each test, where T and Q are the solids flow rates for the coarse and fine streams, respectively. The coal yield to the fine stream was calculated as $Y_Q=1/(1+C)$. The size selectivity values were then calculated from the size distribution data and coarse yield $(1-Y_Q)$. The actual size selectivity values were fitted to the log-logistic function via a non-linear optimization routine to determine the cut size (d50), sharpness index (SI), and apparent bypass (a). The fitted parameters are given in

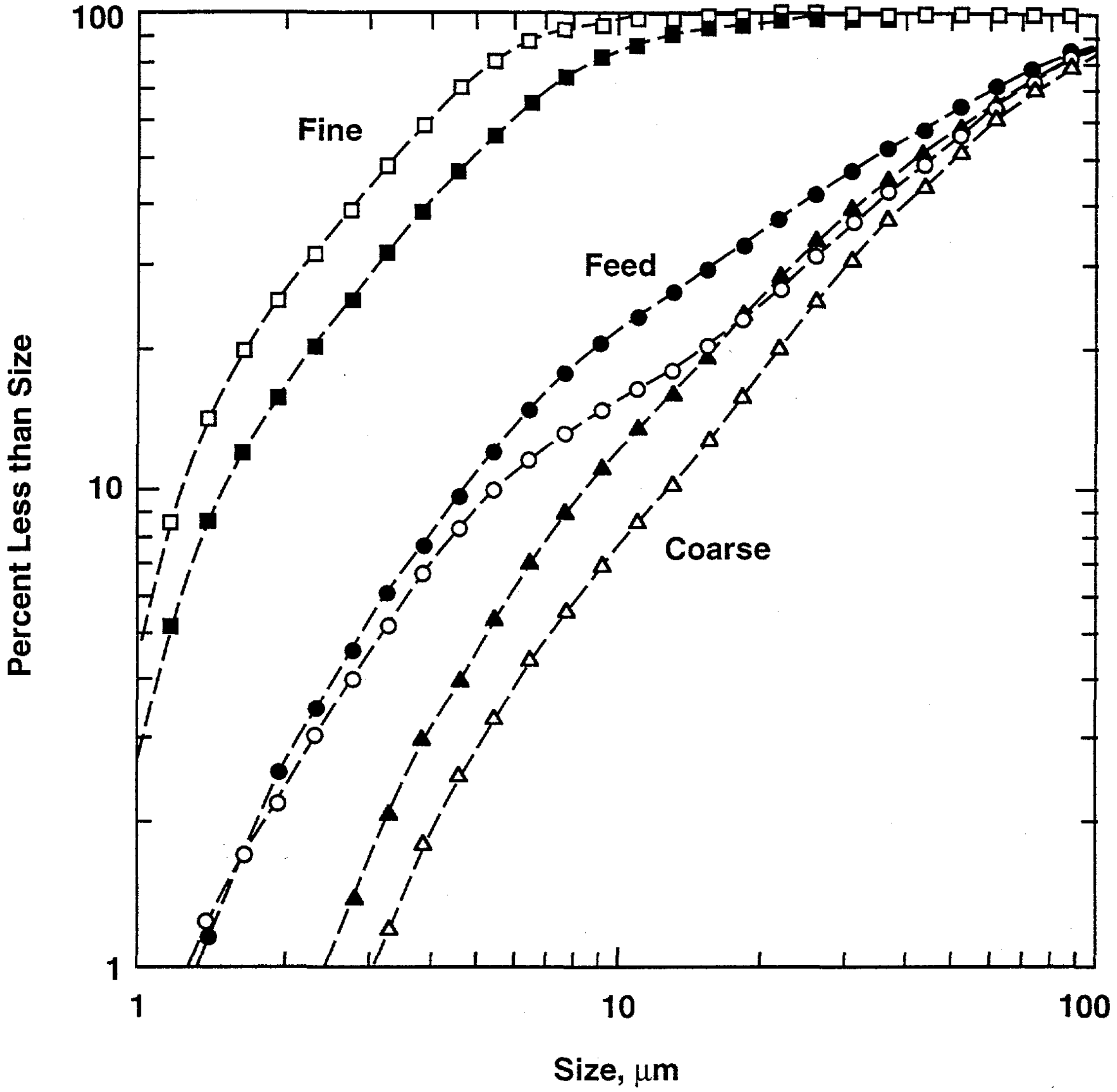


Figure 7-2. FEED AND PRODUCT SIZE DISTRIBUTIONS FOR CENTRIFUGE TESTS 1 AND 2 WHEN SEPARATING -100 MESH UPPER FREEPORT SEAM COAL
(test 1: filled symbols, test 2: open symbols)

Table 7-1, and the curves are shown in Figure 7-3. Overall, the cut size of the centrifuge ranged from about 7 to 10 μm, while the sharpness index ranged from 0.44 to 0.63. The primary impact of the bowl and scroll speeds seemed to be on the apparent bypass values, which ranged from 0.14 to 0.39 (Table 7-1).

7.3 Subtask 1.3 Surface-Based Separation Processes

7.3.1 Evaluation of Flotation System Performance

To evaluate the continuous flotation tests, specially designed batch flotation tests were performed. To incorporate the effect of froth mobility and other froth properties, the froth was allowed to move on its own accord in the batch cell, i.e., no paddling was used. The results were used to obtain a froth factor to permit direct comparison of batch and continuous tests. Further analysis of these batch/continuous comparisons is in progress

7.4 Subtask 1.4 Dry Processing

7.4.1 Integrated Grinding/Separation Circuit

Preliminary testing of the integrated grinding/separator test circuit was completed. The Holmes high-speed pulverizer was used to produce the nominal -100 mesh coal that was subsequently fed to the electrostatic separator. As noted previously, the Holmes pulverizer was also used to prepare the -100 mesh coal, which was used in the batch and continuous triboelectrostatic separations tests. Tests were conducted using Indiana, Pittsburgh, and Upper Freepport seam coals.

The coal was first dried at approximately 105°C for two hours prior to testing. Immediately after the feed coal was pulverized, it fell into a collection funnel, which was lined with copper, and was directed into the venturi feeder. The coal was transported to the electrostatic separator via a nitrogen stream. The continuous rotating disk separator was the same as that used previously (described in an earlier report). The separator was operated at a voltage of approximately +15 kV to minimize the potential for arcing between the disks. Upon completion of the test, the coal was brushed from the disks. The material from the separator disks, collection troughs, and cyclone products were weighed. Ash analyses were then performed on the samples. The results are presented in Tables 7-2 to 7-4, which give the weight distribution and ash values for the material recovered from various parts of the separator circuit.

As seen in Table 7-2, the ash content of the Indiana seam coal was reduced from 9.1% in the feed to 4.6% in the clean coal at a yield of 42.7%. The corresponding ash content of the refuse was 12.4%. For the Pittsburgh seam coal (Table 7-3), the feed ash was reduced from 6.8% to 3.6% at a clean coal yield of 55.5%. The ash content of the refuse stream was 10.9%. In the case of the Upper Freeport seam coal (Table 7-4), the

Table 7-1. Summary of the Operating Conditions and Test Results for the Solid-Bowl Centrifuge (feed rate = 11.4 L/min, weir setting two (second shallowest pool), solids concentration = 10% by weight).

			Yield, %		Characteristic Parameters		
Test	Main Speed, rpm	Back Drive, rpm	Coarse Product	Fine Product	d_{50}, µm	κ	a
1	4,600	4,125	86.6	13.4	9.9	0.47	0.39
2	4,600	3,650	91.3	8.7	7.4	0.63	0.33
3	4,600	2,700	83.3	16.7	7.9	0.52	0.19
4	4,600	800	88.5	11.5	6.7	0.44	0.26
5	3,750	1,850	88.7	11.3	7.2	0.52	0.14

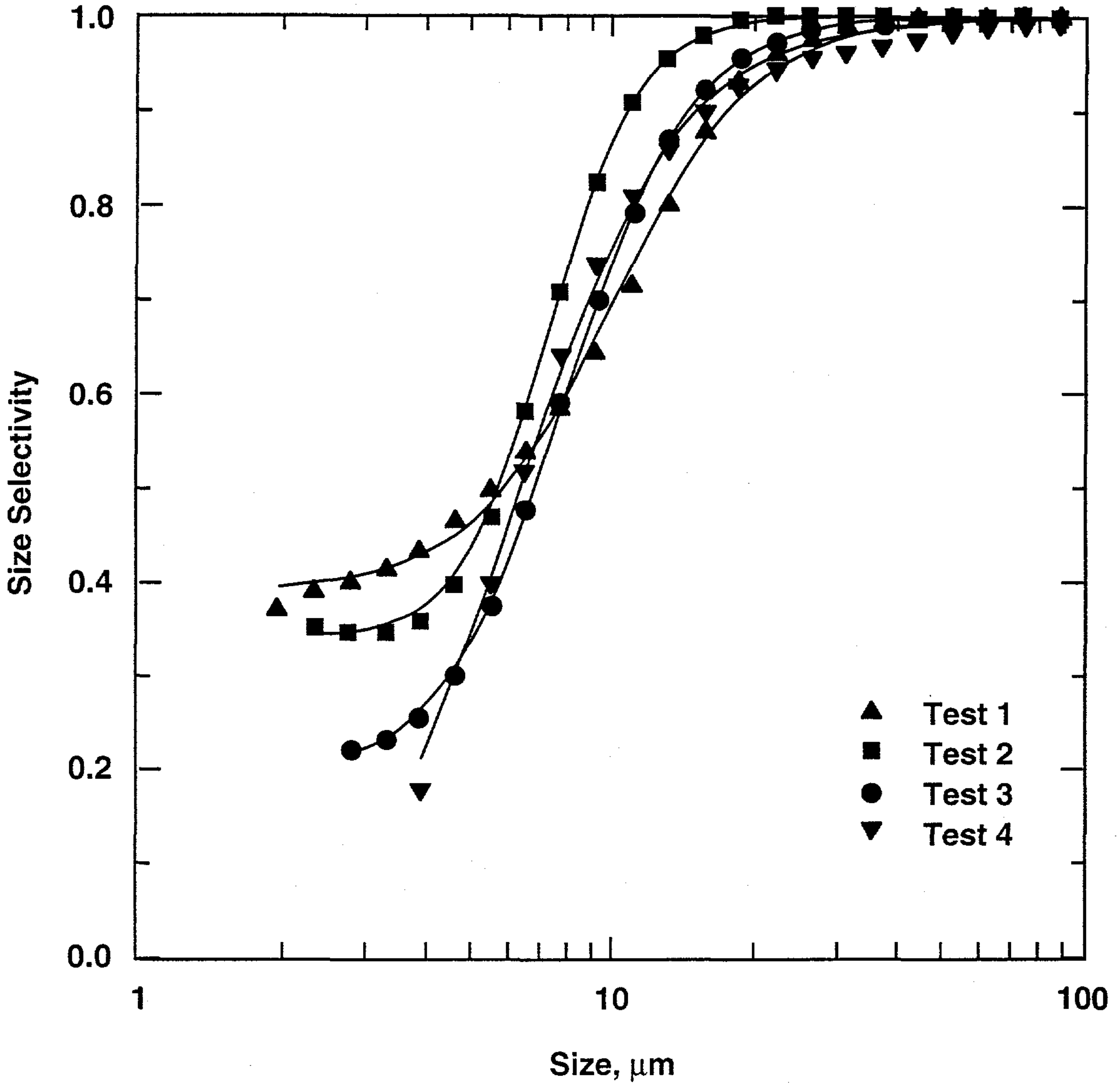


Figure 7-3. EFFECT OF BACK DRIVE SPEED ON THE SIZE SELECTIVITY CURVES IN THE SOLID-BOWL CENTRIFUGE

Table 7-2. Results from the Integrated Pulverizer and Continuous Electrostatic Separator Circuit when Pulverizing Indiana Seam Coal (measured feed ash = 9.3%, calculated feed ash = 9.1%).

	Clean Coal		Refuse Product	
	Wt., %	Ash, %	Wt., %	Ash, %
Electrode (Disk)	19.1	3.8	15.0	20.4
Collecting Trough	21.1	5.4	29.3	9.4
Cyclone	2.5	3.5	13.0	9.8
Total	42.7	4.6	57.3	12.4

Table 7-3. Results from the Integrated Pulverizer and Continuous Electrostatic Separator Circuit when Pulverizing Pittsburgh Seam Coal (measured feed ash = 6.6%, calculated feed ash = 6.8%).

	Clean Coal		Refuse Product	
	Wt., %	Ash, %	Wt., %	Ash, %
Electrode (Disk)	26.1	2.5	16.7	14.2
Collecting Trough	22.2	4.8	25.1	9.0
Cyclone	7.2	4.1	2.7	8.8
Total	55.5	3.6	44.5	10.9

Table 7-4. Results from the Integrated Pulverizer and Continuous Electrostatic Separator Circuit when Pulverizing Upper Freeport Seam Coal (measured feed ash = 11.4%, calculated feed ash = 12.4%).

	Clean Coal		Refuse Product	
	Wt., %	Ash, %	Wt., %	Ash, %
Electrode (Disk)	21.6	4.0	17.5	21.2
Collecting Trough	16.9	7.4	31.2	16.1
Cyclone	3.0	12.5	9.8	12.1
Total	41.5	6.0	58.5	17.0

ash content was reduced from 12.4% to 6.0% at a yield of 41.5%, while the ash content of the refuse material was 17.0%.

For all three coals, the lowest ash material was found on the negative (clean coal) disk and represented approximately 50% of the total clean coal collected. Similarly, the highest ash content material was typically found on the positive (refuse) collecting disk and also represented a significant portion of the refuse material. Even though the splits to the disks, collecting troughs, and product cyclones would change depending on the amount of coal being fed to the unit, the overall clean coal yield and ash content would likely remain constant.

7.4.2 Deagglomeration Testing

Deagglomeration testing utilizing the batch triboelectrostatic separator was completed. A fluidized-bed unit was used for deagglomerating and charging the coal simultaneously. The fluidized-bed unit was constructed out of a 1-5/8 inch diameter steel pipe, which was 8 inches long. The unit was sealed at both ends using threaded steel caps. The fluidized bed consisted of a layer (~3/4 inch thick) of either steel or copper beads, which were supported on a screen located in the middle of the tube. A second screen was located one inch above the lower screen. The nitrogen-entrained coal particles were injected into the fluidized bed from below through a pipe in the side of the steel tube. Contact with the fluidized bed was used to promote deagglomeration and particle charging simultaneously. After passing through the fluidized bed, the coal particles were carried out through a tube, which extended from above fluidized bed down through the bottom cap. The particles discharged into either the copper in-line mixer or a copper transfer pipe prior to injection into the separator.

For this testing, -6 mm Upper Freeport seam coal was pulverized to nominal -100 mesh using disk and Holmes pulverizers. The size reduction was done immediately before the testing. After size reduction, the coal was dried for two hours at 100°C. The dried coal was then fed into a venturi feeder, which was connected to the fluidized bed unit. Nitrogen was used as the transport gas. In the first test, the coal was passed through the fluidized bed (containing the copper beads) and then through the in-line mixer before being injected into the batch electrostatic separator. The batch separator consisted of two 48 inch long by 12 inch wide parallel copper plates, which were spaced 4 inches apart. A voltage of approximately +20 kV was used. This unit was described in detail in earlier reports. Approximately 100 g of coal were used for each test.

Upon completion of the test, the material was recovered from sections spaced along the length of the separator plates. The samples were weighed and the clean coal and refuse yields were calculated. Ash analyses were then performed on all samples. Additional tests were conducted using the following conditions: fluidized bed with steel beads and in-line mixer; fluidzed bed with copper beads and transfer pipe; and, in-line mixer only.

Figure 7-4 shows the variation of clean coal and refuse yields as a function of distance along the plate for all conditions. As seen, the bulk of the clean coal and refuse material was collected along the first 40 cm of the separator plates. Up until this distance, the highest clean coal yield was obtained using only the in-line mixer, while the lowest yield was for the copper beads/transfer pipe combination. However, over the entire length of the separator, the yields were comparable.

Figure 7-5 shows the variation in the cumulative ash as a function of distance for the same tests. The ash content of the clean coal was very similar in all cases. However, the ash contents of the refuse streams were different, especially for the copper beads/transfer pipe combination. The grade-yield curves for these tests are shown in Figure 7-6. As can be seen, for a given yield, the lowest ash content was obtained for the copper beads/in-line mixer combination, followed by the steel beads/in-line mixer combination. This indicates that the fluidized-bed unit may be helping to deagglomerate the particles prior to charging. Furthermore, it also demonstrates that contact with the beads without the in-line mixer may not be sufficient to charge the particles adequately.

7.5 Subtask 1.5 Stabilization of Coal-Water Mixtures

Subtask 1.5 was previously completed.

8.0 PHASE III, TASK 2 EMISSIONS REDUCTION

8.1 Subtask 2.1 SO_2 Reduction

No work was conducted in Subtask 2.1 during this reporting period.

8.2 Subtask 2.2 NO_x Reduction

Pilot-scale activities began during this reporting period. Preliminary testing has been conducted firing natural gas in the down-fired combustor. A summary of the pilot-scale testing follows.

The objectives for this subtask are as follows.

- To identify and/or develop a NO_X reduction catalyst that is compatible with the typical operating conditions and the economic constraints of industrial boilers, specifically:
    1. flue gas temperatures of 550°F (288°C)
    2. O_2 concentrations of 3-5 vol %
    3. H_2O concentration of 10-20 vol %
    4. SO_2 concentrations of 500-1000 ppm
    5. NO concentrations of 100-500 ppm
    6. No regeneration of sorbent/catalyst required
    7. Low maintenance and operating costs

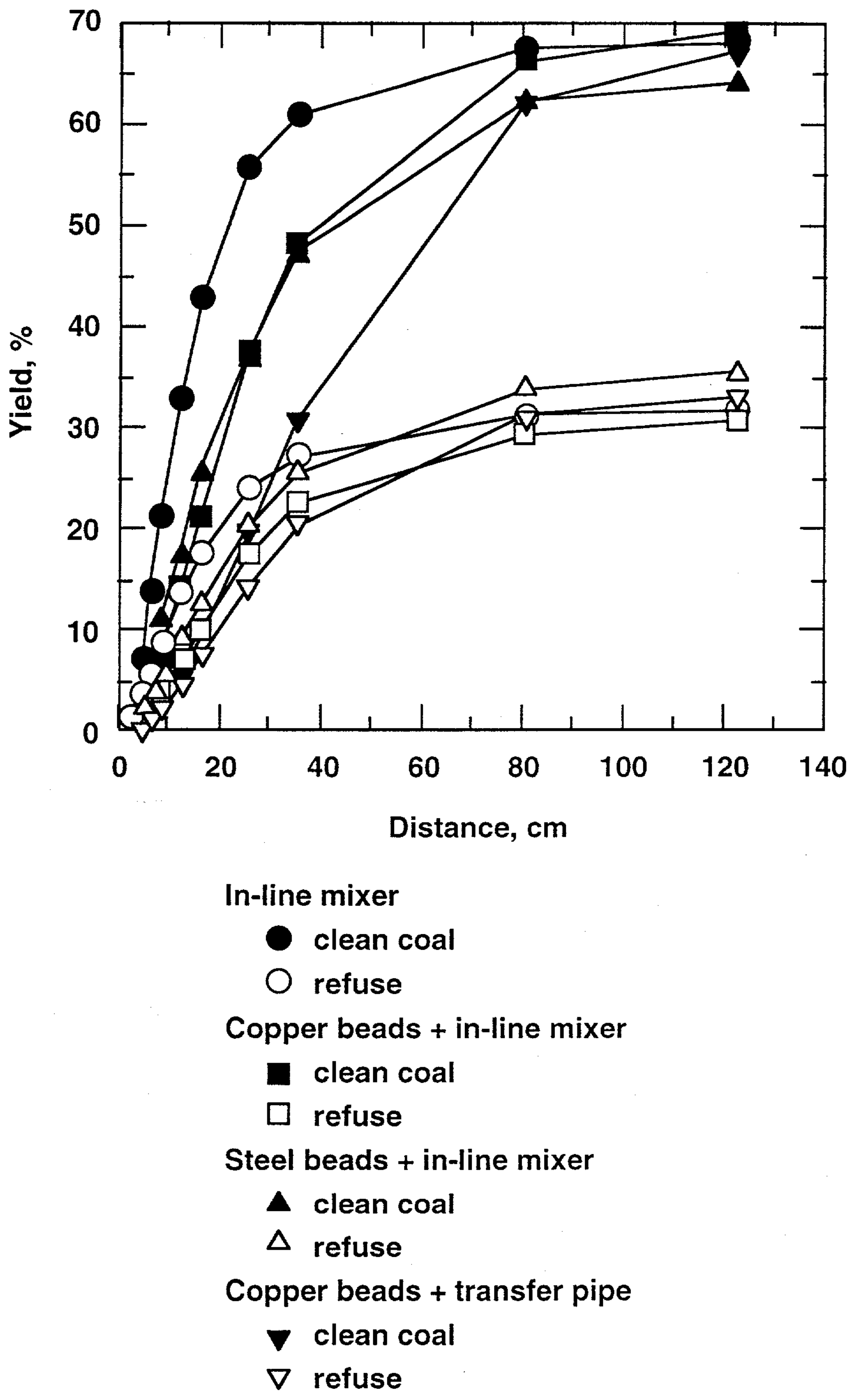


Figure 7-4. CLEAN COAL AND REFUSE YIELDS AS A FUNCTION OF DISTANCE ALONG THE BATCH SEPARATOR FOR DIFFERENT CHARGING/DEAGGLOMERATION TECHNIQUES WHEN PROCESSING -100 MESH UPPER FREEPORT SEAM COAL

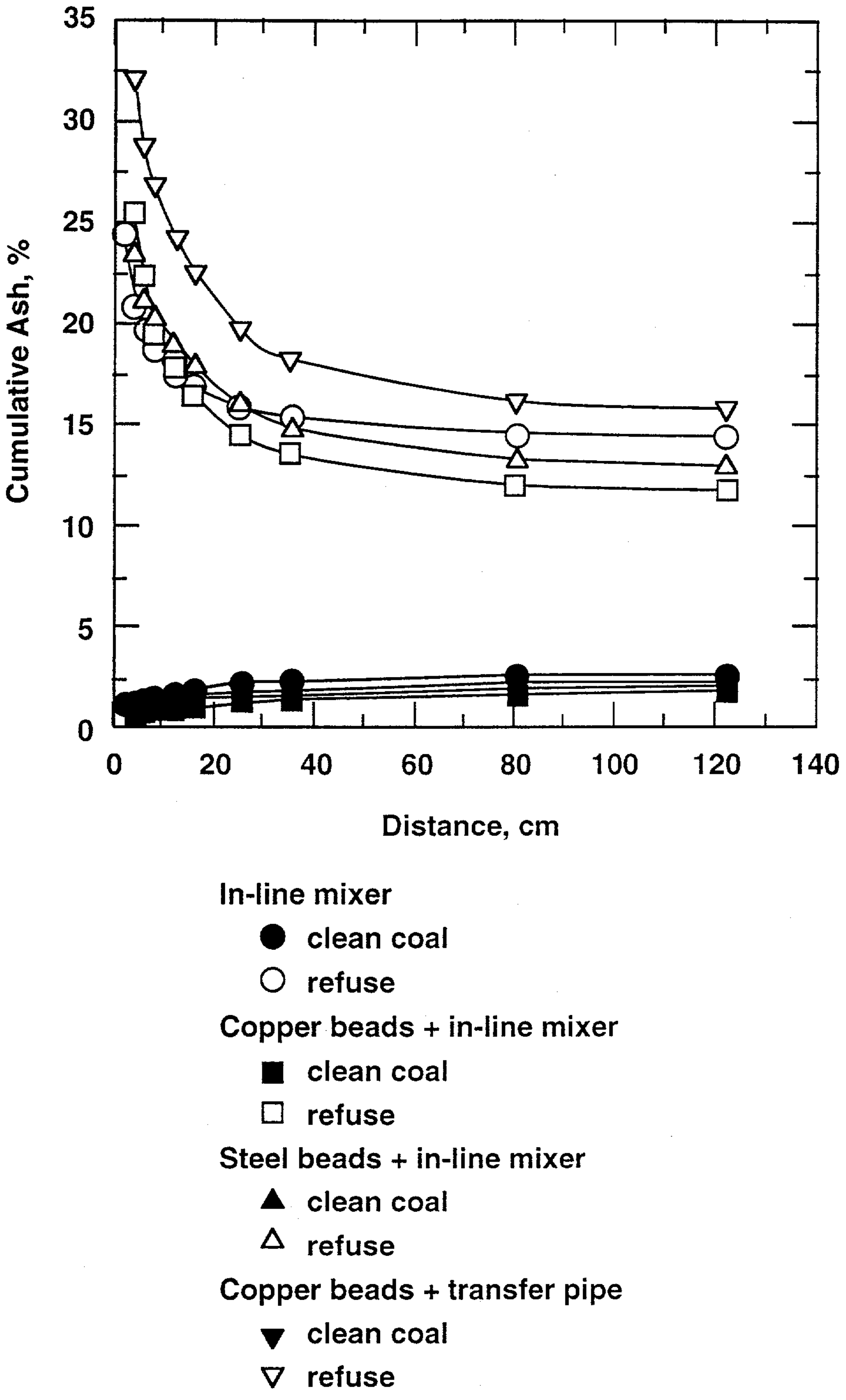


Figure 7-5. CUMULATIVE ASH CONTENT FOR THE CLEAN COAL AND REFUSE STREAMS AS A FUNCTION OF DISTANCE ALONG THE BATCH SEPARATOR FOR DIFFERENT CHARGING/ DEAGGLOMERATION TECHNIQUES WHEN PROCESSING -100 MESH UPPER FREEPORT SEAM COAL

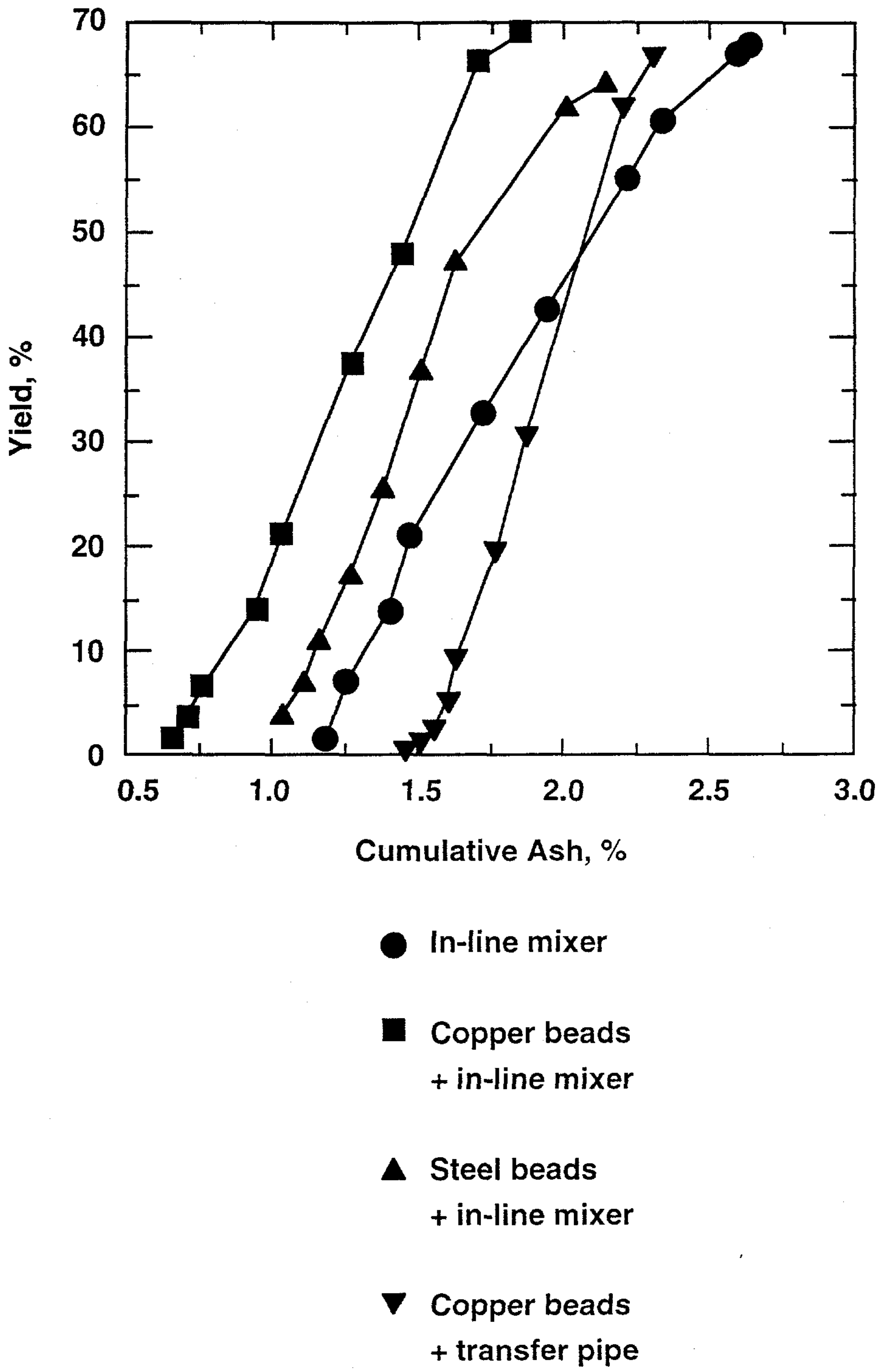


Figure 7-6. YIELD VERSUS CUMULATIVE ASH CONTENT FOR THE CLEAN COAL FOR DIFFERENT CHARGING/DEAGGLOMERATION TECHNIQUES WHEN PROCESSING -100 MESH UPPER FREEPORT SEAM COAL

- To establish the limitations of the candidate NO_X reduction catalyst so that its implementation in pilot and demonstration scale tests will be straightforward, for example, determining the relationship between space velocity and NO_X conversion efficiency for scale-up purposes
- To identify maximum allowable transients that the catalyst can be exposed to before losing effectiveness, such as swings in flue gas temperature and sulfur and unburned hydrocarbon concentrations

Status of Pilot-Scale Activities

The bench-scale testing conducted in Phase II has been extended to the pilot-scale through use of The Energy Institute's down-fired combustor (DFC). The goal of the pilot-scale testing is to develop additional design and operational experience with the NO_x reduction catalyst. With this information from the pilot-scale, the control strategy for the demonstration boiler will be implemented with far greater confidence and certainty as to the influence of flue gas composition on catalyst behavior. Also, the DFC tests will allow for the development and optimization of an ammonia injection system, as well as an investigation into the interactions between ammonia and dry sorbent injection, before testing begins at the demonstration scale. The benefits that will be gained from testing on DFC are substantial and will ensure success at the demonstration scale.

Pilot-Scale Research Plan

The pilot-scale work involves three steps. First, appropriately sized and formulated catalysts on monolith supports were obtained from Engelhard Corp. These monoliths were mounted in the flue of the DFC while the combustor was fired with natural gas. This permitted operation of the catalyst in the absence of SO_2, but with a practical flue gas stream. Second, tests were performed with natural gas firing. These preliminary tests are now complete and results are presented below.

Third, subsequent to the natural gas firing the coated monoliths will be installed in one of the nine bags of the baghouse on the DFC. The mounting of the monoliths will follow the procedure used by Babcock & Wilcox (B&W) and will require some consultation with B&W personnel. To ensure that the flue gas flowrate through each of the nine bags is equal, uncoated monoliths have been acquired from Corning Incorporated (as in-kind support of this research). The uncoated monoliths have the same cell density as the catalyzed monoliths and should generate a roughly equivalent pressure drop. The next set of tests, tentatively scheduled to be in late April, 1997, will involve coal-firing with simultaneous removal of sulfur dioxide (by dry sodium bicarbonate injection) and reduction of NO_x.

An ammonia delivery and injection system will need to be designed and developed to inject ammonia into the flue gas ducting upstream of the DFC. This will require the construction of a tank to store ammonia in or near the new high bay, or a rack of anhydrous ammonia cylinders could be used. Either way, safety considerations will need to be accounted for as this delivery system is designed and constructed.

The primary measurements to be made are: determination of flue gas composition upstream of dry sorbent or ammonia injection; determination of flue gas composition exiting the filter bag containing the monoliths; and measurement of catalyst bed temperature. From these measurements and the typical data obtained during operation of the DFC, the necessary details on catalyst performance will be available to design the NO_x control system for the demonstration boiler.

Pilot-Scale Results

To date, the studies of catalyst behavior have focused on a low temperature, precious metal-based, ammonia SCR catalyst (NOxCat LT) supplied by Engelhard. No other catalyst technology currently available can provide conversion of NO on the order of 90% in the temperature range that the demonstration boiler baghouse operates (350 - 400°F). We have been concerned with the influence of three primary parameters on activity and selectivity of the catalyst: (1) space velocity; (2) catalyst temperature; and (3) feedstream composition.

Conversion efficiency represents the percentage of the incoming NO that has been converted, regardless of the product species to which it is converted. Thus, conversion in and of itself does not sufficiently represent how effective the catalyst is. Selectivity can be defined in a number of ways, but we have chosen to define it as:

$$\% \text{ Selectivity} = (\text{NO reacted} - N_2O \text{ produced}) / \text{NO reacted} \times 100 \qquad (8\text{-}1)$$

where amount of NO reacted = Initial [NO] - Final [NO]. Using these definitions, the results from the bench-scale tests, which were presented in a previous semiannual technical report, can be summarized as follows:

1. With modest SO_2 in the feedstream, the conversion efficiency typically reaches a maximum value of 90% at 240°C (464°F) at low space velocity.
2. Additional SO_2 in the feedstream acts to reduce the peak conversion and the conversion at lower temperatures, while not substantially affecting high temperature conversion.
3. Increased space velocity suppresses conversion and degrades selectivity to N_2.
4. At lower temperatures (~ 160°C), conversion is low but selectivity is high. As temperature increases, the reaction pathway that produces the undesirable

product, N_2O, and the NH_3 oxidation reaction become more prevalent. At an intermediate temperature, NO conversion is high but selectivity worsens as increasing amounts of N_2O are produced by the conversion process. At high temperatures, the dominant reaction pathway is the oxidation of NH_3, and any conversion of NO is hidden by the production of NO from NH_3.

The tests on the DFC firing on natural gas, have produced similar trends to those observed with the bench-scale tests. A key observation is that selectivity for reduction of NO to N_2 is enhanced at low space velocities, as is the overall NO conversion. This feature of catalyst behavior will have a direct impact on the design of the demonstration-scale NO_x control system.

8.3 Subtask 2.3 VOC and Trace Elements

No work was conducted on Subtask 8.3 during this reporting period.

9.0 PHASE III, TASK 3 ECONOMIC ANALYSIS

9.1 Subtask 3.1 Cost and Market Penetration of Coal-Based Fuel Technologies

Subtask 3.1 was previously completed.

9.2 Subtask 3.2 Selection of Incentives for Commercialization of the Coal Using Technology

Subtask 3.2 was previously completed.

9.3 Subtask 3.3 Community Sensitivity to Coal Fuel Usage

Subtask 3.3 was completed during this reporting period. A report titled Economic Valuation of Risk Perceptions: Measuring Public Perception and Welfare Impacts of Electric Power Facilities was prepared. The report is contained in Appendix A.

9.4 Subtask 3.4 Regional/National Economic Impacts of New Coal Utilization Technologies

Subtask 3.4 was previously completed.

9.5 Subtask 3.5 Economic Analysis of the Defense Department's Fuel Mix

Subtask 3.5 was previously completed.

9.6 Subtask 3.6 Constructing a National Energy Portfolio which Minimizes Energy Price Shock Effects

Subtask 3.6 was previously completed.

9.7 Subtask 3.7 Proposed Research on the Coal Markets and their Impact on Coal-Based Fuel Technologies

Subtask 3.7 was previously completed.

9.8 Subtask 3.8 Integrate the Analysis

No work was conducted on Subtask 3.8 during this reporting period.

10.0 PHASE III, TASK 4 EVALUATION OF DEEPLY-CLEANED COAL AS BOILER FUELS

Activities in Task included installing a ribbon mixer into Penn State's micronized coal-water mixture circuit for reentraining filter cake. In addition, three cleaned coals were received from CQ Inc. and three cleaned coals were received from Cyprus-Amax.

10.1 Subtask 4.1 Modify MCWM Preparation Circuit

During this reporting period, the micronized coal-water mixture (MCWM) production circuit was modified to enable the preparation of highly-loaded MCWMs from advanced coal cleaning filter cakes. The MCWM production facility is extremely versatile in that it is capable of producing highly-loaded MCWMs from both coarse beneficiated clean coals (e.g., 2 x 0") as well as deeply-cleaned fine coal filter cakes (e.g., -100 mesh). Installing the filter cake reentrainment circuit included the following: 1) circuit design, 2) ribbon mixer procurement, 3) installation of electrical, water, and air to the ribbon mixer, 4) replumbing of MCWM transfer piping, and 5) installation of a low-profile platform scale. A generalized schematic of Penn State's modified MCWM production facility is presented in Figure 10-1.

The Munson Model HD-36-MS mixer is skid mounted with a capacity of 40 ft^3. The mixer has a 40 HP motor, which can be operated at variable speed, and a flanged double helical ribbon style agitator.

Three filter cakes were received from Cyprus-Amax of Golden, Colorado. The filter cakes were generated as part of a DOE-funded advanced coal cleaning program which focuses on developing the technology needed for the efficient cleaning of fine coal. Penn State will characterize their slurryability, handleablity, combustion performance, and emissions, specifically air toxics.

Cyprus-Amax shipped 50 supersacks of deeply cleaned Taggart seam filter cake, one supersack of Indiana VII seam filter cake, and 44 supersacks of Hiawatha seam filter cake. All of the filter cakes were generated from Cyprus-Amax's pilot-scale advanced column flotation circuit. Only a limited quantity of Indiana VII was received since its moisture content was greater than ~ 50 wt.%. The 95 supersacks are currently being stored at Penn State. Table 10-1 summarizes the composition of the three filter cakes.

Baseline slurryability tests will be conducted on the as-received filter cakes. Particle size manipulation will be conducted, if needed, to improve the MCWM's rheology and stability.

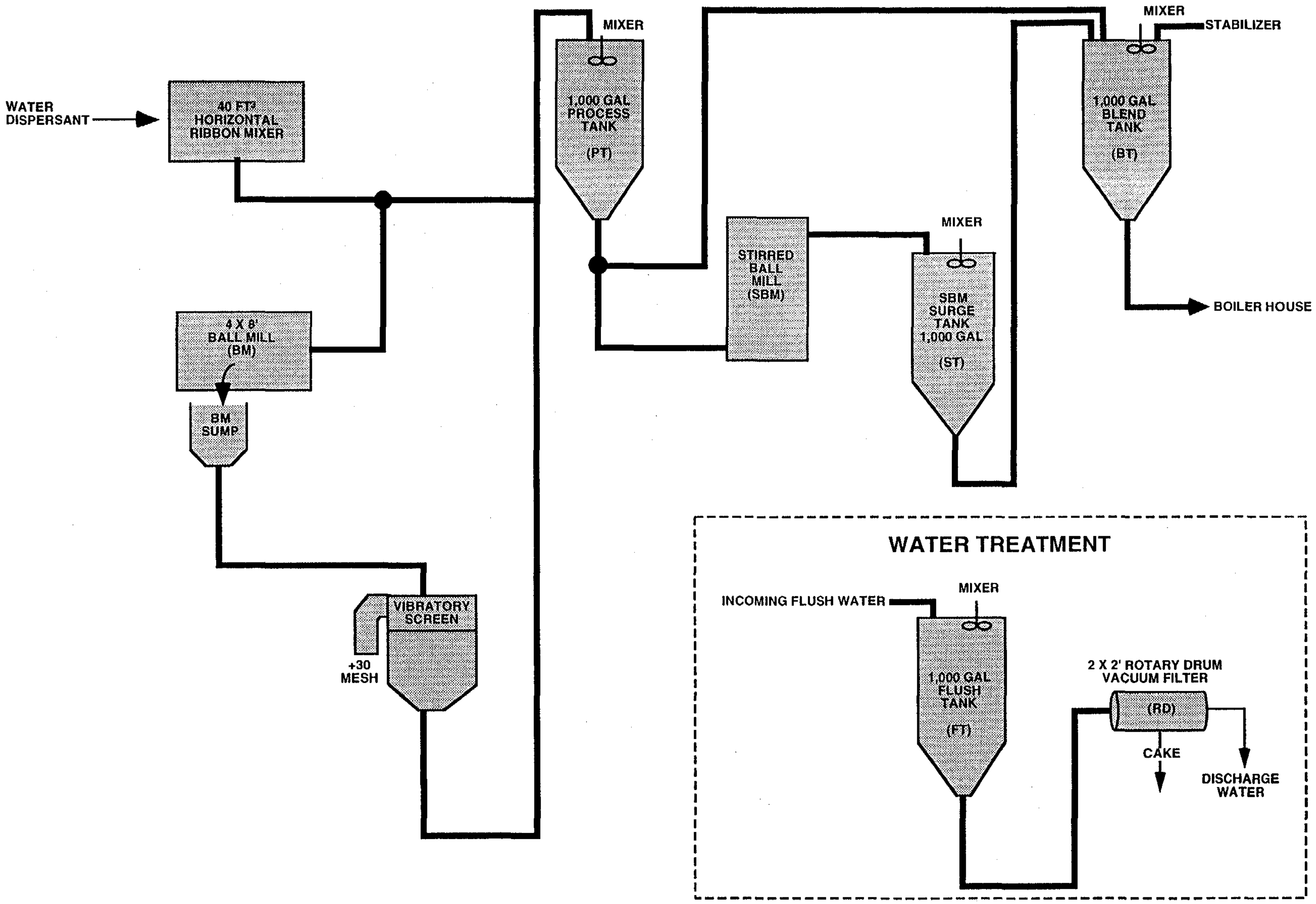


Figure 10-1. SCHEMATIC DIAGRAM OF PENN STATE'S MCWM PRODUCTION CIRCUIT

Table 10-1. Proximate and Ultimate Analysis, Higher Heating Value, and Particle Size Distribution of the Cyprus-Amax Filter Cakes

	Taggart	**Indiana VII**	**Hiawatha**
Proximate Analyis			
Volatile Matter	32.0	36.6	42.7
Ash	1.9	3.4	3.8
Fixed Carbon	66.2	60.0	53.5
Ultimate Analysis			
Carbon	84.1	76.8	77.0
Hyrdrogen	5.3	5.3	5.8
Nitrogen	1.3	1.6	1.3
Sulfur	0.8	0.8	0.8
Oxygen	6.6	12.1	11.3
Higher Heating Value (Btu/lb)	14,848	13,653	13,633
Particle Size Distribution			
Top Size	392.0	97.8	219.0
D (v, 0.9)	99.9	34.5	78.3
D (v, 0.5)	34.2	13.3	31.0
D (v, 0.1)	7.8	4.1	7.1

After the bench-scale formulation tests have been completed, the filter cake will be prepared into MCWM in Penn State's pilot-scale MCWM production facility. The supersacks will be weighed on a 2,500 lb capacity, Aegis low profile 4 x 4' platform scale to weigh the amount of coal fines to the nearest 0.5 lb. The supersack will then be hoisted above the ribbon mixer and allowed to discharge into the mixer's 4 x 5' receiving hopper. The supersacks have a pull bottom, spouted discharge chute. After the filter cake has been discharged into the ribbon mixer, the filter cake will be sampled for its moisture content. The moisture content and the weight of the cake will be entered into a spreadsheet to calculate the amount of water and dispersant needed for the formulation.

Process water will be introduced using an internal spray manifold. Additives will be introduced manually. The MCWM will be mixed and then pumped to a 1,000 gallon, baffled process tank (PT) which is equipped with a five horsepower, center mounted Lightnin mixer. The Lightnin mixer has a lower 18" six bladed R-100 impeller and an upper 30" three bladed A-305 impeller. The process tank will be used in addition to the Munson ribbon mixer to thoroughly reentrain the filter cake. If the formulation does not require particle size manipulation, the MCWM stabilizer will be added. If additional particle size manipulation is required to improve the rheology and stability, the MCWM can be pumped to a stirred ball mill having 1 mm steel shot as the grinding media. The entire stream can be processed or a percentage of the stream can be processed and then blended with the ribbon mixer discharge in a 1,000 gallon blend tank (BT). After the particle size distribution has been modified the stabilizer will be added.

11.0 PHASE III, TASK 5 FINAL REPORT/SUBMISSION OF DESIGN PACKAGE

No work was conducted on this task.

12.0 MISCELLANEOUS ACTIVITIES

There were no miscellaneous activities during this reporting period

13.0 NEXT SEMIANNUAL ACTIVITIES

During the next reporting period, the following will be done:

- Install the ceramic filter system and auxiliary components;
- Install the sodium bicarbonate duct injection system;
- Conduct NO_x catalyst tests;
- Begin VOC and trace elements studies;
- Prepare the final report for Phase II, Task 2, Coal Preparation/Utilization; (except for the atomization testing in Subtask 2.10);
- Prepare the final report for Phase II, Task 3, Economic Analysis;
- Complete Phase III, Task 1, Coal Preparation/Utilization; and

- Complete Phase III, Task 5, Economic Analysis.

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15.0 ACKNOWLEDGMENTS

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The following Penn State staff were actively involved in the program: Michael Anna, David Bartley, Glenn Decker, Howard R. Glunt, Bradley Maben, and Ronald T. Wincek.

Appendix A. Economic Valuation of Risk Perceptions: Measuring Public Perceptions and Welfare Impacts of Electric Power Facilities

ECONOMIC VALUATION OF RISK PERCEPTIONS: MEASURING PUBLIC PERCEPTIONS AND WELFARE IMPACTS OF ELECTRIC POWER FACILITIES

COMPLETION REPORT FOR
Task 3. Community Sensitivity to Coal Fuel Usage
PHASE III
DOD/DOE CONTRACT
#DE-FC22-92-PC92162.

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March 27, 1997

ABSTRACT

This research develops methods that integrate economic valuation with the techniques used in psychology to characterize risk perceptions to value the welfare impacts due to the presence of energy production facilities. A contingent valuation survey, designed with cognitive survey design methods, was administered to elicit quantitative information regarding individuals' perceptions of the risks associated with fossil fuel-based electric power facilities and. the individuals' willingness to pay to prevent or change risk exposure levels. The quantitative measures of risk perceptions are related to the willingness to pay values using maximum likelihood estimation.

The underlying conceptual rationale for valuing changes in perceived risk combines findings from the risk perception literature with expected utility theory. Using an economic model of individual willingness to pay to avoid risks, this study identifies factors that contribute to individual willingness to prevent energy production facilities. Specific focus is placed on developing quantitative measures of perceived risk that can be utilized to derive welfare changes induced by such facilities.

This research measures the individual's *ex ante* marginal willingness to pay to prevent or change their (perceived) risk exposure level from an electric power facility, determined, in part, by the perceived risk attributes. Obtaining the value of individual preferences of risk levels can assist in facility siting decisions by measuring how much individuals will pay to influence decisions or to what extent they will willingly bear the costs of a more expensive, but more desirable fuel.

Results show that welfare impacts, as measured by option price, depend on an individual's perceptions of the health, environmental, aesthetic, and economic impacts as well as their socio-demographic characteristics. Individuals seemed to have difficulty distinguishing between the probability and the severity of a risk in the manner suggested by the definition of risk, although the survey instrument may have been unable to capture the difference. Perceived environmental, health, and aesthetic impacts play a larger role than potential economic impacts in determining option prices, explaining in part why residents may oppose a facility even when it will likely bring economic benefits to an area.

ECONOMIC VALUATION OF RISK PERCEPTIONS: MEASURING PUBLIC PERCEPTIONS AND WELFARE IMPACTS OF ELECTRIC POWER FACILITIES[1]

1. INTRODUCTION

Risk has long been an important focus in psychology. As Slovic, a professor of psychology, [16] says, "[t]he ability to sense and avoid harmful environmental conditions is necessary for the survival of all living organisms." Economists also recognize that individuals place an implicit value on risk, but have only recently begun to incorporate such values in the public decision-making process. This study integrates the economics of welfare measurement with the psychological characterization of risk perceptions. Using methods from cognitive psychology,[2] a contingent valuation survey is developed to elicit quantitative information about individuals' perceptions of the risks associated with locally sited fossil-fuel electric power facilities, including utility and non-utility generators, cogenerators, and independent power producers. Psychometric scales are used to quantify risk perceptions, which are then related to the option price for eliminating or reducing risks. This research extends prior work from the psychology literature by focusing on a specific hazard scenario rather than general "risk" and by examining perceptions of different components making up a risk. The study estimates individuals' marginal willingness to pay as a function of these risk perceptions as well as sociodemographic characteristics conventionally modeled as determinants of WTP. Empirically, the model considers multiple perceived risk components identified through focus groups and cognitive interviews. An implicit factor analysis identified four risk components: health risks, aesthetic risks, environmental

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[1] We wish to thank Jim Shortle and Ann Fisher for many helpful comments. The usual disclaimer regarding errors applies.

[2] Cognitive psychology studies "such processes as understanding language, remembering and forgetting, perception, judgment, and inferring causes (Jabine [10], p. 1)."

risks, and beneficial or detrimental economic changes resulting from facility construction and operation.

The field of risk assessment has only recently been extended into economic valuation, so that values can be assigned to the welfare changes resulting from changes in risk exposure. An industrial facility such as an electric power plant can expose a community to a wide variety of hazards, including environmental and health hazards, amenity or aesthetic effects, and changes in traffic patterns and congestion. In addition, their construction and operation can induce economic impacts in the host community such as changes in employment, price levels, and tax revenues. An associated probability distribution characterizes the likelihood that each consequence due to a facility will actually occur. Individuals make behavioral decisions based upon their perceptions of the probability and severity of impacts from such facilities. In this manner, welfare is based upon each individual's perception of risk.

Regulatory changes in the 1980s and 1990s have prompted a significant increase in the siting of small energy generation facilities close to residential communities. The Energy Information Agency (DOE [5]) predicts a 15 percent increase in new coal-fired generation capability (170 250-MW plants) and a 31 percent increase in oil and natural gas-fired generation capability (925 100-MW facilities) by the year 2010. Some proposed facilities have been vehemently opposed by local residents, regardless of experts' attempts to communicate that the benefits could significantly outweigh any associated risks. Such opposition to otherwise economically efficient projects may arise, in part, because layperson or non-expert risk perceptions related to energy generation facilities differ from those of "experts."

Risk assessments by experts are likely to differ from risk assessments by ordinary citizens (Fisher [7]). Laypeople often react to potential hazards or undesirable facilities in a fashion experts consider disproportionate to the risks involved. Experts have made substantial progress in identifying and measuring "objective" risks but understand less well how individuals perceive risks and how they value changes in risk. Because an individual's behavior and values are based on risk perceptions, a better understanding of risk perceptions and how they influence individual values needs to be developed. Improved understanding of risk perceptions will provide a basis for understanding and anticipating responses to hazards and undesirable facilities and aid in designing risk communication programs to increase understanding of such facilities.

Results from this study show that individuals' willingness to pay for risk prevention or reduction is a function of their perceptions of the health, environmental, aesthetic, and economic impacts as well as their socio-demographic characteristics. Individuals appear unable to distinguish between the probability and the severity of a risk in the manner suggested by the definition of the risk. Perceived environmental, health, and aesthetic impacts play a larger role in determining option prices than potential economic impacts, explaining in part why residents may oppose a facility even when it will likely bring economic benefits to an area.

2. BACKGROUND AND PREVIOUS RESEARCH

Risk Perceptions

Associated with any hazard are a variety of consequences. Risk is a quantitative measure of the likelihood and severity of those consequences, usually expressed in terms of conditional probabilities or other technical and quantitative measures. Scientists and engineers must assign probabilities to the occurrence of hazardous events in order for risk mitigation policy decisions to be made. Expert risk assessments are based upon quantitative and technical data that are often not readily understood by the general public. Perceived risk, though, is a function of the actual impacts of a hazard in addition to many unquantifiable and unique cognitive dimensions that are derived from personal experiences and preferences (Bostrom *et al.* [2]).

Risk perception research entails understanding, from a layperson's point of view, what is known about a hazard, what is thought to cause it, and its perceived impacts. The objective is to learn what people know about a particular hazard and how they incorporate risk information into their personal knowledge set or "mental model." Risk perceptions are then defined as a function of the “true” risk and the differential between layperson and expert mental models. Past research has revealed that laypersons rank as most serious risks that are catastrophic, involuntary, unfamiliar, dreadful, uncontrollable, or having an uncertain and inequitable distribution of consequences. In general, laypersons tend to have greater concern for and overestimate "small" risks and less concern for and underestimate "large" risks (Slovic *et al.* [17]; Slovic [16]; Covello *et al.* [4]).

Slovic [16] mapped the perceived risk of 81 hazards over the factors unknown risk and dread risk. Non-nuclear power generation, coal combustion, and fossil fuels appear in the upper-right quadrant of the perceived risk mapping, that includes risks characterized as "unobservable," "unknown to those exposed," "delayed effect," "new risk unknown to science," "uncontrollable," "catastrophic," "inequitable," "not easily reduced," "of high risk to future generations," and "involuntary."[3] Risks located in this quadrant can be thought of as those most difficult to mitigate through regulatory channels and presenting the greatest challenges to risk communicators and mitigators.

Cognitive dissonance explains systematic differences in the interpretation of information, as well as in individuals' receptivity to new information according to preferences and beliefs (Akerlof and Dickens [1]). Cognitive dissonance theory has also been useful in explaining why a differential between lay and expert risk judgements persists and why individuals may not believe risk information provided by experts. Studies have revealed that risk communication is more effective and more likely to be understood by the targeted public when lay risk perceptions are identified *a priori* (Fisher *et al.* [8]). Effective risk communication requires that the *relevant* risk information be presented so that it is most likely understood by the public in the manner in which it was intended.

The study and characterization of risk perceptions are an established precursor to developing effective risk communication. More recently, the field of risk assessment has been extended into economic valuation of the welfare changes resulting from changes in risk exposure. Determining the welfare impacts of undesirable land uses should include the value individuals place

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[3] For comparison, aviation, handguns, and auto racing appear in the observable, known, but uncontrollable and involuntary quadrant; diagnostic x-rays, caffeine, PVCs appear in the controllable, voluntary but not observable or unknown quadrant; and power mowers, alcohol, and home sports appear in the controllable, voluntary, observable, and known quadrant.

on perceived changes in risk. This study measures laypersons' *ex ante* marginal willingness to pay (WTP or option price) to decrease or completely eliminate a particular risk exposure level, determined in part by the perceived attributes of a risk.

Valuation and Perceived Risks

Slovic's [16] characterizations of perceived risk according to the degree of voluntariness, immediacy of effect, familiarity, controllability, likelihood of catastrophic consequences, dread, and severity of consequences have provided a solid foundation for many subsequent studies. Slovic *et al.* [17] find that (i) different groups, including laypersons and experts, have very different attitudes towards risks, (ii) experts tend to rate risks according to annual fatalities or other technical and quantitative measures, (iii) laypersons rate risks on different criteria than experts, and (iv) laypersons tend to want stricter regulation of the hazards they perceive as most risky.

Empirical studies have tended to value welfare shifts induced by changes in risk for a range of hazards; a few studies have developed a methodology to evaluate changes in the risk of a specific hazard. Although the studies differ in many regards, all combine a quantitative component, such as Slovic's psychometric scales, with a contingent valuation instrument (CVM) to elicit willingness to pay for changes in the risk levels of one or more hazards. The conceptual framework underlying these studies assumes that an individual's utility is a function of socioeconomic characteristics and some variant of risk attributes or risk levels. Applying the theory of cognitive dissonance to economic theory, Akerlof and Dickens [1] incorporated a subjective assessment of risk into an economic valuation of hazardous jobs in the labor market. Römer and Pommerehne [13] developed a contingent valuation instrument to elicit WTP for the reduction of hazardous waste risk in West Berlin; they consider private averting activities and strategic behavior. Savage [14] evaluated risk judgments and their influence on relative WTP values to reduce the exposure levels of four "cognitively different" risks. The study found that people are most likely to have different values for reducing different types of risks.

McDaniels *et al.* [11] model a household's option price for decreased risk exposure ("safety") as a function of the household's socioeconomic characteristics and perceived attributes of each of ten common risks. The perceived characteristics component consists of a household's familiarity with the risk, perceived exposure, and the degree of dread associated with each risk, which are essentially the factor composites Slovic [16] derived in his 1987 study. A CVM instrument using psychometric scales and open-ended valuation questions elicited respondent's willingness to pay for decreases in risk exposure. Their analysis suggests that perceived risk characteristics, perceived exposure levels, age, and income all significantly affect an individual's valuation for a reduction in risk across a range of hazards. In their model with only well-defined risks, personal exposure to the risk was an important determinant, while dread and severity were important factors for the less-defined risks. McDaniels *et al.* consider general risks such as air safety rather than specific risks, and do not separate risk into components such as health and environment.

Smith and Desvousges [18] consider hazardous wastes to explore how marginal valuations of risk changes vary with the size of the baseline risk and the direction of the risk change (i.e., either a decrease or increase in risk levels). Individual risk judgments are related to WTP for changes in perceived risk exposure, income, and other socio-economic characteristics. Marginal valuations to *avoid risk increases* declined with increases in the risk level; the mean valuations to *reduce baseline risk* were greater than the valuation to *avoid risk increases.* The results could imply that valuations to reduce the risk imply a different property right than valuations to avoid a risk increase; valuations to reduce risk and to avoid a risk increase are essentially measuring two different types of changes in utility.

Psychological methods to characterize perceived risk have contributed to improved risk communication methods and provided a solid foundation for risk valuation studies. Studies based upon cognitive psychology have found that a differential exists between expert and non-expert risk judgments and that risk attributes influence risk perceptions. Economic models that incorporate perceived risk have shown that income and perceived risk are strong determinants of WTP to reduce/change risk exposure. In addition, research has found that the stated baseline risk level may be a determinant of WTP values, and that cognitively different risks are likely to generate different values for reducing risk exposure. However, nearly all studies in this area exclude non-health risks and focus on how hazards influence values to change personal exposure to risks. This study extends previous studies to include risks to the environment, the economy, and aesthetics, in addition to human health.

3. THEORY

Expected utility theory is based upon "objective" or true probabilities and the certainty of future states of the world (von Neumann and Morgenstern [19]). Savage [15] and Anscombe and Aumann [2] extended expected utility theory by incorporating subjective probabilities into the expected utility model. Subjective probability is extensively discussed in the economics literature, though little is said about the perceptions of the magnitude or severity of risk consequences. This research assumes that individuals make choices within an expected utility framework according to their perceptions of the probabilities and the consequences; the expected utility model is naturally inclusive of this concept.

The contingent valuation survey used for this analysis elicits individuals' WTP to avoid or reduce exposure risks due to a facility that burns either coal or natural gas to generate electricity. Individuals are uncertain with regard to the likelihood and severity of risk consequences as a result of a particular facility or fuel type. The risks of such a facility can be disaggregated into probability and severity characteristics to emphasize their individual effects on option price.

Let *EN* measure the environmental consequences of an adverse event and *X* the bundle of consumption goods over which the individual maximizes utility. Utility is a state-dependent function of environmental quality and consumption,

$$U = U(X, EN), \quad \text{where} \quad \frac{\partial U}{\partial X} > 0, \ \frac{\partial U}{\partial EN} < 0. \tag{1}$$

Maximizing utility subject to a budget constraint, with I denoting income and P denoting a price vector, results in the *ex post* indirect utility function, $u = v(I, P, EN)$.

Consistent with a framework where policy decisions are made and associated welfare impacts measured, individuals are assumed to make ex ante decisions when facing a risk. An individual may be willing to pay, *ex ante*, to reduce or eliminate a risk, regardless of which state of the world is realized, *ex post*. An *ex ante* payment made independent of the future outcome is referred to as a state-independent payment or an option price (*OP*).

Let π represent the probability of an adverse event occurring and $1\text{-}\pi$ the probability of the event not occurring. If $EN = 0$, the event has no negative environmental consequence. The level of a negative environmental impact associated with the event is measured by $EN = EN^*$. The corresponding option price for reducing EN^* to zero is the solution to

$$\begin{aligned}&(\pi)v(I,\mathrm{P},EN^*)+(1-\pi)v(I,\mathrm{P},0)=\\&(\pi)v(I-OP,P,0)+(1-\pi)v(I-OP,\mathrm{P},0)=v(I-OP,\mathrm{P},0).\end{aligned} \qquad (2)$$

If π=0, the event does not occur. The corresponding option price for reducing π to zero is the solution to

$$\begin{aligned}&(\pi)v(I,\mathrm{P},EN^*)+(1-\pi)v(I,\mathrm{P},0)=\\&(0)v\left(I,\mathrm{P},EN^*\right)+(1-0)v(I-OP,\mathrm{P},0)=v(I-OP,\mathrm{P},0).\end{aligned} \qquad (3)$$

The option price defined in equation 2 reduces the severity of the adverse impact to zero. Freeman [9] defines this as *risk reduction*. In equation 3, the probability of the risky event occurring (π) is reduced to zero, which is termed *risk prevention*. In theory, the option price is identical for either a reduction of *EN* or π to zero. As the utility of expected value and expected utility generally differ, marginal changes in severity are likely valued differently than marginal probability changes which result in equivalent changes in expected value. For this reason, decomposing risk into severity and probability is worthwhile for measuring welfare impacts of risk changes.

Assume individuals facing the construction of an electric power producing plant perceive n possible impacts, EN_i , and associated probabilities, π_i, where $i = 1, ..., n$. Individuals do not know, *ex ante*, the true severity or the true probability of risk consequences due to the plant and must rely upon their perceptions of future states of the world to make utility maximizing decisions. Expected utility takes the form

$$E[U] = \sum_{i=1}^{n} (\pi_i | y) U[X, EN_i | y] \quad \text{where} \quad \sum_{i=1}^{n} \pi_i = 1.^4 \tag{4}$$

Judgments of the probabilities, $\pi_i|y$, and the severity of the risk, $EN_i|y$, are likely to be conditional upon y, the individual's experience, familiarity, and knowledge of the risk and its consequences. Previous studies have found an individual more familiar with hazard consequences is more likely to perceive a higher probability of being exposed to the hazard (Slovic [16]). This does not imply that individuals with pre-existing knowledge or familiarity will always perceive risk to be greater than individuals without previous experience. Perceived severity may be less for individuals with prior experience than those without. The influence of prior experience and knowledge on perceived risk and valuation of risk changes is not explicitly addressed in this study, although such issues were addressed in a preliminary manner in a debriefing questionnaire.

Using the indirect utility representation, $\overline{V}$ is the maximum expected utility given market prices, income, and perceived probability and severity of the risks created by the power plant:

$$V = \sum_{i=1}^{n} (\pi_i | y) v[P_x, I, EN_i | y]. \tag{5}$$

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[4] Individuals may conceivably <u>state</u> perceived probabilities that sum to greater than or less than one. This is a relevant topic in dealing with perceptions based on incomplete information, but is not considered here.

The option price (or ex ante WTP) to prevent the power plant from being built or to reduce its environmental impacts to zero, even when operating, will be

$$\overline{V} = \sum_{i=1}^{n} (\pi_i | y) v[P_x, I, EN_i | y] = v\left(P_x, I - OP, 0\right). \tag{6}$$

Solving for *OP* yields the individual's value for the perceived level of environmental risk of the power plant, holding prices and income constant. The individual's option price, or willingness to pay as elicited from a contingent valuation survey, to change or eliminate perceived risks due to an electric power producer will be a function of prices P_X, income *I*, and the individual's perceptions of the probabilities and severity of the risk consequences, conditional on the individual's knowledge and experience with the risk:

$$OP = OP(P_x, I, \pi_i | y, EN_i | y). \tag{7}$$

In estimation, the model will be expanded to include multiple perceived risk components, including health, aesthetic, and environmental risks, and economic impacts resulting from facility construction and operation.

4. SURVEY DESIGN

Deriving the values individuals place on risk level changes requires the integration of methods for characterizing perceived risk with contingent valuation methods. Advances in cognitive psychology, survey design, contingent valuation, and econometric techniques provide an opportunity to analyze the relationship between an individual's risk perceptions and the value corresponding to changes in risk.

Contingent valuation is considered the most appropriate method for non-market valuation of public goods (Mitchell and Carson [12]) as well as the only method available for measuring non-use values (Freeman [9]). Contingent valuation enables researchers to create a surrogate market, where subjects reveal their values for incremental increases or decreases in the provision of a non-market good. CVM estimates depend upon the researchers' representation of a hypothetical market and are vulnerable to sources of measurement error and the survey's reliability to elicit valid responses. These derived values depend on the entire process of designing, implementing, and analyzing CVM survey instruments.

Many aspects of CVM surveys create cognitive challenges. For example, the survey might involve fairly technical information beyond the respondents' understanding, leading to problems at the comprehension stage. Cognitive psychology methods, including focus groups and verbal protocols, provide a potential solution to some of the shortcomings of CVM survey design. Complete elimination of all measurement error is impossible, but a systematic approach to survey design with a goal of minimizing measurement error helps. This systematic approach is applicable regardless of the mode of survey administration or the anticipated method of data analysis.

The CVM survey used in this analysis was designed to elicit quantitative measures of perceived risk and the payments that individuals would be willing to make to change the perceived risk levels of an electric power facility. To explore whether perceived risk can be defined as the product of perceived severity and perceived probability (as risk is defined as severity times probability), measures of both perceived severity and perceived probability were necessary. Other measures of perceived risk are also considered.

Ten focus groups and twenty-one cognitive interviews were conducted from June 1995 through April 1996 with subjects recruited through local newspapers. These sessions were intended for survey development, not primary data collection, and the sample participants were not considered representative of the population. The objectives were (i) to gather insights into how individuals think about the relationships between the combustion of fossil fuels, electric power facilities, their community, their health, and the environment, (ii) to identify lay terminology for technical aspects of energy production, (iii) to identify lay perceptions of both the risks and benefits of energy production and the presence of an energy production facility, and (iv) to determine what information individuals use to form their perceptions of such facilities.

Discussion during the exploratory sessions revealed that individuals may not associate their own use of electricity with the demand for fossil fuels by electric power facilities. Scenario rejection is likely if individuals do not understand the need for and intended purpose of a facility. A hypothetical facility within three miles of a residential area raised numerous concerns, including health, environmental, economic, aesthetic, land use, intergenerational, and equity concerns. Concern about potential health impacts and air pollution from a facility seemed to be greater than concern about other impacts such as noise, traffic, and economic impacts.

Four primary survey design issues were addressed throughout survey development: implicit factor analysis to determine risk categories, scale format, survey vocabulary, and overcoming survey bias. A two-step process served as an implicit factor analysis to derive composite risk categories. During focus groups and interviews, participants were asked what they thought the future risks might be from a proposed electric power facility three to five miles from their house. Participants then categorized the list into four main groups, as shown in Table I. The subjects labeled the resulting composite risk categories as human health risks, environmental risks, aesthetic risks, and economic impacts.

Scales are used to elicit quantitative measures of qualitative variables. The scale questions were designed to quantify perceptions of the four risk categories. Scale range and units can be varied and depend upon the desired quantitative accuracy and the subject's cognitive ability to distinguish between choices.

Vocabulary refers to the wording of survey text, questions, and scale labels. Focus groups and interview discussions revealed that subjects anchored their interpretation of scale questions on the scale labels and format more than on the actual question. Survey text, question wording, and scale labels were iteratively revised until the subjects' interpretations of the questions concurred with their intended interpretation.

Finally, survey bias refers to the extent to which subjects felt the survey was encouraging them to respond in a particular way. Scales and scenario descriptions were iteratively revised to minimize the extent of bias in the survey. Debriefing questions were also used to check for bias.

The final survey is composed of five sections. The introduction to the survey contains a brief description of the nature of the survey and "warm-up" questions to assess the participant's awareness of their own consumption and expenses for electricity, their proximity to an energy generating facility, and how they rate the riskiness of an electric power facility relative to other "industrial" hazards. The next two sections provide a hypothetical description of the respondent's community, the growing need for electricity in the community, general features of the proposed power plant (size, land requirements, life of project), and regulatory compliance. One section proposes a coal-fired plant and the other a natural gas-fired plant.[5] A set of four scale questions for each risk category follows each scenario to quantify the respondents' perception of the possible risks and impacts resulting from the proposed facility. Following the scale questions, subjects rate their concern for each of the four risk components. Figure 1 shows the impact, severity, probability, and dread questions for the environmental risks due to the coal-fired plant.

The valuation sections asks respondents to vote in favor of or against the proposed facility, and the maximum amount extra they would pay each month on their electricity bill to *prevent* the proposed facilities in their community. The question specifically states why the respondents need to pay their utility company extra to prevent the power plant: "*If the supplier is not able to build this power plant, it will have to increase the price you pay for electricity because the much needed electricity must be purchased at a higher cost from other power producers elsewhere in the state.*" Subjects were reminded of their budget constraint prior to answering the valuation question.

The final section of the survey retrieves socio-demographic information about each respondent. The survey was followed by a debriefing questionnaire to enable researchers to gain additional insight into the respondents' answers and to test sample questions. The final survey contains 63 questions, eight of which are demographic.

Data were collected from written surveys in Harrisburg and State College, Pennsylvania. Subjects were recruited via random digit dialing; the adult with the last birthday was asked to

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[5] Two versions of the final survey were created, alternating the order of the coal-fired and natural gas-fired power plant proposals to eliminate ordering effects. Order effects are tested empirically in the estimation.

participate. Two hundred and twenty surveys were administered. The sample is evenly split by gender, with a mean age of 44 years, a mean education level of 15.6 years, and a mean household income of $46,300.

5. ESTIMATION AND RESULTS

The mean values of the perceived risk attributes for the coal and natural-gas fired plants are presented in Table II. Participants responded to these questions after reading the hypothetical proposals for each plant. In general, a majority of respondents believed both plants would create risks, coal more so than natural gas. Their perceptions of severity and probability of health, environmental, and aesthetic impacts were also more negative for coal than for natural gas. The coal facility generated greater feelings of dread or fear, as well. The differences in perceptions between health, environmental, and aesthetic risks from coal and natural gas were significant at the 1% level for all five measures. The difference in perceptions of the significance or the probability of economic impacts arising from a coal or natural gas plant was not significant, although if economic impacts did occur, participants expected the impacts to be greater for natural gas. Comparisons between perceptions of health, environmental, and aesthetic risks or economic impacts within one fuel are not possible. Given the unique nature of these risk components, the scales are not likely to be comparable, and thus mean measures between factors do not have any ordinal meaning.

The seriousness, probability, and dread variables are all significantly correlated with each other within and between each facility type. Severity and probability are positively correlated with dread and positively correlated with each other. Correlations are generally less prominent for the natural gas-fired plant than the coal-fired plant. The perceived severity, probability, and dread measures for the coal-fired facility are positively correlated with respective measures for the natural gas fired facility.

A measure of perceived risk can be calculated by multiplying perceived severity by perceived probability. Table III reports the mean and standard deviation of this perceived risk measure for each of the four risk categories. Average perceived risk is higher for the coal-fired plant than the natural gas plant in all four categories. Health risks from a natural gas plant are perceived as almost nonexistent.

The dependent variables are the respondent's willingness to pay (WTP) to prevent a coal-fired and natural gas-fired electric power plant. The values range from \$0.00 to \$120.00 for coal with a mean of \$16.98 and from \$0.00 to \$70.00 with a mean of \$13.37 for natural gas. The difference in means is significant at the one percent level. Summary statistics for all variables are found in Tables III and IV. The sociodemographic variables included in all models are income, education, age, gender, and an interaction term between income and education. The interaction term implies that the effect of education on WTP depends on the level of income, that is the relationship between WTP and education depends on income.

The actual model estimated is

$$\begin{aligned} WTP_j = \beta_0 + \beta_1 INC_j + \beta_2 EDUC_j + \beta_3 INC_j * EDUC_j + \beta_4 GENDER_j + \beta_5 AGE_j + \\ \beta_6 VERSION_j + \beta_7 HEALTH_j + \beta_8 ECON_j + \beta_9 ENVIR_j + \beta_{10} AESTH_j + \varepsilon_j \end{aligned} \tag{8}$$

where j indexes individuals, VERSION is a dummy variable referring to whether the coal or natural gas section came first, and HEALTH, ECON, ENVIR, and AESTH are measures of the four perceived risk categories considered. Three different measures were used for the risk attributes. In model 1, risk is measured as the *perceived seriousness* (e.g. CHLTSERI) of each of the four impacts, which is a measure of the severity of the consequences. Model 2 uses the constructed *perceived risk* (e.g. CHLTPRSK) measure of perceived severity times perceived probability, which is closest to the standard definition of risk. Model 3 uses a *weighted measure of perceived seriousness* (e.g. CHLTWSER), constructed by multiplying perceived seriousness times a value from 0 to 1 which reflects the relative importance of each impact to the respondent. Tobit estimation is the appropriate estimation choice because the dependent variables, WTP, are censored at zero (27 percent of the coal valuations and 45 percent of the natural gas valuations were zero). Ordinary least squares estimates would be biased upward and inconsistent.

The regression results are in Table V for all six models estimated. Income is positive and significant in all models, consistent with the hypothesis that individuals with more disposable income are willing to pay more for normal goods of this type. Education is also positive for all models, a common result in nonmarket valuation studies. Age and gender do not seem to play a role in determining an individual's WTP. Version is insignificant in all models, indicating that an individual's stated WTP is independent of the order in which the coal and natural gas valuation questions were presented. Some have suggested that a second WTP question will be invalid, but these results indicate otherwise. It further provides a measure of the reliability of the survey instrument.

When risk perceptions are measured by *seriousness* in model 1, economic impacts and environmental risks significantly impact the respondents' WTP to prevent a coal-fired facility. All four risk components significantly affect the WTP to prevent a natural gas-fired plant. The results are less appealing when risk is measured by the constructed *risk perception* variable. In model 2, only environmental risk for coal and health and aesthetic risks for natural gas are significant. Although this *risk perception* variable most closely resembles the accepted definition of risk, it may be difficult for respondents to differentiate between severity and probability. Alternatively, the survey may not have been able to adequately elicit the difference.

In model 3, risk is measured by a constructed measure which weights perceived seriousness by the importance of each impact to the respondent. The parameter estimates are larger than in model 1 because the size of the independent variables have been reduced by multiplying them by a number between zero and one. The results for natural gas are similar to model 1. For coal, aesthetic and health risks become significant but economic impacts become insignificant.

The negative coefficient on economic impacts indicates individuals are less willing to pay to prevent the plant the larger the economic impacts are perceived. This result suggests that separately identifying positive impacts (economic benefits) from negative impacts (health, environment, or aesthetics) can improve interpretation of individuals' responses to CVM scenarios. It may also provide more detailed information to planning officials and improve risk communication methods.

Overall, regardless of model specification, the evidence is strong that the perception of environmental risks influences a respondent's willingness to pay to avoid a coal-fired electric utility in their community. The results are less strong but suggest health, aesthetic, and economic impacts also influence WTP. For the natural gas-fired facility, health and aesthetic risks influence WTP in all models. The evidence is also strong that environmental risks and economic impacts influence WTP.

6. CONCLUSIONS

Results show that welfare impacts, as measured by option price, depend on an individual's perceptions of the health, environmental, aesthetic, and economic impacts as well as their socio-demographic characteristics. Individuals seemed to have difficulty distinguishing between the probability and the severity of a risk in the manner suggested by the definition of risk, although the survey instrument may have been unable to capture the difference. Perceived environmental, health, and aesthetic impacts play a larger role than potential economic impacts in determining option prices, explaining in part why residents may oppose a facility even when it will likely bring economic benefits to an area. Although this study focused on fossil-fuel electric power facilities, the methodology developed here is transferable to a multitude of hazards imposing welfare impacts which are a function of perceived risk.

The results confirm that CVM values are sensitive to the information set and perceptions of a participant (see Fischhoff and Furby [6] for additional evidence). While the general approach in contingent valuation methodology has been to mold or correct those perceptions in line with "expert" information, this study has explicitly measured those perceptions and related them to willingness to pay. A correct measure of welfare impacts requires consideration of the participants' perceptions rather than the researcher's perceptions of the commodity.

The potential exists to gather comparable data from "experts" to define levels of “true” risk. These could then be compared to laypersons' perceptions to estimate the welfare impacts from a divergence of expert and layperson risk judgements associated with a facility. The survey could also be administered at different phases of a project's life, from proposal through operation or defeat, to examine changes in perceptions and welfare impacts over time. A further extension could examine the determination of an individual's perceptions as a function of prior experience, y. This approach is implicit in programs to identify the impact or value of public information efforts and is of considerable importance in risk communication programs.

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TABLE I

Specific Concerns and Composite Risk Categories

Specific Concerns	Composite Risk Category
Cancer	Human Health Risks
Safety (of workers in the facility)	
Respiratory problems	
Transmission lines	
Ozone depletion	Environmental Risks
Mining—strip mining, water impacts	
Water quality—mine seepage	
Air quality, pollution	
Wildlife impacts	
Disposal of facility waste such as ash, waste heat, and steam	
Land use—location of the facility, land requirements	
Coal economically important to PA	
Cost of pollution control technology	Economic Impacts
Property values	
Cost of electricity (retail)	
Taxes	
Need for additional capacity	
Cost of fuel	
Funding of project development	
Creation of local jobs	
Odor—diesel trucks	Aesthetic/ Amenity Risks
Appearance of the facility	
Noise	
Transportation of fuel to the facility	
Truck traffic	
Dirty emissions	
Transmission lines	
Concern for future generations	Affecting Multiple Categories
Equity—distribution of costs and benefits	
Regulatory compliance and enforcement	
Full disclosure of information	
Fuel choice and characteristics	
Coal—dirty, polluting, environmental damage from coal mining, dust, trucks, acid rain,	
Natural Gas—clean burning, gas leaks and explosions	

TABLE II

Mean Values of Perceived Risk Attributes

	Believe Plant Will Create Risk		Perceived Impact		Perceived Severity		Perceived Probability		Dread	
	Coal	Gas	Coal	Gas	Coal	Gas	Coal	Gas	Coal	Gas
Health	82.3	48.2*	-1.07	-0.19*	3.89	2.45*	50.45	29.41*	-1.19	0.03*
Environmental	94.5	76.3*	-1.57	-0.68*	4.57	3.09*	63.73	44.36*	-1.72	-0.59*
Aesthetic	92.3	76.4*	-1.71	-0.80*	4.42	3.11*	62.27	48.86*	-1.61	-0.34*
Economic	90.4	91.3	0.62	1.54*	4.40	4.38	62.15	59.95	0.08	0.86*
Scale	0-100%		very negative = -4 no impact = 0 very positive = +4		not serious = 1 very serious = 7		0-100%		afraid = -4 neutral = 0 comfort = +4	

*The difference between the coal and natural gas figure is significant at 1%.

TABLE III

Perceptions Measures

PERCEPTION SCALE	FUEL TYPE	VARIABLE NAME	MEAN	STD. DEV.
Seriousness of health impacts	COAL	CHLTSERI	3.89	1.75
	GAS	GHLTSERI	2.45	1.45
Significance of economic impacts	COAL	CECNSERI	4.40	1.34
	GAS	GECNSERI	4.38	1.39
Seriousness of environmental impacts	COAL	CENVSERI	4.57	1.59
	GAS	GENVSERI	3.09	1.59
Seriousness of aesthetic impacts	COAL	CAESSERI	4.42	1.59
	GAS	GAESSERI	3.11	1.57
Probability of health impacts	COAL	CHLTPROB	0.50	0.28
	GAS	GHLTPROB	0.29	0.24
Probability of economic impacts	COAL	CECNPROB	0.62	0.24
	GAS	GECNPROB	0.59	0.24
Probability of environmental impacts	COAL	CENVPROB	0.63	0.27
	GAS	GENVPROB	0.44	0.28
Probability of aesthetic impacts	COAL	CAESPROB	0.62	0.26
	GAS	GAESPROB	0.49	0.28
Health risk = SERIOUSNESS*PROBABILITY	COAL	CHLTPRSK	2.36	1.87
	GAS	GHLTPRSK	0.99	1.23
Economic risk = SIGNIFICANCE *PROBABILITY	COAL	CECNPRSK	2.28	1.56
	GAS	GECNPRSK	1.34	1.23
Environmental risk = SERIOUSNESS*PROBABILITY	COAL	CENVPRSK	3.22	1.98
	GAS	GENVPRSK	1.68	1.63
Aesthetic risk = SERIOUSNESS*PROBABILITY	COAL	CAESPRSK	3.04	1.92
	GAS	GAESPRSK	1.79	1.56
Weighted seriousness of health impacts	COAL	CHLTWSER	1.08	0.56
	GAS	GHLTWSER	0.67	0.44
Weighted seriousness of economic impacts	COAL	CECNSWER	-0.33	1.11
	GAS	GECNWSER	-0.72	0.86
Weighted seriousness of environmental impacts	COAL	CENVWSER	1.28	0.53
	GAS	GENVWSER	0.87	0.49
Weighted seriousness of aesthetic impacts	COAL	CAESWSER	1.03	0.54
	GAS	GAESWSER	0.73	0.47

TABLE IV

WTP and Socio-Demographic Summary Statistics

VARIABLE NAME	VARIABLE DESCRIPTION	MEAN	STD. DEV.	MINIMUM	MAXIMUM
CWTP	Willingness to pay to prevent coal plant ($0.00 bids-26.8%)	$13.72	16.98	$0.00	$120.00
GWTP	Willingness to pay to prevent gas plant ($0.00 bids-45.0%)	$8.41	13.37	$0.00	$70.00
INCOME	Midpoint of income range	$46,300	31,026	$4,999.50	$189,999.50
GENDER	Dummy variable for gender, 1 = Male	0.5091	0.5011	0	1
EDUC	Years of education completed	15.64	3.12	9	31
AGE	Age of respondent (years)	44.03	17.07	18	87
VERSION	Dummy variable for survey version, 1 = ???	0.53	0.50	0	1

TABLE V

Tobit Regression Results (Standard Errors in Parentheses)

	Model 1		Model 2		Model 3	
	Coal	Gas	Coal	Gas	Coal	Gas
CONSTANT	-67.07*	-60.7642*	-51.087*	-44.0057*	-60.0099*	-58.7228*
	(15.73)	(14.5966)	(14.7202)	(14.0162)	(15.3419)	(14.7563)
INCOME	0.00068*	0.0005317*	0.00064*	0.00051*	0.000608*	0.00052*
	(0.00023)	(0.000215)	(0.00023)	(0.000214)	(0.000232)	(0.000217
EDUC	2.5328*	1.8537*	2.333*	1.6029*	2.2007*	1.7198*
	(0.8674)	(0.8117)	(0.856)	(0.8164)	(0.8652)	(0.8226)
INC* EDUC	-0.00004*	-0.0000283*	-0.0000356*	-0.0000261*	-0.0000335*	-0.0000266
	(0.000014)	(0.000013)	(0.000014)	(0.000013)	(0.000014)	(0.000013
AGE	0.0715	0.0737	0.0999	0.0808	0.0699	0.0976
	(0.0872)	(0.08336)	(0.0882)	(0.08413)	(0.0869)	(0.0844)
GENDER	-3.8579	-3.2056	-4.612	-3.2451	-3.1938	-3.0391
	(2.9098)	(2.8561)	(2.8758)	(2.8976)	(2.9077)	(2.8505)
VERSION	3.1739	3.0252	4.0784	3.6096	4.1425	2.8529
	(2.9123)	(2.6994)	(2.9719)	(2.7691)	(2.8416)	(2.7178)
HLTSERI	1.5892	2.6205*				
	(1.2835)	(1.1761)				
ECNSERI	-0.5388*	-0.7591*				
	(0.3222)	(0.3983)				
ENVSERI	3.6424*	2.0495*				
	(1.4159)	(1.2174)				
AESSERI	1.7048	3.5338*				
	(1.1954)	(1.0934)				
HLTPRSK			1.1753	4.2369*		
			(1.22)	(1.4411)		
ECNPRSK			-0.6964	-0.7092		
			(0.4365)	(0.5374)		
ENVPRSK			2.7631*	0.4883		
			(1.206)	(1.2977)		
AESPRSK			1.4865	3.3587*		
			(1.0549)	(1.1137)		
WHLTSER					7.0531*	8.5007*
					(3.1846)	(3.7048)
WECNSER					-1.2322	-2.6873*
					(1.3437)	(1.6251)
WENVSER					10.2932*	11.6373*
					(3.3579)	(3.4963)
WAESSER					6.9441*	9.2607*
					(2.6495)	(3.0972)

*Significant at 5%.

Figure 1

Environmental Risk Questions

The Coal-Fired Power Plant and Your Environment

Environmental impacts could be caused by changes in the air quality, water quality, plants and wildlife, and how the land in your community is used. To answer the following questions, consider how you feel the proposed power plant may be a risk to the environment, and how serious you feel the actual environmental impact(s) could be from the coal-fired power plant. Please think <u>only</u> of the potential impacts on environmental quality as you answer the questions on this page.

Q16. Do you feel that there might be environmental impacts as a result of the coal-fired power plant described on **page 3**? (Circle appropriate number.)

1. NO
2. YES

Q17. Indicate below how positive or negative you feel that the impact(s) to the environment could be from the proposed coal-fired power plant. (Circle appropriate number.)

VERY NEGATIVE IMPACT — NO IMPACT — VERY POSITIVE IMPACT
-4 -3 -2 -1 0 1 2 3 4

Q18. How serious do you feel the risks to the environment could be from the proposed coal-fired power plant? (Circle appropriate number.)

NOT AT ALL SERIOUS — SOMEWHAT SERIOUS — VERY SERIOUS
1 2 3 4 5 6 7

Q19. What do you feel is the chance or likelihood that the coal plant will affect the environment some time in the future? (Circle percentage.)

NO CHANCE THE ENVIRONMENT WILL BE AFFECTED — MAY OR MAY NOT AFFECT THE ENVIRONMENT — DEFINITELY WILL WILL AFFECT THE ENVIRONMENT
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Q20. How would you describe your feelings when you think about the environmental risks from the proposed power plant? (Circle appropriate number.)

I FEEL AFRAID AND DREADFUL — MY FEELINGS ARE NEUTRAL — I FEEL HAPPINESS AND COMFORT
-4 -3 -2 -1 0 1 2 3 4