DOE/FE-017P
Distribution Category UC-101

Comprehensive Report to Congress Clean Coal Technology Program

Development of the Coal Quality Expert

A Project Proposed By
Combustion Engineering, Inc. and CQ, Inc.

May 1990

U.S. Department of Energy
Office of Fossil Energy
Washington, D.C. 20585

TABLE OF CONTENTS

		Page
1.0	EXECUTIVE SUMMARY	1
2.0	INTRODUCTION AND BACKGROUND	6
2.1	Requirement for Report to Congress	6
2.2	Evaluation and Selection Process	7
3.0	TECHNICAL FEATURES	10
3.1	Project Description	10
3.1.1	Project Summary	11
3.1.2	Project Sponsorship and Cost	12
3.2	Description of Coal Quality Expert	12
3.2.1	Overview of Development	12
3.2.2	Process Description	13
3.2.3	Application of Process in Proposed Project	18
3.3	General Features of the Project	21
3.3.1	Evaluation of Developmental Risk	21
3.3.1.1	Similarity of Project to Other Demonstration/Commercial Efforts	21
3.3.1.2	Technical Feasibility	22
3.3.1.3	Resource Availability	22
3.3.2	Relationship Between Project Size and Projected Scale of Commercial Facility	23
3.3.3	Role of the Project in Achieving Commercial Feasibility of the Technology	23
3.3.3.1	Applicability of the Data to be Generated	24
3.3.3.2	Identification of Features that Increase Potential for Commercialization	25
3.3.3.3	Comparative Merits of Project and Projection of Future Commercial Economic and Market Acceptability	26
4.0	ENVIRONMENTAL CONSIDERATIONS	28
5.0	PROJECT MANAGEMENT	29
5.1	Overview of Management Organization	29
5.2	Identification of Respective Roles and Responsibilities	29
5.3	Summary of Project Implementation and Control Procedures	33
5.4	Key Agreements Impacting Data Rights, Patent Waivers, and Information Reporting	33
5.5	Procedures for Commercialization of the Technology	33
6.0	PROJECT COST AND EVENT SCHEDULING	35
6.1	Project Baseline Costs	35
6.2	Milestone Schedule	36
6.3	Recoupment Plan	36

1.0 EXECUTIVE SUMMARY

The FY86 Appropriations Act, P.L. 99-190, included approximately $400 million to support the construction and operation of demonstration facilities using clean coal technologies. The Clean Coal projects cover a broad spectrum of technologies having the following things in common: (1) all are intended to increase the use of coal in an environmentally acceptable manner; and (2) all are ready to be proven at the demonstration level.

In response to the resulting Program Opportunity Notice (PON), fifty-one proposals were received in April 1986. After evaluation, nine projects representing seven different technologies were selected in July 1986 for funding under the Clean Coal Technology (CCT) Program. In addition, a list of alternate candidates was established from which replacement selections could be made should any of the original nine not proceed. On October 7, 1987, and subsequently on December 9, 1988, as a result of project sponsors withdrawing their proposals or the Department of Energy (DOE) terminating negotiations, DOE selected, respectively, four additional and three additional projects from the alternate candidates list.

One of the proposals selected on December 9, 1988 was one proposed by Combustion Engineering, Inc. (C-E) in close collaboration with the Electric Power Research Institute (EPRI) for a computer-based analytical program, the Coal Quality Expert (CQE), to demonstrate the economic and environmental benefits of using higher quality U.S. coals for industrial and electric utility use. EPRI subsequently organized CQ Inc. as a wholly owned for profit subsidiary of EPRI. CQ Inc. has now joined C-E as a co-participant for this project.

The proposed Coal Quality Expert Development Project contains the following activities: (1) testing and data gathering, which involves optimization of coal quality for combustion in different types of coal-burning utilities and (2) the development of the Coal Quality Expert, which is a computer expert system that can simulate human reasoning in a specified area of knowledge.

The Expert System for this project will be designed to enable coal-burning utilities and industries to select the best quality coal in relationship to economics and to federal, state, and local environmental requirements.

Testing and Data Gathering

The testing and data gathering activity includes, (a) coal characterization and cleanability studies, (b) bench-scale combustion testing, (c) pilot-scale combustion testing, and (d) full-scale combustion testing. The results from this activity will be information that permits coal-burning utility and industrial operators to assess the effects of coal cleaning on overall power plant performance and emissions.

Coal Characterization and Cleanability Studies

The following would be accomplished:

Samples of coal from various sources in the United States having different properties will be characterized with regard to size, density, and surface characteristics. Analyses will include measurement of moisture, proximate analysis, sulfur forms, heating value, float/sink characteristics, hardgrove grindability, ash fusion temperatures, ash composition, chlorine content, and gravity fractionation.

An impurities liberation study will be undertaken to determine the extent to which crushing liberates additional coal ash and sulfur from the combustible portions. The intent would be to define the least amount of size reduction that would liberate the maximum amount of impurities.

Coal will be medium- and deep-cleaned using existing coal cleaning techniques, and the combustion characteristics before and after cleaning will be defined, analyzed, and compared. The intent of this portion of work would be to optimize the yield and heating-value recovery of the coal at a specific quality.

Bench-Scale Combustion Testing

Bench-scale combustion studies will be conducted to define coal properties that can be used to reliably predict the combustion and fireside performance of both baseline and improved quality coals.

Pilot-Scale Combustion Testing

Pilot-scale combustion testing will be conducted in pulverized coal and cyclone-fired boilers to assess the differences in pulverization and combustion between baseline and improved quality coal and to measure pulverizer power consumption,

boiler slagging, fouling, convection tube erosion, and electrostatic precipitator performance.

Full-Scale Combustion Testing

Full-scale combustion testing of baseline and improved quality coals will be conducted at six coal-burning utility sites. The objectives of the full-scale combustion testing will be to evaluate the applicability and accuracy of the existing Coal Quality Impact Model (CQIM) and EPRI's Fireside Testing Guidelines and to confirm the results of the laboratory fuel characterizations and pilot-scale combustion testing.

Expert System

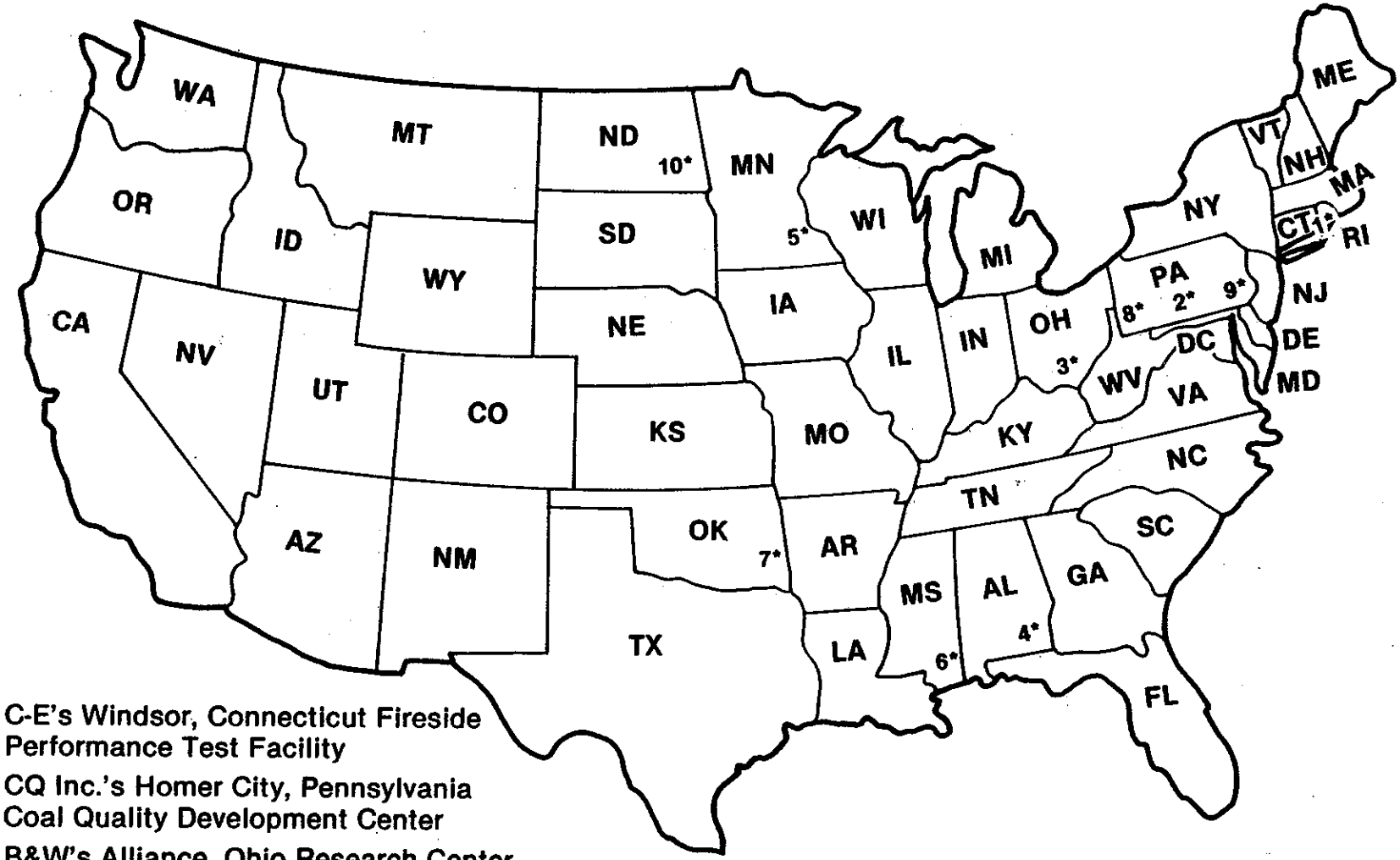
The objective of this activity will be to develop and validate a computer software methodology, the CQE, that will allow accurate and detailed predictions of the impacts of coal quality on total coal-burning utility and industrial plant costs and operations, including compliance with environmental standards.

Coal cleaning and characterization, followed by bench-scale, pilot-scale, and full-scale testing will be performed at various sites, as shown in Figure 1. The coal used for bench- and pilot-scale testing will be cleaned and characterized at the Coal Quality Development Center (CQDC) at Homer City, Pennsylvania. The coal used for field testing will be cleaned at existing commercial facilities, which will be selected later. Bench- and pilot-scale combustion tests will be conducted at the following three sites: the University of North Dakota's Energy and Environmental Research Center (UNDEERC) located in Grand Forks, North Dakota, at C-E's Fireside Performance Test Facility at Windsor, Connecticut, and at Babcock & Wilcox's (B&W) Small Boiler Simulator facility at Alliance, Ohio.

Field testing will be performed at the following six boiler sites:

- The wall-fired 250 MWe Watson Unit 4 boiler owned by Mississippi Power Company and located near Gulfport, Mississippi.

- The tangentially-fired 950 MWe Gaston Unit 5 owned by Alabama Power Company and located near Wilsonville, Alabama.



1 - C-E's Windsor, Connecticut Fireside Performance Test Facility

2 - CQ Inc.'s Homer City, Pennsylvania Coal Quality Development Center

3 - B&W's Alliance, Ohio Research Center

4 - 950 MWe Gaston Unit No. 5, Alabama Power Company, Wilsonville, Alabama

5 - 600 MWe King Unit No. 1, Northern States Power Company, Bayport, Minnesota

6 - 250 MWe Watson Unit No. 4, Mississippi Power Company, Gulfport, Mississippi

7 - 470 MWe Northeastern Unit No. 4, Public Service Company of Oklahoma, Oologah, Oklahoma

8 - 500 MWe Cheswick Station, Duquense Light Power Company, Springdale, Pennsylvania

9 - 600 MWe Homer City Unit No. 2, Penelec/NYSEG, Homer City, Pennsylvania

10 - University of North Dakota's Energy and Mineral Research Center, Grand Forks, North Dakota

FIGURE 1. DEMONSTRATION PROJECT LOCATIONS.

NOJ19,364

- The tangentially-fired 470 MWe Northeastern Unit 4 owned by Public Service Company of Oklahoma and located near Oologah, Oklahoma.

- The cyclone-fired 600 MWe King Unit 1 owned by Northern States Power Company and located near Bayport, Minnesota.

- The wall-fired 600 MWe Homer City Unit No. 2 owned by Penelec/NYSEG and located near Homer City, Pennsylvania.

- The tangentially-fired 500 MWe Cheswick Station owned by Duquesne Light and located near Springdale, Pennsylvania.

The demonstration project will be conducted over a 42-month period. The total project cost is $17,382,258. The co-funders are DOE ($8,691,129), EPRI ($5,931,052), and host site participants and contractors ($2,760,077). Coal cleanability characterization, testing, and CQE specification preparation are scheduled to begin in mid 1990. CQE workstation testing and validation are scheduled to begin in early 1992. Overall project completion is scheduled to occur in mid-1993.

2.0 INTRODUCTION AND BACKGROUND

The domestic coal resources of the United States play an important role in meeting current and future energy needs. During the past 15 years, considerable effort has been directed toward developing improved coal combustion, conversion, and utilization processes to provide efficient and economic energy options. These technology developments permit the use of coal in a cost-effective and environmentally acceptable manner.

2.1 Requirement for Report to Congress

In December 1985, Congress made funds available for a Clean Coal Technology (CCT) Program in Public Law No. 99-190, An Act Making Appropriations for the Department of Interior and Related Agencies for the Fiscal Year Ending September 30, 1986, and for Other Purposes. This Act provided funds "... for the purpose of conducting cost-shared Clean Coal Technology projects for the construction and operation of facilities to demonstrate the feasibility for future commercial applications of such technology..." and authorized DOE to conduct the CCT program. Public Law No. 99-190 provided $400 million "... to remain available until expended, of which (1) $100,000,000 shall be immediately available; (2) an additional $150,000,000 shall be available beginning October 1, 1986; and (3) an additional $150,000,000 shall be available beginning October 1, 1987." However, Section 325 of the Act reduced each amount of budget authority by 0.6% so that these amounts became $99.4 million, $149.1 million, and $149.1 million, respectively, for a total of $397.6 million.

In addition, in the conference report accompanying Public Law No. 99-190, the conferees directed DOE to prepare a comprehensive report on the proposals received, after the projects to be funded had been selected. The report was submitted in August 1986 and was titled "Comprehensive Report to Congress: Proposals Received in Response to the Clean Coal Technology Program Opportunity Notice" (DOE/FE-0070). Specifically, the report outlined the solicitation process implemented by DOE for receiving proposals for CCT projects, summarized the project proposals that were received, provided information on the technologies that were the focus of the CCT Program, and reviewed specific issues and topics related to the solicitation.

Public Law No. 99-190 directed DOE to prepare a full and comprehensive report to Congress on any project to receive an award under the CCT program. This report is in fulfillment of this directive and contains a comprehensive description of the Coal Quality Expert Demonstration Project.

2.2 Evaluation and Selection Process

DOE issued a Program Opportunity Notice (PON) on February 17, 1986, to solicit proposals for conducting cost-shared CCT demonstrations. Fifty-one proposals were received. All proposals were required to meet preliminary evaluation requirements identified in the PON. An evaluation was made to determine if each proposal met those preliminary evaluation requirements and those proposals that did not were rejected.

Of those proposals remaining in the competition, separate evaluations were made for each offeror's Technical Proposal, Business and Management Proposal, and Cost Proposal. The PON provided that the Technical Proposal was of significantly greater importance than the Business and Management Proposal and that the Cost Proposal's significance was minimal; however, everything else being equal, the Cost Proposal was very important.

The Technical Evaluation Criteria were divided into two major categories. The first, "Commercialization Factors," addressed the projected commercialization of the proposed technology. This was different from the proposed demonstration project itself and dealt with all of the other steps and factors involved in the commercialization process. The subcriteria in this section allowed for consideration of the projected environmental, health, safety, and socioeconomic impacts (EHSS); the potential marketability and economics of the technology; and the plan to commercialize the proposed technology subsequent to the demonstration project.

The second major category, "Demonstration Project Factors," dealt with the proposed project itself. Subcriteria in "Demonstration Project Factors" allowed for consideration of the following: technical readiness for scale-up; adequacy and appropriateness of the demonstration project; the EHSS and other site-related aspects; and the reasonableness and adequacy of the technical approach and quality and completeness of the Statement of Work.

The Business and Management Proposal was evaluated to determine the business and management performance potential of the offeror, and was used as an aid in determining the offeror's understanding of the technical requirements of the PON. The Cost Proposal was evaluated to assess whether the proposed cost was appropriate and reasonable, and to determine the probable cost of the proposed project to the Government. The Cost Proposal was also used to assess the validity of the proposer's approach to completing the project, in accordance with the proposed Statement of Work and the requirements of the PON.

Consideration was also given to the following program policy factors:

(1) The desirability of selecting for support a group of projects that represent a diversity of methods, technical approaches, or applications;

(2) The desirability of selecting for support a group of projects that would ensure that a broad cross section of the U.S. coal resource base is utilized, both now and in the future; and

(3) The desirability of selecting for support a group of projects that represent a balance between the goals of expanding the use of coal and minimizing environmental impacts.

An overall strategy for compliance with the requirements of the National Environmental Policy Act (NEPA) was developed for the CCT Program, consistent with the Council on Environmental Quality NEPA regulations and the DOE guidelines for compliance with NEPA. This strategy includes both programmatic and project-specific environmental impact considerations, during and subsequent to the selection process.

In light of the tight schedule imposed by Public Law No. 99-190 and the confidentiality requirements of the competitive PON process, DOE established alternative procedures to ensure that environmental factors were fully evaluated and integrated into the decision-making process to satisfy its NEPA responsibilities. Under terms of the PON, offerors were required to submit both programmatic and project-specific environmental data and analyses as a discrete part of each proposal.

The DOE strategy for NEPA compliance for the CCT Program has three major elements. The first involves preparation of a programmatic environmental impact analysis, for internal DOE use, based on information provided by the offerors and supplemented by DOE, as necessary. This environmental analysis documents that relevant environmental consequences of the CCT Program and reasonable programmatic alternatives were considered in the selection process. The second element involves preparation of a pre-selection project-specific environmental review, also for internal DOE use only. The third element provides for preparation by DOE of publicly available site-specific documents for each project selected for financial assistance under the CCT Program.

No funds from the CCT Program will be provided for detailed design, construction, operation, and/or dismantlement until the third element of the NEPA process has been successfully completed. In addition, each Cooperative Agreement will require an Environmental Monitoring Plan to ensure that significant site- and technology-specific environmental data are collected and disseminated.

After considering the evaluation criteria, the program policy factors, and the NEPA requirements, proposals from nine offerors were initially selected for award. The proposal submitted by C-E was one of the proposals placed on an alternate list, to be eligible for award if one or more of the projects selected did not culminate in an award. In place of a project that did not proceed to an award, the Coal Quality Expert proposal was selected from the alternate list.

3.0 TECHNICAL FEATURES

3.1 Project Description

The C-E/CQ Inc. project will demonstrate the benefits of a computer-based analytical program, the CQE, to improve the selection of fuel by coal burning utilities and industries relative to environmental constraints and cost. The proposed project contains the following activities: (1) Testing and data gathering; and (2) the development of a Coal Quality Expert System.

Bench-scale and pilot-scale coal cleaning and coal cleanability characterization will be performed at the CQDC at Homer City, Pennsylvania. Bench-scale and pilot-scale combustion testing and further coal characterization will be performed at the three sites: the UNDEERC; at C-E's Fireside Performance Test Facility, and at B&W's Alliance Research Center. Field testing will be performed at six operating utility plants. These plants include Alabama Power Company's 950 MWe Gaston Unit No. 5; Mississippi Power Company's 250 MWe Watson Unit No. 4; Northern States Power Company's 600 MWe King Unit No. 1; Public Service Company of Oklahoma's 470 MWe Northeastern Unit No. 4; Penelec/NYSEG 600 MWe Homer City Unit No.2; and Duquesne Light's 500 MWe Cheswick Station. Commercial coal cleaning plants will be selected later and utilized to prepare the fuel for the field tests.

Using the data obtained from the various tests performed, improvements and enhancements will be made to EPRI's Coal Quality Impact Model (CQIM) and specifications will be prepared for the CQE.

Software will be developed for the CQE and user's manuals will be prepared. The software and the manuals will then be tested at ten different utility plants, which will be selected later. Any changes required to the software or user's manuals as a result of the tests will then be incorporated.

The goal of this project is to give coal burning utilities and industries a tool for accurate and detailed predictions of coal quality impacts on power plant costs, operation, and environmental emissions, in order that the best quality and lowest cost fuel can be selected by coal users to meet their specific needs. This program will enable the utilities and industries to select the best quality fuels based on specific federal, state, and local environmental requirements and costs. The goal is to improve the cost effectiveness of reducing the emissions of sulfur oxides (SO_x), particulate matter, and other pollutants.

3.1.1 Project Summary

Project Title:	Development of the Coal Quality Expert
Proposer:	Combustion Engineering, Inc. and CQ Inc. (a wholly owned subsidiary of EPRI)
Project Locations:	Windsor, Connecticut (C-E) - Hartford County Homer City, Pennsylvania (CQ Inc., CQDC) - Indiana County Alliance, Ohio (B&W) - Stark County Grand Forks, North Dakota (University of North Dakota) - Grand Forks County Wilsonville, Alabama (Gaston Station) - Shelby County Bayport, Minnesota (King Station) - Washington County Gulfport, Mississippi (Watson Station) - Harrison County Oologah, Oklahoma (Northeastern Station) - Rogers County Cheswick, Pennsylvania (Cheswick Station) - Allegheny County Homer City, Pennsylvania (Homer City Station) - Indiana County
Technology:	Use CQE to promote clean coal for electric utilities and industrial users.
Application:	Upgrading run-of-mine (ROM) coal for use in existing electric power plants and coal based industries, with future application in new coal-fired plants.
Types of Coal Used:	Alabama, Indiana, Kentucky, Ohio, Pennsylvania and West Virginia Bituminous and Montana, Oklahoma and Wyoming Subbituminous
Product:	Computer Program CQE
Project Size:	For use in all existing and future coal-fired electric utility and industrial plants.
Project Start Date:	May 1990
Project End Date:	November 1993

3.1.2 Project Sponsorship and Cost

Project Sponsor:	Combustion Engineering, Inc. and CQ Inc.
Proposed Co-Funders:	U.S. Department of Energy, Electric Power Research Institute, Host Site Participants, and Contractors
Proposed Project Cost:	$17,382,258

Proposed Cost Distribution:

Participant Share(%)	DOE Share(%)
50	50

3.2 Description of Coal Quality Expert

3.2.1 Overview of Development

Coal cleaning has been commercially demonstrated as a means of reducing sulfur concentrations in some types of coal to levels which allow firing in boilers without the use of scrubbers to meet emissions standards. In addition, coal cleaning reduces the concentrations of mineral impurities and thereby improves boiler performance, reduces maintenance, reduces ash quantities, and increases availability. In some instances coal can be cleaned or blended to a quality level where significantly less costly desulfurization systems can be used.

The CQDC, which is now owned by CQ Inc., has produced cleaned coal from many types of coals over the past eight years. The proposed demonstration will include the use of the CQDC to prepare cleaned coals from at least eight additional coals to expand the database on this scale of production.

Since 1984, C-E has been under contract to EPRI to perform clean coal pilot-scale combustion testing. A total of seven raw coals and 10 clean coals have been analyzed and tested at C-E's Kreisinger Development Laboratory. The testing effort is part of a comprehensive EPRI program to determine the combustion-related effects of fuel quality on power plants.

The CQIM, which determines the performance and economic impacts of firing different quality coals, has been under development at EPRI for several years. The CQIM is based on the data developed at CQDC and Kreisinger Development Laboratory. Recent studies have indicated that significant economic and environmental benefits may be attained by advanced coal cleaning processes. These benefits, however, cannot be accurately and completely assessed for a particular coal unless detailed large-scale combustion testing is accomplished. Currently, industry does not have the capability to reliably predict the performance of cleaned coals without performing these extensive tests and studies. This project will develop and demonstrate simple models and techniques that will allow industry to confidently assess the overall impacts of coal quality and the economic implications during utilization.

3.2.2 Process Description

The proposed project will develop a computer-based analytical program, CQE, that will demonstrate to coal-burning utilities and industries the benefits of using cleaned coal as it relates to total plant operations, environmental emission reductions, and economics. CQE will combine and upgrade several existing computerized models and will add an expert system, as shown in Figure 2. The project is composed of two major categories of work: (1) coal characterization and testing, and (2) development of the expert system. Coal characterization and testing is subdivided into: Coal Characterization and Cleanability Studies, Bench-Scale Fuel Characterization, Pilot-Scale Combustion Testing, and Full-Scale Combustion Testing.

Coal Characterization and Cleanability Studies

Coal characterization and cleanability studies will be conducted to define as-mined coal quality, determine what quality levels of clean coal can be economically produced, and learn if crushing can be used to increase the amount of ash forming mineral matter and mineral matter containing sulfur removed by cleaning. The scale of coal characterization and cleanability testing, which will be conducted at the CQDC in Homer City, Pennsylvania, will be the same as that which is routinely conducted at this center.

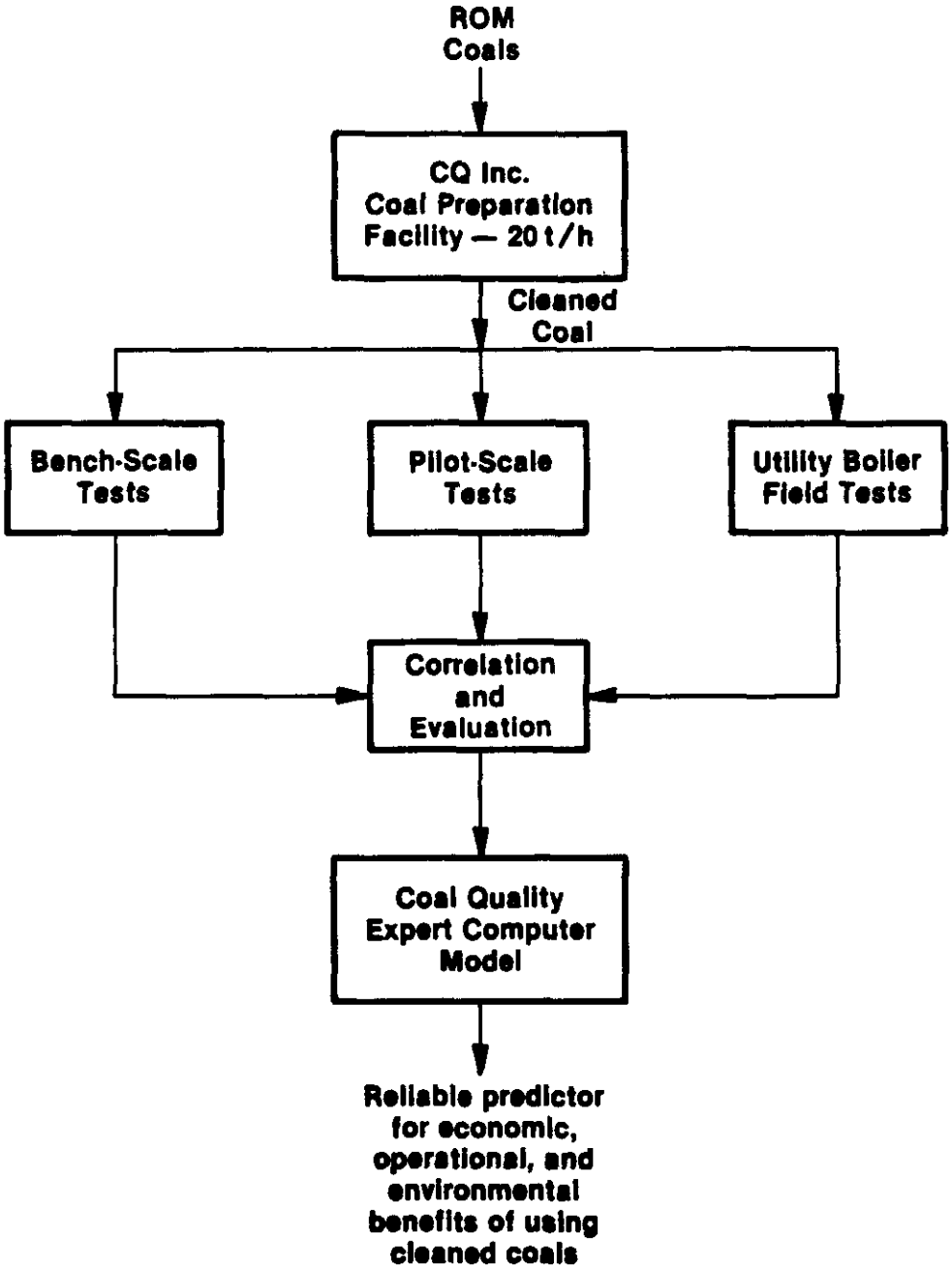


FIGURE 2. COAL QUALITY EXPERT PROCESS FLOW DIAGRAM.

NO/13,589

Bench-Scale Fuel Characterization

Laboratory tests of 26 coal types will be conducted by B&W, C-E, and UNDEERC to study coal properties that could be reliably used to predict the combustion and fireside performance of both baseline and improved quality coals. These include determination of size, chemical composition, and distribution of mineral grains; proximate and ultimate analyses and heating values; and measurements of slag viscosity, and ash sintering. A maximum of 50 pounds of coal would be used for each laboratory test. This testing is at a scale that is similar to that routinely conducted at these facilities.

Pilot-Scale Combustion Testing

Pilot-scale tests on larger volumes of coal (up to 20 tons each of 23 of the 26 test coals) would be conducted in C-E's Fireside Performance Test Facility and B&W's Small Boiler Simulator (20 test coals in the former, 3 in the latter) to evaluate coal properties that influence boiler design and operating factors. The scale of the proposed pilot-scale tests would be the same as or less than tests currently conducted at the CE and B&W facilities.

Full-Scale Combustion Testing

Field test burns of baseline and improved quality coals would be conducted at six coal-burning utilities. The field test burns would provide operating data necessary for an evaluation of the applicability and accuracy of the CQIM and EPRI's Fireside Testing Guidelines and would confirm the results of the laboratory tests. Each field test burn would be conducted for a period of two months. During the first month, the coal-burning utility would burn a coal or blend of coals typical of those it currently uses as fuel; during the second, an improved quality coal would be burned. Except for the temporary installation of test ports, monitoring equipment, and sampling instrumentation, no new construction or alteration of the coal-burning utilities would be required.

At four coal-burning utilities, a single generating unit would be involved in the full-scale combustion testing. the name, size, and location of each unit is as follows:

- Watson, Unit 4 (250 MW), Gulfport, MS;
- Gaston, Unit 5 (880 MW), Wilsonville, AL;
- Northeastern, Unit 4 (445 MW), Oologah, OK; and
- Homer City, Unit 2 (600 MW), Homer City, PA.

The other two coal-fired plants have only one generating unit. These are:

- o King (560 MW), Oak Park Heights, MN; and
- o Cheswick (500 MW), Springdale, PA.

Baseline coal for Gaston, Watson, Northeastern, and King Stations will be a normal blend of two or more coals from existing on-site coal storage. Blending of coals is a common practice at coal-fired utilities because there are generally several coals of varying quality in on-site storage. The improved quality coal for these four stations would be produced by using a larger quantity of low-sulfur coals in blending, thereby producing a blend of lower sulfur coal than the baseline coal.

Baseline and improved quality coals for the Cheswick and Homer City Stations will be a cleaned coal from the coal cleaning plant which is owned by the utility operating each station. The Cheswick Station receives cleaned coal from the Warwick Coal Cleaning Plant in Greene County, Pennsylvania, and the Homer City Station receives cleaned coal from the Islen Coal Cleaning Plant in Indiana County, Pennsylvania, which is adjacent to Homer City Station.

CQE Development

The CQE will be developed by combining a variety of existing coal quality models that will be updated and expanded and then made to interact with an expert system that will use these models and software to answer coal quality questions. The models that makeup the CQE are shown in Figure 3.

The CQIM, which has been under development by EPRI for several years, determines the performance and economic impacts of firing coals of different qualities.

The CQIM is the most important model within the CQE and will be expanded to include the following:

- o An acid rain advisor to assess the optimum methodology for complying with acid rain legislation and to assess retrofit flue gas desulfurization costs
- o An enhanced precipitator impact model
- o SO_3 conditioning effects on precipitator performance

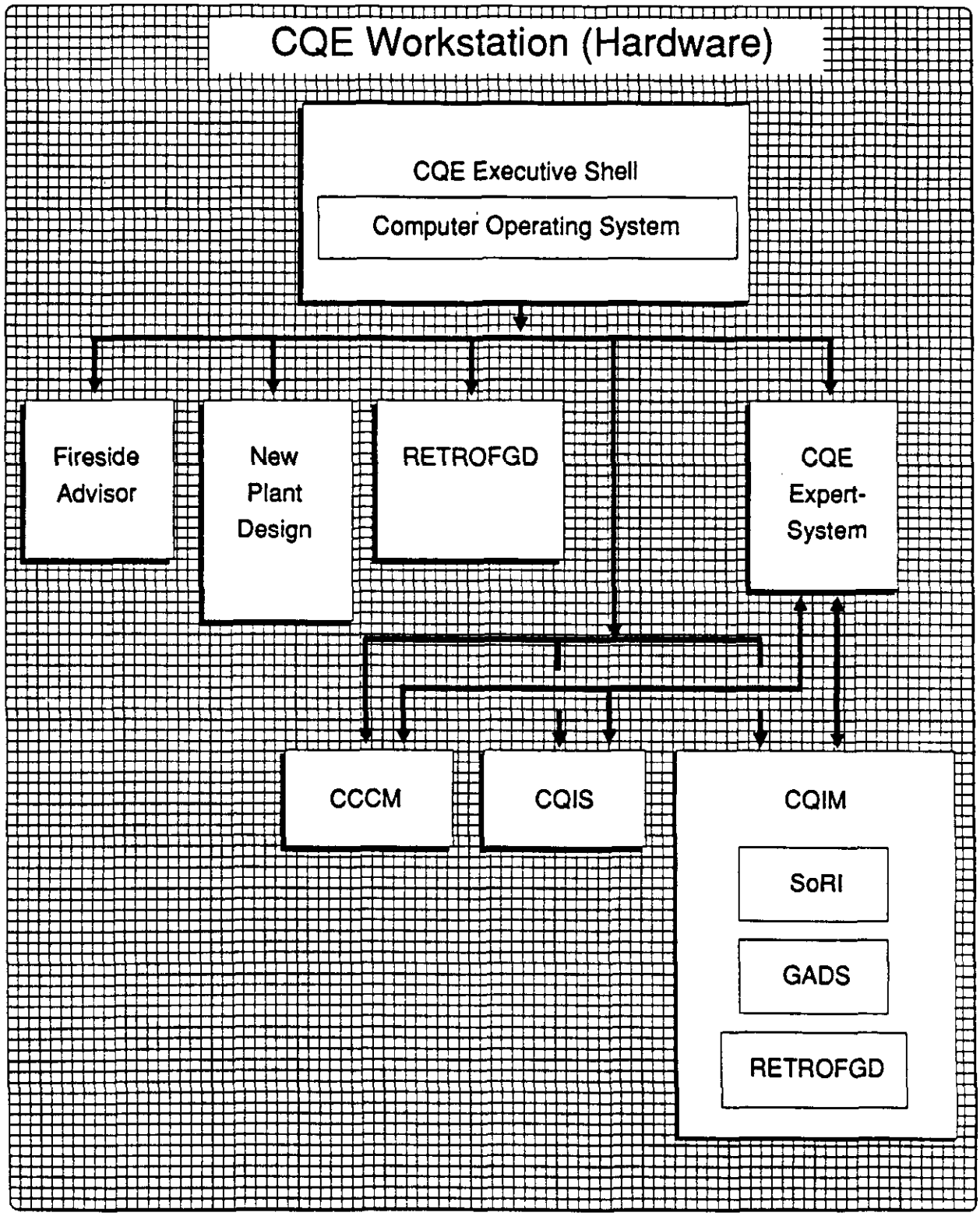


FIGURE 3. CQE COMPONENTS.

NO./19,588

- FGD particulate removal impacts
- Landfill/pond model
- Ball mill model
- NO_x formation model
- C-E twin furnace model
- Low volatile coal treatment effects
- Wet lime FGD model
- New plant design guide
- Enhancement of the reference maintenance/availability database
- A method to convert data from the North American Electric Reliability Council Generating Availability Data System to the form employed within the CQIM
- Full integration of the bench-, pilot-, and full-scale test results into the CQIM.

Other software and databases that will become part of the CQE include the Retrofit Flue Gas Desulfurization (RETROFGD) software, the Fireside Advisor, CQIS database enhancements resulting from the demonstration's coal cleanability characterizations, the Coal Cleaning Cost Model, and the New Plant Construction Cost Model. The RETROFGD software estimates the capital and operating costs of retrofitting various FGD systems to an existing power plant; the Coal Cleaning Cost Model provides capital and operating cost estimates for alleviating firing problems or meeting environmental emissions limits; and the New Plant Construction Cost Model provides capital cost estimates for new plant construction.

The CQE software will be tested and validated at ten different utility sites. Changes required as a result of the tests will be incorporated into the CQE.

3.2.3 Application of Process in Proposed Project

The sites involved in this project and a description of the activities planned for each site are as follows:

Coal Quality Development Center (CQDC)

The CQDC is a commercial-scale coal cleaning demonstration plant and research-oriented coal laboratory operated by CQ Inc., a wholly owned subsidiary of EPRI.

The CQDC is equipped with commercial-scale coal cleaning devices and can clean up to 20 tons of raw coal per hour. The cleaning devices consist of heavy-media

cyclones, concentrating tables, two-stage water-only cyclones, and froth flotation cells. The equipment will be configured into different arrangements during the demonstration to obtain four different degrees of coal cleanliness for each coal.

The specific objectives of the demonstration at the CQDC are to: (1) provide C-E or B&W with 20-ton representative samples of a medium-cleaned coal and a deep-cleaned coal for combustion characterization, (2) demonstrate coal cleanability, (3) trace the general movement of coal throughout the cleaning plant, (4) develop design parameters for new plants, or retrofit circuits for existing plants, (5) determine if any special problems exist in cleaning particular coals, (6) configure particular design and/or operations problems, (7) develop methods to improve unit operations, and (8) develop capital and operating cost estimates for commercial coal cleaning plants.

University of North Dakota's Energy and Environmental Research Center (UNDEERC)

At UNDEERC, a drop tube furnace system will be utilized to determine coal devolatilization yields, nitrogen release efficiencies, and char combustion kinetic parameters.

In addition to the drop tube furnace tests, an analysis of the mineral matter of 19 coals will be performed using a computer-controlled scanning electron microscope.

The specific objectives of the demonstration at UNDEERC are to (1) develop a quicker and less expensive test for deriving ash deposition data and model inputs, (2) determine a better fundamental understanding of ash deposition processes, and (3) develop correlations with other testing.

C-E's Fireside Performance Test Facility

At C-E's Fireside Performance Test Facility, 20 test coals will be characterized in a nominal 4 million Btu/hr test furnace. The test furnace contains waterwall test panels, located in the radiant section of the furnace, which will be used to study the effect of ash slagging, and four banks of air-cooled probes, located in the convection section, which will be used to simulate boiler superheater tubes in order to evaluate convective pass ash deposition.

The specific objectives of the demonstration at the Fireside Performance Test Facility are to (1) provide quantitative data on key performance characteristics of the test coals, (2) provide direct comparison between the performance of different quality coals, and (3) provide a basis for correlation with fundamental fuel properties.

B&W's Small Boiler Simulator

B&W's Small Boiler Simulator is a 6 million Btu/hr wall-fired vertical furnace that simulates the characteristics of B&W's front wall, cyclone equipped coal-fired boilers. Three coals will be tested in this simulator as part of the proposed demonstration.

A limestone or silica feed system consisting of a storage facility, a solids feed system, and measurement and control systems will be added to the simulator. This system will be used if the as-received coal is not suitable for cyclone-furnace firing.

The specific objectives of the demonstration of B&W's Small Boiler Simulator are similar to those at C-E's Fireside Performance Test Facility, except that they will be applicable to cyclone-fired boilers rather than tangentially-fired boilers.

Utility Host Sites

The host boilers for the field tests include Alabama Power Company's tangentially-fired Gaston Unit 5, Mississippi Power Company's wall-fired Watson Unit 4, Northern States Power Company's cyclone-fired King Unit 1, Public Service Company of Oklahoma's tangentially-fired Northeastern Unit 4, Penelec/NYSEG's wall-fired Homer City Unit 2, and Duquesne Light's tangentially-fired Cheswick Unit. These differently fired boilers represent the majority of utility boilers in operation in the United States.

The specific objectives of the demonstrations at the utility host boiler sites are to (1) evaluate full-scale utility pulverizer, boiler, and precipitator operation and performance; and (2) demonstrate the environmental and performance benefits of pre-combustion coal cleaning on full-scale utility units.

3.3 General Features of the Project

3.3.1 Evaluation of Developmental Risk

As with any new technology there is some risk. The Coal Quality Expert System will essentially be a composite of existing computer models as shown in Figure 3. Data collection and analysis is designed to complete the necessary coal cleaning and combustion characterization work needed to enhance and validate EPRI's Coal Quality Information System (CQIS) and Coal Quality Impact Model (CQIM) which has been under development for several years. The parameters used in these models will be confirmed through the combustion tests or the parameters can be adjusted based on test results. This will insure that the models accurately represent the actual impacts that various coals have on boiler operation. Based on the above and the fact that this demonstration model will be a composite of proven, existing models, a low-risk level has been assigned to this project.

3.3.1.1 Similarity of the Project to Other Demonstration/ Commercial Efforts

The work performed during the demonstration is similar to much work previously performed and presently being performed at the CQDC and by C-E for the DOE and EPRI. This work includes:

- Development of Coal Cleaning Plant Performance and Economic Simulator, September 1989 to August 1992
- Thirty coal cleaning characterizations from 1981 to present
- Ohio Coal Cleanability Characterizations, January to December 1988
- Fine Coal Cleaning Process Evaluation, January to August 1989
- Combustion Characterization of Beneficiated Coal-Based Fuels, March 1989 to April 1992
- Combustion Characterization of EPRI Coal Cleaning, September 1984 to September 1988
- Combustion and Gasification Characteristics of Chars from Four Commercially Significant Coals of Different Rank

However, there is no known effort, other than this project, to develop a comprehensive, computer-based system to accurately predict the impact of coal characteristics on boiler operation that is applicable to such a broad range of coals and boilers.

3.3.1.2 Technical Feasibility

Significant coal cleaning and pilot-scale combustion data have already been collected under EPRI Funding. EPRI has developed a computerized CQIS that contains detailed coal quality data on 60 raw coals and 71 clean coals. This data base will be expanded to include the 24 coals (10 raw coals and 14 clean coals) studied during this project. EPRI has also made substantial progress in developing the CQIM for evaluating the performance and economic impacts of coal quality in existing power plants which is the most comprehensive fuel analysis program available to the industry. Thus, a portion of the CQE has already been developed and continued development should pose no unusual problems.

Although a major cleaned coal market is only beginning to develop, the technologies for cleaning coals already exist and are being applied by coal producers. Over the past eight years, the CQDC has produced cleaned coals at demonstration scale using proven technology. The proposed demonstration will include the use of the CQDC to prepare cleaned coals from at least eight additional coals to expand the database on this scale of production.

The cleaned coals to be used for bench- and pilot-scale testing will be produced at the CQDC using equipment configurations previously developed to represent advanced processes suitable for electric utility fuels. Adjustments in the equipment configurations will be made to match the processing of the raw coals versus the desired product coals. The coal to be used for field testing will be cleaned in commercial coal cleaning facilities.

3.3.1.3 Resource Availability

Adequate resources are available for this program.

The project will not increase the host boiler's requirements for major resources such as coal and water and will not generate any additional waste products, such as wastewater and ash. In addition, plant electrical requirements will be minimal.

The operating labor and infrastructure are in place at all facilities, except for field test contractors, who normally are hired on a per-test basis.

This program involves fully operational test facilities, commercial coal cleaning facilities, and electric power generating stations with appropriate facilities and scheduling flexibility to accommodate this project.

Adequate commitments have been obtained by the co-funders to cover their shares of the estimated project costs.

3.3.2 Relationship Between Project Size and Projected Scale of Commercial Facility

The purpose of the proposed project is to develop a computer-based analytical program that will enable industrial coal users and electric utilities to select the best quality fuels for optimum plant performance and cost that will meet environmental emission requirements. The CQE will combine and upgrade several existing computerized models and will add an expert system. The goal is to improve the cost effectiveness of reducing the emissions of sulfur oxides (SO_x), particulate matter, and other pollutants.

Data for the CQE will be obtained from bench- and pilot-scale combustion testing and then evaluated and correlated to full-scale combustion testing.

Based on the above, there will be no scale-up because the CQE model data will already be based on full-scale combustion testing up to 950 MW. Therefore, the demonstration is expected to prove the applicability of the CQE expert system without further demonstration.

3.3.3 Role of the Project in Achieving Commercial Feasibility of the Technology

Recent studies have indicated that significant economic and environmental benefits are derived from improved coal cleaning; however, the current state of knowledge requires detailed large-scale testing to completely assess the commercial viability of cleaning a particular coal. Industry currently does not have the capability to rapidly and reliably predict the performance of cleaned coals without extensive and costly studies. Therefore, the need for quick, inexpensive, and reliable tests which can be used to assess the commercial impacts of coal cleaning is vital to the coal and utility industry. The proposed project will develop and demonstrate an expert system based on simple techniques, such as bench-scale determination of fuel properties, which will allow industry to predict with confidence the overall impacts of coal quality on plant operations and costs that will meet environmental emission requirements.

The CQE expert system will be a composite of existing computer models that have been proven. The major task in formulating the expert system will be to make the individual models compatible and provide a communication link between each model.

To test the CQE software and validate the technical correctness of its output, a series of 10 utility sites will be employed for pre-release testing.

3.3.3.1 Applicability of the Data to be Generated

The various demonstration sites will be fully instrumented to produce accurate and reliable data. Standard published industry standards and test methods will be used as applicable.

During characterization and cleaning at the CQDC, extensive data will be acquired to characterize operation, efficiency, and economics. The data that will be acquired includes:

- Raw coal analysis and flow rate
- Cleaned coal analysis and flow rate
- Waste analysis and flow rate
- Consumption of water, electricity and chemicals

The data will be acquired by collecting solids samples at the inlets and outlets of all unit operations. Devices will be provided to measure the flow rate and density of process slurries.

Minicomputers and mainframe computers will be used to process data.

C-E's drop tube furnace is equipped with a gas analysis system consisting of various type analyzers for NO_2, O_2, SO_2, CO, and CO_2. C-E's Fireside Performance Test Facility is fully instrumented and equipped with an automated data acquisition system to monitor and record all fuel and air inputs accurately. Cooling flows and temperatures are measured to obtain mass and energy balances around the furnace.

At B&W's Small Boiler Simulator, coal characteristics such as unburned combustibles; fly ash loading; cyclone temperature; and gaseous emissions such as O_2, NO_x, CO, and SO_2, will be obtained and recorded by the data acquisition system. The performance of the six utility steam generators will be characterized by acquiring data on base coal and cleaned coal. These data will include:

- Steam temperature, pressures, and flow rates
- Coal analysis and flow rate
- Air temperatures and flow rate

- Flue gas temperatures
- Ash analysis and flow rates
- FGD sludge and analysis and flow rate
- Stack emission concentrations
- Auxiliary equipment power

The power plant data will be acquired using calibrated thermocouples, pressure gauges, and flow meters. Coal, ash, and sludge analyses will be performed using standard industry procedures. Stack emissions will be determined by standard Environmental Protection Agency methods for SO_x and NO_x particulates.

The results of the bench-scale, pilot-scale and field tests will be incorporated into standard boiler performance evaluation techniques to predict the impacts of coal cleaning on full-scale commercial boilers. The performance of the baseline coals will be modeled for comparison with the cleaned coals. This data will be used to expand EPRI's CQIS and CQIM.

3.3.3.2 Identification of Features that Increase Potential for Commercialization

The proposed project will result in the expansion of EPRI's CQIS and CQIM and the development of a CQE which will permit utilities to fully evaluate different coals and different levels of cleaning on specific coals without expensive field testing. This will enable the utilities to purchase the lowest cost clean coals which are best suited to their specific requirements and will hasten the commercial application of coal cleaning technologies.

Coal cleaning equipment is commercially available and consists of equipment such as cyclones, concentrating tables, froth flotation cells, screens, feeders, and conveyors.

Commercialization of coal cleaning technologies will be aided by:

- The environmental benefits of simultaneously removing SO_2 emissions by 20% and reducing ash generation by as much as 50%
- Lowering utility plant capital, operating, and maintenance costs
- Reducing utility plant wastes
- Reducing equipment space requirements
- Reducing fuel transportation costs
- Eliminating boiler derating
- Using commercially available equipment

- Proving the technology on six different utility boilers
- Availability of the Coal Quality Expert computer system which will give coal burning utilities a quick and inexpensive analysis of the advantages of commercially available cleaned coal as it relates to total plant performance, economics, and emission reductions of SO_2, NO_x, and particulates.

Commercialization of the Coal Quality Expert system will be aided by:

- Validation of the expert system logic and its ability to generate useful information to utilities quickly and inexpensively regarding total plant performance, economics, and emission reductions.
- Exposure of the system to numerous participating utilities.
- Implementation of the CQE on mini-computers which are widely available at U.S. utility, industrial and potential export market locations.

The success of this program will allow industry to assess with confidence the impacts of coal quality and will advance the commercialization of coal cleaning. As such, coal cleaning is expected to make further in-roads into the new and retrofit utility boiler market.

3.3.3.3 Comparative Merits of Project and Projection of Future Commercial Economics and Market Acceptability

Advanced coal cleaning technology exists today and its increased use may permit utility coal plant operation without the use of expensive flue gas desulfurization equipment. Therefore, the use of cleaned coal may be attractive to new coal plant projects and in retrofitting oil or gas-fired units to utilize pulverized-coal or coal-water slurries.

Coal cleaning not only reduces the sulfur content of coal, but also reduces coal impurities by as much as 50%, with resulting reductions in transportation, power plant operation, waste disposal, and maintenance costs.

Economic comparisons of intensively cleaned coal usage to baseline coal usage in new, coal-fired electric utility plants show that an average savings of 29% can be expected in the area of coal transportation, 28% in the area of flue gas desulfurization, 21% in the area of power plant waste disposal and power plant operating costs, and 2.5 mills/kwh in overall revenue requirements.

The cost for coal cleaning is estimated to be 12.4% over the cost of run-of-mine coal and is included in the overall revenue figure stated above. The reason for the decrease in revenue requirements is that the cleaning plant capital and operating cost increases are significantly less than the utility plant cost savings.

The use of the CQE will allow utilities to select the best clean coals for their specific boilers by using a computer based system rather than through engineering studies and field testing.

4.0 ENVIRONMENTAL CONSIDERATIONS

The PON requires that upon award of financial assistance, the Participant will be required to submit the environmental information specified in Appendix J of the PON. This detailed site- and project-specific information will be used as the basis for site-specific NEPA documents to be prepared by DOE for the selected project. Such NEPA documents shall be prepared, considered, and published in full compliance with the requirements of 40 CFR 1500-1508 and in advance of a go/no-go decision to proceed beyond preliminary design. Federal funds from the CCT Program will not be provided for detailed design, construction, operation and/or dismantlement until the NEPA process has been successfully completed.

5.0 PROJECT MANAGEMENT

5.1 Overview of Management Organization

The project will be managed by CQ Inc. and C-E. A Project Manager from CQ Inc. has been assigned to this project along with an Assistant Project Manager from C-E. The CQ Inc. Project Manager will be the principal contact with DOE for matters regarding the administration of the agreement.

The DOE Contracting Officer will be responsible for all contract matters and the DOE Contracting Officer's Technical Representative (COTR) will be responsible for technical liaison and monitoring of the project.

A Technical Advisory Panel comprising personnel from EPRI, DOE, the project organizations, academia, and industry who are experts in the fields of coal cleaning, coal combustion, and computer simulation, will be formed to assist the Project Team.

5.2 Identification of Respective Roles and Responsibilities

DOE

The DOE shall be responsible for monitoring all aspects of the project, and for granting or denying all approvals required by this Agreement. The DOE Contracting Officer will be the authorized representative of the DOE for all matters relating to the Cooperative Agreement.

The DOE Contracting Officer will appoint a Contracting Officer's Technical Representative (COTR) who will be the authorized representative for all technical matters and will have the authority to issue "Technical Advice" which may:

- Suggest redirection of the Cooperative Agreement effort, recommend a shifting of work emphasis between work areas or tasks, and suggest pursuit of certain lines of inquiry, which assist in accomplishing the Statement of Work.

- Approve the technical reports and technical information required to be delivered by the Participant to the DOE under the Cooperative Agreement.

The DOE COTR does not have the authority to issue any technical advice which:

- Constitutes an assignment of additional work outside the Statement of Work.
- In any manner causes an increase or decrease in the total estimated cost, or the time required for performance of the Cooperative Agreement.
- Changes any of the terms, conditions, or specifications of the Cooperative Agreement.
- Interferes with the Participant's right to perform the terms and conditions of the Cooperative Agreement.

All technical advice shall be issued in writing by the DOE COTR.

Participant

The Participant (C-E and CQ Inc.) will be responsible for all aspects of project performance under this Cooperative Agreement as set forth in the Statement of Work.

The Participant's Project Manager will be the authorized representative for the performance of all work to be performed under this Cooperative Agreement. He will be the single authorized point of contact for all matters between the Participant and DOE. The Participant will interrelate between the government and all other project sponsors as shown in Figure 4, Project Organization Chart.

In addition to the responsibilities stated above, C-E and CQ Inc. will perform other project tasks. C-E will perform bench-scale and pilot-scale testing for pulverized coal applications, provide expertise in boilermodeling, simulation, and evaluation and assist in the field testing effort. CQ Inc. will perform coal cleaning tests, assist in the final development of the CQE, and disseminate the technology to industry.

Others participating in the project include Babcock and Wilcox Company, Electric Power Technologies, Inc., Black and Veatch, Expert-EASE Systems, Inc., the University of North Dakota's Energy and Mineral Research Center, Alabama Power Company, Mississippi Power Company, Northern States Power

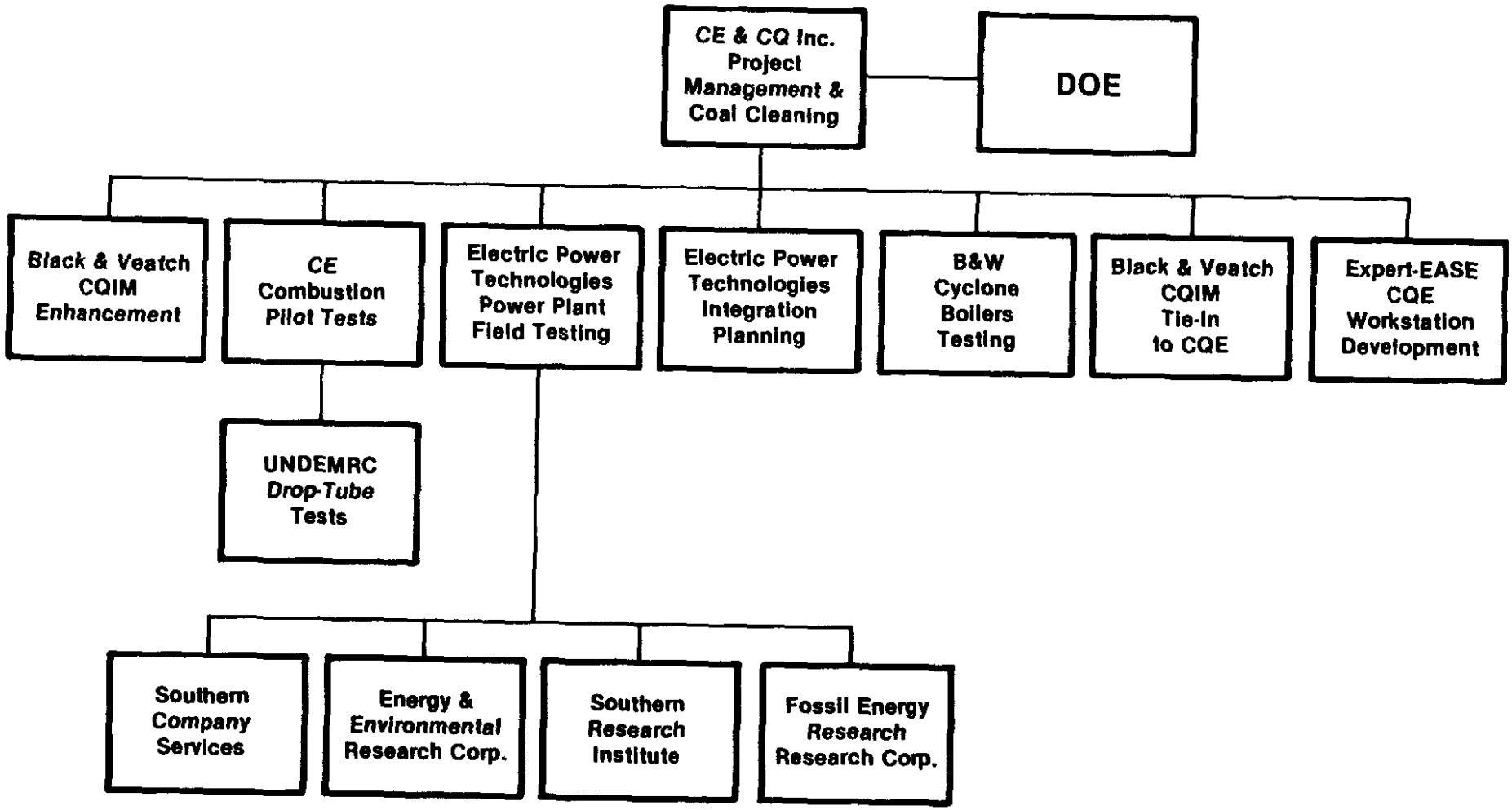


FIGURE 4. PROJECT ORGANIZATION CHART.

NO./19,366

Company, Public Service Company of Oklahoma, Pennsylvania Electric Company, New York State Electric & Gas Corp. and Duquesne Light Company.

Babcock and Wilcox (B&W) will perform bench- and pilot-scale combustion testing on coals fired in cyclone boilers and will assist in the field testing of B&W-designed boilers.

Electric Power Technologies, Inc. (EPT), will manage the field testing and be involved in disseminating field test data to the other project participants. EPT will be assisted by Southern Company Services, Energy and Environmental Research Corp., Southern Research Institute, and Fossil Energy Research Corp.

Black and Veatch is the developer of EPRI's CQIM and will be responsible for its improvement and expansion. Black and Veatch will perform numerous boiler simulations and will be involved in the development and testing of the CQE Workstation.

Expert-EASE Systems, Inc. (EES) will provide the software and services for developing an interface for the CQE and for designing and developing the Coal Quality Expert System knowledge base.

The University of North Dakota's Energy and Mineral Research Center will be a subcontractor to C-E and will perform special bench-scale combustion tests.

Alabama Power Company, Mississippi Power Company, Northern States Power Company, Public Service Company of Oklahoma, Duquesne Light and Penelec/NYSEG will provide host sites.

Coal Quality Hotline

CQ Inc. will provide a new hotline telephone service for all coal quality related problems. Problems and questions will be addressed by CQ Inc. or other project team members, as required. This service will not only assist coal users, but will also provide useful information for developing CQE Expert-System software and in validating the CQIM Expert-System software.

Coal Quality Roundtable

A Coal Quality Roundtable will be formed to discuss current and emerging industry issues and to identify user profiles and objectives for the CQE and Field Testing Guidelines. Technical achievements and results from the testing tasks of the

project will be discussed and will provide feedback on the initial software and workstations. The roundtable will include representatives from the DOE, EPRI, CQ Inc., CE, project contractors, invited industry and prospective users. Four roundtable meetings are planned during the 42-month project.

5.3 Summary of Project Implementation and Control Procedures

All work to be performed under the Cooperative Agreement will fall under one phase.

Budget periods will be established to provide DOE and the participants with decision points at key milestones. Consistent with Public Law No. 99-190, DOE will obligate funds sufficient to cover its share of the cost of each budget period. Throughout the course of this project, reports dealing with the technical, management, cost, and environmental monitoring aspects of the project will be prepared by CQ Inc. and provided to DOE.

5.4 Key Agreements Impacting Data Rights, Patent Waivers and Information Reporting

The key agreements with respect to intellectual property are as follows:

- Standard technical data provisions are included, giving the Government the right to have delivered, all technical data first produced in the performance of the Agreement.

- CQ is expected to be granted a release of copyright from DOE for the software to be developed under the Cooperative Agreement in order to enhance the marketability of the software. DOE and its laboratories will have a free license to use the software for governmental purposes.

5.5 Procedures for Commercialization of the Technology

Commercialization of the CQE system will be enhanced by selecting ten utilities to participate in testing and validation of the expert system. The criteria for selection of the ten sites are:

- Coal type
- Willingness to devote appropriate resources
- National demographics
- Type of applications

o Availability of facilities

Each of the ten test sites will receive user support from the computer software architects depending upon the specific type of assistance required. Feedback from the test sites will be of two general types: (1) identification of actual problems or errors with CQE that must be repaired for the expert system to function properly; and (2) specific circumstances that the test user would like CQE to accommodate. The first type of feedback will be automatically incorporated into the software. The second type of feedback will be evaluated to determine the technical feasibility of the desired modification as well as the budget and schedule implications. The test sites will also provide feedback on the user's instruction manuals to run and interpret the program results.

An effective technology transfer program will accelerate the commercialization of the CQE. It will define the needs of prospective users, provide results and case histories from the technical tasks of the demonstration program, and maintain industry awareness of this project.

A trimester newsletter will be produced and mailed to coal-burning utilities, industrial coal users and architect engineers. The newsletter will build user interest in CQE and provide an avenue for industry feedback to the program.

A project overview brochure will be produced for visitors and for distribution at conferences, exhibits, and meetings. It will explain the tasks which make up the demonstration project, plans for technical integration and expected value.

For demonstration and training purposes, a mock-up of the CQE will be built and contain the initial CQIS, CQIM, and supporting software. It will be expanded and enhanced at each major milestone in the demonstration project, and it will be used as a display at popular coal preparation and power generation conferences.

Other organizations, such as cleaning plant designers and constructors, equipment manufacturers, coal producers, shippers, industrial coal users and the electric utilities will support and be actively involved in commercialization. As more and more cleaned coal is used, more and more operating data will be obtained, which will further help to expand the market.

6.0 PROJECT COST AND EVENT SCHEDULING

6.1 Project Baseline Costs

The total estimated cost for this project is $17,382,258. The Co-Participants (C-E and CQ, Inc.) and the government responsibility for the costs of this project are as follows:

	Dollar Share	Percent Share
TOTAL PROJECT		
Government	$8,691,129	50.0%
Co-Participants	$8,691,129	50.0%

The Co-Participants intend to fund their $8,691,129 cost share by the following cash or in-kind contributions:

EPRI	$5,931,052	Penelec/NYSEG	$115,000
Test Site Coal Donations	335,000	Test Site Field Unit Modifications	320,000
Test Site Coal Cost Differentials	1,548,000	Southern Company Services	117,000
Babcock & Wilcox	25,000	Black & Veatch	300,077
TOTAL		$8,691,129	

At the beginning of each budget period, DOE will obligate funds sufficient to pay its share of the expenses for that budget period.

6.2 Milestone Schedule

As shown in Figure 5, the overall project will be completed in 42 months after award of the Cooperative Agreement. Coal cleanability characterization and pilot-scale combustion tests will start six weeks after the beginning of the project and will last for thirty-one and one-half and thirty-four and one-half months respectively. The utility boiler field testing will begin one month after the beginning of the project and continue for thirty four months. The CQIM will be completed and the CQE specification will be developed starting one month after the project starts and be completed in seventeen months. Actual development of the CQE will start in the sixteenth month and take fifteen months. CQE testing and validation will start two years after the beginning of the project and last for eighteen months.

6.3 Recoupment Plan

In response to the stated policy of the DOE to recover an amount up to the Government's contribution to the project, the Participant has agreed to repay the Government in accordance with the Recoupment/Repayment Plan included in the Cooperative Agreement.

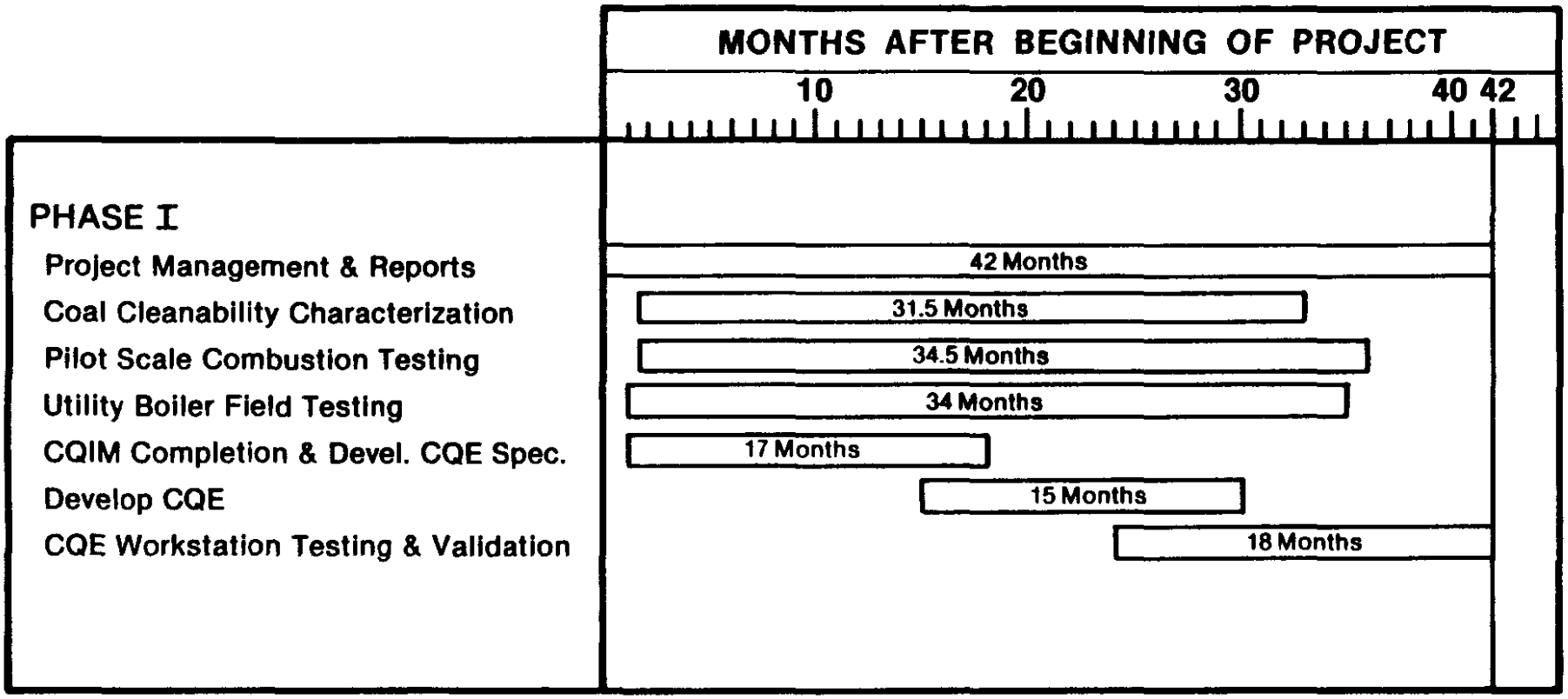


FIGURE 5. OVERALL PROJECT SCHEDULE FOR DEVELOPMENT OF A CQE.

NO./19,367