Distribution Category UC-101

Comprehensive Report to Congress Clean Coal Technology Program

Demonstration of Pulse Combustion in an Application for Steam Gasification

A Project Proposed By:
ThermoChem, Inc.

U.S. Department of Energy
Assistant Secretary For Fossil Energy
Office of Clean Coal Technology
Washington, D.C. 20585

October 1992

September 4, 2001

Monte,

The following reports were obtained from NTIS and should be added to the Compendium. There will be two or three more packages of about this size to send you all of the reports we have. I suggest that once they have all been scanned we add a single item to the What's New portion of the Home Page that says something like "X new reports now available in electronic format". Then on the What's New page itself we could list each of the reports with the appropriate link. Sound reasonable?

1) Comprehensive Report to Congress, Clean Coal Technology Program, Demonstration of Pulse Combustion in an Application for Steam Gasification, Oct. 1992 (DE93000959)
2) Passamaquoddy Technology, L.P., Interim Technical Report, March 1992 (DE92019868)
3) The Encoal Project: Initial Commercial Shipment and Utilization of Both Solid and Liquid Products. Topical Report, March 1995 (DE95009735)
4) Encoal Mild Coal Gasification Project Public Design and Construction Report, December 1994 (DE95009711)
5) Encoal Mild Coal Gasification Project. Annual Report, October 1990 – September 1991, February 1992 (DE92001273)
6) Encoal Mild Coal Gasification Project. Annual Report, October 1993 (DE94012274)
7) Encoal Mild Coal Gasification Demonstration Project. Annual Report, October 1993 – September 1994, March 1995 (DE95009710)
8) Demonstration of an Advanced Cyclone Coal Combustor with Internal Sulfur, Nitrogen, and Ash Control for the Conversion of a 23 MMBtu/Hr Oil Fired Boiler to Pulverized Coal. Final Technical Report, March, 1987 – February 28, 1991, August 1991 (DE92002587)
9) Demonstration of an Advanced Cyclone Coal Combustor with Internal Sulfur, Nitrogen, and Ash Control for the Conversion of a 23 MMBtu/Hr Oil Fired Boiler to Pulverized Coal. Final Technical Report, Appendices, August 1991 (DE92002588)
10) Desulfurization of Flue Gas by the Confined Zone Dispersion Process. Final Report, October 1989 (DE90005529)
11) Environmental Monitoring Plan, LIFAC Sorbent Injection Desulfurization Demonstration Project

Note that report number 8 still has the NTIS cover and back page. Please don't scan either of these pages.

All of these reports (with the exception of 11) are listed on the Compendium with the NTIS number referenced. If you have any trouble locating where to put them in the Bibliography, let me know.

Thanks,
Mark

TABLE OF CONTENTS

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

Public Law No. 101-121 provided $600 million to conduct cost-shared Clean Coal Technology (CCT) projects to demonstrate technologies that are capable of replacing, retrofitting, or repowering existing facilities. Toward that end, a Program Opportunity Notice (PON) was issued by the Department of Energy (DOE) in January 1991. This PON solicited proposals to demonstrate innovative, energy-efficient technologies capable of being commercialized in the 1990s. These technologies were to be capable of (1) achieving significant reductions in the emissions of sulfur dioxide and/or nitrogen oxides from existing facilities to minimize environmental impacts, such as transboundary and interstate pollution, and/or (2) providing for future energy needs in an environmentally acceptable manner.

In response to the PON, 33 proposals were received by DOE in May 1991. After evaluation, nine projects were selected for award. These projects involved both advanced pollution control technologies that can be "retrofitted" to existing facilities and "repowering" technologies that not only reduce air pollution but also increase generating plant capacity and extend the operating life of the facility.

One of the nine projects selected for funding is a project proposed by ThermoChem, Inc. entitled "Demonstration of Pulse Combustion in an Application for Steam Gasification of Coal" (PCASGC). This project will provide a commercial demonstration of the Manufacturing and Technology Conversion International, Inc. (MTCI) process for producing medium-Btu gas by steam gasification of coal using pulse combustion to provide the endothermic heat of reaction.

The PCASGC demonstration project involves the construction of a 428 ton/day (300 ton/day dry basis) fluidized bed, coal gasification unit. The gasifier will use indirect heating to provide the energy required for the steam-coal reaction occurring in the gasifier. The heat will be added to the gasifier by means of bundles of heat exchanger tubes submerged in the fluidized bed. The hot gas for the indirect heating will be generated by pulse combustion of a portion of the product gas, with the heat exchanger tubes acting as the resonance tubes for the pulse combustor. Pulse combustion increases heat transfer rate by a factor of 3 to 5, thus greatly reducing the heat transfer area required in the gasifier. Product gas, consisting predominantly of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4), is cooled and scrubbed to remove ammonia and hydrogen sulfide. The cleaned product gas which is not sent as fuel to the pulse combustor will be used to produce electric power.

Although not part of the demonstration project and not receiving any DOE cost-share funds, a subbituminous coal upgrading (K-Fuel·) plant will be constructed adjacent to the MTCI gasifier. By-product steam from the gasifier will be exported for use by the K-Fuel· plant, and high-temperature, high-pressure by-product water from the K-Fuel· plant will provide process steam and boiler feed water for the gasifier.

The PCASGC Demonstration project will be constructed at Caballo Rojo, Inc.'s Caballo Rojo Mine, located south of Gillette, Wyoming. Coal from the Caballo Rojo Mine will provide the feed coal to the gasifier.

This demonstration will be conducted over 48 months. Project activities include design and engineering, construction, start-up, and operations.

The total project cost is $37,333,474. DOE's share is $18,666,737. The co-funder is ThermoChem, whose share is $18,666,737. Operations are scheduled to begin in 1994, and the project is scheduled for completion in 1996.

2.0 INTRODUCTION AND BACKGROUND

2.1 Requirement for a Report to Congress

On October 23, 1989, Congress made available funds for the fourth clean coal demonstration program (CCT-IV) in Public Law 101-121, "An Act Making Appropriations for the Department of the Interior and Related Agencies for the Fiscal Year Ending September 30, 1990, and for Other Purposes" (the "Act"). Among other things, this Act appropriates funds for the design, construction, and operation of cost-shared, clean coal projects to demonstrate the feasibility of future commercial applications of such "... technologies capable of retrofitting or repowering existing facilities ...." On November 5, 1990, Public Law 101-512 was signed into effect, requiring "a general request for proposals for CCT-IV by no later than February 1, 1991, and to make selections of projects for negotiations no later than eight months after the date of the general request for proposals."

Public Law 101-121 appropriates a total of $600 million for executing CCT-IV. Of this total, $7.2 million are required to be reprogrammed for the Small Business Innovative Research Program (SBIR), and $25.0 million are designated for Program Direction Funds for costs incurred by DOE in implementing the CCT-IV program. The remaining $567.8 million was available for award under the PON.

The purpose of this report is to comply with Public Law 101-512, which directs the Department to prepare a full and comprehensive report to Congress on each project selected for award under the CCT-IV program.

2.2 Evaluation and Selection Process

DOE issued a draft PON for public comment on November 20, 1990, receiving a total of 19 responses from the public. The final PON was issued on January 15, 1991, and took into consideration the public comments received on the draft PON. DOE received 33 proposals in response to the CCT-IV solicitation by the May 17, 1991, deadline.

2.2.1 PON Objective

As stated in PON Section 1.2, the objective of the CCT-IV solicitation was to obtain "proposals to conduct cost-shared Clean Coal Technology projects to demonstrate innovative, energy efficient, economically competitive technologies that are capable of being commercialized in the 1990s. These technologies must be capable of (1) retrofitting, repowering or replacing existing facilities while achieving significant reductions in the emissions of sulfur dioxide and/or the oxides of nitrogen and/or (2) providing for future energy needs in an environmentally acceptable manner."

2.2.2 Qualification Review

The PON established seven Qualification Criteria and provided that, "in order to be considered in the Preliminary Evaluation Phase, a proposal must successfully pass Qualification." The Qualification Criteria were as follows:

(a) The proposed demonstration project or facility must be located in the United States.

(b) The proposed demonstration project must be designed for and operated with coal(s) from mines located in the United States.

(c) The proposer must agree to provide a cost-share of at least 50% of total allowable project costs, with at least 50% in each of the three project phases.

(d) The proposer must have access to, and use of, the proposed site and any proposed alternate site(s) for the duration of the project.

(e) The proposed project team must be identified and firmly committed to fulfilling its proposed role in the project.

(f) The proposer agrees that, if selected, it will submit a "Repayment Plan" consistent with PON Section 7.7.

(g) The proposal must be signed by a responsible official of the proposing organization, authorized to contractually bind the organization to the performance of the Cooperative Agreement in its entirety.

2.2.3 Preliminary Evaluation

The PON provided that a Preliminary Evaluation would be performed on all proposals that successfully passed the Qualification Review. In order to be considered in the Comprehensive Evaluation phase, a proposal must be consistent with the stated objectives of the PON and must contain sufficient information on finance, management, technical, cost, and other areas to permit the Comprehensive Evaluation described in the solicitation to be performed.

2.2.4 Comprehensive Evaluation

The Technical Evaluation Criteria were divided into two major categories: (1) the Demonstration Project Factors were used to assess the technical feasibility and likelihood of success of the project, and (2) the Commercialization Factors were used to assess the potential of the proposed technology to reduce emissions from existing facilities, as well as to meet future energy needs through the environmentally acceptable use of coal, and the cost effectiveness of the proposed technology in comparison to existing technologies.

The Cost and Finance Evaluation criteria were used to determine the business performance potential and commitment of the proposer.

The PON provided that the Cost Estimate would be evaluated to determine the reasonableness of the proposed cost. Proposers were advised that this determination "...will be of minimal importance to the selection..." and that a detailed cost estimate would be requested after selection. Proposers were cautioned that if the total project cost estimated after selection is greater than the amount specified in the proposal, DOE would be under no obligation to provide more funding than had been requested in the proposer's original Cost Sharing Plan.

2.2.5 Program Policy Factors

The PON advised proposers that the following program policy factors could be used by the Source Selection Official to select a range of projects that would best serve program objectives:

(a) The desirability of selecting projects that collectively represent a diversity of methods, technical approaches, and applications.

(b) The desirability of selecting projects in this solicitation that contribute to near-term reductions in transboundary transport of pollutants by producing an aggregate net reduction in emissions of sulfur dioxide and/or nitrogen oxides.

(c) The desirability of selecting projects that collectively utilize a broad range of U.S. coals and are in locations which represent a diversity of EHSS, regulatory, and climatic conditions.

(d) The desirability of selecting projects in this solicitation that achieve a balance between (1) reducing emissions and transboundary pollution and (2) providing for future energy needs by the environmentally acceptable use of coal or coal-based fuels.

(e) The desirability of selecting projects that provide strategic and energy security benefits for remote, import-dependent sites, or that provide multiple fuel resource options for regions which are considerably dependent on one fuel form for total energy requirements.

The word "collectively," as used in the foregoing program policy factors, was defined to include projects selected in this solicitation and prior clean coal solicitations, as well as other ongoing demonstrations in the United States.

2.2.6 Other Considerations

The PON stated that, in making selections, DOE would consider giving preference to projects located in states for which the rate-making bodies of those states treat the Clean Coal Technologies the same as pollution control projects or technologies. This consideration could be used as a tie breaker if, after application of the evaluation criteria and the program policy factors, two projects received identical evaluation scores and remained essentially equal in value. This consideration would not be applied if, by so doing, the regional geographic distribution of the projects selected would be significantly altered.

2.2.7 National Environmental Policy Act (NEPA) Compliance

As part of the evaluation and selection process, the Clean Coal Technology Program developed a procedure for compliance with the National Environmental Policy Act of 1969 (NEPA), the Council on Environmental Quality NEPA regulations (40 CFR 1500-1508), and the DOE guidelines for compliance with NEPA (52 FR 47662, December 15, 1987). DOE final NEPA regulations replacing the DOE guidelines were published in the Federal Register on April 24, 1992 (57 FR 15122). This procedure included the publication and consideration of a publicly available Final Programmatic Environmental Impact Statement (DOE/EIS-0146), issued in November 1989, and the preparation of confidential preselection project-specific environmental reviews for internal DOE use. DOE also prepares publicly available site-specific documents for each selected demonstration project as appropriate under NEPA.

2.2.8 Selection

After considering the evaluation criteria, the program policy factors, and the NEPA strategy as stated in the PON, the Source Selection Official selected nine projects as best furthering the objectives of the CCT-IV PON. These selections were announced on September 12, 1991, during a press conference.

3.0 TECHNICAL FEATURES

3.1 Project Description

ThermoChem will demonstrate the production of medium-Btu fuel gas by the MTCI PCASGC process. Feed to the gasifier will be Powder River Basin subbituminous coal from the Caballo Rojo Mine, which has almost 450 million tons of recoverable reserves. The site for the demonstration is the Caballo Rojo Mine near Gillette, Wyoming, as shown in Figure 1. The product fuel gas from the gasification plant will be utilized to generate electric power, either as a supplemental fuel in a nearby power plant or in an on-site gas turbine system constructed by Enserv, a subsidiary of Wisconsin Power & Light (WPL), using private funding. The by-product steam produced from the waste heat of the gasifier will be consumed by a subbituminous coal upgrading (K-Fuel·) facility which will be located adjacent to the gasifier. The K-Fuel· plant will be constructed and operated by Enserv strictly with private funding; no DOE cost-share funds will be used.

Locating the K-Fuel· plant next to the MTCI gasifier enhances the environmental performance and economics of the PCASGC demonstration project, because water from the K-Fuel· process can be used as boiler feed water for process steam generation, thus eliminating the need for water from other sources. Since this water is delivered to the gasifier at elevated temperature and pressure, a significant portion of the gasifier's process steam requirement can be provided by flashing this water. Any hydrocarbons recovered from this water are sent to the fluidized bed to be gasified. In addition to providing steam to the gasifier, the heat recovery system within the gasification facility will produce enough export high-pressure steam to supply the needs of the K-Fuel· upgrading process. Thus, the gasifier and K-Fuel· processes integrate well. Figure 2 is a block diagram showing how the PCASGC demonstration project interfaces with other facilities.

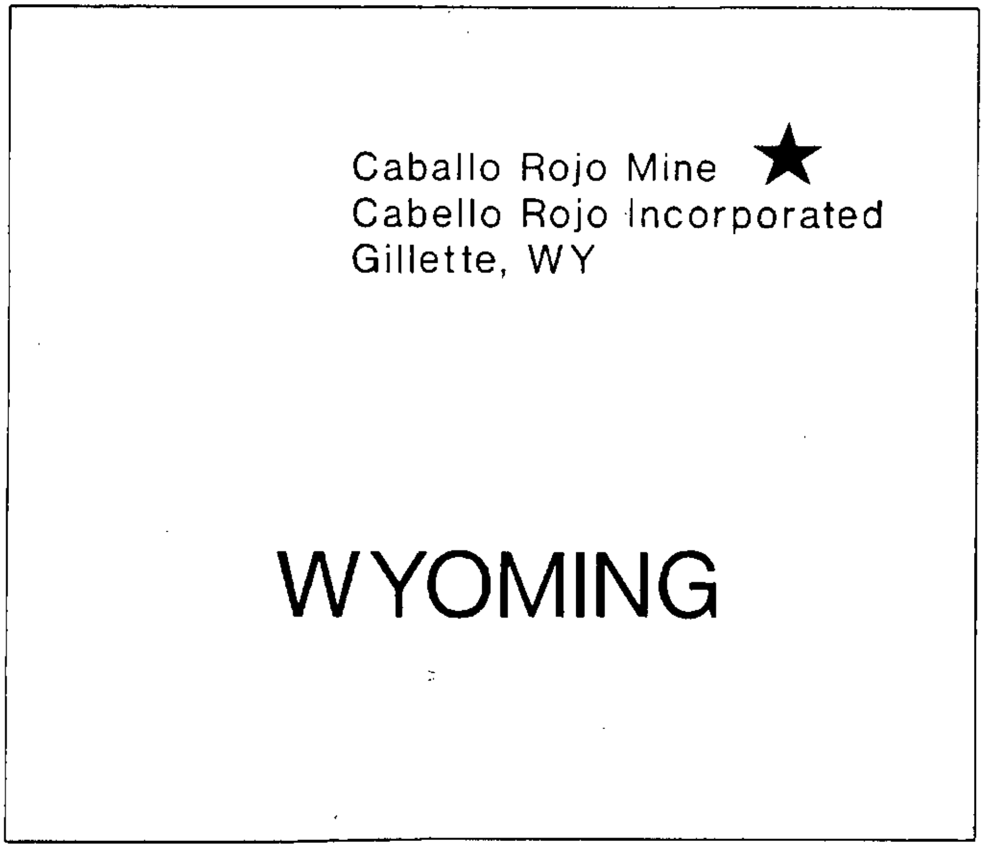

FIGURE 1. PCASGC DEMONSTRATION PROJECT LOCATION

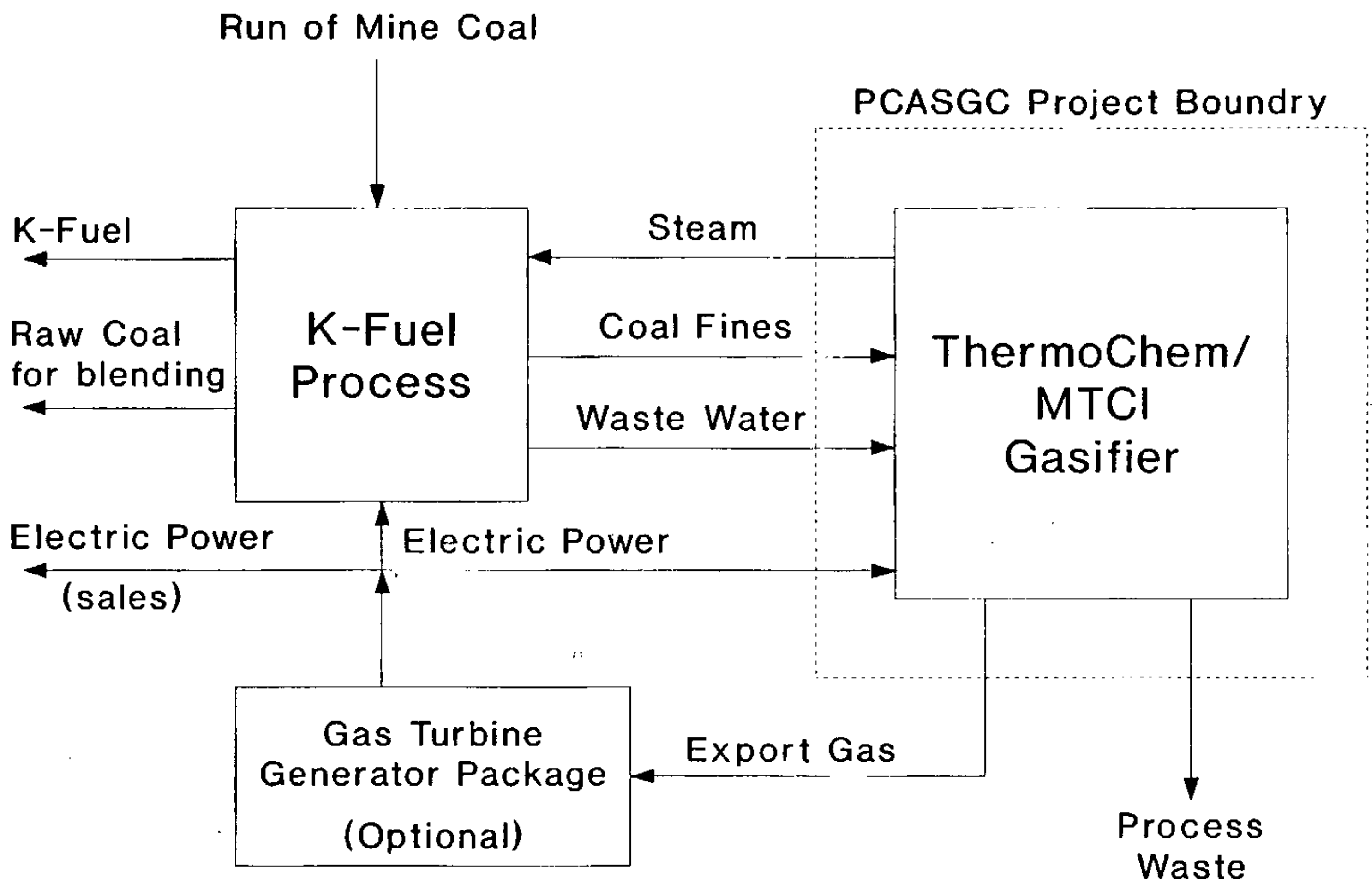

FIGURE 2. BLOCK DIAGRAM SHOWING INTERFACING OF PCASGC PROJECT WITH OTHER FACILITIES

3.1.1 Project Summary

Project Title:	Demonstration of Pulse Combustion in an Application for Steam Gasification of Coal
Proposer:	ThermoChem, Inc.
Project Location:	Caballo Rojo Mine Gillette, Wyoming Campbell County
Technology:	Indirectly heated coal gasification process using pulse combustion as the heat source
Application:	Production of medium-Btu fuel gas and by-product steam
Type of Coal Used:	Powder River Basin subbituminous coal
Product:	Low-sulfur, medium-Btu fuel gas
Project Size:	428 ton/day (300 ton/day on a dry basis)
Project Start Date:	September 1992
Project End Date:	August 1996

3.1.2 Project Sponsorship and Cost

Project Sponsor:	ThermoChem, Inc.	
Estimated Project Cost:	$37,333,474	
Estimated Cost Distribution:	Participant Share (%)	DOE Share (%)
	50	50

3.2 Pulse Combustion in an Application for Steam Gasification of Coal

3.2.1 Overview of Technology Development

Two technologies are incorporated into this demonstration project: pulse combustion and indirectly heated steam gasification of coal. The development of these technologies and their integration is described below.

Pulse combustion involves combustion-induced flow oscillations produced intentionally by the design of the equipment. The benefits of pulse combustion include enhanced heat release rates in the combustion chamber and increased heat transfer rates in the resonance tubes.

Pulse combustors can be divided into two general classes: those in which the pulsations occur naturally, due to combustion-induced instability, and those which require an external device, such as a spark plug or a flapper valve, to maintain the pulse combustion process. The combustor used in this project belongs to the first of these classes. This class of combustors, which can be referred to as self-induced or resonating-pulse combustors, can be divided further into three types, Helmholtz, Schmidt, and Rijke tube type combustors, depending upon the configuration of the combustor and the characteristics of the oscillations.

The pulse combustor type employed by the MTCI and ThermoChem equipment design is the Helmholtz configuration (see Figure 3). The basic Helmholtz configuration consists of an aerodynamic air inlet valve, a combustion chamber, and a tailpipe (or resonance tube). This combustor configuration is inherently reliable, because it has no moving parts (flapper valves). It is especially suitable for the combustion of coal and other solid fuels, since these fuels can quickly erode valve surfaces.

The efficiency of a coal-burning furnace depends upon the rate at which oxygen diffuses to the coal surface. During combustion, a boundary layer of products of combustion (water vapor and carbon oxides) builds up around the particle and acts as an oxygen diffusion barrier. This is particularly important as the coal particles burn and become smaller and more ash-laden, and the oxygen concentration in the surrounding gas decreases. In a Helmholtz pulse combustor, as the burning coal particles flow down the resonance tube, the amplitude of the oscillatory velocity increases and causes vigorous relative oscillatory motion between the burning particle and the surrounding gas. This causes the diffusion barrier around the burning particle to be swept away, thus permitting access of oxygen to the particle and resulting in high carbon burnout and a high heat release rate.

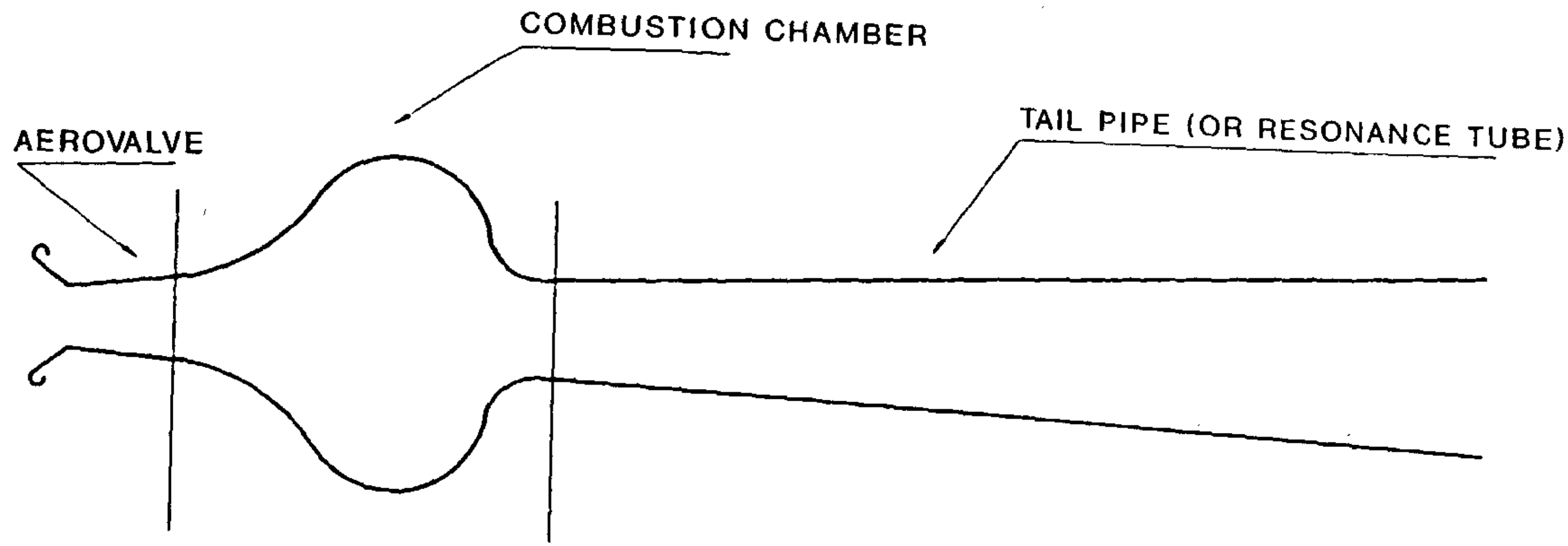

FIGURE 3. HELMHOLTZ-TYPE PULSE COMBUSTOR WITH AN AERODYNAMIC AIR INLET VALVE

In 1982, DOE's Pittsburgh Energy Technology Center (PETC) began actively pursuing the development and testing of coal-fired combustion systems for the residential, commercial, and industrial market sectors. Under a DOE contract, MTCI initiated the development of a new combustor, based on the principle of pulse combustion. The initial pulse combustor development program was conducted in three phases. Phase I included a review of the prior art on pulse combustion and the development of pulse combustor design concepts. This work indicated potentially favorable economics for replacement of oil- and gas-fired equipment with coal-fired pulse combustors. Work in Phase II indicated that pulse combustors for coal applications should be Helmholtz type (chamber and resonance tube) and should employ aerodynamic air inlet valves rather than the more common flapper valves. Phase III involved the fabrication and testing of a laboratory-scale pulse combustor (1 million Btu/hr firing rate) burning a coal-water mixture (CWM). The Phase III results showed that coal can be burned in a pulse combustor at heat release rates up to 10 times higher than those achieved in conventional burners.

Based on the success of the initial pulse combustor development program, MTCI initiated the development of a slagging pulse coal combustor for industrial retrofit applications and a smaller unit (100,000 Btu/hr) for residential applications, both under DOE sponsorship. Under the program for industrial retrofit applications, a slagging tandem pulse coal combustor system with dry coal fuel was developed and optimized at the laboratory scale (2 million Btu/hr). This unit was subsequently scaled up to a 3.5 to 5 million Btu/hr firing rate and tested extensively with CWM. Recently, the design and construction of a 15 million Btu/hr system was completed. In 1989, MTCI was awarded a DOE contract to fabricate, operate, and demonstrate a completely integrated and automated 5 to 6 million Btu/hr system for market evaluation.

One application for the use of pulse combustion is providing heat for the steam gasification of coal. Most commercial processes for coal gasification introduce oxygen into the gasifier and burn part of the coal to provide the heat needed by the process. The attractiveness of the in-situ heat transfer aspect of these partial-oxidation gasification processes has been their relative simplicity compared to the complexity and high cost of indirectly heated systems. Some indirectly heated systems require two vessels and complex solids circulation; other require large heat transfer areas due to poor heat transfer coefficients. The low heat transfer rate of conventional fire tubes used to indirectly heat fluidized-bed reactors is a result of the low heat transfer coefficient on the flue gas side of the fire tube; the heat transfer coefficient between the fire tube and the fluidized-bed material is reasonably high. In a pulse combustor, the flue gas side heat transfer coefficient is increased significantly, resulting in an increase in overall heat transfer rate by a factor of 3 to 5.

In conventional combustor and fire tube arrangements, essentially all the heat is released in the combustion chamber. Therefore, the highest temperature is at the inlet to the fire tubes. The temperature of the flue gas monotonically decreases along the length of the tube, as heat is transferred from the flue gas to the reactor. In pulse combustion, however, not all the fuel burns in the combustion chamber, and combustion persists for a significant length down the resonance tubes (fire tubes) in an oscillating flow field environment. Thus, for the same heat transfer duty, the inlet flue gas temperature to the resonance tubes is lower than in conventional fire tube systems. However, the continued heat release from burning fuel in the resonance tubes maintains a higher bulk flue gas temperature than in the conventional case. Thus, the use of a Helmholtz pulse coal combustor results in an appreciably enhanced convective heat transfer coefficient, a high heat flux, and a reduced surface area requirement.

An important benefit of an enhanced heat transfer rate is the ability of the reactor to support highly endothermic reactions, such as devolatilization and the carbon-steam reaction. Rapid heat transfer in the fluidized bed results in very high rates of devolatilization and pyrolysis. This, in turn, results in the formation of char particles that are extremely porous with high reactivity. High heat transfer rates are essential to support such endothermic reactions in an economically viable reactor with a reasonable throughput.

Several carbon consuming reactions occur in the gasifier, the two most important are:

$$C + H_2O = CO + H_2$$

$$C + CO_2 = 2CO$$

A third reaction of importance is the water-gas-shift reaction:

$$CO + H_2O = CO_2 + H_2$$

Generally, the steam-carbon reaction controls the rate at which carbon is consumed (gasified), and the water-gas-shift reaction determines the composition of the product gas.

MTCI's proprietary pulse-enhanced, indirect, steam gasification technology was first investigated under Phase I and Phase II DOE/SBIR grants during 1984-1986. Under Phase II of this DOE/SBIR grant, testing of the gasifier was limited to biomass feedstocks. In early 1987, Weyerhaeuser Paper Company expressed an interest in testing the MTCI gasifier using black liquor feedstocks.

Preliminary tests were conducted which verified the feasibility of the MTCI gasifier to process black liquor feedstocks safely and effectively. In order to further develop this technology for biomass waste gasification, including black liquor, MTCI secured funding from DOE, the Weyerhaeuser Company, and the California Energy Commission's Energy Technologies Advancement Program (ETAP). The objectives of these projects included process development and verification of the MTCI black liquor recovery technology, testing of a broad spectrum of biomass feedstocks under varying process conditions, and verification of gasifier scaleup to feed rates of 100-200 lb/hr. These projects were completed in early 1989 and yielded extremely successful results which confirmed the commercialization potential of the indirectly heated gasifier technology for biomass and waste gasification.

A series of process characterization tests, covering the temperature range of 1030°F to 1160°F, was conducted using a 67% solids-containing black liquor feedstock. Gasifier performance met or exceeded expectations during the test program which also included a 40-hour test run.

ThermoChem, MTCI, ESI, and Weyerhaeuser are fabricating and installing a 75 ton/day black liquor gasifier for Weyerhaeuser's New Bern, North Carolina, mill, supported in part by a DOE cooperative agreement. The New Bern project uses the same pulse combustor/heat exchanger module, except for the number of tubes, being used in the demonstration project; however, scaleup of the number of tubes is a critical element in the demonstration.

Over the last two years, MTCI has been testing various feedstocks for the indirectly heated gasification reactor. In addition to the early biomass feedstock, MTCI has now tested a wide variety of materials, including wastewater sludge, refuse derived fuel (RDF), lignite, subbituminous coal, and mild gasification char. All these tests were conducted using the gasification system located at MTCI's Santa Fe Springs, California, laboratory. The gasifier is rated at a nominal low-rank coal throughput of 15-30 lb/hr (as received) and approximately 40 lb/hr for other feedstocks. The gasifier is heated by means of heat exchanger tubes immersed in the fluidized bed. These tubes comprise the resonance component of the pulse combustor, which is fired using natural gas fuel.

The discussion above shows that both the pulse combustor and the indirectly heated fluidized-bed gasifier have undergone extensive development and are ready for demonstration.

3.2.2 Process Description

This project will demonstrate the MTCI fluidized-bed gasifier, which incorporates an innovative, indirect-heating process for the thermochemical steam gasification of coal to produce a hydrogen-rich, clean, medium-Btu fuel gas without the need for an oxygen plant. The indirect heat transfer is provided by the MTCI multiple resonance tube pulse combustor technology with the resonance tubes comprising the heat exchanger immersed in the fluidized-bed reactor. The high heat transfer coefficient (3 to 5 times greater than for indirectly heated gasifiers not using pulse combustion) exhibited by the MTCI multiple resonance tube pulse combustor minimizes the required heat transfer surface.

A simplified flow diagram of the MTCI gasifier is shown in Figure 4. Appropriately sized coal and steam are fed to the fluidized-bed gasifier. Steam, which is supplied from waste heat recovery, provides the fluidization gas for the fluidized bed. Immersed in the fluidized bed are a series of heat exchange tube bundles, which serve as resonance tubes for the pulse combustors. Part of the cleaned product gas from the gasifier is burned in the pulse combustors, and the hot flue gas passing through the heat exchange bundles provides the heat necessary to sustain the endothermic gasification reactions. After leaving the heat exchangers, the flue gas flows to a waste heat boiler, where steam is generated, and then to a stack.

The hot product gas from the gasifier goes first to a heat exchanger, where it superheats the gasifier process steam. It then passes through a cyclone for char removal and a waste heat boiler for steam generation. The cooled gas is then scrubbed with water in a venturi scrubber to remove ammonia. Finally, the gas goes to a desulfurizer for removal of hydrogen sulfide. It is planned to use the SulFerox process developed by Dow Chemical Company. This process produces elemental sulfur directly from hydrogen sulfide. The sulfur is discharged as a cake containing 10% to 15% moisture. Part of the clean gas is sent as fuel to the pulse combustor. The remainder of the product gas is sent to electric power production or other uses.

3.2.3 Application of Technology in Proposed Project

ThermoChem will construct a 300 ton/day (dry basis) coal gasification unit to demonstrate the PCASGC process. The gasifier will be located at Caballo Rojo, Inc.'s Caballo Rojo Mine near Gillette, Wyoming. This is a surface mine, producing 12-14 million ton/yr of subbituminous Wyodak (Powder River Basin) coal, with recoverable reserves of 448,600,000 tons. Feed coal for the project will come from the mine, and some of the existing coal handling facilities will be used to transport coal to the project site.

Enserv will construct a coal upgrading (K-Fuel·) plant at the same site, but using private funds with no DOE cost share. The steam requirements of the K-fuel plant will be supplied by by-product steam from the gasifier, and high-

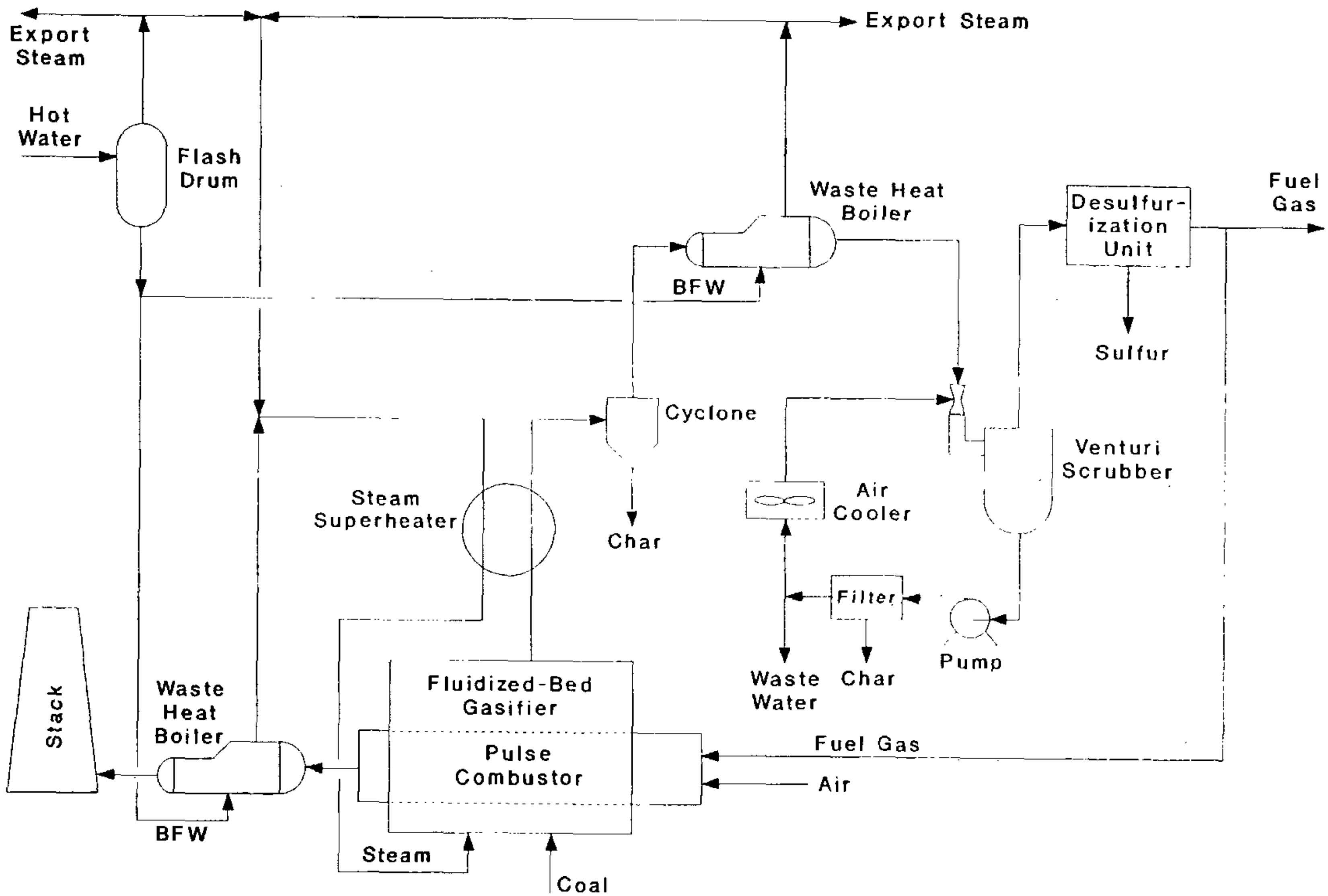

FIGURE 4. SIMPLIFIED FLOW DIAGRAM OF PULSE COMBUSTION FLUIDIZED-BED GASIFIER

temperature, high-pressure process water from the K-Fuel· plant will be flashed to supply the boiler feed water (BFW) and some of the process steam needs of the gasifier. Also, coal fines from the K-Fuel· coal preparation unit will be fed to the gasifier.

The net product gas from the gasifier will either be burned to produce electricity at an existing power station, or Enserv, with private funds and no DOE cost share, will build a gas turbine generator to burn the product gas.

3.3 General Features of the Project

3.3.1 Evaluation of Developmental Risk

Although the throughput for the demonstration project gasifier is a factor of 6 greater than the unit now being fabricated, tested, and installed at Weyerhaeuser's New Bern mill for black liquor recovery, the size and heat load of the pulse combustors require no scaleup, since pulse combustors have been fabricated and tested at higher duties than will be used in the demonstration project.

The resonance tubes that also act as the heat exchanger will require a scaleup from 72 tubes to 252 tubes per bundle. The heater bundles have already been scaled up from 1 to 2, 2 to 8, 2 to 12, 8 to 61, and 8 to 72 tubes. They have been fabricated and tested in these sizes for many gasification applications. Pulse tubes have also been scaled up from 3/8-inch to 1 5/8-inch inside diameter, an increase by a factor of almost 20 in flow area. Pulse combustor firing rates have been scaled up and tested from 10,000 to 15,000,000 Btu/hr, an overall factor of 1,500. ThermoChem feels extremely confident that sufficient scaleup, development, testing, and hardware fabrication experience is available to ensure success at the operational level of 300 ton/day.

Although heat exchanger (resonance) tube fouling is a potential problem, this has not been a problem in the units tested to date. Therefore, fouling is not anticipated to be a problem in the demonstration plant.

3.3.1.1 Similarity of the Project to Other Demonstration/Commercial Efforts

A number of coal gasification processes are either in commercial operation or in the development stage. These processes are generally divided into three major classes: fixed-bed processes, fluidized-bed processes, and entrained-flow processes. The following discussion is limited to representative examples of each type.

Fixed-bed processes have been used extensively in coal gasification. The Lurgi process is in commercial use, and a large number of Lurgi units have been built. The Lurgi process uses a stirred, fixed-bed gasifier equipped with a rotating grate to support the coal. Gasification of coal takes place by reaction with steam and oxygen under high pressure, and coals of all ranks can be gasified. In addition to the synthesis gas product, tars and light oil are produced as by-products. The Lurgi process was developed by the Lurgi Kohle and Mineraloeltechnik GmbH, Frankfurt, Germany. Major process steps are coal preparation, gasification, gas purification, by-product recovery, and liquor treatment. The reactor is provided with lock-hoppers for feeding coal and discharging ash. The gas production capacity per unit has increased from 0.3 million ft^3/min for earlier units to 3.5 million ft^3/min.

The Texaco process, developed by Texaco, Inc., is typical of entrained-flow gasifiers. Coal is fed to the gasifier in the form of a coal-water slurry. The Texaco process gasifies coals of all ranks and produces synthesis gas without any liquid by-product. Major process steps are coal preparation, slurry preparation, gasification, water quench, gas purification, and waste disposal. The Texaco process has been demonstrated at commercial scale.

The Winkler process is a fluidized-bed coal gasification process that has achieved commercial acceptance. All types of coal can be gasified using the Winkler process, but caking coals require pretreatment. Crushed coal (3/8" x 0) is fed into the fluidized bed where carbon reacts with steam and oxygen to produce a gas containing hydrogen, carbon monoxide, carbon dioxide, and methane. A gas with a heating value of 275 Btu/SCF can be produced if the gasifier is oxygen blown. The Winkle gasifier operates at near atmospheric pressure and at a temperature of 1500°F to 1850°F depending upon the feedstock. It produces essentially no tars or hydrocarbons.

The KRW process is typical of pressurized fluidized-bed gasifiers. Crushed and dried coal and limestone are introduced into the pressurized, fluidized bed reactor vessel through a lock hopper system. The bed is fluidized by injecting air or oxygen and steam into the combustion zone through special nozzles. Process steps include coal and limestone preparation, gasification, water quench, calcium sulfite oxidation, gas purification, and waste disposal. The KRW process is being demonstrated by a CCT-IV project.

Indirectly heated gasifiers have a major advantage over partial-oxidation gasifiers for industrial-scale applications, since partial-oxidation gasifiers must be oxygen-blown in order to produce a medium-Btu fuel gas. For a typical industrial-scale operation, air separation is usually uneconomic. Most industrial gasifiers are air blown and produce a low-Btu gas. Although air-blown systems are relatively simple and reliable gas producers, the fuel gas they produce is of limited utility. Several indirectly heated, fluidized-bed gasifiers were under development in the 1970s to produce a medium-Btu gas without requiring an oxygen plant. These systems, such as Battelle's Agglomerating Ash Coal Gasification process, Conoco's CO_2-Acceptor process, and the COGAS process, supply heat for the endothermic steam-carbon reaction by circulating a hot solids stream from a combustor into the gasifier. These processes require two vessels and a fairly complex hot solids circulation system, and the capital cost of the plants is fairly high. Also, since process char is burned to provide heat, the flue gas may have to be desulfurized. Because of their complexity and cost, these systems have not yet achieved commercialization.

The MTCI Pulse Coal Gasification process, which is designed mainly to process low-rank coals, uses an alternative approach to heat a fluidized-bed reactor--heat transfer tubes immersed in the fluidized bed. This approach greatly simplifies the process configuration, since it requires only one reactor vessel, and no complex solids circulation system is involved. However, as employed in other gasifiers, such as that developed by the University of Missouri for gasification of reactive biomass feedstocks, the heat transfer coefficient inside the tubes is so low that a very large surface area is required. The use of pulse combustion in the MTCI process significantly enhances the heat transfer coefficient, which enables the technology to be applied to systems requiring relatively high temperatures, such as coal gasification.

Oxygen-blown, pressurized gasifiers have merit for synthesis gas or combined-cycle power generation at a sufficiently large scale; but, for smaller applications not requiring high-pressure gas, the cost of an oxygen plant and the complexity of feeding solid fuel into a pressure vessel are major deterrents to industrial acceptance.

The fixed-bed systems also have a disadvantage in any application in which fuel gas is the desired product, since by-product hydrocarbon liquids are produced. In high-temperature, entrained-flow systems, no liquid hydrocarbons are produced; and fluidized-bed gasifiers typically do not produce hydrocarbon liquids unless operated at mild gasification temperatures (around 1200°F).

A major drawback of entrained-flow systems is the very low carbon inventory in the gasifier. If coal feed is disrupted, even temporarily, and oxidant flow is not stopped immediately, oxygen can react with hydrogen and carbon monoxide in the gasifier, possibly resulting in an explosion. Due to the use of a fairly reliable slurry feed system, the Texaco gasifier is not prone to this problem; however, other entrained-flow gasifiers have experienced major damage due to the disruption of coal feed. Fixed beds and fluidized beds are inherently safer than entrained beds, because there is always a sufficient carbon inventory to react with oxygen in the event that coal feed is interrupted. The MTCI pulse combustion gasifier (PCG) does not have this risk, because no oxygen is supplied to the gasifier. Thus, although many coal gasification processes have been developed, the MTCI PCG has advantages when low-pressure, medium-Btu gas is required.

3.3.1.2 Technical Feasibility

The project size has been established on the basis of the maturity of the technology; 15 million Btu/hr pulse combustors have already been fabricated, integrated into fire-tube boilers, and tested successfully. The major facet of the technology that requires scaleup is the number of tubes in the resonance section of the pulse combustor. Although the required number of tubes is less than four times the number already fabricated and field tested for the black liquor recovery gasifier to be installed at a Weyerhaeuser mill in New Bern, North Carolina, this scaleup is a critical factor in the demonstration. Also, a greater technical risk is involved in the gasification of coal than in the gasification of black liquor. Gasifier throughput will be scaled up by a factor of 10.

There do not appear to be any critical design issues that have not already been addressed in the design and testing of the 30 ton/day unit. Technical risk is mitigated by the fact that new technology is limited to the gasifier/pulse combustor, with the balance of plant equipment being standard items available in the marketplace. The demonstration plant is a commercial-scale prototype. It is expected that it will, with whatever modifications are required during the start-up period, be replicated for the first market sale.

3.3.1.3 Resource Availability

Adequate resources are available for this project over the 48-month demonstration period. As discussed in Section 6.1, ThermoChem has committed funds adequate to cover the proposed project cost. ThermoChem has also dedicated the personnel necessary to conduct this demonstration program.

Sufficient space is available at the Caballo Rojo Mine site for installation of the equipment required for the demonstration. Arrangements have been made to provide the necessary quantity and quality of coal from the Caballo Rojo Mine. Adequate utilities (water and electric power) are available at the site to meet project needs.

3.3.2 Relationship Between Project Size and Projected Scale of Commercial Facility

The demonstration project involves a plant rated at 300 ton/day (dry basis). This plant size is well within the commercial facility range, since the major market for this version of the technology is likely to involve industrial, rather than utility, applications.

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

The demonstration project is crucial to achieving commercialization of the technology, as it will demonstrate, at full commercial scale, the integrated operation of the pulse combustor and the indirectly heated coal gasifier. This project will confirm plant operability, product quality, and process costs, providing information that is vital to the commercialization effort.

3.3.3.1 Applicability of the Data to be Generated

The demonstration project will test all aspects of the technology at commercial scale, and the product will be burned for electric power production. Data collection, analysis, and reporting will be performed during the operations phase and will include on-stream reliability, thermal efficiencies, and equipment performance. The data that will be generated will be directly applicable to the design of other gas-fired facilities. Although the data will not be directly applicable to coal-fired combustors, there are enough design similarities so that the performance data will be useful in providing guidance in the scaleup of coal-fired pulse combustors. Furthermore, demonstration of pulse combustion at this scale of operation, regardless of fuel, will greatly facilitate the commercialization efforts of all pulse combustors.

3.3.3.2 Identification of Features that Increase the Potential for Commercialization

The CAAA require existing coal-burning furnaces to reduce SO_2 emissions. One option for accomplishing this is to produce a clean gaseous fuel by gasifying coal and desulfurizing the product gas before it is combusted. Other available gasifiers, whether commercial or under development, have the disadvantage of requiring either an oxygen plant in order to produce a medium-Btu fuel gas, a complex circulating solids flow scheme involving two reaction vessels, or a very large heat transfer area in the fluid-bed gasifier. Because the MTCI PCG produces medium-Btu gas in a single-vessel coal gasifier using air and a highly efficient pulse combustor/heat exchanger system that minimizes capital costs, the technology being demonstrated should be the process of choice for many applications. Another advantage of the MTCI PCG is that, unlike fixed-bed gasifiers, very few hydrocarbons heavier than methane are produced, and there are essentially no tars or oils to dispose of. Also, a considerable amount of by-product steam is produced, so the MTCI PCG should integrate well with processes which use large amounts of steam.

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

This project will produce a clean, medium-Btu fuel gas by gasifying coal in an indirectly heated, fluidized-bed reactor. By-product steam will also be produced. As discussed above, the process has advantages over competing processes that are expected to make it economically advantageous in many applications.

The MTCI pulse combustion technology has a wide range of potential applications, including utility steam and power generation. This project will demonstrate the use of pulse combustion for steam gasification of coal to produce medium-Btu fuel gas and by-product steam in conjunction with a low-rank coal upgrading process that will utilize the by-product steam.

Other potential applications include producing medium-Btu fuel gas as a substitute for natural gas in industrial applications. The process could also provide fuel gas for gas turbines in integrated gasification combined cycle (IGCC) power generation. As fuel cells become commercial, the MTCI pulse combustion application for steam gasification of coal could be used to provide hydrogen rich fuel gas.

In addition to these applications, there is a substantial potential in a closely related application in the pulp and paper industry which has more than 350 pulp mills and 600 paper mills in the United States alone. The processing of pulp results in the production of about 88 million ton/yr of by-product black liquor, the dark-colored liquid produced when pulp is made by the sulfate and soda processes. The current practice of using black liquor recovery boilers to produce steam and electricity is inefficient. Replacing these boilers with MTCI gasifiers would significantly improve the conversion efficiency. The estimated market for MTCI gasifiers in this application alone is 28 units annually.

Thus, because of its simplicity of operation and high quality product, the MTCI PCG technology should achieve ready market acceptance, particularly for industrial applications.

4.0 ENVIRONMENTAL CONSIDERATIONS

The NEPA compliance procedure, cited in Section 2.2, contains three major elements: a Programmatic Environmental Impact Statement (PEIS); a preselection, project-specific environmental analysis; and a post-selection, site-specific environmental analysis. DOE issued the final PEIS to the public in November 1989 (DOE/EIS-0146). In the PEIS, results derived from the Regional Emissions Database and Evaluation System (REDES) were used to estimate the environmental impacts expected to occur in 2010 if each technology were to reach full commercialization and capture 100% of its applicable market. These impacts were compared with the no-action alternative, which assumed continued use of conventional coal technologies through 2010 with new plants using conventional flue gas desulfurization to meet New Source Performance Standards.

The preselection, project-specific environmental review, focusing on environmental issues pertinent to decision-making, was completed for internal DOE use. This review summarized the strengths and weaknesses of each proposal in compliance with the environmental evaluation criteria in the PON. It included, to the extent possible, a discussion of alternative sites and processes reasonably available to the offeror, practical mitigating measures, and a list of required permits. This analysis was provided for the consideration of the Source Selection Official in the selection of proposals.

As the final element of the NEPA strategy, the Participant (ThermoChem) will submit to DOE the Environmental Information Volume specified in the PON. This detailed site- and project-specific information will form the basis for the NEPA documents prepared by DOE. These documents, prepared in compliance with the Council on Environmental Quality regulations for implementation of NEPA and the DOE regulations for NEPA compliance, must be approved before Federal funds can be provided for detailed design, construction, and operation activities.

In addition to the NEPA requirements outlined above, the Participant must prepare and submit an Environmental Monitoring Plan (EMP) for the project. The purpose of the EMP is to ensure that sufficient technology, project, and site environmental data are collected to provide health, safety, and environmental information for use in subsequent commercial applications of the technology.

Air pollutants resulting from burning the medium-Btu gas produced in this demonstration project are expected to be low. Most particulate matter is scrubbed from the gas in the venturi scrubber, and only about 1 ton/yr of particulates is expected to be emitted. Most of the sulfur is removed in the desulfurization system, and sulfur emissions are expected to be about 0.07 lb SO_2/million Btu.

Gasifier ash is classified as nonhazardous waste and will be disposed of in a permitted landfill. By-product sulfur will be sold, if possible; otherwise, it will be landfilled. Wastewater will be discharged to an evaporation pond at the site. Test work planned for Phase I will determine whether ammonia needs to be stripped from this water before disposal.

5.0 PROJECT MANAGEMENT

5.1 Overview of Management Organization

The project will be managed by a ThermoChem Project Manager. This individual will be the principal contact with DOE for matters regarding the administration of the Cooperative Agreement between ThermoChem and DOE. The DOE Contracting Officer is responsible for all contract matters, and the DOE Contracting Officer's Technical Project Officer (TPO) is responsible for technical liaison and monitoring of the project.

5.2 Identification of Respective Roles and Responsibilities

DOE

DOE shall be responsible for monitoring all aspects of the project and granting or denying approvals required by the Cooperative Agreement. The DOE Contracting Officer is DOE's authorized representative for all matters related to the Cooperative Agreement.

The DOE Contracting Officer will appoint a TPO 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, or suggest pursuit of certain lines of inquiry which assist in accomplishing the Statement of Work.

- Approve all technical reports, plans, and items of technical information required to be delivered by the Participant to the DOE under the Cooperative Agreement.

The DOE TPO does not have the authority to issue 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 TPO.

Participant

The following organizations will interact effectively to meet the intent of the PON and to assure timely and cost-effective implementation of the PCASGC project from conceptual design to start-up and operation:

- ThermoChem, Inc.
- Manufacturing and Technology Conversion International, Inc. (MTCI)
- Enserv, Inc.
- RMT, Inc.
- Weyerhaeuser Paper Company

ThermoChem will be primarily responsible for reporting to and interfacing with DOE. ThermoChem will be responsible for all phases of the project.

The overall project approach of the Participants will include, but not necessarily be limited to, the following:

- A single project manager will be responsible to DOE and all project Participants for all three project phases.

- ThermoChem will be the primary liaison between the Government and all other organizations, as shown in Figure 5, Project Organization.

- MTCI will design and fabricate the pulse combustor/gasifier system, conduct the system startup and shakedown testing, and provide technical support during the project.

- Enserv will obtain the necessary permits, handle the interfacing of the demonstration plant with other facilities, and operate and maintain the demonstration plant.

- RMT, together with an A&E firm to be selected, will handle design and engineering of the balance of the plant, procurement and construction of the demonstration plant, and provide technical service.

- Weyerhaeuser will serve in a technical advisory and review capacity and evaluate the technology for pulp and paper industry applications.

5.3 Project Implementation and Control Procedures

All work to be performed under the Cooperative Agreement is divided into three phases. These phases are:

Phase I: Design and Engineering (10 months)
Phase II: Construction (14 months)
Phase III: Operations (24 months)

As shown in Figure 6, the total project encompasses 48 months.

Two budget periods will be established. Consistent with P.L. 101-512, DOE will obligate funds sufficient to cover its share of the cost for 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 ThermoChem and provided to DOE.

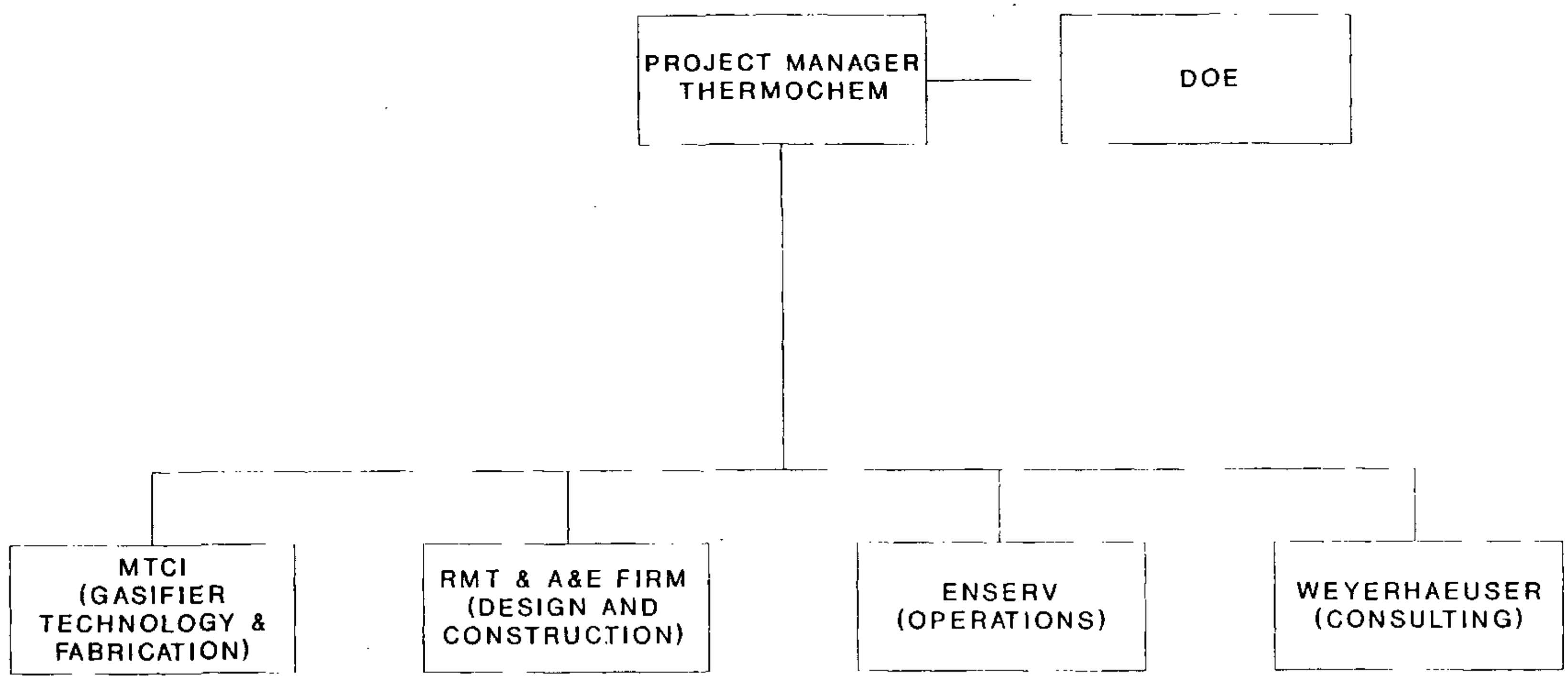

FIGURE 5. PROJECT ORGANIZATION FOR PCASGC DEMONSTRATION PROJECT

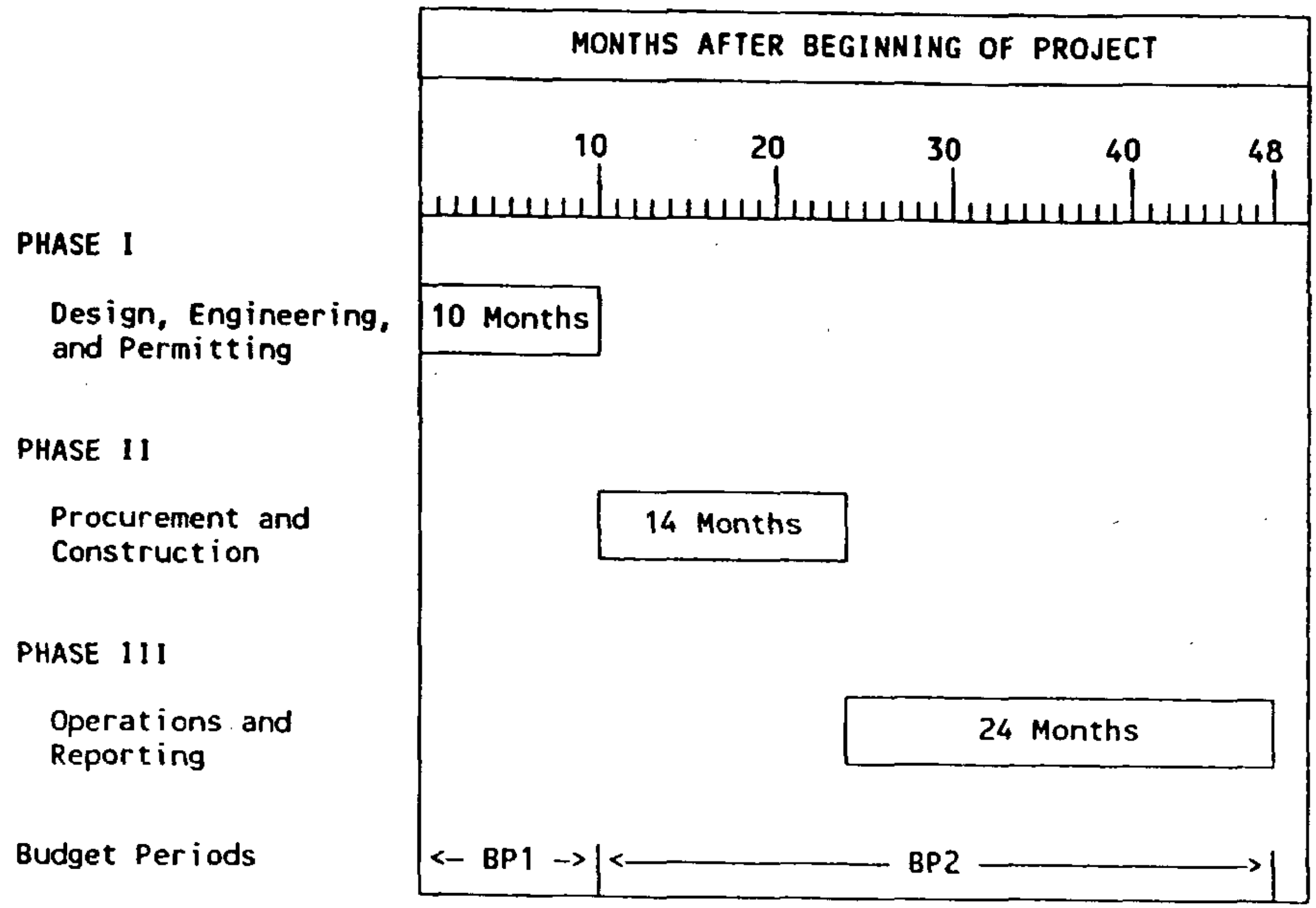

FIGURE 6. OVERALL SCHEDULE FOR PCASGC DEMONSTRATION PROJECT

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

The key agreements with respect to patents and data are:

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

- Proprietary data, with certain exclusions, may be required to be delivered to the Government. The Government has obtained rights to proprietary data and non-proprietary data sufficient to allow the Government to complete the project if the Participant withdraws.

- Rights in background patents and background data of ThermoChem and all of its subcontractors are included to assure commercialization of the technology.

ThermoChem will make such data, as is applicable and non-proprietary, available to the U.S. DOE, U.S. EPA, other interested agencies, and the public.

5.5 Procedures for Commercialization of the Technology

The ThermoChem commercialization strategy is based on control of the manufacturing of the pulse combustor equipment; however, for utility and large industrial applications, ThermoChem will license the balance of the plant.

ThermoChem will retain the right to design, manufacture, and sell industrial and commercial coal-fired retrofit systems both in the U.S. and overseas. ThermoChem will also retain the right to manufacture gasifiers for moderate size gasification plants (up to 1000 ton/day) for black liquor recovery, paper mill sludge gasification, low-rank coal steam reforming, sewage sludge gasification, etc.

In addition to this direct utility and industrial market for PCASGC, a potential market also exists in conjunction with coal upgrading processes, such as K-Fuel·. Enserv believes that within 20 years, K-Fuel· could achieve a 5% penetration of the U.S. coal market. ThermoChem's strategy for penetrating this potential market is to grant to Enserv an exclusive license for the MTCI PCG used in conjunction with beneficiation technology. Enserv plans to market aggressively by identifying the utility and industrial coal consumers whose immediate needs warrant the use of K-Fuel· and obtaining commitments for long-term purchases.

6.0 PROJECT COST AND EVENT SCHEDULING

6.1 Project Baseline Costs

The total estimated cost for this project is $37,333,474. The Participant's share and the Government's share in the costs of this project are as follows:

	Dollar Share ($)	Percent Share (%)
Pre-Award		
Government	248,290	50
Participant	248,290	50
Phase I		
Government	1,258,287	50
Participant	1,258,287	50
Phase II		
Government	11,388,685	50
Participant	11,388,685	50
Phase III		
Government	5,771,475	50
Participant	5,771,475	50
Total Project		
Government	18,666,737	50
Participant	18,666,737	50

Budget Period 1 will include Pre-Award and Phase I; Budget Period 2 will include Phase II and Phase III. At the beginning of each budget period, DOE will obligate funds sufficient to pay its share of expenses for that budget period.

The project will be co-funded by DOE and ThermoChem, as follows:

	BP1	BP2	Total
DOE	$1,506,577	$17,160,160	$18,666,737
ThermoChem	$1,506,577	$17,160,160	$18,666,737
TOTAL	$3,013,154	$34,320,320	$37,333,474

6.2 Milestone Schedule

The overall project will be completed in 48 months. The project schedule, by phase and activity, is shown in Figure 6.

Phase I, which involves design and engineering, will continue for 10 months. Phase II, construction, will last a total of 14 months, and Phase III, operations, will last 24 months.

6.3 Repayment Plan

In response to DOE's stated policy 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 Repayment Agreement, which is consistent with the model repayment agreement in the CCT-IV PON.