January 31, 1994

Mr. Douglas Gyorke
Contracting Offices Representative
U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940, MS 922-H
Pittsburgh, PA 15236

Subject: DOE Contract No. DE-AC22-90PC90155

Dear Mr. Gyorke:

Enclosed is a copy of the 13th Quarterly Technical Progress Report for "Development and Testing of Commercial-Scale, Coal-Fired Combustion Systems: Phase III" for the subject contract and covering the period September 27, 1993 through January 2, 1994 (October - December).

Also enclosed is the Milestone Schedule/Status under the subject contract for the same period (October - December).

If you have any questions, please do not hesitate to contact us.

Sincerely,

Amal M. Mansour
CEO and Chairman of the Board

Enclosures: As stated above

cc: Martin Byrnes, DOE
    R.R. Chandran, MTCI
DISCLAIMER

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TECHNICAL PROGRESS REPORT

October 1993 - December 1993

For:

U.S. Department of Energy
Pittsburgh Energy Technology Center

Under:

DOE Contract No. DE-AC22-90PC90155

Development and Testing of Commercial-Scale, Coal-Fired Combustion Systems: Phase III

By:

MANUFACTURING AND TECHNOLOGY CONVERSION INTERNATIONAL, INC.
P.O. Box 21, Columbia, Maryland 21045-0021

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
This 13th Quarterly Technical Progress Report presents the results of work accomplished during the period September 27, 1993 through January 2, 1994 (October - December) under Contract No. DE-AC22-90PC90155 entitled "Development and Testing of Commercial-Scale, Coal-Fired Combustion Systems: Phase III." The first Quarterly Report included subsections on background and the Statement of Work. These are omitted from this quarterly progress report.

During this 13th quarter, a steam generation cost model was developed to compare the economics of steam production in the commercial-scale, coal-fired pulse combustion system with that in a natural gas- or oil-fired system. The purpose of this model is to define the competitive capital cost range for the MTGI system under a specified set of technical and economic conditions.

A current preliminary estimate of the MTGI pulse coal combustion system capital cost turns out to be about $120,000 and this is within the target range of the U.S. commercial boiler market sector. European differential fuel costs are expected to be more favorable.

Several conceptual arrangements for coal reburn and char burnout were evaluated. The arrangement was selected based on the following considerations viz. utilization of the existing pulse combustor as is, minimization of footprint and vertical space requirement, good mixing of coal, steam and combustion products in the reburn section, and adequate char residence time in the char burnout section.
TABLE OF CONTENTS

1.0 INTRODUCTION ............................................. 1
   1.1 OBJECTIVES ........................................... 1
   1.2 SUMMARY STATUS ...................................... 4

2.0 TECHNICAL DISCUSSION OF WORK ACCOMPLISHED
   DURING THE REPORTING PERIOD ............................. 5

3.0 PLANS FOR NEXT PERIOD .................................... 16

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LIST OF FIGURES

FIGURE 1  COAL REBURNING CHAMBER AND CHAR BURNOUT CYCLONE CONFIGURATION ........................................... 6

FIGURE 2  PULSE COAL COMBUSTION SYSTEM FOR BOILER RETROFIT - NATURAL GAS BURNER REPLACEMENT ...................... 10

FIGURE 3  PULSE COAL COMBUSTION SYSTEM FOR BOILER RETROFIT - NATURAL GAS/OIL COMBINATION BURNER REPLACEMENT ........ 11

FIGURE 4  PULSE COAL COMBUSTION SYSTEM FOR BOILER RETROFIT - NATURAL GAS/OIL COMBINATION BURNER REPLACEMENT (75% Capacity Factor) ................................................. 12

FIGURE 5  RELATIONSHIP BETWEEN PAYBACK PERIOD AND DISCOUNTED-CASH-FLOW RATE OF RETURN .................. 15

LIST OF TABLES

TABLE 1  MODIFIED COMBUSTION SYSTEM DESIGN DATA SUMMARY .................. 7

TABLE 2  STEAM COST MODEL INPUT DATA ........................................ 9
SECTION 1.0

INTRODUCTION

The U.S. Department of Energy’s Pittsburgh Energy Technology Center (PETC) is actively pursuing the development and testing of coal-fired combustion systems for residential, commercial, and industrial market sectors. In response, MTCI initiated the development of a new combustor technology based on the principle of pulse combustion under the sponsorship of PETC (Contract No. DE-AC22-83PC60419). The initial pulse combustor development program was conducted in three phases (MTCI, Development of a Pulsed Coal Combustor Fired with CWM, Phase III Final Report, DOE Contract No. DE-AC22-83PC60419, November 1986). Phase I included a review of the prior art in the area of pulse combustion and the development of pulse combustor design concepts. It led to the conclusion that pulse combustors offer technical and base-of-operation advantages over conventional burners and also indicated favorable economics for replacement of oil- and gas-fired equipment.

1.1 OBJECTIVES

The objective of this Phase III program for the development of a commercial-scale, coal-fired combustion system is to develop and integrate all system components from fuel through total system controls building upon the prior Phase I and II development accomplishments of the MTCI pulse combustion technology and to then field test the complete system in order to evaluate its potential marketability.

The component, system and proof-of-concept test program will be conducted at the MTCI development facility in Baltimore, Maryland. Steady-state tests will be performed to determine combustion efficiency, sulfur capture efficiency, gaseous and particulate emissions, thermal efficiency and turndown ratio of the system as a function of several variables. The parameters to be investigated include: firing rate (1 to 5 MMBtu/hr), multiple air staging (different stoichiometries in the primary, secondary and tertiary air addition zones), Ca/S molar ratio (1 to 3), fuel type (natural gas, 3 different coals), and sorbent
type (limestone and dolomite). Start-up, shutdown, steady-state and upset operations of the system will be to evaluate the operability, reliability and availability of the unit. The actual expenditures incurred in operating and maintaining the system will be monitored and recorded.

The long-term, steady-state site demonstration tests to characterize performance, operability, reliability, availability, emissions compliance, fuel flexibility and economics will be conducted at the Striegel Supply Company's warehouse. After long-term testing ($\approx 1,000$ hours), the unit will be dismantled and inspected to verify the integrity of the materials and the method of construction.

The overall objective of this Phase III for the Development and Testing of a Commercial-Scale, Coal-Fired Combustion System is to demonstrate and analyze the performance of a fully integrated system at the 5 to 6 MMBtu level to evaluate its potential marketability. The application assumes the availability of both a coal-based fuel and the equipment required to deliver such fuel to a building, store it within the building or in a storage container or tank adjacent to the building, and transport it from storage to the burner. The fuel is delivered and stored either in the form of a coal-water fuel or as a dry powder.

This program consists of six technical tasks and two additional tasks for program management and reporting. The latter are omitted from the following discussion. The details of each technical task required to meet the following performance goals as specified in the Statement of Work were briefly described in the first quarterly report.

The Project will focus on advanced systems capable of firing rates in the range of 2 to 5 MMBtu/hr, with the following performance goals:

- **Primary Fuel:** Coal-water fuel or dry powder
- **Secondary Fuel:** Natural gas or petroleum fuels
- **Ignition:** Fully automatic start-up with system purge and ignition verification
Turndown Ratio: 3:1
Reliability/Safety: Comparable to oil-fired commercial boilers
Thermal Efficiency: > 80%
Combustion Efficiency: > 99%
Routine Operating/Maintenance Labor: Less than one dedicated man-hour per day and an additional two man-hours per week
Ash Removal: Dust-free and automatic or semiautomatic
Scheduled Maintenance: ≤ twice a year
Service Life: Overall system ≥ 20 years
Emissions: (3)

1.2 lb SO₂/MMBtu
0.3 lb NOₓ/MMBtu
0.03 lb particulates/MMBtu

(1) The coal(s) must be economically recoverable and have sufficient reserves to support a coal-water fuel industry that supplies the proposer-defined application(s) and geographic market sector(s).

(2) The 1986 PRDA that initiated Phases I and II characterized the fuel as having a mineral matter content less than 1 lb/10^6 Btu and a sulfur content of 0.5 lb or less/10^6 Btu. These restrictions do not apply here; however, it is emphasized that in order to meet the emissions specifications listed and limit the users ash handling requirements, it is assumed that some coal beneficiation will be necessary.

(3) There are wide variations in state and local air pollution control regulations for commercial-scale space-heating systems. In addition, these regulations are all subject to change. Therefore, the aforementioned emissions specification chosen as the goal for this RFP are those that are anticipated to be achieved based on the present state of development of coal cleaning, combustion, and flue gas cleanup technologies. However, for coal-fired systems to become environmentally and hence commercially acceptable, emissions levels will ultimately need to be comparable to those produced by fuel oil-fired commercial-scale units, viz.:

0.4 lb SO₂/MMBtu
0.2 lb NOₓ/MMBtu
0.02 lb particulates/MMBtu
In summary, the system should be designed to enable further emission reductions, e.g., via advanced flue gas treatment, to be readily applied when necessary.

1.2 SUMMARY STATUS

During this 13th quarter, a steam generation cost model was developed to compare the economics of steam production in the commercial-scale, coal-fired pulse combustion system with that in a natural gas- or oil-fired system. The purpose of this model is to define the competitive capital cost range for the MTCI system under a specified set of technical and economic conditions.

A current preliminary estimate of the MTCI pulse coal combustion system capital cost turns out to be about $120,000 and this is within the target range of the U.S. commercial boiler market sector. European differential fuel costs are expected to be more favorable.

Several conceptual arrangements for coal reburn and char burnout were evaluated. The arrangement was selected based on the following considerations viz. utilization of the existing pulse combustor as is, minimization of footprint and vertical space requirement, good mixing of coal, steam and combustion products in the reburn section, and adequate char residence time in the char burnout section.
SECTION 2.0
TECHNICAL DISCUSSION OF WORK ACCOMPLISHED DURING THE REPORTING PERIOD

Task 3: Proof-of-Concept System Tests

Several conceptual arrangements for coal reburn and char burnout were evaluated. The arrangement shown in Figure 1 has been selected based on the following considerations viz. utilization of the existing pulse combustor as is, minimization of footprint and vertical space requirement, good mixing of coal, steam and combustion products in the reburn section, and adequate char residence time in the char burnout section. The bent tailpipe configuration of the pulse combustor has been retained and the tailpipe is integrated with the reburn chamber comprising concave sections such that the tailpipe exit jet impinges on the concave sections and spins around. This is anticipated to aid mixing and enhance coal particle residence time. A bottom exit is provided to minimize particle settling and accumulation. The products from the reburn chamber enter a vertical char burnout chamber tangentially at the bottom. This will aid in minimizing particle settling at the bottom and the cyclonic upflow against gravity will enhance char particle residence time in the chamber and, in turn, the burnout. Both the chambers are refractory-lined (two layers of refractory—high density and low density) and water-cooled. Reburn coal along with steam are proposed for injection into the tailpipe. Steam is being considered as a means of enhancing CH,
radical concentration and promoting CH/
NO reactions such that the coal-steam combination would approximate natural gas reburn chemistry. An initial trial of 1 lb steam/lb reburn coal will be made to establish feasibility. The addition of steam will reduce thermal efficiency by about 1 percent. In the design as suggested here, special care has been taken to avoid the use and direct exposure of high-temperature metal surfaces (pipes, cylinders, etc.) to the hot flue gas so as to minimize erosion and corrosion problems. All the components and connecting sections are lined with refractory. The char burnout cyclone incorporates multiple stage ports for air injection. The integration of the char burnout cyclone eliminates the need for the boiler modifications...
FIGURE 1: COAL REBURNING CHAMBER AND CHAR BURNOUT CYCLONE CONFIGURATION
carried out earlier (radiative shield inside the Morrison tube, swirler, partition disk and the boiler extension). The present arrangement would facilitate ease of boiler retrofit.

Detailed material and energy balance calculations were made in designing the reburn and burnout chambers. Table 1 provides a data summary.

**TABLE 1:**
**MODIFIED COMBUSTION SYSTEM DESIGN DATA SUMMARY**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Combustor Firing Rate</td>
<td>6.25 MMBtu/hr</td>
</tr>
<tr>
<td>Primary Air</td>
<td>4,380 lb/hr</td>
</tr>
<tr>
<td>Combustion Chamber Temperature</td>
<td>2300°F</td>
</tr>
<tr>
<td>Coal</td>
<td>Seacoal</td>
</tr>
<tr>
<td>Sorbent</td>
<td>Pfizer Dolomite</td>
</tr>
<tr>
<td>Ca/S Molar Feed Ratio</td>
<td>2.5</td>
</tr>
<tr>
<td>Reburn Coal</td>
<td>Seacoal</td>
</tr>
<tr>
<td>Reburn Coal Firing Rate</td>
<td>1.25 MMBtu/hr</td>
</tr>
<tr>
<td>Reburn Coal Feed Rate</td>
<td>89 lb/hr</td>
</tr>
<tr>
<td>Steam Injection Rate</td>
<td>1 lb/lb reburn coal</td>
</tr>
<tr>
<td>Reburn Chamber Mean Temperature</td>
<td>2250°F</td>
</tr>
<tr>
<td>Secondary Air Injection Rate</td>
<td>2210 lb/hr</td>
</tr>
<tr>
<td>Overall Excess Air</td>
<td>15%</td>
</tr>
<tr>
<td>Char Burnout Chamber Mean Temperature</td>
<td>2265°F</td>
</tr>
</tbody>
</table>

A materials list has been prepared and procurement initiated. Detailed fabrication drawings of the coal reburn and char burnout chambers have been prepared. Support structure modification drawings have also been generated.
Component fabrication has started and it is expected to take about a month to complete. Pursuant to this fabrication, the pulse combustor section will be decoupled from the boiler, reconfigured and integrated with the coal reburn and char burnout chambers and the boiler.

**Task 4: Evaluate Economics/Prepare Commercialization Plan**

**Subtask 4.1: Economic Evaluation**

A steam generation cost model was developed to compare the economics of steam production in the commercial-scale, coal-fired pulse combustion system with that in a natural gas- or oil-fired system. The purpose of this model is to define the competitive capital cost range for the MTCI system under a specified set of technical and economic conditions.

The model has a number of flexible input variables covering technical, environmental and financial assumptions. In order to simplify this multi-dimensional model, a baseline parameter set was defined. For these baseline parameters, specific fixed values were employed. Selection of these values were based on technological assessment, vendor cost data and current prices.$^{(1,2)}$

Parameters such as capacity factor and differential fuel cost (i.e., natural gas or oil price-coal price per MMBtu) were allowed to vary in order to estimate steam production cost and target capital cost for a coal-fired pulse combustion system. Table 2 summarizes the input parameters for the steam cost model. With coal reburn, the commercial-scale pulse combustion system is expected to fire 7.5 MMBtu/hr at full load. Therefore, gas/oil burner vendors were approached to obtain quotes for a 7.5 MMBtu/hr burner with single-fuel (natural gas) or dual-fuel (natural gas or oil) capability. Current prices for a natural gas burner with blower and controls turned out to be about $14,000 and for a dual-fuel burner system, $32,000.

The results generated from the steam cost model are shown in Figures 2, 3, and 4. Figures 2 and 3 indicate the variation in allowable capital cost for the pulse coal combustion system with differential fuel cost for a unit operating at
<table>
<thead>
<tr>
<th>TABLE 2: STEAM COST MODEL INPUT DATA</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>FUEL</th>
<th>COAL-FIRED PULSE COMBUST. (NAT. GAS)</th>
<th>SINGLE-FUEL BURNER SYSTEM (N.GAS/OIL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORBENT</td>
<td>LIMESTONE or DOLOMITE</td>
<td>-</td>
</tr>
<tr>
<td>FIRING RATE, MMBtu/hr</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>BOILER CAPACITY, PPH @ 15 psig, sat.</td>
<td>5,545</td>
<td>5,545</td>
</tr>
<tr>
<td>COMBUSTION EFFICIENCY, %</td>
<td>99</td>
<td>99.999</td>
</tr>
<tr>
<td>THERMAL EFFICIENCY, %</td>
<td>84</td>
<td>83</td>
</tr>
<tr>
<td>CAPACITY FACTOR</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>ELECTRICITY CONSUMPTION, kWh/1000 lb steam</td>
<td>11.6</td>
<td>3</td>
</tr>
<tr>
<td>FUEL HHV, Btu/lb</td>
<td>12,500</td>
<td>23,400</td>
</tr>
<tr>
<td>FUEL SULFUR, Wt.%</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>FUEL ASH, Wt.%</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>SORBENT Ca/S FEED RATIO</td>
<td>2.5</td>
<td>-</td>
</tr>
<tr>
<td>SORBENT PURITY, Wt.%</td>
<td>90</td>
<td>-</td>
</tr>
<tr>
<td>SULFUR RETENTION, %</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>FUEL COST, $/MMBtu</td>
<td>2.0</td>
<td>Variable</td>
</tr>
<tr>
<td>SORBENT COST, $/ton</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>WASTE DISPOSAL COST, $/ton</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>ELECTRICITY COST, $/kWh</td>
<td>0.075</td>
<td>0.075</td>
</tr>
<tr>
<td>NO. OF OPERATORS PER SHIFT</td>
<td>0.125</td>
<td>-</td>
</tr>
<tr>
<td>NO. OF SHIFTS PER DAY</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>OPERATOR COST, $/hr</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>LABOR OVERHEAD, % Direct</td>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>MAINTENANCE, % Installed</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>TAX &amp; INSURANCE, % Installed</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>CAPITAL COST, $</td>
<td>Variable</td>
<td>14,000</td>
</tr>
<tr>
<td>ENGINEERING, INSTALLATION AND START-UP COST, % Capital</td>
<td>37.5</td>
<td>6.25</td>
</tr>
<tr>
<td>CONTINGENCY, %</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>PAYBACK PERIOD, yr</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ANNUAL INTEREST RATE, %</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>
FIGURE 2: PULSE COAL COMBUSTION SYSTEM FOR BOILER RETROFIT - NATURAL GAS BURNER REPLACEMENT
FIGURE 3: PULSE COAL COMBUSTION SYSTEM FOR BOILER RETROFIT - NATURAL GAS/OIL COMBINATION BURNER REPLACEMENT
FIGURE 4: PULSE COAL COMBUSTION SYSTEM FOR BOILER RETROFIT - NATURAL GAS/OIL COMBINATION BURNER REPLACEMENT (75% CAPACITY FACTOR)
different capacity factors. (Allowable cost is that capital cost that is competitive with gas/oil burner systems.) Figure 2 presents the data for the replacement of a natural gas burner and Figure 3 presents the results for the replacement of a dual-fuel (natural gas and oil combination burner) system. These capital costs were generated by matching the steam costs ($/1000 lb) for the single fuel or dual-fuel burner system with the pulse coal combustion system. Note that the design, engineering, installation and start-up cost was factored into the model as a percent of the allowable capital cost. This percent value was made many times higher for the coal system in comparison to that for the gas/oil system (see Table 2) consistent with the complexity of the coal combustion system in relation to the gas/oil system. The allowable capital cost of the pulse coal combustion system varies with the differential fuel cost and capacity factor as shown in Figures 2 and 3. Commercial boilers are typically said to operate at the 75% capacity factor level. At this load and at the current U.S. commercial sector natural gas price of $5 per MMBtu,$2 the differential fuel cost is $3/MMBtu, making the allowable capital cost of the pulse coal combustion system to fall in the range between $100,000 (Figure 1) and $105,000 (Figure 3).

A current preliminary estimate of the MTCI pulse coal combustion system capital cost turns out to be about $120,000 and this is within the target range of the U.S. commercial boiler market sector. European differential fuel costs are expected to be more favorable (efforts are in progress to obtain current international energy prices for coal, oil and gas) and therefore the allowable capital cost for the pulse coal combustion system is expected to exceed the estimated capital cost indicated above. Note that the MTCI system is multi-fuel (gas, coal and oil) capable and is designed to meet stringent emissions standards. The capital cost projections are based on an after-tax payback period of 5 years which typically could correspond to a pre-tax payback period of 3 to 3.5 years.

Figure 4 shows the allowable capital cost for the pulse coal combustion system as a function of differential fuel cost for two payback periods (5 and 6 years) at a 75% capacity factor. For a differential fuel cost of $3, the allowable capital cost increases to about $120,000 for a 6-year payback period.
Therefore, at current estimates, the MTCI system is marketable with a 6-year payback period and a 75% capacity factor. This corresponds to a 15 percent discounted-cash-flow rate of return (DCFRR) in about 16 years as opposed to a 15 percent DCFRR in 10 years for a 5-year payback period (see Figure 5).

Data on the energy prices for the domestic market (U.S.) have been obtained from the Energy Information Administration (EIA) publication, "Annual Energy Outlook 1983 with Projections to 2010," DOE/EIA-0383(93). Efforts are in progress to obtain data on international energy prices for local, oil and natural gas. The International Energy Annual (1991) only lists petroleum prices and therefore other sources are being consulted for coal and gas prices. Prices of gas- and oil-fired burners with controls for boiler retrofit are also being acquired to perform the comparative economic analysis. The steam cost model spreadsheet has been put together and the economic analysis will be performed as soon as the data on prices become available.

References


FIGURE 5: RELATIONSHIP BETWEEN PAYBACK PERIOD AND DISCOUNTED-CASH-FLOW RATE OF RETURN$^{(3)}$
SECTION 3.0

PLANS FOR NEXT PERIOD

- Complete component fabrication.
- Reconfigure and integrate combustor section with coal reburn and char burnout chambers.