TECHNICAL AND COST PROPOSAL

WRITECOAL™ GASIFICATION PROCESS FOR LOW-RANK COALS FOR IMPROVED INTEGRATED GASIFICATION COMBINED CYCLE WITH CARBON CAPTURE: PHASE II - PILOT-SCALE DEMONSTRATION

Total LRC/NDIC Funding Requested: $549,500

Submitted to:

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March 30, 2010

TABLE OF CONTENTS

Contents **Page**

APPENDICES

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (continued)

Foreword to the Proposal and a Statement of Clarification

A team of co-sponsors and project participants – Western Research Institute (WRI), WY; Energy and Environmental Research Center (EERC), ND; Gas Technology Institute (GTI),Il; FuelCell Energy (FCE), CT; Etaa Energy, NJ; and Washington Division of URS (URS), CO - submitted a proposal entitled, "WRI's Pre-Gasification Treatment of PRB Coals for Improved Advanced Clean Coal Gasifier Design: Phase II - Pilot-scale Demonstration " in response to the State of Wyoming Clean Coal Technology Program administered through the University of Wyoming's School of Energy Resources' Request for Proposals dated Dec. 1, 2009. The proposal was competitively evaluated and selected for an award. This proposal to the NDIC will cover the lignite tests. The additional sponsors of this proposal effort to address lignite applications, in addition to the LRC/NDIC request, are the U.S. Department of Energy, Basin Electric Power Cooperative (BEPC), and Montana-Dakota Utilities (MDU).

ABSTRACT

WRITECoal™ Gasification Process for Low Rank Coals for Improved Integrated Gasification Combined Cycle with Carbon Capture: Phase II - Pilot-scale Demonstration

Objective: To demonstrate at a 1-2MWth pilot-scale the Western Research Institute's (WRI's) WRITECoal™ gasification process for IGCC with CO_2 capture, fuel cell applications, and chemicals production, to identify engineering and scale-up issues and to estimate the cost of WRITECoal™ gasification process.

Scope of Work and Expected Results: North Dakota lignite and PRB coal will be gasified according to WRITECoal™ gasification process in the Gas Technology Institute's (GTI's) subpilot-scale U-GAS® gasifier and in Energy and Environmental Research Center's (EERC's) 1-2 MWth pilot-scale transport reactor gasifier. The testing will address gasifier performance including syngas quality and recycle and scale-up engineering properties of the integrated technology. Hydrogen separation for fuel cell applications will also be performed by EERC and FuelCell Energy (FCE). WRI, GTI, Etaa Energy, Inc. (EEI) and FCE will model the technology performance with low-rank coals and URS will assess its economics. The proposed effort will expand upon, demonstrate and confirm the State of Wyoming Clean Coal Technology Program-funded Phase I results, which showed 5% increase in cold gas efficiency, reduced water consumption, and overall IGCC net efficiency increases of 4% compared to other IGCC cycles.

Duration: 24 months

Total Project Cost: $1,970,022 including NDIC share of $549,500 to meet the cost-share already in place from the State of Wyoming Clean Coal Technology Program/UW School of Energy Resources award of $977,617 and other government/private/industry support of $437,905.

Participants: Western Research Institute; Energy and Environmental Research Center; Gas Technology Institute; FuelCell Energy, Etaa Energy, Inc; and Washington Division of URS.

1.0 PROJECT SUMMARY

1.1 Background

Recent developments on the climate change issue threaten both the existing western high-moisture low-rank coal-fired power industry, as well as future expansion of clean energy from coals such as North Dakota (ND) lignite and Powder River Basin (PRB) subbituminous coal. Research, development and in particular, demonstration efforts leading to commercial deployment and directed at the efficient and clean use of these western coals, including CO_2 capture and storage, will have far reaching impact on the economic future of these western states, as well as provide energy security and a cleaner environment for future generations.

Integrated gasification combined cycle (IGCC) with CO_2 capture, appears to be one of the leading options for new coal-based power plants in that it can produce energy at a higher efficiency and at reduced CO_2 emissions per MWh. The use of western coal, with its low heating value and high-moisture, is at an efficiency disadvantage with eastern bituminous coal due to the high-moisture content of the coal. As such, western coal use in gasification is hampered in the following areas (1) plant efficiency, (2) environmental impact, and (3) overall IGCC costs.

Over the years, gasification technologies have used (and are still being used) with high-moisture low-rank western coals. The major technical challenges associated with the commercialization of CO_2 capture technologies for coal-fired power plants are lowering their costs (capital and operating) and reducing parasitic power demand.

The current and proposed research addresses these challenges. In 2007, the State of Wyoming Clean Coal Technology Program administered through the UW School of Energy Resources, with co-funding from the U.S. Department of Energy, awarded a contract to a team headed by WRI to examine PRB coal gasification at high altitudes integrated with the

WRITECoal™ process. WRI's WRTECoal™ gasification process approach to power generation and CO_2 separation includes WRI's patented WRITECoal™ process and modifications to various gasification processes using high-moisture coals. Specifically, the gasification process uses a two-step approach by splitting the partial heat release and gasification processes in order to:

- Remove the moisture from the coal and use the recovered moisture elsewhere in the plant, thereby increasing the plant efficiency;
- Control the interaction between the coal particle/syngas species and the oxidant through changes in gasifier and downstream components process performance and thereby obtain desired gas quality for end use(s);
- Generate a high CO syngas in the gasifier that can be used for power generation and/or chemicals production; and
- Generate CO_2-rich gas to enable cost-effective CO_2 separation and ultimately its sequestration.

In so doing, this novel lignite-based energy conversion plant produces syngas with high heating values, flue gas with increased CO_2 concentration, and an overall IGCC process with net electrical efficiency <u>increased by as much as 4%</u> compared to other IGCC configurations, when employing carbon capture.

The next logical step in the development, advancement and ultimately commercial deployment of the technology is to conduct pilot-scale testing to confirm the bench-scale and modeling study results and to identify engineering and scale-up issues and to estimate the cost of integrated WRITECoal™ gasification process applications.

1.2 Objectives

Key objectives of the program are:

- Develop efficient energy conversion processes for high-moisture coals. This is achieved by completely separating the gasification and water-gas shift reactions.
- Demonstrate the co-benefits of the WRITECoal™ gasification process with downstream IGCC system modifications and gasifier operation changes.
- Provide technology pathway for co-generation of chemicals (along with power) using high-moisture fuels thereby making the technology application fuel neutral (i.e. applicable to all coal ranks).

1.3 Teaming Arrangement

WRI has teamed with Gas Technology Institute (GTI) and Etaa Energy, Inc. (EEI) with support from the U.S. Department of Energy (DOE) and the Wyoming Clean Coal Technologies Program for the Phase I scope of work. WRI, under the proposed Phase II effort, will be adding team members-Energy and Environmental Research Center (EERC), FuelCell Energy (FCE), Washington Division of URS (URS) and support from the State of Wyoming, the North Dakota Industrial Commission (NDIC), Gas Technology Institute (GTI), Etaa Energy Inc. (EEI), UND EERC's National Center for Hydrogen Technology, FuelCell Energy (FCE) and private/industry and process suppliers, such as Haldor Topsoe and UOP,. The team will address the potential of upgrading of North Dakota lignite and Wyoming PRB coal via WRI's WRITECoal™ Integrated Gasification Combined Cycle (IGCC) process in order to enhance efficiency, reduce freshwater consumption, and reduce hazardous air pollutants, such as CO_2, SO_x, NO_x and mercury at 1-2 MWth and subpilot-scale. The proposed Phase II demonstration effort will involve conducting pilot-scale demonstrations of the WRITECoal™ gasification process, whereby treated coal is gasified in conjunction with EERC's 1-2 MWth-scale gasifier and GTI's subpilot-scale gasifier. The ultimate intent of the Phase II effort is to develop the engineering data and costing information needed to commercially deploy the technology at plants in the west, including North Dakota and Wyoming. The successful demonstration and ultimate deployment will significantly assist this region by maintaining jobs and economic benefits to these States.

1.4 Scope of Work

WRI proposes to demonstrate the WRITECoal™ gasification technology developed for PRB coals under Phase I for gasification/IGCC by conducting pilot-scale demonstrations of the technology subsystems, including the WRITECoal™ gasification process using North Dakota lignite and Wyoming Powder River Basin (PRB) subbituminous coal at 1-2 MWth scale at WRI, WRITECoal™/transport reactor gasification operation (1-2 MWth) at EERC, WRITECoal™/U-GAS® gasification subpilot-scale at GTI operating conditions. In addition, modifications to the downstream systems interaction such as with syngas cooling, water-gas shift reactors, and syngas cleanup subsystems will be evaluated. The test data from this Phase II effort will be analyzed in order to develop a technically and economically viable IGCC system and fuel cell-based IGFC system. The results of the Phase I and II efforts will further define the commercial technical and economic viability of the WRITECoal™ gasification process.

1.5. Tasks to be Performed

The scope of work for the proposed project is contained in following phases and the associated series of tasks:

Phase II Scope of Work

Task 1. Coal Selection and Characterization.

Representative high-moisture North Dakota lignite and Wyoming Powder River Basin coal will be selected and shipped to WRI for 1-2MWth-scale WRITECoal™ testing and the treated coals will be sent for testing in EERC's 1-2 MWth gasifier and GTI's subpilot-scale U-GAS® facility. The coals will be chemically and physically characterized and the reactivity determined for the raw and WRITECoal™-treated fuels by high pressure thermogravimetric analyzer (HPTGA).

Task 2. WRITECoal™ Process 1-2 MWth Pilot-scale Testing

The two selected high-moisture western coals will be tested according to the WRITECoal™ process at WRI's 1-2MWth WRITECoal™ pilot-scale facilities to determine process performance, product properties, and quality of the evolved water for use in water gas shift reactions and other plant operations as related to IGCC with carbon capture processes.

Task 3. Gasification Testing

Two WRITECoal™ treated-coals will be tested using subpilot-scale gasifiers and other techniques to determine reactivity, syngas composition and operating conditions in the pilot-scale Transport Reactor and U-GAS® gasifiers. Testing of the WRITECoal™ product following WRI's overall gasification/IGCC process with carbon capture will be conducted at WRI, EERC and GTI with support from Haldor Topsoe and UOP. The EERC's 1-2 MWth pilot-scale transport reactor gasifier and GTI's subpilot-scale U-GAS® fluidized bed gasifier tests will be used to provide the necessary data to model the WRITECoal™ IGCC system and assess its costs. EERC, through their National Center for Hydrogen Technology, will conduct hydrogen separation studies related to hydrogen production.

Task 4. System Analysis and Modeling of WRITECoal™ Gasification Systems

Data from the WRI process testing as well as both the GTI U-GAS® subpilot-scale gasifier and the EERC 1-2 MWth Transport Reactor Demonstration Unit (TRDU) pilot-scale gasifier demonstrations will be evaluated in order to provide design guidelines and to assess the overall IGCC plant performance. The IGCC plant will define each subsystem using proprietary WRI and GTI models and will assess the overall IGCC efficiency with raw and treated western high-moisture coals. Haldor Topsoe and UOP will assist in assessing the impacts of the WRITECoal™ gasification on their water gas shift (WGS) and SELEXOL® CO_2 removal processes, respectively. FCE will model the WRITECoal™/gasifier application with fuel cells (IGFC). The modeling efforts will use ASPEN Plus® based models and in-house proprietary models at WRI, GTI, FCE and selected vendors. The modeling will address the use of both raw and WRITECoal™-treated lignite and PRB coal, under gasifier conditions resulting from the Transport Reactor and U-GAS® gasifier testing.

Task 5. Engineering Process Design

Upon completion of the data evaluation and modeling, a demonstration-scale WRITECoal™ gasification module (5-10 MWth) will be designed. Key features will include the following:

- Use both PRB and ND lignite and PRB coal in both raw and WRITECoal™-treated forms.
- Non-slagging gasifier, and;
- Operate at 1700-2000º F and up to 1000 psig pressure. The pressure limit will be finalized after evaluation of the downstream process stream development priorities.

The engineering design will prepare the stream flow conditions, the range of applicability of the design, overall dimensions of the reactor components and the expected performance. Detailed engineering/manufacturing drawings will not be prepared.

Task 6. Economic Assessment

Washington Division of URS will perform a cost assessment of the WRITECoal™ gasification process based on the pilot-scale test data. Both capital and O&M costs will be developed and compared with other gasification technologies. Levelized costs of electricity (LCOE) as well as the cost of CO_2 capture will be determined.

1.6 Deliverables

Quarterly, interim, and final reports will be submitted in accordance with the NDIC guidelines. The primary deliverable will be a project final report that documents the testing, data analysis and reduction, design and cost study along with water removal for the application of the WRI process™ to gasification systems. WRI will prepare briefings and technical presentations for NDIC. Test results and conclusions will be presented at U.S. technical conferences as per NDIC guidelines.

1.7 Project Funding

The estimated costs for Phase II of the program are $1,970,022 with a total of $549,500 being requested from the Lignite Research Council/North Dakota Industrial Commission. Matching funding has been committed from the State of Wyoming Clean Coal Technology Program in the amount of $977,617. The EERC National Center for Hydrogen Technology and private/ industry co-sponsors, such as Western Research Institute, Etaa Energy, FuelCell Energy, Montana-Dakota Utilities, and Basin Electric Power Cooperative will provide $442,905 of co-funding.

2.0 PROJECT DESCRIPTION

2.1 Background

Coal utilization will continue to be a key factor in meeting the energy demand in the U.S. and other parts of the world in the next few decades (Bauer, 2009). As shown in Table 2.1.1, the coal use and the CO_2 generation in the U.S. are expected to increase during that time. Without accelerated technology development to address the CO_2 reduction along with options for efficient and greener form of energy supply from coal based technologies, coal use and indirectly the economic progress of the country will be severely impacted.

Table 2.1.1 Dominance of Coal in Energy Supply and CO_2 Emission

Energy Source	Unit	Energy Use		Unit	CO_2 Emission	
		2006	2030		2006	2030
Coal	QBtu/yr	23	26	bmt/yr	2.1	2.5
Gas	QBtu/yr	22	24	bmt/yr	1.2	1.3
Nuclear	QBtu/yr	8	9			
Oil	QBtu/yr	41	38	bmt/yr	2.6	2.6
Renewables	QBtu/yr	6	14			
Total	QBtu/yr	100	111	bmt/yr	5.9	6.4
Change (Total)	%		11	%		8.0

High-moisture lignite represents approximately 25% of the known recoverable coal resources in the U.S. However, the climate change issue threatens both the existing western high-moisture low rank coal-fired power industry as well as future expansion of clean energy from western coal. Research, development and in particular, pilot-scale demonstration efforts leading to commercial deployment and directed at the efficient and clean use of western coals, including CO_2 capture and storage, use of western coals will have far reaching impact on the economic future of these western states, as well as provide energy security and a cleaner environment for future generations.

2.1.1 Gasification Technology for Western High-Moisture Coal Utilization

All coal-based energy technology developments focus on efficiency and environmental enhancements with CO_2 removal. The major technical challenges associated with the commercialization of CO_2 capture technologies for coal-fired power plants are lowering their costs (capital and operating) and reducing parasitic power demand. Specifically, the following issues need to be addressed (Ciferno, 2007) in new designs and especially with western coal-fired IGCC with carbon capture.

Increase Cost-effectiveness – A number of studies by DOE, EPRI and others have established that CO_2 capture technologies are expensive (up to 85% increase in COE) and energy intensive (about a 30% reduction in power). In a DOE study (Ciferno,2007), the Total Plant Costs (TPC) for a supercritical PC plant without carbon capture is $1,575/kW, the TCP for ultra-supercritical plant without carbon capture is $1,641/kW, and the TPC of an IGCC without carbon capture is $1,841/kW. In the same study, the TPC for the above technologies with CCS are shown to be in the range of $2,496 to $2,930/kW (Table 2.1.1/Fig. 2.1.1.1/Ciferno, 2007-modified). Only IGCC shows a COE increase of less than 40% with the addition of carbon capture; however, it has a relatively high (7.8 cents/kWh) levelized cost of electricity (LCOE) without carbon capture.

Reduce Oxygen Supply – Oxy-combustion and oxygen-blown IGCC power plants require a supply of high-purity (95-99%) O_2. Currently cryogenic oxygen production has high capital and operating costs in addition to a high auxiliary power load. Advanced systems such as chemical looping and membrane air separation technologies are expected to reduce costs and associated parasitic power demand.

Table 2.1.1.1. Total Plant Costs and LCOE with Carbon Capture Power Options

	With CO_2 Capture				
Bituminous Coals	**SCPC MEA**	**USC MEA**	**SCPC Oxy-Fuel**	**USC Oxy-Fuel**	**IGCC**
Total Plant Cost, $/kW	$2,857	$2,867	$2,930	$2,898	$2,496
LCOE, cents/kWh	11.4	11.0	11.3	10.7	110.6
% Increase w/ Capture	82	75	80	71	36

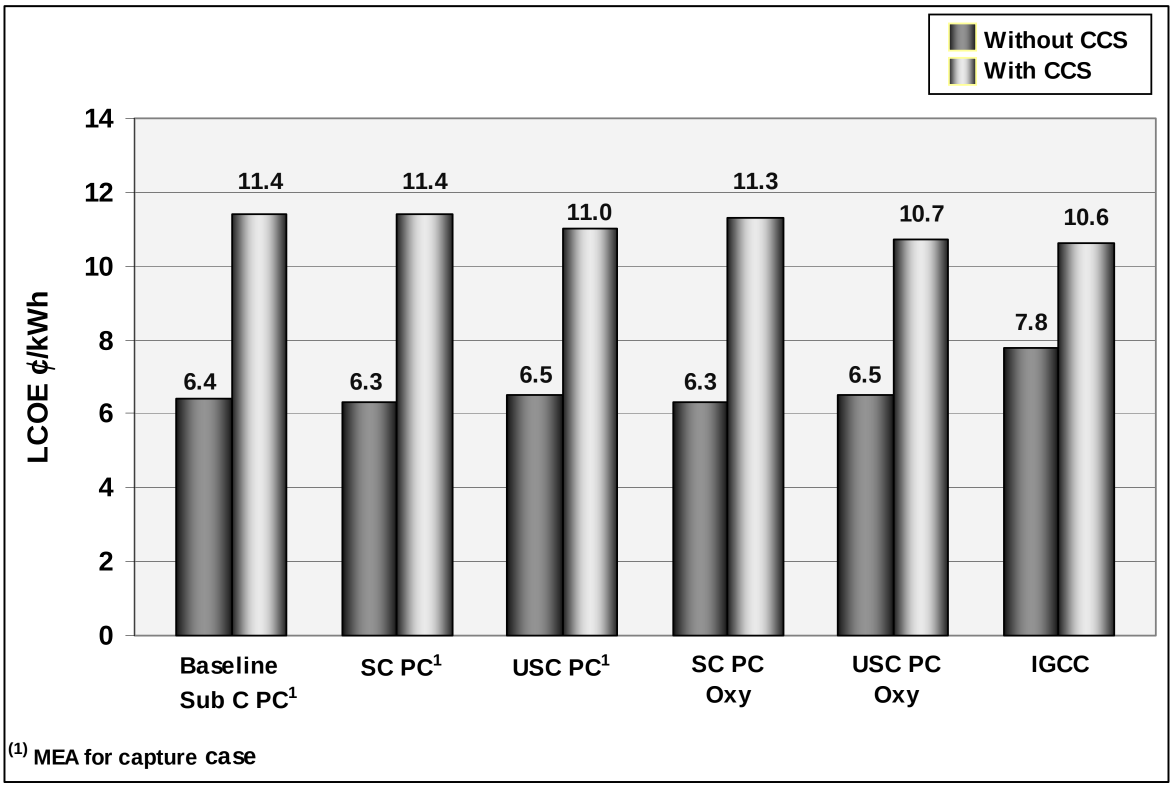

Figure 2.1.1.1. Levelized Costs of Electricity (LCOE) for Various Power Options With and Without Carbon Capture (Modified from Ciferno, 2007)

Increase Energy Efficiency – The integration of energy efficiency enhancing technologies into existing plants offers an opportunity to enhance the overall efficiency of the integrated CO_2 capture-ready power plant (Fig. 2.1.1.2) as well. WRI's WRITECoal™ technology is one such method to increase efficiency. A recent study (Fan and Seltzer, 2009, Bland et al, 2009) has shown a 3-6% increased power output for subcritical plants with WRITECoal™ system integration. In addition, for greenfield plants, the upgrading of sub-critical steam cycles with super-critical or even ultra-super-critical steam cycles improve efficiency to help offset the large parasitic power with carbon capture.

Reduce Parasitic Load – A significant amount of auxiliary power is required to operate CO_2 capture technologies, which results in a de-rating of retrofitted plants. Technologies that reduce the parasitic power are needed to keep the COE at an acceptable level.

Lower Water Use – A significant amount of water is required for CO_2 capture and compression cooling. Methods to reduce water demand, such as air cooling, water recovery (e.g., WRITECoal™ process), and alternate sources offer the opportunity to reduce freshwater raw water demand. The water demand increases significantly with CO_2 capture and DOE data (2007) estimates the water demand with and without CO_2 capture as shown in Fig. 2.1.1.2.

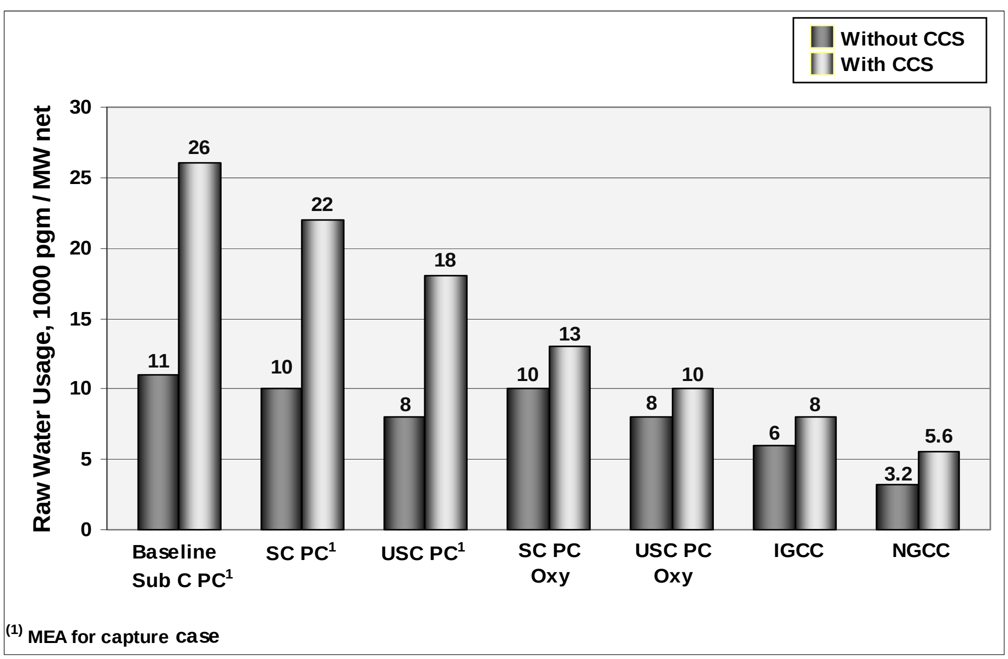

Figure 2.1.1.2. Comparison of Raw Water Usage for Various Power Options With and Without Carbon Capture (Modified from Ciferno, 2007)

Flue Gas Contaminants – Constituents in the flue gas, particularly SO_3, Hg, as well as SO_2 and NO_x are required to be cleaned from the flue gas; they can contaminate certain CO_2 capture technologies, shortening their life spans and leading to increased operational expenses.

The above discussion clearly demonstrates that the gasification pathway is a leading option for converting the coal-bound chemical energy into multiple byproduct energy streams. Conventional gasification process employs a gasifier vessel with input streams of raw or partially dried coal, oxidant, and water/ steam followed by syngas cooling and cleaning and syngas combustion. All gasification technologies build around this approach but they differ in the way the gas-solid interaction takes place, namely, fixed bed, fluidized bed and entrained bed systems. Different process developers may claim advantage over the other in terms of carbon conversion efficiency, ease of operation, and reactor availability. Syngas composition is controlled by other conditions and factors.

2.1.2 Relevance of Coal Rank and Gasifier Performance. The Electric Power Research Institute's Dalton and Novak in 2007 identified key factors for selection of IGCC over other technologies for the application of CCS. These include (1) coal type (characteristics/rank); (2) site characteristics, including elevation; (3) plant and gasifier type; (<1,100 lb/MWh CO_2 emissions via IGCC requires 90% removal from 50% of the syngas); and (4) financing method. It is known that coal rank has a large impact on the IGGC efficiency and ultimate costs of IGCC systems. Booras (2008) pointed out the influence of coal rank on plant efficiency and plant costs (Fig. 2.1.2.1).

Fig. 2.1.2.1 illustrates increase in the heat content between bituminous coal and high moisture coals results in increases in IGCC capital cost. This can be eliminated if the upgrading (moisture removal and recovery) can be accomplished to a large degree using waste heat from the IGCC. As such, coal upgrading technologies, such as the WRITECoal™ process, are part of an advanced western high-moisture low-rank coal-based gasification IGCC technology.

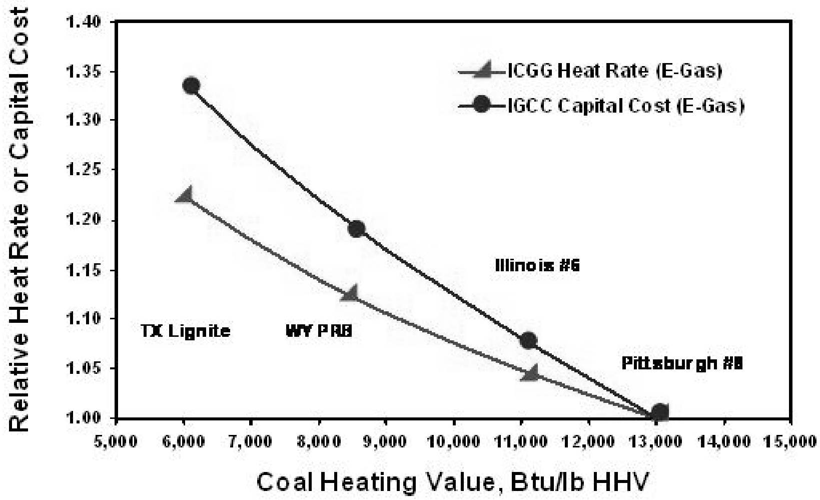

Fig. 2.1.2.1. Correlation Between Coal Rank and IGCC Heat Rate and Cost

(Modified from Booras, 2008)

In summary, IGCC with CCS appears to be one of the leading options for new coal-based power plants that can produce energy at a higher efficiency and at reduced CO_2 emissions per MWh and represents a processing option for future North Dakota lignite-based plants.

2.1.3 High-Moisture Coal and Gasification

Over the years, gasification technologies have planned to use or have used high-moisture coals such as North Dakota lignite and Wyoming PRB subbituminous coals for gasification employing raw coal feed to the gasifier (DOE, 2000). Recent advances address the partial drying of the fuel (Carbo, et al, 2009; Callaghan, 2006; Maurstad, 2009; and Zuideveld, 2005). Although recent advances have addressed the partial drying of the fuel, the development focus has not taken advantage of the attributes associated with near-compete drying such as the WRI WRITECoal™ process for moisture removal prior to being fed into the gasifier.

The current and proposed research addresses these advantages. In 2007, the State of Wyoming through the School of Energy Resources, with co-funding from the U.S. Department of Energy, awarded a contract to a team headed by Western Research Institute to examine PRB coal gasification at high altitudes integrated with the WRITECoal™ process. WRI's WRITECoal™ gasification process is a patent-pending approach to power generation and CO_2 separation that includes integration of WRI's patented WRITECoal™ process with various gasification processes to form a new gasification process with unique and improved performance.

Specifically, the WRITECoal™ gasification process uses a two-step approach by splitting the partial heat release and gasification processes in order to:

- Remove the moisture from the coal and use the recovered moisture elsewhere in the plant, thereby increasing plant efficiency;
- Control the interaction between the coal particle and the oxidant and thereby obtain desired gas quality for end use(s); and
- Generate CO_2-rich gas to enable CO_2 separation before the syngas is used in power generation and/or chemicals production.
- Modify the IGCC downstream subsystems and gasifier operating conditions in order to affect improved IGCC performance and costs.

In so doing, the overall IGCC process net electrical efficiency can be <u>increased by 4%</u> compared to other IGCC configurations, using raw or partially dried coals.

The next logical step in the development and advancement of the technology is to conduct pilot scale testing to confirm the bench-scale and modeling studies and to determine the engineering and scale-up issues or scale-up and cost estimates of WRI's integrated WRITECoal™ gasification process.

2.2. Project Objectives

Key objectives of the program are:

- Develop efficient energy conversion processes for high-moisture coals. This is achieved by completely separating the gasification and downstream IGCC subsystems, such as syngas cooling, water-gas shift reactions and syngas cleaning as well as modified operations of the gasification island.
- Produce a high H_2+CO syngas and thereby provide technology pathway for co-generation of chemicals (along with power) using high-moisture fuels with the net result of making the technology fuel neutral (i.e. applicable to all coal ranks).

The overall project goal is to develop and demonstrate at the pilot-scale an advanced highly efficient IGCC with carbon capture and thereby lower the cost of electricity (COE) compared to other current IGCC system configurations. The proposed development program for the WRITECoal gasification process is designed to meet these objectives and goals.

The project objectives defined in 2007 for Phase I of the project dealt with laboratory and bench-scale testing and modeling as a proof-of-concept effort. Based on the significant Phase I findings, a pilot-scale program was designed (proposed herein), it is envisioned that a larger-scale demonstration of the WRITECoal gasification process may be necessary before commercial deployment (Phase III). The focus for all three Phases is described below.

Phase I (Complete)

- Completed. Assessed water reuse and mercury removal associated with WRI's process and assess the benefits and issues of integrating WRI's process with gasification process, such as GTI's fluid bed gasifier, through laboratory and bench-scale testing and modeling.

Phase II (Proposed Herein)

- For western low-rank high-moisture coals, confirm the Phase I results and conduct subpilot-scale and 1-2 MWth pilot-scale demonstration in the Energy and Environmental Research Institute (EERC)'s transport reactor gasifier and Gas technology Institute (GTI)'s U-GAS® gasifier, and conduct system analysis, modeling, commercial-scale design, in order to acquire engineering data needed for scale-up of the technology to the 5MWth-scale in Phase III.

Phase III (Future)

- If Phase II is successful, a Phase III may be required that addresses engineering-scale, longer-duration testing in a large demonstration (>5MWth) unit. This demonstration would be at a 5 MWth pilot-scale, such as the Flex-Fuel facility and employing an equivalent 5 MWth-scale WRITECoal™ process demonstration unit.

2.3. Program Continuation - Phase II Demonstration

WRI proposes to demonstrate the WRITECoal™ gasification technology developed for PRB coals under Phase I for gasification/IGCC by conducting pilot-scale demonstrations of the technology subsystems, including the WRITECoal™ process at 1-2 MWth scale at WRI, WRITECoal™/transport reactor gasification (1-2 MWth) at EERC and WRITECoal™/U-GAS® gasification subpilot-scale at GTI. A description of WRITECoal™ process facilities, the pilot-scale gasifier at EERC and subpilot-scale U-GAS® gasifier at GTI is presented in Section 2.6. The test data from this Phase II effort will be analyzed for developing a technically and economically viable IGCC system. The results of the Phase I and II efforts will further define the commercial technical and economic viability of the WRITECoal™ gasification process.

2.4 Technology Description

The proposed project addresses an advanced gasification technology that is based in part on WRI's pre-gasification coal upgrading process (WRITECoal™). When the WRITECoal™ process is integrated into the power generation plant with thermally pre-treated feed coal, energy conversion efficiency is increased and emissions, including volatile species such as mercury, arsenic and selenium, are reduced through release from the coal prior to gasification. Targeted use of the recovered water in the gasification process helps control the water-gas-shift reactions resulting in new cycle designs and cycle efficiencies. This integration has impacts throughout the IGCC system allowing for advanced gasification feed systems and gasification design modifications, and the possibility of CO_2 re-use and polygeneration.

There are three of these subsystems that are required for CO_2 capture and storage: water gas shift, acid gas/CO_2 removal and CO_2 compression. IGCC without carbon capture can also be accomplished with an air-blown gasifier and thereby the air separation unit is not included. The WRITECoal™ gasification process can be integrated into either the air blown (without CO_2 capture) or the oxygen blown gasifier (with CO_2 capture). The following discussion centers on the integration of the WRITECoal™ process into an IGCC with carbon capture.

WRITECoal™ Gasification Technology WRI's WRITECoal™ gasification process is a patent-pending approach to power generation and CO_2 separation that includes WRI's patented WRITECoal™ process and various gasification processes such as EERC's transport reactor and GTI's U-Gas™. Specifically, the WRITECoal™ gasification process uses a two-step approach by splitting the partial heat release and gasification processes.

WRI's WRITECoal™ gasification technology (a possible integrated configuration shown in Fig. 2.4.1) is based on the integration of the WRITECoal™ process into a gasifier/IGCC. There are three islands- (a) WRITECoal™ process, (b) gasifier and syngas cleanup, and (c) power generation island. Of these, the WRITECoal™ process island is the island that requires integration to an existing IGCC. High-moisture coal, such as North Dakota lignite and PRB subbituminous coal, is upgraded, using waste heat from the IGCC process. The source of heat and the integration details are proprietary. The moisture in the coal is removed and recovered for use later in the system. The water recovered is then specifically targeted at the low temperature water gas shift (WGS) reaction, thereby reducing the energy required with heating ~30 to 40% of inherent water in the coal mass through the temperature profile of the gasifier.

The treated coal has <0.5 wt% sulfur, <1 wt% moisture and maintains a high O_2 content compared with bituminous coals. The pressure and temperature in the gasifier are maintained to provide lower oxygen consumption from the ASU, by generating CO in the syngas and relying on the low temperature WGS to produce CO_2 and H_2. Less steam from the steam circuit is needed for this WGS step. The syngas cooling and acid gas removal requirements are also lessened with the proposed process. Other portions of the IGCC system are less impacted, but the overall efficiency and system are optimized and as such represents the lowest cost and highest efficiency IGCC cycle for western high-moisture coals as shown later.

"Fig. 2.4.1 Possible Integration of the WRI Technology with an IGCC Island" is shown under Appendix C-Confidential Information.

Process Subsystem Technology Descriptions and Development Status

The following description illustrates the main subsystems of the integrated WRITECoal™-gasifier/IGCC system, primarily the WRITECoal™ process and the Transport Reactor gasifier and the U-GAS® gasifier.

WRI's WRITECoal™ Coal Upgrading Process. WRI has developed a technology that involves the removal of moisture from coal, thereby increasing energy efficiency at power plants, produces water for plant needs, and reduces emissions, particularly mercury prior to combustion/gasification at a stable coal fuel cost.

In the WRI process, the coal is heated to remove the moisture and then heated to a higher temperature in a separate zone to evolve the mercury. A conceptual diagram of the process is shown below in Fig. 2.4.2.

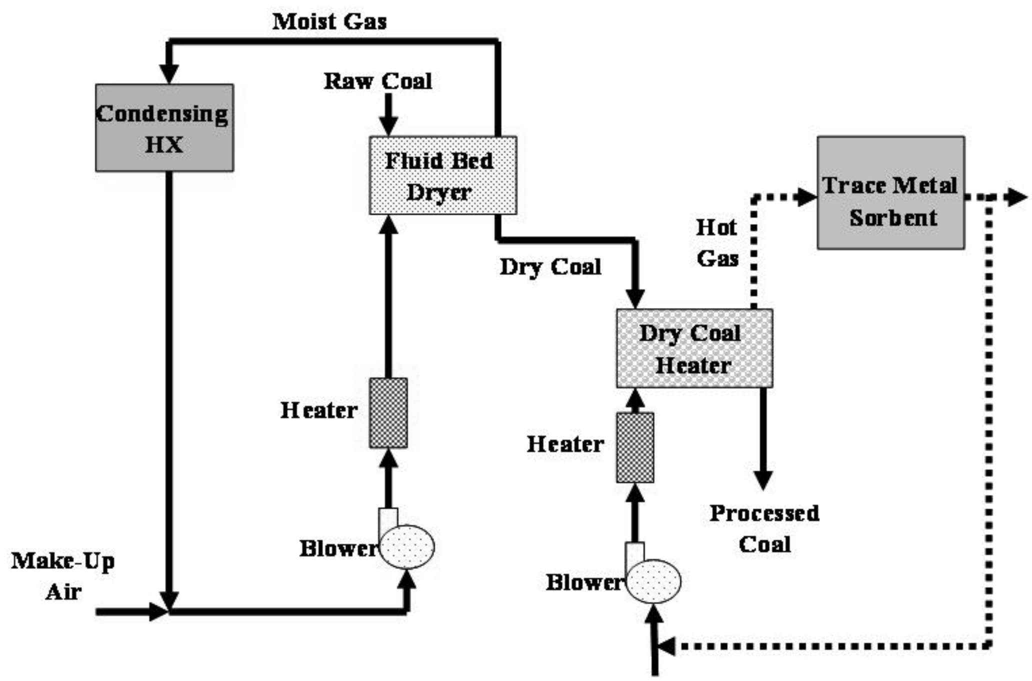

Figure 2.4.2. Schematic of the WRITECoal™ Process

Raw coal, crushed to a suitable size enters the moisture removal zone where it is heated to a temperature not exceeding 300°F. In this zone, the free water and some of the more tightly bound water is volatilized and removed from the zone by a sweep gas. The coal is then transferred to the mercury removal zone where it is heated to a temperature of approximately 550° F. In this zone, 75 to 80% of the mercury in North Dakota lignite or PRB coal is volatilized and removed from the zone by an inert sweep gas. In addition, 25-40% of the selenium and arsenic are also released from the coal. The coal is then ready for additional size reduction via pulverizer and injection into combustors or gasifiers. The sweep gas stream, containing the evolved mercury, passes into the mercury removal equipment and the mercury is captured.

The process is being developed for integration into the power plant (either combustion or gasification) as compared to deployment at the mine site. The advantages of deployment at the power plant are (1) waste heat from the plant can be used for process heat, (2) avoids all dusting and spontaneous combustion issues often associated with dried coal transport and storage, (3) allows the plant to be able to competitively procure coal (not held captive to a single coal supplier), and (4) allows for the moisture liberated during processing to be used at the plant, thereby reducing fresh-water needs. In addition to recovery of moisture, increased plant efficiency and removal of mercury, the process operates at a temperature of 550°F, with little loss of volatile matter from the coal, thereby maintaining the coal's combustion and gasification characteristics. Detailed description of the process and combustion applications can be found in Bland et al (2004, 2006, 2007, 2008, 2009), Guffey et al (2002) and Merriam (1993).

GTI's U-GAS® Gasifier Process. The GTI U-GAS® fluidized bed gasification process (Fig. 2.4.3) is based on a single-stage fluidized bed for production of low-to-medium heating value synthesis gas or 'syngas' from a variety of feedstocks including biomass and wastes. Two versions of the process were developed more or less in parallel, with the U-GAS® technology developed for gasification of all ranks of coal and the RENUGAS® technology for gasification of highly reactive fuels such as peat, biomass, pulp mill residues and wastes. Through this development process it was determined that a single gasifier design could be used for all of these fuels, including mixtures such as biomass and coal.

In the U-GAS® process, fuel is dried to the extent required for handling purposes and conveyed into the gasifier from a lockhopper system. Within the fluidized bed, the fuel reacts with steam and air or oxygen at a temperature of 1,550° F to 2,000° F. The temperature for gasification depends on the type of fuel used and is controlled to maintain high carbon conversion and non-slagging conditions for the ash.

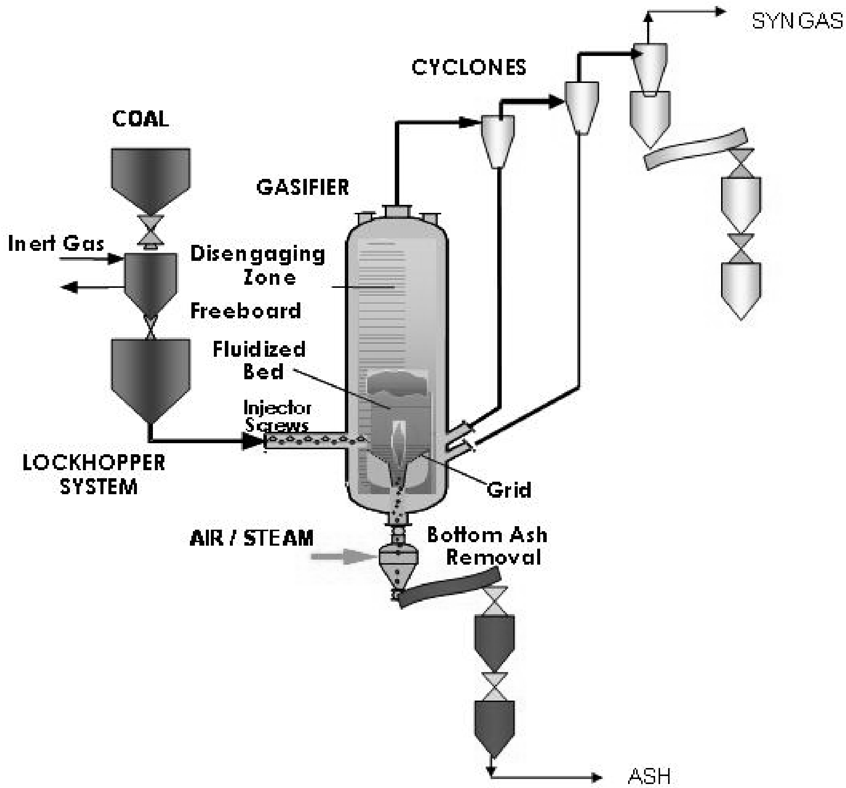

Figure 2.4.3. Schematic of GTI U-GAS® Gasifier

The GTI process accomplishes four important functions in a single-stage fluidized bed gasifier. It decakes, devolatilizes, and gasifies fuel, and if necessary, agglomerates and separates ash from the reacting char. The operating pressure of the gasifier depends on the end use for the syngas and may vary from 40 to 435 psia or more. After cleaning, the product gas can be used as industrial fuel gas for process heating, synthesis gas for production of ammonia, hydrogen or liquids, and for power generation via IGCC or fuel cells.

Reactant gases, including steam, air and/or oxygen are introduced into the gasifier in two areas: 1) through a sloping distribution grid at the bottom of the bed, and 2) through a terminal velocity-controlled ash discharge port at the center of the distribution grid. In both agglomerating and non-agglomerating operating modes, ash is separated by gravity from the fluidized bed and discharged into a lockhopper system for depressurization and disposal. In both operating modes, the gasifier maintains a low level of carbon in the bottom ash discharge stream, making overall carbon conversion of 95% or higher possible. Cold gas efficiencies of over 80% can be achieved.

Fines elutriated from the fluidized bed are typically separated from the product syngas by up to three stages of external cyclone separators, one or two of which may return the fines to the fluidized bed for increased carbon conversion. The product syngas is essentially free of tars and oils due to the temperature and residence time of the gases in the fluidized bed, simplifying downstream heat recovery and gas cleaning operations.

Due to its dry feeding system (as opposed to slurry or paste feeding) non-slagging operation and increased gas and solids residence times compared to entrained bed gasification technology, the GTI U-GAS® gasification process is capable of handling a wide range of fuels with a broad range of fuel properties. For example, the GTI U-GAS® gasifier can handle fuel moisture contents from 1-41% and fuels with ash softening temperatures of 1915 – 2700º F. High-moisture, low-rank coals such as Montana Rosebud and Colstrip mines, Wyoming Big Horn Basin, North Dakota Freedom mine and Saskatchewan lignite from the Shand Power Station have been tested in the GTI gasifier.

Nexant (2005) performed a study of the U-GAS® IGCC without carbon capture. The GTI fluidized bed gasifiers (one operating and one spare) to power one GE 7FB combustion turbine (Zizamoff et al, 2005). An oxygen-blown design was selected for this application to allow for the possible capture and sequestration of CO_2. The plant consumed 2,558 tpd of lignite coal and exported 251 MW of power. It also produced 1,557 lb/hr of sulfur and 21,063 lb/hr of ash. The lignite was dried from 32.2% moisture to 20% moisture before being fed to the gasifier to assist with fuel handling. The estimated cost of the facility was 410M$ (2nd quarter of 2004) or about $1,635 $/kW of export power. Based on the average electricity tariff in North Dakota, the plant has an expected return on investment of 19.4%, with a net present value (NPV) of 175.6 M$ at a 10% discount rate over a 20 year project life. The combustion turbine produced about 211 MW of power. The two steam turbines generated about 91 MW of electric power. The facility had an internal parasitic power load of about 51 MW, reducing the net export power from the facility to 251 MW. The gasifier showed an availability of 87.2%, a cold gas efficiency of 84%, net electrical efficiency of 36.5% and raw water consumption of 1,920gpm. The U-GAS® technology continues to be commercially deployed. Smaller units have been built and operated on a range of the fuels mentioned above. Synthesis Energy Systems (SES) recently installed a U-GAS® gasification system at the Hai Hua plant in China. Photographs of that plant are shown in Fig. 2.4.4. The SES Hai Hua plant is designed for 300 tons/day of coal (25MWe equivalent) and is designed to produce 28,000 scm/h of syngas.

Figure 2.4.4. U-GAS® Hai Hua Gasification Facility in China Built by SES (GTI, 2009)

Transport Reactor Gasification Technology. The Transport Reactor (TR) gasification technology was originally developed by KBR and Southern Company through the U.S. Department of Energy. Southern Company Services (SCS)/Electric Power Research Institute (EPRI) and others. US Department of Energy/EPRI and SCS built and operated an engineering-scale demonstration as part of the Power Systems Development Facility (PSDF) in Wilsonville, Alabama. The commercial version of the process was recently proposed for deployment as the Transport Reactor Integrated Gasification (TRIG) at the Mississippi Power Kemper site by Southern Company (Southern Company, 2009). EERC conducted the early support pilot-scale work for the TR technology development by Southern Company and U.S. DOE.

The KBR transport reactor can operate as a combustor or as a gasifier. As a gasifier, the TR has been tested in the air-blown and oxygen blown configuration. The transport reactor operates at higher solids circulation rates, velocities and riser densities than conventional circulating fluidized beds, resulting in higher throughout, better mixing, and higher mass and heat transfer rates. Because of its operating conditions, the TR is well suited to using high-moisture coal, such as Wyoming PRB coals and western and Gulf Coast lignite. Syngas from the TR gasifier can be used to fuel a gas turbine (IGCC) or a fuel cell (ICFC).

A generalized flow diagram of the TRIG process as tested at the PSDF is shown in Fig. 2.4.5, in which fuel, limestone, steam, and air or oxygen are combined in the mixing zone with solids recirculation from the standpipe and the syngas and char then enters the disengager. The larger particles in the syngas are removed by gravity separation in the disengager and the majority of the remaining particles are removed in the cyclone.

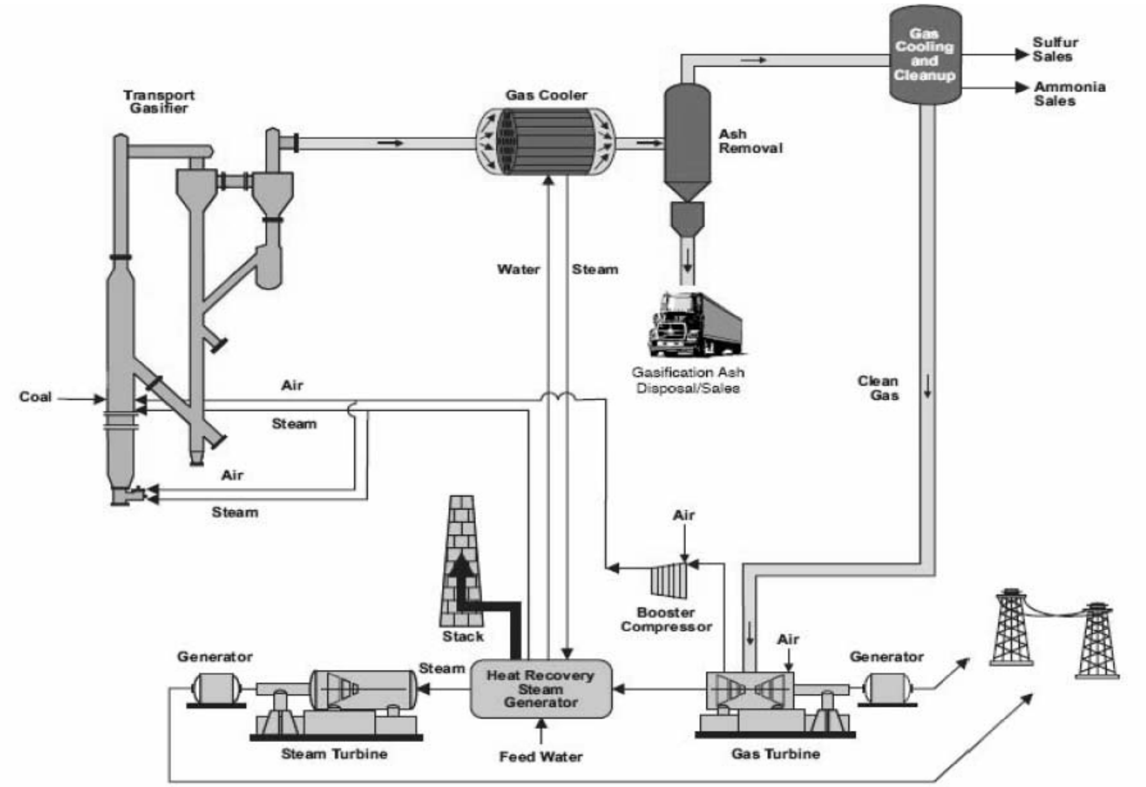

Figure 2.4.5 Generalized IGCC flow diagram employing the TRIG technology (Leonard et al, 2007)

At the PSDF, the gasifier converts coal, air, and steam into approximately 1,000,000 lb/hr of low-Btu syngas at 385 psia and 1,800°F. Limestone is fed to the gasifier at a design rate of 4 tons/hour and captures most of the sulfur in the coal during the gasification process. After solids removal in the disengager and cyclone, the syngas is cooled to 700°F in a fire-tube heat exchanger by raising high-pressure steam. The remaining entrained char is then removed in a HTHP filter using iron aluminide filter elements. Ninety-seven percent of the carbon in the coal is converted to syngas. The remaining carbon, together with reacted and unreacted limestone, and coal ash is removed from the gasifier and the high-temperature high-pressure (HTHP) filters, water is added for dust suppression, and the mixture sent to landfill. A small portion of the cleaned syngas is recycled back to the process to assist solids circulation in the gasifier and to pulse clean the HTHP filter. The remaining syngas is piped to the gas turbine. During system start-up, natural gas-fired burners heat the gasifier before solids are introduced.

Coals of all rank have been tested, including a PRB and an eastern bituminous coal campaign at the PSDF. The performance of the transport gasifier was shown to be better for the low-rank coals than the higher-ranked bituminous coals. Leonard et al, (2007) states that for the gasification island for a 300 MW net IGCC, TRIG design is centered around the KBR air-blown transport gasifier, fed with nominally 140 tons/hour of PRB sub-bituminous coal and supplying fuel to a GE 7FA combined cycle (Fig. 2.4.6).

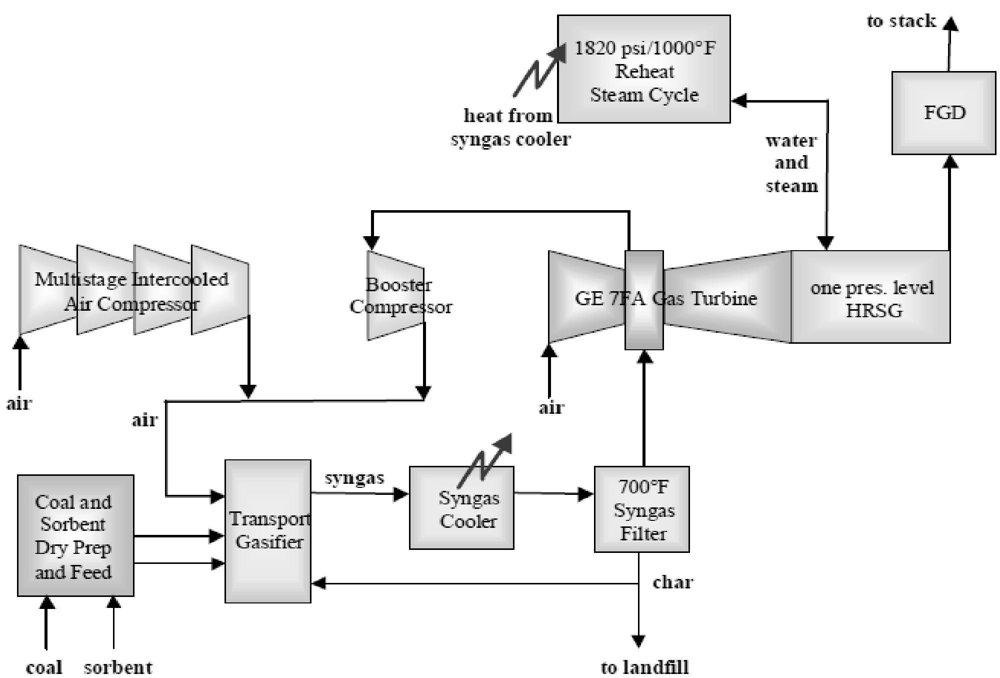

Figure 2.4.6. Schematic of TRIG IGCC Without Carbon Capture (Leonard et al, 2007)

A supplemental air compressor supplied 60 percent of the process air required by the gasifier, and the balance is extracted from the gas turbine. This arrangement has two major benefits: it allows the power output of the gas turbine to be maximized at different ambient conditions by varying the relative air flow rates, and it also greatly increases the operational flexibility of the system, which is critical during startup. The air extracted from the gas turbine compressor is cooled, boosted in pressure, and regeneratively heated before it is mixed with the air from the supplemental compressor.

Published performance estimates (Leonard et al, 2007) for a second of a kind air-blown 300 MWnet TRIG IGCC was 42.0% net efficiency (HHV), a heat rate of 8,130 Btu/kWh, 97% carbon conversion and total plant cost of $1,385/kW (2001$). Recent net efficiency estimate for a 582 MW TRIC carbon capture IGCC with 65% carbon capture for the Mississippi Power Kemper site was 29% (HHV), CO_2 emission was approximately 800 lb/MWh (Southern Company, 2009).

Fuel Cell Energy Technology. FuelCell Energy, Inc. (FCE) has an innovative approach to the fundamental need for clean power with its proprietary and patented ultra high-efficiency power plant design. At the core of this power plant design (shown schematically in Fig. 2.4.7) is FCE's commercial fuel cell technology, Direct FuelCell®(DFC®). The system extends the potential fuel savings of DFC® by combining a non-fired gas turbine and a network of heat exchangers to transfer waste heat from the fuel cell to the turbine, resulting in extra electricity and adding 10 to 15 percentage points to the efficiency of the DFC® approaching 55% overall net electricity efficiency.

The integration of the high efficiency of the fuel cell with the WRITECoal™ gasification process can help reduce parasitic load, improve efficiency and reduce CO_2 emissions. FuelCell Energy's Direct FuelCell® 3000 (DFC3000®) stationary fuel cells can currently be scaled to provide up to 50 megawatts (MW) or more of high-quality electric power while simultaneously generating negligible amounts of harmful emissions such as nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter.

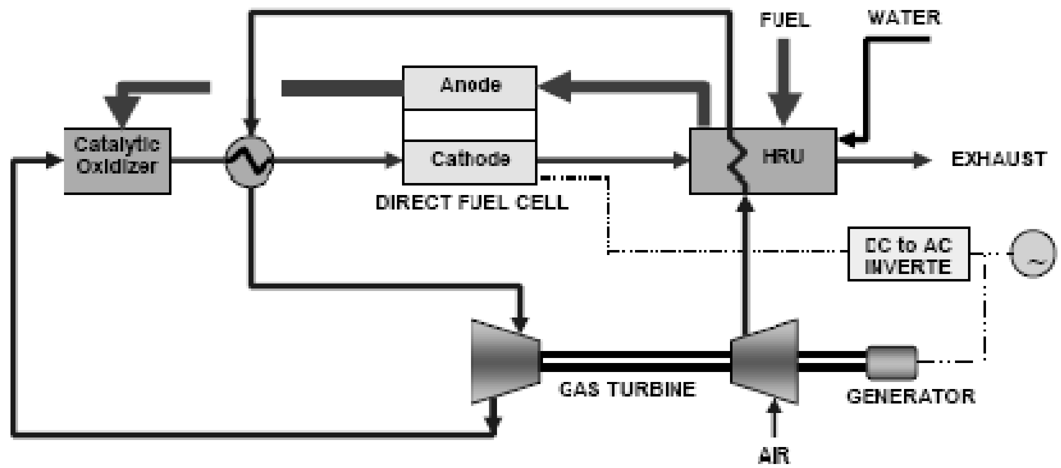

Fig. 2.4.7. DFC/Turbine® Ultra High Efficiency System (FCE, 2009)

FuelCell Energy, Inc. recently completed a field demonstration of its packaged sub-megawatt (sub-MW) class Direct FuelCell/Turbine® (DFC/T®) alpha power plant unit (Fig. 2.4.8). The power

Fig. 2.4.8. The First DFC/T® Power Plant during Factory Alpha Testing (FCE, 2009)

plant achieved an electrical efficiency of 56% (LLV). The plant's overall availability, including hot standby and power generation periods, exceeded 91%, which is a major achievement for a first-of-a-kind alpha unit. Emission monitoring tests of the DFC/T system have shown compliance with the most stringent environmental regulatory standards.

Anticipated Results

The following results are expected from the research project.

- Syngas quality will be significantly different and controllable between standard and WRITECoal™ gasification of lignite, based on pilot-scale results with WRITECoal™ gasification process producing a high H_2+CO (>80%) for IGCC and hydrogen production and fuel cell applications.
- Validation of earlier APSEN model results using the pilot-plant data confirming commercial viability and verifying the Phase I IGCC efficiency with carbon capture.
- Demonstration of the controllability of syngas quality through separate dedicated water-gas shift reactor and associated operating conditions within the gasifier to produce a range of syngas composition for end use, and
- Cost of electricity of WRITECoal™ gasification process will be less than 25% increase with carbon capture.

2.5 Methodologies

The following section describes the methodologies and experimental plan to be used for the project. A two-pronged approach will be pursued. In the first option, a subpilot-scale unit at the GTI will be used, expanding upon the TGA and bench-scale results from Phase I. Lignite and PRB coal will be used as the test fuels. In the second approach, the 1-2 MWth-scale Transport

Reactor test facility at the EERC will be used. Both North Dakota lignite and PRB subbituminous coal will be used on this pilot-scale unit as well. By this approach, WRI will provide the following deliverables and advance the technology development in an accelerated manner.

- HPTGA and subpilot-scale tests provide process data for GTI modeling of large units based on fluidized bed gasification.
- FCE/WRI/Etaa will characterize and evaluate the data from the EERC and GTI gasifiers for the integrated gasification fuel cell (IGFC) applications.
- EERC tests will provide data for WRI and Etaa modeling of the transport reactor.

This approach also ensures that the application of the WRITECoal™ process for low-rank coal gasification can be through both fluidized bed and transport reactor gasifer technologies.

The experimental design of the program can be visualized through a series of test matrices.

2.5.1 Task 1. Coal Selection, Acquisition and Characterization

Two high-moisture western coals, including the North Dakota lignite and PRB subbituminous coal, will be selected and used in the study.

Coal Chemical and Physical Characterization. Each coal will be chemically analyzed (see Table 2.5.1.1).

HPTGA Reactivity Tests A state-of-the-art HPTGA unit, capable of operation at conditions up to 1850°F and 1500 psia will be used to assess the reactivity of the raw and WRITECoal™-treated coals. All the hot wetted parts of the HPTGA unit are made of quartz to eliminate reaction with corrosive and reactive gases, which results in the loss of the reactant species in the gas phase.

Table 2.5.1.1. Coal Chemical and Physical property Testing

Parameter	Method	Parameter	Method
Proximate Analysis (wt.%)	D3180	Forms of Sulfur (wt.%)	D2492
Moisture (total) (wt.%)	D3302	Mercury (ppb dry)	D6721
Ash (wt.%)	D3174	Arsenic (ppb dry)	D6357
Volatile Matter (wt.%)	D5142	Selenium (ppb dry)	D4606
Fixed Carbon (wt.%)	D5142	Free Swelling Index	D 720
Sulfur (wt.%)	D4239	Particle Size Distribution	D 293
Heating Value (HHV)	D5865	Hardgrove Grindability Index	D 409
Ultimate Analysis, including Cl	D5373	Spontaneous Combustion Index	Miron (1990)
Mineral Analysis, including slagging and fouling indices			D 4326

HPTGA tests on the raw and treated WRITECoal™ coals will yield a measure of the coal (feed) reactivity for gasification. The appropriate temperature will be determined from the HPTGA tests. The coal will be devolatilized prior to the test since the char reactions are slow reactions. The devolatilization of the coal takes place in a few minutes. HPTGA will be used to determine the base carbon, defined as that portion of the carbon that is left over after devolatilization is complete. Deliverables include traces of weight loss vs. time and traces of base carbon conversion vs. time (at temperature) as well as comparison to other coals (Fig. 2.5.1.1).

The HPTGA testing will provide an indication of the devolatilization step and the char burnout rate under different temperature, pressure and syngas compositions. The following equation is used to develop the base carbon conversion graphs.

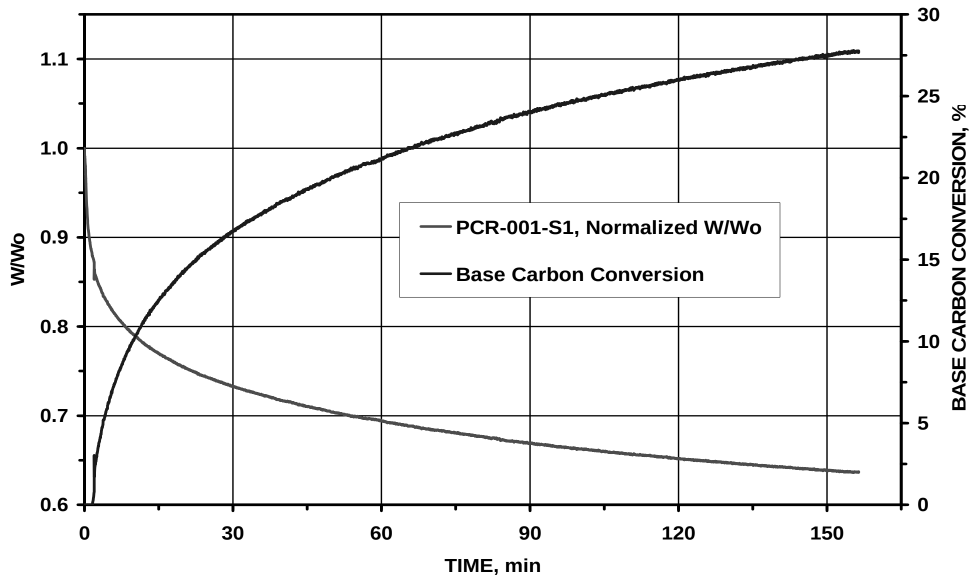

Figure 2.5.1.1. Typical Weight Loss and Carbon Conversion Traces

$$X = \frac{(W/W_o - VM)}{1 - VM - A}$$

X = base carbon conversion

W/W_o = total weight loss fraction referred to original coal

VM = weight loss during the 1 hour nitrogen devolatilization

A = ash mass fraction in feed coal

2.5.2 Task 2. WRITECoal™ Process 1-2 MWth Pilot-scale Testing

This task will address three activities: WRITECoal™ 1-2 MWth Pilot-scale Testing; Recovered Water Testing; and Product Handling/Feeding Testing

WRI 1-2 MWth Pilot-Scale Testing: The crushed (1-inch top size) coals will be processed in WRI's 1-2 MWth pilot-scale facilities following the protocol to produce a treated coal with <1%

moisture and with 65 to 80% mercury removal. WRI pilot-scale testing will employ the continuous-operation mobile 1-2 MWth-scale pilot located at the WRI Advanced Technology Center. The pilot-scale facility will be operated at a fixed residence time and operated at different temperatures. Each test run will include mass balances and will determine closures for water, solids, and trace metals such as mercury, arsenic and selenium. The collected materials (solids, liquids and gases) will be analyzed for moisture and trace metals. Mercury measurement equipment will be operated according to Federal protocol.

Recovered Water Tests: Water quality testing will focus on the water produced from the WRI pilot unit and its need for cleanup, if any, for use in different areas of the gasification/IGCC system. Specifically, in each of these tests, the water quality parameters to be monitored are shown in Table 2.5.2.1.

The water collected during the pilot-scale operation will be used to determine the clean up necessary to use the water in WGS reactor. WRI will work with Haldor Topsoe, a leading supplier of WGS catalyst, to test WRITECoal™ recovered water in the WGS reactor.

Product Handling Testing: The treated coal from the WRI process is typically more friable than the raw coal product and with little or no moisture the material can spontaneously combust. The focus of this effort will address not only spontaneous combustion but also friability/grindability characteristics. Most gasification processes are sensitive to the amount of fines generated. Assessment of particle size distribution and Hardgrove Grindability Index will be key parameters to understanding the product handling characteristics.

The two gasification technologies being examined are both dry feed. The dry coal feed in some cases is problematic and pressurized dry feeders are receiving interest due to a lower moisture need for western low-rank coals, while maintaining a higher gasifier pressure. Methods will be examined that could allow essentially dry feeding at elevated gasifier pressures.

Table 2.5.2.1. WRI's Process Water Quality Parameters and Analysis Methodology

Chemical Parameter	Method	Chemical Parameter	Method
Calcium, mg/L	EPA 6010C	Bicarbonate, mg/L	EPA 310.1
Iron, mg/L	EPA 6010C	Hydroxides, mg/L	EPA 310.1
Magnesium, mg/L	EPA 6010C	Total Alkalinity, mg/L	EPA 310.1
Potassium, mg/L	EPA 6010C	Ammonia, mg/L	EPA 350.3
Silicon, mg/L	EPA 6010C	Ortho-Phosphate, mg/L	EPA 300.0
Sodium, mg/L	EPA 6010C		
Lithium, mg/L	EPA 6010C	Chloride, Total, mg/L	EPA300.0
Sulfate, mg/L	EPA 300	Cyanide, Total, mg/L	SM4500-CNE
Nitrate, mg/L	EPA 300	Mercury, Dissolved, µg/L	EPA245.1
Nitrite, mg/L	EPA 300	Mercury, Total, µg/L	EPA245.2
pH, std. units	EPA 150.1	Arsenic, Dissolved, mg/L	EPA 200.9
Total Dissolved Solids, mg/L	EPA 160.1	Selenium, Dissolved, mg/L	EPA 200.9
Hydrogen Sulfide, mg/L	SM4500 S	Arsenic, Total, mg/L	EPA 200.9
Carbonate, mg/L	EPA 310.1	Selenium, Total, mg/L	EPA 200.9

2.5.3 Task 3. Gasification Testing

The overall objective of this task is to assess the feasibility of using WRITECoal™-treated North Dakota lignite and PRB coals in a U-GAS®-based gasifier to generate syngas for use in evaluations such as in Integrated Gasification Combined Cycle (IGCC) power plant, for generation of chemicals, or in fuel cell application (IGFC). This task will address three activities: subpilot-scale U-GAS® gasifier tests; pilot-scale transport gasifier tests; and pilot-scale syngas upgrading for hydrogen production. The pilot-scale WRITECoal™ gasification demonstrations will be conducted using the EERC 1-2 MWth TRDU and the subpilot-scale U-GAS® gasifier facilities described earlier.

Subpilot-scale Gasification Tests: Subpilot-scale U-GAS® gasifier tests will be conducted in a series of tests as shown in Table 2.5.3.1. A total of four coals (two raw coals and two treated coals) will be tested in oxygen-blown conditions and under operating temperatures and other parameters that were determined from the HPTGA tests.

Table 2.5.3.1. WRITECoal™ U-GAS® Gasifier Test Matrix.

Fuels	Coals	Steam/carbon Ratio	O_2/Coal Ratio	Temp.
Raw Coal	2	2	1	1
Optimized Conditions	one steady state test run			
WRITECoal™-Treated Coal	2	2	1	1
Optimized Conditions	one steady state test run			

Tests will be conducted at one set of pressure, temperature and two stoichiometric conditions. Each steady state condition will be for a period of four hours (minimum). "Steady-state" is defined as a condition wherein the temperature profile in the coal bed is uniform; feed gas, purge gas, and exit gas flow rates are constant; reactor pressure is stable; and the coal feed rate is essentially constant. Data for analysis will be determined over the steady-state portion of the test.

The exit gas is cooled to ambient temperature in two single-stage coolers/condensers. The condensed liquids are collected in a knockout pot, which is drained periodically to obtain liquid products, primarily water. After the exit gas passes through a polishing filter and a back pressure regulator, its volume is measured by a dry test meter. Samples of the exit gas are analyzed by directing a portion of the gas into a micro-gas chromatograph for measuring gas compositions. Data for analysis are determined over the steady-state portion of the test. Fig. 2.5.3.1 shows the measured syngas concentrations during a typical gasification test. The region between the dotted lines in this figure indicates the reaction time during the run.

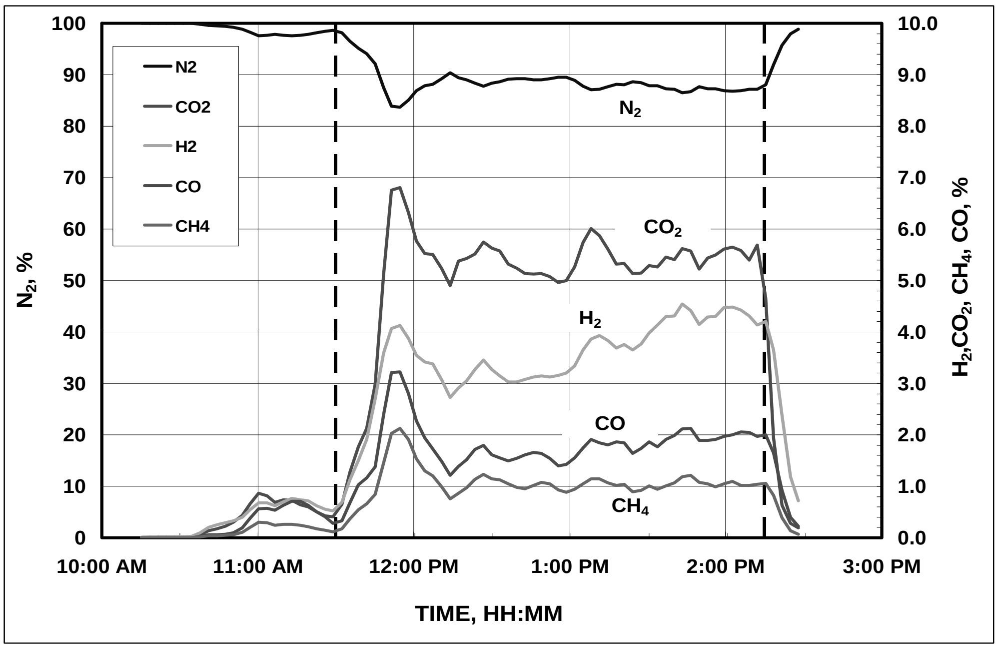

Figure 2.5.3.1. GTI's Subpilot-scale Gasification Unit Output Compositional Data

The testing deliverables will include:

- Test conditions: pressure and temperature, stoichiometric ratio, gasifier fuel feed rate; oxygen/air blown mode,
- Mass and energy balance around the test unit,
- Carbon conversion efficiency,
- Gas heating values,
- Gas composition including H_2S, Hg and other trace metals, phenol etc, and Residue / char characteristics (CaS content).

- These subpilot-scale gasification tests will provide the preliminary engineering data considerations for the Phase II TR and the GTI U-GAS® initial modeling efforts

Transport Reactor Pilot-scale Gasifier Campaign. The goal of the transport reactor gasification campaign is to evaluate the gasification performances of WRI's thermally treated coal in the TRDU and to compare the TRDU performance with non-treated coal. Specifically, the EERC TRDU gasification campaign will (1) evaluate various operating conditions with both raw and treated coals and assess the syngas composition with varying operating conditions, and (2) perform slipstream syngas cleaning and hydrogen separation testing during the gasification test runs.

Fuel will be shipped from WRI to EERC, where it will be further prepared for testing by sizing it to a −10 mesh. The fuel will be stored in inert gas blanketed bunkers at the EERC until it is ready for gasification tests. The fuel will be brought over to the gasification tower in hoppers on an as-needed basis during the test run. Proximate/ultimate and Btu analyses will be performed on each fuel type before and after preparation.

The nominal 160-hour test campaign will evaluate the gasification performance of thermally treated Wyoming coal in the EERC's TRDU. The test runs will focus on comparing the gasification performance of raw coal and WRITECoal™ treated fuel. Each fuel will be gasified under oxygen-blown conditions. Steam-to-coal ratio, oxygen-to-coal ratio, and other parameters will be varied to understand the performance impact each of these variables has on gasification performance. (Table 2.5.3.2.)

Table 2.5.3.2. Test Matrix for the WRITECoal™ Transport Reactor Test Campaign

Fuels	Steam/carbon Ratio	O_2/Coal Ratio	Temp.
Raw Coal	2	2	2
Optimized Conditions	one steady state test run		
WRITECoal™-Treated Coal	2	2	2
Optimized Conditions	one steady state test run		

All of the solids generated during the run will be collected and analyzed so that a carbon conversion based on solids accountability can be calculated for the system. A bank of continuous emission monitors will be used to continuously measure the major components of the syngas stream, including H_2, CO, CO_2, N_2, CH_4, and H_2S. Two online gas chromatographs will also be used to measure the components in the syngas stream, and each will provide a measurement about every 20 minutes. Tars are not typically collected from the TRDU because of the thermal oxidizer, but tars will be collected from the slipstream line, which will enable the estimation of the tar production of each fuel type. The WRITECoal™-treated fuels are expected to generate low tars due to high reactivity of these treated fuels.

<u>Slipstream Hydrogen and CO_2 Separation Testing</u>. A slipstream of the syngas will be taken just after the TRDU's hot-gas filter vessel. The slipstream will be sent to the gas cleanup train through a heat-traced line that runs the length of the gasification tower. The gas will be run through a series of fixed-bed sorbents that will remove the contaminants and maximize the hydrogen in the gas stream. The syngas will first flow through a desulfurization sorbent that will adsorb most of the H_2S from the gas stream. Next, a high temperature water–gas shift catalyst will increase the hydrogen concentration and reduce the CO concentration to about 1% through

the water–gas shift reaction. A chlorine guard bed will be used to remove any HCl in the gas stream and protect the low-temperature shift catalyst, which will further maximize hydrogen and minimize CO. A packed bed of mercury control sorbent will be used to remove mercury from the gas stream. The gas will then travel through a series of quench pots that will remove all tar and moisture before getting sent to a gas booster for compression.

A heated hydrogen separation membrane will be used to perform hydrogen and CO separation on the compressed gas. Hydrogen separation membranes rely on a partial pressure difference of hydrogen as the driving force for hydrogen transport through the membrane material. Therefore, the gas will be compressed to near the maximum operating pressure for the membrane to be tested. The membrane chosen for testing will depend on current ongoing EERC evaluations of hydrogen separation membranes.

A gas chromatograph and a laser gas analyzer will be used to measure the composition of the permeate hydrogen stream and the raffinate CO_2 stream. Gas bag samples of the hydrogen stream will be taken that will be sent to a laboratory gas chromatography for determination of hydrogen purity. Purity of >99.99% is anticipated.

The data from the Task 3 pilot-scale demonstration will serve as the basis for assessing the overall IGCC performance (Task 4) and the basis for the economic evaluation (Task 6).

2.5.4. Task 4. System Analysis and Modeling of WRITECoal™ Gasification Systems

Three modeling efforts will be undertaken as part of this Task: U-GAS® and TR gasifier modeling; integrated gasification combine cycle (IGCC) modeling and integrated gasification fuel cell (IGFC) modeling. Task 4 will also establish preliminary technical tools that will enable WRI to transfer the technology to potential commercial gasifier designers.

Gasifier Modeling Efforts. WRI, Etaa Energy, and GTI will conduct modeling of the proposed gasifiers based on the results of the HPTGA tests, the subpilot-scale test results and the pilot-scale gasification tests. The modeling will use the ASPEN Plus® program, GTI proprietary models and selected vendor modeling of the resultant syngas composition, efficiency, and WGS reactions. The modeling will address the use of raw western high moisture PRB and lignite coals and the WRITECoal™-treated products of those coals under different temperatures and pressures, as well as under both air-blown and oxygen-blown conditions.

In conjunction with GTI's model that is based on the fluidized bed systems, the WRI-Etaa models will further establish a credible in-house tool for evaluating any gasification technology. The key factor is that the carbon conversion efficiency is nearly 100% for the fuels processed through WRITECoal™ methodology. This positive and beneficial factor eliminates the process parameter- and solid-gas contact methodology-dependent gasifier operation that computes the carbon conversion efficiency and attendant gas composition.

IGCC Modeling Efforts. Data from the WRI process testing as well as both the GTI U-GAS® sub-pilot-scale gasifier and the EERC 1-2 MWth TR pilot-scale gasifier demonstrations will be evaluated in order to provide design guidelines and to assess the overall IGCC plant performance. The IGCC plant will define each subsystem using proprietary WRI and GTI models and will assess the overall IGCC efficiency of raw and treated western high-moisture coals. Haldor Topsoe and UOP will assist in assessing the impacts of the WRITECoal™ gasification on their water gas shift (WGS) and SELEXOL® CO_2 removal processes, respectively. The TR data will provide a basis for modeling both the raw and the processed coals using transport reactor gasification design.

WRI and Etaa will evaluate the results and apply the in-house models. These models built on the first order equation that would encompass most of the key reaction taking place in the gasification and downstream processes. The uniqueness of the models is that the input and output can be verified and matched with commercial databases of key components such as gasifiers, gas cooling systems and gas turbines. Overall, the output will also be corroborated with the performance data generated on the large scale commercial facilities- Wabash and Tampa.

IGFC Modeling Efforts. FCE will model the WRITECoal™/gasifier integration with fuel cells. The objective of this activity is to develop a highly efficient Integrated Gasification Fuel Cell (IGFC) system configuration(s) utilizing Solid Oxide Fuel Cell (SOFC) technology and using treated high-moisture PRB and lignite coal as fuel. The IGFC system will also include provisions and necessary processes for capturing in excess of 90 percent of the carbon in the syngas from the gasifier. Additionally, the IGFC system will be designed for reduced net water consumption.

Process flow sheet diagrams and computer simulation models will be developed using ChemCad simulation software (or equivalent). The mass and energy balances will be performed using the simulation models to verify that the systems and components selected for each system configuration concept synergistically support each other and the overall design objectives. Process simulation studies will evaluate alternative process configurations to optimize process parameters and performance. Process simulations will establish preliminary power plant operating conditions and design parameters for process streams, power generation, and efficiency that meet program objectives. Process alternatives include: CO_2 capture and heat recovery, syngas humidification, anode recycle, water recovery and treatment, turbine expander(s), and recuperators. Key fuel cell parameters including fuel utilization, air utilization, cell voltage, and current density will be determined for the system to achieve an optimized system efficiency.

2.5.5. Task 5. Engineering Process Design

Upon completion of the data evaluation and modeling, a demonstration-scale WRITECoal™ gasification module (1-5 MWe) will be designed. Key features will include the following:

- Use both PRB and ND lignite that may use both raw and WRITECoal™.
- Non-slagging gasifier.
- Operate at 1700-2000º F and up to 1000 psig pressure. The pressure limit will be finalized after evaluation of the downstream process stream development priorities.

The engineering design will prepare the stream flow conditions, the range of applicability of the design, overall dimensions of the reactor components and the expected performance. Detailed engineering/manufacturing drawings will not be prepared.

2.5.6. Task 6. Economic Assessment

WRI, GTI and Etaa Energy, Inc. will develop flow streams for the IGCC for a plant nominally rated for 300-500 MWe (gross). Washington Division of URS will estimate the capital and operating cost of the plant located in North Dakota and/or Wyoming for a given set of gasifier operating conditions and a plant design provided by WRI. Deliverables include the following activities:

Capital Cost, $/kW of Installed Capacity - The capital cost estimate will consist of an equipment list for all major equipment, with installation factors developed for each component based on a document that will be assembled by Washington Division URS to serve as the Estimate Basis for the cost estimate. This Estimate Basis will include a description of the primary site and plant criteria, along with the costs for individual consumables, labor, etc. The total installed cost for the plant will be estimated. This will include costs associated with direct and indirect costs at the construction site, using labor rates that are typical for the 2009 time period. All costs will be provided in 2009 dollars for this conceptual design.

Cost of Electricity, cents/kWh - Operating costs will include Fixed, Variable (including cost of fuel and all other consumables and waste disposal costs) and Cost of Capital (using a Fixed Charge Rate) components. These costs will be compiled into the total cost of power generation (cents/kWh) for the conceptual site (design provided by others with Washington Division URS review). Variable costs will be calculated based on consumption rates for fuel, chemicals, water, power, etc. based on a capacity factor for the facility that is established during the development of the Estimate Basis document. This document will also include the unit rates assumed for each of the variable cost components. Fixed costs will consist of operating labor, maintenance costs (calculated as a % of the installed capital costs for equipment), and administrative costs for labor management.

Comparison with Other IGCC Systems. Cost of electricity will be compared to the Wabash or Tampa plants (generation cost for these plants provided by others) assuming that the plants operate with WRITECoal™-treated coal and the respective design coal. The key assumption here would be that the mercury controls in each case achieve the same 90% Hg removal.

2.6 Facilities, Resources and Their Availability

The experimental work will be will be carried out at three well qualified research facilities located at WRI, EERC and GTI. All of the facilities listed below are available and committed to the project. The design, data analysis and large-scale commercial plant concept evaluation and plant costing will be carried out in association with the testing, design and modeling teams. The interaction between the teams will be coordinated by the WRI so that the lignite and PRB coal-based research efforts flow smoothly in a very cost-effective way.

Description of Laboratory and Subpilot-scale Gasification Testing. Laboratory and subpilot-scale gasification equipment will be used in Phase II to establish the scale-up of the WRITECoal™ process to 1-2 MWth scale, establish a range of WRITECoal™-treated fuels in two different gasifiers, fluidized bed and transport reactor gasifiers. The operational characteristics of the WRITECoal™ product, as well as the syngas composition, will be addressed as well as engineering process scale-up assessments. High pressure thermogravimetric analysis and subpilot-scale fluidized bed gasifiers used in Phase I will also be used in Phase II to re-confirm the range of operating characteristics specifically for the proposed pilot-scale demonstrations. The test matrix will be a narrow testing based on the Phase I results and will define the temperature and pressure response around the 'optimum' conditions defined in Phase I.

Description of WRITECoal™ Pilot-scale Testing. Pilot-scale WRITECoal™ process facilities at WRI will be used to assess the WRITECoal™ process, water recovery potential, and trace metals removal (Hg and As) performance as relates to the WRITECoal™ gasification process at two pilot-scales (of 100 lb/hr and 350-750 lb/hr raw fuel flow). The pilot units contain each of the components of a commercial installation, with the exception of an electrical heater which is used for process heat instead of the use of waste and process heat from the power plant.

The 100 lb/hr pilot unit is instrumented for temperature and pressure across the drying and mercury removal steps. The effluent gas stream with increased moisture fraction in the dryer gas is cleaned of the fine coal dust using a cyclone. A slip stream of the dryer gas is diverted through a water-cooled heat exchanger. The coolant flows inside the tube, with the condensate collected at the bottom of the shell side of the heat exchanger. The condenser heat exchanger is designed the same as commercial installation, using the same materials of construction.

Figure 2.6.1 shows the photos of the mobile 1-2 MWth-scale WRITECoal™ pilot plant. This mobile WRITECoal™ processing plant is designed with the flexibility to accept coals ranging in rank from lignite to subbituminous. The unit is also able to be run as a standalone unit or integrated into existing processes due to the inclusion of both electric heat and gas connections on the return leg of the process gas circulation system.

Figure 2.6.1. Photograph of the WRI's Mobile 1-2 MWth Pilot-scale WRITECoal™ Unit

(CHX shown in blue on the right)

Raw feed coal is delivered to the system in super-sacks that discharge to a surge-bin mounted to a metered screw feeder. Raw coal is feed into the process's vibratory fluid bed unit, fabricated by Carrier Vibrating Equipment, at a maximum of either 350 lbs/hr (1 MWth) in its base configuration or 800 lbs/hr (~2MWth) with a modified process deck. Process heat is supplied to the system via two methods; 120 kW of electric heat is used for standalone processing and startup conditions, while 350-850 SCFM of hot gas at temperatures of 250-500^{o}F can be exchanged during integrated system production runs. Moisture from the drying of the feed coal is scavenged using a condensing heat exchanger (CHX) supplied by Steam Plant Systems. The CHX is specially designed for harsh environment by including Teflon shell liners and stainless steel cooling tubes. Treated coal is discharged from the process deck through a rotary valve into a super-sack loader, or onto a conveyor for use in other plant areas.

A slipstream of the dryer gas is diverted through a water-cooled condenser/heat exchanger (CHX). The coolant flows inside the tube, with the condensate collected at the bottom of the shell side of the heat exchanger. The condenser/heat exchanger is designed the same as for commercial installation and uses the same materials of construction as the commercial product.

These units are specifically designed to generate scale-up information and to produce treated product for the pilot-scale gasification tests. The scale-up for the bench-scale to the 100 lb/hr unit has been excellent on degree of moisture and mercury removal and the residence time performance data. The 1-2 MWth pilot-scale testing will allow for a scale-up comparison with real time data.

The pilot-scale (1-2 MWth) gasification Transport Reactor Development Unit (TRDU). located at the EERC nominally fires 200–500 lb of fuel per hour and produces about 400 scfm of syngas. The TRDU is equipped with a hot-gas filter vessel for particulate removal and a thermal oxidizer to convert the combustibles and tars before venting to the stack (Fig. 2.6.2). The high reactivity of the WRITECoal™ treated fuel, as well as the long residence time, is expected to eliminate tars from the syngas. A slipstream can be pulled from the system between the hot-gas filter vessel and the thermal oxidizer that can be used for testing gas cleanup and separation technologies.

The bench-scale warm-gas cleanup train is portable and can be placed at the back-end of the gasifier. The system is capable of reducing sulfur levels to as low as 0.010 ppm, particulate to less than 0.1 ppmw with ceramic/metal candle filters, and fixed bed reactors for reducing mercury or other contaminants. Water gas shift reactors include sour, high-temperature, and low-temperature shift can be inserted at any location in the cleanup train.

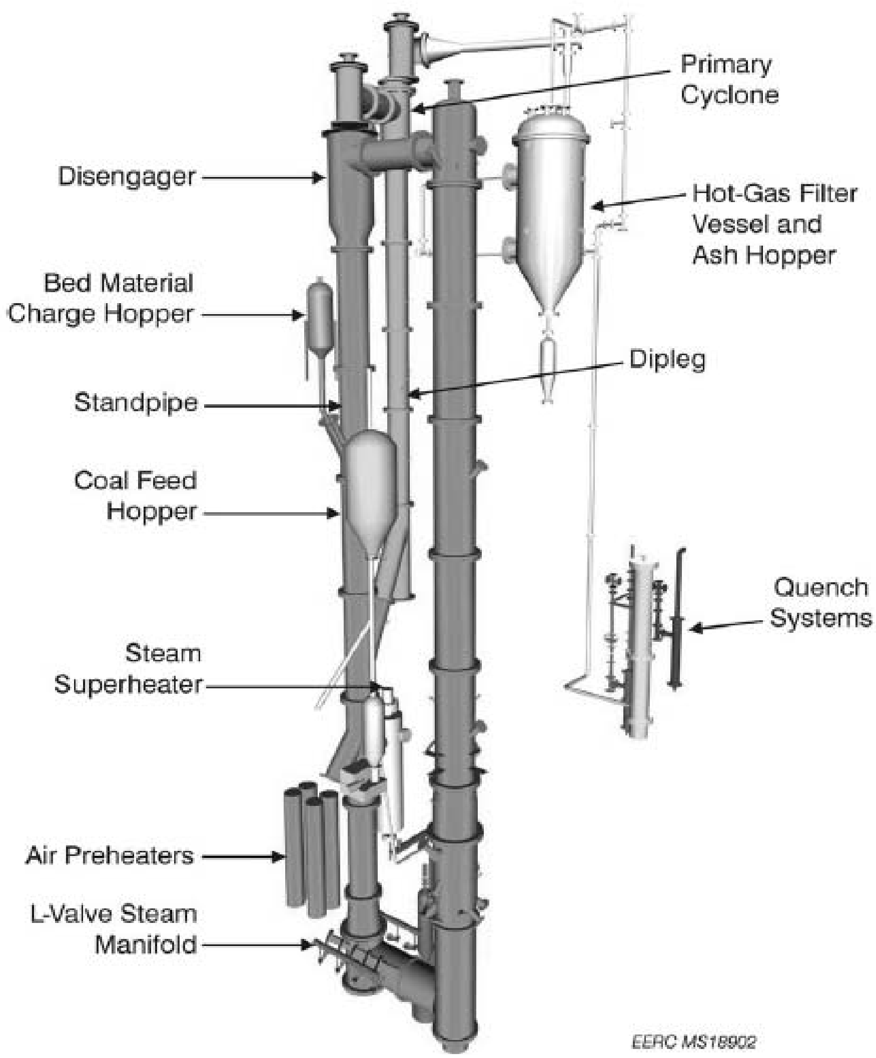

Figure 2.6.2. Schematic of the TRDU. (EERC, 2009)

The gasifier has proven to be a good system for evaluating the operational performance of all ranks of coal and coal–biomass blends. The size of the system enables the gasification reactions to be self-sustaining, but it is still small enough that several different operating conditions can be evaluated in a single day. Previous runs performed with the TRDU and slipstream system have shown that an ultrapure stream of hydrogen could be produced from Texas lignite while maintaining the gas temperature above 400°F. The slipstream was cleaned and conditioned by running through a transport style desulfurizer for bulk desulfurization, a high-temperature shift catalyst, a sulfur polishing bed, a chlorine guard bed, a low temperature shift catalyst, and a mercury control sorbent. The cleaned syngas was then run through a hydrogen separation membrane where it was demonstrated that a pure stream of hydrogen could be produced.

Description of GTI U-GAS® Gasification Testing

GTI's subpilot-scale gasification unit (schematic shown in Fig. 2.6.3) will be used to evaluate the gasification performance of the WRITECoal™-treated fuel. A photograph of the subpilot-scale U-GAS® gasifier at Gas Technology Institute is shown in Fig. 2.6.4.

The gasification reactor consists of a bottom reaction zone made of Haynes (HR-160) alloy, and a top solids-disengaging zone (freeboard) made of Stainless Steel – 316. The reaction zone is electrically heated by a three-zoned furnace while the disengaging zone is insulated without an external heater. An array of thermocouples is used to measure the inside temperatures of the reactor: five in the reaction zone and one in the freeboard. These temperatures are recorded along with the temperatures of other process streams.

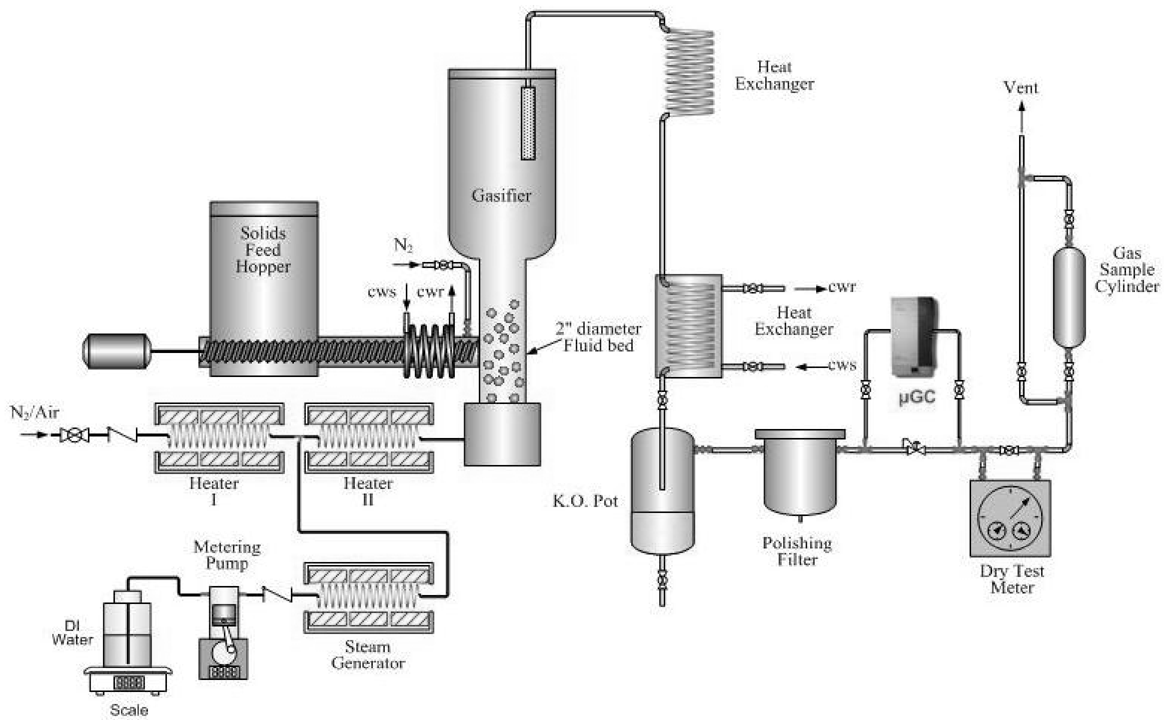

Figure 2.6.3. Schematic of the GTI Subpilot U-GAS® Test Facility

Figure 2.6.4. Photograph of the Subpilot-scale U-GAS® Gasifier to be Used in the Study.

Product liquids are drained and measured at regular intervals. The inlet gases/air/steam feed gases are preheated by electric heaters. Additional heat requirements for the reactor are supplied by electric heaters that compensate for heat losses and also heat up the relatively large (relative to the bed) stainless steel reactor. Power to the heaters will be checked with ammeters and/or watt hour meters to measure the electric and/or power input to the reactor.

Description of Modeling and Economic Evaluations WRI and Etaa will evaluate the results and apply them to in-house models. These models built on the first order equation that would encompass most of the key reactions taking place in the gasification and downstream processes. The uniqueness of the models is that the input and output can be verified and matched with commercial databases of key components such as gasifiers, gas cooling systems and gas turbines. Overall, the output will also be corroborated with the performance data generated on the large scale commercial facilities - Wabash and Tampa.

In collaboration with GTI's models that are based on the fluidized bed systems, the WRI-Etaa models will also establish credible in-house tools for evaluating any gasification technology. The key factor is that the carbon conversion efficiency is nearly 100% for the fuels processed through WRITECoal™ methodology. This positive and beneficial factor eliminates the process parameter- and solid-gas contact methodology-dependent gasifier operation that computes the carbon conversion efficiency and attendant gas composition.

For the IGFC portion of the modeling by FCE, system design and analysis software programs for fuel cell power plant design include ChemCAD for steady state analysis, Intergraph PDS for power plant equipment assembly, Fluent for fluid dynamics and heat transfer, and MATLAB/Simulink for dynamic and process control analyses. In addition to its in-house engineering capabilities, FCE has effectively collaborated with major A&E companies in the area of plant design and process equipment specification.

The proposed modeling effort also establishes technical tool that would enable WRI to transfer the technology to potential commercial gasifier designers.

2.7 Environmental and Economic Impacts of the Project While It Is Underway

The WRI has reviewed the environmental impact of drying, and heat treating about ten 55-gallon drums (4000 lbs) of as-received lignite. The product streams from the process include the high-moisture dryer gas effluent, dry coal (2,400 lbs of lignite with less than 5% moisture) and condensate from the low temperature heat exchanger.

The EERC and the GTI will gasify the raw and treated lignite in their gasifiers. Key product streams include the syngas stream and lignite char/ash. The dust laden syngas gas will be cleaned by state-of-the-art pollution control devices. Importantly, the gasifiers at the EERC and GTI are research units with extensive instrumentation to monitor each process stream with attendant safety precautions. At each location, the responsible state environmental compliance authorities will be notified of the fuel drying and gasifier operation and also the disposal procedures of the by-products. No large scale impact on the air and water streams is expected.

2.8 Need for the Project

Nationally, over 100 new coal projects have been cancelled or postponed reflecting the challenge to growth of the North Dakota lignite industry. Recent rulings by regulatory groups related to the potential of switching to natural gas as the BACT represent a concern for the lignite industry as well as all western coal interests. At the same time, the gain of acceptance of electrical vehicles will surely result if increased electrical demand, much of which will be from coal-fired systems as the lowest cost option. Although the retrofitting of the existing fleet is a concern to protect the current markets for North Dakota lignite, the potential for expanded market with lignite-fired power plants and IGCC must also remain an option with carbon capture.

The proposed WRITECoal™ gasification process provides an option for efficient conversion of high-moisture lignite making it compete very favorably with higher rank coals. Preliminary studies with high-moisture coals such as PRB coal have shown very promising results with higher (>5%) cold gas efficiency; model predictions also show higher IGCC plant efficiency. A successful demonstration of lignite coal processing through similar gasification process will pave way for accelerated and enhanced commercial utilization of lignite; this will also provide a viable avenue for upgrading of lignite for multiple uses (power, chemicals). The project addresses the following aspects important to North Dakota lignite industry.

- Lignite upgrading, including enhanced emission control;
- Lignite-based co-generation including potential evaluation for chemical production/ fuel cell application in addition to power generation; and
- Development, demonstration and refinement of gasification technology resulting in higher efficiency, lower costs especially when coupled with carbon capture.

In conclusion the project addresses three of the top five lignite research program priorities of the LRC/NDIC:

- Emissions/Environmental Issues
- Non-Combustion Uses
- Beneficiation (including coal handling and processing)

3. STANDARDS OF SUCCESS

The following standards of success are expected from the research project.

- Significant improvement in the syngas quality including a high H_2+CO (>80%) for IGCC, hydrogen production and fuel cell applications.
- Demonstration of the controllability of syngas quality through separate dedicated water-gas shift reactor and associated operating conditions within the gasifier to produce a range of syngas composition for different end use,
- Validation of earlier APSEN model results using the pilot-plant data confirming commercial viability and verifying the Phase I net IGCC efficiency with carbon capture, and
- Demonstration of the cost of electricity of WRITECoal™ gasification/IGCC process to be less than 25% increase with carbon capture.

These standards of success are encapsulated in the following list of milestones that are incorporated in the timetable for the project.

Milestone 1.a. Award Contracts by ND Industrial Commission by June, 2010. Assume to be under contract with all funding sponsors by the end of end of May. 2010.

Milestone 1b. Procure Fuels and Characterize Them. Two Fort Union lignite samples from North Dakota will be procured and analyzed for their physical and chemical characteristics by Aug. 31, 2010.

Milestone 2. WRITECoal™ Preparation and Testing. *Lignites will be tested and shipped to gasification testing at EERC* by Nov. 15, 2010. Interim Report 1- Nov. 30, 2010

Milestone 3. Gasifier Test Campaign. *Completion of lignite gasification testing at EERC and GTI and data analysis by Apr. 15, 2011.* Interim Report 2 – Apr. 30, 2011.

Milestone 4. Gasification System Analysis. Impact of the gasifier (including the water gas shift reactor) performance on the overall IGCC system will be studied using in-house models and reported by Aug. 15, 2011. Interim Report 3 – Aug. 31, 2011.

Milestone 5: Engineering Process Design. A 5-10 MWth heat input gasification system with WRITECoal™ will be designed by Oct. 30, 2011. Interim Report 4- Nov. 15, 2011.

Milestone 6. Economic Assessment. The results of the assessment are to be completed by Dec. 31, 2011. Interim Report 5- Jan. 31, 2012.

Milestone 7. Final Report. The final report of the project will be completed by Mar. 31, 2012.

4.0 STATUS OF DEVELOPMENT OF WRITECOAL™ GASIFICATION PROCESS

4.1 In-House Development at Project Team Member Organizations

Western Research Institute (WRI), along with Gas Technology Institute (GTI), Etaa Energy, Washington Division of URS with funding from the State of Wyoming Clean Coal Program and the U.S. Department of Energy are completing Phase I of a multi-Phase R&D effort to advance WRI's WRITECoal™ gasification technology for PRB coal. The project was directed at acquiring, and testing of the performance of the WRITECoal™ process on PRB coal in laboratory/bench-scale gasification tests and in modeling studies. Key results from the Phase I effort are summarized below.

- WRITECoal™ processing of PRB coals produces a low-moisture (<1.5 %), low-sulfur (<0.6%), high Btu (11,000 + Btu/lb, and low Hg -< 0.04 ppm) coal that maintains a high O_2 content compared to bituminous coals.

- The condensate from the WRITECoal™ treatment of PRB coal is of sufficient quality for use in WGS reactions as well as other uses in the plant.

- In gasification, coal is first devolatilized and then the char is consumed. Table 4.1.1 shows the reduced (40%) residence time of the char reaction, the high carbon conversion and the higher carbon conversion associated with devolatization.

Table 4.1.1. Summary of Laboratory-scale Devolatization and Char Burn-out of PRB Coal

Coal Type	Gasification Conditions	Carbon Conversion, %			Char Residence Time, min.
		Devolatization	Char Reaction	Total	
Raw PRB	Syngas/Steam	56.5	99.0	99.6	42
WRITECoal™	Syngas/Steam	73.2	99.0	99.7	25

(Syngas/Steam – 30% H_2; 12% Co; 8% CO_2; 50% H_2O)

- The WRITECoal™ syngas has a high CO + H_2 content of 81 vol. % compared to 40 vol. % for the raw PRB coal case. The WRITECoal™ syngas also has a low CO_2 content of 6.3 vol. % compared to 20.6 vol. % for the raw PRB fluidized bed (FB) gasification case, thereby highlighting the efficient use of the oxygen supplied to the gasifier. The WRITECoal™ syngas has a HHV heating value of 356 Btu/scf compared to 173 Btu/scf for the raw PRB coal case. The high CO content lends the WRITECoal™ syngas to be an excellent feedstock for chemicals manufacturing or use with fuel cells. The lower CO_2

reflects a lower heat input needed to the gasifier and translates into the total cold gas efficiency gain of >5% to levels exceeding 88% (Table 4.1.2).

Table 4.1.2. Summary of the Key Results from the Modeling Studies

	Case A	Case B	Case C	Case D
Coal Raw or WRITECoal™)	**Raw**	**Raw**	**Treated**	**Treated**
Steam to Gasifier	**Yes**	**No**	**Yes**	**No**
CO + H_2 gas Yield	40	56	51	83
CO_2 in Syngas	60	44	49	17
Gas Yield	220	163	181	123
Heating Value of Syngas, Btu/scf-HHV	173	248	222	356
Cold Gas Efficiency	79.2	83.1	84.9	88.2

- Modeling estimates of the overall IGCC process based on the WRITECoal™/U-GAS® gasification process generated, as part of the Phase I effort, show higher overall efficiency compared to other power options with CO_2 capture (Fig. 4.1.1). And lastly, the overall IGCC process results in lower raw water consumption. *It is important to note that for every 1% of net efficiency increase, 20 million tons less of CO_2 is generated by the US coal fleet annually..*

In summary, the testing to-date supports the unique features of the WRITECoal™ advanced gasification design for high-moisture coal-based gasification including: (1) the upgraded high-moisture PRB coal (by complete drying) provides a higher plant efficiency; (2) recovered water from the dryer effluent gas can be injected at desired temperature windows along the syngas path to get optimum shift reaction products (H_2 and CO_2); (3) near complete carbon conversion efficiency is achieved at a shorter residence time than with the raw high-moisture PRB coal; (4) trace metals such as mercury, arsenic and selenium are removed, requiring limited back end clean up; and (5) low-moisture feed may allow alternate feed systems..

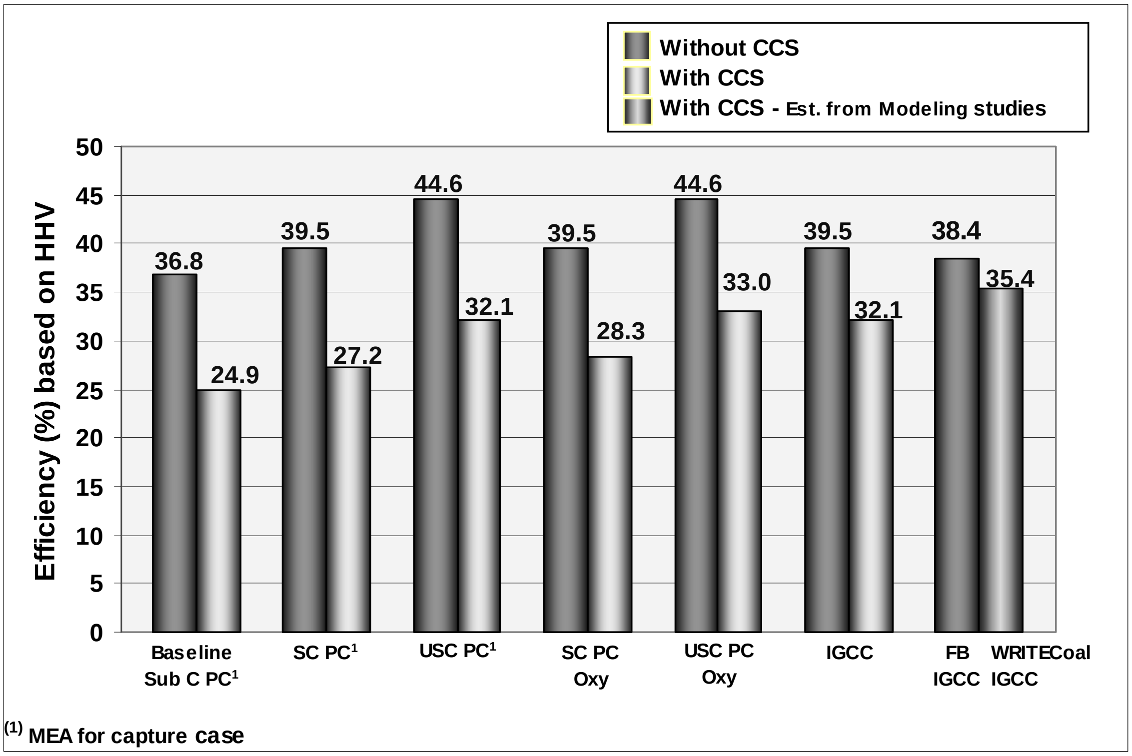

Figure 4.1.1. Efficiency of the WRITECoal™ IGCC Compared to Other Power Options

(modified from Ciferno, 2007)

4.2 Summary of Prior Work by Other Participants and Organizations

The Phase I participants Gas Technology Institute, Etaa Energy and URS were intimately involved in the WRITECoal gasification process development for PRB coals. All the additional team members proposed for the Phase II effort (EERC, FuelCell Energy) have conducted extensive work with gasification, fuel cells, and the supporting vendors UOP and Topsoe Haldor have extensive development work with their associated technologies and products.

5. TEAM AND MEMBER QUALIFICATIONS

Montana-Dakota Utilities and Western Research Institute have assembled a team including EERC, GTI, EEI, FCE, and URS that brings together professionals with science, engineering, and commercialization experience necessary to successfully perform the scope of the project as outlined above. Both Montana-Dakota Utilities and Western Research Institute are very qualified to conduct this project with supporting expertise from EEI, EERC, GTI, FCE and URS in the areas of gasification technology development (GTI and EERC), IGCC system development (GTI and EEI), fuel cell development (FCE), hydrogen membrane technology (EERC), and cost estimation (EEI and URS). The specific areas of expertise that the team members bring to this project include.

- Western Research Institute is the holder of the WRITECoal gasification technology and has extensive experience in the development of clean coal technologies that are applicable to coal upgrading, gasification, emissions management and systems analysis.
- GTI is the international leader in gasification technology development and taking the gasification technologies to commercial scale. In addition,
- EERC has extensive knowledge of the transport reactor gasifier to be tested and in the area of hydrogen production from syngas via hydrogen membranes.
- Etaa Energy, Inc. has considerable processing and combustion experience and has been a partner in the development of the technology with WRI and has extensive experience in coal combustion and energy conversion systems.
- FuelCell Energy is a leader in the development of fuel cells that might have application in an integrated gasification fuel cell (IGFC) configuration.

- URS is a world leader in technology evaluation in the coal-based energy conversion application. URS has extensive experience in plant costing of novel technologies scaled up for commercial application.

All of these team members have proven experience in coal treatment, gasification, and coal-based energy system development and commercialization. Co-research organizations in the team-EERC and GTI- have done pioneering work in coal and biomass gasification areas. The depth of knowledge residing in these two institutions is a very valuable asset to this project. Specifically, the organizations have pilot-scale facilities, dedicated research staff with over 100 years equivalent of gasification technology development experience and involved with leading energy companies and the U.S. government in bringing the gasification technology to large-scale demonstration and commercialization.

Team Organizations

Western Research Institute's Advanced Technology Center houses a range of pilot-scale facilities dealing with a range of energy and environmental issues. WRI's WRITECoal™ pilot facilities are unique to the application with gasification. As a former DOE laboratory, Western Research Institute has a 50 year history of development and deployment of gasification, coal upgrading, coal combustion emissions control and remediation of water and soil contamination. As the IP holder and developer of the proposed technology, WRI is uniquely qualified to carry out both the technical and administrative portions of this project.

Energy and Environmental Research Center's test unit (1-2 MWth heat input) is specifically designed to get scale-up information and to produce treated product for the pilot-scale gasification tests. A slipstream can be pulled from the system between the hot-gas filter vessel and the thermal oxidizer that can be used for testing gas cleanup and separation technologies. The gasifier has proven to be a good system for evaluating the operational performance of all ranks of coal and coal–biomass blends. Previous runs performed with the TRDU and slipstream system have shown that an ultrapure stream of hydrogen could be produced from Texas lignite while maintaining the gas temperature above 400°F.

Gas Technology Institute's Gasification group develops, evaluates, and commercializes advanced, low-cost, highly efficient, clean gasification systems using fossil and renewable fuels to create synthesis gases for production of power, hydrogen, clean liquid fuels and chemicals. In the gas processing arena, GTI's focus is on acid gas removal, sulfur recovery, and improved dehydration technologies. GTI's RENUGAS® and U-GAS® are biomass and coal gasification technologies, respectively, that provide fuel gas for both low-pressure and high- pressure power generation, or as syngas producers for fuel gas, liquid fuels, hydrogen, or substitute natural gas applications. The fluidized-bed RENUGAS and U-GAS technologies are amenable to a wide range of fuel choices. Versatile in size and configuration, they can be adapted to meet many needs. GTI's technology development, conducted over more than 30 years, represents over $165 million in investment as of 2005. RENUGAS and U-GAS are compatible in applications with turbine configurations ranging in size from less than 10 MW to more than 100 MW of electrical capacity, or smaller reciprocating engine applications.

Etaa Energy, Inc. provides design, engineering, and technology development services in the areas of power and steam generation from fossil and bio fuels. Etaa has been a team member in the development of WRITECoal technology. Etaa has performed syngas product quality assessment, and gas clean up system design, testing and analysis of bench-, pilot – and demonstration-scale plants.

FuelCell Energy has extensive experience in the development of fuel cell systems including integrated gasification fuel cell (IGFC). FCE recently completed Phase I of a 10-year, three phase program for the Department of Energy's Office of Fossil Energy Solid State Energy Conversion Alliance (SECA) Coal-Based Systems Cooperative Agreement. The SECA program's overall goal is to develop MW-class coal based syngas (fuel created by reacting coal syngas solid oxide fuel cell (SOFC) power plants for use as high efficiency central generation facilities. FCE recently completed a field demonstration of its packaged sub-megawatt (sub-MW) class Direct FuelCell/Turbine® (DFC/T®) alpha power plant unit. The power plant achieved an electrical efficiency of 56% (based on the lower heating value of natural gas fuel),

URS Washington Division has extensive experience in plant costing of novel technologies scaled up for commercial application. URS has performed numerous techno-economic analysis of advanced energy systems, for Electric Power Research Institute and utilities (using PC Tool® software) and has been in the analysis of both the WRITECoal process for retrofitting existing coal-fired plants and is engaged in the assessment of the WRITECoal gasification process as part of the early modeling and bench-scale testing.

Key Personnel

The qualifications of the key personnel for the project are shown below.

Ms. Andrea Stomberg of Montana-Dakota Utilities will be the Project Manager. Western Research Institute will conduct the testing as outlined herein under the direction of Dr. Alan E. Bland (Vice President), who will serve as the Principal Investigator. Dr. Tengyan Zhang (Lead Engineer), and Mr. Jesse Newcomer (Senior Research Engineer) of Western Research Institute and Dr. Kumar M. Sellakumar (President) of Etaa Energy Inc will assist in directing key components of the testing program. Mr. Joshua Stanislowski (Research Engineer) of EERC and Mr. Mike Roberts (R&D Manager of Gasification and Gas Processing) of Gas Technology Institute will be responsible for operation, data collection and transfer of information from their respective facilities to the Principal Investigator. Mr. Mike Holmes of EERC and Dr. Hossein Ghezel-Ayagh (Director SECA Program) of FuelCell Energy will be evaluating the hydrogen separation from the syngas stream. Mr. Bob Keeth (Project Engineering Manager) of Washington Division of URS will estimate the cost of the WRITECoal gasification IGCC. A brief description of the key personnel and their project responsibilities is provided below. Resumes of the key personnel are given in Appendix A. The resumes of each show the breadth of experience in coal combustion/gasification and coal processing/syngas processing.

Andrea Stomberg, Vice President – Electric Supply at Montana-Dakota Utilities Co. joined the Montana-Dakota Utilities in 1990, and was named to her current position in August 2003. She has overall responsibility for electric generation and transmission engineering and operations in the four states in which Montana-Dakota serves electric customers. Ms Stomberg was an environmental scientist and environmental manager in 1993. Prior to coming to Montana-Dakota, Ms Stomberg worked as an environmental scientist for North American Coal Corporation. Ms. Stomberg holds a bachelor's degree in geology from the University of Washington, a master's degree in soil science from Oregon State University and a master's in business management from the University of Mary. Ms Stomberg will serve as Project Manager with NDIC.

Alan E. Bland, Ph.D.: Dr. Bland is a Vice President at the Western Research Institute. Dr. Bland is WRI's lead for waste and environmental management science and technology R&D that addresses gaseous emissions, water recovery and treatment and solid waste cleanup and reuse issues of clean energy generation and the environmental processes related to mining and energy production, and biotechnology and bioremediation. Current activities include development of WRI's coal upgrading technologies, advanced coal- and biomass-based oxy-combustion and gasification systems, sorbent technologies for trace metals such as mercury, arsenic, selenium and CO_2, water management and treatment options for the power sector, advanced ash management and beneficial reuse options for coal combustion by-products, and conducting power system analysis and techno-economic evaluations of the environmental processes and emerging clean fuel technologies. Dr. Bland has developed and managed several large multi-participant programs for DOE, industry, and the State of Wyoming Clean Coal Program, thus is well qualified to manage such a multi-partnermultii-million dollar program..

Dr. Bland will be responsible for the overall project testing by WRI and will provide the point of reporting to MDU and thereby to NDIC. Dr. Bland will also be responsible for the technology enhancement assessments and will assist in the assessment of the data from the WRI testing and, other project participants.

Other Key Personnel

Other key organizational lead personnel include Dr. Kumar M. Sellakumar (Etaa Energy, Inc.), Michael Roberts (GTI), Michael J. Holmes (EERC), Dr. Hossein Ghezel-Ayagh (FCE) and Robert Keeth (URS). Dr.Tengyan Zhang, Mr. Jesse Newcomer of western research Institute will provide key support in the operations of the WRITECoal process and system analysis and Joshua Stanislowski of EERC will be a key lead in the operation of the EERC Transport Reactor. The resumes of each, provided in Appendix A1, show the breadth of experience in coal combustion/gasification and coal processing/syngas processing.

Kumar M. Sellakumar, Ph.D.: Dr Sellakumar is the President of Etaa Energy Inc , a consulting firm, on contract with Western Research Institute. Etaa Energy is involved in mercury control technology assessments and technology development, combustion of difficult fuels and development of air pollution control technologies for power plants. Prior to joining Etaa Energy Dr. Sellakumar was with Foster Wheeler Power Group, New Jersey for about 15 years. He was Research Manager responsible for the development of fossil energy systems and emission reduction technologies. Dr. Sellakumar will be responsible for the design and fabrication of the PDU, oversight of the combustion tests at the EERC, working with MDU, EERC, GTI, and Washington Division of URS will assist in the integration of the technology in lignite-based gasification system development and cost estimates for the commercial application of the technology.

Michael Roberts is currently Research Manager/Gasification and Gas Processing at Gas Technology Institute. He has been engaged in research and development of the utilization and conservation of fossil-fuel energy, technology improvement, and pollution prevention programs. Mr. Roberts has also been engaged in environmental and energy research on coal, oil shale, and peat processing, as well as catalytic and non-catalytic gas-solids reactions. His duties include design, construction, and operation of process research units and analysis of the data.

Michael J. Holmes is Deputy Associate Director for Research at EERC where he is responsible for emissions control (air toxics, SO2, NOx. H2S and particulate) fuel processing of syngas and feed gas for fuel cells, Mr. Holmes is also a lead of the National Center for Hydrogen Production, a DOE/industry funded program at EERC.

Tengyan Zhang is Lead Engineer at WRI, directly involved in the system design and system modeling of energy systems, including coal and biomass gasification, combustion and oxy-combustion systems as well as WRI coal upgrading technologies. Dr. Zhang will be WRI's lead on the system analysis and modeling of the WRITECoal™ gasification process and IGCC performance.

Jesse Newcomer is a Senior Research Engineer responsible for the operation, data logging and analysis of the WRITECoal™ Process Product Development Unit. Mr. Newcomer is a mechanical engineer with over six years of experience in the research industry. He has proven record of accomplishments on large-scale projects and multi-year efforts to achieve successful technical performance as well as completion on time and within budget.

Joshua Stanislowski is Research Engineer at EERC. Mr. Stanislowski has expertise include fossil fuel combustion for energy conversion with emphasis on trace element control. Mr. Stanislowski has extensive experience with process engineering, process controls, and project management and has a strong background in experimental design and data analysis.

Hossein Ghezel-Ayagh is the Director of Solid State Energy Conversion Alliance (SECA) Program at FuelCell Energy (FCE), Danbury, CT. In this position, Dr. Ghezel-Ayagh directs the development of Solid Oxide Fuel Cell (SOFC) technology and products. He has contributed to the design and development of components for phosphoric acid fuel cell (PAFC), PEM fuel cell, internal reforming carbonate fuel cell (MCFC) and SOFC systems. Dr. Ghezel-Ayagh has also been engaged in evaluation, testing and design of power plant systems using various types of fuels such as natural gas, coal gas and heavy hydrocarbons.

Robert Keeth: Mr. Robert Keeth of URS will perform the design review and cost estimate of the commercial plant. Mr. Keeth has 27 years of experience in pollution control, utility plant design, operation, trouble shooting and economic evaluations. Mr. Keeth was involved in the EPRI-sponsored techno-economic evaluations of emerging mercury control technologies.

6. VALUE TO NORTH DAKOTA

North Dakota lignite is a billion dollar industry, involving thousands of jobs and contributing millions of dollars of revenue to the State annually. In addition, lignite represents 25% of the known coal reserves and North Dakota lignite represents a major fraction of those reserves. However, nationally, over 100 new coal projects have been cancelled or postponed as a result of climate change and carbon capture considerations including the natural gas BACT decisions in recent project reviews discussed earlier in Section.2.8. Although the retrofitting of the existing fleet is a concern to protect the current markets for North Dakota lignite, the potential for expanded market with lignite-fired power plants and IGCC must also remain an option with carbon capture.

Efficiency, cost and environmental performance are the key factors that would influence the continued and increased use of North Dakota lignite. The high moisture content of these coals, for example, is an issue from efficiency and COE perspective, especially if carbon capture is mandated. An advanced gasification IGCC technology that increases overall cycle efficiency, reduces syngas cleanup and handles the moisture issue will make North Dakota lignite a viable and preferred fuel for new power generation in North Dakota.

The WRITECoal™ gasification/IGCC process addresses these factors along with a possibility for making lignite-based coal gasification potentially amenable to producing fuels for IGCC, fuel cell and chemicals production. Without the development and demonstration and ultimately deployable technologies, lignite use could significantly decrease as power plants switch to fuel sources that are more economical in the terms of fuel and emissions control costs and overtake lignite as the fuel of choice for new generation. This would have a compounding negative impact on the lignite industry thus causing a loss of market share, which has a negative impact on the economy of North Dakota through loss of jobs in mining, transportation and power generation.

Successful completion of this program will assess both the technical and economic viability of the technology use in new coal-conversion systems. Successful deployment of this process would maintain and eventually increase the market share for North Dakota lignite. Such deployment would also result in significant environmental improvements, increase the potential use and market of North Dakota lignite as a fuel, and both create and preserve jobs in the lignite industry.

7. PROJECT MANAGEMENT

7.1 Management, Coordination and Control Procedures/Systems

A team of professionals will be bringing together the combination of science, engineering, and commercialization experience necessary to successfully perform the scope of the project. Western Research Institute will conduct the testing as outlined herein under the direction of Dr. Alan E. Bland (Vice President), who will serve as the Principal Investigator. Ms. Andrea Stomberg of Montana-Dakota Utilities will manage the project for NDIC. The project organizational chart is presented in Figure 7.1.

Dr. Tengyan Zhang (Lead Engineer), and Mr. Jesse Newcomer (Senior Research Engineer) of Western Research Institute and Dr. Kumar M. Sellakumar (President) of Etaa Energy Inc will assist in directing key components of the testing program. Mr. Joshua Stanislowski (Research Engineer) of EERC and Mr. Mike Roberts (R&D Manager of Gasification and Gas Processing) of Gas Technology Institute (will be responsible for operation, data collection and transfer of information from their respective facilities to the Principal Investigator. Mike Holmes of EERC and Mr. Hossein Ghezel-Ayagh (Director SECA Program) of FuelCell Energy will be evaluating the hydrogen separation from the syngas stream. Mr. Bob Keeth (Project Engineering Manager) of Washington Division of URS will estimate the cost of the WRITECoal gasification IGCC. A brief description of the key personnel and their project responsibilities is provided below. Resumes of the key personnel are given in Section 5

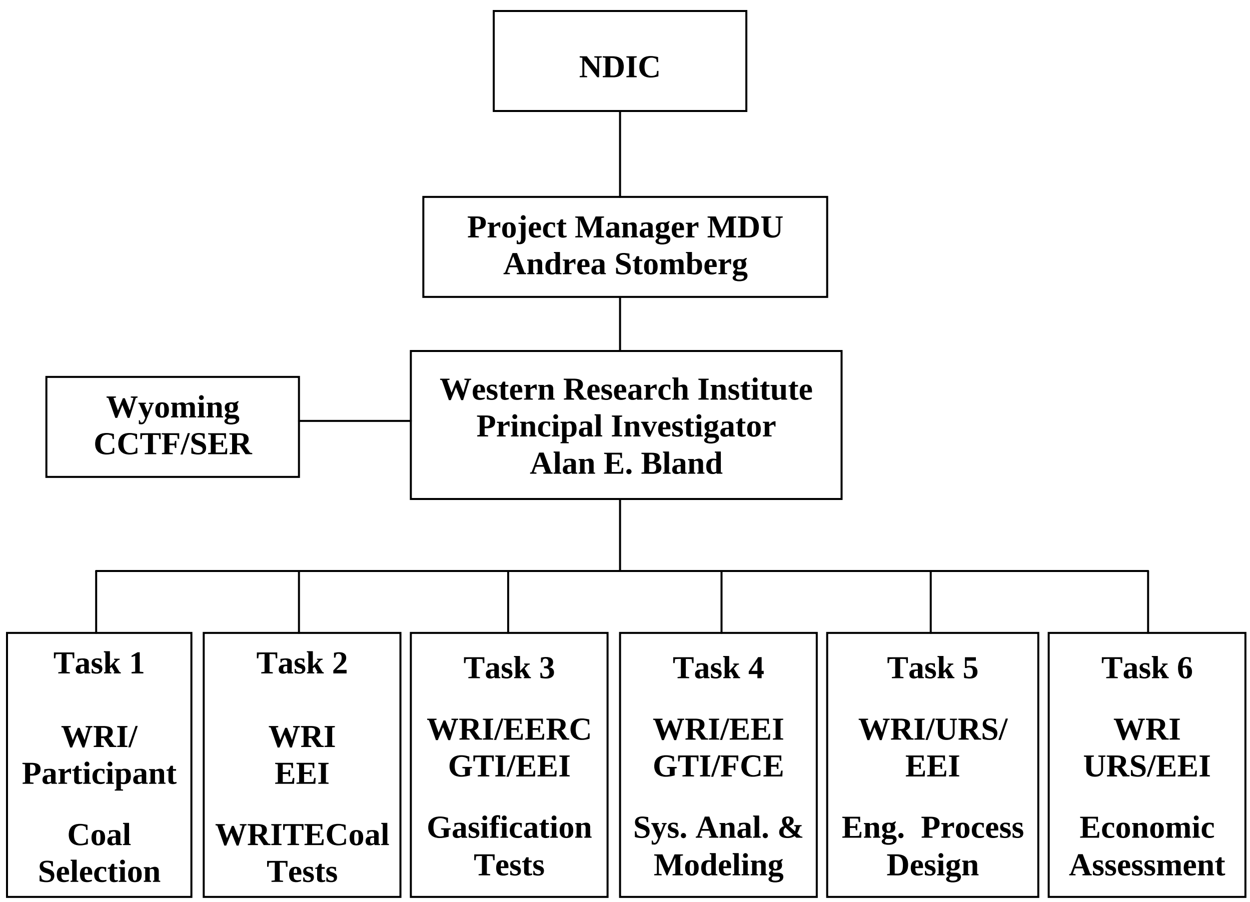

Figure 7.1.1. Project Organizational Chart

All reports, including Interim Reports and the Final Report, will be prepared by Dr. Bland with contributions from other key personnel.

Coal sampling and analyses will be carried out per ASTM procedures by qualified technicians and scientist/engineers, one of whom will be identified to follow the chain of custody procedures to maintain the integrity of samples at all steps. Data collection and storage will be handled by engineers and engineering technicians. The EERC and GTI will also follow QA/QC procedures based on ISO 9000 standards. During parametric testing, a minimum duration of 4 hours of steady state operation is contemplated. A completeness of 100% will be targeted on the key performance parameters. Data will be reviewed for reasonableness and any failed and incomplete tests may be repeated. All lab samples will be analyzed in duplicate and every tenth sample will be measured in triplicate.

7.2 Reporting

The project results will be reported to NDIC in three formats- Interim reports, Special reports and Final report. The Interim Reports will summarize the project's accomplishments and expenditures to date. Special Reports will be submitted if substantial progress on a project occurs earlier than anticipated. The Final Report will be a comprehensive one that will include a single page project summary describing the purpose of the project, the work accomplished, the project's results, and the potential applications of the project as required in the NDIC reporting guidelines. These reports will be submitted to North Dakota Industrial Commission after review by MDU and co-sponsors. The first quarterly report will be made to coincide with the School of Energy Resources reporting schedule in order to minimize the reporting requirements. Teleconference calls with MDU personnel, WRI personnel, and NDIC will take place as the need arises. A draft Final Report on the project will be delivered March 31, 2012 with the finalized version due in April 30^{t}, 2012.

8.0 TIMETABLE

Table 8.1 Timetable

Task Number	Milestone Activity	2010			2011			
		Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 0	**Contracts and Program Initiation**	Prior to 5/15/10						
Task 1	**Selection, Acquisition & Characterization of Fuels**							
	Fuel Selection							
	Fuel Acquisition & Characterization							
Task 2	**WRITECoal™ Preparation and Testing**							
	PRB and Lignite WRITECoal™ 1-2 MWth Tests							
	Fuel Handling and Recovered Water Tests							
Task 3	**Gasifier Test Campaigns**							
	EERC TRDU Gasifier Test Campaign							
	EERC Hydrogen Production Tests							
	GTI U-Gas® Gasifier Test Campaign							
Task 4	**System Analysis**							
	WRITECoal™/Gasifier IGCC with Carbon Capture							
	WRITECoal™/Gasifier H_2 Prod. System Analysis							
	WRITECoal™/Gasifier IGFC System Analysis							
Task 5	**Engineering Process Design**							
	WRITECoal™/Gasifier IGCC Plant							
Task 6	**Economic Assessment of WRITECoal™ IGCC**							
	WRITECoal™/Gasifier Integrated IGCC System							
Task 7	**Project Management and Planning**							
	Interim Reports							
	Final Report							3. 31

9.0 BUDGET AND MATCHING FUNDS

The estimated cost to conduct the project as described in the proposal is $1,970,022. A summary of the project costs and costing details are presented in Table 9.1.

Table 9.1 Budget, Matching Funds and Sources of Funds

Funding Participant	Funding	Cash Match	In-Kind Match	% of Project
LRC/NDIC	$549,500			27.89
State of Wyoming CCTP	$977,617	$977.617		49.62
EERC/DOE	$300,000		$300,000	15.23
Western Research Institute	$100,000	$100,000		5.08
FuelCell Energy	$17,905		$17,905	0.91
Etaa Energy, Inc.	$5,000		$5,000	0.25
Basin Electric Power Cooperative	$10,000	5,000	$5,000	0.51
Montana Dakota Utilities	$10,000		$10,000	0.51
TOTAL	$1,970,022	$1,082,617	$337,905	100.0%
% Match		54.95%	17.15%	

A total of $549,500 is requested from the LRC/NDIC representing 28.1% of the total project costs. The State of Wyoming through the WY Clean Coal Technology Program administered through the UW School of Energy Research is contributing $977,617 cash and Western Research Institute is contributing $100,000 cash to the project. EERC is contributing $300,000 of DOE match to the project as well. The private and industry match amounts to $437,905 of which $100,000 is cash and $300,000 is DOE funds through EERC.

Budget information, including the nature of the cost estimating procedures, is presented in Appendix B.

10.0 TAX LIABILITY STATEMENT

Neither Montana-Dakota Utilities nor Western Research Institute has any outstanding tax liability with the state of North Dakota. Affidavits are provided in Appendix B, Attachment C.

11.0 CONFIDENTIAL INFORMATION

None of the information presented in this proposal is considered confidential except for Fig. 2.4.1'Possible Integration of the WRI Technology with an IGCC Island' referenced in Section 2.4 and placed in Appendix C. Fig 4.2.1 represents the essential features of the WRI WRITECoal™ gasification technology and is being treated as proprietary intellectual property. Appendix B-Budget Details is considered proprietary to the applicant and should not be released to the public.

12. RELATED REFERENCES

Bauer, C., "Energy Production and CO_2 Emissions: Protecting our Air Quality," Air Quality VII International Conference, Oct. 26, 2009, Arlington, VA.

Bland, A., Greenwell, C., Newcomer, J., Sellakumar, K.M., and Carney, B., "*A Novel Pathway for Mercury Removal by Thermal Treatment of Coal"* Proceedings of the 33rd International Technical Conference on Coal Utilization & Fuel Systems, Jun. 1-5, 2008

Bland, A.E., Greenwell, C., Newcomer, J., Sellakumar, K.M., and Carney, B., "*Pilot Testing of WRI's Novel Mercury Control Technology by Pre-Combustion Thermal Treatment of Coal,"* U.S. DOE Mercury Control Conference, Pittsburgh, PA, Dec. 13, 2007.

Bland, A., Newcomer, J., Sellakumar, K.M., Walling, G., Steen, D., and Klunder, E "*Pre-Combustion Thermal Treatment of Coal to Remove Mercury: Process Data Validation with Bench and Pilot-Scale Units – Preliminary Results,"* 20th (Intl.) Western Fuels Conf., Denver, CO, Oct. 24-26, 2006.

Bland, A., J. Newcomer, T. Zhang, K. Sellakumar, "Pilot Testing of WRI's Novel Mercury Control Technology by Pre-combustion Thermal Treatment of Coal", Report to U.S. Department of Energy, Contract No. DE-FC26-98FT40323 Task 79, Jun. 2009.

Booras, G., N. Holt, and R. Schoff, "WPRI Study Cost and Performance Results", 1008 Gasification Technologies Conference, Washington, DC, Oct. 8, 2008.

Callaghan, C., "Kinetics and Catalysis of the Water-Gas-Shift Reaction: A Microkinetic and Graph Theoretic Approach," A Dissertation, Worcester Polytechnic Institute, Mar. 31, 2006

Carbo, et al, "Staged water-gas shift configuration: Key to efficiency penalty reduction during pre-combustion decarbonisation in IGCC," Science Direct, Elsevier Publications, Vol. 1, Issue 1, Feb. 2009, pp 661-668.

Ciferno, J., 2007 (revised) "Pulverized Coal Oxycombustion Power Plants – Final Results", U.S. Department of Energy, National Energy Technology Laboratory, Nov. 1, 2007

Dalton, W.S., and J. Novak, "Overview of Advanced Coal Technology for Electric Power", EPA Advanced Coal Technology Work Group, Washington, DC, Jan. 8, 2007.

DOE, "The Wabash River Coal Gasification Project: An Update", 2000 Web accessed Nov. 6, 2009

EIA, Coal Production in the U.S, 2008, web accessed Nov. 6, 2009, www. coal/page/acr/table1.pdf

EPRI, "Feasibility Study for an Integrated Gasification Combined Cycle Facility at a Texas Site", Electric Power Research Institute Technical Update Report 1014510, Oct. 2006.

Everitt, E., "Integrated Gasification Combined Cycle," Wyoming Coal Gasification Symposium, Casper, Wyoming, Feb. 28, 2007.

Fan, Z., and A. Seltzer., "*System Modeling/Evaluation of WRI's Pre-Combustion Thermal Process Integration to an Existing Utility Plant- Phase I and II Final Report*," Foster Wheeler North America, Inc. Report to Western Research Institute, Subcontract number: 65-125334-00, DOE NETL Cooperative Agreements DE-FC26-98NT42785/DE-FC26-98FT40323, Apr.23, 2009.

Grol, E., "Meeting California's Greenhouse Gas Emission Performance Standard for Western Coal Plants," Annual NETL CO_2 Capture Technology for Existing Plants R&D Meeting, Pittsburgh, PA, Mar. 24-26, 2009.

Guffey, F.D., Bland A.E, and Brown, T.H., "Pre-combustion Removal of Mercury from Coal" *Proceedings of the 27th International Conference on Coal Utilization and Fuel, Systems* Clearwater, FL, Mar. 4-7, 2002.

Kilgroe, J., et al "Control of Mercury Emissions from Coal-Fired Utility Boilers: Interim Report," EPA-600/R-01-109, Dec. 2001.

Leonard, R., T. Pinkston, L. Rogers, R. Rush and J. Wheeldon, The PSDF – Commercial Readiness for Coal Power-Revisited, 2007

Maurstad, et al, “Impact of Coal Quality and Gasifier Technology on IGCC Performance,” GHT8, web accessed Nov. 5, 2009.

Merriam, N., “Removal of Mercury from Powder River Basin Coal by Low-Temperature Thermal Treatment,” *U. S. Department of Energy, Morgantown Energy Technology Center,* DE-FC21-93MC30126, pg. 23, 1993

Miron, Y., Smith, A.C., and Lazzare, C.P., “Sealed Flask Test for Evaluating the Self-Heating Tendency of Coals”, Bureau of Mines Report of Investigation RI9330, 1990

Nexant, Inc., “Task 3 Gasification Plant Cost and Performance Optimization,” Final Report, DOE Contract No DE-AC26-99FT40342, May 2005.

Nizamoff, A. J., S. Kramer, F.S. Lau, S. Olson, M. Roberts, S. Tam, and R. Zabransky, “Lignite-Fueled IGCC Power Plant”, 22nd Annual International Pittsburgh Coal Conference, Sept. 12-15, 2005.

NYSERDA, Hydrogen production, www.nyserda.org, web accessed, Nov. 5, 2009.

Southern Company, “Overview of Commercial TRIG™ and Carbon Management Projects in Southern Company,” Coal Utilization Research Council (CURC) Fall Meeting, Washington D.C., October 15, 2009.

Zuideveld, P.L.,“Shell Coal Gasification Process Using Low Rank Coal,” Gasification Technologies Conference, San Francisco, Oct. 9-12, 2005.

APPENDIX A

RESUMES OF KEY PERSONNEL

Andrea Stomberg

Vice President – Electric Supply

Montana-Dakota Utilities Co.

Stomberg joined Montana-Dakota in 1990, and was named to her current position as Vice President of Electric Supply, in August 2003. She has overall responsibility for electric generation and transmission engineering and operations in the four states in which Montana-Dakota serves electric customers. She started with the company as an environmental scientist and was promoted to environmental manager in 1993. Prior to coming to Montana-Dakota Utilities, Ms Stomberg worked as an environmental scientist for North American Coal Corporation in North Dakota, for ten years. Stomberg holds a bachelor's degree in geology from the University of Washington, a master's degree in soil science from Oregon State University and a Master's in Business Management from the University of Mary.

ALAN E. BLAND, Ph.D.

Vice President

Western Research Institute

365 North 9th Street, Laramie, WY 82072

Phone: (307)0721-2386   Fax: (307) 721-2256   E-Mail: abland@uwyo.edu

PROFESSIONAL EXPERIENCE

Western Research Institute – Laramie, Wyoming

Vice President – Waste and Environmental Management

Dr. Bland is WRI's lead for waste and environmental management science and technology R&D that addresses the gaseous emissions, water recovery and treatment and solid waste cleanup and reuse issues of clean energy generation and the environmental processes related to mining and energy production, and biotechnology and bioremediation. Current activities include development of WRI's coal upgrading technologies, advanced coal- and biomass-based oxy-combustion and gasification systems, sorbent technologies for trace metals such as mercury, arsenic, selenium and CO_2, water management and treatment options for the power sector, advanced ash management and beneficial reuse options for coal combustion by-products, and conducting power system analysis and techno-economic evaluations of the environmental processes and emerging clean fuel technologies. Dr. Bland has developed and managed several large multi-participant programs for DOE, industry, and the State of Wyoming Clean Coal Program ranging in size from $0.5M to $6.0M. Included are WRI's WRITECoal™ upgrading process development, with Etaa Energy, Foster Wheeler and URS ($2.5M), WRI's advanced gasification process with Gas Technology Institute ($3.0M), and WRI's advanced oxy-combustion processes with Etaa Energy, Foster Wheeler, Southern Research Institute, Praxair and Nalco ($6.5M). Dr. Bland acts as a liaison on all technical, contractual, and budgetary matters with DOE, industry and State of Wyoming Clean Coal Task Force for these projects

Ash Management Engineering

Technical Director and Vice President

Prior to joining WRI, Dr. Bland was Technical Director of Ash Management Engineering, where he provided ash management and environmental consulting services to the utility industry in the

U.S. and Canada. Clients included EPRI, Ontario Hydro, Nova Scotia Power and AES. Dr. Bland developed a process for pelletizing ash for backhaul and synthetic aggregate production.

Kentucky Center for Energy Research Laboratory (currently Kentucky Center for Applied Energy Research

Program Manager

Dr. Bland was also Clean Coal Fuels Program Director at the Kentucky Center for Applied Energy Research (formerly Kentucky Energy Research Laboratory), where he was involved in coal preparation and processing equipment performance studies, coal processing computer simulations, fine coal cleaning for synthetic fuels and coal water slurry fuels applications, and was co-developer of the Ken-Flote technology, a counter-current column flotation technology for fine coal cleaning.

PROFESSIONAL AFFILIATIONS

Professional Organizations: American Chemical Society-Fuel and Environmental Chemistry Section; American Association of Petroleum Geologists-Energy Minerals Section, and American Institute of Mining Engineering/Society of Mining Engineering. Dr. Bland represents WRI on the American Coal Ash Association, American Coal Council, and the Coal Utilization Research Council.

Chairs and Committees: Coal Prep Symposium - Advisory Committee; Eastern Oil Shale Symposium - Technical Advisory Committee; Kentucky Coal By-Products Symposium - Organizing Member; International Conference on Fluidized Bed Combustion: - Steering Committee and Environmental Chairman; Organizer of 'Gasification' and CO_2 Sequestration' symposia for School of Energy Resources and State of Wyoming; Subbituminous Energy Coalition - Co-Founder, current and former Chair (focusing on mercury and CO_2 emissions issues).

EDUCATION

B.S. Geology, St. Lawrence University, 1970;
M.S. Geology/Geochemistry, University of North Carolina, 1972;
Ph.D. Geology/Geochemistry, University of Kentucky, 1978

SELECTED PUBLICATIONS AND PROCEEDINGS PAPERS

Related and Non-Related Peer-reviewed Publications

Zhang, Tengyan, L.T. Fan, W.P. Walawender, Maohong Fan, Alan E. Bland Tianming Zuo, and Donald W. Collins, "Hydrogen Storage on Carbon Adsorbents: Review," to be appear in ENVIRONANOTECHNOLOGY, Editors: Maohong Fan, C. P. Huang, Rachid B. Slimane, Ian G. Wright, Alan E. Bland, and Z. L. Wang, Elsevier.

Fan, M., C.P. Huang, T. A. Hatton, R.R. Judkins, A.E. Bland, Z.L Editors. Special issue: application of nanotechnologies in separation and purification. [In: *Sep. Purif. Technol*., 2007; 58(1)]. (2007), 231 pp. CAN 148:171313 AN 2008:123562 CAPLUS

Yang, H., Z. Xu, M. Fan, R.B. Slimane, A. Bland and I. Wright, *"Technical review of progress in carbon dioxide separation and capture"*, Journal of Environmental Science 20 (1), 14-27, 2008.

Yang, H., Z. Xu, M. Fan, A. Bland, and R.R. Judkins *"Adsorption removal of mercury in coal-fired boiler flue gas*", Journal of Hazardous Materials, 146 (1), 1-11, 2007.

Bland, A.E., *"Pilot Testing of WRI's Novel Mercury Control Technology by Pre-Combustion Thermal Treatment of Coal"*, Final Report to U.S. Department of Energy, Morgantown, WV, DE-FC26-98FT40323, February 2008.

Bland. A.E., A Kephart. V. Schmidt, G. Butcher, *"Emissions Monitoring and Control of Mercury From Subbituminous Coal-Fired Power Plants – Phase II"*, Final Report to U.S. Department of Energy, Morgantown, WV, DE-FC26-98FT40323, July 2008.

Bland, A.E., K. Sellakumar, D. Steen, G. Walling, *"Thermal Pre-Combustion Mercury Removal Process for Low-Rank Coal-Fired Power Plants"*, Final Report to U.S. Department of Energy, Morgantown, WV, DE-FC26-98FT40323, August 2007.

Bland, A.E., Sellakumar, K.M., Johnson, L., Walling, G., Steen, D.O., and Klunder, E., *"Mercury Control at Low-Rank Coal-Fired Power Plants by a Pre-Combustion Thermal Treatment Process: Techno-Economic Study"*, Air Quality V Symposium, Washington, D.C., September 19-21, 2005.

Bland, A., Newcomer, J., Sellakumar, K.M., Walling, G., Steen, D., and Klunder, E "*Pre-Combustion Thermal Treatment of Coal to Remove Mercury: Process Data Validation with Bench and Pilot-Scale Units – Preliminary Results,"* 20th (Intl.) Western Fuels Conf., Denver, CO, Oct. 24-26, 2006.

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PROFESSIONAL EXPERIENCE

June 2008 – Present: Senior Research Engineer

Managed day-to-day operations on WRI's WRITE Coal pilot plant for a project, including supervision of technicians and interns, reviewing data, writing technical progress reports, and preparing presentations for DOE and other technical forums. Worked in an inter-disciplinary team to develop testing scopes and scheduling. Worked directly with vendors and sub-contractors to complete fabrication projects totaling over for pilot scale processes in 2008-2009. Developed testing protocols and testing apparatus for multi-pollutant sorbents in warm and hot gas clean up. Performed system integration and evaluation for state-of-the-art gasification technologies on ASPEN. Performed as the lead in design activities from concept to completion on numerous systems in bench-scale to pilot plants.

- Filed for patents as a co-inventor on integrated coal upgrading and flue gas purification technologies for carbon capture readiness of existing coal-fired power plants.
- Completed design and construction of a mobile coal upgrading pilot plant capable of processing 800 lbs per hr of PRB coal.
- Completed production runs and combustion test at EERC achieving over 90% removal of mercury without the use of activated carbon.
- Engineered overall system integrations for various combustion and gasification test facilities ranging in size from 1-5 MW_{th}.
- Competed one-of-a-kind design for a sorbent testing apparatus, including; casements, piping, electrical control systems, gas mixing, and operational manuals.
- Completed systems integration and evaluation of 3 related scenarios for a state of the art gasifier.

January 2005 – June 2008: Research Engineer

Conducted research on pre-combustion removal of mercury from coal on a bench-scale and an existing process development unit at a scale of two tons a day. Assisted in the design and fabrication of a bench scale fluidized bed reactor. Assisted in project management for field site mercury tracing through a PC power plant as well as CEM verification. Also, conducted sample procurement and analysis for long term testing. Conducted experimentation on the bench-scale for fly ash re-usage technology development and new material development for water and air purification. Conducted material testing on fly ash based products and geo-synthetic liner materials. Design and construction of numerous support systems for heavy oil upgrading technologies.

- Developed a bench-scale fluidized bed reactor for batch wise testing of subbituminous coals.
- Verified process improvements on WRI's pre-combustion mercury removal PDU on eight coals including PRB and Lignite coals.
- Developed and constructed a sorbent testing apparatus for endurance testing of multi-pollutant sorbents.

July 2002 – January 2005: Technician/Engineering

Fabrication of material handling equipment for biomass energy conversion technologies. Fabrication and installation of pilot-scale equipment for coal processing equipment. Performed operational tasks for pilot-scale equipment. Performed scheduled testing for bench-scale tests and material testing based on ASTM methods. Learned new skills such as welding, machining using a metal lathe and designing using simple hydraulic systems. Recorded gauge readings, stocked lab equipment, and performed general maintenance.

- Applied basic engineering principles in real world applications.
- Finished construction projects before deadline.

EDUCATION & PROFESSIONAL DEVELOPMENT

University of Wyoming, Laramie, WY

Bachelors of Science in Mechanical Engineering, Fall of 2004

Professional Licenses & Affiliations

EIT Certificate in Wyoming, 2005

Tengyan Zhang

Lead Engineer

Western Research Institute

365 N. 9th Street, Laramie, WY 82072

Phone: (307) 721-2450 Fax: (307) 721-2256 E-Mail: tzhang3@uwyo.edu

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EDUCATION

Ph.D., Chemical Engineering, 2004, *Kansas State University, Manhattan, KS*

M.S., Computing and Information Sciences, 2002, *Kansas State University, Manhattan, KS*

M.S., Chemical Engineering, Dec. 1997, *Tianjin University, Tianjin, China*

B.E., Techno-economics & System Engineering, Specialty of Engineering Economics, 1995, *Tianjin University, Tianjin, China*

B.E., Chemical Engineering, Specialty of Organic Chemical Technology, 1995, *Tianjin University, Tianjin, China*

PROFESSIONAL EXPERIENCE

- Western Research Institute, February 2009-present, *Lead Engineer*
- Department of Chemical Engineering, Kansas State University, June 2004-February 2009, *Research Associate*
- Department of Chemical Engineering, Kansas State University, Jan. 1998-May 2004, *Research Assistant*
- Department of Chemical Engineering, Tianjin University, Sep. 1995-Dec. 1997, *Research Assistant*
- National Pharmaceutical Center, Tianjin, China, Mar. 1995-Oct. 1996, *Process Engineer*
- Sinopec, Summer 1994, *Process engineer (Intern)*

PUBLICATIONS

Zhang, Tengyan, W. P. Walawender, and L. T. Fan, “Enhancing the Microporosities of Activated Carbons,” Separation and Purification Technology, **44**, 247-249 (2005).

Zhang, Tengyan, W. P. Walawender, and L. T. Fan, “Preparation of Carbon Molecular Sieves by Carbon Deposition from Methane,” Bioresource Technology, **96**, 1929-1935 (2005).

Zhang, Tengyan, W. P. Walawender, L. T. Fan, M. Fan, D. Daugaard, and R. C. Brown, “Preparation of Activated Carbon from Forest and Agricultural Residues through CO_2 Activation,” Chemical Engineering Journal, **105**, 53-59 (2004).

Liu, Shiping, Dongming Li, and Tengyan Zhang, “Drop Coalescence in Turbulent Dispersions,” Journal of Chemical Industry and Engineering (in Chinese), **49**, 409-417, 1998.

Yun, Choamun, L. T. Fan, Tengyan Zhang, Young Kim, Sang Yup Lee, Kim Taeyong, Sunwon Park, Ferenc Friedler, Botond Bertok, “Complementary Approach for Thermodynamic Analysis of Metabolic Pathways,” Session on Applied Mathematics and Numerical Analysis, AIChE Annual Meeting, November 8-13, 2009, Nashville, TN.

Zhang, Tengyan, and L. T. Fan, “Significance of Dead-state-based Thermodynamics in Designing a Sustainable Process,” FOCAPD (Foundations of Computer-Aided Process Design), Beaver Run Resort, Breckenridge, **June 7-12,** 2009.

Fan, L. T., Tengyan Zhang, A. Argoti, J. Liu, F. Friedler, and B. Bertok, “Graph-theoretic Approach for Discovering Alternative Synthetic Routes Forming Complex Network,” session on Complex and Networked Systems, AIChE Annual Meeting, Philadelphia PA, November 16-21, 2008.

Zhang, Tengyan, L. T. Fan, and A. P. Mathews, “Sustainability and Thermodynamic Analysis of a Process for Biogas Generation and Utilization,” session on Power Generation, 6th APCSEET (Asia Pacific Conference on Sustainable Energy and Environmental Technologies), Bangkok, THAILAND, May **7-12**, 2007.

KUMAR M. SELLAKUMAR, Ph.D.

240 LONGVIEW ROAD ♦ BRIDGEWATER, NEW JERSEY 08807

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EDUCATION AND TRAINING

B. S., Mechanical Engineering, University of Madras, Chennai, India (1970)

M. S., Design of Thermal Power Equipment, University of Madras, Chennai, India (1972)

M. S. (1982) **and Ph.D., Energy Science**, New York University, New York (1988)

RESEARCH AND PROFESSIONAL EXPERIENCE

Etaa Energy, Inc. Bridgewater, New Jersey **2003-Present**

President

Dr. Sellakumar is responsible for the technical services provided by the company in the areas of air pollution control including mercury control technology development and combustion and energy system design and performance studies. He has over 30 years of experience in research and product development and commercialization of new technologies. His current projects include pre-thermal treatment of coal to remove mercury, and other pollution control from combustion and gasification systems.

Foster Wheeler Development Corporation, Livingston, New Jersey **1988-2003**

Product Development Manager, 1997-2003

Dr. Sellakumar was responsible for the development of fossil energy systems emission reduction technologies. He also consulted on boiler performance, fuels and combustion, boiler heat transfer, emission reduction technologies and ash management issues. He was actively involved in the development of reliable hot gas filter systems for clean coal projects and has been playing a pioneering role in the testing and development of various types of particulate and gas cleaning system, combustor/gasifier-filter-gas turbine system integration, material selection and new energy technologies development including multi-fuel applications. He was a key individual in providing technical input to commercial designs.

Assistant Research and Development Manager, 1993-1997

- Conceptualized, built and successfully demonstrated a pilot–scale (15000 lb/hr) material transfer and cooling system to handle pressurized hot solids (800-1600ºF) to low-pressure, low temperature vessels. Two patents awarded. Commercial design developed.
- Tested Gas Turbine (GT) materials for coal-based energy systems.

Research Specialist, 1990-1993

- Evaluated and developed hot flue gas cleanup systems for combined cycle power plants. Technology development has reached the commercial threshold. Two patents awarded.
- Successfully managed clean coal projects funded by the DOE and Illinois Clean Coal Research Institute/Electric Power Research Institute. Contract values ranged from $0.16m to $3m.

Research Engineer, 1988-1990

- Saved the company $0.1m by designing a Distributed Control System configuration and graphics (Bailey Network 90) and training engineers.
- Conducted pilot tests and developed process design parameters for burning gob in CFBs. Prior to joining Foster Wheeler in 1988, Dr Sellakumar worked at BHEL, India (1972-1983) and at New York University, New York (1983 and 1988) in energy and pollution control R&D.

PUBLICATIONS

50 technical papers in fluidization, energy and environmental systems

Bland, A., Newcomer, J., Sellakumar, K.M., Walling, G., Steen, D., and Klunder, E "*Pre-Combustion Thermal Treatment of Coal to Remove Mercury: Process Data Validation with Bench and Pilot-Scale Units – Preliminary Results,*" 20th (Intl.) Western Fuels Conf., Denver, CO, Oct. 24-26, 2006….

Bland, A., Sellakumar, K.M., Johnson, L., Walling, G., Steen, D., and Klunder, E., "*Beneficial Options for the Pre-Combustion Thermally Treated Subbituminous Coal: Initial Findings,*"22nd Intl. Pittsburgh Coal Conf., Pittsburgh, Sep. 12-15, 2005

Bland, A., Sellakumar, K.M., Guffey, F., Walling, G., Steen, D., and Klunder, E., "*A Novel Approach to Mercury Control by Pre-Combustion, Thermal Treatment of Low-Rank Coals,*" AWMA's 97th Annual Conf., Indianapolis, IN, June 22-25, 2004

Wu, S., Hiltunen, M., and Sellakumar, K.M. "*Combustion of Pitch and Related Fuels in Circulating Fluidized Beds,*" CFB-7, Niagara Falls, Canada, May 5-8, 2002

Manjunath, A., Cotton, J., Ekambaram, A., Sellakumar, K.M. and Palonen, J., *"Efficient and Clean Biomass Gasification and Combustion Technologies for Bagasse"*" Int. Workshop on Alternative Bagasse Cogeneration, New Delhi, Feb. 27, 1999.

Tuncay, J., Sellakumar, K.M., and Lee, S.H.D., *"Alkali Emission Measurement in Atmospheric Circulating Fluidized Bed Combustors,*□ CFB-5 Conf., Beijing, China, May 26, 1996

Sellakumar, K. M., Isaksson, J., and Provol, S. J., *"High Pressure High Temperature Gas Cleaning Using An Advanced Ceramic Tube Filter,"* 11th Intl. Conf. on Fluidized Bed Combustion, Montreal, Canada, Apr. 21-24, 1991.

SELECTED PATENTS

Dr. Sellakumar holds seven US patents related to coal utilization and flue gas cleaning.

SYNERGISTIC ACTIVITIES

Life Member, Association of Energy Engineers, Atlanta

Member, Air &Waste Management Association, Pittsburgh

Associate Member, Subbituminous Energy Coalition, Laramie, WY

Past member,

- Executive Committee, and Director, Particulate Solid Research Institute, Chicago,
- Council of Industrial Boiler Owners (CIBO) Energy and Environmental Committees, Washington D.C.
- Iowa State University Research Center Program Review Panel.

Clean Coal Technology and Boiler Specialist in the US DOE Team - India-U.S. "Coal Working Group" Meetings, Apr. 2003 and June 2007, Washington DC and Nov. 2004, Apr. 2006 and Aug. 2007, New Delhi.

Mr. Michael J. Roberts, P.E.

Name: Michael J. Roberts	Gas Technology Institute 1700 South Mt. Prospect Des Plaines, IL 60018
Title: R&D Manager Gasification and Gas Processing	
Phone Number: 847-768-5518	
E-mail Address: mike.roberts@gastechnology.org	

Summary: *Michael Roberts is an R&D Manager in the Gasification and Gas Processing Department, heading the membrane and hydrogen separation group. Mr. Roberts is also responsible for the small scale gasification activity, including coal and biomass.*

Education:

University	Degree	Area of Specialization	Year
Illinois Institute of Technology	M.Ch.E.	Chemical Engineering	1983
Illinois Institute of Technology	B.S.	Chemical Engineering	1969

Positions:

1970 – Present: GTI, Des Plaines, IL – R&D Manager in Gasification & Gas Processing

Since joining GTI, Mr. Roberts has been engaged in research and development of the utilization and conservation of fossil-fuel energy, technology improvement, and pollution prevention programs. Mr. Roberts has also been engaged in environmental and energy research on coal, oil shale, and peat processing, as well as catalytic and non-catalytic gas-solids reactions. His duties include design, construction, and operation of process research units and analysis of the data.

Related Project Experience

2003-present - Mr. Roberts is directing small-scale catalytic and non-catalytic coal gasification for several industrial clients. He is also project manager and principal investigator for a U.S. D.A. project (prime is Earth Resources Inc.) to gasify chicken litter to produce hydrogen, fertilizer, and chemicals. Mr. Roberts is also in charge of several projects utilizing membranes for hydrogen separation, funded by the ICCI, GRI, and DOE.

Publications/Presentations:

M. Roberts, "Illinois Coal Gasification/Reforming Using Low-Temperature Plasma", Presented at the AIChE Symposium on Refinery Processing and In-Plant Energy Conversion and Optimization, Chicago,IL October 9-10, 2006.

M. Roberts, F. Lau, F and R. Zabransky (GTI), and S Kramer, A. J. Nizamoff, S. Olson, and S. Tam (Nexant, Inc.) 2005. "Gasification Alternatives for Industrial Applications An Industrial Application for Eastern Coal," 22nd Int. Pittsburgh Coal Conference, Sept. 12-15, 2005.

A. J. Nizamoff, S. Kramer, S. Olson, and S Tam (Nexant, Inc.); F. Lau, M. Roberts, and R. Zabransky (GTI). 2005. "Lignite-Fueled IGCC Power Plant," 22nd Annual International Pittsburgh Coal Conference, Pittsburgh, PA, September 12-15, 2005.

A. Nizamoff, S. Kramer, S. Olson and S. Tam (Nexant Inc.); F. Lau, D. Stopek, and M. Roberts, (GTI). 2004. "Gasification of Lignite for Power Generation," Western Fuels Symposium 19th Int. Conference on Lignite, Brown, and Subbituminous Coals, Billings, MT, October 12-14, 2004.

Patents or Copyrights:

Number	**Patent Title**	**Date**
5,934,892	"Process and Apparatus for Emissions Reduction Using Partial Oxidation of Combustible Material," J. Rabovitser, M. J. Khinkis and M. J. Roberts	1999

MICHAEL J. HOLMES
Deputy Associate Director for Research
Energy & Environmental Research Center (EERC)
University of North Dakota (UND)
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018 USA
Phone (701) 777-5000, Fax (701) 777-5181
E-Mail: mholmes@undeerc.org

Principal Areas of Expertise
Mr. Holmes' principal areas of interest and expertise include emission control (air toxics, SO_2, NO_x, H_2S, and particulate), fuel processing for production of syngas and feed gas for fuel cells, and process development and economics for advanced energy systems. He has had project management responsibilities on several large-scale projects. He is currently the project manager on two large consortium projects (totaling $7.9 million) to perform long-term field testing of mercury control technologies at lignite-fired utilities. Other examples of project management experience include the end of Phase II and all of Phase III of the Advanced Emissions Control Development Program (multimillion dollar program focused on mercury control); a program to demonstrate the feasibility of vitrifying low-level radioactive wastes in a slagging combustion system; and several programs for development of spraying systems (dry scrubbing, wet scrubbing, duct injection technology, oil lighters, and heavy oil burners). Mr. Holmes has also had process engineering responsibilities in these and other energy and environmental related projects, as well as experience on multiple commercial contracts in the areas of dry scrubbing, wet scrubbing, and natural gas processing.

Qualifications
M.S., Chemical Engineering, University of North Dakota, 1986.
B.S., Chemistry and Mathematics, Mayville State University, 1984.

Professional Experience

2005 – Deputy Associate Director for Research, EERC, UND. Mr. Holmes currently oversees fossil energy research areas at the EERC, including hydrogen production, advanced energy systems, and emission control technology projects involving mercury, SO_2, NO_x, H_2S, and particulate.

2001 – 2004 Senior Research Advisor, EERC, UND. Mr. Holmes was involved in research in a range of areas, including emission control, fuel utilization, process development, and process economic evaluations. Specific duties included marketing and managing research projects and programs, providing group management and leadership, preparing proposals, interacting with industry and government organizations, designing and overseeing effective experiments as a principal

JOSHUA J. STANISLOWSKI
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E-Mail: jstanislowski@undeerc.org

Principal Areas of Expertise
Mr. Stanislowski's principal areas of interest and expertise include fossil fuel combustion for energy conversion with emphasis on trace element control. He has extensive experience with process engineering, process controls, and project management. He has a strong background in gauge studies, experimental design, and data analysis.

Qualifications
B.S., Chemical Engineering, University of North Dakota, 2000.

- Extensive computer experience with Windows, word processors, spreadsheets, and database software and analytical chemistry, organic chemistry, and chemical engineering laboratory work
- Senior classes included reactor design, mass transfer, separations, thermodynamics, and process controls
- Senior design project on the formation of phosphoric acid from phosphate rock
- In-depth courses in statistical methodology including experimental design and analysis

Professional Experience:

2005 – Research Engineer, EERC, UND. Mr. Stanislowski's areas of focus include mercury control technologies and coal gasification. His responsibilities involve project management and aiding in the completion of projects. His duties include design and construction of bench- and pilot-scale equipment, performing experimental design, data collection, data analysis, and report preparation.

2001–2005 Process Engineer, Innovex, Inc., Litchfield, MN.

- Innovex, Inc. is a world-class supplier of flexible circuits to such companies as Seagate, Maxtor, Phillips, and Samsung. Innovex processes plated or laminated copper foils through a roll-to-roll process for the formation of flexible circuits.

- Employed as process engineer for various process lines including copper plating, nickel plating, tin-lead plating, gold plating, polyimide etching, copper etching, chrome etching, and resist strip and lamination. Process engineering is a high-risk, fast-paced position where critical decisions are made daily. Responsible for all aspects of the process line including quality control, documentation, final product yields, continuous process improvement, and operator training. Have gained extensive knowledge of statistical process control and statistical startup methodology. Continuously using statistical analysis and experimental design as part of daily work. Proficient with MiniTab statistical software. Excellent communication skills with all levels of employees from operations to management.

- Normal duties include designing and overseeing experiments as a principal investigator; writing technical reports and papers, including standard operating procedures and process control plans; presenting project and experimental results to suppliers, customers, clients, and managers; engineering design and calculations; and hands-on mechanical work when troubleshooting process issues.

- Demonstrated ability to coordinate activities with varied entities through extensive project management and leadership experience:

  – Led team in reduction of excess copper, which resulted in an annual scrap reduction of approximately $1 million.

  – One of approximately 25 team leaders for companywide Six Sigma initiative. Led a diverse team consisting of engineers, operators, and technicians. Team won first place out of all teams for improving chrome etch bath control.

  – One of 25 team leaders for second companywide Six Sigma initiative. Team won first place for scrap reduction and cycle time improvement.

  – Led team in reduction of circuit bites. Team was successful in reducing defect levels by 70%.

  – Team leader for polyimide stringer reduction. Worked directly with major vendors and customers to reduce defects. Successful in lowering defect level by a factor of ten.

  – Team leader for design, implementation, and process line startup of new polyimide etching line. Worked with mechanical engineers, electrical engineers, and technicians to solve various equipment and process-related issues. Project was completed on time and resulted in improved throughput and yield.

1998–2000 Student Research Assistant, EERC, UND.
Worked as a temporary employee while attending the University and worked full time during the summer. Worked on a wide variety of projects:

- Performed data entry for Center for Air Toxic Metals® (CATM®) database. Duties included interpreting data from coal combustion and emission reports, performing calculations, organizing data, and working with database software. Worked with U.S. Geological Survey to transfer coal quality data to the CATM database. Researched technical literature for coal quality and combustion emission data for entry into the database. Gained knowledge of environmental systems and energy conversion technologies.

- Worked on CATM database programming to make it more user-friendly and intuitive. Made improvements to the database structure under the guidance of the programming engineer.

- Wrote a technical paper/peer review on the utilization of the CATM database and submitted to *Fuel Processing Technology*.

- Helped to develop program for contamination cleanup, which included interpreting and organizing technical data and aiding programmers and engineers in the formation of the database.

- Aided engineer with research proposal that included researching data on using aerogels for emission control and hands-on work preparing samples for bench-scale testing.

- Worked with engineers on development of nationwide mercury emissions model. Organized and analyzed data and aided in interpretation of results.

Other Experience

- Six Sigma Green Belt Certified –August 2004. This includes learning a very structured problem-solving methodology and applying statistical methods to achieve results. In-depth instruction in designing and running experiments.

- Team member for numerous Six Sigma Black Belt Teams. Implemented Six Sigma problem-solving methodology and aided in the successful completion of numerous process improvement teams.

- Supported the introduction of new product lines over multiple process steps.

Publications and Presentations

- Has coauthored several publications.

HOSSEIN GHEZEL-AYAGH **DIRECTOR, SECA PROGRAM**

FUELCELL ENERGY, INC.

Hossein Ghezel-Ayagh is the Director of Solid State Energy Conversion Alliance (SECA) Program at FuelCell Energy (FCE), Danbury, CT. In this position, he directs the development of Solid Oxide Fuel Cell (SOFC) technology and products. He joined FCE in 1983 where he has been involved in research activities related to energy and electrochemical conversion devices. Hossein has participated in various aspects of fuel cell product development including materials research, electrocatalysis, stack design, and fuel processing. He has contributed to the design and development of components for phosphoric acid fuel cell (PAFC), PEM fuel cell, internal reforming carbonate fuel cell (MCFC) and SOFC systems. He has also been engaged in evaluation, testing and design of power plant systems using various types of fuels such as natural gas, coal gas and heavy hydrocarbons. He has authored chapters in two books: "Handbook of Fuel Cells" and "Recent Trends in Fuel Cell Science and Technology".

EDUCATION AND TRAINING

Ph.D., Chemical Engineering, Illinois Institute of Technology, 1981

MS, Chemical Engineering, Illinois Institute of Technology, 1977

BS, Chemical Engineering, Abadan Institute of Technology, 1971

RESEARCH AND PROFESSIONAL EXPERIENCE

- Lead the development of coal based Solid Oxide Fuel Cell (SOFC) systems under a Department of Energy's SECA Program. Manage the development of SOFC cell, stack and systems at FCE. Lead a technical team at FCE and Versa Power Systems (VPS) for development of the next generation scaled-up SOFC technology. Manage design activities for development of system process flow, equipment cost and plant layout for integrated gasification/SOFC power plants. Direct the evaluation of coal gasification, syngas clean-up and carbon dioxide separation technologies for optimization of cost and performance of the coal-based SOFC power systems.

- Managed a DOE Vision 21 project for design, fabrication and testing of the hybrid fuel cell/gas turbine power plants. Led the development of novel cycles for generation of power at high efficiencies by integration of direct reforming molten carbonate fuel cells with gas turbines. Fabricated and tested a packaged 300-kW hybrid fuel cell unit with record-breaking efficiencies in its class.

- Managed a co-operative agreement with Department of Energy for "Development of Direct FuelCell (DFC) for Combined Power and Carbon Dioxide Sequestration" under the award No. DE-FC26-04NT42206. Led the R&D efforts resulting in the successful laboratory tests of the DFC based carbon capture concept. Oversaw system flow sheet development, mass and energy balances and economic analysis for the DFC-based carbon capture systems.

- Managed the development of advanced control algorithms for hybrid fuel cell/gas turbine systems under a STTR project sponsored by Department of Energy (DE-FG02-02ER86140). Led the R&D efforts for development of artificial neural networks and model based control strategies to accommodate power plant transients, startup, shutdown and trip to hot standby. Developed dynamic simulation computer codes to verify the applicability and robustness of the advanced control designs.

SELECTED PUBLICATIONS

- F. Mueller, F. Jabbari, J. Brouwer, R. Roberts, S. T. Junker, and H. Ghezel-Ayagh, "Control Design for a Bottoming Solid Oxide Fuel Cell Gas Turbine Hybrid System", *Journal of Fuel Cell Science and Technology*, August 2007, Volume 4, Issue 3, pp. 221-230

- Roberts, J. Brouwer, F. Jabbari, T. Junker, and H. Ghezel-Ayagh, "Control Design of an Atmospheric Solid Oxide Fuel Cell/Gas Turbine Hybrid System: Variable versus Fixed Speed Gas Turbine Operation", *Journal of Power Sources*, Volume 161, October 2006, Pages 484-491.

- H. Ghezel-Ayagh, J. Walzak, D. Patel, J. Daly, H. Maru, R. Sanderson and W. Livingood, "State of Direct Fuel Cell/Turbine Systems Development", *Journal of Power Sources*, Volume 152, December 2005, Pages 219-225.

- M. Farooque, and H. Ghezel-Ayagh, " Part 7: Molten Carbonate Fuel Cells and Systems, System Design", Handbook of Fuel Cells, Fundamentals, Technology and Applications, Volume 4: Fuel Cell Technology and Applications, Part 2, Edited by W. Vielstich, A. Lamm, and H. Gasteiger, Published by John Wiley and Sons, LTD, ISBN: 0-471-40026-9, Chapter 68, pp. 942-968, 2003.

Patents:

- Z.-H. Wang, and H. Ghezel-Ayagh, "Enhanced high efficiency fuel cell/turbine power plant", *U.S. Patent No. 6,896,988,* May 24, 2005.

- H. Ghezel-Ayagh, A.J. Leo, and R. Sanderson, "High-Efficiency Fuel Cell System", *U.S. Patent No. 6,365,290,* April 2002.

- B.S. Baker, and H. Ghezel-Ayagh, “Fuel Cell System”, *U.S. Patent 4,532,192*, Jul. 30, 1985.

Conference Papers/Proceedings /Presentations:

- H. Ghezel-Ayagh, D. Patel, and R. Sanderson, “Development of an Electrochemical Membrane for Combined Carbon Dioxide Capture and Power Generation”, Eighth Annual Conference on Carbon Capture and Sequestration, May 4 – 7, 2009
- H. Ghezel-Ayagh, J. Walzak, S. Jolly, D. Patel, P. Huang, R. Way, C. Willman, K. E. Davis, D. Stauffer, V. Vaysman, B. Borglum, E. Tang, M. Pastula, R. Petri, and M. Richards, “Centralized Integrated Coal Gasification Solid Oxide Fuel Cell Power Plants”; Proceedings of ICEPAG2009 International Colloquium on Environmentally Preferred Advanced Power Generation February 10-12, 2009, Newport Beach, California.
- H. Ghezel-Ayagh, J. Walzak, D. Patel, A. Adriani, M. Lukas, S. Jolly,”Multi-Megawatt Direct FuelCell/Turbine Product Development”, Proceedings of ICEPAG2009 International Colloquium on Environmentally Preferred Advanced Power Generation February 10-12, 2009, Newport Beach, California.
- H. Ghezel-Ayagh, J. Doyon, J. Walzak, S.Jolly, D. Patel, A. Adriani, P. Huang, D. Stauffer, V. Vaysman, J. S. White, B, Borglum, E. Tang, R. Petri, and C. Sishtla, “Coal-Based Solid Oxide Fuel Cell Systems”, 2008 Fuel Cell Seminar & Exposition, Phoenix, Arizona, October 27-30, 2008
- H. Ghezel-Ayagh, D. Patel, and R. Sanderson, “Carbon Sequestration Systems Using Direct Fuel Cell for Combined Carbon Dioxide Separation and Power Generation”, 2008 Fuel Cell Seminar & Exposition, Phoenix, Arizona, October 27-30, 2008
- H. Ghezel-Ayagh, J. Walzak, D. Patel, S. Jolly, M. Lukas, F. Michelson, and A. Adriani, “Ultra High Efficiency Direct Fuel Cell Systems for Premium Power Generation”, 2008 Fuel Cell Seminar & Exposition, Phoenix, Arizona, October 27-30, 2008
- H. Ghezel-Ayagh, R. Sanderson, D. Patel, S. T. Junker, S. Jolly, and C. Willman, “Novel Carbon Dioxide Separation Using High Temperature Direct Fuel Cell® Technology for Carbon Sequestration”, Twenty-Fifth Annual International Pittsburgh Coal Conference. Pittsburgh, PA, USA, September 29 – October 2, 2008.

ROBERT J. KEETH, PE

Project Engineering Manager

Washington Group International

7800 E. Union Avenue, Suite 100, Denver, Colorado 80237

Phone: (303) 843-3179 E-Mail: Robert.Keeth@wgint.com

EXPERIENCE SUMMARY

Mr. Keeth has more than 27 years of experience working in all areas of sulfur oxides, nitrogen oxide, mercury and particulate control systems, including pilot plant and full-scale utility design, operation, troubleshooting and economic evaluations. Mr. Keeth has published more than 50 reports and papers dealing with the technical and economic evaluations of air pollution control technologies, including the EPRI "Economic Evaluation of FGD Systems", "Opacity and Mist Eliminator Trouble-shooting Guidelines", "FGDCOST Model & User's Manual", "Integrated Emissions Control – Process Reviews" and the "IECCOST Model & User's Manual."

Recent work has included projects for multiple utility clients to develop the most cost-effective compliance strategies to meet future air pollution control regulations. Current projects focus on the development of economic models used to develop capital and operating cost estimates for both circulating fluid bed boilers, as well as integrated emissions control systems including both commercial and developing control technologies for NOx, SO_2/SO_3, mercury, CO_2 and particulate emissions from fossil fuel fired power generating plants. Recently completed an evaluation of more than 50 developing technologies that are capable of multi-pollutant control within a single system. Also managing projects that provide utility clients with economic models to evaluate system-wide compliance options based on any future set of regulatory requirements for all primary pollutants.

Professional Engineer in Colorado – P.E., #33764

APPENDIX B

BUDGET DETAILS

APPENDIX B: BUDGET DETAILS

Attachment A

a. Detailed Cost Estimate

ALL BUDGETARY INFORMATION IN THIS SECTION ARE CONFIDENTIAL

The continuation project is expected to be initiated in May of 2010 and will last 24 months. Requested is $549,500 of cash match from NDIC. This will be matched with $977,617 from the Wyoming Clean Coal Technology Program and $442,905 cash and in-kind match from Western Research Institute, Energy and Environmental Reasearch Center, FuelCell Energy, Etaa Energy, Montana-Dakota Utilities Co, and Basin Electric Power Cooperative.

Appendix B, Cost Estimate, is comprised of several exhibits. Exhibit A is the project budget and contains the budget Information. Exhibit B gives detailed information for the direct cost elements and cosponsor participation. Exhibit C describes the guidelines that the Institute uses for preparing cost estimates and budgets. Exhibit D shows the provisional indirect rate agreement from the U.S. Department of Energy for Fiscal Year 2009.

EXHIBIT B

Budget Details

Labor Costs – Labor costs are delineated in the budget table, and it shows the hours of labor, the rates (escalated by $5.25%) for outlying years and presents the labor OH rate calculations and costs.

Travel Costs – Costs associated with the attendance of WRI personnel to present visit sub-contractors, particularly EERC and GTI. Travel also includes travel to National and/or DOE sponsored meeting. These costs do not include G&A. Estimated costs are $15,000 between SER and DOE. A listing of proposed travel is presented below.

Destination, Purpose	Trips/people /days	Airfare	Hotel	Per Diem	Rental Car	Personal Vehicle	Parking Tolls	Total
GTI								
Pilot Testing/Modeling	2x2x3	$1,600	$380	$165	$180	$160	$80	$5,130
EERC								
Pilot Testing	1x2x8	$1,600	$1,330	$440	$480	$160	$130	$4,140
Carbon Capture Mtg.	1x1x4	$800	$285	$220	$240	$160	$65	$1,770
Gasification Technology Conf	1x1x3	$800	$190	$165	$180	$160	$55	$1,550
TOTAL								**$12,590**

The costs do not include G&A.

Subcontractors. WRI will use subcontractors for portions of the scope of work, where their facilities and services are not available in-house at WRI. The list of subcontractors is provided below along with their costs and in-kind match to the project.

Subcontractors	Costs	In-Kind
Gas Technology Institute	$325,000	
Energy and Environmental Research Center	$259,000	$300,000
Etaa Energy	$175,000	$5,000
Washington Div. of URS	$95,000	
FuelCell Energy	$101,463	$17,905
Quality Electric	$34,000	
TOTAL	**$860,463**	**$319,905**

The costs do not include G&A.

Supplies – Costs include the costs for supplies for pilot operations, office supplies, and are detailed below. Estimated costs are $75,814. These costs include taxes and shipping. These costs do not include G&A.

Supplies	Costs
Rental of crusher/screener	$13,000
Shipping coal to WRI and to GTI and EERC	$9,780
Miscellaneous gases	$4,080
Containers & supersaks for coal and samples	$3,424
Rental covering for coal	$19,460
Pilot equipment replacement parts	$16,260
Rental of crane	$2,600
Licenses and software	$4,400
Power for operation of pilot unit	$3,200
TOTAL	**$75,814**

Fuel costs are supplied by coal industry at no cost to project.

Construction – These costs represent the costs associated with siting the pilot-scale WRITECoal equipment and associated excavation, graveling, and other related costs. Estimated costs are $22,500 from Coulthard Construction.

Other Costs – These costs include analytical costs for those analyses that WRI cannot perform in-house. Estimated costs are $11,700. These costs include shipping of samples, but they do not include G&A.

EXHIBIT C

Guidelines for Preparing Cost Estimates and Budgets

Labor Utilization -- The Institute uses the following technique for estimating labor utilization: professional judgment of task managers for person-hours required to perform the work. The Institute may use knowledge gained from prior contract activity to estimate person-hours.

Labor Rates – Hourly rates are based on weighted averages using estimated person-hours and actual hourly labor rates of individuals identified to perform the work. As a baseline, hourly labor rates are based upon rates paid to employees for the most recent month.

Salary Increase Provision -- The Institute applies a salary increase provision to direct labor cost estimates. The estimated salary increase provision is five percent compounded by year.

Travel Costs -- The Institute uses currently applicable Institute or Federal Travel Regulation (FTR) rates for estimating ground transportation and subsistence costs (lodging, meals, and incidental expenses) for employee travel.

Equipment Costs -- For equipment estimates, the Institute uses vendor quotes, catalog prices, historical costs, costs from current invoices or the professional judgment of task managers from contracts of a similar nature. Freight, postage, and tax are included in the equipment price estimates.

Supply Costs -- For supplies, materials, or parts estimates, the Institute uses vendor quotes, catalog prices, historical costs, from current invoices or the professional judgment of task managers from contracts of a similar nature.

Contractual (Subcontract) Costs -- For estimates of contractual (subcontract) costs, the Institute uses subcontractor proposals, vendor quotes, historical costs, costs from current invoices or the professional judgment of task managers from contracts of a similar nature.

Other Direct Costs -- For each other direct cost (ODC) proposed, the Institute uses technical input on the anticipated costs for such items, or the Institute uses vendor quotes or catalog prices. Other direct costs may include, but are not limited to, analytical services, vehicle use, computer software, dry ice and liquid nitrogen, freight and postage, maintenance and repair, printing and reproduction, and rents and leases.

Indirect Costs -- The Institute's Fiscal Year 2010 Provisional Indirect Billing Rate Agreement from the U.S. Department of Energy, National Energy Technology Laboratory is shown as Exhibit E. WRI's Fiscal Year 2010 Approved Provisional Indirect Billing Rates were used to prepare this cost proposal.

EXHIBIT E

Table of Matching Funds Committed /Prospective From Each Source

Funding Participant	Funding	Cash Match	In-Kind Match	% of Project
LRC/NDIC	$549,500			27.89
State of Wyoming CCTP	$977,617	$977.617		49.62
EERC/DOE	$300,000		$300,000	15.23
Western Research Institute	$100,000	$100,000		5.08
FuelCell Energy	$17,905		$17,905	0.91
Etaa Energy, Inc.	$5,000		$5,000	0.25
Basin Electric Power Cooperative	$10,000	5,000	$5,000	0.51
Montana Dakota Utilities	$10,000		$10,000	0.51
TOTAL	$1,970,022	$1,082,617	$337,905	100.0%
% Match		54.95%	17.15%	

Attachment B

Tax Liability Affidavits – MDU and WRI

Western Research
INSTITUTE

365 North 9th Street
Laramie, WY 82072
(307) 721-2011
(307) 721-2345 fax

March 29, 2010

Andrea Stomberg
Vice-President-Electric Supply
Montana-Dakota Utilities
400 North Fourth Street
Bismarck, ND 58501

Dear Ms. Stomberg:

This letter certifies that, to the best of my knowledge, the University of Wyoming Research Corporation d.b.a. Western Research Institute of Laramie, Wyoming, does not have any outstanding tax liability with the State of North Dakota.

Sincerely,

Donald W. Collins

Donald W. Collins, Jr.
Chief Executive Officer

pc. Alan Bland, WRI
Dawn Geldien, WRI
File

www.westernresearch.org

MONTANA-DAKOTA
UTILITIES CO.
A Division of MDU Resources Group, Inc.

400 North Fourth Street
Bismarck, ND 58501
(701) 222-7900

March 29, 2010

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Ave.
Bismarck ND 58505

Dear Ms. Fine:

This letter certifies that, to the best of my knowledge, Montana-Dakota Utilities Co. does not have any outstanding tax liability with the State of North Dakota. This certification is made to fulfill the requirements of NDAC 43-03-04-01 (15).

Sincerely,

Richard Holland

Richard Holland

Attachment C

Letters of Commitment – WRI

Western Research
INSTITUTE

365 North 9th Street
Laramie, WY 82072
(307) 721-2011
(307) 721-2345 fax

March 29, 2010

Andrea Stomberg
Vice-President-Electric Supply
Montana-Dakota Utilities
400 North Fourth Street
Bismarck, ND 58501

Dear Ms. Stomberg:

This letter is to confirm the binding commitment of the University of Wyoming Research Corporation, d.b.a. Western Research Institute, to conduct the proposed research project being submitted to the North Dakota Industrial Commission (NDIC) entitled, "WRITECoal Gasification Process for Low-Rank Coals for Improved Integrated Gasification Combined Cycle with Carbon Capture: Phase II-Pilot-Scale Demonstration". The Phase I of this program was funded by the School of Energy Resources under the State of Wyoming's Clean Coal Technology Program and by WRI's Cooperative Agreement with the U.S. Department of Energy, National Energy Technology Laboratory. The successful results from that Phase I effort has led to our request for a Phase II effort, proposed herein.

The WRITECoal gasification technology allows for high efficiency (cold gas efficiency of 88%), high H_2+CO syngas ideal for IGCC as well as chemicals production, reduced toxic emissions thereby lowering the cost of syngas cleanup, and finally the WRITECoal gasification IGCC with 90 % carbon capture yields net cycle efficiency of over 3% higher than that for other gasifier/IGCC cycles.

However, before industry will invest in the technology, pilot-scale demonstrations at 1-2 MWth and even >5MWth are needed to resolve process engineering design and confirm performance and economics. Such a program is offered in this Phase II proposal.

The State of Wyoming has already approved their matching cash for the project in the amount of ($977,617). Western Research Institute will also co-fund the Phase II effort with $100,000 cash to be used for various project costs, if the North Dakota Industrial Commission approves our application. Other co-funding has been committed from other governmental and private/industry partners.

We look forward to working with you on this NDIC application and proposed project and we are resolute in seeing this technology be placed in the coal industry to the benefit of North Dakota and its citizens.

Sincerely,

Donald W. Collins, Jr.
Chief Executive Officer
Western Research Institute

pc. Alan E. Bland, WRI
File

Attachment D

Letters of Commitment –Co-sponsors

MONTANA-DAKOTA
UTILITIES CO.
A Division of MDU Resources Group, Inc.

400 North Fourth Street
Bismarck, ND 58501
(701) 222-7900

March 29, 2010

Alan E. Bland, Ph.D.
Vice-President
Western Research Institute
365 North 9th Street
Laramie, WY 82072

Subject: Clean Coal Proposal

Dear Dr. Bland:

We are pleased to submit this letter of support and commitment by Montana-Dakota Utilities Co. (MDU) to cosponsor Western Research Institute's (WRI) proposal entitled "WRITECoal Gasification Process for Low-Rank Coals for Improved Integrated Gasification Combined Cycle with Carbon Capture: Phase II – Pilot-Scale Demonstration" being submitted to the SER under the State of Wyoming Clean Coal Technology Program and to the North Dakota Industrial Commission (NDIC), Lignite Research Council.

MDU has been actively involved in a number of technologies that show promise in increasing efficiency and reducing emissions from coal combustion, and IGCC has become an option for addressing carbon capture for new coal-fired power plants. We consider that Western Research Institute's thermal treatment of coal, when integrated with gasification, may have the potential to improve efficiency, reduce emissions and recover water for plant use, but recognize that pilot-scale demonstration is a necessary step to develop commercial application. The proposal provides for that pilot-scale demonstration.

MDU is pleased to offer cost share support of the proposed program in the amount of $10,000 in the form of in-kind contributions related to management efforts with the North Dakota Industrial Commission project support. MDU would be the host utility for the NDIC involvement. It is understood that MDU's funding will provide cost share to the State of Wyoming.

Peter Thiessen, Staff Engineer, will coordinate this test program and can be reached at (701) 222-7723 or at Peter.Thiessen@mdu.com.

We wish you success with the proposal and hope that the State of Wyoming and NDIC responds positively to this worthwhile and promising technology.

Regards,

Andrea Stomberg
Vice-President – Electric Supply

UNIVERSITY
OF WYOMING

Mark Northam, Director
School of Energy Resources
Dept. 3012, 1000 E. University Avenue
Laramie, Wyoming 80271
Phone (307) 766-6858
e-mail mnortham@uwyo.edu

February 5, 2010

Al Bland
Vice President, WRI
365 North 9th St.
Laramie, WY 82072

Dear Al:

Thank you for the proposal that you submitted for consideration for the 2009 State of Wyoming Clean Coal RFP which requested matching funds of $977,617 for the proposal, *"WRI's Pre-Gasification Treatment of Low Rank Coals for Improved Advanced Clean Coal Gasifier Design: Phase I: Pilot-Scale Demonstrations"*. The Clean Coal Task Force (CCTF) met recently to review the proposals submitted for funding. There were ten proposals submitted for a total request of $14,420,146. After a thorough competitive review, your proposal was endorsed by the CCTF and will be recommended to the Minerals Committee with the contingency that you submit a report within 14 days that describes progress made, and projects the completion date of the initial project, *"Pre-Gasification Treatment of PRB Coals for Improved Advanced Clean Coal Gasifier Design."*.

We want to thank you for the time and effort that you devoted to preparation of the proposal, and to express our congratulations. If you have any questions about the contingency, please don't hesitate to contact me.

Sincerely,

MA Northam

Mark Northam
Director, School of Energy Resources

Etaa Energy, Inc.

March 27, 2010

Western Research Institute
Attn: Dr. A. Bland
365 N 9th St
Laramie WY 82072

Dear Dr. Bland:

Sub: NDIC Clean Coal Technology Research Program(2010)-
Sponsorship Letter

I am pleased to inform you that Etaa Energy, Inc will co-sponsor the research program entitled, "WRITECoal Gasification Process for Low-rank Coals for Improved Integrated Gasification Combined Cycle with Carbon Capture: Phase II - Pilot-scale Demonstration." Etaa will cost share with a funding of $5,000.00 throughout the 24 months of the project.

Best Regards,

K. M. Sellakumar

Kumar M. Sellakumar, Ph.D.
President
Email: ksellakumar@etaaenergy.com

Cc: Ms. Dawn Geldien, Manager, Business Operations, Western Research Institute

240 Longview Rd, Bridgewater, NJ 08807♦ Ph:(908) 872-5459♦Fax: (908) 252-9650

FuelCell Energy

November 30, 2009

Donald Collins
Chief Executive Officer
Western Research Institute
365 North 9th Street
Laramie, WY 82072

Subject: Western Research Institute's Pre-Gasification Treatment of Low Rank Coals for Improved Advanced Clean Coal Gasifier Design: Phase II: Pilot-Scale Demonstrations

Dear Mr. Collins:

FuelCell Energy (FCE) is pleased to support Western Research Institute's project for development of the gasification systems utilizing high-moisture Powder River Basin (PRB) coal and Lignite. The pre-gasification treatment system of low rank coals, developed by Western Research Institute (WRI), is an important process enabling the conversion of the very valuable natural resources into syngas and ultimately into high-efficiency electric power using fuel cells.

FCE will provide $17,905 cost share to the project as a contribution to the development of the Integrated Gasification Fuel Cell (IGFC) system. FCE will participate in this project by providing expertise in development of fuel cell power islands integrated with low-rank coal fueled gasfication systems. The efficient conversion of PRB coal and lignite to electric power is the goal of the proposed program which has environmental and economic benefits to the public by reducing greenhouse gas concentrations and supporting the power industry based on domestic fuels.

FuelCell Energy (Nasdaq: FCEL) develops and markets Ultra-Clean stationary fuel cell power plants that generate electricity with up to twice the efficiency of conventional fossil fuel plants – and with virtually no air pollution. With more than 40 years of experience, we are recognized as a global leader in the development, manufacture, and commercialization of stationary electric power generation. We are also continuing to innovate and to commercialize new concepts in support of clean energy. One of our current technical thrust areas is development of a coal based Solid Oxide Fuel Cell (SFOC) system with an unsurpassed efficiency approaching 60% HHV and greater than 90% carbon dioxide capture capability.

We look forward to working with WRI in development of large stationary Integrated Gasification Fuel Cell power plants of future utilizing PRB coal and lignite.

Best regards,

Christopher Bentley
Executive Vice President
FuelCell Energy, Inc.

FuelCell Energy, Inc. 3 Great Pasture Road Danbury, CT 06813
phone 203.825.6000
fax 203.825.6100
www.fuelcellenergy.com

BASIN ELECTRIC
POWER COOPERATIVE

1717 EAST INTERSTATE AVENUE
BISMARCK, NORTH DAKOTA 58503-0564
PHONE 701-223-0441
FAX: 701/224-5336

March 31, 2010

Mr. Alan E. Bland, Vice President
Western Research Institute
365 North 9th Street
Laramie, WY 82072

Dear Mr. Bland:

Subject: Letter of Interest and Financial Commitment for the Proposal by the WRI: ""WriteCoal™ Gasification Process for Low-Rank Coals for Improved Integrated Gasification Combined Cycle with Carbon Capture: Phase II – Pilot-Scale Demonstration."

As Senior Vice President of Generation of Basin Electric Power Cooperative (BEPC), I am pleased to submit this letter of support and interest to participate in the testing activities that are described in Western Research Institute's (WRI) proposal for "WriteCoal™ Gasification Process for Low-Rank Coals for Improved Integrated Gasification Combined Cycle with Carbon Capture: Phase II – Pilot-Scale Demonstration."

Basin Electric has a particular interest in this program because we own and operate several units that utilize lignite and sub-bituminous coal. Coal will continue to play a major role in meeting energy demands in the 21st Century. This program's research is ensuring that coal can be utilized as cleanly and efficiently as possible in future facilities that can expand the use of North Dakota lignite.

Basin Electric is pleased to support this proposed program by supplying up to four tons of lignite and four tons of Powder River Basin sub-bituminous coal to WRI's facilities at Laramie, WY, to be processed for IGCC pilot testing. Our estimate for the value of the delivered coal is about $5,000. In addition, we will contribute $5,000 cash for a total combined value of $10,000 cash and in-kind.

Please coordinate this test program with Bob Eriksen, Basin Electric's Sr. Environmental Compliance Administrator, at (701) 557-5654 or beriksen@bepc.com.

Sincerely,

Wayne Backman /dz

Wayne Backman
Senior Vice President, Generation

rle/dz
cc: Ron Harper
Bob Eriksen
Mike Fluharty
Mike Paul
Mike Eggl