September 30, 2005

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Dear Ms. Fine:

Subject: EERC Proposal No. 2006-0055

Enclosed please find an original and seven copies of the subject proposal. The Energy & Environmental Research Center (EERC) is pleased to submit this proposal entitled "Gasification of Lignites to Produce Liquid Fuels, Hydrogen, and Power" for consideration for funding through the North Dakota Industrial Commission. This project will provide information that is critical to the effective utilization of lignites and upgraded lignites in gasification processes to produce electric power, hydrogen, feedstocks for liquid fuels, and carbon dioxide. Lignites offer both challenges and opportunities for coal gasification. The ultimate goal is to minimize the challenges and take advantage of the unique properties of lignite. Also enclosed is the $100 application fee.

If you have any questions, please contact me by telephone at (701) 777-5177 or by e-mail at sbenson@undeerc.org.

Sincerely,

Steven A. Benson
Senior Research Manager

SAB/sml

Enclosures

c/enc: Harvey Ness, Lignite Research Council

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN, AND POWER

EERC Proposal No. 2006-0055

Submitted to:

Ms. Karlene Fine

North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Proposal Amount: $225,000

Submitted by:

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Dr. Steven A. Benson, Project Manager

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Research Development and Compliance

September 2005

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ABSTRACT

The United States has a significant resource of highly reactive lignite coal that can be readily gasified to form a synthesis or fuel gas for the production of electric power, synthetic liquid fuels, or hydrogen. This project is aimed at addressing key technical challenges facing the use of lignites in gasification processes through a consortium of coal-fired electric utilities and state and federal government agencies. The goal of the project is to provide essential information on the impacts of moisture and inorganic impurities on gasifier and gas cleanup technology performance. This project will be conducted over a 2-year period. Year 1 will be aimed at conducting small pilot-scale testing of the impact of lignite and upgraded lignite properties on particulate, trace elements, mercury, and sulfur removal as well as carbon dioxide and hydrogen separation for selected lignites. Year 2 will focus on conducting tests on the larger-scale pilot transport reactor gasification system to evaluate overall gasification processes while determining the impacts of impurities and moisture on advanced sulfur removal, hydrogen purification, and carbon dioxide separation processes at a slipstream scale. The total 2-year project cost is $2,640,380. The total cost for the Year 1 effort is $1,200,000. The U.S. Department of Energy (DOE) through the Energy & Environmental Research Center (EERC)–DOE National Center for Hydrogen Technology is providing 80% of the project and requires a 20% cost share by industry. The funding scenario proposed for the $240,000 industry share is to obtain $30,000 from each of five industry sponsors combined with $90,000 from the North Dakota Industrial Commission (NDIC). The total project cost for Year 2 is $1,440,380, with 75% of the funding to be obtained from DOE. The program for the second year requires 25% industry cost share of $360,000 in cash. The funding scenario proposed for Year 2 of the project is to have five sponsors provide $45,000 each combined with $135,000 from NDIC.

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN, AND POWER

PROJECT SUMMARY

This project will provide information critical to the effective utilization of lignites and upgraded lignites to produce electric power, hydrogen, feedstocks for Fischer–Tropsch processes to produce liquid fuels, and carbon dioxide. Lignites offer both challenges and opportunities for coal gasification. The most significant technical challenges that lignite must overcome in order to be a viable fuel for future gasification technology include high moisture content and inorganic impurities.

The high moisture content decreases gasifier efficiency and significantly impacts lignite use in slurry-fed gasification systems. However, if hot-gas cleanup is employed, the high-moisture gases can be used for power generation in combined-cycle systems, resulting in improvements in efficiency.

The inorganic impurities contribute to ash-related performance problems in the gasifier, syngas cooler, and hot-gas cleanup system. In addition, some of the inorganic impurities (S, Hg, and trace elements) can contribute to emissions. Currently, there is insufficient understanding of methods to decrease the challenges such as ash deposition, bed agglomeration, and hot-gas filter plugging resulting from sodium–ash interactions, sulfide, and other condensed-phase formation in the use of lignite in gasification and gas cleanup systems. Moreover, methods to reduce the emissions of S, Hg, and other trace elements must be further tested. In addition, the detrimental properties can also prove to be attractive properties in gasification systems where the high moisture can increase gas flow in turbines for power generation and provide moisture for water–gas shift reactions, and the impurities, specifically the alkali (Na)- and alkaline-earth (Ca and Mg)-rich inorganic components, catalyze the gasification reactions allowing for lower-

temperature gasification. The selection of the gasification technology and gas cleanup system must consider the challenges and take advantage of the unique characteristics of lignite coal. The use of lignite in lower-temperature nonslagging gasification systems must be considered since the high temperatures will increase the quantity of vaporized inorganic species that will be condensed in downstream gas cooling and gas cleanup systems, causing significant challenges in maintaining cleanliness, and will certainly decrease the availability of the gasification system. System availability is a key challenge facing gasification today and its acceptance by the utility industry. This project will focus on the challenges and unique opportunities for the use of lignite in gasification, gas cleanup, and gas separation systems.

Year 1 will be aimed at conducting small pilot-scale testing of selected lignites and upgraded lignites to determine the impact of lignite properties on particulate, mercury, and sulfur removal as well as carbon dioxide and hydrogen separation for selected lignites. Year 2 will focus on conducting tests on the larger-scale pilot transport reactor integrated gasification (TRIG) system at the Energy & Environmental Research Center (EERC) to evaluate the overall gasification processes while also determining the performance of hot-gas cleanup systems, advanced sulfur removal, hydrogen purification, and carbon dioxide separation processes at a slipstream scale.

PROJECT DESCRIPTION

Goal and Objectives

The goal of the project is to determine the advantages and challenges of using lignite and upgraded lignite in a gasification system to create fuel gas to produce electricity or a synthesis gas to produce liquid fuels, hydrogen, and carbon dioxide. The specific objectives are as follows:

1. To conduct gasification testing on selected lignites and upgraded lignites (dried and cleaned) that will provide information on synthesis/fuel gas characteristics relative to use as a combustion fuel for electricity generation, feedstock for liquid fuels, and a source for hydrogen.
2. To determine the ability to perform warm/hot-gas cleanup of gasborne impurities such as condensed vapors, particulate, and trace element control, including mercury.
3. To test highly efficient sulfur removal techniques to remove sulfur species to below the limits required for power systems and extend this work to meet the limits for the use of hydrogen in refineries and fuel cells.
4. To test carbon dioxide separation and removal technologies in order to produce a clean hydrogen stream and CO_2.

In order to meet the project objectives, the work plan will be conducted over a 2-year period. Year 1 will focus on parametric testing of gasification and gas cleanup conditions and processes for six selected lignite and upgraded lignite coals. Based on the results of the parametric testing, the optimum lignite and upgraded lignite, sorbents, catalysts, and gas separation membranes will be identified for larger-scale TRIG testing in Year 2. Year 2 testing will involve two 10-day test campaigns on the selected lignites. During the two test campaigns, the overall operability of the gasifier will be evaluated in terms of conversion efficiency, product gas characteristics, ash deposition behavior, sulfur capture in the gasifier, warm/hot-gas cleanup efficiency, sulfur and trace element, including Hg, removal, and gas separation.

Methodology

Year 1 – Parametric Gas Cleanup Testing

Task 1 – Feedstock Characterization and Detailed Test Plan Development

1.a – Fuel Characterization. Extensive characterization of up to six lignites is planned, including standard fuel analyses (proximate, ultimate, heating value, and bulk ash composition) in addition to more advanced techniques such as trace element analyses, computer-controlled scanning electron microscopy (CCSEM), and chemical fractionation to determine the association and abundance of major, minor, and trace inorganic elements. The form of the inorganic impurities in the lignite influences their fate and behavior in the gasification system. The lignites will include run-of-mine as well as upgraded lignite. Selection of the lignites for testing will be based on sponsor's input and lignite properties.

1.b – Test Plan Development. In close cooperation with the Project Steering Group that includes a coal company, a utility, the North Dakota Industrial Commission (NDIC), the Lignite Energy Council, and the U.S. Department of Energy (DOE), the EERC will develop a detailed test plan to evaluate the gasification performance of the selected lignites and upgraded lignites in a bench-scale bubbling-bed gasifier combined with a gas cleanup system. The bench-scale testing will examine lignite and upgraded lignite reactivity and the removal of impurities, as well as address the integration of various sulfur removal technologies with hydrogen and carbon dioxide separation processes with a coal-derived fuel gas. The test plan will be aimed at evaluating the effects of operating temperature, oxidant-to-fuel and steam-to-fuel ratios on the fuel-gas heating value, and the carbon conversion for these selected lignite and upgraded lignites, in addition to testing the water–gas shift, hydrogen separation, and carbon dioxide separation processes. Sorbents for sulfur removal will be selected based on effectiveness and availability. In addition, testing the use of a high-temperature mercury sorbent for gasification systems will be incorporated into the test matrix. Work will focus on accomplishing warm- or hot-gas cleanup to facilitate the highest efficiency in the combined gasification power cycle.

Task 2 – Testing of Gas Desulfurization, Hydrogen, and Carbon Dioxide Purification Concepts

The 4-lb/hr continuous fluid-bed reactor (CFBR) reactor will be operated to produce a synthesis gas for the testing of gas cleanup. During the testing phase of Task 2, the gasification conditions used in the CFBR will be optimized to provide a realistic gas stream for testing gas cleanup and separation options. As part of work conducted in Task 2 using the CFBR on the selected lignites and upgraded lignites, the conversion rates and gas qualities will be determined as a function of the oxidant-to-fuel ratio, reactor temperature, and fuel characteristics.

Figure 1 shows the 4-lb/hr CFBR that will be used for the gasification tests. The unit has been used for past gasification projects. Gases used for fluidization are mixed in a gas manifold. The unit was designed such that the top of the fluid bed is above the coal injection point. A solids offtake leg at the top of the bed is the primary means of solids removal from the reactor. The reactor currently has two ceramic fiber heaters to maintain the vessel's temperature and eliminate hot spots. Using external heaters allows the evaluation of internal and external heating methods for process development and scale-up. The reactor is capable of operation at a maximum of 155 psig and 840°C (1500°F).

A 3-in.-diameter cyclone is used for solids removal from the gas stream. A ball valve allows the changing of the solids catchpot while the system is operating. The cyclone is heated with a ceramic fiber heater capable of operating at a temperature of 900°C (1650°F).
An 8-in.-long section of 2-in. 316H stainless steel Schedule 80 pipe has also been utilized as a pressure vessel to either contain a fixed bed of zinc-based sorbent to reduce the H_2S

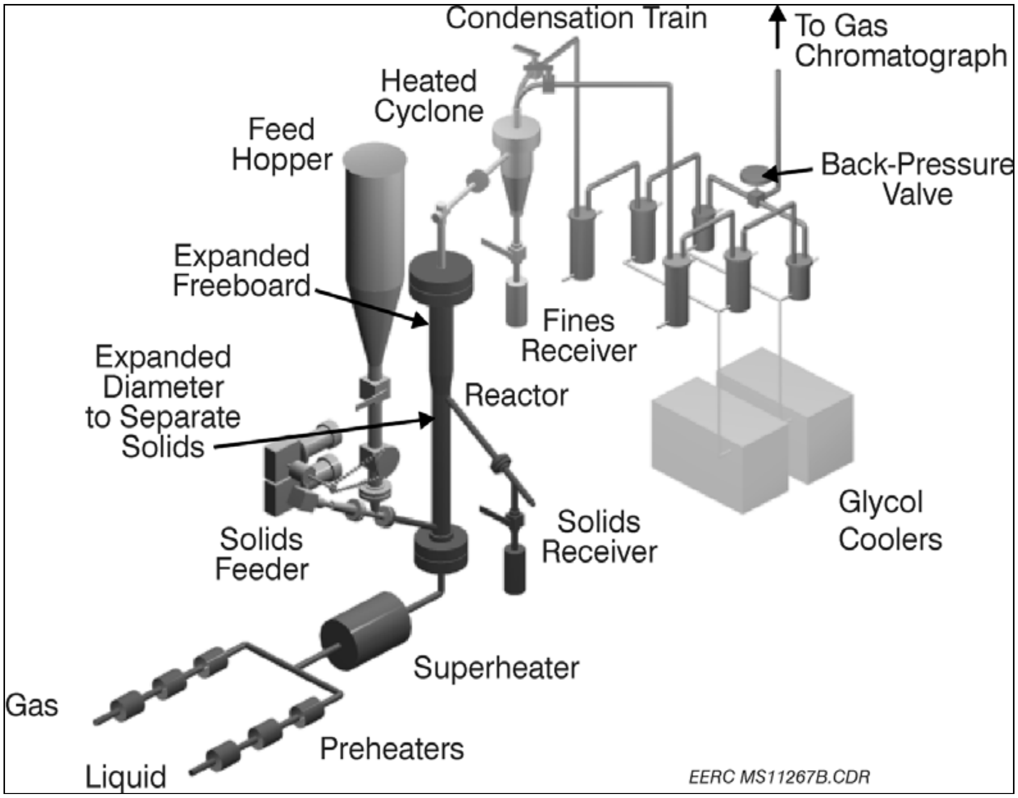

Figure 1. CFBR.

concentrations or to contain a calcium-based sorbent for the removal of chlorine gases from the fuel gases.

The CFBR is equipped with a hot-gas filter vessel (HGFV). The HGFV was designed and constructed to test hot-gas candle filters for their ability to obtain high-temperature, high-pressure operational data on various filter elements. The vessel is 10 in. i.d. and 60 in. long (including cone, vessel, and cap) and can handle a gas flow up to 30 scfm at 843°C (1550°F) and 150 psig. The backpulse system is designed to supply a minimum of 3 candle volumes per pulse for the longest candle filters and even higher volumes for the shorter candle filters.

2.a – Design and Construction of Bench-Scale Systems for Sulfur Control, Hydrogen Separation, and Carbon Dioxide Separation. In this task, a set of reactor systems will be designed and constructed that will allow for parametric testing of various sulfur capture and hydrogen and carbon dioxide separation technologies that would be sized to operate on the full flow from the 4-lb/hr CFBR/HGFV and then as a slipstream on the EERC pilot-scale transport reactor development unit (TRDU) or pilot-scale TRIG gasifier. Descriptions of the existing CFBR and TRDU systems are included in Appendix A. Additional equipment would consist of a sulfur removal process utilizing a metal oxide-based regenerable sorbent possibly followed by a zinc oxide or other oxide (oxide selection and degree of polishing will depend on the sulfur tolerance of the particular membrane) followed by either sour- or conventional-shift conversion to maximize hydrogen before entering a high-temperature metal-based membrane for producing high-purity hydrogen. This system would be designed to operate continuously to simulate real-world operating conditions utilizing actual coal-derived syngas. The system will be modular so that gas cleanup can be accomplished consistent with the anticipated end use.

2.b – Bench-Scale Testing with Continuous Fluid-Bed Reactor

2.b.1 Sulfur Removal Testing with Bench-Scale Unit. Removal of sulfur, as well as halogens, is best conducted in stages to ultimately get to a near-zero level. The first step would be the removal of some of the sulfur, with limestone or dolomite added to the CFBR/HGFV system for bulk removal. This will remove the sulfur components down to equilibrium levels for the $CaCO_3 + H_2S = CaS + CO_2 + H_2O$ reaction, with about 20% to 30% removal occurring under the oxygen-blown conditions. This lower sulfur removal as compared to air-blown operation is a result of the high CO_2 and H_2O partial pressures that result under oxygen-blown operation. This removal will take place with the particulate and mercury step in the hot-gas cleanup phase in the CFBR/HGFV. The next steps to achieve high levels of sulfur removal will be accomplished with additional sulfur capture downstream of the HGFV, as illustrated in Figure 2. This process

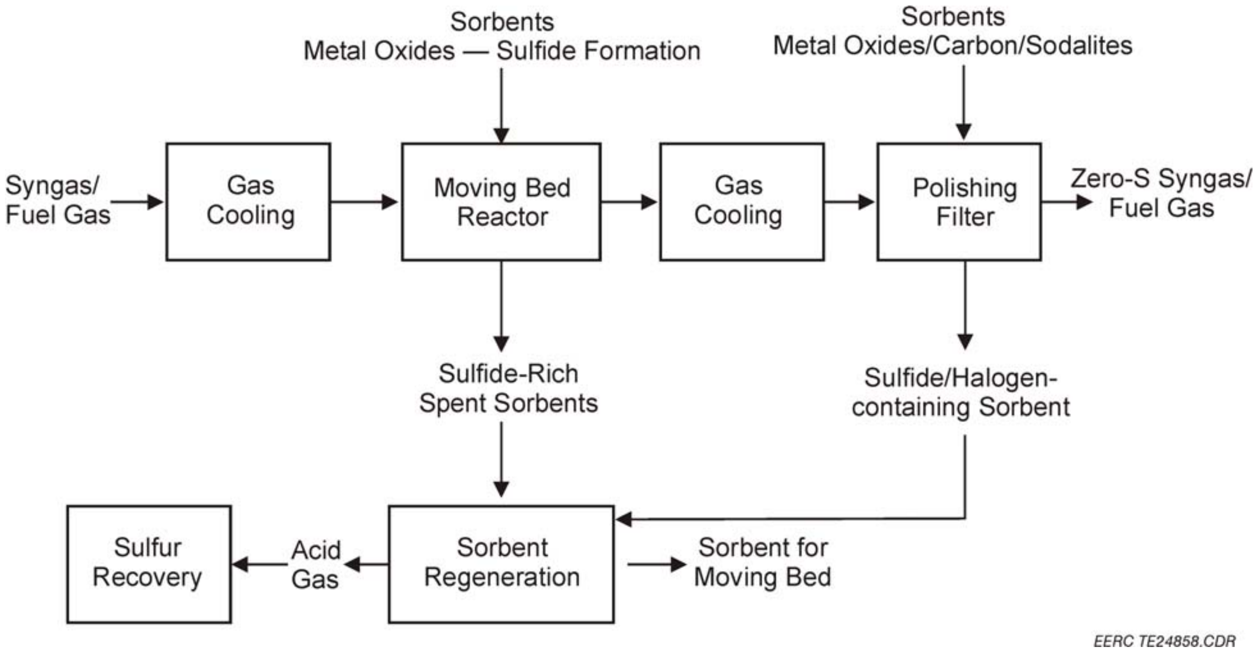

Figure 2. Sulfur removal concept for near-zero sulfur levels.

involves capturing the sulfur in the form of sulfides through the use of selected metal oxides. The formation of numerous types of sulfides, including metal oxides, has been documented by many researchers (Penner et al., 1987; Erickson et al., 1995; Zygarlicke et al., 2001). Metal oxides have been used to remove sulfur species from coal-derived synthesis gas (Newby et al., 2001). These metal oxides include transition metals such as iron oxide, zinc oxide, copper oxide, and others. The sorbents have the potential to be regenerated, and the sulfur can be recovered. The reactions of the synthesis gas or fuel gas would be conducted in either a moving- or fluid-bed reactor, which would reduce the level of sulfur to the 10–20-ppm range. A final polishing step would involve using a fixed bed to reduce sulfur and other species such as halogens and, possibly, any mercury that remained. The sorbents to be injected would include metal oxides, carbons, and sodalites. Sodalites are aluminosilicate phases that have a cubo-octahedral structure that can react with sulfur and halogen species (Benson, 1987). These phases have been identified in various ash residual materials and offer the opportunity for use as polishing sorbents. The exiting gases would be ultrapure relative to the levels of sulfur, with concentrations less than 1 ppm.

Four weeks of testing on the bench-scale CFBR using the lignites and upgraded lignite selected in Task 1 are planned. This testing will determine the issues associated with integrating the sulfur equipment with the requirements for synthesis gas properties for liquid fuels production as well as for hydrogen and/or carbon dioxide membranes. These tests would start out as short-duration tests to establish any operating and durability issues. Once key conditions have been established, longer-term 5-day test periods on the equipment will be conducted in order to identify the best combination of sorbents and operating conditions that result in the highest removal of sulfur. These operating conditions and sorbents will be used to determine the optimum conditions for testing on the larger-scale TRIG system.

Capture of the sulfur species will be conducted in either a moving- or fluid-bed reactor by forming sulfides through the use of selected metal oxides. A series of metal oxides has been tested that includes many of the transition metals such as iron oxide, zinc oxide, copper oxide, and others. The components have the potential to be regenerated, and the sulfur can be recovered. It is anticipated that the moving bed would reduce the level of sulfur into the 10–20-ppm range. A second step would involve using a fixed bed to reduce sulfur and other species such as halogens and, possibly, any mercury that remained. The sorbents to be injected would include metal oxides, carbons, and sodalites. The exiting gases would be ultrapure relative to the levels of sulfur, with concentrations less than 1 ppm. In addition, advanced highly reactive mercury removal sorbents will be added to the sorbent materials in the fixed bed, and mercury measurements will be conducted to determine mercury removal efficiency. Greater than 95% removal is anticipated based on past testing.

2.b.2 Carbon Dioxide Separation. Carbon dioxide separation will be tested utilizing higher-operating-temperature CO_2 separation membranes in conjunction with water–gas shift reactors to enhance hydrogen production through the water–gas shift equilibrium by removing one of the products from the shift reaction. Several of these membranes are under development by organizations such as Media and Process Technologies and Eltron Research, Inc. (Eltron) Additional separation options for CO_2 will be considered, if appropriate.

2.b.3 Hydrogen Separation Using Catalysts and Membranes. High-purity hydrogen separation testing will be conducted utilizing either metallic or ceramic membranes in the 300°–500°C temperature range. IdaTech, Inc., has a sulfur-tolerant Pd–Cu membrane available for testing. Eltron has also been working on a hydrogen separation membrane and could be subcontracted to provide such a membrane. If cold-gas cleanup is utilized, hollow-fiber polymeric membranes could be utilized as long as extra-high-purity H_2 is not required. Data could also be acquired from vendors concerning the use of conventional pressure-swing adsorption (PSA) as a H_2 purification option. The project will purchase materials from IdaTech or Eltron for testing.

Task 3 – Gas Cleanup for Particulate and Trace Elements Including Mercury

This task will involve the sampling and analysis of the entrained ash materials or inorganic species upstream and downstream of filters and beds to determine the fate and behavior in the gas cleanup components described in Task 2. The inorganic species consist of major, minor, and trace elements and are known to contribute to plugging gas filters, as well as poisoning catalysts. The task is aimed at determining the abundance of forms of inorganic species in the ash stream upstream and downstream of the gas cleanup systems. This information will provide an understanding of the potential impact of these species on system performance as well as removal ability. The ash streams and catalysts will be analyzed to determine the abundance and forms of major, minor, and trace elements by various analytical methods including inductively coupled plasma–mass spectrometry (ICP–MS), x-ray fluorescence analysis (XRFA), x-ray diffraction (XRD), particle size, carbonate analysis, loss on ignition (LOI), reactive sulfide, and SEM analysis.

Task 4 – Management and Reporting

4.a – Management and Summary Progress Reporting. Summary reports will be provided on a quarterly basis. Additionally, regular conference calls with project participants will be conducted to allow for the exchange of information and input on test plans.

4.b – Presentations and Travel. Also incorporated in the management task are two detailed project presentations at sites to be selected by the Project Steering Group. The first presentation will be conducted after the CFBR test campaigns have been completed.

4.c – Final Report. This task will provide a detailed final report discussing all of the project results.

Year 2 – Pilot-Scale TRIG Testing (subtasks continued from Year 1)

Task 1 – Feedstock Characterization and Detailed Test Plan Development

1.a – Fuel Selection. One lignite and one upgraded lignite or other combination of lignites will be selected for testing in Year 2. This decision will be based on a combination of results obtained in Year 1, chemical composition of interest, and input from the Project Steering Group.

1.b – Test Plan Development. In close cooperation with the Project Steering Group, which will involve project sponsors from the private sector and DOE, a detailed test plan will be developed to evaluate the gasification performance of the selected lignites, gas cleanup, and gas separation. Specifically, the test plan will be aimed at evaluating the effects of operating temperature, air-blown versus oxygen-blown operation, oxidant-to-fuel and steam-to-fuel ratios on the fuel-gas heating value as well as carbon conversion. Testing of warm- to hot-gas cleanup along with removal of sulfur, sodium, and other impurities will be conducted. Catalysts for water–gas shift and membranes from hydrogen separation and carbon dioxide separation processes will be selected based on the Year 1 results.

Task 2 – Testing of Gas Desulfurization, Hydrogen, and Carbon Dioxide Purification Concepts

2.c – Gasification Testing of Selected Lignites. Two 10-day test campaigns will be conducted using the TRDU gasification system equipped with a hot-gas filter system on selected coals to produce a fuel gas for testing of gas cleanup and separation technologies. The pilot-scale TRDU or TRIG shown in Figure 3 consists of a riser reactor with an expanded mixing zone at the bottom, a disengager, and a primary cyclone and standpipe. The standpipe is connected to the mixing section of the riser by a L-valve transfer line. All of the components in the system are refractory-lined and designed mechanically for 150 psig (11.4 bar) and an internal temperature of 1090°C (2000°F). The premixed coal and limestone/dolomite feed to the transport reactor can be admitted through three nozzles, which are at varying elevations. Two of these nozzles are located near the top of the mixing zone (gasification), and the remaining one is near the bottom of the mixing zone (combustion). During operation of the TRDU, feed is admitted through only one nozzle at a time.

The coal feed is measured by an rpm-controlled metering auger. Oxidant is fed to the reactor through two pairs of nozzles at varying elevations within the mixing zone. Hot solids from the standpipe are circulated into the mixing zone, where they come into contact with the nitrogen and the steam being injected into the L-valve. This feature enables spent char to contact

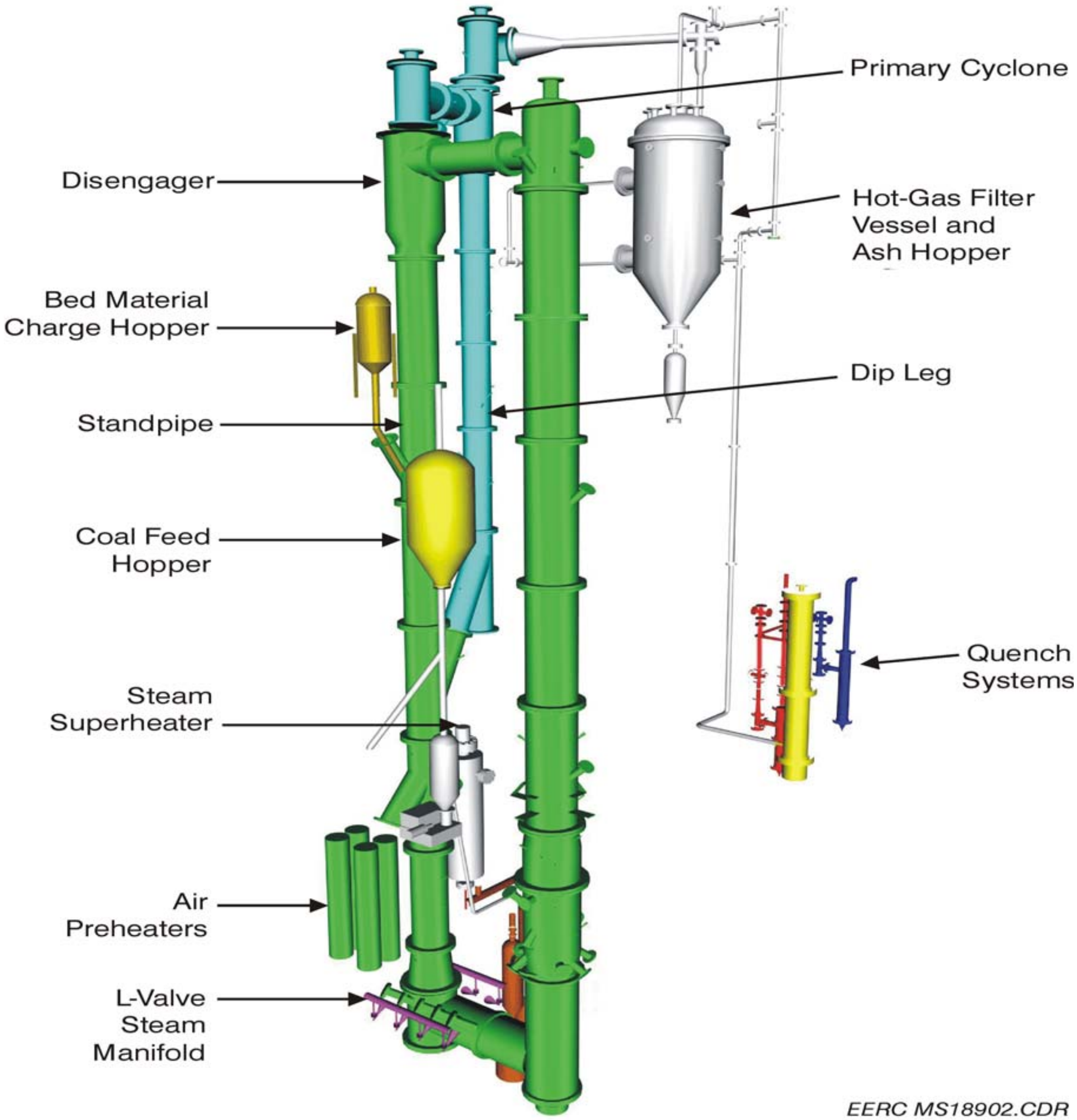

Figure 3. TRDU – pilot-scale TRIG.

steam prior to the fresh coal feed. This staged gasification process is expected to enhance process efficiency. Gasification reactions are carried out in the riser as coal, sorbent, and oxidant (with steam for gasification) flow up the reactor. The bulk of entrained solids leaving the riser is separated from the gas stream in the disengager and circulated back to the riser via the standpipe. A solids stream is withdrawn from the standpipe via an auger to maintain the system's solids inventory. Gas exiting the disengager enters a primary cyclone. The dipleg solids have been recirculated back to the standpipe through a loop seal at the bottom of the dipleg. Gas exiting this cyclone enters a jacketed-pipe heat exchanger before entering the HGFV.

The TRDU is equipped with an HGFV and is designed to handle all of the gas flow from the TRDU at its expected operating conditions. The vessel is approximately 48 in. i.d. (121.9 cm) and 185 in. (470 cm) long and is designed to handle gas flows of approximately 325 scfm at temperatures up to 815°C (1500°F) and 120 psig (8.3 bar). The vessel is sized such that it could handle candle filters up to 1.5 m long; however, 1-m candles were utilized in the 540°C (1000°F) gasification tests to date. Candle filters are 2.375 in. (6 cm) o.d. with 4-in. (10.2-cm) center line-to-center line spacing.

The gasifier conditions will be varied as described generally in Year 2, Task 1. The characteristics of the fuel gas will be compared with results obtained from past testing. Specifically, the performance of the lignites will be evaluated in terms of the following performance indicators:

- Carbon conversion – The TRIG gasification system has been shown to have the best performance in terms of carbon conversion. Carbon conversions have typically been in the mid to upper 90s with the low-rank coals.

- Composition of product gas – An analysis of the product gas will be conducted over a range of oxidant-to-fuel and steam-to-fuel ratios to determine optimum conditions for lignites as well as optimum properties for liquid fuel production.
- Heating value of the product gas – The heating value of the fuel gas will be determined and compared to other lower-rank and high-rank coals. The low-rank coals have exhibited fuel-gas heating values around 120 Btu/scf in air-blown mode and generally above 225 Btu/scf in oxygen-blown mode. Oxygen-blown operation results in a fuel gas with a high composition of H_2 and CO_2 as a result of the higher steam injection leading to increased hydrogen production from increased water–gas shifting.
- Sodium capture testing – Sodium species will be captured using selected sorbents or gettering components to minimize impacts on hot-gas filter performance.
- Hg control testing – The ability to control mercury in the HGFV will be evaluated during both tests. Advanced, highly reactive sorbents will be injected upstream of the HGFV to determine mercury removal efficiency. Greater than 95% removal is anticipated, based on past testing. The injection rates for the enhanced sorbent will be varied to achieve selected removal rates.

2.d – Slipstream Testing of Optimum Gas Cleanup and Purification Methods. The slipstream system will be installed on the TRIG for testing the optimum removal of sulfur and other impurities such as trace elements from fuel gas. The selection of the removal configuration, operating conditions, and sorbent type will be based on the small-scale testing as determined in Task 2.b.2. At the same time, downstream of the sulfur removal equipment, slipstream testing of fuel gas from the TRIG will also be completed utilizing the optimum CO_2 and H_2 separation/

purification membranes tested in Task 2.b.3. The slipstream testing conducted during the TRIG gasification testing will involve the following:

- Sulfur capture – The capture of sulfur species will be conducted in three steps. The first is to capture sulfur in the TRIG gasification system through the addition of dolomite or limestone to the coal during gasification, which will result in the removal of 20% to 30% of the sulfur from the fuel gas. This removal will take place across the hot-gas filter upstream of the slipstream. The second step to remove sulfur species from the fuel gas will be conducted using a moving- or fluid-bed reactor by the formation of metal sulfides based on findings in Year 1. Samples of the reacted bed materials will be evaluated for their ability to be regenerated. A third step using a barrier filter with sorbent to reduce sulfur and other halogen and trace species, including mercury, will be conducted using the optimum sorbent identified in Year 1. The goal is to produce a fuel gas that has near-zero sulfur levels.
- Sodium and other condensed-phase capture – The level of sodium and other condensed-phase capture will be integrated with the sulfur capture testing. The dolomite or limestone addition will be augmented with sodium-gettering materials, such as clay minerals and other materials.
- Carbon dioxide separation – Separation of carbon dioxide will be tested utilizing higher-operating-temperature CO_2 separation membranes. These membranes will be utilized in conjunction with water–gas shift reactors/catalysts to enhance hydrogen and CO_2 formation through the water–gas shift equilibrium by removing one of the products from the shift reaction. Several of these membranes are currently under development from organizations such as Media and Process Technologies and Eltron Research, Inc.

- Hydrogen separation – High-purity hydrogen separation testing will be conducted utilizing the best membrane in the temperature range of 300°–500°C as identified in Year 1. The EERC will work closely with IdaTech or Eltron to test hydrogen separation membranes.

2.e – Ash Material Analysis and Data Reduction. This task will involve the analyses of all ash streams for bulk chemical and physical properties. Analyses include XRFA and XRD, particle size, carbonate analysis, LOI, reactive sulfide, and SEM point count and morphology for any ash deposition and agglomeration samples generated. The particle size, carbonate, and LOI analyses will be performed on samples from each day of operation, while the XRFA and XRD analyses will be performed every third day at the end of the operation on a certain feedstock to approximate as closely as possible a steady-state sample. Analytical analyses will be completed within 4 weeks of the completion of each test campaign.

The ash will also be assessed to determine the best management options. These materials are referred to as coal utilization by-products (CUBs). The first phase of characterization primarily should address environmental performance of the CUBs produced. Environmental performance is evaluated primarily through the use of laboratory leaching tests. The EERC recommends that several leaching tests be performed to develop a set of data appropriate both for permitting and for determining the appropriateness for a variety of management options. The leaching tests include short- and long-term leaching protocols to facilitate an understanding of changes in leachate quality over time. Additionally, EERC researchers are willing to work with appropriate regulatory authorities to determine their specific needs. The leachates generated will be analyzed for a suite of parameters that will include environmentally sensitive elements such as lead, arsenic, selenium, and mercury. Input from the appropriate regulatory agency will be used to develop a comprehensive list of parameters to be determined in leachates generated. Appropriate duplicate leaching tests will be included. Leachate data will be evaluated against regulatory limits and data from an existing CUB characteristics database. In addition to the leaching experiments, the bulk composition of the CUB, including the same list of trace elements noted above, as well as major and minor constituents and the major elemental composition, will be determined. Other fundamental information—including pH, moisture, LOI, particle size, and density—will also be developed to provide preliminary information relevant to material handling and potential for utilization. Analytical testing will be completed within 4 weeks of the completion of each test campaign.

Task 3 – Gas Cleanup for Particulate and Trace Elements Including Mercury

This task will involve the analysis specifically of the entrained ash materials or inorganic species to determine the removal across the warm- and HGFV that is part of the pilot-scale TRIG system. The removal of the following components will be examined across the HGFV:

- Particulate and sulfur species – The removal of ash or inorganic species consisting of major, minor, and trace elements across the high-temperature filter system of the TRIG will be determined. Analysis of the filters and downstream materials will be examined for species that are known to contribute to plugging gas filters as well as poisoning catalysts. The task is aimed at determining the abundance of forms of inorganic species in the ash stream upstream and downstream of the gas cleanup systems. This information will provide an understanding of the potential impact of these species on system performance as well as removal ability.
- Sodium gettering – The removal of sodium through the addition of gettering agents upstream of the HGFV will be examined.

- Mercury control and measurement – The removal of mercury at high temperatures will be evaluated using treated sorbents. These sorbents have been shown to be very effective in removing mercury from coal combustion systems and have recently been tested for short periods of time on the TRIG gasification system. During each campaign, sorbent injection upstream of the gas filter system or packed-bed contactors will be tested for mercury control. Mercury measurement will be conducted using continuous mercury monitors and a modified version of the Ontario Hydro/Method 29 sampling method for mercury speciation and multimetals.

Task 4 – Management and Reporting

4.a – Management and Summary Progress Reporting. This task is for project management and the preparation of summary progress reports. Summary reports will be prepared after each test campaign. In addition to the reports, regular conference calls with project participants will be conducted to allow for exchange of information and input on test plans.

4.b – Presentations and Travel. Also incorporated in the management task are two detailed project presentations at sites to be selected by the Project Steering Group. The first presentation will be conducted after the CFBR test campaigns have been completed.

4.c – Final Report. This task will provide a detailed final report discussing all of the project results.

Facilities

The EERC and its partners will apply an impressive combination of skills, resources, capabilities, and facilities to meet and exceed project objectives. The EERC's 216,000 square feet of laboratory, technology demonstration, and office space, located on the University of North Dakota (UND) campus provides facilities, equipment, and experienced personnel. Most of the major pieces of equipment and facilities required for this project are already available at the EERC. The key equipment described in detail in the appendix available for this project includes the CFBR, bench-scale HGFV, TRDU, and HGFV. Details of the equipment available for this project are described in Appendix A.

Anticipated Results

This project will provide essential information critical to the effective utilization of lignites and upgraded lignites to produce a synthesis gas or fuel gas for electric power, hydrogen, feedstocks for Fischer–Tropsch processes to produce liquid fuels, and carbon dioxide. The most significant technical challenges that lignite must overcome in order to be a viable fuel for future gasification technology include high moisture content and inorganic impurities. Year 1 will be aimed at conducting small pilot-scale testing of selected lignites and upgraded lignites to determine the impact of lignite properties on particulate, mercury, and sulfur removal as well as carbon dioxide and hydrogen separation for selected lignites. Year 2 will focus on conducting tests on the larger-scale pilot TRIG system at the EERC to evaluate the overall gasification processes while also determining the performance of advanced sulfur removal, hydrogen purification, and carbon dioxide separation processes at a slipstream scale. Even though the testing is being conducted using fluidized-bed and transport reactor technology, the gas cleanup testing will have relevance to all gasification systems. Key deliverables will include quarterly and final reports that will incorporate all data, interpretations, and conclusions regarding testing lignite gasification, gas cleanup, and gas separation system. The report will identify the challenges and opportunities for the use of lignite gasification to produce a fuel gas for electric power generation or a syngas for liquid fuel production, hydrogen, and carbon dioxide. This information is essential in identifying the best technologies for the use of lignites and ensures that the design and operating parameters of gasification, gas cleanup, and gas separation technologies address both the challenges and opportunities for lignites. The report will address the use of lignite in high- and low-temperature gasification systems while considering the impact on downstream gas cooling and gas cleanup systems. Downstream problems can cause significant challenges in maintaining cleanliness and will certainly decrease the availability of the gasification system. System availability is a key challenge facing gasification today and its acceptance by the utility industry.

STANDARDS OF SUCCESS

The overall success of the project will be based on the ability to provide information to determine the challenges and opportunities for the use of North Dakota lignite in coal gasification and gas cleanup processes. Testing will be conducted using pilot-scale equipment with a proven track record of providing relevant data that has been used for scale-up purposes in the past.

The ability to assess the success of the project is based primarily on the EERC's quality management system (QMS). To ensure successful projects, the EERC adheres to an organizationwide QMS. It is authorized and supported by EERC management to define the requirements and the organizational responsibilities necessary to fulfill governmental and client requirements relating to quality assurance/quality control (QA/QC), applicable regulations, codes, and protocols.

BACKGROUND

Introduction

Lignite coals offer both challenges and opportunities for use as a feedstock for coal gasification. Application of gasification and gas cleanup technologies that utilize lignites must consider the high moisture content, high coal reactivity, noncaking properties, inorganic materials—ash/slag and trace elements, lower sulfur levels—and high oxygen contents. Gasification of lignite can be used to produce low-, medium-, and high-Btu gas as described below:

1. Low-Btu gas production can utilize air-blown gasification that will produce <200 Btu/scf (higher heating value [HHV]), having the major gas components N_2(50%), H_2, CO, CO_2, and CH_4. This gas can be used in a combined cycle gas turbine system to produce electric power. In order to achieve higher efficiencies and take advantage of the high moisture content in lignite, hot-gas cleanup must be employed. In addition, it requires the removal of sulfur, alkali, and other components that can impact turbine blades.
2. Medium-Btu gas production requires oxygen-blown gasification to produce 300 to 600 Btu/scf (HHV). The major gas components in the product gas are H_2, CO, and CH_4. This gas can be used as a chemical feedstock and for power generation. For use as a chemical feedstock, the gas will require a high degree of sulfur removal. The high moisture is not a drawback because water vapor is required for shift conversion reactions downstream. For use in a combined-cycle gas turbine system to produce power, the higher moisture levels are not a problem if hot-gas cleanup is employed. However, challenges in the removal of sulfur, alkali, and other constituents to levels needed to protect the turbine blades require development.
3. High-Btu gasification requires oxygen-blown gasification followed by methanation or direct hydrogasification of carbonaceous material to produce 900 to 1000 Btu/scf (HHV). The major gas component is CH_4. Methane production involves shift

conversion and methanation of medium-Btu gas and takes advantage of high moisture content to achieve the shift reaction. The process to produce high Btu gas can involve catalytic gasification that takes advantage of the catalytic effects of the alkali and alkaline-earth elements. In addition, direct hydrogasification of lignite can be considered.

Lignite chemical and physical characteristics have a significant impact on the performance, operation, and maintenance of combustion and gasification systems. Many lignites are known for their variability, especially in the abundance and forms of major, minor, and trace inorganic impurities. Overcoming the impacts of these inorganic impurities is the most significant challenge facing the use of lignite. During the gasification process, these inorganic species produce inorganic vapors, liquids, and solid particles that can cause challenges to the operation of the gasifier. These challenges include maintaining slag flow in entrained gasifiers, ash deposition on gasifier refractory and heat-transfer surfaces, plugging and blinding filters, reacting with regenerable sorbents, and forming gas-phase components such as hydrogen sulfide, halogens, and trace elements (mercury, selenium, arsenic, lead, antimony, and others) that are difficult to remove and control.

Lignite Properties

Lignite consists mainly of partially coalified plant materials, water, and inorganic impurities. The organic component of the lignite is very reactive and can be readily combusted or gasified. The reactivity of lignite based on testing conducted by Johnson (1975) is illustrated in Figure 4. Lignite is the most reactive of the primary coal types; therefore, operating temperatures for gasification can be lower than those necessary for gasification of higher-rank coals.

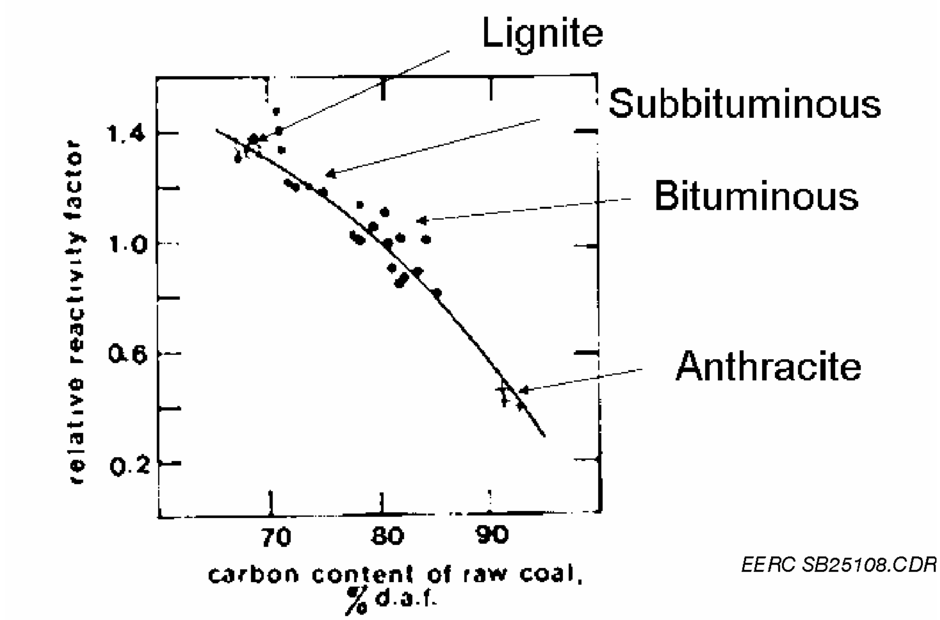

Figure 4. Relative reactivity of coal as a function of carbon content (Johnson, 1975).

The inorganic impurities in coal occur as discrete minerals, organically associated cations, organically bonded elements, and inorganic components dissolved in pore water (Benson et al., 1993). The fraction of inorganic components that are organically associated elements is the most abundant in lignite. Lignitic coals contain have high levels of oxygen; some of that oxygen is in the form of carboxylic acid groups. These groups act as bonding sites for cations such as sodium, magnesium, calcium, potassium, strontium, and barium (other minor and trace elements may also be associated in the coal in this form). During combustion or gasification these organically associated inorganic elements have the potential to be vaporized. In addition to the organically associated components, significant quantities of mineral grains are found in lignite. The major mineral groups found in lignites as well as other coals include silicates, aluminosilicates, carbonates, sulfides, sulfates and phosphates, as well as some oxides. During gasification and combustion, the mineral grains associated with coal particles can readily react with organically associated elements and form low-melting-point phases, while the minerals that are not associated with organic material do not. The reactions and interactions of the inorganic components upon gasification and gas cooling are complex and have been extensively studied at the EERC for higher-rank coals.

Gasification Process Testing Experience

The early efforts in the area of gasification at the EERC focused on slagging fixed-bed gasification of North Dakota Lignite (Energy Resources Co., Inc., 1980). Numerous tests were conducted to determine the gasification potential of North Dakota lignites in slagging fixed-bed gasifiers. The results showed that lignites could be readily gasified; however, problems resulting from impurities and variability were issues relative to performance. More recently, the EERC conducted a project involving the fate and behavior of major, minor, and trace elements in entrained gasification systems utilizing bituminous coals (Erickson et al., 1999). In addition, extensive research on the impact of ash on the performance of entrained gasification systems was conducted during a project entitled Coal Ash Behavior in Reducing Environments (Erickson et al., 1995; Zygarlicke et al., 2001). This 8-year program was funded by Destec Energy, Inc., Dow Chemical Company, Chevron, Shell Development Company, the Energy Research Center of the Netherlands, the Electric Power Research Institute, Babcock-Hitachi, ELCOGAS, KEMA Nederlands, Krupp Uhde, SenterNovem, and DOE. The project examined slag flow behavior in slagging gasifiers, ash deposition on gasifier and heat-transfer surfaces, and plugging of hot-gas filters. This project resulted in the development of computer-based models to predict ash formation, slag flow behavior, and deposition in various regions of the gasifier. Research on the behavior of trace elements in gasification systems was conducted in a project entitled “Trace Element Emissions” (Erickson et al., 1999). This project provided key information on the fate of trace elements in gasification systems. Work was focused on developing information that could be used to predict the vaporization and condensation of trace elements during gasification and syngas cooling.

The TRDU or TRIG gasification systems have been under development for the past 10 years through programs conducted at the EERC and Southern Company. The EERC installed a pilot-scale Kellogg Brown & Root, Inc. (KBR), transport reactor, or TRIG, gasification system to conduct testing of the gasification process, gas cleaning, and gas separation technologies. This project was supported by DOE National Energy Technology Center (NETL), Southern Company, and KBR. Since the original installation, the EERC has conducted several projects on bituminous, subbituminous, and lignite coals for industry and has continued development of the technology through funding from DOE NETL. Details of the system design and operation can be found in Appendix A. Data from the EERC TRIG gasification system were used to scaleup the technology at the Power Systems Development Facility (PSDF) near Wilsonville, Alabama.

While there are challenges firing lignite in entrained gasifiers (Breton, 2002), lignites have the potential to be excellent feedstocks for coal gasification systems such as the TRIG system. The attractive properties of lignites include their high reactivity, alkali- and alkaline-earth-rich inorganic composition, high-moisture, and high-volatile-matter content. These highly reactive lignites are well-suited for the TRIG system. Unlike the entrained gasification systems, the TRIG system can utilize lower-heating-value coal such as lignite since it uses a dry feed system. The TRIG system will produce a synthesis gas stream that is rich in hydrogen and carbon monoxide. Figure 5 illustrates the carbon conversion rates and product gas characteristics for data obtained from the EERC TRIG system. The results show that lignite has an 80% conversion rate over a range of conditions and producing a product gas or synthesis gas of 175 to 200 Btu/scf (HHV Cor.).

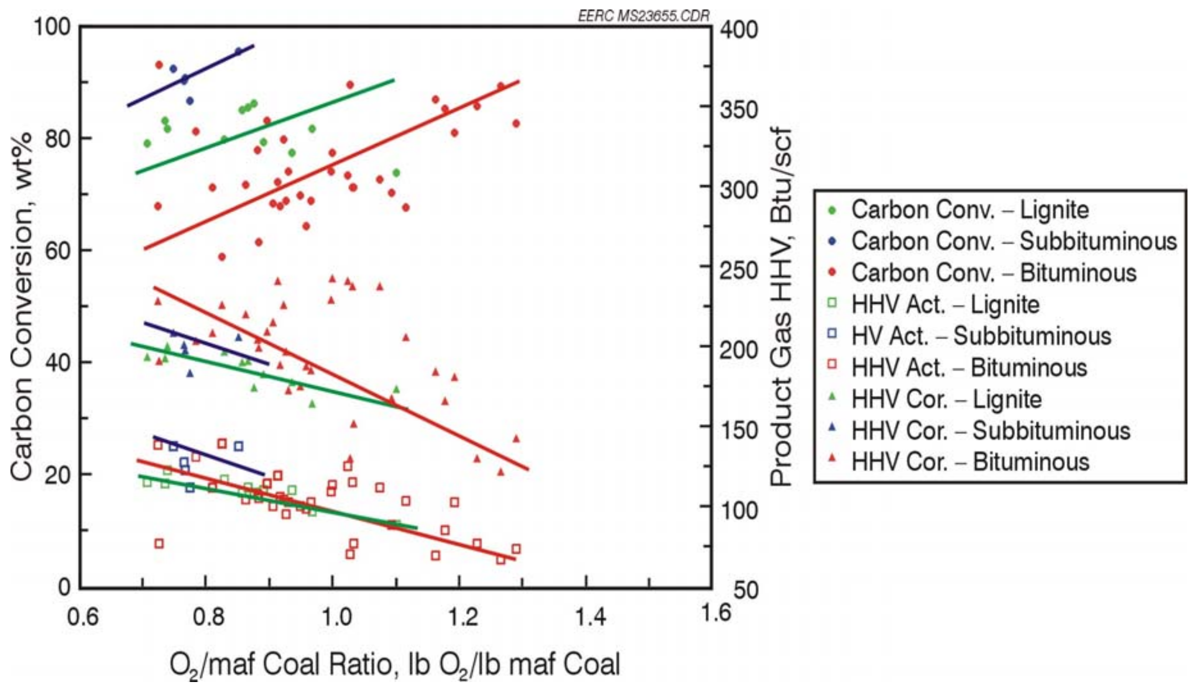

Figure 5. Carbon conversion rates and product gas heating value as a function of oxygen (HHV Act. – measured heating value, HHV Cor. – corrected for nitrogen purge gases used in TRDU/TRIG system).

Gas Cleanup for Particulate and Trace Elements Including Mercury

Hot- and warm-gas cleanup for the control of particulate and mercury has been the focus of ongoing programs at the EERC. The removal of particulate and unburned carbon has been demonstrated for several coals using the TRIG system and at the proof-of-concept-scale PSDF system. Recently, the EERC tested the use of highly reactive mercury sorbents for use at temperatures over 500°F (260°C) in gasification systems. The results of this work showed a greater than 95% removal of mercury from the warm fuel gas (Swanson, 2004), a significant finding since the existing technology (Rutkowski, 2002) requires cooling the gases to less than 100°F (38°C) prior to removing mercury with presulfided activated carbon.

Carbon Dioxide Separation and Removal

The first choice for the separation of the carbon dioxide would involve a higher-temperature CO_2 separation membrane. The performance of this membrane on an actual coal-derived syngas would be investigated as a part of this program. As a fallback position, the use of recently developed cold-gas CO_2 separation membranes could be tested. Data on fuel gas constituents also will be provided to suppliers of conventional cold-gas removal processes such as rectisol or an amine scrubber for their evaluation as a possible process. The cold CO_2 removal step would probably then be conducted after the hydrogen separation step shown in Figure 2 in order to obtain higher efficiencies from the TRIG process's thermal energy.

Hydrogen Recovery

Once the sulfur has been removed from the gases, the technologies of the production of ultrapure hydrogen streams can be tested. These include higher-temperature palladium-based membranes that are capable of providing 99.9+% hydrogen purity. Some palladium-based membranes such as Pd–Cu are also capable of tolerating some sulfur, potentially reducing the amount of sulfur removal necessary and possibly even eliminating the polishing filter. Recently developed but commercially available lower-temperature polymeric hollow-fiber membranes could also be tested as part of this program should the hydrogen purity requirements be lower than 99%. Data can also be shared with commercial suppliers of conventional PSA equipment for their projections on how this fuel gas mixture would respond to hydrogen purification.

QUALIFICATIONS

The EERC is a research facility that operates as a business unit of UND. The EERC has an annual budget of $20.4 million and has worked with over 800 clients in all 50 states and in 47 countries. The EERC has a multidisciplinary staff of more than 270 who has expertise and partnerships in a broad spectrum of energy and environmental programs, including over 50 years of research experience on lignite properties and variability; gasification processes; ash-related impacts; the fate of pollutants including Hg, particulate, and acid gases; Hg sampling, measurement, and speciation; development, demonstration, and commercialization of combustion and environmental control systems; conducting field testing and demonstrations; and advanced analysis of materials. During this project, we will rely on EERC plant operations, technicians, chemists, and engineers who will assist with the design, fabrication, and operation of the equipment.

VALUE TO NORTH DAKOTA

There are both challenges and opportunities for the gasification of North Dakota lignite. The selection of a gasification technology and a gas cleanup system must consider the challenges and take advantage of the unique characteristics of lignite coal. Currently, there is insufficient understanding of methods to decrease the challenges in the use of lignite in gasification and gas cleanup systems because of lignite variability, sodium and ash interactions, sulfide formation, condensed-phase characteristics, and mercury and trace element behavior. In addition, there is insufficient experience in taking advantage of the highly reactive lignites, the catalytic effects of alkali and alkaline-earth elements during gasification, requirements for water in downstream water–gas shift reactions, and the increase in gas flow in combined-cycle systems as a result of moisture. This project will aid in understanding the unique opportunities for the use in lignite gasification, gas cleanup, and gas separation systems.

MANAGEMENT

An organizational chart is shown in Figure 6. Overall project direction will come from the Project Steering Group, which will consist of DOE and the industrial partners providing funding for the project. An advisory board will be set up. This board will provide project guidance to Project Manager Dr. Steven Benson, who will be assisted by three principal investigators for the project, including Dr. Michael Swanson, Dr. Michael Jones, and Dr. Li Yan. A project kickoff

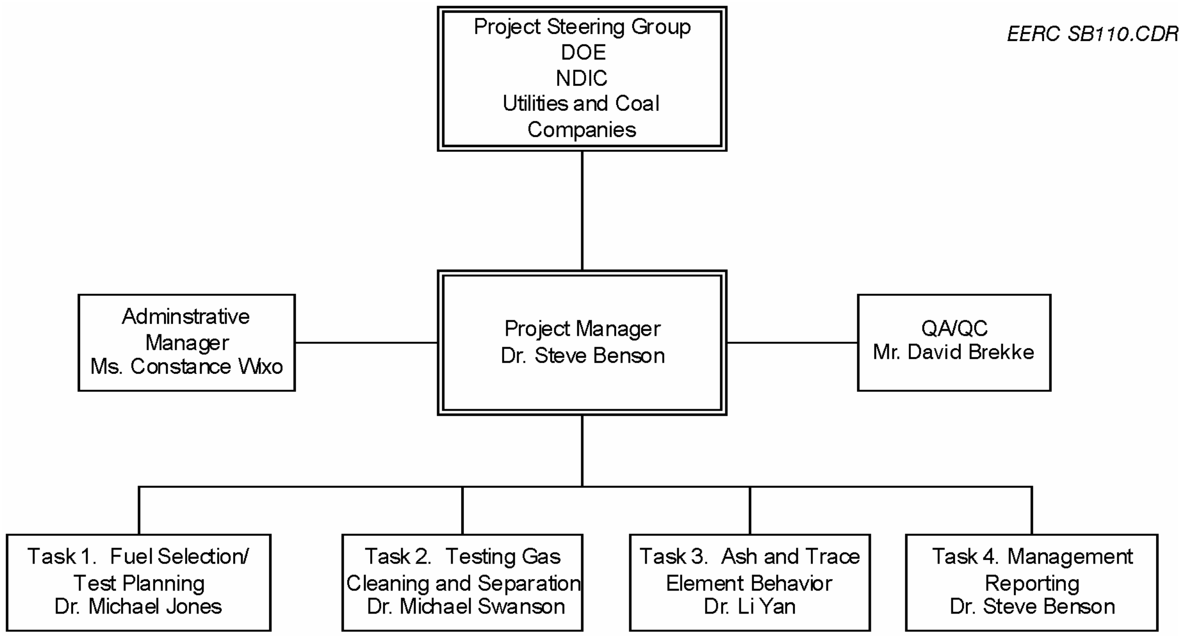

Figure 6. Overall management structure of project.

meeting will be held in order to decide on the coals to be tested and agree on the scope of work. Conference calls with project sponsors will be held monthly to discuss progress. Meetings will be held at the EERC quarterly or as agreed on by the Project Steering Group to discuss the progress and direction of the project. Ms. Constance Wixo will provide administrative support, and Mr. David Brekke will provide direction regarding the QA/QC program. Short descriptions of key personnel follow:

- Dr. Benson is a Senior Research Manager/Advisor at the EERC. He received his Ph.D. in Fuel Science from the Pennsylvania State University and his B.S. in Chemistry from Moorhead State University. Dr. Benson has over 25 years of experience in research, development, demonstration, and commercialization projects in advanced combustion and gasification systems. His principal areas of interest and expertise include development and management of complex multidisciplinary programs focused on solving environmental and energy problems, including 1) technologies to improve the performance of combustion/gasification and associated air pollution control systems; 2) transformations and control of air toxic substances in combustion and gasification systems; 3) advanced analytical techniques to measure the chemical and physical transformations of inorganic species in gases; 4) computer-based models to predict the emissions and fate of pollutants from combustion and gasification systems; 5) advanced materials for power systems; 6) impacts of power system emissions on the environment; 7) national and international conferences and training programs; and 8) state and national environmental policy. Dr. Benson has authored or coauthored over 210 publications and is the editor of eight books and Fuel Processing Technology special issues.

- Dr. Swanson is a Senior Research Manager at the EERC. He is involved with the demonstration of advanced power systems such as pressurized fluidized-bed combustors (PFBC) and integrated gasification combined cycle (IGCC), with an emphasis on hot-gas cleanup issues. Dr. Swanson received a Ph.D. in Energy Engineering, an M.B.A., an M.S. in Chemical Engineering, and a B.S. in Chemical Engineering from the University of North Dakota. Dr. Swanson's principal areas of interest and expertise include PFBC, IGCC, hot-gas cleanup, coal reactivity in low-rank coal combustion, supercritical solvent extraction, and liquefaction of low-rank coals. Dr. Swanson has been extensively involved for the last 10 years in testing an advanced gasification technology known as the TRIG system that is focused on low-rank coals. He has also been involved with the demonstration of other advanced power systems such as PFBC and IGCC, with an emphasis on hot-gas cleanup issues. In addition, he has authored or coauthored over 80 publications.

- Dr. Jones is a Senior Research Advisor at the EERC and an Adjunct Professor of Physics at the University of North Dakota. Dr. Jones received his Ph.D. in Physics at the University of North Dakota in 1978 and his M.S. in 1973 and his B.S. in 1971 from Bemidji State University. Dr. Jones's principal areas of interest and expertise include management of, and technical direction for, multidisciplinary science and engineering research teams focused on a wide range of integrated energy and environmental technologies. Specific program areas of interest include clean and efficient combustion and gasification of low-grade fuels, matching of fuel characteristics to system design and operating parameters, development of advanced power systems based on low-grade fuels, ash behavior in combustion and gasification systems, and analysis of inorganic materials from fuels. Special emphasis is given to low-rank coal systems; activities range from field testing of full-scale power plants, to pilot-scale studies, to laboratory investigations that examine both fuel and system characteristics and their impacts on overall performance. Projects emphasize a cradle-to-grave approach from resource assessment, to optimum utilization systems, to minimization of emissions and waste management featuring by-product utilization. He has authored or coauthored over 85 publications.
- Dr. Yan is a Research Engineer at the EERC of the University of North Dakota, where he is principally involved in the computational analysis of fuel characteristics in power plants and environmental impacts associated with fuel utilization. He received his Ph.D. in Chemical Engineering from the University of Newcastle, Australia, in 2000 and his M.E. and B.E. in Thermal Engineering from Tsinghua University, Beijing, China, in 1993 and 1990, respectively. Prior to his position at the EERC, he served as a

Postdoctoral Research Associate at the Department of Chemical Engineering, University of Newcastle, and as a Research Associate with the Institute of Nuclear and New Energy Technology at Tsinghua University. Dr. Yan's principal areas of interest and expertise include coal mineral characterization techniques, ash-related issues in power plant boilers, CFBC and gasification, and thermal/energy system analysis, optimization, and management. Specifically, he has been working on ash deposition; SO_3 removal; mercury speciation, emissions, and control; computational fluid dynamics modeling; advanced coal characterization techniques; and spray dryer absorbers. Dr. Yan worked on a pilot-scale fluidized-bed coal gasification system gas and steam cogeneration technology. In this technology, the circulating solid materials (semi-char), collected by a cyclone dust separator on the top of a fluidized-bed combustor was directed into a bubbling-bed gasifier in order to provide a sufficient heat source for gasification reactions. He has authored or coauthored over 20 professional publications.

TIMETABLE

The schedule for Year 1 of the project is shown in Table 1. The schedule for Year 2 pilot-scale TRIG testing is shown in Table 2. The schedule is aimed at providing key information on the characteristics of the synthesis gas, ability to remove impurities, and ability to provide adequate gas separation within 8 months after the beginning of the second year of the project.

BUDGET

A budget is attached that provides and overview of the costs of the project. The total project cost, on a cost-reimbursable basis, is $2,040,380.

Table 1. Schedule for Year 1 Testing Activities by Task

EERC SB25109.CDR

ID	Task Name	Start	Finish
1	Task 1 Feedstock Characterization and Detailed Test Plan	11/8/2005	3/27/2006
2	1.a Fuel Characterization	12/5/2005	2/10/2006
3	1.b Detailed Test Matrix	1/9/2006	3/17/2006
4	Task 2 Bench-Scale Testing of Gas Desulfurization, Hydrogen, and Carbon Dioxide Purification Concepts	10/31/2005	6/30/2006
5	2.a Design and Construction of a Bench-Scale System	12/5/2005	2/24/2006
6	2.b Bench-Scale Testing with Continuous Fluidized-Bed Gasifier	2/13/2006	9/8/2006
7	2.b.1 Sulfur Removal Testing	2/13/2006	6/30/2006
8	2.b.2 Carbon Dioxide Separation	5/19/2006	7/27/2006
9	2.b.3 Hydrogen Separation	5/15/2006	8/25/2006
10	Task 3 Gas Cleanup for Particulate and Trace Elements Including Hg	2/13/2006	8/2/2006
11	Task 4 Management and Reporting	12/8/2005	12/6/2006
12	4.a Progress Reporting	12/9/2005	12/7/2006
13	4.b Presentations and Travel	5/29/2006	10/13/2006
14	4.c Final Report Year 1	9/4/2006	11/24/2006

Table 2. Schedule for Year 2 Pilot-Scale TRIG Testing Activities by Task

EERC SB25111.CDR

ID	Task Name	Start	Finish
1	Task 1 Feedstock Characterization and Detailed Test Plan	11/1/2006	12/28/2006
2	1.a Fuel Characterization	11/1/2006	12/5/2006
3	1.b Detailed Test Matrix	11/1/2006	12/19/2006
4	Task 2 Bench-Scale Testing of Gas Desulfurization, Hydrogen, and Carbon Dioxide Purification Concepts	11/1/2006	7/3/2007
5	2.c TRIG Gasification Testing	11/3/2006	6/5/2007
6	2.c.1 Gasification Testing of First Texas Lignite	11/30/2006	2/15/2007
7	2.c.2 Gasification of Second Texas Lignite	2/28/2007	5/8/2007
8	2.d Slipstream Testing of Optimum Gas Cleanup and Purification Methods	12/7/2006	5/3/2007
9	2.e Ash Materials Analysis	4/2/2007	5/28/2007
10	Task 3 Gas Cleanup for Particulate and Trace Elements Including Hg	12/14/2006	6/4/2007
11	Task 4 Management and Reporting	11/1/2006	10/30/2007
12	4.a Progress Reporting	11/1/2006	10/30/2007
13	4.b Presentations and Travel	5/2/2007	9/18/2007
14	4.c Final Report Year 1	8/3/2007	10/25/2007

MATCHING FUNDS

The total project cost for Year 1 is $1,200,000, with 80% of the funding ($960,000) to be obtained from DOE through the EERC–DOE National Center for Hydrogen Technology (NCHT). The program for the first year requires 20% industry cost share of $240,000 in cash. The current plan for obtaining the industry match is to have five sponsors provide $30,000 each combined with $90,000 from the North Dakota Industrial Commission for Year 1 of the project. If more than five sponsors for the project are obtained, the cost for each sponsor will be decreased or additional work will be performed based on input from the project sponsors. The total project cost for Year 2 is $1,440,380, with 75% ($1,080,380) of the funding, to be obtained from DOE through the EERC–DOE NCHT. The program for the second year requires 25% industry cost share of $360,000 in cash. The current plan for obtaining the industry match is to have five sponsors provide $45,000 each combined with $135,000 from the NDIC for Year 2 of the project. If more than five sponsors for the project are obtained, the cost for each sponsor will be decreased.

Additional letters of support for the project are anticipated in the near future from industrial partners. Verification of TXU Generation Company, LP's participation in the project is available upon request.

TAX LIABILITY

The EERC—a research organization within UND, which is an institution of higher education within the state of North Dakota—is not a taxable entity.

CONFIDENTIAL INFORMATION

No confidential information is included in this proposal.

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APPENDIX A

DESCRIPTION OF EQUIPMENT

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Continuous Fluid-Bed Reactor (CFBR)

Figure A-1 shows the 4-lb/hr CFBR used for gasification tests. The CFBR was originally designed as a pyrolysis unit for a U.S. Department of Energy mild gasification program but has since been used for gasification and pyrolysis on a variety of projects. Gases used for fluidization are mixed in a gas manifold. Bottled gas, house nitrogen, house air, and any liquid desired (such as water) are first preheated, then mixed and heated to reaction temperature in a superheater (20 ft of 3/8-in. tubing coiled into an 18-in. ceramic fiber heater). Two bottled gases in combination with either house air or house nitrogen and a liquid can be used.

The reactor is constructed of 316H stainless steel Schedule 80 pipe. The first (bottom) section is made of 3-in. pipe and is 33 in. long. The next (top) reactor section is made of 4-in. pipe, 18.75 in. long. The two sections are connected with a 316H weld reducer. The unit was designed such that the top of the fluid bed lies 33 in. above the coal injection point. A solids offtake leg at the top of the bed is the primary means of solids removal from the reactor. A ball valve facilitates the collection of product while the system is operating. The reactor has two ceramic fiber heaters to maintain the vessel's temperature and eliminate hot spots. Using external heaters allows the evaluation of internal and external heating methods for process development and scaleup. The reactor is capable of operation at a maximum of 155 psig and 840°C (1500°F).

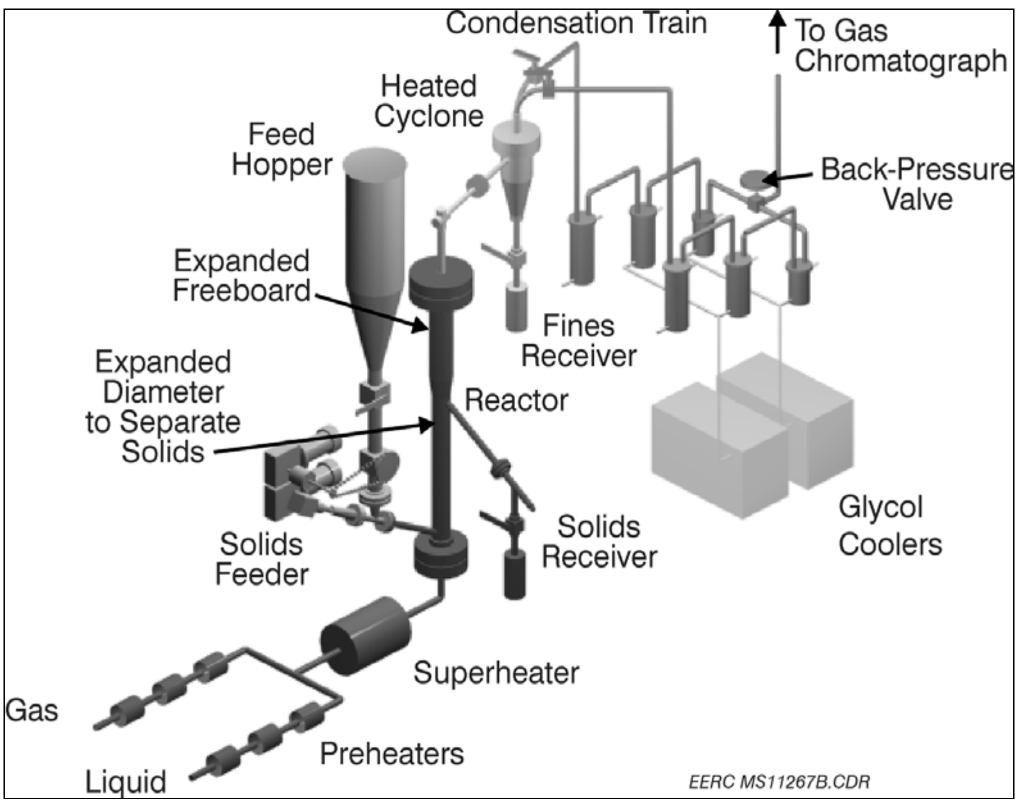

Figure A-1. Schematic of CFBR.

A 3-in.-diameter cyclone is used for solids removal from the gas stream. A ball valve allows the changing of the solids catchpot while the system is operating. The cyclone is heated with a ceramic fiber heater capable of operating at a temperature of 900°C (1650°F). An 8-in.-long section of 2-in. 316H stainless steel Schedule 80 pipe has also been utilized as a pressure vessel to either contain a fixed bed of zinc-based sorbent to reduce the H_2S concentrations or to contain calcium-based sorbent for the removal of chlorine gases from the fuel gases.

Three 4-in.-diameter vessels are used to remove all condensables from the gas stream. Two separate trains were installed: one for mass balance sampling and the other for heatup, unsteady-state conditions, and cooldown. The first condenser pot is indirectly cooled by water and typically cools the gas stream from 300°C (570°F) to 95°C (200°F). The next two condensers, also indirect, are glycol-cooled. The exit gas temperature is typically 10°C (50°F). A glass-wool filter is used to capture aerosols passed through the condenser system. A wet scrubber has also been used to neutralize any chlorine still present in the gas stream, before the gas is sent through a product gas meter.

A Genesis software package is used for process control and data acquisition. Pressure drop across the bed is measured by two transmitters, and thermocouples throughout the unit measure temperature. Temperature and pressure readings are recorded every 30 seconds, and these data are directly transferred to Lotus spreadsheets. Online continuous emission monitors for H_2, CO, CH_4, CO_2, and H_2S together with an online Foxboro 931C gas chromatograph are utilized for measuring gas compositions. If desired, the gas composition of the coal-derived gas stream can be adjusted slightly by adding bottled gas to the gas stream entering the reactor.

Bench-Scale HGFV

A bench-scale HGFV that could be used in conjunction with the CFBR (for gasification/pyrolysis) was built to test hot-gas candle filters for their ability to obtain high-temperature, high-pressure operational data on various filter elements. This vessel is designed to handle all of the gas flow from the CFBR at its nominal design conditions. The vessel is 10-in. i.d. and 60 in. long (including cone, vessel, and cap) and can handle a gas flow up to 30 scfm at 843°C (1550°F) and 150 psig. The tube sheet is interchangeable to handle different-sized filters. The filters are sealed in the tube sheet by a bolted metal plate and Nextel fiber gaskets which counteract the upward force imparted across the candle filter by the filter’s differential pressure. The vessel is sized such that it could handle three candle filters up to 18 in. long with a 2.375-in. o.d. This would provide candle space of 3.85-in. center line-to-center line and enable filter face velocities as low as 2.5 ft/min to be tested in the CFBR. Higher face velocities would be achieved by using shorter candles or higher gas flow rates. Ports are added in the filter vessel for allowing temperature and pressure measurements to be obtained. The ash letdown station consists of two high-temperature valves to act as lock hoppers to isolate the ash hopper from the filter vessel.

The nitrogen backpulse system is constructed from existing materials utilized from a previous hot-gas filter test system. The backpulse system is designed to supply a minimum of three candle volumes per pulse for the longest candle filters and even higher volumes for the shorter candle filters. The nitrogen is capable of being heated up to 816°C (1500°F) before entering the filter vessel, although most tests utilize room temperature nitrogen for backpulsing. The length and volume of nitrogen displaced into the vessel is controlled by the regulated pressure (up to 600 psig) of the cold-nitrogen reservoir and the solenoid valves used to control the timing of the cold-gas pulse, which displaces the hot nitrogen into the filter vessel. An electrically heated ½-in. pipe is used to connect the CFBR to the HGFV.

Transport Reactor Development Unit (TRDU)

The pilot-scale TRDU has an exit gas temperature of up to 980°C (1800°F), a gas flow rate of 325 scfm (0.153m^3/s), and an operating pressure of 120 psig (9.3 bar). The TRDU system can be divided as follows: the coal feed section, the TRDU, and the product recovery section. The TRDU proper, as shown in Figure A-2, consists of a riser reactor with an expanded mixing zone at the bottom, a disengager, and a primary cyclone and standpipe. The standpipe is connected to the mixing section of the riser by a L-valve transfer line. All of the components in the system are refractory-lined and designed mechanically for 150 psig (11.4 bar) and an internal temperature of 1090°C (2000°F). Detailed design criteria and a comparison to actual operating conditions on the design coal are given in Table A-1.

The premixed coal and limestone feed to the transport reactor can be admitted through three nozzles, which are at varying elevations. Two of these nozzles are located near the top of the mixing zone (gasification), and the remaining one is near the bottom of the mixing zone (combustion). During operation of the TRDU, feed is admitted through only one nozzle at a time.

The coal feed is measured by an rpm-controlled metering auger. Oxidant is fed to the reactor through two pairs of nozzles at varying elevations within the mixing zone. For the combustion mode of operation, additional nozzles are provided in the riser for feeding secondary air. Hot solids from the standpipe are circulated into the mixing zone, where they come into contact with the nitrogen and the steam being injected into the L-valve. This feature enables spent char to contact steam prior to the fresh coal feed. This staged gasification process is expected to enhance process efficiency. Gasification or combustion and desulfurization reactions are carried out in the riser as coal, sorbent, and oxidant (with steam for gasification) flow up the reactor. The solids circulation into the mixing zone is controlled by fluffing gas in the standpipe, J-leg aeration flows, and the solids level in the standpipe.

The riser, disengager, standpipe, and cyclones are equipped with several internal and skin thermocouples. Nitrogen-purged pressure taps are also provided to record differential pressure across the riser, disengager, and cyclones. The data acquisition and control system scans the data points every one-half second and is saving the process data every 30 s. The bulk of entrained solids leaving the riser is separated from the gas stream in the disengager and circulated back to the riser via the standpipe. A solids stream is withdrawn from the standpipe via an auger to maintain the system's solids inventory. Gas exiting the disengager enters a primary cyclone. The dipleg solids have been recirculated back to the standpipe through a loop seal at the bottom of the dipleg. Gas exiting this cyclone enters a jacketed-pipe heat exchanger before entering the HGFV. The warm particulate-free gases leaving the HGFV are vented directly into a thermal oxidizer where they are combusted.

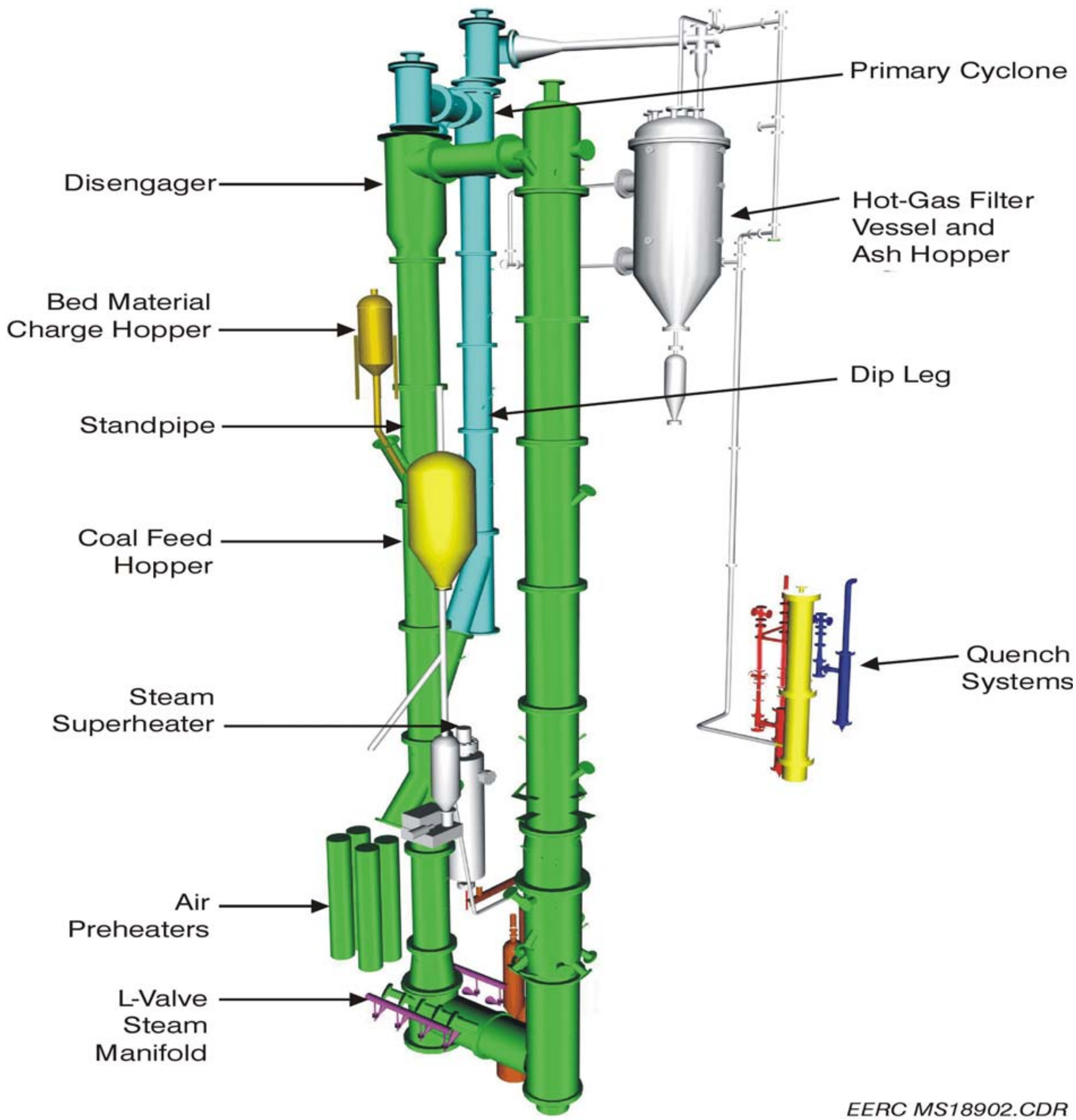

Figure A-2. TRDU.

Table A-1. Summary of TRDU Design and Operation on the Design Coal

Parameter	Design	Actual
Coal	Illinois No. 6	Illinois No. 6
Moisture Content, %	5	8.5
Pressure, psig	120 (9.3 bar)	120 (9.3 bar)
Steam/Coal Ratio	0.34	0.34
Air/Coal Ratio	4.0	2.3
Ca/S Ratio, mole	1.5	2.0
Air Inlet Temperature, °C	427	180
Steam Preheat, °C	537	350
Coal Feed Rate, lb/hr	198 (89.9 kg/hr)	220 (99.9 kg/hr)
Gasifier Temperature, maximum °C	1010	950
T, maximum °C	17	60 to 100
Carbon Conversion,[1] %	>80	76.5
HHV[2] of Fuel Gas, Btu/scf	100	110
Heat Loss as Coal Feed, %	19.5	13
Riser Velocity, ft/sec	31.3	25
Heat Loss, Btu/hr	252,000	320,000
Standpipe Superficial Velocity, ft/sec	0.1	0.38

[1] Carbon conversion = (wt carbon feed wt carbon removed)/wt carbon feed × 100.
[2] Higher heating value.

Hot-Gas Filter Vessel (HGFV)

This vessel is designed to handle all of the gas flow from the TRDU at its expected operating conditions. The vessel is approximately 48-in. i.d. (121.9 cm) and 185 in. (470 cm) long and is designed to handle gas flows of approximately 325 scfm at temperatures up to 815°C (1500°F) and 120 psig (8.3 bar). The refractory has a 28-in. (71.1-cm) i.d. with a shroud diameter of approximately 22-in. (55.9 cm). The vessel is sized such that it could handle candle filters up to 1.5 m long; however, 1-m candles were utilized in the 540°C (1000°F) gasification tests to date. Candle filters are 2.375-in. (6-cm) o.d. with a 4-in. (10.2-cm) center line-to-center line spacing. The filter design criteria are summarized in Table A-2.

The total number of candles that can be mounted in the current geometry of the HGFV tube sheet is 19. This enables filter face velocities as low as 2.0 ft/min to be tested using 1.5-m candles. Higher face velocities are achieved by using fewer candles. The majority of testing has been performed at a face velocity of approximately 4.0 to 4.5 ft/min. This program has tested a Industrial Filter & Pump ceramic tube sheet and Fibrosic and REECER SiC candles, silicon carbon-coated and SiO_2 ceramic fiber candles from the 3M company, along with sintered metal (iron aluminide) and Vitropore silicon carbon ceramic candles from Pall Advanced Separation Systems Corporation. In addition, granular SiC candles from U.S. Filter/Schumacher and composite candle filters from McDermott Technologies and Honeywell were tested. Current testing has focused on Pall's iron aluminide metal filters. Also, candle filter fail-safes from Siemens-Westinghouse Science and Technology Center have been tested.

Table A-2. Design Criteria and Actual Operating Conditions for the Pilot-Scale HGFV

Operating Conditions	Design	Actual
Inlet Gas Temperature	540°C	450°–580°C
Operating Pressure	150 psig (10.3 bar)	120 psig (8.3 bar)
Volumetric Gas Flow	325 scfm (0.153 m^3/s)	350 scfm (0.165 m^3/s)
Number of Candles	19 (1 or 1.5 meter)	13 (1 meter)
Candle Spacing	4 in. ℄ to ℄ (10.2 cm)	4 in. ℄ to ℄ (10.2 cm)
Filter Face Velocity	2.5–10 ft/min (1.3 to 2.3 cm/s)	4.5 ft/min (2.3 cm/s)
Particulate Loading	<10,000 ppmw	< 38,000 ppmw
Temperature Drop Across HGFV	<30°C	25°C
Nitrogen Backpulse System Pressure	up to 600 psig (42 bar)	250 to 350 psig (17 to 24 bar)
Backpulse Valve Open Duration	up to 1-s duration	¼-s duration

The ash letdown system consists of two sets of alternating high-temperature valves with a conical pressure vessel to act as a lock hopper. Additionally, a preheat natural gas burner attached to a lower inlet nozzle on the filter vessel can be used to preheat the filter vessel separately from the TRDU. The hot gas from the burner enters the vessel via a nozzle inlet separate from the dirty gas.

The high-pressure nitrogen backpulse system is capable of backpulsing up to four sets of four or five candle filters with ambient-temperature nitrogen in a time-controlled sequence. The pulse length and volume of nitrogen displaced into the filter vessel is controlled by regulating the pressure (up to 600 psig [42 bar]) of the nitrogen reservoir and controlling the solenoid valve pulse duration. Figure 1 also shows the filter vessel location and process piping in the EERC gasifier tower. A recently installed heat exchange surface now allows the hot-gas filter to operate in the 500° to 1200°F range instead of the higher temperature range of 800° to 1000°F utilized in previous testing. This additional heat exchange surface was added to allow gas cooling to the temperature where Hg removal is likely to occur. Ports for obtaining hot high-pressure particulate and trace metal samples both upstream and downstream of the filter vessel were added to the filter system piping.

APPENDIX B

BUDGET

SUMMARY BUDGET - ALL YEARS

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN AND POWER
NDIC
PROPOSED START DATE: 11/01/2005
EERC PROPOSAL #2006-0055

		YEAR ONE		YEAR TWO		TOTAL		NDIC SHARE		OTHER COST SHARE		DOE SHARE	
CATEGORY		**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**
TOTAL DIRECT LABOR		11,339	$ 365,907	12,746	$ 433,211	24,085	$ 799,118	971	$ 45,088	1,616	$ 75,032	21,498	$ 678,998
FRINGE BENEFITS - % OF DIRECT LABOR	50%		$ 182,955		$ 216,606		$ 399,561		$ 22,545		$ 37,516		$ 339,500
TOTAL LABOR			$ 548,862		$ 649,817		$ 1,198,679		$ 67,633		$ 112,548		$ 1,018,498
OTHER DIRECT COSTS													
TRAVEL			$ 12,787		$ 11,562		$ 24,349		$ 1,908		$ 3,179		$ 19,262
COMMUNICATION - PHONES & POSTAGE			$ 770		$ 1,675		$ 2,445		$ 396		$ 659		$ 1,390
OFFICE (PROJECT SPECIFIC SUPPLIES)			$ 2,040		$ 2,996		$ 5,036		$ 783		$ 1,305		$ 2,948
SUPPLIES			$ 15,000		$ 11,180		$ 26,180		$ 2,153		$ 3,713		$ 20,314
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)			$ 9,500		$ 10,600		$ 20,100		$ 2,029		$ 3,435		$ 14,636
EQUIPMENT > $5000			$ 65,000		$ -		$ 65,000		$ -		$ -		$ 65,000
FEES			$ 170,845		$ 274,408		$ 445,253		$ 69,328		$ 115,546		$ 230,379
TOTAL OTHER DIRECT COST			$ 275,942		$ 312,421		$ 588,363		$ 76,597		$ 127,837		$ 383,929
TOTAL DIRECT COST			$ 824,804		$ 962,238		$ 1,787,042		$ 144,230		$ 240,385		$ 1,402,427
FACILITIES & ADMIN. RATE - % OF MTDC			$ 375,196		$ 478,142	VAR	$ 853,338	56%	$ 80,770	56%	$ 134,615	47.7%	$ 637,953
TOTAL ESTIMATED COST			$ 1,200,000		$ 1,440,380		$ 2,640,380		$ 225,000		$ 375,000		$ 2,040,380

NOTE: Due to limitations within the University's accounting system, the system does not provide for accumulating and reporting expenses at the Detailed Budget level. The Summary Budget is presented for the purpose of showing how we propose, account, and report expenses. The Detailed Budget is presented to assist in the evaluation of the proposal.

DETAILED BUDGET - ALL YEARS

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN AND POWER
NDIC
PROPOSED START DATE: 11/01/2005
EERC PROPOSAL #2006-0055

			YEAR ONE TOTAL		YEAR TWO TOTAL		ALL YEARS TOTAL		NDIC SHARE		OTHER COST SHARE		DOE SHARE	
LABOR	**LABOR CATEGORY**	**HOURLY RATE**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**
BENSON, S.	PROJECT MANAGER	$ 54.21	860	$ 46,621	580	$ 31,441	1,440	$ 78,062	246	$ 13,336	409	$ 22,172	785	$ 42,554
SWANSON, M.	PRINCIPAL INVESTIGATOR	$ 44.39	720	$ 31,961	550	$ 24,416	1,270	$ 56,377	222	$ 9,854	370	$ 16,425	678	$ 30,098
JONES, M.	PRINCIPAL INVESTIGATOR	$ 53.72	348	$ 18,695	770	$ 41,364	1,118	$ 60,059	180	$ 9,669	299	$ 16,063	639	$ 34,327
YAN, L.	RESEARCH SCIENTIST/ENGINEER	$ 32.38	744	$ 24,090	552	$ 17,873	1,296	$ 41,963	241	$ 7,804	402	$ 13,016	653	$ 21,143
--------------	SENIOR MANAGEMENT	$ 53.73	557	$ 29,927	722	$ 38,793	1,279	$ 68,720	-	$ -	-	$ -	1,279	$ 68,720
--------------	RESEARCH SCIENTIST/ENGINEER	$ 29.47	3,428	$ 101,023	4,919	$ 144,963	8,347	$ 245,986	-	$ -	-	$ -	8,347	$ 245,986
--------------	RESEARCH TECHNICIAN	$ 20.07	1,622	$ 32,554	1,325	$ 26,592	2,947	$ 59,146	-	$ -	-	$ -	2,947	$ 59,146
--------------	TECHNOLOGY DEV. OPER.	$ 20.73	2,200	$ 45,606	2,300	$ 47,679	4,500	$ 93,285	-	$ -	-	$ -	4,500	$ 93,285
--------------	TECHNOLOGY DEV. MECH.	$ 23.04	600	$ 13,824	600	$ 13,824	1,200	$ 27,648	-	$ -	-	$ -	1,200	$ 27,648
--------------	TECHNICAL SUPPORT SERVICES	$ 16.08	260	$ 4,181	428	$ 6,883	688	$ 11,064	82	$ 1,319	136	$ 2,186	470	$ 7,559
			11,339	$ 348,482	12,746	$ 393,828	24,085	$ 742,310	971	$ 41,982	1,616	$ 69,862	21,498	$ 630,466
ESCALATION ABOVE CURRENT BASE			5.0%	$ 17,425	10.0%	$ 39,383	VAR	$ 56,808		$ 3,106		$ 5,170		$ 48,532
TOTAL DIRECT LABOR				$ 365,907		$ 433,211		$ 799,118		$ 45,088		$ 75,032		$ 678,998
FRINGE BENEFITS - % OF DIRECT LABOR		50%		$ 182,955		$ 216,606		$ 399,561		$ 22,545		$ 37,516		$ 339,500
TOTAL LABOR				$ 548,862		$ 649,817		$ 1,198,679		$ 67,633		$ 112,548		$ 1,018,498
OTHER DIRECT COSTS														
TRAVEL				$ 12,787		$ 11,562		$ 24,349		$ 1,908		$ 3,179		$ 19,262
COMMUNICATION - PHONES & POSTAGE				$ 770		$ 1,675		$ 2,445		$ 396		$ 659		$ 1,390
OFFICE (PROJECT SPECIFIC SUPPLIES)				$ 2,040		$ 2,996		$ 5,036		$ 783		$ 1,305		$ 2,948
SUPPLIES				$ 15,000		$ 11,180		$ 26,180		$ 2,153		$ 3,713		$ 20,314
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)				$ 9,500		$ 10,600		$ 20,100		$ 2,029		$ 3,435		$ 14,636
EQUIPMENT > $5000				$ 65,000		$ -		$ 65,000		$ -		$ -		$ 65,000
NATURAL MATERIALS ANALYTICAL RES. LAB.				$ 72,553		$ 95,011		$ 167,564		$ 38,889		$ 64,816		$ 63,859
FUELS & MATERIALS RESEARCH LAB.				$ 3,711		$ 10,895		$ 14,606		$ 1,798		$ 2,996		$ 9,812
ANALYTICAL RESEARCH LAB.				$ 37,170		$ 67,513		$ 104,683		$ 11,393		$ 18,988		$ 74,302
PARTICULATE ANALYSIS				$ -		$ 21,450		$ 21,450		$ 3,700		$ 6,167		$ 11,583
PROCESS CHEM. & DEV. LAB.				$ 1,581		$ 1,146		$ 2,727		$ 189		$ 315		$ 2,223
FUEL PREP. AND MAINTENANCE				$ 3,024		$ 12,672		$ 15,696		$ 2,138		$ 3,564		$ 9,994
CONTINUOUS FLUIDIZED-BED REACTOR				$ 15,120		$ 50,160		$ 65,280		$ 8,653		$ 14,421		$ 42,206
GRAPHICS SUPPORT				$ 2,835		$ 10,297		$ 13,132		$ 1,699		$ 2,832		$ 8,601
SHOP & OPERATIONS SUPPORT				$ 4,851		$ 5,264		$ 10,115		$ 869		$ 1,447		$ 7,799
OUTSIDE LABS				$ 30,000		$ -		$ 30,000		$ -		$ -		$ -
TOTAL OTHER DIRECT COST				$ 275,942		$ 312,421		$ 588,363		$ 76,597		$ 127,837		$ 383,929
TOTAL DIRECT COST				$ 824,804		$ 962,238		$ 1,787,042		$ 144,230		$ 240,385		$ 1,402,427
FACILITIES & ADMIN. RATE - % OF MTDC			VAR	$ 375,196	VAR	$ 478,142	VAR	$ 853,338	56%	$ 80,770	56%	$ 134,615	47.7%	$ 637,953
TOTAL ESTIMATED COST				$ 1,200,000		$ 1,440,380		$ 2,640,380		$ 225,000		$ 375,000		$ 2,040,380

DETAILED BUDGET - YEAR ONE

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN AND POWER
NDIC
PROPOSED START DATE: 11/01/2005
EERC PROPOSAL #2006-0055

			TOTAL YEAR ONE		**NDIC SHARE**		**OTHER COST SHARE**		**DOE SHARE**	
LABOR	**LABOR CATEGORY**	**HOURLY RATE**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**
BENSON, S.	PROJECT MANAGER	$ 54.21	860	$ 46,621	150	$ 8,132	250	$ 13,552	460	$ 24,937
SWANSON, M.	PRINCIPAL INVESTIGATOR	$ 44.39	720	$ 31,961	131	$ 5,815	219	$ 9,722	370	$ 16,424
JONES, M.	PRINCIPAL INVESTIGATOR	$ 53.72	348	$ 18,695	53	$ 2,847	87	$ 4,674	208	$ 11,174
YAN, L.	RESEARCH SCIENTIST/ENGINEER	$ 32.38	744	$ 24,090	150	$ 4,857	250	$ 8,095	344	$ 11,138
--------------	SENIOR MANAGEMENT	$ 53.73	557	$ 29,927	-	$ -	-	$ -	557	$ 29,927
--------------	RESEARCH SCIENTIST/ENGINEER	$ 29.47	3,428	$ 101,023	-	$ -	-	$ -	3,428	$ 101,023
--------------	RESEARCH TECHNICIAN	$ 20.07	1,622	$ 32,554	-	$ -	-	$ -	1,622	$ 32,554
--------------	TECHNOLOGY DEV. OPER.	$ 20.73	2,200	$ 45,606	-	$ -	-	$ -	2,200	$ 45,606
--------------	TECHNOLOGY DEV. MECH.	$ 23.04	600	$ 13,824	-	$ -	-	$ -	600	$ 13,824
--------------	TECHNICAL SUPPORT SERVICES	$ 16.08	260	$ 4,181	11	$ 177	19	$ 305	230	$ 3,699
			11,339	$ 348,482	495	$ 21,828	825	$ 36,348	10,019	$ 290,306
ESCALATION ABOVE CURRENT BASE		5%		$ 17,425		$ 1,091		$ 1,818		$ 14,516
TOTAL DIRECT LABOR				$ 365,907		$ 22,919		$ 38,166		$ 304,822
FRINGE BENEFITS - % OF DIRECT LABOR		50%		$ 182,955		$ 11,460		$ 19,083		$ 152,412
TOTAL LABOR				$ 548,862		$ 34,379		$ 57,249		$ 457,234
OTHER DIRECT COSTS										
TRAVEL				$ 12,787		$ -		$ -		$ 12,787
COMMUNICATION - PHONES & POSTAGE				$ 770		$ 101		$ 167		$ 502
OFFICE (PROJECT SPECIFIC SUPPLIES)				$ 2,040		$ 244		$ 406		$ 1,390
SUPPLIES				$ 15,000		$ 188		$ 312		$ 14,500
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)				$ 9,500		$ 280		$ 520		$ 8,700
EQUIPMENT > $5000				$ 65,000		$ -		$ -		$ 65,000
NATURAL MATERIALS ANALYTICAL RES. LAB.				$ 72,553		$ 22,500		$ 37,500		$ 12,553
FUELS & MATERIALS RESEARCH LAB.				$ 3,711		$ -		$ -		$ 3,711
ANALYTICAL RESEARCH LAB.				$ 37,170		$ -		$ -		$ 37,170
PARTICULATE ANALYSIS				$ -		$ -		$ -		$ -
PROCESS CHEM. & DEV. LAB.				$ 1,581		$ -		$ -		$ 1,581
FUEL PREP. AND MAINTENANCE				$ 3,024		$ -		$ -		$ 3,024
CONTINUOUS FLUIDIZED-BED REACTOR				$ 15,120		$ -		$ -		$ 15,120
GRAPHICS SUPPORT				$ 2,835		$ -		$ -		$ 2,835
SHOP & OPERATIONS SUPPORT				$ 4,851		$ -		$ -		$ 4,851
OUTSIDE LABS				$ 30,000		$ -		$ -		$ 30,000
TOTAL OTHER DIRECT COST				$ 275,942		$ 23,313		$ 38,905		$ 213,724
TOTAL DIRECT COST				$ 824,804		$ 57,692		$ 96,154		$ 670,958
FACILITIES & ADMIN. RATE - % OF MTDC			VAR	$ 375,196	56%	$ 32,308	56%	$ 53,846	47.7%	$ 289,042
TOTAL ESTIMATED COST				$ 1,200,000		$ 90,000		$ 150,000		$ 960,000

DETAILED BUDGET - YEAR TWO

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN AND POWER
NDIC
PROPOSED START DATE: 11/01/2005
EERC PROPOSAL #2006-0055

			TOTAL		NDIC		OTHER COST		DOE	
		HOURLY	YEAR TWO		SHARE		SHARE		SHARE	
LABOR	**LABOR CATEGORY**	**RATE**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**
BENSON, S.	PROJECT MANAGER	$ 54.21	580	$ 31,441	96	$ 5,204	159	$ 8,620	325	$ 17,617
SWANSON, M.	PRINCIPAL INVESTIGATOR	$ 44.39	550	$ 24,416	91	$ 4,039	151	$ 6,703	308	$ 13,674
JONES, M.	PRINCIPAL INVESTIGATOR	$ 53.72	770	$ 41,364	127	$ 6,822	212	$ 11,389	431	$ 23,153
YAN, L.	RESEARCH SCIENTIST/ENGINEER	$ 32.38	552	$ 17,873	91	$ 2,947	152	$ 4,921	309	$ 10,005
--------------	SENIOR MANAGEMENT	$ 53.73	722	$ 38,793	-	$ -	-	$ -	722	$ 38,793
--------------	RESEARCH SCIENTIST/ENGINEER	$ 29.47	4,919	$ 144,963	-	$ -	-	$ -	4,919	$ 144,963
--------------	RESEARCH TECHNICIAN	$ 20.07	1,325	$ 26,592	-	$ -	-	$ -	1,325	$ 26,592
--------------	TECHNOLOGY DEV. OPER.	$ 20.73	2,300	$ 47,679	-	$ -	-	$ -	2,300	$ 47,679
--------------	TECHNOLOGY DEV. MECH.	$ 23.04	600	$ 13,824	-	$ -	-	$ -	600	$ 13,824
--------------	TECHNICAL SUPPORT SERVICES	$ 16.08	428	$ 6,883	71	$ 1,142	117	$ 1,881	240	$ 3,860
			12,746	$ 393,828	476	$ 20,154	791	$ 33,514	11,479	$ 340,160
ESCALATION ABOVE CURRENT BASE		10%		$ 39,383		$ 2,015		$ 3,352		$ 34,016
TOTAL DIRECT LABOR				$ 433,211		$ 22,169		$ 36,866		$ 374,176
FRINGE BENEFITS - % OF DIRECT LABOR		50%		$ 216,606		$ 11,085		$ 18,433		$ 187,088
TOTAL LABOR				$ 649,817		$ 33,254		$ 55,299		$ 561,264
OTHER DIRECT COSTS										
TRAVEL				$ 11,562		$ 1,908		$ 3,179		$ 6,475
COMMUNICATION - PHONES & POSTAGE				$ 1,675		$ 295		$ 492		$ 888
OFFICE (PROJECT SPECIFIC SUPPLIES)				$ 2,996		$ 539		$ 899		$ 1,558
SUPPLIES				$ 11,180		$ 1,965		$ 3,401		$ 5,814
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)				$ 10,600		$ 1,749		$ 2,915		$ 5,936
EQUIPMENT > $5000				$ -		$ -		$ -		$ -
NATURAL MATERIALS ANALYTICAL RES. LAB.				$ 95,011		$ 16,389		$ 27,316		$ 51,306
FUELS & MATERIALS RESEARCH LAB.				$ 10,895		$ 1,798		$ 2,996		$ 6,101
ANALYTICAL RESEARCH LAB.				$ 67,513		$ 11,393		$ 18,988		$ 37,132
PARTICULATE ANALYSIS				$ 21,450		$ 3,700		$ 6,167		$ 11,583
PROCESS CHEM. & DEV. LAB.				$ 1,146		$ 189		$ 315		$ 642
FUEL PREP. AND MAINTENANCE				$ 12,672		$ 2,138		$ 3,564		$ 6,970
CONTINUOUS FLUIDIZED-BED REACTOR				$ 50,160		$ 8,653		$ 14,421		$ 27,086
GRAPHICS SUPPORT				$ 10,297		$ 1,699		$ 2,832		$ 5,766
SHOP & OPERATIONS SUPPORT				$ 5,264		$ 869		$ 1,447		$ 2,948
OUTSIDE LABS				$ -		$ -		$ -		$ -
TOTAL OTHER DIRECT COST				$ 312,421		$ 53,284		$ 88,932		$ 170,205
TOTAL DIRECT COST				$ 962,238		$ 86,538		$ 144,231		$ 731,469
FACILITIES & ADMIN. RATE - % OF MTDC		VAR		$ 478,142	56%	$ 48,462	56%	$ 80,769	47.7%	$ 348,911
TOTAL ESTIMATED COST				$ 1,440,380		$ 135,000		$ 225,000		$ 1,080,380

DETAILED BUDGET - FEES

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN AND POWER
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		YEAR ONE		YEAR TWO		ALL YEARS	
NATURAL MATERIALS ANALYTICAL RES. LAB.	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
CCSEM	$520	26	$ 13,520	42	$ 21,840	68	$ 35,360
CHEMICAL FRACT.	$1,314	6	$ 7,884	2	$ 2,628	8	$ 10,512
HIGH SPEED COMPUTING	$66	-	$ -	25	$ 1,650	25	$ 1,650
MISCELLANEOUS (HOURLY)	$86	40	$ 3,440	40	$ 3,440	80	$ 6,880
MORPHOLOGY (HOURLY)	$189	120	$ 22,680	60	$ 11,340	180	$ 34,020
POINT COUNT	$503	20	$ 10,060	-	$ -	20	$ 10,060
XRD	$169	36	$ 6,084	117	$ 19,773	153	$ 25,857
XRFA	$181	30	$ 5,430	142	$ 25,702	172	$ 31,132
SUBTOTAL			$ 69,098		$ 86,373		$155,471
ESCALATION		5%	$ 3,455	10%	$ 8,638	VAR	$ 12,093
TOTAL NATURAL MATERIALS ANALYTICAL RES. LAB.			$ 72,553		$ 95,011		$167,564

FUELS & MATERIALS RESEARCH LAB.	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
ASH DETERMINATION	$27	-	$ -	2	$ 54	2	$ 54
ASH FUSION	$203	6	$ 1,218	-	$ -	6	$ 1,218
BTU	$47	12	$ 564	7	$ 329	19	$ 893
CARBONATE ANALYSIS	$92	-	$ -	44	$ 4,048	44	$ 4,048
DRY SIEVE	$49	12	$ 588	29	$ 1,421	41	$ 2,009
MALVERN PART. SIZE	$53	-	$ -	39	$ 2,067	39	$ 2,067
MISCELLANEOUS	$76	-	$ -	10	$ 760	10	$ 760
MOISTURE %	$42	-	$ -	13	$ 546	13	$ 546
PROXIMATE ANALYSIS	$52	12	$ 624	7	$ 364	19	$ 988
SULFUR	$45	12	$ 540	7	$ 315	19	$ 855
SUBTOTAL			$ 3,534		$ 9,904		$ 13,438
ESCALATION		5%	$ 177	10%	$ 991	VAR	$ 1,168
TOTAL FUELS & MATERIALS RESEARCH LAB.			$ 3,711		$ 10,895		$ 14,606

ANALYTICAL RESEARCH LAB.	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
COAL DIGESTION	$145	6	$ 870	2	$ 290	8	$ 1,160
CVAA	$30	136	$ 4,080	192	$ 5,760	328	$ 9,840
FILTERING	$11	58	$ 638	54	$ 594	112	$ 1,232
GFAA	$40	679	$ 27,160	891	$ 35,640	1,570	$ 62,800
ICP	$37	-	$ -	300	$ 11,100	300	$ 11,100
LEACHING	$77	-	$ -	60	$ 4,620	60	$ 4,620
MIXED ACID DIGESTION	$51	52	$ 2,652	52	$ 2,652	104	$ 5,304
pH	$12	-	$ -	60	$ 720	60	$ 720
SUBTOTAL			$ 35,400		$ 61,376		$ 96,776
ESCALATION		5%	$ 1,770	10%	$ 6,137	VAR	$ 7,907
TOTAL ANALYTICAL RESEARCH LAB.			$ 37,170		$ 67,513		$104,683

TOTAL COMBUSTION TEST SERVICES			$ -		$ -		$ -

PARTICULATE ANALYSIS	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
EPA DUST LOADING	$210	-	$ -	30	$ 6,300	30	$ 6,300
MERCURY CEM (PER DAY)	$264	-	$ -	50	$ 13,200	50	$ 13,200
SUBTOTAL			$ -		$ 19,500		$ 19,500
ESCALATION		5%	$ -	10%	$ 1,950	VAR	$ 1,950
TOTAL PARTICULATE ANALYSIS			$ -		$ 21,450		$ 21,450

PROCESS CHEM. & DEV. LAB.	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
PREP/GC/CHN	$49	24	$ 1,176	19	$ 931	43	$ 2,107
TGA	$55	6	$ 330	2	$ 110	8	$ 440
SUBTOTAL			$ 1,506		$ 1,041		$ 2,547
ESCALATION		5%	$ 75	10%	$ 105	VAR	$ 180
TOTAL PROCESS CHEM. & DEV. LAB.			$ 1,581		$ 1,146		$ 2,727

FUEL PREP. & MAINTENANCE	**RATE/HR.**	#	**$COST**	#	**$COST**	#	**$COST**
FUEL PREP. AND MAINTENANCE	$18	160	$ 2,880	640	$ 11,520	800	$ 14,400
SUBTOTAL			$ 2,880		$ 11,520		$ 14,400
ESCALATION		5%	$ 144	10%	$ 1,152	VAR	$ 1,296
TOTAL FUEL PREP. & MAINTENANCE			$ 3,024		$ 12,672		$ 15,696

CONTINUOUS FLUIDIZED-BED REACTOR	**RATE/HR.**	#	**$COST**	#	**$COST**	#	**$COST**
CONTINUOUS FLUIDIZED-BED REACTOR	$36	400	$ 14,400	-	$ -	400	$ 14,400
TRDU / CARBONIZER	$114	-	$ -	400	$ 45,600	400	$ 45,600
SUBTOTAL			$ 14,400		$ 45,600		$ 60,000
ESCALATION		5%	$ 720	10%	$ 4,560	VAR	$ 5,280
TOTAL CONTINUOUS FLUIDIZED-BED REACTOR			$ 15,120		$ 50,160		$ 65,280

GRAPHICS SUPPORT	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
GRAPHICS (HOURLY)	$45	60	$ 2,700	208	$ 9,360	268	$ 12,060
SUBTOTAL			$ 2,700		$ 9,360		$ 12,060
ESCALATION		5%	$ 135	10%	$ 937	VAR	$ 1,072
TOTAL GRAPHICS SUPPORT			$ 2,835		$ 10,297		$ 13,132

SHOP & OPERATIONS SUPPORT	**RATE**	#	**$COST**	#	**$COST**	#	**$COST**
TECHNICAL DEVELOPMENT HOURS	$1.65	2,800	$ 4,620	2,900	$ 4,785	5,700	$ 9,405
SUBTOTAL			$ 4,620		$ 4,785		$ 9,405
ESCALATION		5%	$ 231	10%	$ 479	VAR	$ 710
TOTAL SHOP & OPERATIONS SUPPORT			$ 4,851		$ 5,264		$ 10,115

DETAILED BUDGET - TRAVEL

GASIFICATION OF LIGNITES TO PRODUCE LIQUID FUELS, HYDROGEN AND POWER
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RATES USED TO CALCULATE ESTIMATED TRAVEL EXPENSES

DESTINATION	ECON AIRFARE	LODGING	PER DIEM	CAR RENTAL	REGIST.
Dallas, TX	$ 900	$ 150	$ 51	$ 60	$ -
Morgantown, WV (via Pittsburgh, PA)	$ 1,200	$ 100	$ 39	$ 60	$ -
Pittsburgh, PA	$ 1,200	$ 150	$ 47	$ 60	$ 525

PURPOSE/DESTINATION	NUMBER OF TRIPS	NUMBER OF PEOPLE	NUMBER OF DAYS	AIRFARE	LODGING	PER DIEM	CAR RENTAL	MISC.	REGIST.	TOTAL
Kickoff meeting/Morgantown, WV (Pittsburgh, PA)	1	2	2	$ 2,400	$ 200	$ 156	$ 120	$ 80	$ -	$ 2,956
Intermediate Review/Dallas, TX	1	2	3	$ 1,800	$ 600	$ 306	$ 180	$ 120	$ -	$ 3,006
Final Review/Dallas, TX	1	3	3	$ 2,700	$ 900	$ 459	$ 180	$ 180	$ -	$ 4,419
Conference/Pittsburgh, PA	1	1	3	$ 1,200	$ 300	$ 141	$ 180	$ 60	$ 525	$ 2,406
TOTAL ESTIMATED TRAVEL -YEAR ONE										$ 12,787
Kickoff meeting/Morgantown, WV (Pittsburgh, PA)	1	2	2	$ 2,400	$ 200	$ 156	$ 120	$ 80	$ -	$ 2,956
Second Test Review/Dallas, TX	1	2	2	$ 1,800	$ 300	$ 204	$ 120	$ 80	$ -	$ 2,504
Final Review/Dallas, TX	1	3	2	$ 2,700	$ 450	$ 306	$ 120	$ 120	$ -	$ 3,696
Conference/Pittsburgh, PA	1	1	3	$ 1,200	$ 300	$ 141	$ 180	$ 60	$ 525	$ 2,406
TOTAL ESTIMATED TRAVEL -YEAR TWO										$ 11,562
TOTAL ESTIMATED TRAVEL - ALL YEARS										$ 24,349

DETAILED BUDGET - EQUIPMENT

Fabricated Equipment	$COST
Electric Heaters	$ 6,000
Differential pressure transmitters	$ 10,400
Temperature Controllers	$ 1,500
Mass flow controllers	$ 4,500
Data acquisition hardware and software	$ 6,000
Small pressurized feed system	$ 10,000
Lock hopper vessels and valves	$ 6,000
Pipe, flanges, tube fittings, valves, and miscellaneous	$ 20,600
TOTAL ESTIMATED EQUIPMENT - YEAR ONE	$ 65,000

BUDGET NOTES

ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

Background

The EERC is an independently organized multidisciplinary research center within the University of North Dakota (UND). The EERC receives no appropriated funding from the state of North Dakota and is funded through federal and nonfederal grants, contracts, or other agreements. Although the EERC is not affiliated with any one academic department, university academic faculty may participate in a project, depending on the scope of work and expertise required to perform the project.

The proposed work will be done on a cost-reimbursable basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, subcontracts) is for planning purposes only. The principal investigator may, as dictated by the needs of the work, reallocate the budget among approved items or use the funds for other items directly related to the project, subject only to staying within the total dollars authorized for the overall program. Escalation of labor and EERC fee rates is incorporated in the budget when a project's duration extends beyond the current fiscal year. Escalation is calculated by prorating an average annual increase over the anticipated life of the project. The current escalation rate of 5% is based on historical averages. The budget prepared for this proposal is based on a specific start date; this start date is indicated at the top of the EERC budget or identified in the body of the proposal. Please be aware that any delay in the start of this project may result in an increase in the budget.

Salaries and Fringe Benefits

As an interdisciplinary, multiprogram, and multiproject research center, the EERC employs an administrative staff to provide required services for various direct and indirect support functions. Direct project salary estimates are based on the scope of work and prior experience on projects of similar scope. Technical and administrative salary charges are based on direct hourly effort on the project. The labor rate used for specifically identified personnel is the current hourly rate for that individual. The labor category rate is the current average rate of a personnel group with a similar job description. For faculty, if the effort occurs during the academic year and crosses departmental lines, the salary will be in addition to the normal base salary. University policy allows faculty who perform work in addition to their academic contract to receive no more than 20% over the base salary. Costs for general support services such as grants and contracts administration, accounting, personnel, and purchasing and receiving, as well as clerical support of these functions, are included in the EERC facilities and administrative cost rate.

Fringe benefits are estimated on the basis of historical data. The fringe benefits actually charged consist of two components. The first component covers average vacation, holiday, and sick leave (VSL) for the EERC. This component is approved by the UND cognizant audit agency and charged as a percentage of direct labor for permanent staff employees eligible for VSL benefits. The second component covers actual expenses for items such as health, life, and unemployment insurance; social security matching; worker's compensation; and UND retirement contributions.

Travel

Travel is estimated on the basis of UND travel policies which can be found at: http://www.und.edu/dept/accounts/employeetravel.html. Estimates include General Services Administration (GSA) daily meal rates. Travel includes scheduled meetings and conference participation as indicated in the scope of work.

Communications (phones and postage)

Monthly telephone services and fax telephone lines are generally included in the facilities and administrative cost. Direct project cost includes line charges at remote locations, long-distance telephone, including fax-related long-distance calls; postage for regular, air, and express mail; and other data or document transportation costs.

Office (project-specific supplies)

General purpose office supplies (pencils, pens, paper clips, staples, Post-it notes, etc.) are provided through a central storeroom at no cost to individual projects. Budgeted project office supplies include items specifically related to the project; this includes duplicating and printing.

Data Processing

Data processing includes items such as site licenses and computer software.

Supplies

Supplies in this category include scientific supply items such as chemicals, gases, glassware, and/or other project items such as nuts, bolts, and piping necessary for pilot plant operations. Other items also included are supplies such as computer disks, computer paper, memory chips, toner cartridges, maps, and other organizational materials required to complete the project.

Instructional/Research

This category includes subscriptions, books, and reference materials necessary to the project.

Fees

Laboratory, analytical, graphics, and shop/operation fees are established and approved at the beginning of the university's fiscal year.

Laboratory and analytical fees are charged on a per sample, hourly, or daily rate, depending on the analytical services performed. Additionally, laboratory analyses may be performed outside the University when necessary.

Graphics fees are based on an established per hour rate for overall graphics production such as report figures, posters for poster sessions, standard word or table slides, simple maps, schematic slides, desktop publishing, photographs, and printing or copying.

Shop and operation fees are for expenses directly associated with the operation of the pilot plant facility. These fees cover such items as training, safety (protective eye glasses, boots, gloves), and physicals for pilot plant and shop personnel.

General

Freight expenditures generally occur for outgoing items and field sample shipments.

Membership fees (if included) are for memberships in technical areas directly related to work on this project. Technical journals and newsletters received as a result of a membership are used throughout development and execution of the project as well as by the research team directly involved in project activity.

General expenditures for project meetings, workshops, and conferences where the primary purpose is dissemination of technical information may include costs of food (some of which may exceed the institutional limit), transportation, rental of facilities, and other items incidental to such meetings or conferences.

Facilities and Administrative Cost

The facilities and administrative rate (indirect cost rate) included in this proposal is the rate that became effective July 1, 2005. Facilities and administrative cost is calculated on modified total direct costs (MTDC). MTDC is defined as total direct costs less individual items of equipment in excess of $5000 and subcontracts/subgrants in excess of the first $25,000 for each award.

APPENDIX C

RESUMES OF KEY PERSONNEL

DR. STEVEN A. BENSON
Senior Research Manager/Advisor
Energy & Environmental Research Center (EERC)
University of North Dakota (UND)
PO Box 9018, Grand Forks, ND 58202-9018 USA
Phone (701) 777-5000 Fax (701) 777-5181
E-Mail: sbenson@undeerc.org

Principal Areas of Expertise
Development and management of complex multidisciplinary programs focused on solving environmental and energy problems, including 1) technologies to improve the performance of combustion/gasification and associated air pollution control systems; 2) transformations and control of air toxic substances in combustion and gasification systems; 3) advanced analytical techniques to measure the chemical and physical transformations of inorganic species in gases; 4) computer-based models to predict the emissions and fate of pollutants from combustion and gasification systems; 5) advanced materials for power systems; 6) impacts of power system emissions on the environment; 7) national and international conferences and training programs; and 8) state and national environmental policy.

Qualifications
Ph.D., Fuel Science, Materials Science and Engineering, The Pennsylvania State University, 1987.
B.S., Chemistry, Moorhead State University (Minnesota), 1977.

Professional Experience
1999 – Senior Research Manager/Advisor, EERC, UND. Dr. Benson is responsible for leading a group of about 30 highly specialized scientists and engineers whose aim is to develop and conduct projects and programs on power plant performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide. Efforts have focused on the development of multiclient jointly sponsored centers or consortia that are funded by a combination of government and industry sources. Current research activities include computer modeling of combustion and environmental control systems, performance of selective catalytic reduction technologies for NO_x control, carbon-based NO_x reduction technologies, mercury control technologies, particulate matter analysis and source apportionment, the fate of mercury in the environment, toxicology of particulate matter, and in vivo studies of mercury-selenium interactions. The computer-based modeling efforts utilize various kinetic, thermodynamic, artificial neural network, statistical, computation fluid dynamics, and atmospheric dispersion models. These models are used in combination with models developed at the EERC to predict the impacts of fuel properties and system operating conditions on system efficiency and emissions. Dr. Benson is Program Area Manager for Modeling and Database Development for the U.S. Environmental Protection Agency (EPA) Center for Air Toxic Metals® (CATM®) at the EERC. He is responsible for identifying research opportunities and preparing proposals and reports for clients.

1994 – 1999 Associate Director for Research, EERC, UND. Dr. Benson was responsible for the direction and management of programs related to integrated energy and environmental systems development. Dr. Benson led a team of over 45 scientists, engineers, and technicians. In addition, faculty members and graduate students from Chemical Engineering, Chemistry, Geology, and Atmospheric Sciences have been involved in conducting research projects. The research, development, and demonstration programs involve fuel quality effects on power system performance, advanced power systems development/demonstration, computational modeling, advanced materials for power systems, and analytical methods for the characterization of materials. Specific areas of focus included the development and direction of EPA CATM at the EERC (CATM, a peer-reviewed, EPA-designated Center of Excellence, is currently in its 12th year of operation and has received funding of over $12,000,000 from government and industry sources), ash behavior in combustion and gasification systems, hot-gas cleanup, and analytical methods of analysis. He was responsible for the identification of research opportunities and the preparation of proposals and reports for clients. Dr. Benson left this position to focus efforts on Microbeam Technologies' Small Business Innovation Research (SBIR).

1986 – 1994 Senior Research Manager, Fuels and Materials Science, EERC, UND. Dr. Benson was responsible for management and supervision of research on the behavior of inorganic constituents, including air toxic metals during combustion and gasification, hot-gas cleanup (particulate gas-phase species control), fundamental combustion, and analytical methods of inorganic analysis, including SEM and microprobe analysis, Auger, XPS, SIMS, XRD, and XRF. Responsible for identification of research opportunities, preparation of proposals and reports for clients, and publication.

1989 – 1991 Assistant Professor (part-time), Department of Geology and Geological Engineering, UND. Dr. Benson was responsible for teaching courses on coal geochemistry, coal ash behavior in combustion and gasification systems, and analytical methods of materials analysis. Taught courses on SEM/microprobe analysis and mineral transformations during coal combustion.

1984 – 1986 Graduate Research Assistant, Fuel Science Program, Department of Materials Science and Engineering, The Pennsylvania State University.

1983 – 1984 Research Supervisor, Distribution of Inorganics and Geochemistry, Coal Science Division, UND Energy Research Center. Dr. Benson was responsible for management and supervision of research on the distribution of major, minor, and trace inorganic constituents and geochemistry of coals and ash chemistry related to inorganic constituents and mineral interactions and transformations during coal combustion and environmental control systems.

1980 – 1983 Research Chemist, U.S. Department of Energy (DOE) Grand Forks Energy Technology Center. Dr. Benson performed research on surface and/or chemical analysis and characterization of coal-derived materials by SEM, XRF, and thermal analysis in support of projects involving SO_x, NO_x, and particulate control; ash deposition; heavy metals in combustion systems; coal gasification; and fluidized-bed combustion.

1979 – 1980 Research Chemist, DOE Grand Forks Energy Technology Center. Dr. Benson performed research on the application of such techniques as differential thermal analysis, differential scanning calorimetry, thermogravimetric analysis, and energy-dispersive XRF analysis with application to low-rank coals and coal process-related material. In addition, research was performed on the use of x-ray analysis to measure trace elements in fuels and conversion products.

1977 – 1979 Chemist, DOE Grand Forks Energy Technology Center. Dr. Benson performed analysis on coal and coal derivatives by techniques such as wavelength-dispersive x-ray analysis, argon plasma spectrometry, atomic absorption spectrometry, thermal analysis, and elemental analysis (CHN).

1976 – 1977 Teaching Assistant, Department of Chemistry, Moorhead State University.

Professional Memberships and Activities

United States Senate Committee on the Environment and Public Works

- ► One of three technical panelists invited to provide testimony on mercury control for the coal-fired power industry.
- ► American Chemical Society (ACS)
  - Chair – Fuel Division 2004 – Duties comprise coordinating all aspects of the division, including publications and national conferences.
  - Fuel Division – Participates on the Executive Committee involved in the coordination and direction of division activities, including outreach, programming, finances, and publications.
  - Councilor, Fuel Division – Represents the Fuel Division at the National ACS Council meeting.
  - Chair Elect, Fuel Division – August 2002 – Elected to be Chair of the Fuel Division.
  - Member, Committee on Environmental Improvement (CEI) – The committee provides advice and direction to the ACS governance on policies and programs related to the environment. Since becoming a member of the committee, we have developed policy statements on Global Climate Change, Reformulated Gasoline and MtBE, and Energy Policy. These policy statements are used to assist legislators in developing national environmental policy. Members of CEI also provide testimony on a variety of environmental issues.
- ► American Society for Mechanical Engineers (ASME)
  - Advisory Member, ASME Committee on Corrosion and Deposition Resulting from Impurities in Gas Streams. Developed several conferences through the International Engineering Foundation.

- ► Mercury Reduction Initiative – Minnesota Pollution Control Agency (MPCA)
  - Participated in meetings for the mercury reduction initiative and provided advice regarding mercury control technologies for electric utilities and MPCA for voluntary mercury reduction strategies.
- ► Elsevier Science, *Fuel Processing Technology*
  - Editorial board member whose role is to provide advice and direction for the journal.

Publications and Presentations

- Has authored/coauthored over 210 publications and is the editor of eight books and *Fuel Processing Technology* special issues.

DR. MICHAEL L. JONES
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Principal Areas of Expertise

Dr. Jones' principal areas of interest and expertise include management of and technical direction for multidisciplinary science and engineering research teams focused on a wide range of integrated energy and environmental technologies. Specific program areas of interest include clean and efficient combustion of low-rank fuels, matching of fuel characteristics to system design and operating parameters, development of advanced power systems based on low-rank fuels, fundamentals of combustion, ash deposition in combustion systems, and analysis of inorganic materials. Projects emphasize a cradle-to-grave approach from resource assessment, to optimum utilization systems, to minimization of emissions and waste management featuring by-product utilization.

Qualifications

Ph.D., Physics, University of North Dakota, 1978.
M.S., Physics, University of North Dakota, 1973.
B.S., Physics, Bemidji State University (Minnesota), 1971.

Professional Experience

1994 – Adjunct Assistant Professor, Physics, UND.

1983 – Associate Director, Industrial Relations and Technology Commercialization, EERC, UND. Dr. Jones' responsibilities include planning, staffing, and technical direction of combustion research, including projects in combustion chemistry, ash fouling and slagging, fluidized-bed combustion, coal–water fuels combustion, SO_x/NO_x removal, and particulate removal and characterization. Special emphasis is given to low-rank coal systems; activities range from field testing of full-scale power plants to pilot-scale studies and laboratory investigations that examine both fuel and system characteristics and their impact on overall performance.

1990 – Adjunct Professor, Department of Chemical Engineering, The University of Utah, Salt Lake City, Utah.

1979 – 1983 Grand Forks Energy Technology Center, U.S. Department of Energy. Dr. Jones' responsibilities included technical direction of research and development projects related to combustion technology for low-rank coals, with specific responsibility for fundamental research on pulverized coal combustion. Directed research on new, specialized analytical procedures for determination of inorganics and trace elements in coal and materials derived from coal combustion and conversion processes. Instrumentation included methods Auger/ESCA spectrometer, scanning electron microscope, x-ray diffraction, x-ray fluorescence, argon plasma spectrometer, and atomic absorption spectrometer.

Professional Memberships

- Adjunct Membership, Graduate Faculty, University of North Dakota, 1994
- Chair, ASME Research Committee on Corrosion and Deposits from Combustion Gases
- Utility Advisory Task Force for DOE-FE Study on RCRA Impact on Coal-Fired Utilities
- Sigma Xi – The Scientific Research Society
- Society for Applied Spectroscopy
- The Combustion Institute
- North Dakota Academy of Science

Publications and Presentations

- Has authored or coauthored over 80 publications

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Principal Areas of Expertise

Dr. Swanson's principal areas of interest and expertise include pressurized fluidized-bed combustion (PFBC), integrated gasification combined cycle (IGCC), hot-gas cleanup, coal reactivity in low-rank coal (LRC) combustion, supercritical solvent extraction, and liquefaction of LRCs.

Qualifications

Ph.D., Energy Engineering, University of North Dakota, 2000. Dissertation: Modeling of Ash Properties in Advanced Coal-Based Power Systems.
M.B.A., University of North Dakota, 1991.
M.S., Chemical Engineering, University of North Dakota, 1982.
B.S., Chemical Engineering, University of North Dakota, 1981.

Professional Experience

1999 – Senior Research Manager, EERC, UND. Dr. Swanson is currently involved with the demonstration of advanced power systems such as PFBC and IGCC, with an emphasis on hot-gas cleanup issues.

1997 – 1999 Research Manager, EERC, UND.

1990 – 1997 Research Engineer, EERC, UND.

1986 – 1990 Dr. Swanson supervised a contract with the U.S. Department of Energy (DOE) to investigate the utilization of coal–water fuels in gas turbines. He has designed, constructed, and operated research projects that evaluated the higher reactivity of LRCs in short-residence-time gas turbines and diesel engines.

1983 – 1986 Dr. Swanson's responsibilities included the design, construction, and operation of supercritical fluid extraction (SFE) and coal liquefaction apparatus; characterization of the resulting organic liquids and carbonaceous chars; and preparation of reports.

1982 – 1983 Associated Western Universities (AWU) Postgraduate Fellowship, DOE Grand Forks Energy Technology Center. Dr. Swanson's responsibilities included the design and construction of a SFE apparatus.

1981 – 1982 Graduate Teaching Assistant, Department of Chemical Engineering, UND.

Summer 1982 Research Assistant, Department of Civil Engineering, UND.

1980 – 1981 AWU Student Participant, DOE Grand Forks Energy Technology Center.

Professional Memberships

- American Institute of Chemical Engineers
- American Chemical Society, Fuel Chemistry Division

Publications and Presentations

- Has authored or coauthored over 70 publications

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Principal Areas of Expertise

Dr. Yan's principal areas of interest and expertise include coal mineral characterization techniques, ash-related issues in power plant boilers, circulating fluidized-bed combustion and gasification, and energy system analysis and management. In particular, Dr. Yan has accumulated over 10 years of experience in modeling studies on various aspects of coal utilization.

Qualifications

Ph.D., Chemical Engineering, University of Newcastle, Australia, 2000.
M.E., Thermal Engineering, Tsinghua University, Beijing, China, 1993.
B.E., Thermal Engineering, Tsinghua University, Beijing, China, 1990.

Professional Experience

2001 – Research Engineer, EERC, UND. Dr. Yan is principally involved in computational analysis of fuel characteristics in power plants and environmental impacts. Specifically, he has been working on ash deposition; SO_3 removal in air preheaters; mercury speciation, emissions, and control; computational fluid dynamics modeling; advanced coal characterization techniques; and spray dryer absorbers. He devised a number of mechanistic models dealing with ash formation, ash slagging on furnace walls, SO_3 (sulfuric acid) condensation and nucleation, and mercury kinetic transformations.

2000 – 2001 Postdoctoral Research Associate, Department of Chemical Engineering, University of Newcastle. Dr. Yan participated in Black Coal CRC Projects on computer-controlled scanning electron microscopy and image analysis of coal minerals and Ash Effects Predictor for pulverized fuel-fired boilers, including refining and incorporating an advanced ash formation model into the Ash Effects Predictor, modeling ash deposition on the tube surface under cross-flow conditions, and collaborating with CSIRO to develop QEM*Scan for coal minerals and trace element analysis.

1993 – 1996 Research Associate, Institute for Techno-Economics and Energy System Analysis, Tsinghua University. Dr. Yan was involved in the following projects:

- China Climate Change Country Study Project, Element III – Technology Selection for Mitigation of Greenhouse Gas Emissions (funded by U.S. Department of Energy) – comprehensive assessment of advanced and clean coal technologies for power generation in China.

- A Case Study of Electrical Power System: Application of Integrated Resources Planning and Demand Side Management on Liaoning Provincial Power Grid (supported by International Energy Initiative [IEI]) – designed and managed subprojects based on the DEFENDUS methodology from IEI and complemented with demand-side management.

- Development of Energy Efficient and Environmentally Sound Industrial Technologies in Asia – case study on energy efficiency and environmental impacts from the pulp and paper industry in China.

- Integrated Resources (Energy) Planning for China by 2020 (sponsored by Asia-Pacific Development Centre) – methodology development and national electricity demand/supply analysis.

- Strategies of Reasonable Utilization of Energy in Developing Countries (Second Phase) – Case Study of Cogeneration (Combined Heat and Power) in China: Evaluation and Prospects (sponsored by the European Community) – expert consulting and data collection, analysis, and presentation.

- Energy Demand Forecast for China by the Year 2050 (funded by the former Energy Department of China) – energy consumption forecast in the coal mining industry, based on business as usual scenario and least-cost planning.

Professional Memberships

- Combustion Institute of Australia
- Australian Institute of Energy
- Energy Research Society of China

Publications and Presentations

- Has authored or coauthored numerous publications