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May 29, 2009

Ms. Karlene Fine
North Dakota Industrial Commission
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

The Department of Chemical Engineering, under the direction of and with the full support of President Robert Kelley is happy to present the attached proposal for consideration by the North Dakota Industrial Commission. The key deliverable for the project is a preliminary design and cost for a clean and efficient power system to produce steam and electricity for the University of North Dakota campus using technologies specifically designed for North Dakota lignite. In addition, the ability to utilize the power system platform for education and testing will be evaluated. It is anticipated that results will be translatable to other entities within the North Dakota system.

Any technical questions regarding the proposed effort can be directed to Dr. Steve Benson at 701-777-5177 or at stevebenson@mail.und.edu. Administrative questions can be directed to our Office of Research, Development, and Compliance at 701-777-4278 or rdc@mail.und.edu.

Sincerely

Michael D. Mann
Professor and Chair
Department of Chemical Engineering

John LaDuke
Associate Vice President for Research
Research, Development, and Compliance

ADVANCED POWER SYSTEMS INITIATIVE: LIGNITE FEASIBILITY STUDY

Submitted to:

Ms. Karlene Fine
North Dakota Industrial Commission
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Proposal Amount: $400,000

Submitted by:

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May 29, 2009

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ABSTRACT

The overall goal of this project is to determine the feasibility of constructing a clean advanced lignite-fired power system to produce steam and electricity for the University of North Dakota (UND) campus, and to provide a platform for educating next generation of energy experts and to test emerging energy technologies of interest to the lignite industry. The specific objectives include: 1) assess future steam, electricity, energy education, and testing needs; 2) identify key challenges related to lignite utilization that impact system design and performance; 3) review and identify energy conversion and emission control technology options for lignite for producing steam and electricity for the UND campus; 4) develop preliminary design and costs for selected technology options, and 5) recommend most promising systems and outline next steps in developing the UND campus cogeneration plant.

The key deliverable for the project is a preliminary design and cost for a clean and efficient power system to produce steam and electricity for the University of North Dakota campus using technologies specifically designed for North Dakota lignite. Another deliverable is the development of a framework or roadmap for utilizing the power system platform for education and for testing new technologies related to energy, the environment, and the use of indigenous North Dakota lignite. The results of the work will be incorporated into a final report that will be used to determine the feasibility of an advanced power systems initiative at UND.

The team assembled to conduct the project includes UND Campus Planning, UND Department of Chemical Engineering, Envergex LLC, and an Architect & Engineering (A&E) firm. The proposed project will be initiated upon approval of the project by the NDIC. It is anticipated that the proposed work will be carried out over 12 months with a start date of approximately August 1, 2009. The total cost of the project is $400,000.

PROJECT SUMMARY

The steam generators used to produce steam for district heating at the University of North Dakota (UND) are aging and in need of replacement. The overall goal of this project is to determine the feasibility of constructing a clean advanced lignite-fired power system to produce steam and electricity for the UND campus while providing opportunities to educate the next generation of energy experts and to test emerging energy technologies of interest to the lignite industry. The specific objectives include the following: 1) assess future steam, electricity, energy education, and testing needs for the lignite industry; 2) identify key challenges related to lignite utilization that impact system design and performance; 3) review and identify energy conversion and emission control technology options for lignite for producing steam and electricity for the UND campus; 4) develop preliminary design and costs for selected technology options; and 5) recommend most promising systems and outline next steps in developing the UND campus cogeneration energy plant.

Lignite coal is an abundant domestic energy resource with significant reserves. The primary use for North Dakota lignite is mine-mouth electrical power plants, which generate some of the lowest-cost electricity in the United States. However, future environmental regulations will require cost-effective control of mercury and carbon dioxide in addition to control of currently regulated pollutants, including nitrogen oxides, sulfur oxides, and particulates. These new environmental regulations pose a tremendous challenge for both new and existing power plants. In addition, integrating highly efficient lignite-fired systems with renewable and carbon-free resources such as wind, biomass, and geothermal, combined with some degree of carbon capture and sequestration, will be the key to decreasing carbon dioxide emissions.

Lignite coal because of its unique chemical and physical properties presents both challenges and opportunities for efficient utilization. Lignite coals, as well as most biomass, have high moisture and ash containing high levels of alkali and alkaline-earth components. This combination can present challenges to efficient utilization, if the system is not designed properly. On the other hand, lignite is highly reactive and has high conversion efficiencies in combustion and gasification systems. Further, the alkali- and

alkaline-earth-rich ash captures sulfur and other gas-phase species within the conversion and gas cleanup systems. Most power and air pollution control equipment vendors do not appreciate the unique properties of lignite and apply design criteria developed for subbituminous and bituminous coals that are not completely appropriate.

The current energy system at UND consists of three coal-fired stoker boilers that supply heated steam heat to well over six million square feet of space through fourteen miles of direct buried steam lines. The boilers can provide up to 231,000 lb/hr of steam. The amount of coal fired in 2008 was about 56,000 tons. The campus used about 76 million KWH of electricity in 2008, which was supplied from the electrical grid. The University has backup electric generators and backup gas/oil-fired boilers to provide steam. The new system will target supply of both the electricity and steam needs of the campus, with likely some export of electricity to the grid.

The team assembled to conduct the project includes UND Campus Planning, UND Department of Chemical Engineering, Envergex LLC, and an Architect and Engineering (A&E) firm. The total cost of the project is $400,000.

PROJECT DESCRIPTION

Goals and Objectives

The goal of this project is to determine the feasibility of constructing a clean advanced lignite-fired power system to produce steam and electricity for the UND campus while providing opportunities for education, research, and development and testing of new and innovative energy-related technologies for lignite utilization. The objectives include 1) perform an assessment of future steam, electricity, and energy education needs for UND and determine synergistic research and development infrastructure that can be used to provide benefit to the lignite industry; 2) identify key technological barriers related to lignite utilization; 3) review and identify energy conversion and emission control technology options for lignite for producing steam and electricity for the UND campus; 4) develop preliminary design and costs for selected technology options; and 5) recommend the most feasible systems and .outline next steps in developing the UND campus cogeneration energy plant.

Work Plan

Task 1. Assessment of Future Energy and Education Needs

To properly evaluate options for a new cogeneration system the needs of the campus must be fully understood. This includes both the physical requirements (steam and electricity) and the intellectual needs (research and education). Task 1 will provide the framework for the preliminary feasibility design.

A. Description of Current System

The current steam generating system at the University of North Dakota will be described and key data will be obtained as to load demand, operations, performance, and emissions. This system will be compared to other steam plants in the North Dakota University System and other state operated facilities to ensure that the information generated as part of this study will have benefit to other institution considering updating their energy supplies. .

B. Projected Steam and Electric Power Needs

The current steam requirements and usage trends for district heating and campus electrical will be compiled and analyzed to estimate future needs. This information will be used to help size the new plant.

C. Projected Education and Research Needs

UND is moving forward with programs and curriculum to provide relevant educational opportunities for the next generation of energy experts. UND is also conducting work to overcome key barriers in energy generation using the state's abundant lignite resource, while mitigating concomitant environmental impact. This is being achieved through the development of new information and emerging technologies that are derived from both basic and applied research programs at the University targeting lignite utilization. With respect to this program, the work scope will include a review of the key challenges and barriers to the efficient and reliable use of lignite, and will translate the challenges into research and testing needs. Testing capabilities will be integrated into the design criteria for the system to allow future research to more fully address these barrier issues. Examples of testing capabilities may include supercritical and ultra supercritical steam loops for materials testing with application to ultra-high efficiency steam power plants, oxy-firing, and flue gas slipstreams to examine gas cleaning and CO_2-separation technologies.

Task 2. Overview of Past Experience Utilizing Lignite

The primary purpose of this task is to determine the current state-of-the-art for the utilization of lignite. This information will be used in Task 3 to identify system options to be considered for implementation into the detailed design of the new steam plant.

A. Lignite Properties

Lignite properties must be considered in the designing an efficient and reliable energy generation systems. The primary properties that will impact the design of any future system will be identified and categorized to ensure they are considered when optimizing future designs. The factors that will be examined include: moisture, reactivity, sulfur content, ash behavior, regulated emissions, and mercury and CO_2. Lignite coals have high levels of moisture, which contributes to their low heating value. Moisture reduction of the feed coal prior to firing, using waste or low-grade heat, can deliver higher system efficiency. Moisture reduction will also decrease the gas flow from the energy conversion devices increasing throughput for a given size of plant. Reactivity of lignite is high and provides opportunity for high carbon conversion in gasification and combustion systems at lower peak temperatures. The sulfur content of North Dakota lignite is higher than subbituminous coals from neighboring Montana and Wyoming, and would benefit from further reduction. Ash in lignite is typically high in alkali and alkaline-earth elements that can result in low fusion temperatures and high sulfation potential that can cause slagging and fouling of heat transfer surfaces as well as bed agglomeration in fluid-bed boilers. High mercury removals are possible with low sorbent consumption using enhanced activated carbons for lignite coals. Carbon dioxide production is higher as a result of lower heating value and resulting decreases in efficiency. Technologies must be considered that will take advantage of lignite's unique properties and the potential for CO_2 utilization and sequestration in North Dakota.

B. Beneficiation Systems

A review of beneficiation systems to remove moisture, ash-forming components, and sulfur as applied to lignite will be examined. The properties of potential beneficiated products will be evaluated to determine if additional storage and handling systems will be required; for example, storage for a briquette versus dried coal.

Moisture reduction for lignite coal is very challenging for lignite because of the reactivity and friability of the dried lignite product. The dried lignites are prone to spontaneously ignite and create hard-to-handle dusty materials. Several technologies will be reviewed including fluidized-bed or indirect dryers (similar to that used at Great River Energy's Coal Creek station), flash drying (technology offered by White Coal Pty., Australia), and compaction. Compaction has the potential to addresses the "reactive" nature of dried lignite. The compaction process results in the formation of a briquette with collapsed pores, with reduced moisture re-adsorption potential and reactivity to oxygen. Another potential advantage is that biomass may be incorporated with the coal during the drying and briquetting process.

In addition to drying, lignite beneficiation processes for ash and sulfur reduction will also be reviewed. Consideration will be given to the form of the mineral and organic forms of the ash forming components in the coal, when applying methods of removing or modifying the form of the inorganic ash-forming species. Air jigs offer methods to remove the mineral components and associated sulfur from the coal (Laumb and others, 2007). The organically associated alkali and alkaline-earth elements require alternative methods of modification to minimize their impact on the performance of combustion and gasification systems.

C. Combustion Systems

1. Pulverized Fuel-Fired Combustion

Pulverized coal combustion systems have been successfully applied to utilize lignite from the Northern Great Plains. The performance and maintenance experience of these systems will be reviewed. Surveys of plant performance have been conducted by Selle (1986). The survey information included furnace sizing and convective pass tube spacing to accommodate the characteristics of lignite. This information will be updated through discussion with the utility industry and boiler vendors. The key elements for boiler design to accommodate lignite firing will include: 1) increased residence time and heat extraction in the water-wall section to reduce furnace exit-gas temperatures (net plant heat input per plan area), 2) aggressive soot-blowing, 3) heat transfer tubes – no extended surfaces, and 4) adequate inter-surface spacing to prevent bridging and provide access for cleaning.

Steam conditions, including subcritical or supercritical, will be examined. The capability for including test sections for ultrasupercritical boiler heat transfer surfaces will be evaluated.

2. Fluidized-Bed Combustion

Fluidized-bed combustion technologies, including circulating fluidized-bed (CFB), will be evaluated as a potential combustion system for the UND Steam plant. CFB technology has the combined benefit of reducing emissions and the potential to increase fuel flexibility. CFBs are operated at 1500° to 1700°F bed temperatures that result in lower NOx production compared to pulverized coal firing, and provide in-furnace SO_2 control (up to 90%) when utilizing a limestone bed along with the inherent alkali and alkaline-earth components of the ash. Selective noncatalytic reduction (SNCR) can be used to further reduce NOx emissions. CFB can utilize a wide range of fuel types and can easily incorporate biomass.

One of the main drawbacks of CFB is bed agglomeration and ash deposition when firing lignite coals and biomass that have high levels of alkali elements (sodium and potassium). This requires utilization of bed materials that are not prone to agglomeration and heat transfer tube spacing and soot-blowing that will mitigate ash deposition on convective pass surfaces.

Oxy-firing (use of pure O_2 for combustion), for a portion of the overall combustion system, will be evaluated for consideration, as it is one of the strategies that is emerging for coal-fired power boilers. At a minimum, a test loop with oxy-firing will likely be included in the overall design.

D. Gasification and Combined Cycle

Gasification systems will be evaluated for their potential application for the UND Steam Plant. Much of this evaluation is currently underway and will be published in late 2009 (Benson and Sondreal, 2009). The technologies are categorized as entrained-flow, fixed-bed, fluidized-bed, or transport reactor systems and then further classified by their use of either dry or slurry coal feed and either dry-ash or slag discharge. Both air-blown and oxygen blown systems will be reviewed. The selection of an optimum design depends on the effect of coal properties on the operation of the gasifier and the desired gas exit conditions in relation to downstream process conditions. We will examine the use of syngas in combined cycle as well as directing the syngas to a steam power boiler. The use of a gasifier may also offer advantages to incorporate biomass co-firing.

E. Gas Cleanup Systems

1. Particulate Control

Particulate control systems will be evaluated for their ability to remove the particulate characteristics of the fly ash produced from lignitic coal. Lignites produce a multimodal size distribution of particulate with super- and submicrometer modes. The use of electrostatic precipitation and fabric filters will be evaluated along with technologies used to enhance the performance of these devices such as acoustic agglomeration. Efforts will be aimed at identifying the optimum system capable of high removal efficiencies combined with low operation and maintenance costs.

2. Sulfur Control

Both wet and dry scrubbers will be evaluated. Measures to better utilize the alkali and alkaline-earth-rich ash derived from lignite to capture SO_2 will be considered.

3. NOx Control

NOx control strategies, including combustion control (low-NOx burners and overfire air), selective non-catalytic reduction (SNCR), and selective catalytic reduction (SCR) technologies, will be evaluated. High-dust SCR technologies for lignite firing have shown that they are prone to plugging and blinding (Benson and others, 2005). Evaluation of low-dust and tail-end SCR installation will also be conducted.

4. Mercury Control

Mercury emission control technologies will be examined. Sorbent injection (activated carbon-based) utilizing enhanced activated carbons will be evaluated and compared to other methods such as oxidation and removal via flue gas desulfurization scrubbers. Much of this review for lignite-fired systems has been evaluated by Benson (2007).

5. Carbon Dioxide Reduction

There are three primary methods for reducing CO_2 emissions from coal-based energy systems: 1) increasing coal-to-electric power conversion efficiency, 2) capturing and sequestering the emitted CO_2 emitted from the fossil fuel conversion, and 3) utilizing renewable fuel resources. Integrating efficient carbon capture with IGCC technologies leverages both of the first two methods and represents an attractive future generation strategy for coal-based power systems. Method 3 involves the integration of renewable energy resources such as wind, solar, and the use of biomass as a fuel. Currently commercial or near-commercial CO_2 separation systems will be reviewed for potential inclusion in the flue gas cleanup train. At a minimum, test loops of one or more CO_2 separation technologies will likely be included as part of the overall design.

Task 3. Identification of System Options for Evaluation

In this task, we will prepare a Request for Proposal to be sent to several A&E firms. The selected A&E firm will work with the project team in the following task to support the selection of the core technology to be used for the campus cogeneration plant. In Task 4, the A&E firm will perform preliminary engineering and develop budget costs for the selected approach.

A. Preliminary System Performance Criteria

The information developed in Tasks 1 and 2 will be used to develop a set of criteria for selection of the technologies to be included in the request for proposals to the A&E firms. The criteria will be developed as follows:

1. Evaluate Conversion System Options

The conversion system options (for example, combustion versus gasification; pulverized coal firing versus fluidized bed; steam boiler versus combined cycle) to be further evaluated will be based on the past experience of commercial availability of system, and system efficiency, reliability, and maintenance requirements when firing lignite coals. In addition, vendors will be contacted to discuss improvements made to accommodate the unique properties of lignite. Ranking criteria will be based on past experience (performance, reliability, and maintenance costs), vendor input on improvements, guarantees, and cost.

2. Evaluate Gas Cleanup System Options

Criteria for selecting options for gas cleanup systems will be based on compatibility with the conversion system options selected. The ability to exceed current emissions standards and be compatible with CO_2 separation and capture technologies will be part of the criteria.

3. Evaluate Potential Education and Research Opportunities

The potential to integrate a research and education platform into the basic cogeneration plant will be evaluated. This platform would be used to educate the next generation of energy experts and also to provide a unique opportunity to test emerging technologies while producing steam and electricity for UND. It is envisioned that the cogeneration plant will consist of a core technology to produce steam and electricity with options to facilitate conducting research and testing. The core technology will provide a clean and uninterrupted source of steam and electricity for the UND campus. In so doing, the core system will provide continuous operations for conducting on-line measurements, advanced control system testing, and operations training. The core system will provide the critical infrastructure and stability required to support the research and testing systems proposed in this initiative. We anticipate that the research and testing platform will ultimately include laboratory space along with auxiliary systems for testing of new energy innovations of interest to the lignite industry. This work would be conducted by faculty, students, and post-doctoral associates in cooperation with industry and government.

The overall evaluation criteria in this task for selection of the core technology will include the lignite industry's interest in the core technology, the ability to integrate testing of emerging technologies associated with the core technology, the potential for advancing the state of knowledge on efficient lignite utilization, and the ability of the core technology to provide educational opportunities for faculty, students, post doctoral researchers, and industry partners.

B. Core Technology and Options Description

Because the proposed cogeneration system will be retrofitted into the existing steam plant, understanding the implementation of the various technology options within the constraints of tying it to the existing facility is of paramount importance. Elements of these constraints include 1) the electrical and thermal interconnections between the new cogeneration plant and the existing energy system, 2) specific site data for plant location, 3) aesthetic and environmental concerns, 4) location of water supply and liquid discharge facilities, 5) site access and storage for plant inputs (especially coal and biomass), and 6) size of proposed plant and space available. The overall process options, including those for lignite beneficiation, lignite-to-energy conversion, flue gas cleanup, and the incorporation of education and testing capabilities, will be selected from the data developed in the previous items of this task.

For each option being considered, data will be reviewed for the following items:

a. Net power and useful thermal input

b. Fuel consumption

c. Preliminary capital cost including modification and tie-in with site and utility interfaces

d. Operating and maintenance costs

e. Technical risk and system reliability

f. Availability and reliability of fuel supply (biomass)

g. Emission profile (e.g., NOx, SO_2, particulate, CO_2, Hg)

h. Standby charges

i. Environmental impact and permitting risk

These data will be reviewed by the project team, including the A&E firm along with the university review panel, and a decision will be made as to the best process and system for the UND campus.

Task 4. Preliminary Design and Costs for Selected Technology Options

Based on the selected core technology and options, a detailed description of the cogeneration plant will be prepared including a discussion of each major component. This description will include equipment performance characteristics, technical specifications, and operating interfaces. The work will be performed mainly by the A&E firm selected in Task 3. The preliminary engineering will include the following outputs:

a. Process flow diagrams

b. Heat and mass balances; water balances

c. Equipment list and preferred/possible vendors list

d. Site plan indicating the preferred location and utility and site interconnections

e. Facility arrangements to establish space requirements

f. Operational strategy (start-up, shutdown, emergency, load following, back-up)

g. Budget costs estimates for total project based on cost quotations from suppliers

h. O&M requirements

i. Emissions – air, water, solid

j. Project implementation schedule and key milestones

Task 5. Project Management and Reporting

The following activities will track progress and document the results of this work,

a. Meetings/conference calls to discuss all results, conclusions, and recommendations. These will be made at a minimum on a monthly basis during the course of the project.

b. Selection of an engineering firm to assist with Tasks 3 and 4. This will be made through the University of North Dakota system. Standard procedures will be followed to identify and select the A&E firm. Funding of $125,000 has been allocated for the engineering effort.

c. Writing and submission of draft task reports will be submitted in accordance with the project schedule.

d. Writing and submission of a Final report to project sponsors.

DELIVERABLES

The key deliverables will consist of task reports and a final report conducted through the course of the project. The primary deliverable will be an assessment of feasibility of replacing the current UND combustion system with state-of-the-art boilers to produce steam and electricity for the UND campus as well as providing educational opportunities for students. It is anticipated that the results can be translated to other steam plans in the university system and to other state institutions.

STANDARDS OF SUCCESS

The overall success of the project will be based on the ability to provide information to determine the feasibility of replacing the UND boilers with new conversion and environmental control systems that will utilize lignite efficiently and cleanly. In addition, the success will be based on being able to use the UND co-generation facility as a platform for educating the next generation of energy experts and as a testing platform for advanced and emerging technologies.

BACKGROUND

Steam Plant History

The University of North Dakota has utilized centralized heating systems since early in its history. The first system, what is now Chandler Hall, was constructed to house a coal boiler to provide both steam heat and electrical power for the entire campus. In 1928, the plant was moved to its current location on the south central portion of campus. The system continued to provide steam and electrical service until 1962 when the low-pressure turbine and electrical generator were retired. The original 1928 boilers were replaced in 1953 by a 60,000-lb/hr Brothers boiler, which continues in operation to this day. In 1965, the University commissioned a second medium-capacity boiler with the installation of a 75,000-lb/hr-rated B&W unit. A Zurn boiler was added in 1978 with a 72,750-lb/hr capacity. Four gas/oil boilers have also been installed to back-up the coal-fired units. They consist of two Nebraska 60,000-lb/hr units, a 30,000-lb/hr Murray unit, and a 60,000 lb/hr Cleaver Brooks unit.

Today, the three coal-fired boilers supply steam heat to well over six million square feet of space through fourteen miles of direct buried steam line. Although primarily used for heating purposes, the steam also supplies service for absorption chilling, humidification, and autoclave operation. Current university research programs require dependable high-quality electrical service. To meet this requirement the university has made a commitment to generate its own electrical power.

The university has undertaken the quest to replace the current aging boilers with a new lignite-fired system that will produce steam and electricity efficiently with near-zero emissions while serving as an educational and testing platform for advanced power design.

Lignite Properties and Beneficiation

The chemical and physical properties of the lignite dictate how they will respond to utilization processes. Lignite is a younger fuel that consists of coalified plant remains that contains a unique combination of moisture and inorganic impurities. These unique properties need to be considered in identifying and designing an appropriate combination of technologies that will produce steam and electricity efficiently and cleanly.

The water present in lignite is associated in several forms that include moisture on the surface, within pores, and associated with mineral components (Schobert, 1995). The impurities or inorganic constituents are distributed within the lignite matrix in several forms, including: 1) organically associated inorganic elements; 2) coal-bound, included minerals; and 3) coal-free, excluded minerals. Lignite contains higher levels of organically associated cations as compared to than higher-rank coals because of the abundance of oxygen that can act as bonding sites. These carboxylic acid groups can act as ion exchange sites for cations such as sodium, calcium, magnesium, potassium, strontium, and barium (Benson and Holm, 1985). Lignite also contains impurities in the form of minerals such as clays, carbonates, sulfides, oxides, and quartz. The association of the inorganic components in the coal influences the interactions and transformations of these components during combustion.

The form and abundance of the impurities in lignite influences the carbon conversion process as well as their fate in the process. The organically associated elements—consisting of sodium, calcium, and magnesium—will catalyze combustion and gasification processes, resulting in lowering the temperature for operation. These elements will also form vapors and small particles that readily react with sulfur oxides and other vapor-phase species. A disadvantage associated with these elements is that they will also contribute to the formation of deposits in ceramic/refractory surfaces, cyclones, heat transfer surfaces, and gas filters. Formation of these deposits will lead to operability problems, with the potential to shut down the system. In addition, these elements have a tendency to concentrate in the fine particulate that have an influence on the selection of downstream gas cleanup technologies.

In the past, incentives to beneficiate lignites were small. However, because of the potential for increased environmental regulations for SOx, NOx, particulate matter, and mercury, upgrading must be considered. As described earlier, lignites present challenges because of their unique chemical and physical properties that include high moisture contents, complex associations of ash-forming components, high reactivity, and high oxygen content.

The removal of the water content results in particle shrinkage and formation of void space leading to weakening the structure of the coal particles. The weakened structure results in a more friable coal matrix that will produce more fines upon handling. In addition, the increase in void space or pore volume provides more surface area for reaction with oxygen causing spontaneous heating and combustion. This is a major challenge for lignite and because of the high reactivity, the coal must be utilized immediately upon drying and cannot be transported. Several groups have been developing thermal and mechanical treatment techniques to reduce water in lignite and to produce a low-pore-volume material in the form of a briquette. Investigations have been conducted on the use of increased temperature and pressure to upgrade peat, cellulose, lignin, and lignite (Orem and others, 1996; Huang, 1996; Shearer and Moore, 1996; Bergins 2003; Bergins 2004; and Bergins and others, 2007). The lower porosity of the compressed/briquetted lignite limits the diffusion of gases into and out of the pores, resulting in a decrease in the potential for spontaneous heating that can result in combustion. This technology has the potential to produce upgraded lignite that can be transported and stored without the problem of spontaneous heating and combustion.

In lignite, the inorganic component or ash-forming component is associated with the organic structure as well as discrete mineral grains in the coal. The inorganic components associated with the organic structure can constitute up to 50% of the inorganic content of the coal. The organically associated elements will not be removed by physical cleaning techniques. The discrete mineral impurities are the components that can be removed by cleaning; however, many of the discrete minerals are finely dispersed within the coal matrix and difficult to remove. An extensive survey of sulfur reduction potential of 455 coal samples was conducted (Cavallaro and others, 1976). Of the 455 samples, 44 were lignite or subbituminous coals. Data on ash showed a reduction ranging from 20% to 60% and a sulfur reduction ranging from 15% to 20%. The data from the coals show that some coals are better candidates for cleaning than others. The coals that were good candidates had higher ash contents.

Air jigs have the potential to remove mineral impurities form lignite. The air jig uses air to stratify and separate the coal from the coarse mineral components. A nuclear device is used to measure coal properties at the end of the air jig and is used to determine the separation point between the clean coal and the coarse minerals. Testing conducted on North Dakota lignite indicates that the air jig is capable of reducing the ash, sulfur, and mercury content of lignite coals while increasing the overall heating value. Average reductions of 15%, 22%, and 28% were achieved for ash, sulfur, and mercury, respectively. In general, coals with higher ash contents will benefit more from the air jig process than coals with lower ash contents. Higher heating value was increased by an average of 2%. Pyrite compounds are significantly reduced in the air jig process (Laumb and others, 2007).

Combustion System Design

Pulverized Lignite-fired Combustion Systems

Pulverized coal-fired combustion systems designed to fire lignite coals must be able to cool the gases and ash particles sufficiently to minimize sticking to heat transfer surfaces. Over time and based on experience with high-sodium lignite coals, boilers have evolved to minimize furnace wall slagging and convective pass fouling.

Examples of two combustion boilers in North Dakota designed to burn high-sodium lignite (6% to 10% Na_2O in ash) show how boilers have evolved to accommodate sodium-based slagging and fouling. The first boiler, Leland Olds 1, began operation in 1966 and was subject to severe slagging and fouling issues. The Antelope Valley 1 boiler was designed in the mid-1980's to burn a similar high-sodium coal. Past experience (with Leland Olds 1 and other boilers) was taken into account during the design of Antelope Valley 1. The furnace volume of the Antelope Valley boiler is more than twice that of the Leland Olds 1 boiler (1950 ft^3/MW vs. 828 ft^3/MW). The Antelope Valley 1 furnace plan heat release rate was designed to be less than that of Leland Olds 1 (1.32 vs. 1.47 million $BTU/ft^2/hr$). The Antelope Valley 1 furnace height is 273 ft, nearly twice that of Leland Olds 1 (at 140 ft), and the distance from the top burner to the furnace arch was increased from 44 ft (Leland Olds 1) to 114 ft (Antelope Valley 1). In addition to these design changes, tube bank spacing was also increased for the Antelope Valley 1 design. The first convection tube bank spacing was increased from 18 inches (Leland Olds 1 design) to 24.5 inches, and the minimum spacing increased from 4.5 inches (Leland Olds 1) to 6 inches. More wall blowers were also included in the Antelope Valley 1 design, with 78 wall blowers/100 MW capacity (40/100 MW for the Leland Olds 1 boiler). Although these design changes resulted in increased capital costs for construction, the improved design of Antelope Valley 1 is not load-limited because of slagging and fouling and has a higher availability and lower operating and maintenance costs.

Fluidized-Bed Combustion Systems

The efficient and reliable combustion of lignite in a fluidized-bed combustion system, including bubbling-bed and circulating fluidized-bed combustion (CFBC), requires the consideration of lignite's unique properties in the design, operating conditions, and selection of bed materials. Past work has shown that the alkali and alkaline-earth elements will interact with surfaces of other particles and bed materials resulting in bed agglomeration and ash accumulations on heat transfer surfaces (Hajicek and others, 1995 and Mann and others, 1992, Mann and others, 1999). Fluidized-bed systems operate at lower temperatures that allow for the capture of sulfur oxides with alkali and alkaline-earth-element-rich ash and bed materials. This results in the formation of low-melting-point silicates and sulfates that can contribute to the formation of agglomerates and ash deposits. This problem is characteristic of lignites that contain high alkali (sodium and potassium) and alkaline-earth (magnesium and calcium) elements. The key factors that are related to agglomerate formation include 1) the composition of the coal ash, 2) composition of the bed material, 3) temperature of the bed, 4) presence of localized reducing conditions in the bed, and 5) the degree of fluidization. In order to alleviate agglomeration and deposition problems when firing lignite, the fluidized bed must be carefully designed to manage temperature, maintain fluidization, and manage sodium levels in the bed through the selection of bed materials and additives.

Gas Cleanup Systems for Combustion

Air pollution control devices currently employed on lignite-fired power plants include electrostatic precipitators, wet scrubbers, and dry scrubbers. Lignite-associated challenges for these systems include the formation of fine particulate that is difficult to remove in electrostatic precipitators and wet scrubbers. The dry scrubbers, consisting of a spray dryer and fabric filters, show good particulate and sulfur control.

NOx reduction technologies currently utilized on lignite-fired systems consist of combustion modification that includes low-NOx burners and overfire air. Selective noncatalytic reduction systems are currently being installed. Selective catalytic reduction (SCR) catalysts have experience plugging and blinding in slipstream studies (Benson and others, 2005).

Gasification System Design

Lignite coals have physical and chemical characteristics that significantly affect their performance as coal gasification feedstocks relative to bituminous coals. Currently, the use of lignite as a feedstock for gasification is limited to Dakota Gasification for the production of synthetic natural gas. However, the range of potential application for lignite gasification technology varies from low-pressure, low-Btu gas generation to high-pressure pipeline gas designs. These systems employ fixed-, fluidized-, and entrained-flow gasifiers blown with air or oxygen (and in some cases, hydrogen or steam), that operate in non-slagging, agglomerating or slagging modes with or without the aid of catalysts. Testing the application of lignite coals for various gasifiers commercially available or under development is far from exhaustive even though lignites, because of their high reactivity, can be good gasification feedstocks, and in many cases better overall than bituminous coals. The temperature, pressure, and composition of the gas leaving the gasifier should match the requirements of the gas cleaning and separation processes and end-use application to minimize cost and efficiency penalties associated with gas cooling, compression, and downstream processing. High-temperature entrained-flow gasifiers with exit gas temperatures in the range of 1040° to 1430°C (1904° to 2606°F) produce mainly CO and H_2 at ratios generally between 1:1 and 2:1, along with CO_2 in proportion to the amount of oxygen used to supply heat—which is greater for a slurry-feed gasifier compared to a dry-feed gasifier. Fixed-bed gasifiers with exit gas temperatures between 260° and 540°C (500°– and 1004°F) and fluidized-bed/transport gasifiers between 820° and 1000°C (1508° and 1832°F) produce syngas typically containing 3% to 5% CH_4 and ratios of CO to H_2 governed by the effect of excess steam on the water-gas shift reaction (Sondreal and others, 2006). For high-efficiency gasification to produce electricity and steam, gas cleanup needs to be conducted at high temperatures or at least moderate temperatures. A review of technology applications for hot or warm gas cleanup has been conducted (Benson and Sondreal, 2009).

QUALIFICATIONS

The University of North Dakota School of Engineering and Mines has been conducting research, development, and demonstration programs involving lignitic coals for nearly 70 years. The early studies in the late 1930s and early 1940s involved gasification of lignite as well as lignite upgrading. Today numerous projects are being conducted that include liquid fuel development from biomass, ash formation and behavior studies, membrane separation of CO_2, particulate sampling, hydrogen production, catalysis formulation and testing, and computer modeling and simulations (computational fluid dynamics modeling, ASPEN, ChemCad, and FACT).

VALUE TO NORTH DAKOTA

The use of North Dakota lignite is facing major challenges because of problems associated with of moisture, sulfur, and ash behavior. However, lignite has advantageous properties that in many cases are overlooked. This project is aimed developing a preliminary design of an efficient clean conversion system that is designed specifically to fire North Dakota lignite to produce steam and electricity while providing a platform for education and testing technologies.

MANAGEMENT

The overall management structure of the project is illustrated in Figure 1. Dr. Steven Benson will be responsible for oversight of the project. The University of North Dakota President, Vice President for Finance and Operations, and Campus planning will provide vision and direction on the future needs of UND. An advisory team will be assembled to provide input and review of direction and status of the project. The group will be led by a representative of the North Dakota Industrial Commission. The Lignite Technology Working Group (LTWG) represents all the utilities and coal companies in North Dakota. Key individuals from industry and the Department of Energy's National Energy Technology Laboratory will be invited to participate on the advisory team.

The two key Principal Investigators include Drs. Michael Mann, Chair of the Chemical Engineering Department at UND, and Srivats Srinivasachar President of Envergex LLC. Dr. Mann will be responsible for Task 1. Dr. Srinivasachar will be a subcontractor on this project and he will lead Task 2 and provide supporting roles in Tasks 3 and 4. The A&E or engineering firm will take the lead role for Task 4 under the direction of Dr. Benson. Dr. Benson will be responsible Task 5, reporting and project management. A UND chemical engineering student pursuing a Masters degree will participate in the project by providing systems engineering support when examining design options. The graduate student will report to Dr. Benson.

Project Manager

Dr. Steve Benson, Professor of Chemical Engineering, has more than 25 years in coal utilization and environmental control technologies and has managed numerous projects involving government and industry participants. The projects include the development of 1) methodologies to minimize the effects of inorganic components on the performance of combustion/gasification and air pollution control systems; 2) fate and control of air toxic substances such as mercury in combustion and gasification systems; 3) advanced analytical techniques to determine the chemical and physical transformations of fuel-derived impurities in combustion gases; 4) computer-based codes to predict the effects of coal quality on system performance; 5) advanced materials for coal-based power systems; and 6) training programs. Dr. Benson has a B.S. in Chemistry from Minnesota State University (Moorhead) and a Ph.D. in Fuel Science from the Pennsylvania State University.

Principal Investigators

Dr. Michael D. Mann

Dr. Mann, Professor and Chair of the Chemical Engineering Department, has spent his entire career in the energy industry. While working at the Energy & Environmental Research Center he helped establish and manage research in the areas of fluidized bed combustion, fouling and slagging in pc-fired systems, and advanced gasification technologies. He has looked specifically at the impacts of fuel properties on system performance, and the impacts of implementing emission control devices on the overall system performance. Dr. Mann joined the faculty of Chemical Engineering in 1999, and his current research interests include still performance issues in advanced energy systems firing coal and biomass; but have expanded to include renewable and sustainable energy systems with a focus on integration of fuel cells with renewable resources through electrolysis and the development of energy strategies coupling thermodynamics with political, social, and economic factors. Dr. Mann is co-director of SUNRISE, UND's research group focused on the development and implementation of sustainable energy resources. Under his leadership, the Department of Chemical Engineering was awarded two of UND highest departmental honors: the 2007 UND Departmental Award for Excellence in Teaching and the 2005 UND Departmental Award for Excellence in Research. He has a M.S. in Chemical Engineering, and MBA, and a Ph.D. in Energy Engineering from the University of North Dakota.

Dr. Srivats Srinivasachar

Dr. Srinivasachar has extensive commercial experience in developing pollution control and energy efficiency improvement strategies for the coal-fired utility industry. Dr. Srinivasachar previously worked at ALSTOM Power, Inc., a leading coal-fired boiler manufacturer and a vendor of environmental control systems for coal-fired power plants.

Dr. Srinivasachar has developed several new products for improvements to low-NO_x firing, sulfur dioxide emission control, particulate control, boiler efficiency enhancements and mercury capture. He holds seven patents and has authored over 50 publications with demonstrated expertise in coal conversion and environmental control systems.

At Envergex, Dr. Srinivasachar is pursuing commercial production and supply of low-cost and high-performance activated carbon-based sorbents for mercury control. Dr. Srinivasachar received registration of trademark for mercury sorbents, ESORB-HG®, from the US Patent and Trademarks office in March 2009 (Registration Number: 3589943). Envergex has manufactured and supplied commercial quantities and successfully demonstrated ESORB-HG® sorbent to several utility customers at full-scale, and responded to commercial bid requests for sorbent supply

Dr. Srinivasachar teamed with the University of North Dakota Energy & Environmental Research Center and a utility partner on a project to perform process design, preliminary engineering, and plant capital and O&M costing to implement an innovative technology for activated carbon manufacturing integrated to a power plant. Dr. Srinivasachar/Envergex was also awarded a Small Business Innovation Research grant in June 2007 from DOE for a project for a novel method for reducing mercury re-emission from wet flue gas desulfurization (FGD) scrubbers.

During his previous work at ALSTOM Power, Inc., Dr. Srinivasachar was in the forefront of advancing methods for controlling mercury emissions from coal-fired power plants. He is the inventor and developer of Mer-Cure™, a sorbent-based technology for mercury control at ALSTOM. Dr. Srinivasachar scaled the product through pilot-scale evaluation and commercial-scale testing, and led the successful demonstration of this technology at three full-scale utility plants. Dr. Srinivasachar holds US Patent 6,848,374 on this subject technology.

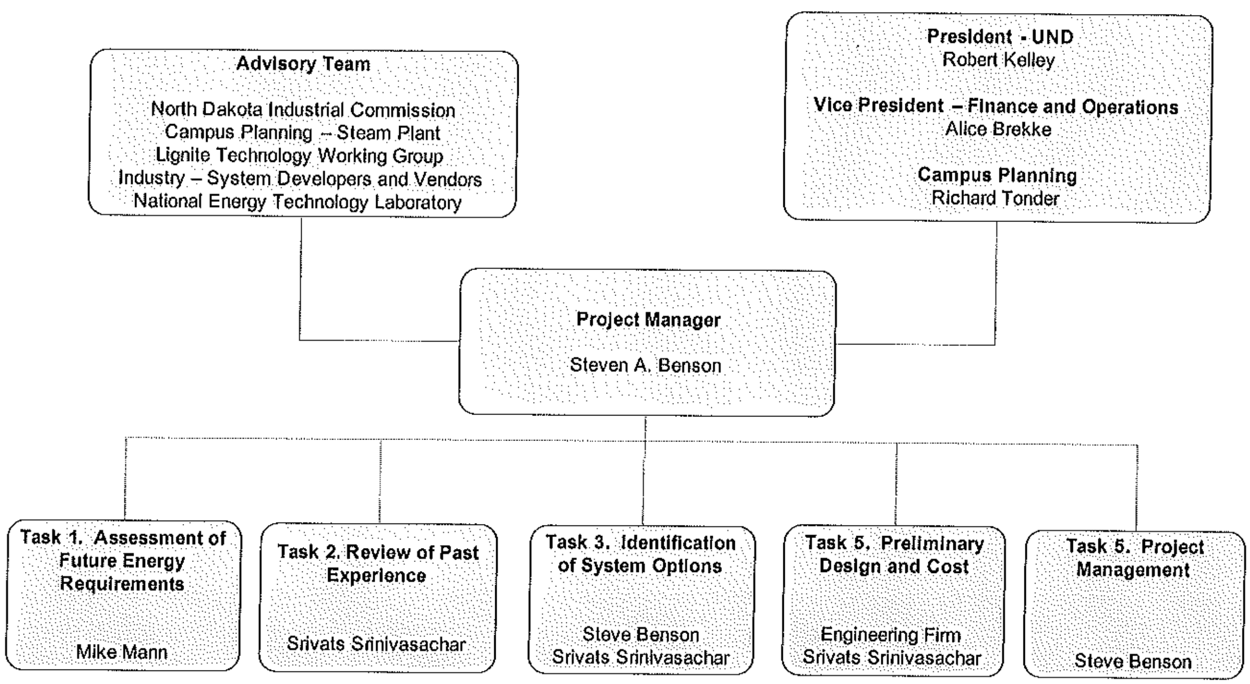


Figure 1. Overall project management organizational chart.

PROJECT TIMETABLE

The proposed project will be initiated upon approval of the project by the NDIC. It is anticipated that the proposed work will be carried out over 12 months, with a start date of approximately August 1, 2009. The project schedule and milestones are summarized in Table 1.

TABLE 1. Project Schedule and Milestones

Task

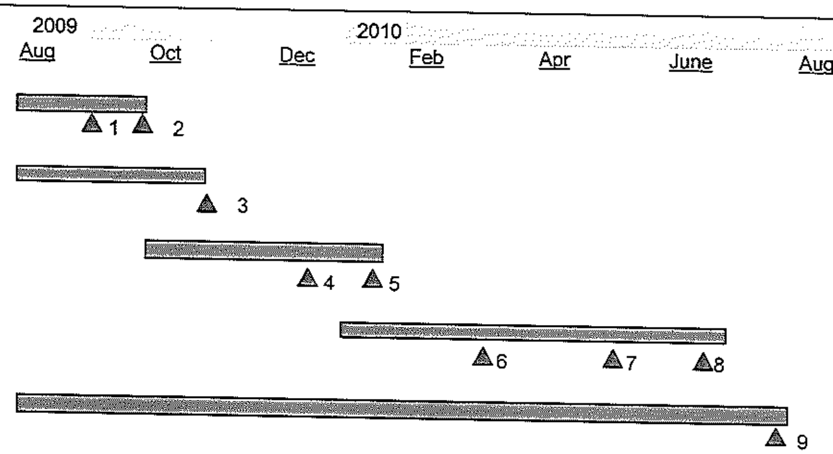
1 Assessment of Future Energy Need

2 Review of Past Experience

3 Identification of System Options

4 Preliminary Design and Costs for Selected Technology with Options

5 Project Management and Reporting



Milestones:

1– Steam and power plant specifications; fuel choices, load demand
2 – R&D elements - opportunities and specifications
3 - Interim report - lignite utilization and processing - industry experience
4 - Report outlining system options and costs for utilizing lignite relevant for UND site
5 - Selection of core lignite-to-energy technology for UND with options
6 - Preliminary design of selected technology (process design and emissions)
7 - Preliminary design of selected technology (Equipment, vendors, and layout)
8 - Preliminary costs of selected approach
9 - Final Project Report

BUDGET

The budget for the overall project is attached that provides the overall cost of the project. The funding for the engineering firm is shown, and selection of that firm will follow standard University procedures.

MATCHING FUNDS

None

TAX LIABILITY

No outstanding tax liabilities to the state of North Dakota.

CONFIDENTIAL INFORMATION

No confidential information is included in the proposal.

REFERENCES

Benson, S.A.; Laumb, J.D.; Crocker, C.R.; Pavlish, J.H. SCR Catalyst Performance in Flue Gases Derived from Subbituminous and Lignite Coals. Fuel Process. Technol. 2005, 86, 577–613.

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UNIVERSITY OF NORTH DAKOTA
BUDGET SUMMARY
Advanced Power System Initiative: Lignite Feasibility Study

Start date:	**8/1/2009**
End date:	**7/31/2010**

DESCRIPTION	Year 1
Faculty Salaries	$79,669
Graduate Student Salaries	$6,500
Undergraduate Student Salaries	$0
UND Other Personnel	$0
Total Fringe Benefits	$20,617
TOTAL PERSONNEL	**$106,787**
TRAVEL	$4,000
SUPPLY/MATERIALS	$4,513
WAIVERS/SCHOLARSHPS/FELLOWSHPS	$0
TOTAL OPERATING	**$8,513**
SUBCONTRACTS > $25,000	$226,846
TOTAL SUBCONTRACTS	**$226,846**
EQUIPMENT >$5,000	$0
TOTAL EQUIPMENT	**$0**
TOTAL DIRECT COST	**$342,146**
F&A (INDIRECT COST)	$57,855
TOTAL COST	**$400,000**

Due to the limitations within the Universities accounting system, the system does not provide for accumulating and reporting of expenses at the detail level outlined above. The costs will be accounted for and reported at the category level. The detail above is presented for proposal

BUDGET DETAILS

Personnel

Direct project salaries are estimated based on the scope of work and prior experience. The proposed work will occur during the twelve month period of performance and will be done in conjunction with the other academic duties of the faculty.

The budget includes a ¼ time graduate research assistantship (GRA) to support the research. The current stipend rates set by the UND Graduate School are used for budgetary purposes.

Fringe Benefits

Fringe benefits are estimated for proposal purposes only, on award implementation, only the true cost of each individual's fringe benefit plan will be charged to the project. Fringe benefits are comprised of the following: social security, state retirement, TIAA-CREF, health insurance, unemployment, worker's compensation, life insurance, and disability. Estimated rates are 25% for faculty, $750 a 12-month year for graduate students, and 0% for undergraduate students.

Travel

It is anticipated travel required to support this effort will include 4 trips to Bismarck and two trips to the firm subcontracted to perform the A&E services specified as a part of Task 3.

Materials and Supplies

Any related items that do not exceed $5000 per unit are included under the Supplies category, and includes communications such as long-distance telephone including fax-related long distance calls; postage for regular, air, and express mail and other data or document transportation costs. Project-specific office supplies include items specifically related to this project such as paper, pens, binders, along with duplicating and printing. The costs associated with analytical work to support this project is also billable to materials and supplies.

Subcontracts

As a part of the proposed effort, UND will subcontract with an A&E firm to perform preliminary engineering and to develop budget costs. The firm will be selected based upon their knowledge and experience utilizing lignite coals in advanced power systems. The amount of $125,000 has been included in the budget for this effort.

A subcontract will be issued to Envergex to assist in the assessment of UND future energy needs, and to assist in the selection and design of technologies. The cost of the proposed work is $101,846.

Indirect Costs

The indirect cost rate included in this proposal is the federally approved rate for the University of North Dakota (35%). Indirect costs are calculated based on the Modified Total Direct Costs (MTDC), defined as the Total Direct Costs of the project less individual items of equipment $5,000 or greater, subcontracts in excess of the first $25,000 for each award, and graduate tuition waivers.

APPENDIX A

RESUMES OF KEY PERSONNEL

STEVEN A. BENSON, Professor of Chemical Engineering

Research Areas of Expertise

Dr. Benson's principal areas of interest and expertise include development and management of complex multidisciplinary research programs that are focused on solving environmental and energy problems associated with the utilization of renewable and fossil fuel resources. These programs include: 1) technologies to improve the performance of combustion/gasification and associated air pollution control systems; 2) transformations and control of trace elements in combustion and gasification systems; 3) carbon dioxide separation and capture technologies from combustion and gasification derived gases, 4) advanced analytical techniques to measure the chemical and physical transformations of inorganic species in gases; 5) computer-based models to predict the emissions and fate of pollutants from combustion and gasification systems; 6) advanced materials for power systems; 7) impacts of power system emissions on the environment; 8) harvesting diffuse energy resources; 9) national and international conferences and training programs; and 8) state and national environmental policy.

Education

Minnesota State University	Chemistry	B.S. 1977
Pennsylvania State University	Fuel Science	Ph.D. 1987

Professional Experience

2008 – present	Professor, Chemical Engineering, University of North Dakota
1999 – 2008	Senior Research Manager/Advisor, Energy & Environmental Research Center, University of North Dakota (EERC, UND).
1994 – 1999	Associate Director for Research, EERC, UND.
1991 – Present	President, Microbeam Technologies Incorporated.
1989 – 1991	Assistant Professor of Geological Engineering, Department of Geology and Geological Engineering, UND.
1986 – 1994	Senior Research Manager, Fuels and Materials Science, EERC, UND.
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
1979 – 1983	Research Chemist, U.S. Department of Energy Grand Forks Energy Technology Center, Grand Forks, North Dakota.
1977 – 1979	Chemist, U.S. Department of Energy, Grand Forks Energy Technology Center, Grand Forks, North Dakota.

Synergistic Activities

- Senior Research Manager/Advisor Energy & Environmental Research Center, Dr. Benson was responsible for leading a group of about 30 highly specialized group of chemical, mechanical and civil engineers along with scientists whose aim is to solve problems on combustion and gasification system performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide (PI on over $13 million).

- Current Research Support: "Advances in the Fundamental Understanding of Coal Combustion Emission Mechanisms", DOE EPSCoR IIP/ND EPSCoR , $2,500,000, 7/06 – 7/09; "Lignite Gasification Technology Summary Report", DOE and Lignite Energy Council, $100,000.
- Lignite Energy Council, Distinguished Service Award, Research & Development, 1997; College of Earth and Mineral Science Alumni Achievement Award, Pennsylvania State University, 2002; Lignite Energy Council, Distinguished Service Award, Research & Development, 2003; Lignite Energy Council, Distinguished Service Award, Government Action Program (Regulatory), 2005; Lignite Energy Council, Distinguished Service Award, Research & Development, 2008.
- Five Patent Applications: "Method and Apparatus for Capturing Gas phase Pollutant," 2005; "Removal and Recovery of Deposits from Coal Gasification Systems," 2007; Activated Carbon Production Plant," 2008; "Method for Improving Mercury Capture in Particular from Sulfur Bearing Gases," 2008; An Apparatus for Improving Water Quality by Means of Gasification, 2007.
- Provided testimony to the United States Senate Committee on the Environment and Public Works – Mercury emissions control at coal-fired power plants - 2008 and 2005.

Selected Topical Reports/Special Issues

- Controlling Mercury Emissions for Utilities Firing Lignites from North America, North Dakota Industrial Commission, 2007, 376 p.
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MICHAEL D. MANN, Professor and Chair of Chemical Engineering

Research Areas of Expertise

Dr. Mann's principal areas of interest and expertise include performance issues in advanced energy systems firing coal and biomass; renewable and sustainable energy systems with a focus on integration of fuel cells with renewable resources through electrolysis; production of fuel and specialty chemicals from crop oils; and development of energy strategies coupling thermodynamics with political, social, and economic factors. Dr. Mann is co-director of SUNRISE, UND's research group focused on the development and implementation of sustainable energy resources.

Education

Mayville State University	Chemistry, Mathematics	B.A., 1979
University of North Dakota	Chemical Engineering	M.S., 1981
University of North Dakota	Business Administration	M.B.A., 1987
University of North Dakota	Energy Engineering	Ph.D., 1997

Professional Experience

2008	Interim Dean, School of Engineering and Mines, University of North Dakota
2006-*present*	Professor, Department of Chemical Engineering, University of North Dakota
2005-*present*	Chair, Department of Chemical Engineering, University of North Dakota
1999-2006	Associate Professor of Chemical Engineering, University of North Dakota
2000-2005	Director, Engineering Doctoral Program, University of North Dakota
1999-*present*	Senior Research Advisor, Energy& Environmental Research Center (EERC)
1994 – 1999	Senior Research Mgr, Advanced Processes and Technologies, EERC, UND.
1985 – 1994	Research Manager, Combustion Systems, EERC, UND.
1981 – 1985	Research Engineer, Wastewater Treatment and Reuse, EERC, UND

Selected Publications

- Hrdlicka, J.A., Seames, W.S., Mann, M.D., Muggli, D.S., and Horabik, C.A., "Mercury oxidation in flue gas using gold and palladium catalysts on fabric filters", *Engineering Science and Technology*, (2008), 42 (17), pp. 6677-6682.
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- 6,053,954, "Methods to Enhance the Properties of Hydrothermally Treated Fuels", 2000

SRIVATS SRINIVASACHAR, President Envergex LLC.

Research Areas of Expertise

- Expertise in energy and environmental engineering, power plant systems, and cross-industry products
- Current focus on identifying new business opportunities, setting vision, developing business plans, and implementing strategies for new products/processes
- Successfully executed projects for multiple clients with multi-industry, cross-functional, and international project teams – exceeding performance goals, ahead of schedule and with cost efficiency
- Strong experience in generating financing with industry and government
- Led product and process development groups. Managed large multi-contractor projects
- Obtained multiple patents and published over 50 technical papers

Education

2003-2004 Boston University, School of Management
Boston, MA
Master of Business Administration

1981-1986 Massachusetts Institute of Technology
Cambridge, MA
Sc.D. degree in Chemical Engineering

1976-1981 Indian Institute of Technology
Madras, India
Bachelor of Technology, Chemical Engineering

Professional experience

Present ***President, Envergex LLC*** ***Sturbridge, MA***

- President

  Pursuing commercial production and supply of low cost and high performance activated carbon-based sorbents for mercury control. Working with partners to set up a venture for low-cost manufacturing of these sorbents.

  Continuing to develop and test formulations and treatment methods to maximize the performance of mercury sorbents for different coals and air pollution control system configurations

  Received from the US Patent and Trademarks office registration of trademark for mercury sorbents, ESORB-HG®, in March 2009 (Registration Number: 3589943)

Manufactured and supplied commercial quantities and successfully demonstrated ESORB-HG® sorbent to several utility customers at full-scale, and responded to commercial bid requests for sorbent supply

Awarded a Small Business Innovation Research grant in June 2007 from DOE for a project for a novel method for reducing mercury re-emission from wet flue gas desulfurization (FGD) scrubbers.

Developed a business plan for coal and biomass to liquids venture to commercialize technology developed at a university

Teamed with University of North Dakota Energy & Environmental Research Center and a utility partner to perform process design, preliminary engineering, and plant capital and O&M costing to implement an innovative technology for activated carbon manufacturing integrated to a power plant

Developed a technical and business strategy to increase manufacturing process energy efficiencies at a major building materials company

1993 – 2006 ALSTOM Power, Inc./ABB Combustion Engineering, Inc., Windsor, CT

- Technical Manager, Environmental Control Technology (March 2003-2006)
  Developed new product for control of mercury emission from coal-fired power plants. Set product strategy, positioned the differentiated product competitively, secured intellectual property, developed business plan, established partnership with component suppliers and external research organizations, led product development team, identified and successfully executed 3 commercial demonstration projects, scaled the product through laboratory, pilot and commercial scale, obtained industry, government and internal funding ($ 13 million)
- Principal Consulting Engineer, New Product Business Development (Oct. 1999 to March 2003)
- Environmental Group Leader, (Oct. 1997 – Sept. 1999)
  Minimizing pollutant emissions from a new gasification-based power plant technology
- Senior Consulting Engineer, (1994 – 1997)

1986-1993 Physical Sciences Inc. Andover, MA

- Manager, Environmental Remediation and Resource Utilization (1992-93)
  Directing R&D for an emerging business area. Negotiated with strategic partner for funding. Secured and managed an EPA Superfund project to remediate heavy metal-contaminated soils.
- Principal Research Scientist (1986-92)
  Principal Investigator on a multi-million dollar university-industry project. Created test methods and software for electric utilities to evaluate savings with various fuel switching options and predict fuel quality impacts on slagging and fouling in coal-fired power plants

Patents

U.S. Patent 6,848,374-Control of Mercury Emissions from Solid Fuel Combustion
U.S. Patent 6,749,681-Method of Producing Cement Clinker and Electricity
U.S. Patent 6,601,541-Method of Producing Steam and Calcined Raw Meal
U.S. Patent 6,089,171-Minimum Recirculation Flame Control Pulverized Solid Fuel Nozzle Tip
U.S. Patent 6,089,023-Steam Generator System Operation
U.S. Patent 5,556,447 and 5,245,120-Process for Treating Metal-Contaminated Materials

Selected Publication List

1. Benson, S.A., Crocker, C.R., Hanson, S.K., McIntyre, K.A., Just, B.J., Raymond, L.J., Pflughoeft-Hassett, D.F, Srinivasachar, S., Barry, L.T. and Doeling, C.M., "JV Task 115-Activated Carbon Production from North Dakota Lignite – Phase IIA," Final Report, U.S. Department of Energy Cooperative Agreement No. DE-FC26-98FT40321, June 2008
2. Kang, S.K., Srinivasachar, S. and Brickett, L.A., " Full-Scale Demonstration of Mer-Cure™ Technology for Mercury Emissions Control in Coal-Fired Boilers, " 31st International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL May 2006
3. Srinivasachar, S. and Kang, S.K., "Field Demonstration of Enhanced Sorbent Injection for Mercury Control," DOE-NETL Program Review Meeting, July 2005, Pittsburgh, PA
4. Srinivasachar, S. and Kang, S.K., "Field Demonstration of Enhanced Sorbent Injection for Mercury Control," Quarterly Report October-December 2005, DOE-NETL, Pittsburgh, PA
5. Senior, C.L., Bool, L.E., **Srinivasachar, S.,** Pease, B.R. and Porle, K., "Pilot-Scale Study of Trace Element Vaporization and Condensation during Combustion of a Pulverized Sub-bituminous Coal," Fuel Processing Technology, 63(2-3), 149-165, 2000
6. Liu, B.B., **Srinivasachar, S.,** and Helble, J.J., "The Effect of Chemical Composition on the Fractal-Like Structure of Combustion-Generated Inorganic Aerosols," Aerosol Science and Technology, 33(6), 459-469, 2000
7. Pease, B.R., **Srinivasachar, S.**, Porle, K., Haythornthwaite, S. and Ruhl, J., "Ultra-high Efficiency ESP Development for Fine Particulate and Air Toxics Control – Phase I and II: Mercury Removal Investigations," Proc. – 15th Annual International Pittsburgh Coal Conference, 1580-1598, 1998

APPENDIX B

ENVERGEX LETTER AND BUDGET

Envergex LLC
10 Podunk Road
Sturbridge, MA 01566

May 29, 2009

Dr. Steven A. Benson
Department of Chemical Engineering
University of North Dakota
P.O. Box 9018
Grand Forks, ND 58202-9018

Ref: Request for Proposal for Proposed Project "Advanced Power Systems Initiative: Lignite Feasibility Study"

Dear Steve,

This letter of commitment is to support the University of North Dakota (UND), Department of Chemical Engineering's in its proposed project to evaluate the feasibility of constructing a clean advanced lignite-fired power system to produce steam and electricity for the UND campus. The cogeneration facility has the additional objective of providing opportunities to test emerging energy technologies of interest to the lignite industry and to educate the next generation of energy experts at the university.

Envergex will provide project support to accomplish the various tasks outlined in the project proposal including:

- Assessment of future energy needs for the UND campus and opportunities for synergistic research and development facilities development for emerging energy technologies
- Review and research of lignite utilization technologies for energy generation
- Identification and analysis of fuel conversion, power generation and gas cleanup system options for the UND campus with selection of core technology and options for further evaluation
- Preliminary design, engineering and costing of selected technology option(s)

The overall budget for Envergex for the proposed work is $ 101,846, and includes six (6) trips to UND for coordination, work execution, and meetings on the project . The estimated period of performance is for twelve (12) months starting August 1, 2009. If the project is expanded and additional support is required, Envergex will provide that scope as part of the subcontract with additional funding.

Envergex LLC is committed to the development, testing, and commercialization of advanced environmental control technologies for the utility power generation industry. The development of a high efficiency and low carbon footprint campus energy facility using indigenous North Dakota lignite, and which provides a research platform for the development of energy efficient, environmentally sound and cost-effective technologies for lignite utilization is a critical need for the University and the State of North Dakota, and Envergex is pleased to be a participant in the subject proposal.

If you have any questions or comments, please feel free to contact me by phone at (508) 347-2933 or by e-mail at srivats.srinivasachar@envergex.com. I look forward to this opportunity to team with Department of Chemical Engineering at the University of North Dakota.

Sincerely,

Srivats Srinivasachar
President
Envergex LLC
E-mail: srivats.srinivasachar@envergex.com

Attachments: Budget

BUDGET

Budget Explanation: Year 1 (08/1/09 to 07/30/10)

Applicant Name: Envergex LLC

Proposed Funding Opportunity Number:
ADVANCED POWER SYSTEMS INITIATIVE: LIGNITE FEASIBILITY STUDY
Department of Chemical Engineering, University of North Dakota

Direct Labor (480 hours @ $70/hour)	$	33,600	
Fringe Benefits (31.93% of direct labor)		10,730	
Total Direct Costs			44,330
Labor Overhead (46.15%)			20,460
General and Administrative (52.85%)			26,856
Supplies			-
Travel			-
Estimated Profit			-
Total:			$ 91,646
Travel:			
Trips			
Trips to UND (North Dakota)		6	
Cost (1 trip = $ 1,700)	$	10,200	
Grand Total:			$ 101,846

Campbell, Shirley K.

From: Fine, Karlene K.
Sent: Friday, July 17, 2009 10:05 AM
To: Campbell, Shirley K.
Subject: FW: Addition: Advanced Power Systems Initiative: Lignite Feasibility Study

-----Original Message-----
From: Steve Benson [mailto:stevebenson@mail.und.nodak.edu]
Sent: Monday, June 01, 2009 4:53 PM
To: Fine, Karlene K.
Cc: JeffBurgess@lignite.com; Mike Mann
Subject: Addition: Advanced Power Systems Initiative: Lignite Feasibility Study

Karlene,

VALUE TO NORTH DAKOTA

The coal currently fired in the University of North Dakota to produce steam is a subbituminous coal from Montana. A key benefit of this proposed project is the development of a preliminary design for a system that produces steam and electricity for institutions such at UND. The system design could be utilized at other institutions throughout the region that utilizes North Dakota lignite.

I would appreciate it if you would include this with the proposal. I apologize for any inconvenience.

Thank you for your help.

Sincerely,

Steve

Steven A. Benson, Ph.D.
Professor
Department of Chemical Engineering
Harrington Hall Room 323
241 Centennial Drive Stop 7101
Grand Forks, ND 58202-7101
Office: (701)777-5177
Fax: (701)777-3773