Energy & Environmental Research Center
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May 1, 2001

Ms. Karlene Fine
Industrial Commission of North Dakota
600 East Boulevard Avenue
State Capitol, 10th Floor
Bismarck, ND 58505-0310

Dear Ms. Fine:

Subject: EERC Proposal No. 2001-0080

Enclosed please find the original and six copies of the proposal entitled "Low-Temperature NO_x Reduction Using High-Sodium Lignite-Derived Chars".

If you have any questions, please contact me at (701) 777-5177, fax at (701) 777-5181, or e-mail at sbenson@undeerc.org.

Sincerely,

Steven A. Benson
Senior Research Manager/Advisor

SAB/cs

Enclosures

Energy & Environmental Research Center

LOW-TEMPERATURE NO_x REDUCTION USING HIGH-SODIUM LIGNITE-DERIVED CHARS

EERC Proposal No. 2001-0080

Submitted to:

Ms. Karlene Fine

Industrial Commission of North Dakota
600 East Boulevard Avenue
State Capitol, 10th Floor
Bismarck, ND 58505-0310

Amount Requested from ICND: $320,000
Total Project Cost: $1,020,000

Submitted by:

Steven A. Benson
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Office of Research and Program Development

May 2001

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LOW-TEMPERATURE NO_x REDUCTION USING HIGH-SODIUM LIGNITE-DERIVED CHARS

ABSTRACT

The primary goal of this project is to demonstrate the ability of lignite-derived char to effectively reduce NO_x levels from combustion gases produced from cyclone-fired combustion systems using North Dakota lignite. The secondary goal is to determine the ability of the high-sodium char to convert gas-phase Hg^0 derived from lignite to an oxidized form as it is passed through the lignite-derived char. To meet these goals, the following objectives must be met: 1) demonstrate the production of larger quantities (4 to 10 lb/hr) of highly reactive lignite-derived char that will provide information required to scale up the process; 2) demonstrate the ability of the char to reduce NO_x from flue gases in a small-scale combustion system combined with a circulating fluidized-bed reactor (CFBR) (including fluidized- and fixed-bed modes) – parametric testing will be conducted to determine the impact of the NO reduction temperature, oxygen concentration, and inlet concentration of NO on char performance; 3) measure the mercury species upstream and downstream of the CFBR; and 4) conduct a technical and economic evaluation associated with the development of the technology.

Expected results include determining the feasibility of producing a low-cost char from high-sodium lignite, demonstrating the ability of the char to reduce NO_x, demonstrating the feasibility of using a CFBR as a flue gas contacting device, determining the ability of the char to transform Hg^0 to Hg^{2+} across the bed of char, and evaluating the technical and economic feasibility of the technology. The duration of the project is 2 years. The total project cost is $1,020,000. The funding requested from the Industrial Commission of North Dakota is $320,000. The Energy & Environmental Research Center, Ohio State University, BNI Coal Ltd., and Minnkota Power Cooperative are teaming to conduct the project.

LOW-TEMPERATURE NO_x REDUCTION USING HIGH-SODIUM LIGNITE-DERIVED CHARS

PROJECT SUMMARY

Regulations are being enacted to bring down the level of emitted NO_x from coal-fired power plants. In December 1999, 392 power plants in 22 states were ordered to curtail NO_x emissions by 50% by March 2003. In response, technologies for NO_x reduction are being tested, and some systems are being installed, such as the selective catalytic reduction (SCR) process. Alternative technologies are also being examined. Recently, a char derived from a high-sodium North Dakota lignite has been shown to have a very high reactivity to convert NO_x to N_2 and CO_2 at temperatures between 300° to 600°C (572° to 1112°F) (Gupta and others, 1999a, b). These tests were conducted on a laboratory scale. The reduction of NO by carbon occurs by the following overall reactions:

$$2NO + C \rightarrow CO_2 + N_2 \qquad [1]$$

$$2NO + 2C \rightarrow 2CO + N_2 \qquad [2]$$

Economic analysis of the North Dakota lignite char-based technology for the reduction of NO_x emissions has shown that it has potential to be competitive with SCR technologies. SCR technologies cost \$1000–\$3000/ton of NO_x reduced, while it is estimated that North Dakota lignite char technology will cost \$200–\$1500/ton of NO_x reduced. The technology has been tested on a bench scale, and the results are very promising. The lignite-derived char showed the highest reactivity with respect to NO_x reduction as compared to other commercially available activated carbons. This technology has the potential to offer significantly lower costs than SCR technology and will utilize significant quantities of North Dakota lignite by creating a new market for North Dakota lignite char. In addition, the long-term reliability of SCR technologies to reduce NO_x in lignite-fired boilers is questionable because of the potential blinding of the catalyst (Hartenstein and others, 1999). The technology for the use of lignite was recently patented (Fan and Gupta, 2001).

The primary goal of this project is to demonstrate the ability of lignite-derived char to effectively reduce NO_x levels from combustion gases produced from cyclone-fired combustion systems utilizing North Dakota lignite. The secondary goal is to determine the ability of the high-sodium char to convert gas-phase elemental mercury derived from western U.S. coals to an oxidized form as it is passed through the lignite-derived char. In order to meet the goals of the project, the following objectives must be met:

- Demonstrate the production of larger quantities (4 to 10 lb/hr) of highly reactive lignite-derived char that will provide information required to scale up the process.
- Demonstrate the ability of the char to reduce NO_x from flue gases in a small-scale combustion system combined with a circulating fluidized-bed reactor (CFBR) (including fluidized- and fixed-bed modes). Parametric testing of the CFB system using lignite-derived char will be conducted to determine the impact of the NO reduction temperature, oxygen concentration, and inlet concentration of NO on the performance of the char.
- Measure the mercury species upstream and downstream of the CFBR.
- Conduct a technical and economic evaluation associated with the development of the technology.

PROJECT DESCRIPTION

Goal

The primary goal of this project is to demonstrate the ability of lignite-derived char to effectively reduce NO_x levels from combustion gases produced from a cyclone-fired combustion system firing North Dakota lignite. The secondary goal is to determine the ability of the high-sodium char to convert gas-phase elemental mercury derived from lignite to an oxidized form as it is passed through the lignite-derived char.

Objectives

In order to meet the goals of the project, the following specific objectives have been identified:

- Demonstrate the production of larger quantities (4 to 10 lb/hr) of highly reactive lignite-derived char that will provide information required to scale up the process.
- Demonstrate the ability of the char to reduce NO_x from flue gases in a small-scale combustion system combined with a CFBR. Parametric testing will be conducted to determine the impact of the NO reduction temperature, oxygen concentration, and inlet concentration of NO on the performance of the char.
- Measure the mercury species upstream and downstream of the CFBR.
- Conduct a technical and economic evaluation associated with the development of the technology.

Work Plan

This section describes in detail the research methods and plans that will be employed to successfully complete each objective. The following tasks have been outlined.

1. Char production

a. Determine the availability and variability of high-sodium lignite types.

b. Select lignite types for testing.

c. Produce chars by performing pyrolysis (devolatilization) of the coal.

d. Characterize the chars to determine surface area and porosity and compare to bench-scale studies.

e. Conduct bench-scale testing and compare past results to past testing conducted at Ohio State University (OSU).

2. NO_x reduction testing using selected chars

a. Design and construct a CFBR to be linked to the existing conversion and environmental process simulator (CEPS) (feed rate 4 to 5 lb/hr).

b. Testing the CEPS–CFB combination. The firing conditions of the CEPS will be adjusted to produce a flue gas stream composition similar to that produced by a cyclone-fired boiler.

c. The char-based NO_x reduction is characterized by short gas–solid contact time (10–1000 ms). However, given the relatively lower reaction temperature and the low concentration of oxygen, it takes comparatively longer time for the char to react completely. This can be achieved in a CFB. Testing will be conducted with the combined system to determine the following:

i. Reaction temperature

ii. Contact time

iii. Particle size

iv. Oxygen concentration

d. Determination of the heat produced in the reduction process.

3. Measure elemental mercury oxidation across CFB
    a. Using mercury speciating continuous emission monitors (CEMs) to determine mercury speciation across the CFB.
    b. Validate speciation with the Ontario Hydro method for Hg speciation.
4. Perform evaluation of the technical and economic feasibility of the process
    a. Technical evaluation.
    b. Economic evaluation – evaluate the overall economics of the process as well as determine the feasibility of using the heat produced in the process in the steam cycle.
5. Project coordination and reporting
    a. Conference calls.
    b. On-site meetings at the Energy & Environmental Research Center (EERC).
    c. Written reports will be provided on a quarterly basis, and a final report will be prepared that will include all results, interpretations, and conclusions of the project.

Deliverables

The deliverables for the project will include the most cost-effective means of producing a char, the effectiveness of NO_x reduction using lignite char, and the cost estimate of the overall process. The final report will include all results, interpretations, conclusions, and directions for future work.

STANDARDS OF SUCCESS

The standards by which the success of the project will be measured will include the ability of the technology to reduce NO_x and a comparison of the cost of the reduction to SCR processes. The NO_x reduction achieved in this project will be compared to results obtained in the bench-scale studies. If comparable reductions are achieved, the project will be considered successful. During the course of the project, standard quality assurance procedures will be implemented.

This project is required to be in compliance with the EERC Quality Management System and any project-specific quality assurance procedures, thus assuring that any requirements relating to quality and compliance with applicable regulations, codes, and protocols are adequately fulfilled. The EERC Quality Assurance Manager implements and oversees all aspects of quality assurance/quality control (QA/QC) for all research, development, and demonstration projects and will review the QA/QC components of this project. The EERC maintains a wide range of analytical and testing laboratories that follow nationally recognized or approved standards and methods put forth by the U.S. Environmental Protection Agency (EPA), American Society for Testing and Materials (ASTM), National Institute of Standards and Technology (NIST), and other agencies.

BACKGROUND

Introduction

In order to meet the regulation criteria, only SCR processes have been proven successful so far. However, this technology is fraught with numerous disadvantages. Some of the shortcomings of SCR are the high cost of catalysts, the need for an external reductant (ammonia) storage and handling system, catalyst poisoning by arsenic and sulfur dioxide leading to a shorter life, ammonia slippage, inability to adapt to changing load conditions, formation of low-temperature sulfate/phosphate deposits that blind catalysts, oxidation of SO_2 to SO_3, and formation of sticky chemicals (ammonium bisulfite) that complicate the downstream SO_x reduction processes and the plugging of the air preheater. However, only SCR has the high degree of NO_x reduction capability necessary to meet regulations and today sells for about $1000–$3000/ton of NO_x removed, depending on the application.

OSU, with the assistance of the EERC, has successfully developed another technology that has the same advantages as SCR without any of its associated problems. *This technology primarily involves the reaction between NO and carbon in a slightly oxidizing atmosphere.* The reaction occurs over the temperature range of 350°–700°C, thus providing a suitable alternative for the SCR system.

The carbon-based technology has many advantages. The NO is reduced to benign products such as nitrogen and carbon dioxide. The extent of NO reduction can be as high as 100%, depending on the contact time that can be provided between the flue gas and the solid carbonaceous reactants (usually tens to hundreds of milliseconds). The process is unaffected by the presence of known catalyst poisons and blinding agents that cause problems in SCR processes.

Lignite containing high levels of sodium (5%–12%, ash basis) occurs naturally in North Dakota. A steam-activated char from high-sodium lignite coal was produced by the EERC. Lignite coal has unique properties (high reactivity, high sodium) that lead to easier activation and yield a much higher surface area and porosity than other carbons tested at OSU. Figure 1 illustrates the NO reduction using high-sodium lignite char (HSLC) in a bench-scale reactor as a function of temperature. This char showed the best performance and proved very effective in reducing NO, even at 400°–500°C in the presence of 2% oxygen. The char requirement was calculated to be about 8–12 g carbon/g NO reduced, depending on the reaction conditions. The excellent performance of this char combined with the fact that it originates from a natural source

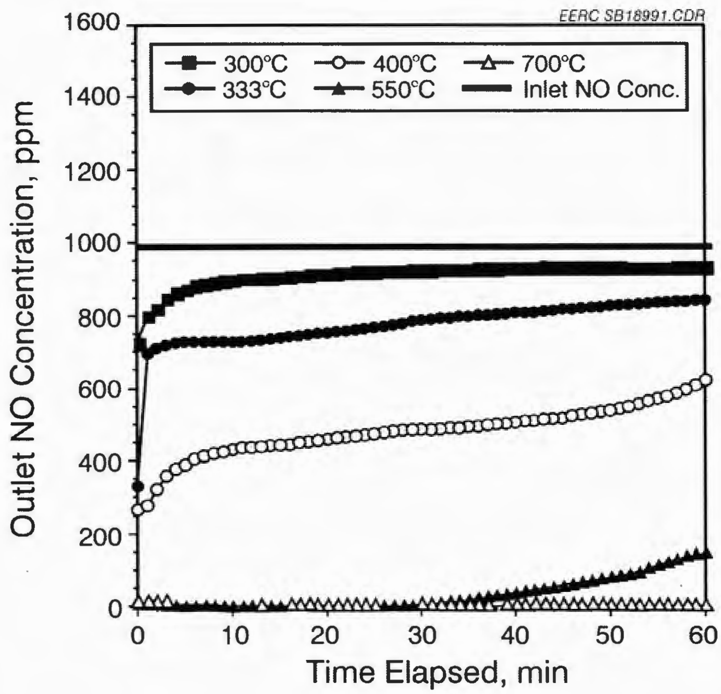

Figure 1. Effect of temperature on isothermal reduction of NO in high-sodium lignite char (flow: 1000 mL/min; inlet NO concentration: 1000 ppm; weight of carbon: 800 mg; oxygen concentration 2%).

and does not require the addition of other agents (sodium) can provide significant impetus to develop this technology further.

There are other advantages besides the ability of char to reduce NO effectively. The reaction, like most gasification reactions, is exothermic in nature. Preliminary calculations performed show that the heat output produced because of the reaction is substantial (about 5%–8% of the original heat output of the boiler). Economic analysis of this process was conducted, including all the necessary peripheral equipment and process requirements. The resulting cost of this technology is about $200–$1500/ton of NO_x reduced, which is as competitive as SCR on a similar basis. The analysis did not include the extra heat generation that leads to significant revenue generation.

NO_x Issues

High-temperature combustion of fossil fuels leads to the formation of a variety of oxides of nitrogen such as NO and NO_2, collectively known as NO_x. The oxidation of nitrogen (present in the combustion air) and the fuel-bound nitrogen (present in various heterocyclic polyaromatic compounds in coal) leads to the formation of NO_x. High combustion temperatures employed in pulverized coal combustion generally lead to the formation of NO. The oxidation of the emitted NO by atmospheric oxygen (photocatalytic reaction) and ozone leads to the formation of NO_2 at ambient temperature in the atmosphere. A third type of nitrogen oxide, N_2O, is formed as a result of low-temperature coal combustion as seen in fluidized-bed combustion.

The emission of NO_x has exceeded 20 million tons annually in the United States alone. Statistics show that besides transportation sources such as cars and trucks, which account for 45% of this figure, 32% of NO_x is emitted from thermal power plants. Internal combustion (IC) engines, industrial boilers, process heaters, and gas turbines complete the balance (Baumbach, 1996). The regulatory bodies have targeted the major sources of NO_x such as stationary power plants and automobiles for the past 15–20 years.

These gases have adverse effects on human and plant life and create well-documented pollution problems. NO forms methemoglobin in blood thereby reducing its oxygen-carrying capacity. NO_2 is a respiratory tract irritant. The conversion of NO_2 to nitric acid contributes to acid rain and its associated menace. It also oxidizes oxygen to ozone, which plays a key role in smog formation. N_2O has a long life in the atmosphere, and its accumulation increases the heat retention capacity of the atmosphere (greenhouse effect). Given these adverse effects, regulations to curb the emission of NO_x, which came into effect in 1969 for the first time in Ventura County, California, are continuously getting more stringent (Muzio, 1997). Most recently, 392 power plants in 22 states were ordered to curtail NO_x emissions by 50% by March 2003. This translates to a reduction in the NO_x emitted by about 500,000 tons at a cost of about $2000/ton NO_x reduced (Columbus Dispatch, December 11, 1999). The main reason cited for this action was that a positive correlation between the increase in the medical cases of respiratory system deficiencies and NO emissions could be established. In the face of the impending stringent NO_x regulations, economical NO_x removal from flue gas is thus essential for the long-term economic viability of the fossil fuel-based thermal power plants.

Extensive investigations have been done in the area of NO_x abatement. Primary measures target the reduction of NO_x in the combustion unit. These techniques involve lowering the combustion temperature by staged combustion, lower air preheating, flue gas recirculation, and the use of low-NO_x burners (Muzio, 1997). Although these modifications are relatively inexpensive, the percentage of NO_x reduction achieved by these primary measures is only 35%–60%, thus falling short of achieving compliance. These processes also lead to a higher level of unburned carbon in the fly ash, leading to a loss of thermal efficiency. Additional fuel can be injected over the combustion zone to create a reducing atmosphere where the fuel (coal/gas) reacts with NO to form N_2 and CO/CO_2 at a high temperature of about 1100°C (Chen and Ma, 1996, and Burch and others, 1994). This reburning technique leads to the formation of side products such as HCN and NH_3. The amount of reburning fuel can be as high as 30% of the total fuel and usually requires very fine sizing of the coal (80% under 325 mesh). This demonstration, conducted by New York State Electric & Gas Corporation, found that using 18.5% coal as a reburning fuel resulted in 56% NO_x emission.

Secondary measures such as selective noncatalytic reduction (SNCR) were introduced in 1970. SNCR involves the reduction of NO to nitrogen gas using reducing agents such as ammonia and urea at an optimum temperature in the 850°–1000°C range. However, being temperature sensitive, SNCR leads to ammonia slippage (at lower temperature) and conversion to NO itself (at higher temperature) (Gullet and others, 1992). To achieve compliance, complementary processes such as SCR were employed. SCR achieves similar NO_x reduction by catalysis. Some of the common catalysts employed include molecular sieves and metal and metal oxides supported on alumina, silica, or titania. These catalysts reduce the operating temperature of the reduction processes from 850°–1000°C to 280°–450°C. The SCR technique entails higher capital and operating costs due to the additional reductant and catalyst requirements (Cho, 1994). Other relatively benign reductants like CO, H_2, CH_4, and acetone suffer from higher selectivity to oxygen in the flue gas (Tsujimura and others, 1983a, b, and Jang and others, 1997). Mature SCR technologies also suffer from gas-phase poisons such as sulfur dioxide and arsenic, which lead to the formation of ammonium bisulfite, and oxidize sulfur dioxide to SO_3, complicating SO_x removal downstream. Being temperature sensitive, these technologies do not adapt well to changing boiler load conditions.

Carbon-based technologies have also been used for NO_x reduction. At high temperatures, micronized coal has been demonstrated as a reburning fuel in fossil fuel-fired boilers to reduce NO. Combined SO_x–NO_x processes have been developed where carbon is used as a catalyst for the reduction of NO with ammonia at temperatures below 200°C (Hjalmarsson and Soud, 1990). However, recent studies have spurred the development of another carbon-based technology. In this method, carbon is used as a reducing agent for NO_x reduction at a *substantially lower temperature* (300°–700°C) than that required by reburning. Moreover, the NO_x reduction takes place *in an oxidizing atmosphere* (0%–4 % oxygen), without requiring any external reducing agent. The majority of the carbonaceous reductant is consumed by oxygen. The primary challenge in commercializing technology would involve reducing the consumption of carbon (ton of carbon required per ton of NO reduced) by improving the selectivity of the carbon-NO reaction in the face of the other competing reactions, mainly the carbon–oxygen reaction. Figure 2 shows a schematic diagram of a power plant with a CFB containing the carbon-based material integrated between the economizer and air heater.

Catalysis of Carbon–NO Reaction

Some inorganic species catalyze the NO–carbon by lowering the reaction temperature. These inorganic constituents could be either inherently present or deliberately added to the carbon matrix. Chan and others (1983) observed that the char with high ash content catalyzed the NO_x reduction. They noted that the ash rich in ion-exchangeable calcium could be responsible for the catalytic effect. The EERC conducted research to determine the impact of nonexchangeable carbons on combustion values of lignite chars (McCollor and others, 1988). They found that

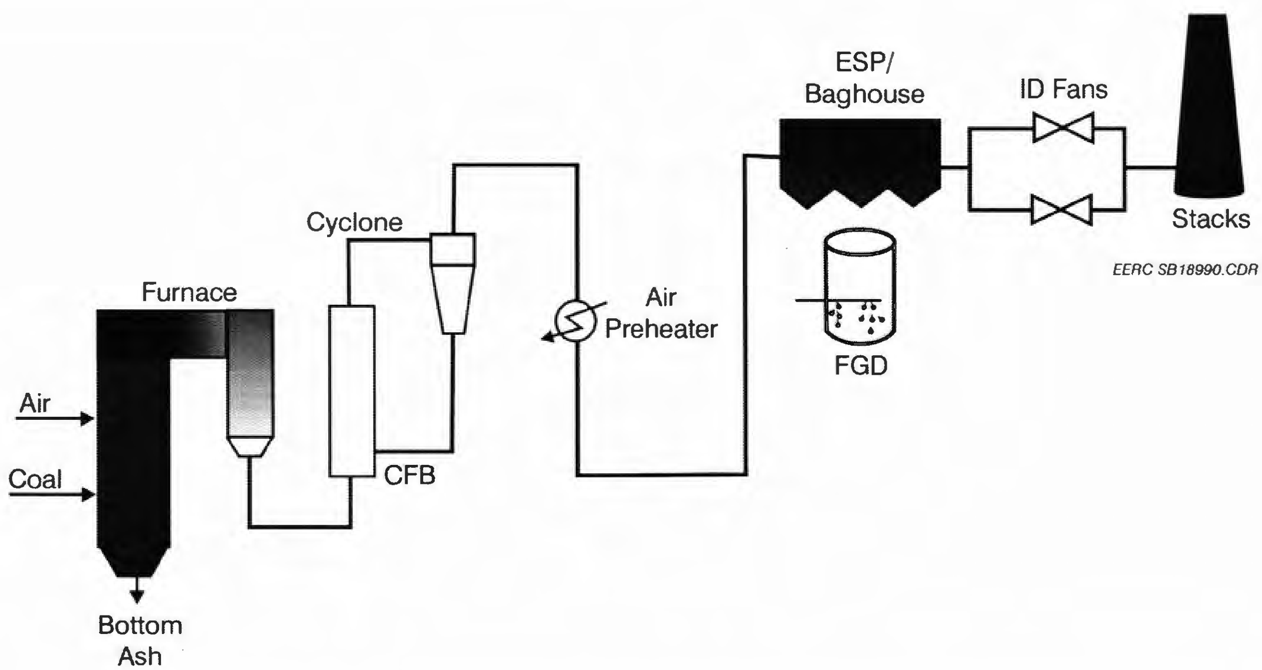

Figure 2. Integration of the CFB containing the carbon-based technology for NO_x reduction.

elements such as Ca, Na, and K catalyze the combustion, resulting in increased particle temperatures. The review paper (Aarna and Suuberg, 1997) reveals that demineralization of the coal char led to perceptible reduction in the rate of the NO reduction, sometimes the reduction being ten times lower than the parent char. Alkali and alkaline earth metals have been proven catalysts in coal gasification, water–gas shift reaction, and methanation of CO, which necessitate oxygen transfer between the gaseous reactant and carbon. With this premise, studies have been done on carbon impregnated with K, Ca, etc. The catalytic role of calcium in char oxidation has been well established through a series of studies involving impregnation/ion-exchange techniques (Radovic and others, 1983; Hengel and Walker, 1984; Levendis and others, 1989; and Gopalakrishnan and others, 1994). Researchers have shown that by integrating these inorganic species into the carbon matrix the NO–carbon interaction takes place via an alternate pathway, thus reducing the temperature of chemisorption (Kapteijn and others, 1984).

The role of metallic impregnates remains unclear. However, the consensus is that the first step involves the abstraction of the oxygen atom from a NO molecule by the metallic species. This metal–oxygen complex then passes the chemisorbed oxygen to the adjacent carbon species. This process provides an alternate route to the traditional direct abstraction of oxygen by the carbon surface. Hence, this alternate pathway catalyzes the reaction by lowering the activation barrier.

QUALIFICATIONS

A brief description of the qualifications of the principal investigator and other key personnel is listed below. Short resumes can be found in Appendix A.

Principal Investigator: Dr. Steven A. Benson, Senior Research Manager/Advisor at the EERC, will serve as Principal Investigator for the project. Dr. Benson holds a Ph.D. in Fuel

Science, Materials Science and Engineering from the Pennsylvania State University in 1987 and a B.S. in Chemistry from Minnesota State University, Moorhead, in 1977. Dr. Benson's principal areas of expertise include the management of complex multidisciplinary programs focused on solving energy production and environmental problems. Program areas 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) the fate and behavior of air toxic substances in combustion and gasification systems; 3) advanced analytical techniques to determine the chemical and physical transformations of inorganic species 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 designed to improve the global quality of life through energy and environmental research activities.

Co-Principal Investigator: Dr. Himanshu Gupta will be hired as a Research Engineer at the EERC if this project is awarded. Dr. Gupta holds a Ph.D. Chemical Engineering from OSU, a M.S. in Biochemical Engineering from Purdue University, and a B.S. in Chemical Engineering from the Indian Institute of Technology. Dr. Gupta has been involved in the development of a low-cost char-based technology for the complete reduction of NO_x emission from combustion flue gases. Dr. Gupta is one of the inventors of the patented technology. He has also conducted research involving the capture of trace toxic metals (selenium) on activated carbon sorbents, hot-gas cleanup technologies using regenerable sorbents for removal of hydrogen sulfide in advanced power generation systems (IGCC), and technology for the separation of carbon dioxide from combustion flue gas, and is writing a book with Professor Fan dealing with fine sorbent technologies for flue gas cleanup.

Co-Principal Investigator: Professor L.S. Fan, is a Distinguished University Professor and Chairman of the Department of Chemical Engineering at OSU. Professor Fan received his B.S. (1970) from National Taiwan University and his M.S. (1973) and Ph.D. (1975) from West Virginia University, all in Chemical Engineering. In addition, he earned a M.S. (1978) in Statistics from Kansas State University. His expertise is in fluidization and multiphase flow, powder technology, particulates, and multiphase reaction engineering. He is a consultant to 20 corporations, including Exxon, Shell, Amoco, Dupont, and Union Carbide. He is the U.S. Editor of the *International Journal of Powder Technology* and a consulting editor of the *AIChE Journal* and the *International Journal of Multiphase Flow*. He is also the Editor-in-Chief of the Particle Technology book series published by Elsevier as well as Noyes. Professor Fan is the founder of the International Conference Series on Gas–Liquid and Gas–Liquid–Solid Reactor Engineering and the founding Chairman of the Particle Technology Forum, an international organization under the aegis of the American Institute of Chemical Engineering (AIChe).

Co-Principal Investigator: Dr. Edwin Olson is a Senior Research Advisor at the EERC. He received his Ph.D. in Chemistry and Physics from the California Institute of Technology in 1964. Prior to taking a position at the EERC, Dr. Olson taught chemistry and biochemistry at South Dakota State University and has also taught at the University of Notre Dame and Idaho State University. Dr. Olson's principal areas of interest and expertise include carbon and coal structure and reactivity, mercury sorption chemistry, enzyme-catalyzed esterification and desulfurization reactions, chromatography, organic trace analysis, mass spectrometry, and organic spectroscopy. Dr. Olson is a member of several professional organizations, including the American Chemical Society and Sigma Xi. He has also authored or coauthored over 150 publications.

Other Assigned Personnel: Dr. Michael Swanson is a Senior Research Manager at the EERC. He is currently involved with the demonstration of advanced power systems such as pressurized fluidized-bed combustors and integrated gasification combined cycle, with an emphasis on hot-gas cleanup issues. Dr. Swanson received a Ph.D. in Energy Engineering in 2000, a M.B.A. in 1991, a M.S. in Chemical Engineering in 1982, and a B.S. in Chemical Engineering in 1981, all from the University of North Dakota. Dr. Swanson's principal areas of interest and expertise include pressurized fluidized-bed combustion, integrated gasification combined cycle, hot-gas cleanup, coal reactivity in low-rank coal combustion, supercritical solvent extraction, and liquefaction of low-rank coals. Dr. Swanson is a member of the American Institute of Chemical Engineers and the American Chemical Society. In addition, he has authored or coauthored over 70 publications.

Mr. Jason Laumb is a Research Engineer at the EERC. He received a M.S. in Chemical Engineering in 2000 and a B.S. in Chemistry in 1998, both from the University of North Dakota. Prior to his current position, Mr. Laumb served as a Scanning Electron Microscopy Applications Specialist with Microbeam Technologies, Inc. Mr. Laumb's principal areas of interest and expertise include predicting slag viscosity and boiler performance based on fuel quality and control technologies to remove mercury from combustion systems. He has coauthored several professional publications.

The work will be conducted at the EERC and Ohio State University. Description of the facilities at the EERC and OSU are summarized below.

EERC

The EERC is one of the world's major energy and environmental research organizations. Since its founding in 1949, the EERC has conducted research, testing, and evaluation of fuels, combustion and gasification technologies, emissions control technologies, ash use and disposal, analytical methods, groundwater, waste-to-energy systems, and advanced environmental control systems. Today's energy and environmental research needs typically require the expertise of a total-systems team that can focus on technical details while retaining a broad perspective.

OSU

The Reaction Engineering Laboratory is well equipped to perform experiments in the area of gas–solid reaction engineering. The laboratory facilities for char synthesis include:

- Electric tube and muffle furnaces for devolatilization
- Isotech water pump for steam activation
- Vacuum ovens, etc.

The progress of NO_x reduction by char can be followed using the following:

- Thermogravimetric analyzer (TGA)
- Chemiluminescence NO_x analyzer (NO/NO_2)
- $CO/CO_2/SO_2$ gas analyzers
- Oxygen analyzer
- Gas chromatograph
- In situ DRIFTS to track changes in surface composition of char
- Flowmeters, etc.

The char particle characterization would employ the following:

- Particle-size analyzer (Sedigraph)
- Morphological properties (BET 2000)
- TGA

VALUE TO NORTH DAKOTA

This project has the potential to enhance lignite use in two ways. The first is a technology for reduction of NO_x from cyclone-fired boiler. The second is to create a significant new market for lignite char. Based on laboratory results obtained on the reduction of NO_x by char at OSU, it can be concluded that a high-surface-area char with high alkali content would be the most suitable candidate. The total amount NO_x emissions in the United States from coal-fired power plants is estimated to be 6.5 million short tons (DOE, 2000). This technology has the potential to significantly increase the use of lignite-derived char to reduce the NO_x from lignite-fired boilers and may be exported to be used to reduce NO_x in other coal-fired facilities in the United States.

MANAGEMENT

Overall management of the project will be the responsibility of Dr. Benson. Dr. Benson will work closely with project sponsors and project team members to ensure the project is completed on time and within budget. An organizational chart for the project is shown in Figure 3.

A project kick-off meeting will be held at the EERC to initiate the project. Once the project is initiated, monthly or as-needed conference calls will be held with project sponsors and team members to review project status. Quarterly reports will be prepared and submitted to project sponsors for review. Two detailed project review meetings will be held at the EERC during the course of the project. The timing of those meetings will be held at key project milestones. A meeting at the end of the project will be held to review the findings and discuss directions for the project.

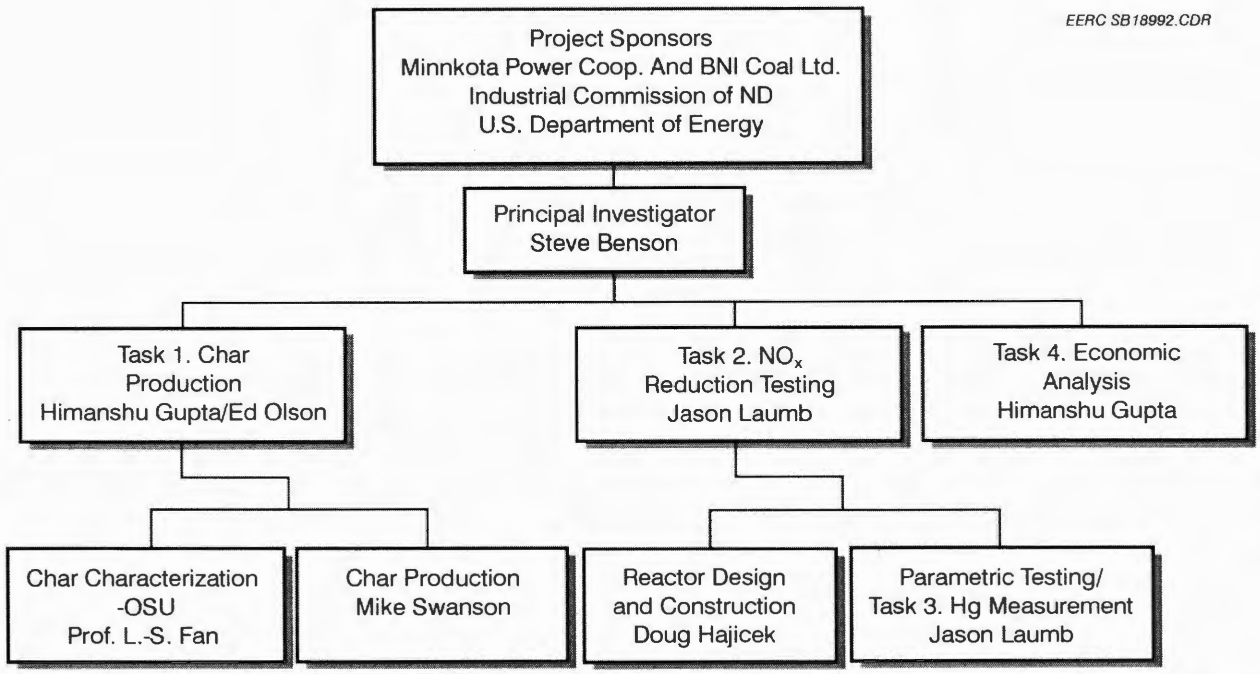

Figure 3. Project organizational chart.

SCHEDULE

The duration of the project is 2 years. Details of the project schedule and milestones are shown in Table 1. Table 2 contains a description of the milestones.

BUDGET

The costs of the project are shown in the attached budget breakdown. The costs of the project include the costs of equipment associated with the construction of a small CFBR system. The components included are listed in the detailed budget. Equipment to conduct some of the analysis necessary to the project is also being purchased by OSU and is summarized in the OSU budget.

MATCHING FUNDS

The proposed funding sources for the project are shown in Table 3.

TABLE 1

Overall Project Schedule

Project Year	Year 1	Year 2
Project Month	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12
Task 1. Char Production		
a. Identify high-sodium lignite types	1 2	
b. Select lignite types for testing	1 2 3 4	
c. Produce chars in 4-lb/hr reactor	1 2 3	4
d. Characterize chars	1 2 3	4
e. Conduct bench-scale testing at OSU	1 2 3	4
Task 2. NO_x Reduction Testing Using Selected Chars		
a. Design and construct CFB for CEPS	1 2	
b. Shakedown testing the CEPS–CFB combination	1	
c. Parametric testing of char in CFB with baseline coal		1 2 3 4
d. Determine heat release during NO_x conversion		1
Task 3. Measure Elemental Mercury Oxidation Across CFB		
a. Determine mercury speciation across CFB for lignite		1 2
b. Validate speciation with the Ontario Hydro method		1
Task 4. Perform Evaluation of the Technical and Economic Feasibility of the Process		
a. Technical evaluation		1
b. Economic evaluation		1
Task 5. Project Coordination and Reporting		
a. Conference calls or meetings	1 2 3 4 5	6 7 8 9
b. On-site EERC meetings – at key milestones	1 2	3 4
c. Reporting	1 2 3 4	5 6 7 8

TABLE 2

Description of Milestones

Task 1. Char Production
a. Identify high-sodium lignite types
1. Conduct coring of lignite to obtain fresh samples for analysis
2. Complete chemical analysis of samples
b. Select lignite types for testing
1. Select and collect first lignite sample for complete testing in CEPS/CFB
2. Select and collect second lignite sample for complete testing in CEPS/CFB
3. Select and collect third lignite sample for complete testing in CEPS/CFB
4. Select and collect fourth lignite sample for complete testing in CEPS/CFB
c. Produce chars in 4-lb/hr reactor
1. Perform shakedown testing of 4-lb/hr reactor for pyrolysis and steam activation for first coal
2. Perform pyrolysis and steam activation of second coal
3. Perform pyrolysis and steam activation of third coal
4. Perform pyrolysis and steam activation of fourth coal
d. Characterize chars
1. Perform surface area and porosity measurements of first coal
2. Perform surface area and porosity measurements of second coal
3. Perform surface area and porosity measurements of third coal
4. Perform surface area and porosity measurements of fourth coal
e. Conduct bench-scale testing at OSU
1. Test the first char using OSU bench-scale reactor to determine potential for NO_x reduction and comparison to past studies
2. Test the second char using OSU bench-scale reactor to determine potential for NO_x reduction and comparison to past studies
3. Test the third char using OSU bench-scale reactor to determine potential for NO_x reduction and comparison to past studies
4. Test the fourth char using OSU bench-scale reactor to determine potential for NO_x reduction and comparison to past studies
Task 2. NO_x Reduction Testing Using Selected Chars
a. Design and construct CFB for CEPS
1. Design CFBR
2. Complete construction of the CFBR
b. Shakedown testing the CEPS–CFB combination
1. Complete shakedown testing with baseline coal

Continued . . .

TABLE 2 (continued)

c. Parametric testing of chars in CFB with baseline coal
1. Determine the impact of CFB temperature on the conversion of NO
2. Determine the impact contact time in the CFB on the conversion of NO
3. Determine the impact of char particle size on the conversion of NO in CFB
4. Determine the impact oxygen concentration on the conversion of NO in CFB
d. Determination of heat release resulting from NO_x reduction
Task 3. Measure Elemental Mercury Oxidation Across CFB
a. Determine mercury speciation across CFB for lignite
1. Complete testing for lignite
b. Validate speciation with the Ontario Hydro method
1. Complete validation of CEM measurements
Task 4. Perform Evaluation of the Technical and Economic Feasibility of the Process
a. Technical evaluation
1. Complete detailed evaluation of the technical feasibility of the process
b. Economic evaluation
1. Complete economic evaluation of the technical feasibility of the process
Task 5. Project Coordination and Reporting
a. Conference calls or meetings
b. On-site meetings at EERC Kickoff and at key milestones (2, 3)
c. Reports – Quarterly and Final

TABLE 3

Project Funding

Funding Source	Amount
North Dakota Industrial Commission	$320,000
EERC through EERC–DOE Cooperative Agreement	$380,000
BNI Coal Ltd. – Cash	$40,000
BNI Coal Ltd. – Cash–Equivalent Cost Share	$240,000
Minnkota Power Cooperative – Cash	$40,000
Total Project Cost	$1,020,000

TAX LIABILITY

None.

CONFIDENTIAL INFORMATION

None.

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BUDGET

LOW TEMPERATURE NOx REDUCTION USING
HIGH SODIUM LIGNITE-DERIVED CHARS
NDIC/MINNKOTA-BNI/DOE
PROPOSED START DATE: 09/01/01
EERC PROPOSAL #2001-0080

	CHAR PRODUCTION TASK 1		NOx REDUCTION TESTING USING SELECTED CHAR TASK 2		MEASUREMENT O Hg OXIDATION ACROSS CFB TASK 3		TECHNICAL AND ECONOMIC FEASIBILITY TASK 4		PROJECT COORDINATION AND REPORTING TASK 5		PROJECT TOTAL: TOTAL		PROJECT TOTAL: NDIC SHARE		PROJECT TOTAL: MINNKOTA/BNI COMMERCIAL SHARE		PROJECT TOTAL: EERC JSRP SHARE	
CATEGORY	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**	**HRS**	**$ COST**
DIRECT LABOR	1,989	$56,117	4,498	$127,557	860	$27,249	968	$29,696	1,252	$37,923	9,567	$278,542	3,412	$99,213	1,228	$34,944	4,927	$144,385
FRINGE BENEFITS		$18,197		$42,689		$9,573		$10,894		$11,782		$93,135		$34,489		$13,009		$45,637
TOTAL LABOR		$74,314		$170,246		$36,822		$40,590		$49,705		$371,677		$133,702		$47,953		$190,022
OTHER DIRECT COSTS																		
TRAVEL		$2,818		$2,818		$2,818		$0		$876		$9,330		$3,432		$870		$5,028
SUPPLIES		$2,000		$3,250		$500		$200		$100		$6,050		$2,306		$514		$3,230
EQUIPMENT > $5,000		$0		$50,000		$0		$0		$0		$50,000		$0		$0		$50,000
COMMUNICATIONS - PHONES & POSTAGE		$500		$790		$0		$249		$546		$2,085		$992		$409		$684
OFFICE (PROJECT SPECIFIC SUPPLIES)		$700		$1,300		$0		$600		$1,060		$3,660		$1,325		$404		$1,931
REPAIRS		$0		$2,000		$0		$0		$0		$2,000		$300		$200		$1,500
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)		$750		$1,702		$0		$0		$0		$2,452		$1,140		$300		$1,012
FEES (AND SUBCONTRACTS)		$57,094		$42,672		$1,013		$0		$0		$100,779		$76,860		$1,298		$22,621
TOTAL OTHER DIRECT COST		$63,862		$104,532		$4,331		$1,049		$2,582		$176,356		$86,355		$3,995		$86,006
TOTAL DIRECT COST		$138,176		$274,778		$41,153		$41,639		$52,287		$548,033		$220,057		$51,948		$276,028
INDIRECT COST - % OF MTDC											VAR	$231,967	54%	$99,943	54%	$28,052	46%	$103,972
TOTAL EERC COST												$780,000		$320,000		$80,000		$380,000
CASH EQUIVALENT CONTRIBUTION - BNI												$240,000		$0		$240,000		$0
TOTAL PROJECT COST												$1,020,000		$320,000		$320,000		$380,000

NOTE: Due to limitations within the University's accounting system, the system does not provide for accumulating and reporting expenses at the task level. The Project Total Columns are presented for the purpose of how we propose, account, and report expenses by sponsor. The Task levels are presented to assist in the evaluation of the proposal.

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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. 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. Financial reporting will be at the total project level.

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 indirect cost of the EERC.

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 include estimated 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 indirect 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 and analytical fees are established and approved at the beginning of each fiscal year, and charges are based on a per sample or hourly rate depending on the analytical services performed. Additionally, laboratory analyses may be performed outside the University when necessary.

Graphics services 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.

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

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Indirect Cost

The indirect cost rate included in this proposal is the rate that became effective July 1, 1995. Indirect 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 of each award.

BUDGET

LOW TEMPERATURE NO_x REDUCTION USING
HIGH SODIUM LIGNITE-DERIVED CHARS
NDIC/MINNKOTA-BNI/DOE
PROPOSED START DATE 09/01/01
EERC PROPOSAL #2001-0080

CATEGORY	CHAR PRODUCTION TASK 1 HRS	CHAR PRODUCTION TASK 1 $ COST	NOx REDUCTION TESTING USING SELECTED CHAR TASK 2 HRS	NOx REDUCTION TESTING USING SELECTED CHAR TASK 2 $ COST	MEASUREMENT O Hg OXIDATION ACROSS CFB TASK 3 HRS	MEASUREMENT O Hg OXIDATION ACROSS CFB TASK 3 $ COST	TECHNICAL AND ECONOMIC FEASIBILITY TASK 4 HRS	TECHNICAL AND ECONOMIC FEASIBILITY TASK 4 $ COST	PROJECT COORDINATION AND REPORTING TASK 5 HRS	PROJECT COORDINATION AND REPORTING TASK 5 $ COST
DIRECT LABOR	1,989	$56,117	4,498	$127,557	860	$27,249	968	$29,696	1,252	$37,923
FRINGE BENEFITS		$18,197		$32,689		$9,573		$10,894		$11,782
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OTHER DIRECT COSTS										
TRAVEL		$2,818		$2,818		$2,818		$0		$876
SUPPLIES		$2,000		$3,250		$500		$200		$100
EQUIPMENT > $5,000		$0		$50,000		$0		$0		$0
COMMUNICATIONS - PHONES & POSTAGE		$500		$790		$0		$249		$546
OFFICE (PROJECT SPECIFIC SUPPLIES)		$700		$1,300		$0		$600		$1,060
REPAIRS		$0		$2,000		$0		$0		$0
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)		$750		$1,702		$0		$0		$0
FEES (AND SUBCONTRACTS)		$57,094		$42,672		$1,013		$0		$0
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INDIRECT COST - % OF MTDC										
TOTAL EERC COST										
CASH EQUIVALENT CONTRIBUTION - BNI										
TOTAL PROJECT COST										

CATEGORY	PROJECT TOTAL: TOTAL HRS	TOTAL $ COST	NDIC SHARE HRS	NDIC SHARE $ COST	MINNKOTA/BNI COMMERCIAL SHARE HRS	MINNKOTA/BNI COMMERCIAL SHARE $ COST	EERC JSRP SHARE HRS	EERC JSRP SHARE $ COST
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OTHER DIRECT COSTS								
TRAVEL		$9,330		$3,432		$870		$5,028
SUPPLIES		$6,050		$2,306		$514		$3,230
EQUIPMENT > $5,000		$50,000		$0		$0		$50,000
COMMUNICATIONS - PHONES & POSTAGE		$2,085		$992		$409		$684
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