EERC
Energy & Environmental Research Center
UNIVERSITY OF NORTH DAKOTA
15 North 23rd Street — PO Box 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181
Web Site: www.undeerc.org

March 27, 2003

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

Dear Ms. Fine:

Subject: EERC Proposal No. 2003-0126

Enclosed are the original and six copies of the proposal entitled "Pilot- and Full-Scale Demonstration of Advanced Mercury Control Technologies for Lignite-Fired Power Plants." The lignite-fired power industry has been proactive in advancing the understanding of and identifying control options for mercury in coal combustion flue gases. Approximately 1 year ago, the EERC began a series of Hg-related discussions with the North Dakota Mercury Task Force. This proposal is submitted on behalf of these industry partners to address the challenges to be met in controlling mercury emissions from lignite-fired power plants. Also enclosed is the $100 application fee.

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

Sincerely,

Steven A. Benson
Senior Research Manager

SAB/cs

Enclosures

c/enc: Harvey Ness, Lignite Research Council

EERC
Energy & Environmental Research Center

UNIVERSITY OF NORTH DAKOTA

15 North 23rd Street — PO Box 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181
Web Site: www.undeerc.org

June 27, 2003

Ms. Karlene K. Fine
Executive Director and Secretary
Industrial Commission of North Dakota
State Capitol, 10th Floor – Dept. 405
600 East Boulevard Avenue
Bismarck, ND 58505-0840

Dear Karlene:

Subject: NDIC Agreement FY03-XLIX-120, Pilot- and Full-Scale Demonstration of Advanced Mercury Control Technologies for Lignite-Fired Power Plants
UND Funds 4971 and 4972

Enclosed is one fully executed original of the subject agreement that has been signed by an authorized official of the University of North Dakota Energy & Environmental Research Center.

If you have any questions or require further information, please contact me at (701) 777-5271 or via e-mail at tolarson@undeerc.org. Thank you for your assistance in getting this agreement to us so promptly. Your help is greatly appreciated.

Sincerely,

Tobe M. Larson
Contracts Officer
Business and Operations

TML/jdk

Enclosure

c: Tom Erickson, EERC
John Hendrikson, EERC
Steve Benson, EERC

Energy & Environmental Research Center

PILOT- AND FULL-SCALE DEMONSTRATION OF ADVANCED MERCURY CONTROL TECHNOLOGIES FOR LIGNITE-FIRED POWER PLANTS

EERC Proposal No. 2003-0126

Submitted to:

Ms. Karlene Fine

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

Amount of Request: $150,000

Submitted by:
Steven A. Benson
Kevin C. Galbreath
Michael J. Holmes
Jason D. Laumb
John H. Pavlish
Li Yan
Ye Zhuang
Jill M. Zola

Energy & Environmental Research Center
University of North Dakota
PO Box 9018
Grand Forks, ND 58202-9018

Steven A. Benson, Project Manager

Dr. William D. Gosnold Jr., Interim Director
Office of Research and Program Development

March 2003

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ABSTRACT

The overall objective of the project is to test innovative Hg control technologies to reduce Hg emissions by 50%–90% in flue gases from ND lignite-fired power plants at costs of ½ to ¾ of current estimated costs. ND lignite-derived flue gases contain >85% Hg^0, which is difficult to control in existing air pollution control devices and less reactive with injected sorbents compared to oxidized forms of Hg. The objectives are focused on determining the feasibility of Hg oxidation for increased Hg capture in wet and dry scrubbers, incorporation of additives and technologies that enhance Hg sorbent effectiveness in electrostatic precipitators (ESPs) and baghouses, use of amended silicates in lignite-derived flue gases for Hg capture, and use of Hg adsorbents within a baghouse. The approach involves of pilot- and full-scale testing. Pilot-scale work will be conducted to test Hg capture upstream of an ESP using sorbent enhancement and Hg oxidation and control with a dry scrubber. Full-scale work will test the impact of cofiring tire-derived fuel on Hg oxidation and capture in an ESP. Full-scale slipstream testing of a low-temperature catalyst to oxidize Hg and the control of Hg using a baghouse insert will be performed.

The total project cost is $1,300,000. $1,000,000 is requested from DOE, utility sponsors providing aggregate funding of $100,000 include Minnkota Power, Basin Electric Power Cooperative, Otter Tail Power Company, Great River Energy, Montana–Dakota Utilities, BNI Coal Ltd., Westmoreland, and North American Coal Company; equipment vendors providing in-kind cost share totaling a minimum of $50,000 include W.L. Gore & Associates, ADA Technologies, Haldor-Topsoe, ALSTOM, and Babcock & Wilcox; and $150,000 is requested from NDIC.

PILOT- AND FULL-SCALE DEMONSTRATION OF ADVANCED MERCURY CONTROL TECHNOLOGIES FOR LIGNITE-FIRED POWER PLANTS

PROJECT SUMMARY

North Dakota lignite-fired power plants have shown a limited ability to control Hg emissions in currently installed electrostatic precipitators (ESPs), dry scrubbers, and wet scrubbers (1). This low level of control can be attributed to the high proportions of Hg^0 present in the flue gas. Speciation of Hg in flue gases analyzed as part of the U.S. Environmental Protection Agency (EPA) information collection request (ICR) for Hg data showed that Hg^0 ranged from 56% to 96% and the oxidized Hg ranged from 4% to 44%. The Hg emitted from power plants firing ND lignites ranged from 45% to 91% of the total Hg, with the emitted Hg being greater than 85% elemental. The higher levels of oxidized Hg were only found in a fluidized-bed combustion system. Typically, the form of Hg in the pulverized and cyclone-fired units was dominated by Hg^0 being greater than 85% elemental, and the average emitted from ND power plants is 6.7 lb/TBtu (1, 2).

The overall objective of this Energy & Environmental Research Center (EERC) project is to develop and evaluate advanced and innovative concepts for controlling Hg emissions from ND lignite-fired power plants by 50% to 90% at costs of ½ to ¾ of current estimated costs. The specific objectives are focused on determining the feasibility of the following technologies: Hg oxidation for increased Hg capture in wet and dry scrubbers, incorporation of additives and technologies that enhance Hg sorbent effectiveness in ESPs and baghouses, use of amended silicates in lignite-derived flue gases for Hg capture, and use of Hg adsorbents within a baghouse.

The scientific approach to solving the problems associated with controlling Hg emissions from lignite-fired power plants involves conducting testing of processes and technologies that

have shown promise on a bench, pilot, or field scale: 1) ACI injection upstream of an ESP combined with sorbent enhancement, 2) Hg oxidation and control using wet and dry scrubbers, 3) enhanced oxidation at a full-scale power plant using tire-derived fuel (TDF) and oxidizing catalysts, and 4) testing of Hg control technologies in the *Advanced Hybrid*™ filter insert.

PROJECT DESCRIPTION

Goals and Objectives

The overall objective is to test advanced innovative mercury control technologies to reduce Hg emissions from ND lignite-fired power plants by 50% to 90% at costs of ½ to ¾ of current estimated costs. Power plants firing ND lignite produce flue gases that contain >85% Hg^0, which is difficult to collect. The specific objectives are focused on determining the feasibility of the following technologies: Hg oxidation for increased Hg capture in wet and dry scrubbers, incorporation of additives and technologies that enhance Hg sorbent effectiveness in ESPs and baghouses, use of amended silicates in lignite-derived flue gases for Hg capture, and use of Hg adsorbents within a baghouse.

Work Plan

The work plan for this proposed project consists of six tasks outlined as follows:

- Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs
- Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers
- Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation
- Task 4 – Particulate and Mercury Control for ND Lignites Using the *Advanced Hybrid*™ Filter Technology
- Task 5 – Field Testing of Sorbents and Gore Technology
- Task 6 – Project Reporting and Management

It is anticipated that the U.S. Department of Energy (DOE) funding for this project will occur in increments of $300,000 and $700,000, thus the work plan has been delineated into two phases. Phase I of the project will consist of a portion of Task 2, Task 5, and Task 6 and Phase II will consist of the remainder of the work plan.

PHASE I

Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers

Task 2.1 – Pilot-Scale Spray Dryer Absorber (SDA) Refurbishment. An existing pilot-scale SDA will be refurbished and modified to simulate the SDAs used in some ND power plants.

Task 2.2 – Elemental Mercury Oxidation Additives. Potential Hg^0 oxidation additives will be evaluated using the PTC equipped with the refurbished SDA. Pilot-scale testing will involve a ND lignite coal with short-term (1–2-hr) screening tests of several oxidation additives including chloride compounds (e.g., sodium chloride, hydrogen chloride, copper chloride) and potassium iodide, followed by long-term (8–10-hr) evaluations of two or more of the most promising additives. In most cases, the additives will be blended with the coals. Gaseous hydrogen chloride will be injected into the PTC.

Hg^0 and total Hg levels will be measured on a nearly continuous basis using a continuous emission monitor (CEM) at the inlet and outlet locations of the SDA. Slaked lime slurry feed and the SDA product solids will be analyzed for Hg content. Additive blend ratios and injection rates will be varied to evaluate the effectiveness of additives to oxidize Hg^0. Economic analyses will be performed for the additives that are most effective.

Task 5 – Field Testing of Sorbents and Gore Technology

This task will test how effectively Hg can be captured by using a sorbent-based technology and the recently announced Gore technology in conjunction with a baghouse at a power plant in North Dakota. The Gore technology consists of a proprietary baghouse insert downstream of the fabric filter that has shown a high potential to control Hg. An existing baghouse will be skid-mounted and transported to a power plant in North Dakota and connected in slipstream fashion to allow for testing actual flue gases. Additions to the existing baghouse unit for remote field application will include a control room for remote operation, piping and flanges for connection to plant ductwork, a variable-speed fan, and a sorbent injection system for Hg control.

The skid-mounted baghouse will be installed downstream of an existing particulate control device at a plant determined by the ND Mercury Task Force. The proposed plan will test the Gore technology first, followed by sorbent injection tests. The Gore technology will be installed, tested, and monitored for Hg capture effectiveness. Inlet and outlet Hg measurements will be taken using the Ontario Hydro (OH) procedure during the first week only. Following the first week of testing, Hg sampling will be conducted at 2 weeks, 2 months, and 4 months. For these measurements, EPA Method 101A will be used to determine the total Hg (only) removed across the baghouse system. CEMs at the inlet and outlet will also be used for a 1-week interval at the beginning and end, along with the 101A sampling activities. At the end of the 4-month test, the Gore technology will be removed. Subsequently, the sorbent injection system will begin injecting a sorbent determined by the ND Hg Task Force. This test is planned to last 1 week and will involve injecting the sorbent at selected rates at the inlet to the skid-mounted baghouse. During this period, CEMs will be operated and OH sampling will be conducted.

Results from the tests will be reduced, compiled, interpreted, and reported. Mercury removal efficiencies for both the sorbent-based and Gore technologies will be calculated, compared, and reported.

Task 6 – Project Reporting and Management

This task will involve coordination of all testing conducted within the various tasks and subtasks of the project. During the course of the project, meetings will be held involving the PIs and Co-PIs to ensure communication and joint planning of tests. Reporting will consist of regular meetings with sponsors and project participants, quarterly reports, and a final report.

PHASE II

Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs

This task will evaluate and further the ability to control Hg emissions in lignite-fired power systems equipped with an ESP, as well as provide valuable information for enhancing Hg control in other unscrubbed systems. Testing will be performed using sorbent injection on the EERC's particulate test combustor (PTC) (580-MJ/hr [550,000-Btu/hr] pulverized coal-fired unit) equipped with an ESP to evaluate Hg sorbent effectiveness in coal combustion flue gases.

This task will include testing for a full week with up to two ND lignite coals with one activated carbon and the ADA-amended silicate. In addition, a sorbent enhancement technology developed by ALSTOM Power, Inc., will be used to enhance a sorbent for injection in the flue gas duct upstream of the ESP. During activated carbon injection (ACI), several additives and sorbent enhancements will be tested to quantify the improvements in Hg removal with each. The initial testing will involve shorter-term screening tests for evaluation of the sorbent enhancement additives (roughly two per day). Initial ACI testing will include ramping up the sorbent injection rate stepwise to generate results of removal efficiency as a function of injection rate for the test coal. The sorbent injection rate will then be adjusted back down to a value that provides moderate Hg removal (roughly 50%) and held at that point while gradually introducing a given additive to determine the improvement in removal efficiency. A final full-day test will be performed to obtain longer-term results on the performance of a selected additive. This final additive will be selected based on performance during screening tests and with consideration of cost, availability, and any issues associated with use in a utility system. Based on the test results, initial economic evaluations will be performed to determine the cost savings per pound of Hg removal in comparison to the baseline case of ACI without additives.

Throughout testing, two mercury CEMs, also referred to as continuous mercury monitors (CMMs), will be used to measure the Hg levels and to periodically determine the vapor-phase speciation upstream of the carbon injection system and downstream of the ESP. OH sampling will be used to validate the CEM measurements and provide ESP particulate capture efficiency and full Hg speciation information. A total of ten OH measurements are planned, with four at the inlet and six at the outlet. EPA Method 26A measurements will be performed upstream of the carbon injection system to measure the chloride levels for two of the tests.

Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers

Task 2.1 – Pilot-Scale Spray Dryer Absorber (SDA) Refurbishment

Task 2.2 – Elemental Mercury Oxidation Additives. Tasks 2.1 and 2.2 will be completed in Phase I of the project.

Task 2.3 – Sorbent Injection. NORIT Americas Inc., DARCO® FGD, and lignite-based activated (steam activated at 800°C, 1472°F) Luscar char (derived from Fort Union lignite) will also be injected upstream of the SDA while burning a ND lignite in the PTC. One of the sorbents will be pretreated with an EERC proprietary material to enhance its sorption capacity. Flue gas desulfurization (FGD), activated Luscar char, and the pretreated sorbent will be injected in the absence and presence of the most effective Hg^0 oxidation additive identified in Task 2.2. In addition, a proprietary sorbent enhancement technology developed by ALSTOM will be tested. CEMs will be used to measure Hg^0 and total Hg at the inlet and outlet of the SDA during each test. After each test, slaked lime slurry feed and the SDA product solids will be analyzed for Hg and carbon contents.

Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation

Task 3.1 – Impacts of Cofiring Tire-Derived Fuels. The efforts in this subtask involve testing the ability of cofiring TDF with ND lignite to increase the oxidized and particulate forms of mercury at a fluid-bed-fired power plant (Montana–Dakota Utilities Heskett Station Unit 2, 85 MW, ESP). Testing will include a baseline run firing 100% lignite at full load and up to 10% TDF (Btu basis). Chip size of the TDF will be less than 1 × 1 in. in order to completely burn out in the fluidized bed. Hg species levels in the flue gas phase (elemental vs. oxidized and particulate bound) will be measured at the inlet and the outlet of the ESP by the OH method with and without cofiring the TDF. In addition, EPA Method 26A measurements will be performed to determine the chloride levels for both of the tests. Coal and TDF will be sampled and analyzed for basic proximate, ultimate, sulfur, and ash compositional analysis. Levels of Cl, Zn, and Hg will also be determined in the coal and TDF since Cl and Zn likely contribute to Hg oxidation. Total Hg collection efficiency of the ESP and the Hg speciation information will be determined.

Task 3.2 – Impacts of Oxidation Catalysts – Coyote Station Slipstream Testing. This task involves testing a Hg oxidation agent. Maghemite combined with very small amounts of HCl has been shown to oxidize Hg^0 in simulated flue gases. Currently, a slipstream reactor to test NO_x reduction catalysts is being installed at Otter Tail Power's Coyote Station in North Dakota under an existing EERC project. In Task 3.2, maghemite will be incorporated into a catalyst matrix by Haldor-Topsoe and placed into the reactor. Small amounts of HCl will be added, and the impact on Hg speciation will be measured across the reactor by CEMs and OH measurements. Only two OH samples will be taken (1 per day). The remaining Hg analyses will be done with a CEM.

Task 4 – Particulate and Mercury Control for ND Lignites Using the Advanced Hybrid™ Technology

The task includes reconfiguring the PTC with an ESP followed by the Advanced Hybrid system to simulate a full-scale retrofit system. The single-wire tubular ESP will be operated at slightly reduced power to simulate the first one or two ESP fields in a full-scale system, with a goal of removing approximately 90% of the fly ash. Flue gas exiting the ESP with a reduced fly ash level will be routed to the pilot-scale (200-acfm) Advanced Hybrid™ unit.

Two sorbents (activated carbon and silicate-based sorbent) will be injected near the Advanced Hybrid™ inlet. Both continuous and batch injection modes will be tested at a flue gas temperature of 300°F. Specific sorbent injection rates will be determined based on the measured Hg concentration in flue gas. For continuous injection, the feed rate will be varied from 2500–12,000 lb sorbent/lb Hg, and for batch injection the ratio will be set at 6000:1. The sorbent that shows the best performance will be tested at a higher flue gas temperature of 400°F both in continuous and batch injection modes. Mercury CEMs will be used to measure Hg^0 and total Hg vapor at the ESP inlet, Advanced Hybrid™ inlet, and Advanced Hybrid™ outlet. Mercury sampling with the OH method will be conducted to provide Hg species information, dust loading, and particulate collection efficiencies for the retrofit Advanced Hybrid™ unit. EPA Method 26A samples will be carried out at the Advanced Hybrid™ inlet to determine the chloride level in flue gas entering into the Advanced Hybrid™ unit. Results from the tests will be reduced, compiled, interpreted, and reported. Mercury removal efficiencies for both sorbents will be calculated, compared, and reported across the ESP, the Advanced Hybrid™, and the ESP–Advanced Hybrid™.

Task 5 – Field Testing of Sorbents and Gore Technology

This task will be completed in Phase I of the work plan.

Task 6 – Project Reporting and Management

This task will involve coordination of all testing conducted within the various tasks and subtasks of the project. During the course of the project, meetings will be held involving the principal investigators (PIs) and Co-PIs to ensure communication and joint planning of tests. Reporting will consist of regular meetings with sponsors and project participants, quarterly reports, and a final report.

DELIVERABLES

Quarterly reports and a final report will be prepared as the key project deliverables. In addition, quarterly meetings will be held with the ND Hg Task Force members and the U.S. Department of Energy (DOE) to provide updates on progress and accomplishments.

STANDARDS OF SUCCESS

The overall success of the project will be based on the ability to demonstrate the feasibility of mercury oxidation and control in pilot-scale and field testing. The success of the control technologies will be based on their ability to control the emissions of mercury by up to and potentially exceeding 90% control. The ability to assess the success of the control technologies is based primarily on the EERC's quality management system.

To ensure successful projects, the EERC adheres to an organizationwide quality management system (QMS). It is authorized and supported by EERC management to define the requirements and the organizational responsibilities necessary to fulfill governmental and client requirements relating to quality assurance/quality control (QA/QC), applicable regulations, codes, and protocols. Table 1 outlines project QC. Specific to the measurement and control of mercury emissions, the following quality parameters have been defined.

Table 1. Project Quality Measures

QA/QC Control Measure	Purpose/Clarification
EERC QMS, including *Quality Manual* and quality policy and procedures.	Ensure organizationwide compliance with QMS and applicable regulations, codes, and protocols – based on ISO9000 standards. Authorized and supported by EERC top management.
Project-Independent QA Manager at the EERC (David Brekke).	Assist research managers to plan QA for projects, does reviews and random audits for compliance assurance
Perform Hg mass balance with values 100% ± 20%.	Determine total amount of Hg to be accounted for and determine removal rates: measured at inlet to air pollution control device (APCD) and stack. Also based on coal Hg and F_d factors.
EERC expertise in OH method and Hg CEM sampling.	Understand potential problems that can occur, troubleshoot, ability to get valid data under difficult conditions.
OH field and blank analysis in on-site mobile laboratory.	Determine if contamination exists in sampling conditions and if recovery is complete. Rapid feedback allows immediate action to correct problems in the field.
Hg CEM calibrations – at least daily. If target not met, may require that additional calibration or maintenance be done and repeat QA/QC check.	PS Analytical: sample clean air drawn through carbon trap followed by injecting known Hg standard. This procedure is done four times to determine scatter (internal QA/QC EERC standard is that $R^2 = 0.999$).
OH samples compared to CEM data.	After calibration, two concurrent OH samples taken that should be ±20% of CEM data taken during period.
Chain-of-custody procedures.	Ensure integrity of samples at all steps, including sample identification, analysis, and storage.
Interim team audit: URS to QA/QC one EERC plant and vice versa.	Use expertise of team members to ensure consistent quality. Double check analytical systems.
Team direction by consortium and DOE	Ensure that communication issues and problems are addressed to ensure objectives of project are attained.
Quarterly conference calls (or as needed).	Ensure effective communications between all team members, address developing issues, resolve problems.
Information transfer via ftp site.	Allows efficient transfer of data between team members.

The most important aspect of QA/QC is the expertise of the team conducting mercury measurements. The EERC research personnel are highly trained and experienced using the OH sampling method, having conducted hundreds of sampling tests. In fact, the EERC was involved in development and validation of the OH method (www.netl.doe.gov/coalpower/environment/ mercury/methods.html). In addition, the EERC sampling team members are considered experts in the operation of Hg CEMs, which are still considered to be in the developmental phase. The EERC has successfully demonstrated these instruments for 2 weeks or longer at nine different power plants over the past 3 years. The EERC has actively used these instruments in bench-, pilot-, and full-scale tests for over 7 years.

Table 2 overviews the measures for accuracy, precision, and completeness as documented in the OH method (American Society for Testing and Materials [ASTM] D6784-02). The stringent quality rules of the OH method will be exceeded to include two field blank and spikes per week (versus one called for in the method) during the longer-term testing at each sample location per test condition. If the field blank does not meet the criteria listed, the data must be flagged and corrective action is taken to discover the source of the contamination.

Table 2. Data Quality Objectives for Flue Gas Mercury Analyses by OH Method

Measure	Objective	Approach
Accuracy	<10% of sample value or <10X instrument detection limit	Reagent blanks – analyze one blank per batch of each reagent.
Accuracy	Field blank <25% of sample value	Collect and analyze one field blank at inlet and one at outlet per day.
Accuracy	Field and laboratory spikes <15% of true value	Collect and analyze one field-spiked sample at inlet and one per day.
Precision	<10%	All laboratory samples analyzed in duplicate; every tenth sample analyzed in triplicate.
Completeness	100%	Any failed or incomplete test will be reviewed and, if necessary, repeated.*

* Whether a test failed or is incomplete will be determined by the sampling manager in consultation with the principal investigator. Any failed or incomplete data that are not considered to cause an invalidation of a test will be flagged.

BACKGROUND

This project is aimed at developing and evaluating advanced and innovative concepts for controlling Hg emissions from ND lignite-fired power plants. ND lignite-fired power plants have shown a limited ability to control Hg emissions in currently installed ESPs, dry scrubbers, and wet scrubbers (1). This low level of control can be attributed to the high proportions of Hg^0 present in the flue gas. Speciation of Hg in flue gases analyzed as part of the EPA ICR for Hg data showed that Hg^0 ranged from 56% to 96% and the oxidized Hg ranged from 4% to 44%. The Hg emitted from power plants firing ND lignites ranged from 45% to 91% of the total Hg, with the emitted Hg being greater than 85% elemental. The higher levels of oxidized Hg were only found in a fluidized-bed combustion system. Typically, the form of Hg in the pulverized and cyclone-fired units was dominated by Hg^0 being greater than 85% elemental, and the average emitted from ND power plants is 6.7 lb/TBtu (1, 2).

ND Lignite Characteristics: In general, ND lignitic coals are unique because of a highly variable ash content, ash that is rich in alkali and alkaline-earth-rich elements, high oxygen levels, high-moisture levels, and low chlorine content. Based on the ICR data, ND lignites contain about 8 lb/TBtu Hg as compared to 6 lb/TBtu for Powder River Basin (PRB) coals, 6.5 lb/TBtu for Illinois Basin, 9.5 lb/TBtu for Appalachian, and 12.5 lb/TBtu for Gulf Coast lignites (1). The composition of a coal has a major impact on the quantity and form of Hg in the flue gas and, as a result, on the ability of APCDs to remove Hg from flue gas. Coal containing chlorine levels greater than 200 ppm produces Hg in flue gas that is dominated by more easily removable mercuric compounds (Hg^{2+}), most likely mercuric chloride ($HgCl_2$). Appalachian and Illinois Basin coals typically have chlorine levels greater than 200 ppm. Conversely, experimental results indicate that low-chlorine (<50-ppm) coal combustion flue gases (typical of

ND lignite) contain predominantly Hg^0, which is substantially more difficult to remove than Hg^{2+} (3). Additionally, the generally high calcium contents of lignite coals may reduce the oxidizing effect of the already low chlorine content by reactively scavenging chlorine species (Cl, HCl, and Cl_2) from the combustion flue gas. The level of chlorine in flue gases of recently tested lignites from ND and Saskatchewan lignite ranged from 2.6 to 3.4 ppmv, with chlorine contents ranging from 11 to 18 ppmw in the coal on a dry basis, respectively.

ND Power Plants: ND power plants are minemouth plants that fire ND lignites from several seams. The steam generators at the plants are 2070-MW tangentially fired, 466-MW wall-fired, 2075-MW cyclone-fired, and 85-MW fluidized-bed combustion (FBC). The associated particulate collection system includes a 3221-MW ESP and 1390-MW fabric filter (FF). The associated sulfur dioxide control technologies include 1641 MW with none, 1390 MW dry FGD, 1580 MW wet FGD, and 85 MW FBC. The development of control technologies for ND lignite-fired power plants is focused on the most feasible and economical technology that has the potential to attain over 90% Hg emission control.

Mercury Control Options: The technologies utilized for the control of Hg will ultimately depend upon the EPA-mandated emission limits. Options for controlling Hg emissions are being investigated that have the potential to attain over 90% control of Hg emissions. ICR data and test data of Hg control from ND lignite-fired systems indicate that low Hg reactivity poses technical and economic challenges and that new Hg control technologies are needed for lignite. Currently, the Hg control strategies at ND lignite-fired power plants involve first enhancing of existing control technologies and second investigating and developing new control technologies. The strategies include sorbent injection with and without enhancements upstream of an ESP or FF and Hg oxidation upstream of a wet or dry FGD. The new technologies being investigated include Hg capture using the Advanced Hybrid™, gold-coated materials, baghouse inserts, and carbon beds (4).

Sorbent Injection for removing Hg involves adsorption of Hg species by a solid sorbent injected upstream of a particulate control device such as a fabric filter (baghouse) or ESP. Many potential Hg sorbents have been evaluated (4). These evaluations have demonstrated that the chemical speciation of Hg controls its capture mechanism and ultimate environmental fate.

Activated carbon injection is the most mature technology available for Hg control. Activated carbons have the potential to effectively sorb Hg^0 and Hg^{2+} but depend upon the carbon characteristics and flue gas composition (4). Most activated carbon research has been performed in fixed-bed reactors that simulate relatively long-residence-time (gas–solid contact times of minutes or hours) Hg capture by a FF filter cake (5–7). However, it is important to investigate short-residence-time (seconds) in-flight capture of Hg^0 because most of the coal-burning boilers in the U.S. employ cold-side ESPs for controlling particulate matter emissions. The projected annual cost for activated carbon adsorption of Hg in a duct injection system is significant. Carbon-to-mercury weight ratios of 3000–18,000 (lb carbon injected/lb Hg in flue gas) have been estimated to achieve 90% Hg removal from a coal combustion flue gas containing 10 $\mu g/Nm^3$ of Hg (8). More efficient carbon-based sorbents are required to enable lower carbon-to-mercury weight ratios to be used, thus reducing the costs. Recent testing conducted at the EERC, as shown in Figures 1 and 2, illustrates the effectiveness of sorbents injected upstream of the ESP and baghouse, respectively.

The EERC pilot-scale ESP and ESP–FF Hg removal efficiencies for the Fort Union lignite coals from Saskatchewan and ND (Poplar River and Freedom coals) flue gases are compared in Figures 1 and 2 to those obtained at full-scale utility boilers, while injecting activated carbons

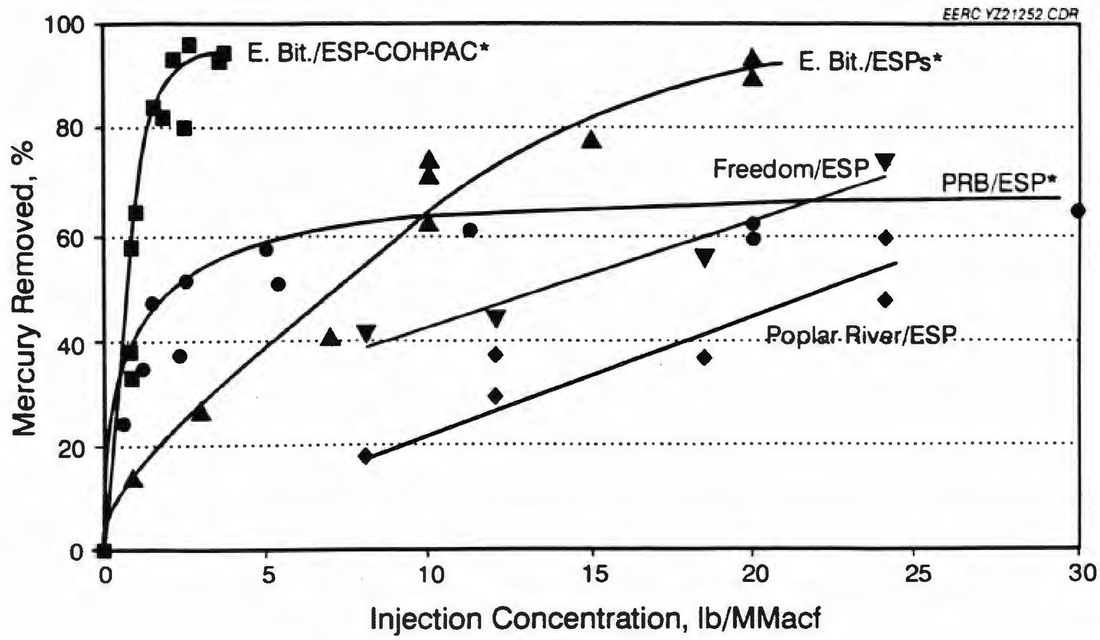


Figure 1. Pilot-scale ESP (8) and full-scale COHPAC and ESP (9) Hg removal efficiencies as a function of activated carbon injection rate.

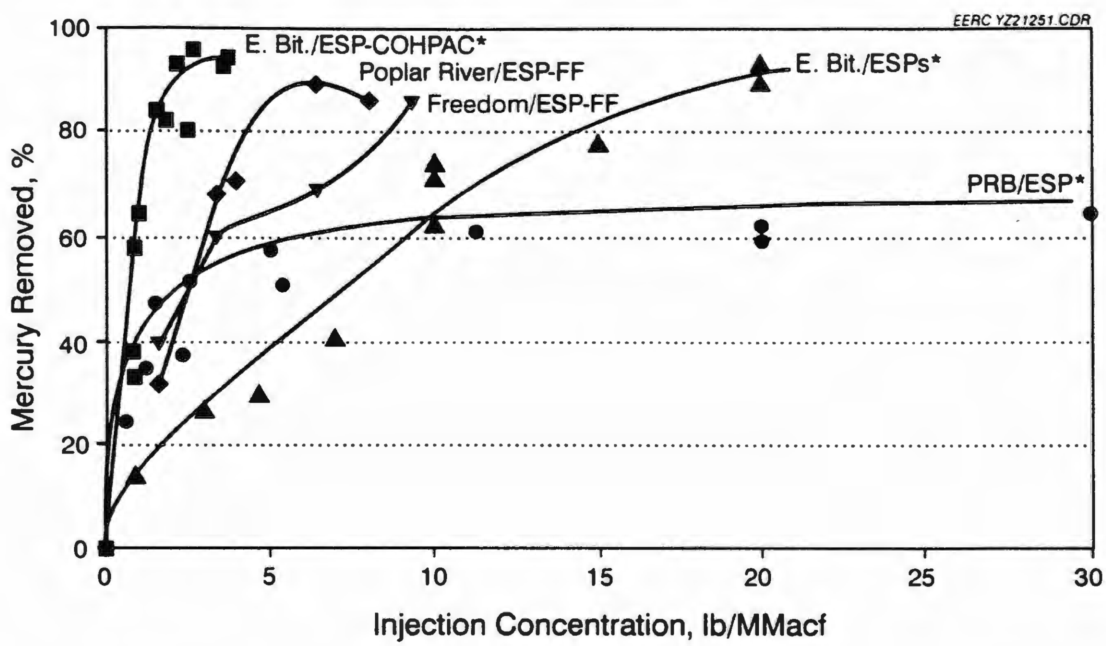


Figure 2. Pilot-scale ESP–FF (8) and full-scale COHPAC and ESP (9) Hg removal efficiencies as a function of activated carbon injection rate.

into a bituminous coal combustion flue gas upstream of a COHPAC (pulse-jet FF) and into bituminous and PRB subbituminous coal combustion flue gases upstream of an ESP. Coal type (i.e., composition) is an important parameter that affects the Hg removal efficiency of a control device. During the pilot-scale lignite and utility-scale eastern bituminous coal tests, Hg removal efficiency increased with increasing activated carbon injection rates. Conversely, Hg removal efficiency was never greater than 70%, regardless of the activated carbon injection rate into the PRB subbituminous coal combustion flue gas. This limitation is probably caused by the low amount of acidic flue gas constituents, such as HCl, that promote Hg-activated carbon reactivity.

Testing conducted at a lignite-fired power plant equipped with a spray dryer baghouse firing Fort Union lignite indicated poor performance of conventional ACI to control Hg (10). The results indicate control efficiency of less than 35% for NORIT FGD and lignite-activated carbon (LAC). The poor results are due to the low acid gas containing flue gas and the high proportion of Hg^0 in the flue gas stream. The iodine-impregnated activated carbon (IAC) showed approximately 90% control.

Researchers at the EERC and elsewhere are striving to attain a better understanding of Hg species reactions on activated carbon surfaces in order to produce more efficient sorbents. Functional groups containing inorganic elements such as chlorine or sulfur appear to have a significant role in bonding Hg (11–13). Recently, detailed analysis of sorbents derived from lignites exposed to flue gas and Hg^0 indicated the key species impacting oxidation and retention of Hg on the surface of the carbon contain chlorine and sulfur (14, 15). The chlorine reacts to form organically associated chlorine on the surface, and it appears that the organically associated chlorine on the carbon is the key site responsible for bonding with the Hg^{2+} species.

Amended silicate injection shows promise in controlling Hg emissions at coal-fired power plants (16). The amended silicates have shown improvement factors of 1.5 to 2 in controlling Hg emissions over activated carbon from subbituminous coal testing in a pilot-scale test. The amended silicates have not been tested using ND lignites.

Mercury Oxidation: Mercury oxidation technologies being investigated for Fort Union lignites include catalysts, chemical agents, and cofiring materials. The catalysts that have been tested include selective catalytic reduction (SCR) catalysts for NO_x reduction, noble metal-impregnated catalysts, and oxide-impregnated catalysts. The chemical agents include chlorine-containing salts and cofiring fuels that contain oxidizing agents (10).

SCR catalysts have been tested for their ability to oxidize Hg. The ability to oxidize Hg has shown mixed results. Mercury speciation sampling has been conducted upstream and downstream of SCR catalysts at power plants that fire bituminous and subbituminous coals (17). The results of testing indicate evidence of Hg oxidation across SCR catalysts when firing bituminous coals. However, when firing subbituminous coal, the results indicate limited oxidation, and more testing needs to be conducted on low-rank coals. The ability of the SCR system to contribute to oxidation appears to be coal specific and is related to the chloride, sulfur, and calcium content of the coal as well as temperature and specific operation of the SCR catalyst including space velocity.

Mercury oxidation catalysts have shown high potential to oxidize Hg^0. Results in testing a slipstream at a ND power plant indicated over 80% conversion to oxidized Hg for periods of up to 6 months (10). Tests were also conducted using iron oxides and chromium, with little success of oxidation. Galbreath and others (18) have conducted short-term pilot-scale testing with maghemite (γ-Fe_2O_3) additions and were able to transform about 30% of the Hg^0 in ND lignite combustion flue gases to Hg^{2+} and/or Hg(p) and with an injection of a small amount of HCl (100 ppmv) nearly all of the Hg^0 to Hg^{2+}. Theoretically, the use of chloride compounds to oxidize Hg^0

to Hg^{2+} makes sense. The evidence includes chemical kinetic modeling of bench-scale test results indicating that the introduction of chloride compounds into the high-temperature furnace region will most likely result in the production of atomic chlorine and/or molecular chlorine, which are generally thought to be the dominant Hg^0 reactants in coal combustion flue gases (4).

Fuel additives for mercury oxidation and sorbent enhancement have recently been tested at the EERC. The results of the addition of materials with coal at very low levels along with the ACI upstream of an ESP–FF, *Advanced Hybrid™*, and ESP only are illustrated in Figure 3. The first part of the figure shows the baseline data for Hg emissions ranging from 9 to 12 $\mu g/Nm^3$, with 80% to 90% of the Hg in the elemental form. The second case is activated carbon injection followed by the addition of Additive 2, showing a reduction in Hg emissions to 90% removal. The third case is the Advanced Hybrid™, which produced nearly 90% control efficiency. The final ESP-only case also indicated up to 90% control. The control efficiency for the ESP-only case showed significant potential improvement over past results obtained with the ESP-only illustrated in Figure 1. This technology also has the potential to improve dry FGD baghouse control efficiency.

Sorbent enhancement technologies have also been investigated by ALSTOM. The sorbent preparation system enhances sorbent performance by changing the physical and chemical nature of the sorbent. The enhancement is expected to be applicable to a significant number of sorbents currently utilized for Hg control. The potential for sorbent enhancement has shown an increase in capture from 68% to over 90% capture of Hg. These tests evaluated the performance of baseline and enhanced sorbents in entrained flow. Sorbents were injected in a duct with synthetic flue gas followed by an ESP.

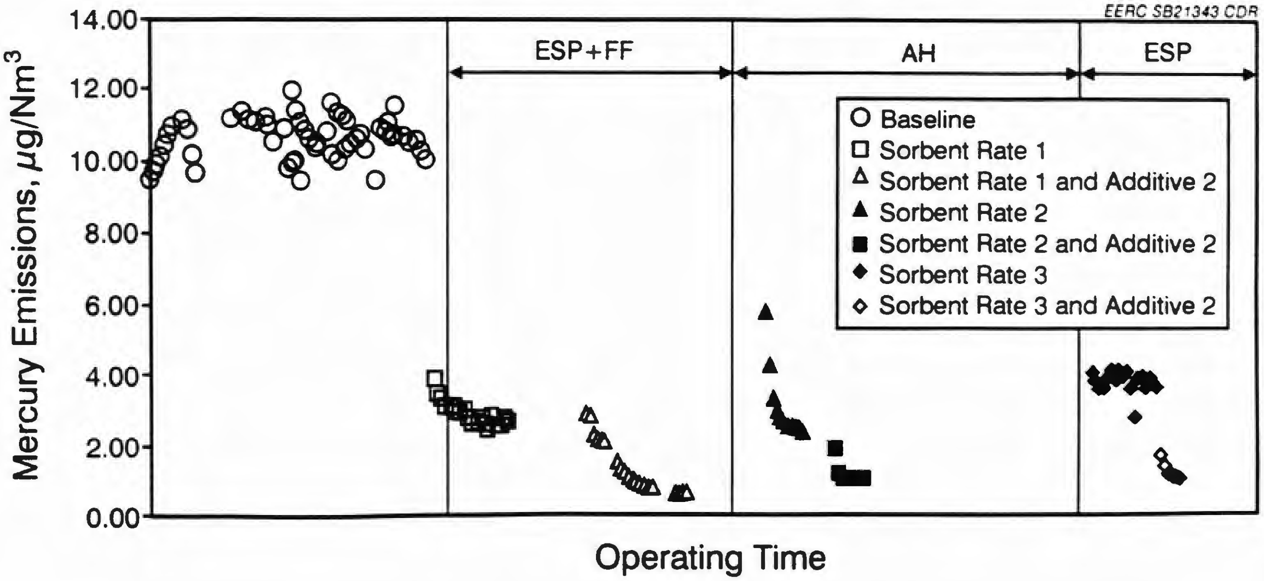


Figure 3. Hg emissions for activated carbon injection combined with additives.

Cofiring TDF at Otter Tail Power's Big Stone Plant has been suspected to contribute to very high reactivity of Hg with fly ash and also with carbon sorbents while firing a low-chlorine PRB coal (19). At periods of operation that coincide with cofiring TDF, enhanced Hg oxidation and removal of Hg by a particulate control device (PCD) have been observed. When about 3%–5% (Btu basis) TDF was cofired with coal at the power plant, measurements showed that the average PCD inlet Hg speciation was 55% particulate bound, 38% oxidized, and 6.4% elemental. Without carbon injection to the PCD, the natural Hg capture efficiency of the PCD was 49%. Furthermore, a carbon injection rate of 24 kg carbon/million m^3 flue gas resulted in a 91% total Hg capture efficiency at the PCD. These field test results indicate that the TDF cofiring has the effect of changing the speciation of Hg at the inlet to the PCD that facilitates Hg collection at the PCD.

Since 1995, DOE has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC) (19). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*™ filter by Gore. The

Advanced Hybrid™ combines the best features of ESPs and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The *Advanced Hybrid*™ provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The *Advanced Hybrid*™ appears to have unique advantages for Hg control over baghouses or ESPs as an excellent gas–solid contactor. The *Advanced Hybrid*™ technology can be a very cost-effective retrofit technology for plants with existing ESPs.

QUALIFICATIONS

The EERC of the University of North Dakota 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. The EERC team has more than four decades of basic and applied research experience producing energy from all ranks of coal, with particular emphasis on low-rank coals. As a result, the EERC has become the world's leading low-rank coal research center. EERC research programs are designed to embrace all aspects of energy-from-coal technologies from cradle to grave, beginning with fundamental resource characterization and ending with waste utilization or disposal in mine land reclamation settings.

The future of North Dakota energy production depends upon developing connections between energy and environment that will allow the extraction of sufficient energy and other resources from our environment in a manner that does not jeopardize its integrity and stability.

Several successful EERC projects, including over 20 field tests, have been conducted at various utilities throughout the United States to perform flue gas sampling, air toxic emission monitoring, fly ash collection, and fouling and slagging deposit sampling. Several of those field tests involved working with plant slipstreams or direct sampling using custom-designed and manufactured sampling equipment.

The EERC has been a leader in mercury research for several years and is viewed as an expert in the field. In recent years, EERC researchers have been in the forefront of advancing the understanding of mercury chemistry, measurement, transformations, solid–gas interactions, and the development of control technologies.

VALUE TO NORTH DAKOTA

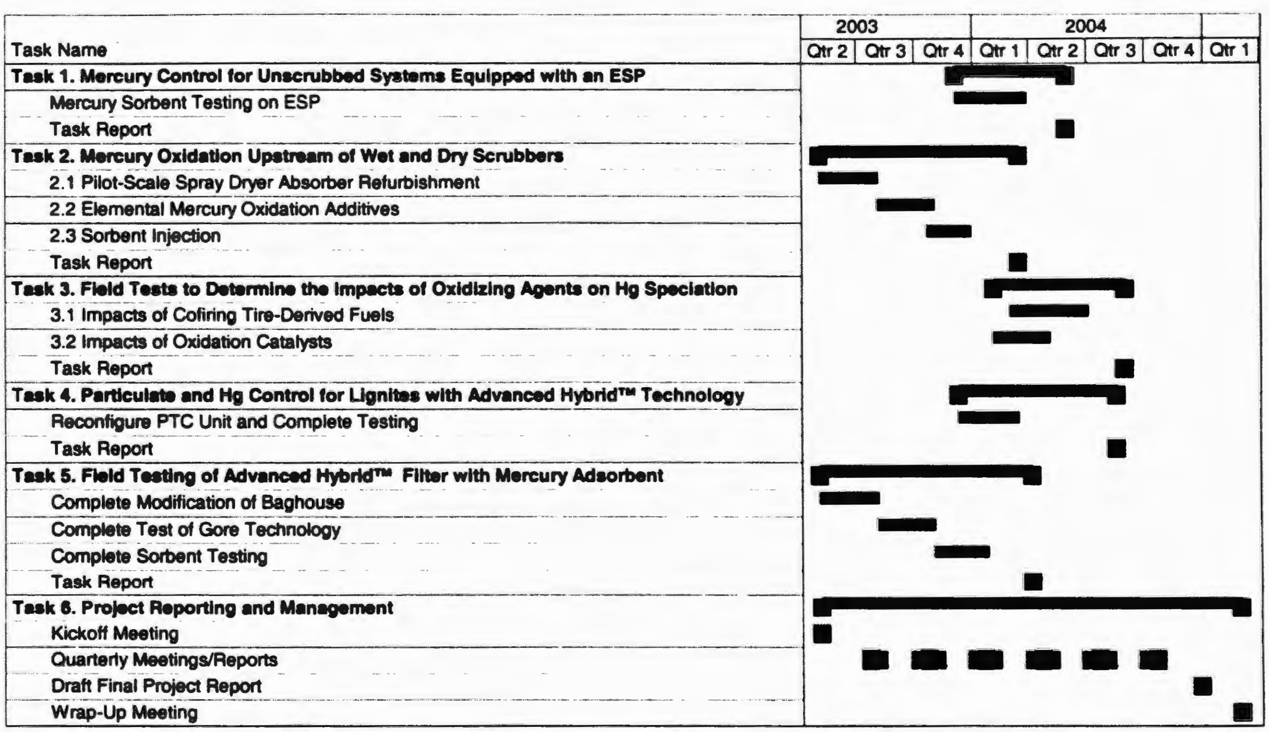
A major challenge facing North Dakota lignite-fired power plants is the control of mercury emissions. The mercury species in combustion flue gases produced from North Dakota lignite plants is primarily elemental and much more difficult to control than oxidized mercury forms. The project is aimed at evaluating a range of potential technologies to oxidize and control the emissions of mercury during the combustion of ND lignites. Developing effective Hg control technologies for ND lignites will aid in maintaining and potentially increasing the use of lignite for power generation in the future.

MANAGEMENT

Dr. Steven A. Benson will be the EERC Project Manager (PM) responsible for the oversite of the project. Dr. Benson has more than 25 years in coal utilization and environmental control technologies and has managed numerous projects involving government and industry participants. Ms. Jill Zola has contracts tracking and fuel properties experience. Ms. Zola will assist PM and PI milestone and personnel tracking, available funding by task, and compile technical information. The PIs have extensive experience in all aspects of developing and demonstrating Hg control technologies. The PIs by task include Mr. Mike Holmes (Task 1) who has over 15 years of experience in emission control technologies; Mr. Kevin Galbreath (Task 2) who has over 12 years of experience on Hg measurement and sorbent development; Mr. Jason Laumb (Task 3) who has over 4 years of experience in conducting testing of system performance; and Mr. John Pavlish (Tasks 4 and 5) who has 18 years of experience in pollution control technologies and power plant performance. The Co-PIs include Dr. Li Yan and Dr. Ye Zhaung who will assist the PIs in conducting the tasks.

Resumes of key personnel are included in Appendix A.

PROJECT TIME LINE



Phase I of the project will be initiated upon receipt of DOE funding and approval of the project by NDIC. Phase I, involving Tasks 2 and 5, will begin immediately and a project kickoff meeting will be scheduled as soon as is convenient for all project sponsors. Phase II is scheduled to begin upon receipt of the second increment of funding from DOE, which is anticipated in August 2003.

BUDGET

The budget outlining the costs for the project is included. The total cost of the project is $1,300,000.

MATCHING FUNDS

The funds requested are broken down as follows:

Total Project Cost	$1,300,000
DOE	$1,000,000
North Dakota Industrial Commission (NDIC)	$150,000
Utility Support (cash)	$100,000
Equipment Vendors (in-kind)	$50,000

Of the total project cost of $1,300,000, the request from DOE is $1,000,000. The utility sponsors providing aggregate funding of $100,000 include Minnkota Power, Basin Electric Power Cooperative, Otter Tail Power Company, Great River Energy, Montana–Dakota Utilities, BNI Coal Ltd., Westmoreland, and North American Coal Company. Equipment vendors who have committed to provide in-kind cost share totaling a minimum of $50,000 include W.L. Gore & Associates, ADA Technologies, Haldor-Topsoe, ALSTOM, and Babcock & Wilcox. The request from NDIC is $150,000. Letters of commitment are enclosed in Appendix B.

TAX LIABILITY

None.

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BUDGET

PILOT AND FULL-SCALE DEMONSTRATION OF ADVANCED MERCURY CONTROL
TECHNOLOGIES FOR LIGNITE-FIRED POWER PLANTS
NDIC/MULTICLIENT ND UTILITIES/US DOE
PROPOSED START DATE: 05/01/2003
EERC PROPOSAL #2003-0126

CATEGORY		TOTAL HRS	TOTAL $COST	COMMERCIAL SHARE HRS	COMMERCIAL SHARE $COST	ND UTILITIES SHARE HRS	ND UTILITIES SHARE $COST	NDIC SHARE HRS	NDIC SHARE $COST	NDIC PHASE 1 HRS	NDIC PHASE 1 $COST	NDIC PHASE 2 HRS	NDIC PHASE 2 $COST	DOE SHARE HRS	DOE SHARE $COST
TOTAL DIRECT LABOR		12,252	$ 342,161	2,379	$ 66,952	971	$ 27,317	1,408	$ 39,635	402	$ 12,316	1,006	$ 27,319	9,873	$ 275,209
FRINGE BENEFITS - % OF DIRECT LABOR	55%		$ 184,766		$ 36,154		$ 14,751		$ 21,403		$ 6,651		$ 14,752		$ 148,612
TOTAL LABOR			$ 526,927		$ 103,106		$ 42,068		$ 61,038		$ 18,967		$ 42,071		$ 423,821
OTHER DIRECT COSTS															
TRAVEL			$ 26,956		$ 6,740		$ 2,500		$ 4,240		$ 275		$ 3,965		$ 20,216
COMMUNICATION - PHONES & POSTAGE			$ 2,448		$ 602		$ 244		$ 358		$ 86		$ 272		$ 1,846
OFFICE (PROJECT SPECIFIC SUPPLIES)			$ 4,079		$ 1,003		$ 405		$ 598		$ 126		$ 472		$ 3,076
REPAIRS			$ 3,329		$ 832		$ 341		$ 491		$ 262		$ 229		$ 2,497
SUPPLIES			$ 25,525		$ 5,914		$ 2,611		$ 3,303		$ 1,740		$ 1,563		$ 19,611
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)			$ 10,590		$ 2,502		$ 882		$ 1,620		$ 234		$ 1,386		$ 8,088
EQUIPMENT > $5000			$ 115,800		$ -		$ -		$ -		$ -		$ -		$ 115,800
FEES			$ 159,047		$ 39,557		$ 15,051		$ 24,506		$ 2,348		$ 22,158		$ 119,490
TOTAL OTHER DIRECT COST			$ 347,774		$ 57,150		$ 22,034		$ 35,116		$ 5,071		$ 30,045		$ 290,624
TOTAL DIRECT COST			$ 874,701		$ 160,256		$ 64,102		$ 96,154		$ 24,038		$ 72,116		$ 714,445
FACILITIES & ADMIN. RATE - % OF MTDC		VAR	$ 375,299	56%	$ 89,744	56%	$ 35,898	56%	$ 53,846	56%	$ 13,462	56%	$ 40,384	47.7%	$ 285,555
TOTAL EERC COST			$ 1,250,000		$ 250,000		$ 100,000		$ 150,000		$ 37,500		$ 112,500		$ 1,000,000
MULTI-CLIENT COST SHARE - IN-KIND			$ 50,000		$ 50,000		$ 50,000		$ -		$ -		$ -		$ -
TOTAL PROJECT COST			$ 1,300,000		$ 300,000		$ 150,000		$ 150,000		$ 37,500		$ 112,500		$ 1,000,000

BUDGET NOTES

ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

Background

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

The proposed work will be done on a cost-reimbursable basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, subcontracts) is for planning purposes only. The principal investigator may, as dictated by the needs of the work, reallocate the budget among approved items or use the funds for other items directly related to the project, subject only to staying within the total dollars authorized for the overall program and in accordance with federal regulations A-21 and A-110. 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 EERC facilities and administrative cost rate.

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

Travel

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

Communications (phones and postage)

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

Office (project-specific supplies)

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

Data Processing

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

Supplies

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

Instructional/Research

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

Fees

Laboratory 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.

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

General

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

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

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

Facilities and Administrative Cost

The facilities and administrative rate (indirect cost rate) included in this proposal is the rate that became effective July 1, 2002. Facilities and administrative cost is calculated on modified total direct costs (MTDC). MTDC is defined as total direct costs less individual items of equipment in excess of $5000 and subcontracts/subgrants in excess of the first $25,000 for each award.