April 1, 2005

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

Dear Ms. Fine:

Subject: EERC Proposal No. 2005-0233, "Investigation of Mercury and Carbon-Based Sorbent Reaction Mechanisms – Comparison of Surface Analysis Techniques"

Enclosed are the original, six copies, and a PDF of the subject proposal. The lignite-fired power industry has been proactive in advancing the understanding of, and identifying control options for, mercury in coal combustion flue gases. This proposal is submitted to address the knowledge gaps in mercury–sorbent interactions to meet the challenges of 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) 777-5018 or by e-mail at ccrocker@undeerc.org.

Sincerely,

Charlene R. Crocker
Research Scientist

CRC/kal

Enclosures

c/enc: Harvey Ness, Lignite Research Council

INVESTIGATION OF MERCURY AND CARBON-BASED SORBENT REACTION MECHANISMS

EERC Proposal No. 2005-0233

Submitted to:

Ms. Karlene Fine

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

Proposal Amount: $19,500

Submitted by:

Charlene R. Crocker
Edwin S. Olson
Steven A. Benson

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

Charlene R. Crocker, Project Manager

Dr. Barry I. Milavetz, Interim Director
Research Development and Compliance

March 2005

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INVESTIGATION OF MERCURY AND CARBON-BASED SORBENT REACTION MECHANISMS – COMPARISON OF SURFACE ANALYSIS TECHNIQUES

ABSTRACT

The goal of the project is to improve the mercury capture efficiency of carbon-based sorbents through a better understanding of mercury–sorbent reaction mechanisms. This fundamental investigation of the physicochemical surface characteristics of sorbents exposed to flue gas-containing mercury vapors will provide information for the development of more effective and lower-cost sorbents to control elemental mercury emissions from combustion systems firing low-chlorine North Dakota lignite coals. The proposed project focuses on analytical techniques that illuminate the surface bonding on carbon sorbents. The approach employs two surface analysis techniques: x-ray photoelectron spectroscopy and x-ray absorption fine structure spectroscopy. The research is designed to result in the refinement of the understanding of the structural features of sorbents before and after exposure to mercury in a coal flue gas stream and will clarify elemental mercury capture in low-chlorine fuel combustion.

The project is scheduled for 7 months with a total cost of $60,000, of which $21,000 is requested from the U.S. Department of Energy. Industry partner SaskPower has committed $19,500 in cash. A one-to-one match of $19,500 is requested from the North Dakota Industrial Commission.

INVESTIGATION OF MERCURY AND CARBON-BASED SORBENT REACTION MECHANISMS – COMPARISON OF SURFACE ANALYSIS TECHNIQUES

PROJECT SUMMARY

Sorbent injection for removing mercury involves adsorption of mercury species by a solid sorbent injected upstream of a particulate control device such as a fabric filter (FF [baghouse]) or electrostatic precipitator (ESP). Many potential mercury sorbents have been evaluated (1). Activated carbon injection (ACI) is the most mature technology available for mercury control. For activated carbons (ACs) to be successful, they must effectively chemisorb both elemental (Hg^0) and oxidized mercury [Hg(II)]. Testing has demonstrated that the chemical speciation of mercury in the flue gas controls its capture mechanism and ultimate environmental fate. The capture and retention of mercury on carbon-based sorbents are dependent upon the particle size, chemical and physical characteristics of the sorbent surface, and flue gas composition. These factors have had a major impact on the effectiveness of mercury control using AC sorbents.

Most AC mercury control research has been performed in fixed-bed reactors that simulate relatively long residence-time (gas–solid contact times of minutes or hours) mercury capture by an FF filter (2–4). However, it is important to increase the reactivity of the sorbents for short residence-time (seconds) in-flight capture of Hg^0 because most of the coal-burning boilers in the United States employ cold-side ESPs to control particulate matter emissions. The annual cost for AC adsorption of mercury in a duct injection system is significant. Carbon-to-mercury weight ratios of 3000–18,000 (grams of carbon injected per gram of mercury in flue gas) to achieve about 90% mercury removal from a coal combustion flue gas containing 10 μg/Nm^3 of mercury (5). More efficient carbon-based

sorbents are required to enable lower carbon-to-mercury weight ratios to be used, thus reducing the operating costs of carbon injection.

The goal of this Energy & Environmental Research Center (EERC) program is to improve the mercury capture efficiency of carbon-based sorbents in flue gases typical when firing lignite and other low-chlorine, low-sulfur fuels through a better understanding of mercury–sorbent surface bonding. Since halogens such as chlorine play a critical role in promoting the reactivity of AC sorbents, this work will investigate chlorine structures developed prior to flue gas exposure and mercury and chlorine structures during and after exposure to (simulated) low-acid flue gas using x-ray photoelectron spectroscopy (XPS) and x-ray absorption fine structure (XAFS) spectroscopy, analytical techniques for surface chemistry analysis.

PROJECT DESCRIPTION

Goals and Objectives

The goal of this EERC program is to improve the mercury capture efficiency of carbon-based sorbents through a better understanding of mercury–sorbent reaction mechanisms. We will investigate the ability of XPS and XAFS to characterize the chemical bonding of mercury and chlorines on the carbon sorbent surface. The activities of this project will enhance the ongoing EERC investigation of mercury–sorbent reaction mechanisms.

The objectives of the project are to evaluate the information provided by each technique and determine the best strategy for using one or both techniques in analyzing surface chemistry and reactions of carbon-based sorbents.

Work Plan

The work plan includes sample preparation and analysis, data reduction, interpretation, and reporting. These activities will be completed in conjunction with ongoing activities of the Carbon

Consortium. Preexposure structures to be examined will represent the effects of chlorine concentration, loading method, aging, and carbon type on chlorine structures in the starting carbon sorbent material. One pretreated carbon sorbent will be exposed to low-acid simulated flue gas to examine the mercury structure and changes to the chlorine structure during exposure to Hg^0 and Hg(II) (as mercury chloride). These results will be compared to previously prepared untreated carbons which were analyzed by XPS.

Approximately nine samples will be prepared and analyzed by either or both surface techniques. Carbon sorbent preparation, exposure to simulated flue gas, data analysis, interpretation, and reporting will take place at the EERC. XPS analyses will be performed at Evans PHI in Chanhassan, Minnesota. The University of Kentucky will perform the XAFS analyses at one or more of the Synchrotron facilities in Canada and the United States. We expect that the XAFS mercury analyses will be performed at the Canadian Light Source in Saskatoon. Based on the analytical equipment available at each site, the XAFS halogen analyses will need to be performed at the Synchrotron facilities in New York or California.

Reporting for this project will consist of meetings with partners and project participants in conjunction with the Carbon Consortium, quarterly reports, and a final report.

Deliverables

An improved understanding of the gas–sorbent interactions for mercury emission control will result from the proposed research. Specific anticipated results include:

- An evaluation of halogen bonding on the carbon sorbent surface.
- A comparison of the ability of two surface analysis techniques to describe the bonding on the carbon sorbent surface with respect to chlorine, sulfur, and mercury.
- An evaluation of the effects of variations in the sorbent surface modifications.

- Presentation of the results at a technical conference and to the U.S. Department of Energy (DOE) in conjunction with the Carbon Consortium.
- Quarterly and final reports detailing the progress and results of the research.

Facilities

The proposed research will be carried out using the EERC's Process Chemistry and Development Laboratory (PCDL) and Mercury Research Laboratory (MRL). XPS analysis will be performed at Evans PHI. The University of Kentucky will perform the XAFS analyses at one or more of the Synchrotron facilities in Canada and the United States.

The PCDL can develop and analyze different types of product and by-product streams. These analyses provide the data for the calculation of material balances, conversions, and product qualities for several EERC engineering projects. Equipment is in place for ashing, solubility testing, numerous American Society for Testing and Materials standard tests, coal cleaning, and a variety of general and specialized analytical testing, including wet-chemical testing.

The MRL specializes in bench-scale systems studying mercury, SO_x/NO_x, catalysts, sorbents, and related work. Two bench-scale systems capable of simulating flue gas conditions such as temperature, particulate loadings, air-to-cloth ratios, and various gas concentrations (e.g., SO_2, O_2, CO, CO_2) are used. The MRL has mercury continuous emission monitors (CEMs) to perform bench-scale mercury-screening activities. The PCDL and MRL have over 10 years of experience developing and screening potential sorbents and filter materials, evaluating catalyst materials, and performing SO_x/NO_x in flue-gas research.

Evans PHI provides analytical services using highly specialized surface analysis instrumentation. XPS, also known as electron spectroscopy for chemical analysis, is the most widely used surface analysis technique because it is relatively simple to use. For certain elements, including

halogens, nitrogen, and sulfur, XPS can readily distinguish a number of chemical bonding configurations and other valuable data. Evans PHI has experienced instrument analysts and technical support engineers who continuously train on the latest surface analysis equipment and techniques.

Several facilities are available to provide XAFS analyses. We expect that mercury analyses will be performed at the facility in Saskatchewan. Based on the analytical equipment available at each site, the halogen analyses will need to be performed at one of the Synchrotron facilities in New York or California. For some compounds of mercury, XAFS can distinguish chemical bonding to oxygen without interference by other elements.

Environmental impacts of this research will be minimal. Technological and economic impacts of the ultimate product could be substantial in terms of Hg^0 control in lignite-fired combustion systems. The U.S. Environmental Protection Agency (EPA) determined that mercury emissions from power plants pose significant public health hazards and must be reduced. EPA has announced new mercury control regulations that mandate coal-fired power plants to reduce mercury emissions by 21% by 2010 and 69% by 2018, based on the current estimate of 48 tons of annual mercury emissions. ACI is the most mature technology available for mercury control. Development of a process to make sorbents capable of effective elemental mercury control will greatly benefit lignite production facilities by creating a new market in providing coal for sorbent and combustion facilities in meeting the new regulations.

STANDARDS OF SUCCESS

The success of the project will be based on the ability to develop an understanding of the role of surface analysis techniques in elucidating the chemical bonding on the surface of carbon sorbents.

Since the project is a scientific investigation as opposed to a field-testing exercise, the achievement of these goals will be measured by appropriate scientific and engineering standards. Of

primary importance is the publication of project results in a refereed journal in conjunction with the Carbon Consortium project.

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

The most important aspect of QA/QC is the expertise of the team conducting sorbent testing and spectroscopic measurements. EERC research personnel are highly trained and experienced, having conducted hundreds of sampling tests. In addition, EERC team members are experts in the operation of Hg CEMs, which are still in the developmental phase. The EERC has successfully demonstrated these instruments for 2 weeks or longer at 60 different power plants over the past 6 years. The EERC has actively used these instruments in bench-, pilot-, and full-scale tests for 10 years.

BACKGROUND

During the pilot-scale lignite and utility-scale Fort Union coal tests using ESP and ESP–FF particulate controls, maximum mercury removal efficiencies for ACI ranged from 45% to 75% and 85%, respectively, with 7–25 lb/MMacf carbon injection concentration required. Conversely, mercury removal efficiency was never >70%, regardless of the ACI rate, into the Powder River Basin subbituminous coal combustion flue gas. This limitation is probably caused by the small

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 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.
EERC Expertise in Analytical Methods and CEM Sampling for Hg	Understand potential problems that can occur, troubleshoot, ability to get valid data under difficult conditions.
Hg CEM Calibrations 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 a known Hg standard. This procedure is done four times to determine scatter (internal QA/QC EERC standard: $R^2 = 0.999$).
Chain-of-Custody Procedures	Ensure integrity of samples at all steps, including sample identification, analysis, and storage.
Interim Team Audit	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.

amount of acidic flue gas constituents, such as HCl, that promote mercury-activated carbon sorption. Testing conducted at a lignite-fired power plant equipped with a spray dryer baghouse firing Fort Union lignite indicated that conventional ACI ineffectively controlled mercury (6). The results indicate poor control efficiency for injection of flue gas desulfurization (FGD) carbon (NORIT DARCO® FGD) in a spray dryer baghouse system (7). The poor results are the result of the low-acid flue gas and the high proportion of elemental mercury in the flue gas stream. The iodine-impregnated AC showed approximately 90% control.

Researchers at the EERC and elsewhere are striving to attain a more thorough understanding of mercury species reactions on AC surfaces in order to produce more efficient sorbents. Mercury-reactive surface functional groups thought to have an impact on mercury capture include acidic carboxyl, lactone, hydroxyl, and carbonyl functionalities or alkaline pyrone and chromene functionalities (8–11). Functional groups containing inorganic elements such as bromine, chlorine, or sulfur are also possibilities (12–14). Although halogen- and sulfur-bearing surface functional groups are not well characterized, the beneficial role of halogens and sulfur in capturing mercury species on ACs is well established (8, 15). Recently, Laumb and others (16) and Benson and others (17) have characterized sorbents exposed to flue gas and elemental mercury, and the results indicate that the key surface components that impact the oxidation and retention of mercury on the surface of the carbon result from the chemisorption of the chlorine and sulfur species from the flue gas. The chlorine species react to form organically associated chlorine on the surface, and it appears that the organically associated chlorine on the carbon is the key site for bonding with the Hg(II) species.

Olson and others (18) developed a model of the chemical mechanism of mercury oxidation and binding that offers more detail on the nature of the bonding site and its interaction with flue gases and mercury. This model uses the concept of zigzag carbene structures recently proposed by Radovic and Bockrath (19). A zigzag-edge carbene site is a basic binding site for which the various acid–gas components and the Hg(II) compete, including the HCl which is important in promoting the oxidation of Hg^0. This mechanism appears to involve the reaction with HCl to form stable carbenium ion intermediates. Figure 1 provides more details of the role of the chlorine adduct to the carbon. The conversion of carbene to carbenium ion by HCl and other acids generates an oxidation site and is consistent with the promotion effect of acids on mercury oxidation. The mechanistic model shows Hg^0 oxidation by the carbenium ion to the organomercury intermediate and subsequent

oxidation by NO_2 to the bound Hg(II) species. A detailed understanding of these mechanisms will help us develop more effective and lower-cost sorbents. Ultimately, the refined model will have the potential to be used to describe flue gas–AC interaction and to predict capture efficiency. In addition, knowledge developed from this model will be useful for stabilizing Hg(II) on the sorbent and promoting the kinetics of mercury capture. A better understanding of the interactions and effects of flue gas constituents and conditions will result in an improved mechanistic model and the development of more effective sorbents for mercury capture and control.

Direct observation of mercury species on the carbon surface is challenging. Two analytical tools that have the potential to provide insight to chemical interactions with the carbon are XPS and XAFS spectroscopy. Both are direct speciation techniques that utilize the x-rays given off by excited atoms. XPS detection measures bond energies of the excited atoms that comprise the surface structure and is currently used on coal-derived sorbents to distinguish chlorine species. XAFS examines atomic structure through the determination of bond type, distance, and number of bonds present. The technique has not been applied to the analysis of treated carbon sorbents. Given adequate levels of mercury and good calibration standards, XAFS has the potential to characterize mercury speciation on the carbon sorbent surface directly. The combination of these techniques may provide better insight into surface structures than either technique alone, and it will describe the mechanisms that can enhance carbon surfaces for mercury capture and control. Analytical techniques that could directly characterize mercury and halogen bonding on the surface of carbon-based sorbents would be a major enhancement to the consortium-funded research.

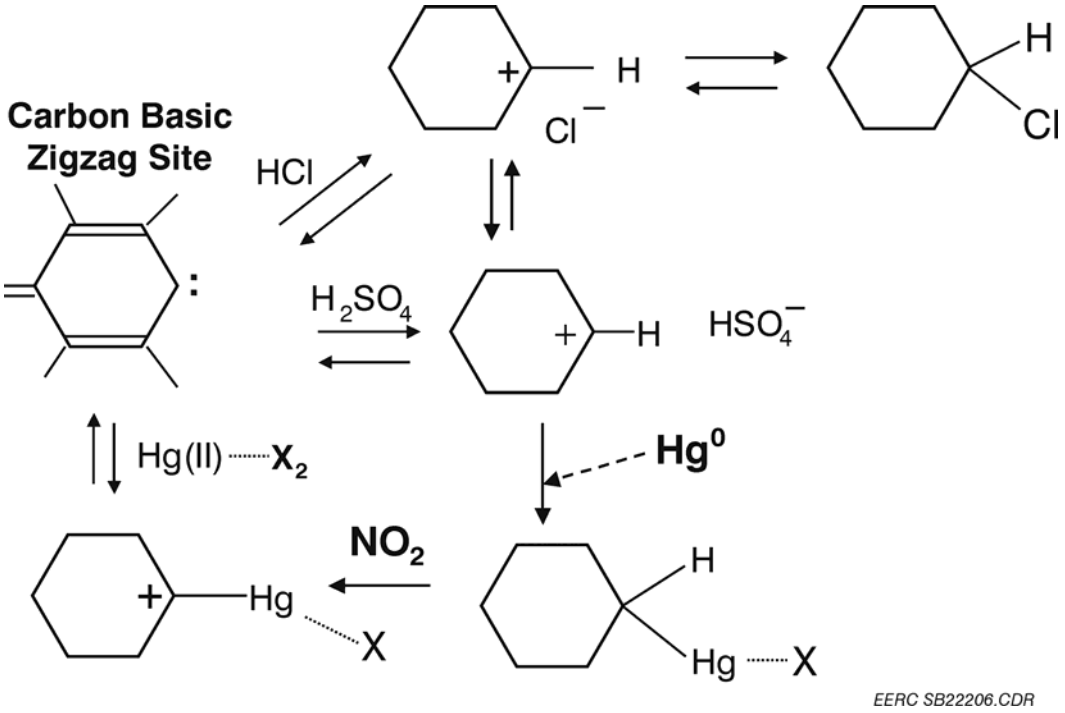


Figure 1. Oxidation site model for activated carbon—the role of hydrochlorination in generating carbenium oxidant (20).

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 as the U.S. Bureau of Mines Robertson Lignite Research Laboratory, the EERC has conducted research, testing, and evaluation of fuels, combustion, and gasification technologies; emission 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 the 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.

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 in combustion flue gases of North Dakota lignite plants is primarily elemental and much more difficult to control than oxidized mercury. This project aims to provide support tools in the quest for insight into the mercury capture and oxidation properties of carbon-based sorbents to develop improved, cost-effective sorbents to oxidize and control mercury emissions during the combustion of North Dakota lignites. Developing effective mercury control technologies for North Dakota lignites will help to maintain and potentially increase the use of lignite for power generation.

MANAGEMENT

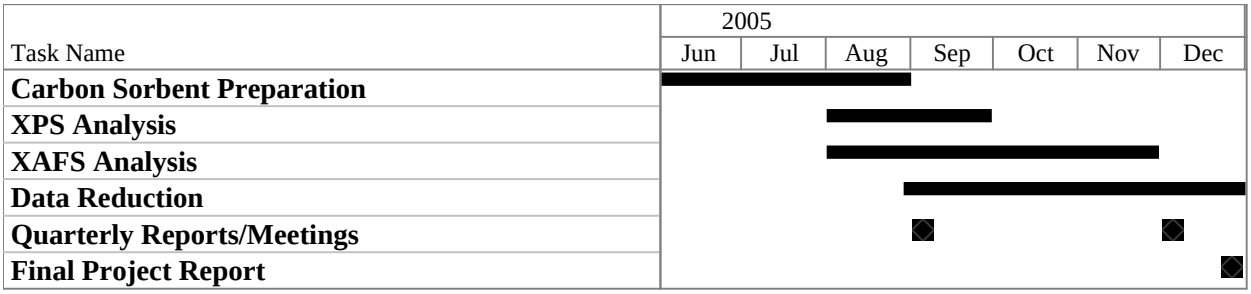
Ms. Charlene R. Crocker will be the EERC Project Manager responsible for the oversight of the project. Ms. Crocker has 11 years of experience in mercury and chlorine analysis and measurement in coal combustion and sorbent development. Principal Investigators Dr. Edwin S.

Olson and Dr. Steven A. Benson will assist with project tasks. Dr. Olson has more than 40 years of experience in carbon and coal structure and reactivity, mercury analysis, emission, adsorption chemistry, coal liquefaction, and gasification catalysis. Dr. Benson has more than 25 years in coal utilization and environmental control technologies and has managed numerous projects involving government and industry participants. They will be assisted by experienced EERC technicians.

Resumes of key personnel are included in Appendix A.

PROJECT TIMETABLE

The project will be initiated upon receipt of DOE funding and approval of the project by the North Dakota Industrial Commission (NDIC). It is anticipated that the proposed work will be carried out over a 7-month time frame.



BUDGET

The budget outlining the costs for the project is enclosed. The total cost of the project is $60,000.

The EERC is requesting NDIC to commit $19,500 to this project. Once we have NDIC's commitment, we will submit the proposal to DOE, requesting approval of its share of the funding.

Three items are required from NDIC for inclusion in our proposal to DOE.

- A formal commitment to the project. This can be a letter of commitment, a purchase order, or a signed contract.

- A biographical sketch or resume for NDIC's project manager and/or key technical contributor.
- A short overview of NDIC.

MATCHING FUNDS

The total cost of the project is $60,000. Cost-share funding to be requested from the EERC–DOE Jointly Sponsored Research Program is $21,000. Funding requested from NDIC is $19,500. Industry partner SaskPower is providing $19,500 cash cost share. Industry sponsor support from SaskPower is included in Appendix B.

TAX LIABILITY

None of the participants in this research proposal have outstanding tax liabilities to the state of North Dakota.

CONFIDENTIAL INFORMATION

No confidential information is expected to result from performance of this project.

REFERENCES

1. Center for Air Toxic Metals®. *Final Report Series*; 1996–2002.
2. Dunham, G.E.; Miller, S.J.; Laudal, D.L. *Investigation of Sorbent Injection for Mercury Control in Coal-Fired Boilers*; Final Report Prepared for EPRI and DOE; Energy & Environmental Research Center: Grand Forks, ND, Sept 1998.
3. Olson, E.S.; Sharma, R.K.; Miller, S.J.; Dunham, G.E. Identification of the Breakthrough Oxidized Mercury Species from Sorbents in Flue Gas. In *Proceedings of the Specialty Conference on Mercury in the Environment*; Minneapolis, MN, Sept 15–17, 1999; pp 121–126.

4. Miller, S.J.; Dunham, G.E.; Olson, E.S. Controlling Mechanisms That Determine Mercury Sorbent Effectiveness. In *Proceedings of the Air & Waste Management Association 92nd Annual Meeting & Exhibition*; St. Louis, MO, June 20–24,1999; Paper 99-898.

5. Pavlish, J.H.; Sondreal, E.A.; Mann, M.D.; Olson, E.S.; Galbreath, K.C.; Laudal, D.L.; Benson, S.A., Status Review of Mercury Control Options for Coal-Fired Power Plants. *Fuel Process. Technol.* **2003**, *82*, 2–3, 89–165.

6. Pavlish, J.H.; Holmes, M.J.; Benson, S.A.; Crocker, C.R.; Galbreath, K.C. Mercury Control Technologies for Utilities Burning Lignite Coal. In *Proceedings of Air Quality III: Mercury, Trace Elements, and Particulate Matter Conference*; Arlington, VA, Sept 9–12, 2002..

7. Sjostrom, S.; Richardson, C.; Chang, R. *Evaluation of Mercury Emissions and Control Options for Great River Energy*, Final Report, North Dakota Industrial Commission, June 2001.

8. Ghorishi, S.B.; Keeney, R.M.; Serre, S.D.; Gullett, B.K.; Jozewicz, W.S. Development of a Cl-Impregnated Carbon for Entrained-Flow Capture of Elemental Mercury. *Environ. Sci. Technol.* **2002**, *36*, 4454–4459.

9. Coughlin, R.W.; Ezra, F.S. *Environ. Sci. Technol.* **1968**, *2*, 4, 291–297.

10. Tessmer, C.H.; Vidic, R.K.; Uranowski, L.J. *Environ. Sci. Technol.* **1997**, *13*, 7, 1872.

11. Liu, W.; Vidic, R.D.; Brown, T.D. Optimization of Sulfur Impregnation Protocol for Fixed-Bed Application of Activated Carbon-Based Sorbents for Gas-Phase Mercury Removal. *Environ. Sci. Technol.* **1998**, *32*, 531–538.

12. Vidic, R.D.; McLaughlin, J.B. Uptake of Elemental Mercury Vapors by Activated Carbons. *J. Air Waste Manage. Assoc.* **1996**, *46*, 241–250.

13. Krishnan, S.V.; Gullett, B.K.; Jozewicz, W. Sorption of Elemental Mercury by Activated Carbon. *Environ. Sci. Technol.* **1994**, *28*, 1506–1512.

14. Nelson, S.G., Jr. U.S. Patent 20040003716, 2004.

15. Dunham, G.E.; Olson, E.S.; Miller, S.J. Impact of Flue Gas Constituents on Carbon Sorbents. In *Proceedings of the Air Quality II: Mercury, Trace Elements, and Particulate Matter Conference*; McLean, VA, Sept 19–21, 2000; Paper A4-3.

16. Laumb, J.D.; Benson, S.A.; Olson, E.S. X-Ray Photoelectron Spectroscopy Analysis of Mercury Sorbent Surface Chemistry. In *Proceedings of Air Quality IV: Mercury, Trace Elements, and Particulate Matter Conference*, Arlington, VA, Sept 22–24, 2003; To be published in a special issue of *Fuel Process Technol.*

17. Benson, S.A.; Olson, E.S.; Crocker, C.R.; Pavlish, J.P.; Holmes, M.J. Mercury Sorbent Testing in Simulated Low-Rank Coal Flue Gases. In *Proceedings of the 6th Electric Utilities Environmental Conference*; Jan 27–30, 2003.

18. Olson, E.S.; Laumb, J.D.; Benson, S.A.; Dunham, G.E.; Sharma, R.K.; Mibeck, B.A.; Miller, S.J.; Holmes, M.J.; Pavlish, J.H. Chemical Mechanisms in Mercury Emissions Control Technologies. *J. Phys. IV France*, **2003**, 107, p. 979.

19. Radovic, L.R.; Bockrath, B. *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* **2000**, *47*, 4, 886.

20. Olson, E.S.; Laumb, J.D.; Benson, S.A.; Dunham, G.E.; Sharma, R.; Mibeck, B.A.; Crocker, C.R.; Miller, S.J.; Holmes, M.J.; Pavlish, J.P. The Mechanistic Model for Flue Gas-Mercury Interactions on Activated Carbons. Presented at the Conference on Air Quality IV: Mercury, Trace Elements, and Particulate Matter, Arlington, VA, Sept 22–24, 2003.

SUMMARY BUDGET

INVESTIGATION OF MERCURY AND CARBON-BASED SORBENT REACTION MECHANISMS - COMPARISON OF SURFACE ANALYSES
DOE
PROPOSED START DATE: JUNE 1, 2005
EERC PROPOSAL #2005-0233

	TOTAL		SASK POWER SHARE		NDIC SHARE		EERC JSRP SHARE	
CATEGORY	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**
TOTAL DIRECT LABOR	307	$ 11,366	38	$ 1,513	120	$ 4,238	149	$ 5,615
TOTAL FRINGE BENEFITS		$ 5,644		$ 757		$ 2,080		$ 2,807
TOTAL LABOR		$ 17,010		$ 2,270		$ 6,318		$ 8,422
OTHER DIRECT COSTS								
TRAVEL		$ 2,534		$ -		$ 2,534		$ -
COMMUNICATION - PHONES & POSTAGE		$ 58		$ 40		$ 10		$ 8
OFFICE (PROJECT SPECIFIC SUPPLIES)		$ 132		$ 26		$ 38		$ 68
SUPPLIES		$ 100		$ 100		$ -		$ -
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)		$ 80		$ 64		$ -		$ 16
FEES		$ 19,304		$ 10,000		$ 3,600		$ 5,704
TOTAL OTHER DIRECT COST		$ 22,208		$ 10,230		$ 6,182		$ 5,796
TOTAL DIRECT COST		$ 39,218		$ 12,500		$ 12,500		$ 14,218
FACILITIES & ADMIN. RATE - % OF MTDC	VAR	$ 20,782	56%	$ 7,000	56%	$ 7,000	47.7%	$ 6,782
TOTAL ESTIMATED COST		$ 60,000		$ 19,500		$ 19,500		$ 21,000

DETAILED BUDGET

INVESTIGATION OF MERCURY AND CARBON-BASED SORBENT REACTION MECHANISMS - COMPARISON OF SURFACE ANALYSES
DOE
PROPOSED START DATE: JUNE 1, 2005
EERC PROPOSAL #2005-0233

					SASK POWER SHARE		NDIC SHARE		EERC JSRP SHARE	
LABOR	**LABOR CATEGORY**	**HOURLY RATE**	**TOTAL HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**	**HRS**	**$COST**
CROCKER, C.	PROJECT MANAGER	$ 28.38	68	$ 1,930	14	$ 397	30	$ 851	24	$ 682
OLSON, E.	PRINCIPAL INVESTIGATOR	$ 46.60	66	$ 3,076	10	$ 466	20	$ 932	36	$ 1,678
BENSON, S.	PRINCIPAL INVESTIGATOR	$ 54.21	40	$ 2,168	10	$ 542	20	$ 1,084	10	$ 542
----------	SENIOR MANAGEMENT	$ 53.73	20	$ 1,075	-	$ -	-	$ -	20	$ 1,075
----------	RESEARCH SCIENTIST/ENGINEER	$ 29.47	69	$ 2,033	-	$ -	37	$ 1,090	32	$ 943
----------	RESEARCH TECHNICIAN	$ 20.07	24	$ 482	-	$ -	-	$ -	24	$ 482
----------	UNDERGRAD-RES.	$ 9.69	8	$ 78	-	$ -	8	$ 78	-	$ -
----------	TECHNICAL SUPPORT SERVICES	$ 16.08	12	$ 193	4	$ 64	5	$ 80	3	$ 49
			307	$ 11,035	38	$ 1,469	120	$ 4,115	149	$ 5,451
ESCALATION ABOVE CURRENT BASE		3%		$ 331		$ 44		$ 123		$ 164
TOTAL DIRECT LABOR				$ 11,366		$ 1,513		$ 4,238		$ 5,615
FRINGE BENEFITS - % OF DIRECT LABOR - STAFF		50%		$ 5,643		$ 757		$ 2,079		$ 2,807
FRINGE BENEFITS - % OF DIRECT LABOR - UNDERGRAD-RES.		1%		$ 1		$ -		$ 1		$ -
TOTAL FRINGE BENEFITS				$ 5,644		$ 757		$ 2,080		$ 2,807
TOTAL LABOR				$ 17,010		$ 2,270		$ 6,318		$ 8,422
OTHER DIRECT COSTS										
TRAVEL				$ 2,534		$ -		$ 2,534		$ -
COMMUNICATION - PHONES & POSTAGE				$ 58		$ 40		$ 10		$ 8
OFFICE (PROJECT SPECIFIC SUPPLIES)				$ 132		$ 26		$ 38		$ 68
SUPPLIES				$ 100		$ 100		$ -		$ -
GENERAL (FREIGHT, FOOD, MEMBERSHIPS, ETC.)				$ 80		$ 64		$ -		$ 16
PARTICULATE ANALYSIS				$ 2,472		$ -		$ -		$ 2,472
GRAPHICS SUPPORT				$ 232		$ -		$ -		$ 232
OUTSIDE LAB - UNIV OF KENTUCKY				$ 13,600		$ 10,000		$ 3,600		$ -
OUTSIDE LAB - PEI				$ 3,000		$ -		$ -		$ 3,000
TOTAL OTHER DIRECT COST				$ 22,208		$ 10,230		$ 6,182		$ 5,796
TOTAL DIRECT COST				$ 39,218		$ 12,500		$ 12,500		$ 14,218
FACILITIES & ADMIN. RATE - % OF MTDC			VAR	$ 20,782	56%	$ 7,000	56%	$ 7,000	47.7%	$ 6,782
TOTAL ESTIMATED COST				$ 60,000		$ 19,500		$ 19,500		$ 21,000

DETAILED BUDGET - FEES

			TOTAL
PARTICULATE ANALYSIS	**RATE**	#	**$COST**
BENCH SCALE SIMULATOR (PER HOUR)	$117	16	$ 1,872
MERCURY CEM (PER DAY)	$264	2	$ 528
SUBTOTAL			$ 2,400
ESCALATION		3.0%	$ 72
TOTAL PARTICULATE ANALYSIS			$ 2,472
GRAPHICS SUPPORT	**RATE**	#	**$COST**
GRAPHICS (HOURLY)	$45	5	$ 225
SUBTOTAL			$ 225
ESCALATION		3.0%	$ 7
TOTAL GRAPHICS SUPPORT			$ 232

DETAILED BUDGET - TRAVEL

INVESTIGATION OF MERCURY AND CARBON-BASED SORBENT REACTION MECHANISMS - COMPARISON OF SURFACE ANALYSES
EERC PROPOSAL #2005-0233

RATES USED TO CALCULATE ESTIMATED TRAVEL EXPENSES

DESTINATION	AIRFARE	PER MILE	LODGING	PER DIEM	CAR RENTAL
New York (state)	$ 1,100	$ -	$ 180	$ 51	$ 60
Minneapolis, MN	$ -	$ 0.31	$ 90	$ 51	$ -

PURPOSE/DESTINATION	NUMBER OF TRIPS	NUMBER OF PEOPLE	NUMBER OF MILES	NUMBER OF DAYS	AIRFARE	MILEAGE	LODGING	PER DIEM	CAR RENTAL	MISC.	TOTAL
XAFS Analysis/New York (state)	1	1	0	3	$ 1,100	$ -	$ 360	$ 153	$ 180	$ 60	$ 1,853
XPS Analysis/Minneapolis, MN	1	2	700	2	$ -	$ 217	$ 180	$ 204	$ -	$ 80	$ 681
TOTAL ESTIMATED TRAVEL											$ 2,534

BUDGET NOTES

ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

Background

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

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

Salaries and Fringe Benefits

As an interdisciplinary, multiprogram, and multiproject research center, the EERC employs an administrative staff to provide required services for various direct and indirect support functions. Direct project salary estimates are based on the scope of work and prior experience on projects of similar scope. Technical and administrative salary charges are based on direct hourly effort on the project. The labor rate used for specifically identified personnel is the current hourly rate for that individual. The labor category rate

is the current average rate of a personnel group with a similar job description. For faculty, if the effort occurs during the academic year and crosses departmental lines, the salary will be in addition to the normal base salary. University policy allows faculty who perform work in addition to their academic contract to receive no more than 20% over the base salary. Costs for general support services such as grants and contracts administration, accounting, personnel, and purchasing and receiving, as well as clerical support of these functions, are included in the EERC facilities and administrative cost rate.

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

Travel

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

Communications (phones and postage)

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

Office (project-specific supplies)

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

Data Processing

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

Supplies

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

Instructional/Research

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

Fees

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

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

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

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

General

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

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

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

Facilities and Administrative Cost

The facilities and administrative rate (indirect cost rate) included in this proposal is the rate that became effective May 11, 2004. Facilities and administrative cost is calculated on modified total direct costs (MTDC). MTDC is defined as total direct costs less individual items of equipment in excess of $5000 and subcontracts/subgrants in excess of the first $25,000 for each award.

APPENDIX A

RESUMES OF KEY PERSONNEL

CHARLENE R. CROCKER
Research Chemist
Energy & Environmental Research Center (EERC)
University of North Dakota (UND)
PO Box 9018, Grand Forks, North Dakota 58202-9018 USA
Phone: (701) 777-5000 Fax: (701) 777-5181
E-Mail: ccrocker@undeerc.org

Principal Areas of Expertise

Ms. Crocker's principal areas of interest and expertise include mercury and halogens in coal combustion, developing carbon-based mercury control sorbents, airborne particulate matter instrumentation, water quality monitoring and analytical methods, development and implementation of fish consumption surveys, general public and K–12 education, laser-induced breakdown spectroscopy (LIBS), atomic absorption spectroscopy (AAS) (flame, graphite furnace, and hydride generation), inductively coupled plasma spectroscopy (ICP), trace element analysis of water, coal and coal by-products, and atomic fluorescence spectroscopy (AFS).

Qualifications

B.S., Chemistry, University of North Dakota, 1994
B.A., French, Colby College, Waterville, ME, 1986

Professional Experience

2002 – Research Scientist, Responsibilities include managing projects relating to environmental management and air quality; collaborating with other scientists on development of carbon-based flue gas sorbents, particulate matter (PM) sampling, development of water quality education and CO_2 sequestration public outreach materials, evaluation of bioassesssment tools, fish consumption survey development, proposal and report writing, data analysis, presentation of results, and budget tracking; developing PM sampling protocols; participating in development of a water-based geoscience education program and outreach activities for school children; directing activities of student assistants.

1994 – 2002 Research Chemist, Responsibilities include managing projects relating to environmental management and air quality; collaborating with other scientists on particulate matter (PM) sampling, fish consumption survey development, corrosion of ceramic and alloy materials, coal ash, water purification, and surface decontamination research; proposal and report writing, data analysis, presentation of results, and budget tracking; developing PM sampling protocols; participating in development of a water-based geoscience education program and outreach activities for school children; directing activities of student assistants; developing and implementing analytical methods employing LIBS. Previous duties performed in the Analytical Research Laboratory focused on water quality and energy-related analyses. Responsibilities included preparing and analyzing ultratrace element samples in aqueous and inorganic media using AAS, ICP, and IC; recording and disseminating analytical results and quality control checks;

performing research on ultratrace elemental analysis of mercury using AFS; and preparing reagents and solutions.

1993 – 1994 Research Assistant, EERC, UND. Ms. Crocker's responsibilities included preparing and analyzing ultratrace element samples in inorganic media; performing research on ultratrace element analysis of mercury in air using AFS; and preparing reagents and solutions.

1990 Naturalist, Deep Portage Conservation Reserve, Hackensack, Minnesota. Ms. Crocker's responsibilities included planning and conducting environmental education programs for children and adults; evaluating curriculum; and organizing lending of educational learning stations.

1988 – 1990 Sanctuary Manager, Wetlands, Pines & Prairie Audubon Sanctuary, Warren, Minnesota. Ms. Crocker's responsibilities included planning and conducting environmental education programs; organizing chapter meetings; publishing the Sanctuary newsletter; and performing administrative tasks.

1988 Park Ranger/Interpreter, Boston Harbor Islands State Park, Boston, Massachusetts. Ms. Crocker's responsibilities included interpreting natural and human history; developing special programs and leading walking tours of the islands; and conducting school programs.

Publications and Presentations

Has coauthored several publications

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

Principal Areas of Expertise

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.

Qualifications

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

Professional Experience

1999 – Senior Research Manager/Advisor, EERC, UND. Responsible for the direction of projects and programs on the impact of inorganic species on the performance of combustion and associated environmental control systems. Specific areas of focus include the direction of the EPA Center for Air Toxic Metals at the EERC, advanced methods of materials analysis, and application of computer models to energy and environmental issues.

1994 – 1999 Associate Director for Research, EERC, UND. Responsible for the direction of programs related to integrated energy and environmental systems development. EERC research, development, and demonstration programs involve fuel quality effects on power system performance, advanced power systems development/demonstration, computational modeling, advanced materials for power systems, and analytical methods for the characterization of materials. Specific areas of focus included the direction of the EPA Center for Air Toxic Metals at the EERC, ash behavior in combustion and gasification systems, hot-gas cleanup, and analytical methods of analysis. Responsible for identifying research opportunities and the preparation of proposals and reports for clients.

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

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

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

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

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

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

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

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

Professional Memberships

- The Combustion Institute
- ASME Research Committee on Corrosion and Deposits from Combustion Gases
- American Chemical Society, Fuel Division Member
- Industrial Liaison, American Chemical Society Division of Fuel Chemistry

Publications and Presentations

- Has authored/coauthored over 180 publications and is the editor of six books and Special Issues

DR. EDWIN S. OLSON
Senior Research Advisor
Energy & Environmental Research Center (EERC)
University of North Dakota (UND)
PO Box 9018, Grand Forks, North Dakota 58202-9018 USA
Phone: (701) 777-5000 Fax: (701) 777-5181
E-Mail: eolson@undeerc.org

Principal Areas of Expertise

Dr. Olson's principal areas of interest and expertise include carbon and coal structure and reactivity, mercury sorption, water purification chemistry, enzyme-catalyzed esterification and desulfurization reactions, chromatography, organic trace analysis, mass spectrometry, and organic spectroscopy.

Qualifications

Ph.D., Chemistry and Physics, California Institute of Technology, 1964.
B.A., Chemistry, magna cum laude, St. Olaf College, 1959.

Professional Experience

1994 – Senior Research Advisor, EERC, UND. Novel activated carbons for air and water treatment were designed and tested.

1988 – President, Universal Fuel Development Associates, Inc. Dr. Olson served as Project Manager for Phase I and II Small Business Innovation Research projects involving water purification, nonaqueous enzymatic solubilization of coal materials, oxygenate synthesis from agricultural materials. and DBP removal from drinking water and for DOE projects involving geotechnical characterizations and fine-particle catalysts for coal liquefaction.

1983 – 1994 Research Supervisor, Fuel Conversion and Process Chemistry Division, EERC, UND. Dr. Olson performed hydrotreating and HDS catalyst, and coal liquefaction, and gasification research and analytical methods development.

1980 – 1983 Research Chemist, Grand Forks Energy Technology Center, U.S. Department of Energy. Dr. Olson developed analytical methods for coal conversion products by GC, MS, HPLC, and NMR and trace organics in air, water, and fly ash.

1968 – 1980 Professor of Chemistry, South Dakota State University. Taught graduate/under-graduate courses in organic, biochemistry, and instrumental analysis. Research in homogeneous catalysts, organic synthesis.

1977 Visiting Professor, University of Notre Dame (summer).

1972 – 1976 Visiting Staff Member, Los Alamos Scientific Laboratory (summers).

Dr. Olson also has experience at the University of California, Los Angeles, Department of Biochemistry, and at Idaho State University, Department of Chemistry.

Publications and Presentations (over 180 total)
Recent refereed Publications

- Olson, E.S.; Laumb, J.D.; Benson, S.A.; Dunham, G.E., Sharma, R.K..; Mibeck, B.A.; Miller, S.J.; Holmes, M.J.; Pavlish, J.H. *J. Phys. IV France* **2003**, *107*, 979.

- Olson, E.S.; Sharma, R.K.; Aulich, T.R. Ester Fuels and Chemicals from Biomass. *Appl. Biochem. Biotechnol*. **2003**, *105-108*, 843.

- Olson, E.S.; Sharma, R.K.; Pavlish, J.P. On the Analysis of Mercuric Nitrate in Flue Gas by GCMS. *Anal. Bioanal. Chem*. **2002**, *374*, 1045.

- Pavlish, J.P.; Sondreal, E.A.; Mann, M.D.; Olson, E.S.; Galbreath, K.C.; Laudal, D.L.; Benson, S.A. A Status Review of Mercury Control Options for Coal-Fired Power Plants. *Fuel Process. Technol*. **2003,** *82*, 89.

- Olson, E.S.; Kjelden, M.R.; Schlag, A.J.; Sharma, R.K. Levulinate Esters from Biomass Wastes. In *Chemicals and Materials from Renewable Resources*; Bozell, J.J., Ed.; ACS Symposium Series 784; American Chemical Society, Ch. 5, 2001, pp 51–63.

- Galbreath, K.C.; Zygarlicke, C.J.; Olson, E.S.; Pavlish, J.H.; Toman, D.L. Evaluating Mercury Transformation Mechanisms in a Laboratory-Scale Combustion System. *The Science of the Total Environment* **2000**, *261*, 149–155.

- Miller, S.J.; Dunham, G.E.; Olson, E.S.; Brown, T.D. Flue Gas Effects on a Carbon-Based Mercury Sorbent. *Fuel Process. Technol.* **2000**, *65–66*, 343–363.

- Olson, E.S.; Miller, S.J.; Sharma, R.K.; Dunham, G.E.; Benson, S.A. Catalytic Effects of Carbon Sorbents for Mercury Capture. *J. Hazard. Mater.* **2000**, *74*, 61–79.

- Oldfield, C.; Pogrebinsky, O.; Simmonds, J.; Olson, E.S.; Kulpa, C.F. Elucidation of the Metabolic Pathway for Dibenzothiophene Desulphurization by *Rhodococcus* Sp. Strain IGTS8 (ATCC 53968). *Microbiol.* **1997,** *143*, 2961–2973.

- Timpe, R.C.; Kulas, R.W.; Hauserman, W.B.; Sharma, R.K.; Olson, E.S.; Willson, W.G. Catalytic Gasification of Coal for the Production of Fuel Cell Feedstock. *Int. J. Hydrogen Energy* **1997**, *22* (5), 487–492.

- Olson, E.S.; Sharma, R.K. Naphthene Upgrading with Pillared Synthetic Clay Catalysts. *Energy Fuels* **1996**, *10*, 587.

- Sharma, R.K.; Olson, E.S. Catalytic Hydrotreating with Pillared Synthetic Clays. In *Hydrotreating Technology for Pollution Control*; Occelli, M.L.; Chianelli, R., Eds.; Dekker: New York, 1996; p 313.

- Olson, E.S.; Singh, H.K.; Yagelowich, M.; Diehl, J.W.; Heintz, M.J.; Sharma, R.K.; Stanley, D.C. Nonaqueous Enzymatic Solubilization of Coal–Derived Materials. *Fuel* **1993**, *72* (12), 1687–1693.

- Olson, E.S.; Singh, H.K.; Yagelowich, M. Nonaqueous Enzymatic Synthesis of Ester Fuels. In *Proceedings of the 1st Biomass Conference of the Americas*; Burlington, VT, Aug 30, 1993; Vol. 2, pp 837–847.

- Denome, S.A.; Olson, E.S.; Young, K.D. Identification and Cloning of Genes Involved in Specific Desulfurization of Dibenzothiophene by *Rhodococcus rhodocrous* IGTS8. *Appl. Environ. Microbiol.* **1993**, *59*, 2837–2843.

- Denome, S.A; Stanley, D.C; Olson, E.S.; Young, K.D. Metabolism of Dibenzothiophene and Naphthalene in *Pseudomonas*: Complete DNA Sequence of an Upper Naphthalene Catabolic Pathway. *J. Bacteriol.* **1993**, *175*, 6890–6901.

- Gallagher, J.R.; Olson, E.S.; Stanley, D.C. Microbial Desulfurization of Dibenzothiophene: A Sulfur-Specific Pathway. *FEMS Microbiol. Lett.* **1993**, *107*, 31–36.

- Olson, E.S.; Stanley, D.C.; Gallagher, J.R. Characterization of Intermediates in the Microbial Desulfurization of Dibenzothiophene. *Energy Fuels* **1993**, *7*, 159–164.

- Olson. E.S. K/T Amino Acids from Coal Gasification. *Nature* **1992**, *357*, 202.

- Olson, E.S.; Sharma, R.K. Catalytic Upgrading of Biomass Derivatives to Transportation Fuels. In *Energy from Biomass and Wastes XVI*; Klass, D.L., Ed.; Inst. Gas Technol.: Chicago, IL, 1992; pp 739–751.

- Sharma, R.K.; Olson, E.S. Catalytic Hydrodesulfurization with Hydrotalcites. In *Processing and Utilization of High-Sulfur Coals IV*; Dugan, P.R.; Quigley, D.R.; Attia, Y.A., Eds.; Elsevier: Amsterdam, 1991; pp 377–384.

- O'Brien, R.A.; Worman, J.J.; Olson E.S. Carbon Dioxide in Organic Synthesis: Preparation and Mechanism of Formation of N-(3)-substituted Hydantoins. *Synth. Commun.* **1991**, *22* (6).

- Olson, E.S.; Diehl, J.W. Anisotropy in Dilute Solutions of Coal-Derived Materials. *Coal Structure and Reactivity*; Queens College, Cambridge, UK, Sept. 5–7, 1990; *Fuel* **1991**, *70*, 349–351.

- Diehl, J.W.; Kleinjan, S.B.; Olson, E.S. A Gas Chromatographic/Fourier Infrared Spectroscopy/ Mass Spectrometry/Atomic Emission Detection/Flame Ionization Detection System. *Spectrosc. Int. J.* **1990**, *8*, 43–72.

- Sharma, R.K.; Diehl, J.W.; Olson, E.S. Hydrodesulfurization with a New Solid Acid Catalyst. In *Processing and Utilization of High-Sulfur Coals III*; Markuszewski, R.; Wheelock, T.D., Eds.; Elsevier: Amsterdam, 1990; pp 735–743.

- Olson, E.S.; Diehl, J.W. Characterization of Coal Liquefaction Products by GC/FT-IR/MS. Presented at the 25th International Symposium on Advances in Chromatography, Minneapolis, MN, Aug 29, 1988; *J. Chromatogr.* **1989**, *468*, 309–317.

APPENDIX B

INDUSTRY SPONSOR SUPPORT

AGREEMENT

This document sets forth the Agreement between the following parties: the University of North Dakota Energy & Environmental Research Center, a public institution of higher education and an instrumentality of the state of North Dakota organized under the constitution of the state, having its principal place of business in Grand Forks, North Dakota (hereinafter referred to as CONTRACTOR), and Saskatchewan Power Corporation, having its principal place of business in Regina, Saskatchewan (hereinafter referred to as SPONSOR). The parties to this Agreement are sometimes hereinafter referred to individually as a "Party" and collectively as the "Parties."

WHEREAS CONTRACTOR is willing to conduct a project entitled "Investigation of Mercury And Carbon-Based Sorbent Reaction Mechanisms – Comparison of Surface Analysis Techniques" (Project) and SPONSOR and U.S. Department of Energy (DOE) wish to receive the results of said evaluation.

THEREFORE, SPONSOR and CONTRACTOR agree as follows.

Article 1 – Scope of Work

CONTRACTOR agrees to perform the scope of work as set forth in CONTRACTOR's Proposal No. 2005-0147, entitled "Investigation of Mercury And Carbon-Based Sorbent Reaction Mechanisms – Comparison of Surface Analysis Techniques," dated December 14, 2004, appended hereto and incorporated as APPENDIX A, Scope of Work & Budget.

Article 2 – Period of Performance

The Agreement will become effective and will commence on December 15, 2004. CONTRACTOR shall use its best efforts to complete the Project by December 31, 2005. CONTRACTOR may extend the planned completion date of the Project to reflect actual performance. Notification of the new planned completion date will be forwarded to SPONSOR.

Article 3 – Deliverables

CONTRACTOR shall use its best efforts to submit the reports/deliverables described in APPENDIX A, Scope of Work & Budget, in accordance with the time frames specified in the same appendix.

Article 4 – Consideration and Payment

The total cost to perform the Scope of Work defined in APPENDIX A is estimated to be US$60,000, with anticipated funding as follows: US$19,500 from Saskatchewan Power Corporation, US$19,500 from the North Dakota Industrial Commission (NDIC), and US$21,000 from DOE. It is understood that funding received from NDIC and DOE will be authorized under separate agreement with CONTRACTOR. In the event that the cofunding is not secured at the amounts proposed, we will negotiate changes to the scope of work and budget with SaskPower.

SPONSOR shall pay the fixed amount of US$19,500 upon execution of this Agreement.

Article 5 – Intellectual Property

It is not anticipated that this Project will result in any inventions, discoveries, or improvements. However, CONTRACTOR will promptly notify SPONSOR and DOE if any inventions, discoveries, or improvements are developed under this Project which it believes are potentially patentable or otherwise protectable.

Any and all inventions, discoveries, or improvements developed under this Project will be the sole and exclusive property of CONTRACTOR.

Oversight responsibility for Contractor's revenue-generating intellectual property and the primary holder of such property resides with the Energy & Environmental Research Center Foundation (EERCF). The EERCF is associated with the Contractor; however, it is a separate legal entity with a board of directors. Negotiations relating to intellectual property for the Contractor begin with the Contracts Officer, with input and approval from the Associate Director of Industrial Relations and Technology Commercialization. Intellectual property terms and conditions must be accepted by the Contractor's Director, then approved by the EERCF Board of Directors.

SPONSOR is aware that CONTRACTOR is also receiving federal funding for the Project that is the subject of this Agreement and that CONTRACTOR's obligations to SPONSOR regarding intellectual property such as patents, data, and copyrights may be secondary to CONTRACTOR's obligations to the federal government. Nothing in this Agreement prevents SPONSOR from asserting its rights in such property against the federal government.

Article 6 – Title to Equipment

CONTRACTOR shall retain title to all equipment purchased and /or fabricated by it or on its behalf with funds provided by SPONSOR under this Agreement.

Article 7 – Public Information Releases

The Parties shall coordinate in advance on all public information releases to be issued concerning this Project if the release contains a reference to CONTRACTOR, SPONSOR , or DOE. Such releases shall not be issued without prior approval from the referenced parties' authorized representatives.

Article 8 – Confidentiality

During the course of this Project, it is not anticipated that confidential or proprietary information will be disclosed. Should it become necessary for either party to disclose confidential or proprietary information, a separate nondisclosure agreement will be prepared and executed by the parties.

Article 9 – Independent Contractor

CONTRACTOR is an Independent Contractor, not a partner or joint venturer, and shall not act as an agent for SPONSOR, nor shall CONTRACTOR be deemed to be an employee of SPONSOR for any purpose whatsoever. CONTRACTOR shall not have any authority, either express or implied, to enter into any agreement, to incur any obligations on behalf of SPONSOR, or to commit SPONSOR in any manner whatsoever without SPONSOR's express prior written consent.

Article 10 – Termination

If CONTRACTOR shall fail to fulfill one or more of its obligations under this Agreement or breach any one or more of the terms and conditions of this Agreement, SPONSOR may, upon its election, at any time terminate this Agreement by giving not less than thirty (30) days' prior written notice of termination to CONTRACTOR specifying any such breach or default. In the event of termination pursuant to this Article, CONTRACTOR shall stop all work hereunder. No costs incurred after the effective date of termination will be allowable, except 1) those costs which CONTRACTOR could not reasonably avoid or eliminate, 2) those costs which were otherwise authorized by the termination notice, or 3) those costs which were incurred in CONTRACTOR's satisfactory fulfillment of its obligations under this Agreement. In no event will the total of payments under this Agreement, if terminated, exceed the amount authorized by SPONSOR in Article 4 of this Agreement.

Either party may terminate this Agreement for convenience by thirty (30) days' written notice to the other party. In the event of such termination, CONTRACTOR shall immediately stop all work and shall be reimbursed for allowable costs incurred under such termination and for all costs incurred after the effective date of such termination, which CONTRACTOR could not reasonably avoid or eliminate or which were otherwise authorized by the termination notice. In no event will the total of payments under this Agreement, if terminated, exceed the amount authorized by SPONSOR in Article 4 of this Agreement.

Article 11 – Notices

All notices, demands, offers, and other communications required or permitted hereunder shall be in writing and shall be deemed to have been given when received at the addresses noted below. The following are the separate addresses for technical and contractual concerns:

SPONSOR	Technical Matters	Contractual Matters
Name	David Smith	
Address	Saskatchewan Power Corporation 2025 Victoria Avenue Regina, Saskatchewan S4P 0S1 CANADA	
Phone	(306) 566-2290	
Fax	(306) 566-3348	
e-mail	dsmith@saskpower.com	
CONTRACTOR		
Name	Charlene Crocker	Paul Arnason
Address	Energy & Environmental Research Center University of North Dakota PO Box 9018 Grand Forks, ND 58202	Energy & Environmental Research Center University of North Dakota PO Box 9018 Grand Forks, ND 58202
Phone	(701) 777-5018	(701) 777-XXXX
Fax	(701) 777-5181	(701) 777-5181
e-mail	ccrocker@undeerc.org	parnason@undeerc.org

Article 12 – Liability

Each Party shall be responsible for claims, losses, damages, and expenses which are proximately caused by the negligence or wrongful acts or omissions of that party, or its employees, agents, or representatives acting within the scope of their employment. The liability of CONTRACTOR is subject to the conditions and limitations contained in Chapter 32-12.2 of the North Dakota Century Code. Nothing herein shall preclude either party from asserting against third parties any defenses to liability it may have under the law or be construed to create a basis for a claim or suit when none would otherwise exist. This provision shall survive the termination of this Agreement.

SPONSOR agrees to inform CONTRACTOR in the event either an investigation or claim arises out of the performance of this contract and shall provide CONTRACTOR with reasonable access to information involving such investigation or claim. SPONSOR shall notify CONTRACTOR of the disposition of any such investigation or claim.

Article 13 – Governing Law

This Agreement shall be governed by, construed, and enforced in accordance with the laws of the state of North Dakota.

Article 14 – Miscellaneous

The headings in this Agreement are inserted for convenience and identification only and are in no way intended to describe, interpret, define, or limit the scope, extent, or intent of this Agreement or any provision hereof.

The terms of this Agreement are binding upon and inure to the benefit of the successors and assigns of the respective parties.

This Agreement, with attached APPENDICES, constitutes the entire agreement between the parties relative to the subject matter.

Except for changes in work pursuant to Article 2, all changes, alterations, or modifications to this Agreement will be in writing and signed by the authorized officials of the parties hereto.

If one or more of the provisions of the Agreement are held invalid, illegal, or unenforceable in any respect, the validity, legality, and enforceability of the remaining provisions shall not be in any way be affected or impaired thereby.

IN WITNESS WHEREOF, the parties hereto have executed this Agreement on the day and year last specified below:

SASKATCHEWAN POWER CORPORATION

Per _____

Name _____

Title _____

Date _____

Per _____

Name MYRON GULKA-TIECHKO

Title ASSISTANT SECRETARY

Date Dec 20/04

SaskPower APPROVED FOR EXECUTION DS

UNIVERSITY OF NORTH DAKOTA ENERGY & ENVIRONMENTAL RESEARCH CENTER

By _____

Name Dr. Barry I. Milavetz

Title Interim Director. Research Development and Compliance

Date 12/21/2004

per Barry I. Milavetz

SaskPower

RECEIVED
JAN 18 2005
EERC ACCT

PURCHASE ORDER ACCEPTANCE OF TENDER

PO Number 4500125137 **Date** 12/31/2004

Contact person/Telephone
Mike Dundas/306-566-2762
Our fax number
306-566-2777

4022101
UNIVERSITY OF NORTH DAKOTA ENERGY
AND ENVIRONMENTAL RESEARCH CENTER
PO BOX 9016
15 NORTH 23RD ST
GRAND FORKS ND 58202-9018
USA
Please deliver to:
AS INSTRUCTED.
CANADA

Tax Status:
0% GST, 0% Saskatchewan PST

Terms of delivery.: Prepaid SITE
Terms of payment.: Pay immediately on Receipt

Item	Material Order qty.	Unit	Description Price per unit	Net value
00010			Bench and pilot study on mercury	
	19,500	EACH	1.00	19,500.00

TO COVER FOR THE COST OF A BENCH AND PILOT SCALE STUDY ON MERCURY AND CARBON BASED SORBENT REACTION MECHANISMS.

ALL IN ACCORDANCE WITH:
1.AGREEMENT BETWEEN SASKPOWER AND THE UNIVERSITY OF NORTH DAKOTA DATED 12/20/2004.

Total 19,500.00 USD

BUYER'S SIGNATURE _____
For Purchasing Supervisor