Energy & Environmental Research Center
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March 31, 2020

Ms. Karlene Fine
Executive Director
ATTN: Lignite Research Development and Marketing Program
North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: EERC Proposal No. 2020-0150 Entitled "Laboratory-Scale Coal-Derived Graphene Process"

The Energy & Environmental Research Center (EERC) of the University of North Dakota submits the subject proposal to develop a technological process for converting North Dakota (ND) lignite and other U.S. coals into high-value solid carbon products such as graphene.

Enclosed please find an original and one copy of the subject proposal along with a check for $100. The EERC, a research organization within the University of North Dakota, an institution of higher education within the state of North Dakota, is not a taxable entity; therefore, it has no tax liability.

This transmittal letter represents a binding commitment by the EERC to complete the project described in this proposal. If you have any questions, please contact me by telephone at (701) 777-5051 or by e-mail at aazenkeng@undeerc.org.

Sincerely,

Dr. Alexander Azenkeng
Digitally signed by Dr. Alexander Azenkeng
DN: cn=Dr. Alexander Azenkeng, o=University of North Dakota, ou=EERC, email=aazenkeng@undeerc.org, c=US
Date: 2020.03.31 11:34:57 -05'00'

Alexander Azenkeng
Senior Scientist
Advanced Energy Systems

Approved by:

Charles D. Gorecki
Digitally signed by Charles D. Gorecki
DN: cn=Charles D. Gorecki, o=Energy & Environmental Research Center, ou=University of North Dakota, email=cgorecki@undeerc.org, c=US
Date: 2020.03.31 11:35:47 -05'00'

Charles D. Gorecki, CEO
Energy & Environmental Research Center

AZ/kal

Enclosures

Lignite Research, Development and Marketing Program

North Dakota Industrial Commission

Application

Project Title: Laboratory-Scale Coal-Derived Graphene Process

Applicant: University of North Dakota Energy & Environmental Research Center

Principal Investigator: Dr. Alexander Azenkeng

Date of Application: March 31, 2020

Amount of Request: $162,500

Total Amount of Proposed Project: $931,564

Duration of Project: 36 months

Point of Contact (POC): Dr. Alexander Azenkeng

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ABSTRACT

Objective: The Energy & Environmental Research Center (EERC) proposes to develop a technological process for converting North Dakota (ND) lignite and other U.S. coals into high-value solid carbon products such as graphene for use in multiple applications. The scope of work will also include an economic feasibility analysis and analysis of product target markets and technology gaps for scale-up or commercialization.

Expected Results: The proposed work is expected to result in 1) development of methods to substantially improve the quality of ND lignite and other coal feedstocks as a suitable precursor for graphene and/or its derivatives, 2) demonstration of a laboratory-scale process for making graphene from the improved coal residue, and 3) preliminary techno-economic feasibility and technology gap analysis based on the data generated to provide insight into the direction of future research.

Project Duration: 36 months, with an anticipated start date of May 1, 2020.

Total Project Cost: The total project cost is $931,564. The EERC is requesting $162,500 from the North Dakota Industrial Commission (NDIC) Lignite Research, Development and Marketing Program. The U.S. Department of Energy (DOE) is providing $744,064, and North American Coal Corporation (NACoal), the commercial partner, is providing $25,000.

Participants: NDIC, DOE, NACoal, and the EERC.

PROJECT SUMMARY

The Energy & Environmental Research Center (EERC), in partnership with the North Dakota Industrial Commission (NDIC) Lignite Research, Development and Marketing Program (LRP), the U.S. Department of Energy (DOE), and North American Coal Corporation (NACoal), proposes to develop a technological process for converting North Dakota (ND) lignite and other U.S. coals into high-value solid carbon products such as graphene in an effort to enhance the ND lignite and other domestic U.S. coals' value chain. Graphene is known for its extraordinary mechanical, electrical, and optical properties, which make it suitable for a wide range of applications across multiple industries.

The scope of work comprises five steps: 1) coal pretreatment with demonstrated EERC methods, 2) graphitization of treated coal residues, 3) exfoliation of graphite to graphene or its derivatives, 4) preliminary techno-economic feasibility analysis, and 5) analysis of product target markets and technology gaps. These steps will be applied to ND lignite as well as anthracite, bituminous, and subbituminous coals to advance the current state of technology within the state and nationwide.

The benefits of this project to North Dakota include enhancing, preserving, and protecting the lignite industry and advancing economic growth via new opportunities for lignite markets in nonenergy sectors such as the electronics industry and high-energy storage applications, including fast-charging, higher-capacity lithium-ion batteries. In addition, the results of the preliminary techno-economic feasibility analysis and the analysis of technology gaps will be useful for evaluating the commercialization prospects of this technology, with the aim not only to enhance the ND lignite value chain, but also to enhance the value of other domestic U.S. coals for national economic security.

PROJECT DESCRIPTION

Introduction

The Energy & Environmental Research Center (EERC), in partnership with the North Dakota Industrial Commission (NDIC) Lignite Research, Development and Marketing Program (LRP), the U.S. Department of Energy (DOE), and North American Coal Corporation (NACoal), proposes to develop a technological process for converting North Dakota (ND) lignite and other U.S. coals into high-value solid carbon products such as graphene in an effort to enhance the domestic U.S. coals value chain. Graphene is a highly sought material because of its excellent mechanical, thermal, electrical, and optical properties. As a result, there are numerous graphene applications across multiple industries including electronics, automotive, aerospace, sports, and building and construction. Forms of graphene that possess these properties include graphene oxide (GO) and reduced graphene oxide (rGO) (Marcano et al., 2010), graphene nanosheets (GNS) (Shamsaei et al., 2018), and graphene quantum dots (GQDs) (Ye et al., 2013). Advancement of these high-value solid-carbon products could revolutionize near- and long-term daily experiences based on new reinforced lightweight components such as auto parts, sporting equipment, aircraft defrosters, durable and long-cycling-life lithium-ion batteries, and a new generation of optical display screens made from GQDs.

According to a study by the Graphene Council (2020), device-grade graphene for high-end devices sells at about $1500/kg or ~ $1.4 million/ton, and low-grade graphene used to make enhanced concrete composite mixtures sells at about $20/kg or ~$18,000/ton. Currently, most of the graphene products are made from graphite, which sells at about $1000/ton (Reid, 2018). Given the comparatively low coal prices (based on 2018 market price) reported by the Energy Information Administration (2020), i.e., approximately $20/ton for lignite, $14/ton for subbituminous coal, $59/ton for bituminous, and $100/ton for anthracite, it is economically advantageous to develop technologies for making graphene from coal to cut cost and to enhance the coal value chain.

Despite the many important applications of graphene, its production from coal still faces serious challenges. For example, the presence of inorganic minerals and heteroatoms (e.g., S, N, O) in coals makes it difficult to make high-quality graphite that can be exfoliated to make graphene. Also, studies of lower-rank coals are limited partly because these are highly oxidized coals, have low aromatic content, and have high ash-bearing inorganic mineral and heteroatom content. However, lower-rank coals contain some aromatic domains that can be harnessed to make materials such as GQDs.

Considering the challenges mentioned above, this proposal seeks to develop a laboratory-scale coal-derived graphene (CDG) process to produce graphene and/or its derivatives starting from ND lignite and other U.S. coals. Additionally, analysis of the process's economic feasibility and technology gaps for scale-up or commercialization, as well as evaluation of potential markets for these carbon products, will be performed.

Objectives

The overall objective of the proposed project is to develop a technological process for converting ND lignite and other U.S. coals into high-value solid carbon products such as graphene and to conduct an economic feasibility analysis and analysis of product target markets and technology gaps for scale-up or commercialization.

Methodology

To achieve the objective of the project, the methodology comprises six tasks that are described in detail below.

Task 1.0 – Project Management and Planning. The EERC will manage and direct the project in accordance with the stated objectives to meet all technical, schedule, and budget requirements. All project activities will be led and coordinated by the EERC with the aim to effectively accomplish the work. The EERC will ensure that project plans, results, and decisions are appropriately documented and project reporting and updating requirements are satisfied. Any modifications to the project timetable, technical approach, cost, or scope of work after award will be considered in consultation with the project sponsors to accurately reflect the current status of the work being performed.

Task 2.0 – Coal Pretreatment and Equipment Fabrication/Acquisition

Subtask 2.1 – Equipment Fabrication. Two custom-designed stainless-steel reactors, including a demineralizer reactor (DR) and a fluidized-bed reactor (FBR), will be fabricated at the EERC for the pretreatment and chemical modification (hydrogenation/reduction), respectively, of the coal samples. An existing high-temperature (~1800°C) furnace will be retrofitted with a condensate trap (CT) to condense the volatile organic matter that is liberated from the coals during carbonization. The condensate will be characterized to determine the yield and composition.

Subtask 2.2 – Coal Pretreatment. The crushed raw coal samples will be pretreated using demonstrated EERC cleaning methods to remove inorganic and heteroatom impurities. The samples will be analyzed before and after cleaning to determine the coal moisture, volatile matter, fixed carbon, ash content, and elemental composition (C, H, N, O, and S) by proximate and ultimate analysis techniques, with oxygen being determined by difference. In addition, x-ray fluorescence (XRF) and x-ray diffraction (XRD) analyses will be performed.

Subtask 2.3 – Acquisition of New Equipment, Installation, and Training. A laboratory high-temperature graphite (LHTG) furnace with an upper limit of ~3000°C will be purchased to perform graphitization of the treated coal materials. A Raman spectrometer, which is generally the preferred instrument for determining defects and quality of graphene, will also be purchased and used to characterize the graphite and graphene products. Upon delivery of the equipment, service engineers from the vendors will conduct installation and training at the EERC.

Task 3.0 – Graphitization of Treated Coal Products. This task will involve preparation and characterization of graphite starting from the treated coal feedstocks described in Task 2.0. The cleaned lignite and other coal residues will be further chemically treated to remove heteroatoms. Carbonization of the treated coals will be carried out in a high-temperature furnace, and the volatile fractions will be collected in a CT for analysis. The quality of the coal after carbonization will be further improved by controlled heat treatment at ~1500°C. The final coal residue will be graphitized at ~2800°C for 4 hours in the LHTG furnace. The graphitized coal products will be characterized by field emission scanning electron microscopy (FESEM), quantitative XRD, and Raman spectroscopy techniques to determine the product quality and quantity. Commercially available graphite (control) samples will also be analyzed for comparison with those made in this study from the selected coals.

Task 4.0 – Exfoliation of Graphite to Graphene. Based on the quality of graphite synthesized in Task 3.0, exfoliation will be performed according to the modified Hummer's method (using a mixture of H_2SO_4 and H_3PO_4 along with $KMnO_4$ and H_2O_2) to obtain graphene and/or its derivatives. If the quality of the synthesized graphite is low, aqueous-phase acid exfoliation methods will be used to prepare GQDs from the enhanced coal residues. Analytical characterization of the final products will be conducted using FESEM and Raman spectroscopy.

Task 5.0 – Economic Feasibility Analysis. An economic analysis will be performed to determine the overall process feasibility. Specifically, all process input/output parameters (power usage, temperature, pressure, and yields) determined in Tasks 2.0–4.0 will be assessed and used for process modeling. To assist in the performance of this task, a technical software package including Aspen Plus and Aspen Process Economic Analyzer will be utilized for the techno-economic assessment.

Task 6.0 – Analysis of Product Target Markets and Technology Gaps.

Subtask 6.1 – Analysis of Product Target Markets. This subtask will involve research of potential markets for graphene, GO, rGO, and GQDs in specific application areas and/or industries based on available literature information as well as information obtained in this project. Some of the parameters that will be considered for this subtask include overall market overview and product summary, competitive advantages, target market segments, requirements for market entry, and identification of niche market opportunities.

Subtask 6.2 – Analysis of Technology Gaps. Technology gaps for scale-up or commercialization will be evaluated based on the results and experiences obtained in this work as well as those gleaned from available literature. Knowledge gained from this study about process parameters (power usage, temperature, pressure, yields of output streams); coal pretreatment requirements and conditions; product stability, quality, and quantity; process safety; and the nature of waste streams or associated environmental impacts will be used to determine additional technical research and development (R&D) requirements for scale-up or commercialization.

ANTICIPATED RESULTS

The proposed work is expected to result in 1) development of methods to substantially improve the quality of ND lignite and other U.S. coal feedstocks as a suitable precursor for graphene and/or its derivatives, 2) demonstration of a laboratory-scale process for making graphene from the improved coal residue, and 3) preliminary techno-economic feasibility and technology gap analysis based on the data generated to provide insight into the direction of future research.

FACILITIES AND RESOURCES

The EERC employs a multidisciplinary staff of about 220 and has 254,000 square feet of state-of-the-art offices, laboratories, and technology demonstration facilities. The EERC's high-temperature research laboratory focuses on evaluating the temperature-dependent physical properties of ash and other ceramic materials, including viscosity, thermal stability, strength, and corrosion up to 1700°C using many furnace systems under any atmosphere.

TECHNIQUES

The EERC's laboratory equipment and analytical techniques will be utilized in this project, along with experienced and highly skilled personnel who can perform the required analyses. The Coal Lab has several capabilities that will be used in this project, specifically proximate and ultimate analyses of coal samples before and after pretreatment. The Natural Materials Analytical Research Laboratory is equipped with an FESEM, XRD, and XRF that will be used for additional characterization of the coal and the resulting graphene products. In addition to these existing analytical techniques, equipment, and capabilities, a LHTG furnace and Raman spectrometer will be purchased to facilitate the synthetic graphite process and to further characterize the graphite and graphene by Raman spectroscopy. The EERC also possesses Aspen Plus and Aspen economic analyzer software that will be used to conduct the techno-economic analysis.

ENVIRONMENTAL, TECHNOLOGICAL, AND ECONOMIC IMPACT

The environmental impact of the project is expected to be minimal because all project activities will be performed at EERC facilities, where all laboratory experimental procedures undergo an internal environmental compliance review to ensure compliance with North Dakota Department of Health policies and applicable national regulations.

The long-term economic impact comes from providing technological solutions that enhance the value chain of lignite and other domestic U.S. coals and, thus, create new opportunities for new lignite markets in nonenergy sectors such as the electronics industry and high-energy storage applications such as fast-charging, higher-capacity lithium-ion batteries. In addition, the results of the preliminary techno-economic feasibility analysis and the analysis of technology gaps will be extremely useful for evaluating the commercialization prospects of this technology, with the aim not only to enhance the ND lignite value chain, but also to enhance the value of other domestic U.S. coals for national economic security.

The successful development and commercialization of graphene-making technologies will represent a significant advancement to the science and utilization of coals, especially given the attractive properties of graphene and the opportunity to use coal for other valuable applications other than energy. Hence, developing this technology in ND using local coal feedstocks and other U.S. coals will help to promote the lignite industry nationally and globally.

WHY THE PROJECT IS NEEDED

North Dakota has about 25 billion tons of untapped, economically minable lignite reserves that are the main source of coal for ND’s lignite-based energy industry. This project will help to enhance, preserve, and protect the lignite industry by researching new materials and technologies that have applications in nonenergy sectors such as electronics, automotive, aerospace, sports, and building and construction. High-value carbon products such as graphene, with excellent mechanical, thermal, electrical, and optical properties, present an opportunity to enhance and diversify the lignite utilization portfolio.

STANDARDS OF SUCCESS

The project will be carried out over the course of 3 years, with the following metrics for measuring success:

- Produce clean coal residues with residual ash content of 5 wt% or less
- Demonstrate heteroatom reduction of about 20% in the chemically treated coal residues
- Demonstrate increase in fixed carbon and decrease in volatile matter to enhance the coal residue quality as a graphene precursor
- Produce a report of the economic feasibility analysis, including analysis of product target markets and technology gaps

BACKGROUND

The EERC has been involved in coal beneficiation research since the 1980s, and several techniques for coal cleaning such as froth flotation, float–sink, acid cleaning, and chemical fractionation methods have been demonstrated over the years (O'Keefe et al., 1993; Benson and Holm, 1985; Musich et al., 1994). While the goal for these past efforts was to produce beneficiated coal products that are more environmentally friendly, these experiences are expected to be utilized in fine-tuning the cleaning of lignite and other U.S. coals for a new purpose of making coal a better precursor for high-value solid carbon products. A recent exploratory research effort to investigate the making of graphene or its derivatives from lignite, funded through the ND State Energy Research Center, has also provided an opportunity to begin the process of determining what needs to be done to enhance lignite's quality as a precursor for solid carbon products. The proposed project will expand on this initial work and consider a high-temperature synthetic graphite approach, followed by exfoliation of the graphite to graphene or GQDs. To provide some context about the scientific/technical challenges and the opportunities of coal-derived graphene work, the properties and structure of graphene and different coal ranks are summarized below. Additionally, current efforts to make graphene from coal and some of the challenges faced in using coal as a feedstock to make graphene are briefly discussed.

Graphene and Its Properties

Graphene was discovered nearly 15 years ago through mechanical exfoliation of graphite (Novoselov et al., 2004). Structurally, graphene is a 2-D array of aromatic rings that are fused together in a continuous sheet that is one atom thick. Other forms of graphene include GNS, which are a few layers of graphene stacked together; GO, which is an oxidized graphene sheet; and rGO, which closely resembles graphene, except that rGO has a few oxygen functionalities. A summary of the various graphene forms is shown in Figure 1. Graphene has been widely researched in recent years, exploring its extraordinary mechanical, thermal, and electrical properties (Shamsaei et al., 2018). Thus graphene, GO, rGO, GQDs, and GNS can serve as useful, low-cost alternatives in the fabrication of electronic devices and other tools that have low volume and high impact. Hence utilizing relatively cheap coal or coal-derived raw materials for producing such high-value carbon materials creates new opportunities by integrating coal into the value chain of industries that typically do not use coal in their manufacturing processes.

Large-scale production of graphene has yet to be implemented partly because most approaches currently start from graphite, which is a very expensive raw material for graphene. Additional limitations include lack of technological process economic feasibility data, product yields, and analysis of target markets. Many approaches for making graphene have recently been reviewed (Powel and Beall, 2015; Novoselov et al., 2012). Based on their reviews, the most commonly employed method for making graphene is exfoliation of graphite to produce GO, which is then chemically reduced to graphene (Yao et al., 2016; Hummers and Offeman, 1958). In this proposed study, data on process feasibility and yields of products will be obtained to advance the current state of technology toward commercialization.

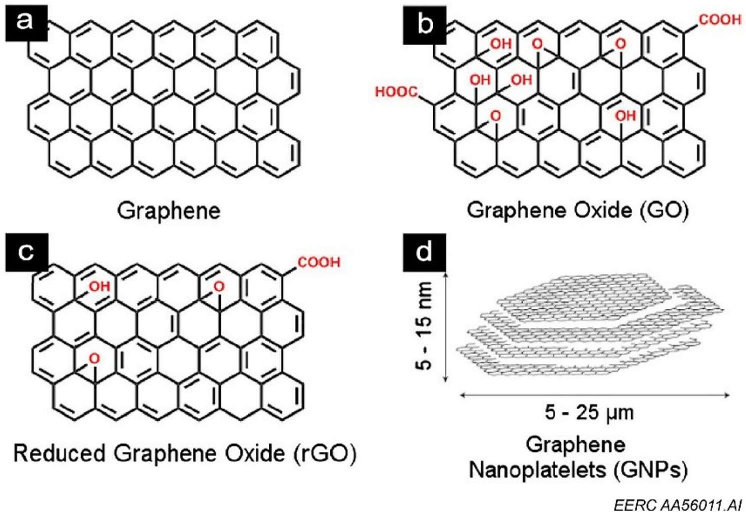

Figure 1. Structural models of graphene products (Shamsaei et al., 2018).

Coal Structural Models and Graphene Moieties

Figure 2 shows different structural models for coal and their corresponding ranks (Fakoussa and Hofrichter, 1999), which indicate that low-rank coals are more oxidized and have smaller aromatic content. As the coal rank increases, the aromatic content also increases, especially the fused aromatic rings in the higher ranks. The higher content of volatile fractions, inorganic mineral impurities and heteroatoms, and oxygen-rich functional groups in coals such as lignite pose serious challenges to graphitization and, thus, production of graphene from these coals. Hence these structural and chemistry (functional groups) differences/attributes are critical to understanding the fundamental aspects of any technological processes to make high-value solid carbon products from these coals and which products are feasible from a given coal type.

In this project, methods that have been demonstrated at the EERC over the years will be used to pretreat or clean the coals to remove the inorganic impurities. The cleaned coals will then be subjected to additional chemical reactions, carbonized and annealed, and then graphitized and exfoliated to obtain graphene. The chemical reaction step aims to reduce the concentration of heteroatoms such as oxygen functional groups in lignite to investigate the feasibility of making a graphitizable product that would be used to make graphene or GQDs using an approach reported by Ye and others (2013).

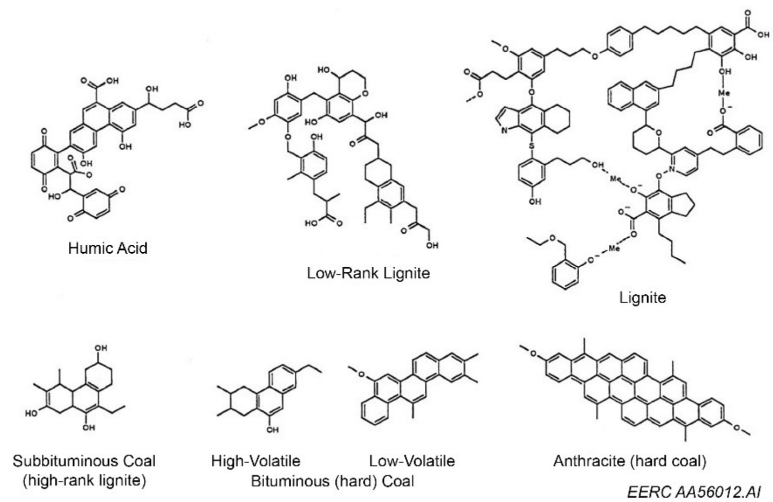

Figure 2. Structural models for coals of different rank (Fakoussa and Hofrichter, 1999).

Current Efforts to Make Graphene from Coal

While the production of graphite from coal or coal-derived products has been widely studied (Xing et al., 2018), direct production of graphene and/or its derivatives from coal is rare and is still poorly understood. A literature search shows only two processes that are being developed for making graphene directly from coal, including the electrochemical coal-to-graphene (C2G) process at the University of Ohio (Botte, 2019) and a GQD process at Rice University (Ye et al., 2013). These two processes both utilized bituminous coal as the starting material, although the Rice study also used coke and anthracite. Powell and Beall (2015) have reported the production of humic acid (HA) from leonardite (highly oxidized lignite). The HA was suggested to be a potential GO alternative, but the properties of the resulting HA are somewhat inferior to GO from higher-rank coals. This finding is consistent with the fact that lignite has a smaller concentration of fused benzene rings that make the graphene sheet layers stronger. A general lesson from these studies is that low-rank coals are a challenging feedstock for making graphene or other high-value solid carbon products because the aromatic domains are often isolated and less fused. However, proper harnessing of the isolated aromatic units through chemical modifications proposed herein and heat treatment can improve graphene strength or enable production of other useful carbon nanomaterials such as GQDs that do not necessarily require extensive 2-D fused benzene ring layers.

Coal Utilization Challenges and Opportunities

Many of the inorganic constituents present in coal are problematic not only for coal's utilization as an energy resource but also when coal is used to make other high-value carbon products such as graphene. To mitigate these issues, the EERC has developed several advanced coal-cleaning processes over the years beginning in the 1980s. Some of the most effective approaches include chemical fractionation or selective leaching method, which uses chemical solvents (water, HCl, ammonium acetate) to leach out ash-enriching inorganic elements such as Na, K, and Ca in ND lignite at 87% efficiency (O'Keefe et al., 1993; Benson and Holm, 1985). Other more widely known methods such as froth floatation and float–sink (Demir, 1998; Musich et al., 1994) that resulted from previous DOE advanced coal-cleaning programs in the 1980s have been demonstrated up to the pilot scale at the EERC (Musich et al., 1994).

For example, a sulfur content reduction of 44% (i.e., 0.45 wt% in the cleaned product) demonstrated on a ND lignite sample would be sufficient to make the highest-quality needle coke or graphite materials (with sulfur cutoff content of 0.4 wt%) that are typically used for high-power and ultrahigh-power applications such as industrial electrodes for aluminum production (Reid, 2018). Hence, fine tuning of the methods already demonstrated at the EERC will provide significant improvement to the raw coals prior to graphitization. Other challenges associated with the use of these coals for making graphene and proposed mitigation strategies are summarized in Table 1.

The mitigation strategies proposed in Table 1 suggest that there are opportunities to improve the quality of low-rank coals, potentially increase the graphitizability, and thus provide a possibility of making graphene-based products. Some studies have shown improved carbon strength and graphitizability upon thermal annealing at ~1500°C. Based on previous study, the proposed chemical reduction steps followed by heat treatment at 1500°C will be performed on all coals to explore the feasibility of making graphene from lower-rank coals by exfoliation. Evaluation of the product quality and quantity will indicate whether graphene materials can be produced from low-rank coals using the proposed chemical modifications, which would further advance the current state of technology for making graphene from low-rank coals.

Table 1. Summary of Challenges with Different Coals and Mitigation Strategies

Coal Type/Rank	Challenge	Mitigation Strategy
Anthracite	1. Low H/C ratio 2. Inorganic minerals	1. Use H_2 donors 2. Demineralization pretreatment
Bituminous	1. Inorganic minerals 2. Volatile carbon	1. Demineralization pretreatment 2. Devolatilization/carbonization
Subbituminous	1. Inorganic minerals 2. Volatile carbon 3. Oxygen-rich functional groups	1. Demineralization pretreatment 2. Devolatilization/carbonization 3. Chemical reduction
Lignite	1. Inorganic minerals 2. Volatile carbon 3. Oxygen-rich functional groups	1. Demineralization pretreatment 2. Devolatilization/carbonization 3. Chemical reduction

QUALIFICATIONS

The Principal Investigator (PI), Dr. Alexander Azenkeng, holds a Ph.D. in Physical Chemistry and M.Sc. and B.Sc. degrees in Chemistry. He has more than a decade of work experience at the EERC, which includes managing one of the EERC's biggest laboratories, other large projects, and supervising and mentoring other employees. Dr. Azenkeng will lead Tasks 1.0, 3.0, and 4.0 and will assist with Task 5.0. Mr. Jason Laumb is the project advisor, and he holds a M.Sc. degree in Chemical Engineering and a B.Sc. in Chemistry. Mr. Laumb is an Assistant Director of Advanced Energy Systems at the EERC, with more than two decades of work experience in developing multiclient jointly sponsored centers or consortia projects and leading a multidisciplinary team of 15 research scientists. Ms. Melanie Jensen is the lead in Tasks 2.0 and 6.0. She holds a B.Sc. in Chemical Engineering and a B.A. in Anthropology.

Ms. Jensen is a Senior Chemical Engineer and Lead for the CO_2 Capture and Infrastructure Engineering Team at the EERC, with 34 years of work experience, which includes direct coal liquefaction, conversion of low-rank coals to liquid products, and removal of heteroatoms from synthetic aviation fuel. Mr. Joshua Strege is the lead for Task 5.0. He holds M.Sc. and B.Sc. degrees in Chemical Engineering. Mr. Strege is a Principal Process Engineer for Energy Systems Development at the EERC, with nearly 15 years of work experience on coal and biomass gasification systems and techno-economic assessment studies using Aspen Plus software.

Resumes of key personnel are included in Appendix A.

VALUE TO NORTH DAKOTA

The value of this project to North Dakota includes enhancing, preserving, and protecting the lignite industry and advancing economic growth via new opportunities for lignite markets in nonenergy sectors such as the electronics industry and high-energy storage applications, including fast-charging, higher-capacity lithium-ion batteries. In addition, the results of the preliminary techno-economic feasibility analysis and the analysis of technology gaps will be useful for evaluating the commercialization prospects of this technology, with the aim not only to enhance the ND lignite value chain, but also to enhance the value of other domestic U.S. coals for national economic security. If this technology is successful, the overall economic impact would be enormous, given that lignite, which sells at about $20/ton, can be used to make a product with a selling price of about $1.4 million/ton for device-grade graphene or $18,000/ton for low-grade graphene used in enhanced concrete mixes. Hence, developing such a promising technology in ND would be significant not only for the lignite industry, but also for the associated support businesses.

MANAGEMENT

The overall management of this project will involve several components, including proper organization of all project activities, roles and responsibilities of project participants, a clear decision-making and communication strategy, management of risks, and evaluation points to be used to ensure that the project is meeting its schedule and objectives. These components are described in detail below.

Organization of Project Activities

The project organizational chart shown in Figure 3 includes the project partners, PI, project advisor, task leads, as well as the activities to be led by each key personnel. The entire team will work together to realize the scope of work laid out in the project description section.

Roles and Responsibilities of Project Participants

The EERC is the sole applicant and will be responsible for carrying out all tasks proposed. The PI and various task leads, shown in the project organization chart (Figure 3), are all employees at the EERC who

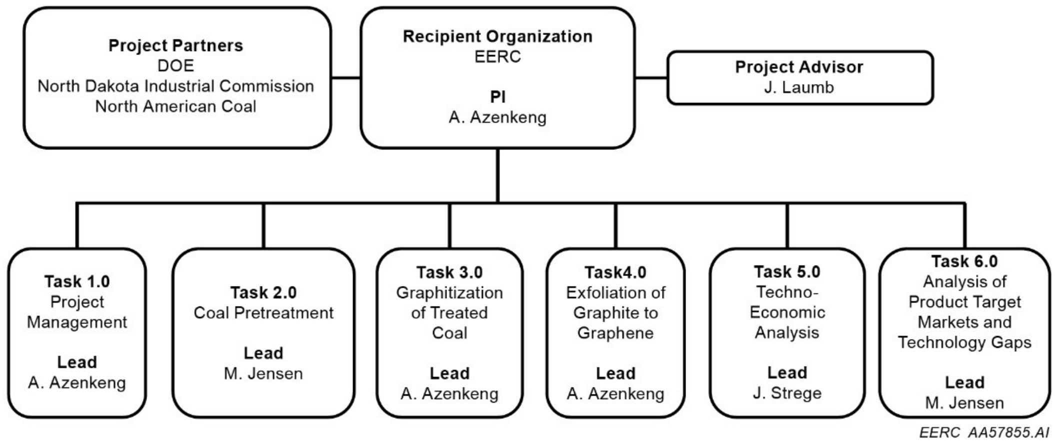

Figure 3. Project organizational chart.

will work together throughout the implementation of the project. The PI will coordinate all technical aspects of the project, including any potential intellectual property that may ensue from the work. Other project partners include DOE, NDIC, and NACoal. These partners will provide cash cost share as well as provide valuable advisory roles during project implementation.

Decision-Making and Communication Strategy

Several strategies will be put in place to ensure effective communication during the implementation of the proposed scope of work. Project update meetings will be held on a regular basis to ensure that the project's objectives are progressing according to schedule. Decisions affecting the project scope, cost, and schedule will be made in coordination with the project sponsors via regular phone calls, e-mail correspondence, conference calls, and/or WebEx presentations. Additionally, the project sponsors will also receive regular quarterly updates/reports of project accomplishments, challenges, and any variance from the project objectives.

Risk Management Plan

The EERC has integrated risk management practices throughout all aspects of multidisciplinary programs and has developed an adaptive management approach that ensures successful project implementation while remaining flexible to each project's unique attributes. To aid in the completion of project goals and objectives, the EERC will implement its risk assessment process, which includes 1) risk identification,

2) risk analysis, 3) risk evaluation, and 4) risk treatment. A preliminary analysis of the potential risks associated with the proposed scope of work did not identify situations or events that have a high likelihood of significantly impacting the success of the project. An ALARA (as low as reasonably achievable) approach is being used to adopt mitigation strategies for risks identified through the risk management plan. Our initial assessment of the financial; cost/schedule; technical/scope; management, planning, and oversight; environmental, health, and safety (EH&S); and external factor risks that can potentially impede the progress of the project has determined that these risks are low for the proposed work.

Evaluation Points

The evaluation point log for the project is organized by task and includes planned completion dates and verification methods as shown in Table 2. The assumed start date for the project is May 1, 2020, and will span a period of 36 months. If the actual project start date happens to be earlier or later, this table and the

Table 2. Project Evaluation Point Log and Schedule

Task/ Subtask	Evaluation Point Title	Planned Completion Date	Verification Method
1.0	M1 – Project Kickoff Meeting	End of Month 3	Submit presentation file to project sponsors.
2.1	M2 – Completion of DR, FBR, CT Fabrication	End of Month 4	Reported in subsequent quarterly report.
2.2	M3 – Completion of Coal Pretreatment	End of Month 6	Reported in subsequent quarterly report.
2.3	M4 – Completion of LHTG Furnace Installation and Training	End of Month 9	Reported in subsequent quarterly report.
3.0	M5 – Completion of Coal Graphitization	End of Month 16	Reported in subsequent quarterly report.
4.0	M6 – Completion of Graphene Products	End of Month 22	Reported in subsequent quarterly report.
5.0	M7 – Initial Economic Analysis Results Available	End of Month 28	Reported in subsequent quarterly report.
6.1	M8 – Completion of Analysis of Product Target Markets	End of Month 30	Reported in subsequent quarterly report.
6.2	M9 – Completion of Analysis of Technology Gaps	End of Month 32	Reported in subsequent quarterly report.

project timetable will be updated accordingly. The verification methods will include providing data and reports to project sponsors, in addition to meetings held at periodic points to provide detailed updates of the findings and future directions. The evaluation points are also marked in the project timetable in Figure 4.

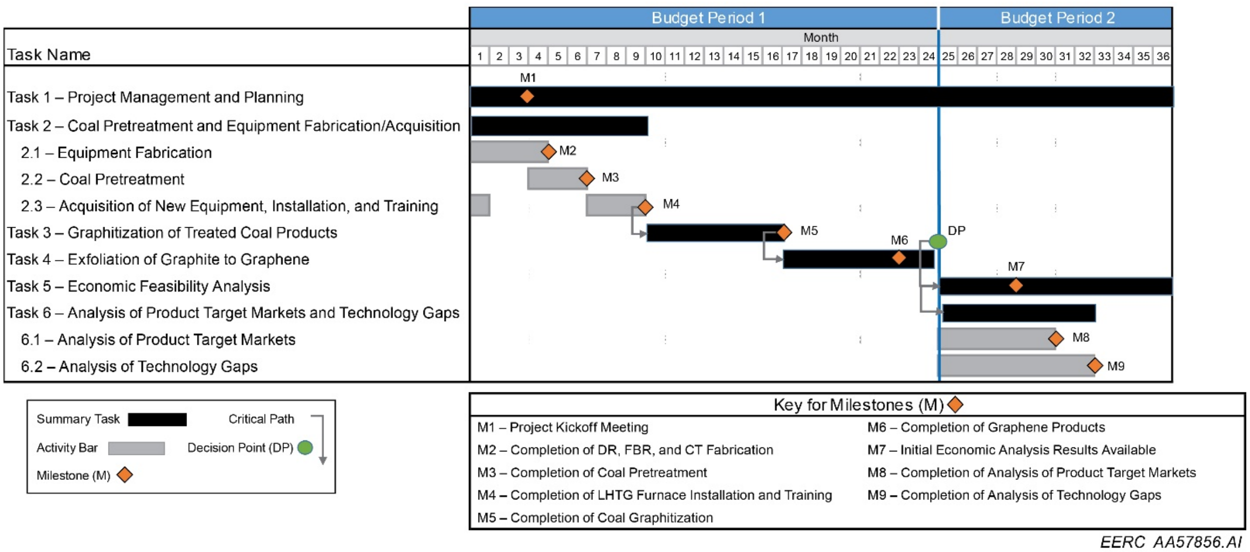

Figure 4. Project timetable.

TIMETABLE AND DELIVERABLES

The timetable for each task is summarized in Figure 4 and includes a link between the scope and schedule, as well as the corresponding start and completion dates. The main deliverables for this project are summarized in Table 3 and include the anticipated scheduled completion dates.

Table 3. Project Deliverables and Schedule

Task/Subtask	Deliverable Title	Due Date
1	D1 – slides of project kickoff meeting	90 days after award
2–4	D2 – interim report on coal pretreatment, graphitization, and exfoliation	End of Month 25
5–6	D3 – interim report on economic feasibility study and analysis of product target markets and technology gaps	End of Month 33

BUDGET AND MATCHING FUNDS

The total cost for this project is $931,564. The total request from NDIC LRP is $162,500. Cost share includes $744,064 in cash from DOE and another $25,000 cash from NACoal. A letter of support from NACoal is provided in Appendix C. A letter from DOE notifying the EERC of selection for award for this project is found also in Appendix C; the EERC is currently on final negotiations with DOE. The project funding profile is shown in Table 4. If the request for funding from NDIC is not successful, the overall project realization will be significantly limited.

Table 4. Budget Breakdown

Project Associated Expense	NDIC Share (Cash)	DOE Share (Cash)	NACoal Share (Cash)	Total Project
Labor	$ 99,673	$ 202,757	$ 15,540	$ 317,970
Travel	$ -	$ 19,812	$ -	$ 19,812
Equipment > $5000	$ -	$ 333,930	$ -	$ 333,930
Supplies	$ 4,400	$ 7,845	$ 85	$ 12,330
Communications	$ -	$ 130	$ -	$ 130
Printing & Duplicating	$ 56	$ 155	$ -	$ 211
Food	$ -	$ 256	$ -	$ 256
Laboratory Fees & Services				
Natural Materials Analytical Research Lab	$ -	$ 38,453	$ -	$ 38,453
Graphics Services	$ -	$ 1,416	$ -	$ 1,416
Shop & Operations	$ 3,538	$ -	$ -	$ 3,538
Technical Software Fee	$ -	$ 1,304	$ -	$ 1,304
Engineering Services Fee	$ 306	$ 386	$ -	$ 692
Total Direct Costs	$ 107,973	$ 606,444	$ 15,625	$ 730,042
Facilities & Administration	$ 54,527	$ 137,620	$ 9,375	$ 201,522
Total Project Costs	$ 162,500	$ 744,064	$ 25,000	$ 931,564

Please note that equipment will be purchased and fabricated with DOE's share as discussed in Task 2 and also described in the budget notes provided in Appendix D.

TAX LIABILITY

The EERC, a department within the University of North Dakota, is a state-controlled institution of higher education and is not a taxable entity; therefore, it has no tax liability.

CONFIDENTIAL INFORMATION

The proposed work does not contain any confidential information.

APPENDIX A

RESUMES OF KEY PERSONNEL

DR. ALEXANDER AZENKENG
Senior Research Scientist
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5051 (phone), 701.777.5181 (fax), aazenkeng@undeerc.org

Principal Areas of Expertise

Dr. Azenkeng applies chemistry principles to studies involving multiple research portfolios, including computational simulations to elucidate reaction mechanisms and properties of molecules during coal combustion; chemical transformations in low-rank coal upgrading; coal–biomass gasification technologies; chemical analysis of materials by scanning electron microcopy (SEM); material corrosion evaluation in oil and gas applications; CO_2–amine reaction chemistry; the chemistry of CO_2 capture, utilization, and sequestration (CCUS); geochemical interactions of CO_2 with petroleum reservoir minerals and formation liquids; application of nuclear magnetic resonance (NMR) spectroscopy technology in unconventional oil & gas reservoir rock characterization; improved methods for analyzing rare-earth elements (REEs) in coals and other geologic media.

Qualifications

Ph.D., Theoretical Physical Chemistry, University of North Dakota, 2007.
Dissertation: Theoretical Studies of Low-Lying Electronic States of Lithium, Titanium, and Mercury Compounds; supervised by Prof. Mark R. Hoffmann.
M.Sc., Chemistry, University of Buea, Cameroon, 1998.
Thesis: Preparation of Iron (III) and Nickel (II) Oxide Thin Films from the Corresponding Metal Acetylacetonates via Pyrolysis.
B.Sc., (magna cum laude) Chemistry, University of Buea, Cameroon, 1996; with professional minor in Chemical Processing Technology.

Professional Experience

2008–Present: Senior Research Scientist, EERC, UND. Dr. Azenkeng applies chemistry principles to studies involving multiple research portfolios, including chemical analysis of materials by SEM, material corrosion evaluation in oil and gas applications, CO_2 capture using aqueous amine solvents, CO_2 sequestration in geologic formations, and chemical transformations in low-rank coal upgrading. He is currently involved in developing analytical approaches to better characterize organic shale and tight rock formations for potential CO_2 storage and improved methods for analyzing rare-earth elements (REEs) in coals, geologic samples, and produced water from oil and gas operations.

2007–2008: Temporary Researcher, EERC, UND. Dr. Azenkeng's work focused on NO_x emission control technologies, CO_2 capture technologies, and gasification technologies.

2005–2007: Graduate Research Assistant, EERC, UND. Dr. Azenkeng's work focused on quantum mechanical modeling of Hg oxidation reactions on activated carbon surfaces.

Professional Memberships

Microscopy Society of America, 2010–Present
North Dakota Academy of Sciences, 2004–Present
American Chemical Society, 2002–Present

Publications and Presentations

Books and Book Chapters

Ralston, N.V.C.; Azenkeng, A.; Raymond, L.J. Mercury-Dependent Inhibition of Selenoenzymes and Mercury Toxicity. In *Methylmercury and Neurotoxicity*; Ceccatelli, S., Aschner, M., Eds.; Current Topics in Neurotoxicity 2; Springer: New York, 2012; pp 91–99.

Peer-Reviewed Publications

Laumb, J.D.; Glazewski, K.A.; Hamling, J.A.; Azenkeng, A.; Watson, T.L. Wellbore Corrosion and Failure Assessment for CO_2 EOR and Storage: Two Case Studies in the Weyburn Field. *International Journal of Greenhouse Gas Control* **2016,** *54*, 479–489.

Olson, E.S.; Azenkeng, A. Laumb, J.D.; Jensen, R.R.; Benson, S.A.; Hoffman, M.R. New Developments in the Theory and Modeling of Mercury Oxidation and Binding on Activated Carbons in Flue Gas. In *Air Quality VI: Mercury, Trace, Elements, SO_3, Particulate Matter, and Greenhouse Gases*, Special Issue of *Fuel Process. Technol.* **2009**, *90* (11), 1360–1363.

Conference and Other Presentations

Azenkeng, A.; Mibeck, B.A.F.; Eylands, K.E.; Butler, S.K.; Kurz, B.A.; Heebink, L.V. Advanced Characterization of Unconventional Oil and Gas Reservoirs to Enhance CO_2 Storage Resource Estimates – Organic Structure and Porosity of Organic-Rich Shales. Presented at Mastering the Subsurface Through Technology Innovation, Partnerships & Collaboration: Carbon Storage & Oil & Natural Gas Technologies Review Meeting, Pittsburgh, PA, Aug 1–3, 2017.

Klenner, R.C.L.; Braunberger, J.R.; Sorensen, J.A.; Eylands, K.E.; Azenkeng, A.; Smith, S.A. A Formation Evaluation of the Middle Bakken Member Using a Multimineral Petrophysical Analysis Approach. Paper presented at the SPE/AAPG/SEG Unconventional Resources Technology Conference, Denver, CO, Aug 25–27, 2014; URTeC Paper No. 1922735.

Laumb, J.D.; Azenkeng, A.; Heebink, L.V.; Jensen, M.D.; Raymond, L.J. CO_2 Utilization Technologies for Lignite-Based Generation. Poster Abstract in *Proceedings of Air Quality IX: An International Conference on Environmental Topics Associated with Energy Production*; Arlington, VA, Oct 21–23, 2013.

Laumb, J.D.; Kay, J.P.; Holmes, M.J.; Cowan, R.M.; Azenkeng, A.; Heebink, L.V.; Hanson, S.K.; Jensen, M.D.; Letvin, P.A.; Raymond, L.J. Economic and Market Analysis of CO_2 Utilization Technologies – Focus on CO_2 Derived from North Dakota Lignite. *Energy Procedia* **2013**, *37*, 6987–6998.

Laumb, J.D.; Kay, J.P.; Holmes, M.J.; Cowan, R.M.; Azenkeng, A.; Heebink, L.V.; Hanson, S.K.; Jensen, M.D.; Letvin, P.A.; Raymond, L.J. Economic and Market Analysis of CO_2 Utilization Technologies – Focus on CO_2 Derived from North Dakota Lignite. Paper presented at the 11th International Conference on Greenhouse Gas Control Technologies (GHGT-11), Kyoto, Japan, Nov 18–22, 2012.

Azenkeng, A. Development of an Improved CCSEM Technique for Quantitative Coal Mineralogy. Presented at the 28th Annual International Pittsburgh Coal Conference, Pittsburgh, PA, Sept 12–15, 2011.

Technical Reports

Azenkeng, A. *Evaluation of Lime Kiln Ash Ring Samples for Environmental Energy Services, Inc*.; Final Report for Environmental Energy Services, Inc.; EERC Publication 2018-EERC-08-03; Energy & Environmental Research Center: Grand Forks, ND, Aug 2018.

Azenkeng, A.; Kurz, B.A.; Gorecki, C.D. *An NMR-Based Method for Fluid Typing and Proportion Estimation for the Potential for CO_2 Storage or CO_2 EOR in the Middle Bakken Formation*; Final Report included in *Subtask 4.1 – Strategic Studies* Final Report (Aug 10, 2015 – May 31, 2017) for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-

FE0024233; EERC Publication 2017-EERC-05-13; Energy & Environmental Research Center: Grand Forks, ND, May 2017.

Azenkeng, A.; Pavlish, B.M.; Lentz, N.B.; Galbreath, K.C.; McCollor, D.P. *Feasibility of Hydrothermal Dewatering for the Potential to Reduce CO_2 Emissions and upgrade Low Rank Coals*; Final Report (June 25, 2008 – Dec 31, 2009) for the University of Wyoming; EERC Publication 2010-EERC-02-02; Energy & Environmental Research Center: Grand Forks, ND, Feb 2010.

Hanson, S.K.; Azenkeng, A.; Laumb, J.D.; McCollor, D.P.; Pavlish, B.M.; Buckley, T.D.; Botnen, L.S. *Subtask 3.7 – Beneficiated Lignite Market Study*; Final Report (Aug 1, 2009 – June 30, 2010) for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-08NT43291; EERC Publication 2010-EERC-06-09; Energy & Environmental Research Center: Grand Forks, ND, June 2010.

MELANIE D. JENSEN
Senior Chemical Engineer, CO_2 Capture and Infrastructure Engineering Team Lead
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5115 (phone), 701.777.5181 (fax), mjensen@undeerc.org

Principal Areas of Expertise
Ms. Jensen's principal areas of expertise include carbon capture and CO_2 transport infrastructure, high-pressure/high-temperature processes, production of fuels from coal and renewables, waste cleanup technologies, adsorption system design and operation, low-temperature plasma technologies, photocatalytic processes, statistical experimental design, and system modeling.

Education
B.S., Chemical Engineering, University of North Dakota, 1983.
B.A., Anthropology, University of North Dakota, 1978.

Professional Experience
2011–Present: Senior Chemical Engineer, CO_2 Capture and Infrastructure Engineering Team Lead, EERC, UND. Ms. Jensen's responsibilities include supervising a team of engineers and scientists who perform research in the areas of CO_2 capture, compression, and transport via pipeline. The team also documents surface facility design at regional CO_2 storage sites. Specific activities in the carbon capture and storage (CCS) area include matching CO_2 capture technologies with utility and industrial sources, suggesting appropriate compression technologies, and developing theoretical pipeline networks to optimize the transport of the CO_2 for storage or beneficial use. Ms. Jensen and her team also perform life cycle analyses of products to determine their carbon intensities. In addition, the engineering team develops carbon management plans for utilities or industries. Ms. Jensen and the team also study and evaluate coal combustion, water treatment, and photocatalytic processes. Ms. Jensen assists with the advancement and demonstration of advanced compression processes and advises on direct liquefaction projects. She works to develop fuels from alternate sources such as biomass or CO_2. Ms. Jensen designs, develops, operates, and/or evaluates complex processes and equipment, including CO_2 capture systems. She develops statistically designed experimental matrices; tracks, reduces, and interprets data generated during research projects; and derives empirical models describing system behavior. Ms. Jensen develops integrated, multiproject programs to meet both the immediate and long-term needs of clients; prepares or assists with the preparation of proposals and supporting documentation; develops comprehensive QA/QC plans; and prepares patent applications. Her project management activities include detailed program planning; scheduling of equipment and personnel; budget monitoring; maintenance of project schedules; dissemination of research results through reports, papers, and presentations; and communication with clients.

1985–2011: Research Engineer, EERC, UND. Ms. Jensen performed research in the areas of CO_2 capture and storage, reaction engineering, coal combustion, reburning, hazardous waste treatment, gas-phase particulate and mercury collection, photocatalytic processes, fuel production from biomass, contaminated water cleanup, and phytoremediation. She designed, developed, operated, and/or evaluated complex processes and equipment, including column CO_2 capture systems, high-pressure/high-temperature coal conversion systems, low-temperature plasma systems, and multicolumn sorption systems. She identified promising carbon sequestration opportunities by matching CO_2 capture technologies with point sources, pairing those combinations with nearby geologic sinks, and performing the preliminary compressor and pipeline specifications. She evaluated and compared characterization, remediation, and decontamination technologies for application to waste treatment/cleanup programs. Ms. Jensen developed statistically designed experimental matrices; tracked, reduced, and interpreted data generated during research projects; and derived empirical models describing system behavior. Ms. Jensen also developed integrated, multiproject programs to meet both the immediate and long-term needs of clients; prepared or assisted with the preparation of proposals and supporting documentation; developed comprehensive QA/QC plans; and prepared patent applications. Her project management activities included detailed program planning; scheduling of equipment and personnel; budget monitoring; maintenance of project schedules, dissemination of research results through reports, papers, and presentations; and communicating with clients.

Patents

Rindt, J.R.; Hetland (Jensen), M.D. Direct Coal Liquefaction Process. U.S. Patent No. 5256278, October 26, 1993.

Publications and Presentations

Has authored or coauthored numerous publications.

JOSHUA R. STREGE
Principal Process Engineer, Energy Systems Development
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
Phone: 701.777-5080, Fax: 701.777-5181, E-Mail: jstrege@undeerc.org

Principal Areas of Expertise

Mr. Strege's principal areas of interest and expertise include process modeling and techno-economic assessments, specifically in regard to power generation and CO_2 capture and storage. He has several years of experience in operating equipment for high-pressure gasification as well as designing and operating syngas cleanup and conversion processes including hot-gas cleanup, cold-gas cleanup, and liquid synthesis.

Qualifications

M.S., Chemical Engineering, University of North Dakota, 2005. Thesis: High-Temperature Corrosion of Potential Heat Exchange Alloys under Simulated Coal Combustion Conditions.

B.S., Chemical Engineering, University of North Dakota, 2005.

Training: Project Management training through PM College, Six-Sigma Green Belt, and Design Flow Technology (DFT).

Skills: Microsoft Office suite (Excel, MS Project, Word, and Access) and advanced VBA macro programming and SQL server integration; CAD design and engineering drawing creation (PTC Creo Parametric).

Professional Experience

October 2019–Present: Principal Process Engineer, Energy Systems Development, EERC, UND. Mr. Strege leads the process engineering team in process modeling and techno-economic analysis efforts across applied research projects encompassing CO_2 capture and transport, advanced power cycle technology development, and other energy conversion technologies.

2013–September 2019: Project Manager and Senior Engineer, Cirrus Aircraft. Mr. Strege's responsibilities as Project Manager included building an 80-member team to develop and manufacture composite products for small aircraft under contract with an outside client. As Senior Engineer, he led a team of engineers and technicians responsible for reducing waste, implementing root cause and corrective actions on product defects and downstream issues, and developing and implementing software solutions for improved tracking and accountability across all departments.

2005–2013: Research Engineer, EERC, UND. Mr. Strege participated in and managed several multiyear, multiclient projects aimed at researching and developing alternative energy and fuel sources. Specific projects included hydrotreating of waste vegetable oils for conversion to drop-in-compatible JP-8 jet fuel, assessing the feasibility of modern warm-gas cleanup technologies for liquid fuel synthesis via the Fischer–Tropsch process, and design and testing of cold-gas cleanup reactors for syngas. He also participated in pilot-scale studies comparing the postcombustion CO_2 capture efficiency of a variety of proprietary and conventional amine-based solvents.

2000–2005: Student Research Assistant, EERC, UND. Mr. Strege's responsibilities included design and development of instrument control software. In addition, he studied corrosion rates and mechanisms of high-temperature alloys as part of his master's research.

Publications and Presentations
Has authored and coauthored numerous professional publications and presentations.

JASON D. LAUMB
Assistant Director for Advanced Energy Systems
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, ND 58202-9018 USA
701.777.5114 (phone), 701.777.5181 (fax), jlaumb@undeerc.org

Principal Areas of Expertise
Mr. Laumb's principal areas of interest and expertise include biomass and fossil fuel conversion for energy production, with an emphasis on pollution control and ash effects on system performance. He has experience with trace element emissions and control for fossil fuel combustion systems, with a particular emphasis on air pollution issues related to mercury and fine particulates. He also has experience in the design and fabrication of bench- and pilot-scale combustion and gasification equipment.

Qualifications
M.S., Chemical Engineering, University of North Dakota, 2000.
B.S., Chemistry, University of North Dakota, 1998.

Professional Experience
September 2019–Present: Assistant Director for Advanced Energy Systems, EERC, UND. Mr. Laumb assists the EERC executive team by providing leadership on projects related to advanced energy systems. Mr. Laumb leads a multidisciplinary team of scientists and engineers working on advanced energy technologies from pollution control to new energy platforms. Specific areas of interest include CO_2 capture, techno-economic modeling, environmental control systems, supercritical CO_2 power cycles, and advanced gasification technologies. Current research activities are focused on low-carbon-intensity power cycles for fossil fuel fired systems.

2008–August 2019: Principal Engineer, Advanced Energy Systems Group Lead, EERC, UND. Mr. Laumb led a multidisciplinary team of 30 scientists and engineers to develop and conduct projects and programs on power plant performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide. Efforts focused on development of multiclient jointly sponsored centers or consortia funded by government and industry sources. Research activities included computer modeling of combustion/gasification and environmental control systems, performance of SCR technologies for NO_x control, mercury control technologies, hydrogen production from coal, CO_2 capture technologies, particulate matter analysis and source apportionment, the fate of mercury in the environment, toxicology of particulate matter, and in vivo studies of mercury–selenium interactions.

2001–2008: Research Manager, EERC, UND. Mr. Laumb led projects involving bench-scale combustion testing of various fuels and wastes as well as a laboratory that performs bench-scale combustion and gasification testing. He served as principal investigator and managed projects related to the inorganic composition of coal, coal ash formation, deposition of ash in conventional and advanced power systems, and mechanisms of trace metal transformations during coal or waste conversion and wrote proposals and reports focused on energy and environmental research.

2000–2001: Research Engineer, EERC, UND. Mr. Laumb assisted in the design of pilot-scale combustion equipment and wrote computer programs to aid in the reduction of data, combustion calculations, and prediction of boiler performance. He was also involved in the analysis of combustion control technologies' ability to remove mercury and the suitability of biomass as boiler fuel.

1998–2000: SEM Applications Specialist, Microbeam Technologies, Inc., Grand Forks, North Dakota. Mr. Laumb gained experience in power system performance including conventional combustion and gasification systems; knowledge of environmental control systems and energy conversion technologies; interpreting data to predict ash behavior and fuel performance; assisting in proposal writing to clients and government agencies such as the National Science Foundation and the U.S. Department of Energy; preparing and analyzing coal, coal ash, corrosion products, and soil samples using SEM/EDS; and modifying and writing FORTRAN, C+, and Excel computer programs.

Professional Membership
American Chemical Society

Publications and Presentations
Has coauthored numerous professional publications.

APPENDIX B

REFERENCES

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Musich, M.A.; Young, B.C.; Knudson, C.L. *Upgraded North Dakota Lignite – Production of Test Quantities*; Final Report for the Lignite Research & Development Program Contract No. LMFS-94-15; EERC Publication 94-EERC-10-10; Energy & Environmental Research Center: Grand Forks, ND, Nov. 1994.

Novoselov, K.S.; Fal'ko, V.I.; Colombo, L.; Gellert, P.R.; Schwab, M.G.; Kim. K. A Roadmap for Graphene. *Nature* **2012**, *490*, 192–200.

Novoselov, K.S.; Geim, A.K.; Morozov, S.V.; Jiang, D.; Zhang, Y.; Dubonos, S.V.; Grigorieva, I.V.; Firsov, A.A. Electric Field Effect in Atomically Thin Carbon Films. *Science* **2004**, *306*, 666–669.

O'Keefe, C.A.; Eylands, K.E.; Pflughoeft-Hassett, D.F. Application of Selective Leaching Technique for Major, Minor, and Trace Element Analysis in Coal. *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* **1993**, *38*, 966–971.

Powell, C.; Beall, G.W. Graphene Oxide and Graphene from Low Grade Coal: Synthesis, Characterization and Applications. *Current Opinion in Colloid & Interface Science* **2015**, 20, 362–366.

Reid, I. Non-Energy Uses of Coal, CCC/291, 2018. www.iea-coal.org/non-energy-uses-of-coal-report-ccc291/ (accessed Feb 2019).

Shamsaei, E.; de Souza, F.B.; Yao, X.; Benhelal, E.; Akbari, A.; Duan, W. Graphene-Based Nanosheets for Stronger and More Durable Concrete: A Review. *Construction and Building Materials* **2018**, *183*, 642–660.

Xing, B.; Zhang, C.; Cao, Y.; Huang, G.; Liu, Q.; Zhang, C.; Chen, Z.; Yi, G.; Chen, L.; Yu, J. Preparation of Synthetic Graphite from Bituminous Coal as Anode Materials for High Performance Lithium-Ion Batteries. *Fuel Process Technology* **2018**, *172*, 162–171.

Yao, Y.; Fu, K.K.; Yan, C.; Dai, J.; Chen, Y.; Wang, Y.; Zhang, B.; Hitz, E.; Hu, L. Three-Dimensional Printable High-Temperature and High-Rate Heaters. *ACS Nano* **2016**, *10*, 5272−5279.

Ye, R.; Xiang, C.; Lin, J.; Peng, Z.; Huang, K.; Yan, Z.; Cook, N.P.; Samuel, E.L.G.; Hwang, C-C.; Ruan, G.; Ceriotti, G.; Raji, A-R.O.; Martí, A.A.; Tour, J.M. Coal as an Abundant Source of Graphene Quantum Dots. *Nature Communications* **2013**, *4*, 2943, doi: 10.1038/ncomms3943.

APPENDIX C

LETTERS OF SUPPORT

LaVern K. Lund
Vice President – Engineering & Business Development

Telephone: 972-448-5400
E-Mail: vern.lund@nacoal.com

March 20, 2020

Mr. Jason Laumb
Assistant Director, Advanced Energy Systems
Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Re: Laboratory-Scale Coal-Derived Graphene Process

Dear Jason:

North American Coal Corporation (NACoal) is interested in supporting EERC's application to the Lignite Research and Development Program for developing a lignite-based graphene derivative. This material could then be used for carbon anodes in lithium ion batteries, as well as other uses.

NACoal is the largest lignite producer in the United States and one of the top 10 coal producers in the United States. We mine and market coal for use in power generation, SNG production, activated carbon production, as well as, providing selected value-added mining services for other natural resources companies. Our corporate headquarters are in Plano, Texas, near Dallas, and we operate surface coal mines in North Dakota, Mississippi, Texas, New Mexico, and Louisiana.

NACoal is pleased to provide a total cost-share of up to $25,000, over the 3-year term of the project, subject to project award by the Lignite Research Program, the US Department of Energy and final review.

Best of luck on your application.

Very truly yours,

THE NORTH AMERICAN COAL CORPORATION

LaVern K. Lund
Vice President – Engineering & Business Development

January 22, 2020

SENT VIA ELECTRONIC MAIL

Sheryl Eicholtz-Landis
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018
slandis@undeerc.org

SUBJECT: Selection of Application for Negotiation Under Funding Opportunity Announcement Number DE-FOA-0001992, Maximizing the Coal Value Chain

Dear Ms. Landis:

On December 20, 2018, the U.S. Department of Energy (DOE) issued the subject Funding Opportunity Announcement (FOA). On October 3, 2019, notification letters were sent to applicants whose applications were not selected under the FOA. Subsequently, DOE identified additional funding available for this work. As a result, I am pleased to inform you that the application from your organization for the project titled "Laboratory-Scale Coal-Derived Graphene Process" has been selected for negotiations leading to a financial assistance award.

Since some time has passed since your organization submitted this application, the DOE requests confirmation that your organization is still interested in pursuing this award. Please respond to this letter to decline or confirm your commitment to pursuing this award (see table below). If you confirm your commitment, please also confirm the following regarding your original application:

- Initial-proposed Key Personnel remain committed to this work;
- Any team members, or acceptable replacements, are committed to this work; and
- Your organization still has access to any resources offered in the application.

Additionally, to expedite the award process, please complete and submit the documentation listed below within the scheduled due dates. Failure to meet the submission deadlines may result in cancellation of further award negotiations and recission of the selection.

<table>
<tr><th>Document</th><th>Due (Business days from date of letter)</th><th>Submission Type</th><th>Send Information to</th></tr>
<tr><td>Confirmation of Commitment</td><td>3</td><td>Email</td><td>DOE CS</td></tr>
<tr><td>Pre-Award Information Sheet</td><td>7</td><td>Email</td><td>DOE CS</td></tr>
<tr><td>Foreign National (FN) Information (1)</td><td>21</td><td>Hard Copy</td><td>DOE CS – 3610 Collins Ferry Road, PO Box 880, Morgantown, WV 26507</td></tr>
<tr><td colspan="4">Note (1): Provide the following information for each FN at the subrecipient or partner organization who is located in the U.S. and who is planned to have frequent communication with the National Energy Technology Laboratory (NETL) Project Manager. Questions regarding FN processing should be directed to the NETL Project Manager.
For the identified FN(s), submit the required information as follows:
1) Completed form NETL 142.1-1A “Request for Unclassified Foreign National Access (Short Form)” (Attachment D)
2) A color copy of the LPR (Lawful Permanent Resident) Card or Visa;
3) A color copy of their passport;
4) A copy of their resume; and
5) Copies of any other documents that allow the individual to be in the United States.
NETL recommends that FN packages be sent via overnight carrier to protect any identifiable personal identifiable information (PII).</td></tr>
</table>

Receipt of this letter does not authorize you to commence with performance of the project. DOE makes no commitment to issue an award and assumes no financial obligation with the issuance of this letter. Only an award document signed by the Contracting Officer obligates DOE to support the project.

Please provide the requested documents to the attention of Sheldon Funk, who is the Contract Specialist from the Finance and Acquisition Center handling the administrative portion of your application. Mr. Funk can be reached at 304-285-0204 or Sheldon.Funk@netl.doe.gov. Anthony Zinn is the NETL Project Manager from the Project Management Division handling the technical portion of your application and can be reached at 304-285-5424 or Anthony.Zinn@netl.doe.gov

On behalf of the Department, I would like to express a sincere appreciation of your interest and participation in this program.

Sincerely,

Kelly Haught

Kelly Haught
Contracting Officer
Finance and Acquisition Center

Enclosures

cc: FOA File
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APPENDIX D

BUDGET NOTES

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ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

BACKGROUND

The EERC is an independently organized multidisciplinary research center within the University of North Dakota (UND). The EERC is funded through federal and nonfederal grants, contracts, and other agreements. Although the EERC is not affiliated with any one academic department, university faculty may participate in a project, depending on the scope of work and expertise required to perform the project.

INTELLECTUAL PROPERTY

The applicable federal intellectual property (IP) regulations will govern any resulting research agreement(s). In the event that IP with the potential to generate revenue to which the EERC is entitled is developed under this project, such IP, including rights, title, interest, and obligations, may be transferred to the EERC Foundation, a separate legal entity.

BUDGET INFORMATION

The proposed work will be done on a cost-reimbursable basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, etc.) and among funding sources of the same scope of work is for planning purposes only. The project manager may incur and allocate allowable project costs among the funding sources for this scope of work in accordance with Office of Management and Budget (OMB) Uniform Guidance 2 CFR 200.

Escalation of labor and EERC recharge center rates is incorporated into the budget when a project's duration extends beyond the university's current fiscal year (July 1 – June 30). Escalation is calculated by prorating an average annual increase over the anticipated life of the project.

The cost of this project is based on a specific start date indicated at the top of the EERC budget. Any delay in the start of this project may result in a budget increase. Budget category descriptions presented below are for informational purposes; some categories may not appear in the budget.

Salaries: Salary estimates are based on the scope of work and prior experience on projects of similar scope. The labor rate used for specifically identified personnel is the current hourly rate for that individual. The labor category rate is the average rate of a personnel group with similar job descriptions. Salary costs incurred are based on direct hourly effort on the project. Faculty who work on this project may be paid an amount over the normal base salary, creating an overload which is subject to limitation in accordance with university policy. As noted in the UND EERC Cost Accounting Standards Board Disclosure Statement, administrative salary and support costs which can be specifically identified to the project are direct-charged and not charged as facilities and administrative (F&A) costs. Costs for general support services such as contracts and IP, accounting, human resources, procurement, and clerical support of these functions are charged as F&A costs.

Fringe Benefits: Fringe benefits consist of two components which are budgeted as a percentage of direct labor. The first component is a fixed percentage approved annually by the UND cognizant audit agency, the Department of Health and Human Services. This portion of the rate covers vacation, holiday, and sick leave (VSL) and is applied to direct labor for permanent staff eligible for VSL benefits. Only the actual approved rate will be charged to the project. The second component is estimated on the basis of historical data and is charged as actual expenses for items such as health, life, and unemployment insurance; social security; worker's compensation; and UND retirement contributions.

Travel: Travel may include site visits, fieldwork, meetings, and conferences. Travel costs are estimated and paid in accordance with OMB Uniform Guidance 2 CFR 200, Section 474, and UND travel policies, which can be found at http://und.edu/finance-operations (Policies & Procedures, A–Z Policy Index, Travel). Daily meal rates are based on U.S. General Services Administration (GSA) rates unless further limited by UND travel policies; other estimates such as airfare, lodging, ground transportation, and miscellaneous costs are based on a combination of historical costs and current market prices. Miscellaneous travel costs may include parking fees, Internet charges, long-distance phone, copies, faxes, shipping, and postage.

Equipment: The EERC budgeted two pieces of equipment to be purchased. The first is a LHTG furnace with an upper limit of ~3000°C to perform graphitization of the treated coal materials. The second is a Raman spectrometer to characterize the graphite and graphene products. The cost of the equipment is estimated at $181,190 for the LHTG furnace and $139,240 for the Raman spectrometer.

In addition, the EERC will fabricate a demineralizer reactor (DR) and a reaction fluidized-bed reactor (RFBDR). The DR will be used for coal pretreatment work with an estimated cost of $5000. The RFBDR will be used for carbonization and condensation work with an estimated cost of $8500.

Supplies: Supplies include items and materials that are necessary for the research project and can be directly identified to the project. Supply and material estimates are based on prior experience with similar projects. Examples of supply items are chemicals, gases, glassware, nuts, bolts, piping, data storage, paper, memory, software, toner cartridges, maps, sample containers, minor equipment (value less than $5000), signage, safety items, subscriptions, books, and reference materials. General purpose office supplies (pencils, pens, paper clips, staples, Post-it notes, etc.) are included in the F&A cost.

Subcontracts: Not applicable.

Professional Fees: Not applicable.

Communications: Telephone, cell phone, and fax line charges are included in the F&A cost; however, direct project costs may include line charges at remote locations, long-distance telephone charges, postage, and other data or document transportation costs that can be directly identified to a project. Estimated costs are based on prior experience with similar projects.

Printing and Duplicating: Page rates are established annually by the university's duplicating center. Printing and duplicating costs are allocated to the appropriate funding source. Estimated costs are based on prior experience with similar projects.

Food: Expenditures for project partner meetings where the primary purpose is dissemination of technical information may include the cost of food. The project will not be charged for any costs exceeding the applicable GSA meal rate. EERC employees in attendance will not receive per diem reimbursement for meals that are paid by project funds. The estimated cost is based on the number and location of project partner meetings.

Professional Development: Fees 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 the development and execution of the project by the research team.

Operating Fees: Operating fees generally include EERC recharge centers, outside laboratories, and freight.

EERC recharge center rates are established annually and approved by the university.

Laboratory and analytical recharge fees are charged on a per-sample, hourly, or daily rate. Additionally, laboratory analyses may be performed outside the university when necessary. The estimated cost is based on the test protocol required for the scope of work.

Graphics recharge fees are based on an hourly rate for production of such items as report figures, posters, and/or images for presentations, maps, schematics, Web site design, brochures, and photographs. The estimated cost is based on prior experience with similar projects.

Shop and operations recharge fees cover specific expenses related to the pilot plant and the required expertise of individuals who perform related activities. Fees may be incurred in the pilot plant, at remote locations, or in EERC laboratories whenever these particular skills are required. The rate includes such items as specialized safety training, personal safety items, fall protection harnesses and respirators, CPR certification, annual physicals, protective clothing/eyewear, research by-product disposal, equipment repairs, equipment safety inspections, and labor to direct these activities. The estimated cost is based on the number of hours budgeted for this group of individuals. Engineering services recharge fees cover specific expenses related to retaining qualified and certified design and engineering personnel. The rate includes training to enhance skill sets and maintain certifications using Webinars and workshops. The rate also includes specialized safety training and related physicals. The estimated cost is based on the number of hours budgeted for this group of individuals.

Software solutions services recharge fees are for development of customized Web sites and interfaces, software applications development, data and financial management systems for comprehensive reporting and predictive analysis tools, and custom integration with existing systems. The estimated cost is based on prior experience with similar projects.

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

Facilities and Administrative Cost: The F&A rate proposed herein is approved by the U.S. Department of Health and Human Services and is applied to modified total direct costs (MTDC). MTDC is defined as total direct costs less individual capital expenditures, such as equipment or software costing $5000 or more with a useful life of greater than 1 year, as well as subawards in excess of the first $25,000 for each award.