Consideration for NDIC Cost Share to Support a DOE Study of Mitigation of Alkali Promoted Ash Deposition and Emissions from Coal Combustion

Submitted to:
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Funding Request from NDIC: $400,000

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PUBLIC VERSION

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Abbreviations

Barr	Barr Engineering Co.
CFD	Computational Fluid Dynamics
CO_2	Carbon Dioxide
DFC	down-fired combustor
DLPI	Dekati® Low Pressure Impactor
DOE	U.S. Department of Energy
ESP	electrostatic precipitators
K	potassium
MCL	Material Characterization Laboratory
MRY	Milton R Young
MRY1	Milton R Young Unit 1
MTI	Microbeam Technologies Inc.
Na	sodium
NDIC	North Dakota Industrial Commission
NETL	National Energy Technology Laboratory
PC	pulverized coal
PMP	Project Management Plan
PRB	Powder River Basin
SCR	Selective Catalytic Reduction
SEM	Scanning Electron Microscopy
SOPO	North Dakota Industrial Commission
TEA	Techno-Economic Assessment
TRL	Technology Readiness Level

UND	University of North Dakota
UND-IES	University of North Dakota Institute for Energy Studies
WRP	workforce readiness plan

Abstract

Barr Engineering Co. is proposing to lead a multi-faceted team to study and demonstrate technology that will reduce the formation and presence of aerosols in the combustion zone of a lignite-fired utility boiler. The team includes lignite coal combustion experts from Microbeam, Envergex, the University of North Dakota and MLJ Consulting. The primary objective for this project is to validate a proposed sorbent technology for mitigating fouling-related challenges in a coal-fired power generation facility thus eliminating fouling-related downtime. The sorbent will reduce the formation of aerosol particles that accumulate on heat transfer surfaces and result in lower boiler efficiency. Aerosols are also problematic for amine-based carbon capture systems, and effective control of aerosol formation will advance lignite combustion units toward a carbon-capture-ready status. The impact of mitigating slagging and fouling is significant and expected to: 1) Increase plant revenues due to a reduction in outage time, 2) Reduce overall boiler temperatures due to better heat rate efficiency, 3) Reduce NOx emissions from lower furnace temperatures, 4) Reduce in fuel consumption from improved heat rate, 5) Decrease parasitic power from less fan power, and 6) Improve fuel flexibility/tolerance for low quality fuels. For a 250 MW facility, we anticipate annual savings of over $2 million dollars.

The total proposed project costs is $4,996,410. The project has been selected for award by DOE with funding of $3,996,998. The funding from DOE is contingent on a cost share funding of $999,412 from project co-sponsors. Barr has received commitments from Minnkota Power ($200,000 in kind), Otter Tail Power ($100,000), North American Coal ($100,000) and the University of North Dakota ($199,412 in kind). This application is requesting $400,000 of North Dakota Industrial Commission (NDIC) funding over three years to meet the cost share requirement. The three-year project is expected to be carried out from September 1, 2019 to August 31, 2022.

1 Project Summary

Barr Engineering Co. is proposing to lead a multi-faceted team to study and demonstrate technology that will reduce the formation and presence of aerosols in the combustion zone of a lignite-fired utility boiler. The primary sponsor of the project is the U.S. Department of Energy (DOE) and Barr is currently working to finalize a grant agreement with the National Energy Technology Laboratory (NETL). While Barr is providing a significant project management and engineering support role for the project, the genesis of this technology concept lies with coal combustion expertise held with Microbeam Technologies Inc., Envergex, the University of North Dakota Institute for Energy Studies (UND-IES), and MLJ Consulting. The team recognizes that addressing this operational problem represents an opportunity to improve generation efficiency and carbon capture readiness. As such, it is in keeping with state and federal objectives to improve and maintain coal resource utilization. This two-phase project seeks to accomplish the following:

1) Conduct bench-scale testing to select an optimal sorbent,
2) Field demonstration of sorbent injection at a full-scale power plant for fouling mitigation,
3) Developing a benchmark and screening tool for identifying low cost sorbents capable of mitigating fouling and slagging,
4) Performing a Techno-Economic Assessment (TEA) of the proposed technology, and
5) Advancing the technology to a DOE-defined Technology Readiness Level (TRL) of 7 (full-scale demonstration).

This is project will help the State of North Dakota and the Lignite industry by creating a low-cost retro-fit feature that can improve the performance of other high-alkali fuels and other boiler configurations. Not only will power plants have the technology to reduce fouling and overall boiler and furnace temperatures when using high alkali coals, but they also have the ability to use more fuel types that were not possible due to boundaries of the equipment. This technology will also help plants explore ways to reduce aerosols which is needed for the consideration in Carbon Capture technology.

2 Project Description

Barr is proposing to lead a multi-faceted team to study and demonstrate technology that will reduce the formation and presence of aerosols in the combustion zone of a lignite-fired utility boiler. The following sections provide details about the project objectives, methodologies, organization and impacts.

2.1 Overall Project Objectives

The primary objective of this project is to validate a proposed sorbent technology for mitigating fouling-related challenges in a coal-fired power generation facility thus eliminating fouling related downtime.

2.2 Project Objectives

The project is sub-divided into two phases:

- Bench-scale (budget period 1) where the objective is to down-select the optimal sorbent for field demonstration and develop a detailed design and costing for the demonstration equipment and campaign and;
- Demonstration phase (budget period 2) with an objective to perform a field demonstration of the proposed technology as a fouling mitigation strategy in a full-scale commercial electricity-generation facility and develop a TEA for commercial deployment.

Specific technical objectives include:

1) Field demonstration of sorbent injection at a full-scale power plant for fouling mitigation,
2) Developing a benchmark and screening tool for identifying low cost sorbents capable of mitigating fouling and slagging,
3) Performing a TEA of the proposed technology, and
4) Advancing the technology to a TRL of 7.

2.3 Methodology

The work scope is sub-divided into two 18-month budget periods for a total duration of 36 months. In the first budget period, the bench campaign will focus on screening multiple sorbents at the laboratory scale at relevant operating conditions. Data from the screening test will be used to finalize the design and sizing of the field test equipment and establish procurement targets for the screened sorbents. A "go/no go" decision point at the end of this phase will determine progress to next budget period.

The second budget period will focus on the field demonstration testing campaign and consist of:

1) installation of test equipment at test site,
2) equipment shakedown and sorbent procurement,
3) a parametric testing campaign,
4) data reduction and consolidation of the parametric test campaign,
5) optimized conditions testing, and
6) updated TEA including commercial and marketing strategy.

Tasks to be performed include the following:

Task 1 – Project Management and Planning. Barr will manage and direct the project in accordance with a Project Management Plan (PMP) to meet all technical, schedule and budget objectives and requirements. Barr will coordinate activities in order to effectively accomplish the work. Barr will document project plans, results and decisions appropriately to allow for project reporting and briefings. Barr will update the PMP 30 days after award and as necessary throughout the project to accurately reflect the current status of the project. Examples of when it may be appropriate to update the PMP include: (a) project management policy and procedural changes, (b) changes to the technical, cost, and/or schedule baseline for the project; (c) significant changes in scope, methods, or approaches; or (d) as otherwise required to ensure that the plan is the appropriate governing document for the work required to accomplish the project objectives. Management of project risks will occur in accordance with the risk management methodology delineated in the PMP in order to identify, assess, monitor and mitigate technical uncertainties as well as schedule, budgetary, and environmental risks associated with all aspects of the project. The results and status of the risk management process will be presented during project reviews and in quarterly progress reports with emphasis placed on the medium- and high-risk items. Barr will update the Technology Maturation Plan as necessary throughout the project to accurately reflect the current status of the technology maturation.

Tasks will be managed primarily from Barr's offices; however, there will be several on-site meetings held either at UND, at Barr's Bismarck Office or on-site at Center, ND.

Task 2 – Laboratory Scale Testing. Laboratory testing will be managed and executed by UND-IES at their facilities.

Subtask 2.1 – Feedstock selection, preparation and characterization: A high sodium coal will be obtained from the field test facility. The coal will be pulverized to 80% finer than 200 μm, and then characterized for proximate, ultimate and ash chemical composition. The sorbent materials will be procured, crushed and pulverized to the desired particle size distribution. The sorbent materials will consist of commercially available materials and low-cost affordable alternatives. A screening and benchmarking tool for predicting sorbent performance will be developed by comparing morphology and chemistry of the commercial and low-cost sorbents.

Subtask 2.2: Coal Testing and Analysis: Prior to testing, modifications/upgrades of UND's 10 kW down-fired combustor (DFC) will be performed through addition of an independent sorbent injection system, automated operation/data logging, refractory replacement and improved combustion temperature control and profile. The extended combustion zone will provide temperature flexibility to better simulate relevant temperature profiles expected in a full scale facility. The different sorbent materials will be evaluated for their effectiveness as sorbents for the vapor phase alkali components and for their ability to capture the alkali. From these tests, specific compositions/materials will be down-selected for pilot testing and for performance attributes (loading, particle size) that determine effectiveness. Test procedures consist of 1) baseline pulverized coal combustion testing to determine fate of alkali during combustion in the DFC. De-volatilized alkali are expected to condense out as ultra-fine and fine aerosol particulates. Particulate sampling at the exit of the combustor will be conducted with a pre-separator cyclone in series with a Dekati® Low Pressure Impactor (DLPI) – a state-of-the-art 13-stage cascade impactor for measuring gravimetric particle size distribution of very small particles. The cyclone removes a majority of particles larger than 10 micron from the sample gas stream. 2) Fuel-Sorbent testing. The sorbent will be co-fed to the DFC along with coal at a fixed loading. Previous technology development showed a sorbent-coal loading of 2% providing acceptable performance. This screening step will establish the benchmark parameters for each sorbent and the best sorbent will be down-selected for field demonstration. A total of 15 tests (5 sorbents x 3 levels) are planned. 3) Extended testing of pilot coal with down-selected sorbent. This testing will focus on key technology attributes of particle size (3 levels) and loading (3 levels) for the pilot test campaign. A correlation between technology attributes will be developed to facilitate design and procurement of the pilot scale test system and sorbent materials. 4) Analysis of ash samples. Samples collected during testing in the previous steps will be analyzed to determine the fate and occurrence of alkali. Samples collected on the DLPI stages will be subjected to Scanning Electron Microscopy (SEM) for qualitative data results (morphology) and elemental analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine fate of elements.

Task 3 – Sorbent Injection Modelling - CFD: Modelling using Computational Fluid Dynamics (CFD) will be performed to identify injection locations that improve targeting of problematic boiler zones. A dynamic model of the host facility boiler will be combined with a virtual reality engine to overlay injection location and dosage maps to achieve maximum coverage of problem areas. Process conditions (temperatures, gas volumes/flowrates), problem locations and design specifications will be obtained from the demonstration facility for this task. Existing injection locations (over-fired air, or cyclone vent ports) will be investigated. Additional injection locations will included if needed. This modelling will be performed by UND-IES.

Task 4 – Equipment Design and Sizing for Field Demonstration: Based on the results of Task 2, scale-up considerations for sorbent preparation, loading and injection will be evaluated for the field demonstration. Factors may impact the existing coal-feed systems and down-stream particulate controls systems will also be evaluated. This task will require close communication with demonstration facility, equipment suppliers and Barr. Most of the design work will be conducted at Barr offices in collaboration with the team and the host site. This task will be sub-divided into the following sub-tasks:

Subtask 4.1: Develop general process flow diagram: Identify all major process equipment for the power plant; specifically sorbent injection system and preparation equipment and additional plant retrofits (injection ports) that will be required for the testing.

Subtask 4.2: Develop material and energy balances: Balance around the power plant boiler and around major pieces of equipment of importance.

Subtask 4.3: Detailed Design of injection equipment: Sub-divided into the following key steps:

1) Work closely with demonstration facility to identify layout for optimal location of sorbent delivery equipment.

2) Develop pneumatic conveying design by identifying piping runs for sorbent transport to delivery location and determining critical process parameters (pressure drop for horizontal, vertical and pipe bend runs; blower duty) needed to achieve injection specifications from Task 3.

3) Create stream tables showing operating pressures, temperatures, compositions, and enthalpies for all streams entering.

4) Develop equipment and utilities list of all equipment/utilities required for demonstration of the proposed technology.

5) Estimate utility requirements for sorbent system and identify interconnection locations.

Subtask 4.4: Perform Sensitivity analysis: Analyze critical sorbent injection parameters and their effects on operating parameters and overall plant performance and economics. The critical parameters are:

1) Optimal quantity of sorbent required, and

2) Optimal particle size of injected sorbent.

Subtask 4.5: Cost Evaluation of Field Demonstration: Detailed costing for demonstration will be finalized. Final vendor quotes for the sorbent delivery system will be obtained. The sampling and data collection activities will be updated. Cost share requirements for the test campaign will be re-evaluated with the demonstration facility to confirm objectives are still feasible.

Subtask 4.6: Finalize technical design with optimized parameters from demonstration Site. After a review of the sub-tasks above by the test facility and equipment suppliers, a final design package for the field demonstration program will be prepared. The final design will be used for the "go/no go" decision point. A workforce readiness plan (WRP) will be developed with a successful "go" decision.

Task 5 – Procurement, Installation and Construction: Testing equipment will consist of a sorbent hopper and delivery/injection system. This testing will be initiated and executed at Minnkota Milton R Young Unit 1 (MRY1) in Center, ND. We will also be doing onsite coordination at the Center Mine in the same area. This task is sub-divided into the following sub-sections:

Sub-task 5.1: Equipment mobilization: Transportation of testing equipment to test location. Preliminary quotes have been obtained from potential sorbent injection vendors for renting a sorbent delivery system capable of handling 5 tons per hour injection rates. Final quotes will be determined in Task 4 (subtask 4.5).

Sub-task 5.2: Equipment installation and shakedown: Testing equipment will be integrated with the plant facility (utility hook-ups, delivery lances, and electrical connections). Prior to installation, injection ports will be installed at the demonstration facility during regular scheduled outage in accordance with the detailed design from Task 4.

Sub-task 5.3: Sorbent and Coal Procurement: Test sorbents will be procured in sufficient quantities as required by the test campaign and delivered to the plant.

Sub-task 5.4: Installation of Sampling Equipment: A comprehensive sampling campaign is planned with objective of developing an alkali mass balance for the facility before and during the testing. Key sampling locations will include coal feeders/conveyor belt, bottom and fly ash hoppers, plant stack and convective region using deposition probes.

Sub-task 5.5: Equipment De-mobilization: upon completion of Task 6 and Task 8, the test equipment will be de-mobilized.

Task 6 – Parametric Testing – Field Demonstration: This task will consist of the actual sorbent injection test campaign and will focus on evaluating key technology attributes for the sorbent injection: *effect of grind and effect of feed rate as a function of fuel quality and plant performance.* This task will be the responsibility of the entire project team who will work closely with the test facility and injection equipment vendors/suppliers. Success of this task will require close coordination between the power plant, sampling team and injection team. Power plant data will be collected real time during testing and injection will be adjusted accordingly to match load. Key performance attributes for the plant during injection will consist of *coal feed rate/boiler heat input, furnace exit gas temperature (FEGT), boiler heat rate, boiler pressure drop, fan power, economizer outlet flue gas temperature, heat recovery after soot blowing and opacity and electrostatic precipitators (ESP) performance.* Sampling at different locations of the facility will be ongoing during testing to monitor possible effects of the injection campaign. Sampling locations and methodologies are identified in Table 1.

Table 1. Sampling Matrix during Field Demonstration Testing

Location	Sampling Method	Objective
Coal Feeder	Grab sample	Determine alkali input to boiler
Boiler deposits /bottom slag	Grab sample	Analyze furnace slag for changes in quality
Pre – ESP	DLPI	Fate of alkali by particulate size
Post – ESP	Grab sample	Determine effect of sorbent injection on ESP performance
ESP	Ash collection	Collect ash from ESP to test quality and alkali content
Stack	EPA Method 5	Verify impact of injection on stack emissions and loading

Task 7 – Data Reduction and Evaluation of Parametric Testing: Upon completion of Task 6, the data collected will be reviewed, boiler performance will be determined and an alkali mass balance established. Boiler performance will be determined from key plant data collected in Task 5. A mass balance of the alkali will be developed based on analyses of coal samples, slag and ash. This balance will be correlated with plant operating conditions to identify trends. An updated testing program will be developed for the extended test campaign using the results of the data reduction. The TEA and TMP will also be updated to reflect the data obtained from the parametric test campaign. The data evaluation will involve all team members at their respective locations.

Task 8 – Extended Sorbent Testing: This task will consist of an extended sorbent injection test campaign after identifying optimum parameters from Task 6 and 7 at the same MRY1 location. During this test campaign, data from the full stream elemental analyzer and coal tracker at the host facility will be used to control sorbent injection in real time. Procedure, data and samples collected during testing will be similar to Task 6. Injection parameters during testing will be maintained at optimum conditions determined in Task 6.

Task 9 – Data Reduction and TEA: Upon reduction of the data from the extended injection testing, the TEA will be finalized following a similar format as the NETL report "*Cost and Performance Baseline for Fossil Energy Plants – Volume 1a: Bituminous Coal and Natural Gas to Electricity (Rev 3, July 6, 2015)*," aka Bituminous Baseline Study. The TEA will be adjusted for a 500 MW facility. The TEA will include:

1) Itemized equipment list for equipment unique to the mitigation modification,
2) Itemized capital cost estimate of the power plant modification,
3) Itemized operating and maintenance cost estimates related to the mitigation process, and
4) First year cost of electricity using the methodology described in the NETL "*Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance*."

2.4 Anticipated Results

The technology provides the following benefits for facilities burning high alkali fuels:

1) For cyclone fired units, it allows the facility to burn lower quality fuel with a low ash melting point and operate at lower temperatures. *The lower temperatures facilitate deeper staging for reduced NO_x formation.*

2) The sorbent injected increases the melt point of ash in the boiler which when coupled with the lower temperatures from deeper staging means *less slagging and overall less NO_x formation*. Allery et al.[1] reported a 15 to 18% decrease in NO_x emissions from a cleaner boiler. We expect similar reduction levels.

3) A cleaner convective pass from reduced fouling after capture of alkali by sorbent that would result in a *1% improvement in heat rate, which corresponds to annual fuel savings of $400,000/year* (average heat rate of 11,000Btu/KWh, 80% capacity factor, fuel cost $2/MMBtu). This is backed by a recent study performed at Coyote Station (a project sponsor) by MTI that saw a deterioration in heat rate of 5% (11,000 Btu/KWh to 11,500 Btu/KWh) when fuel quality dropped.

4) Reduced outage time. Milton R. Young Station has four outages annually of 3 to 4 days each. *We anticipate reducing annual outages to three, with durations of 2 to 3 days per outage.* Allery et al. also report a 4 day reduction in outages from improved slag control. The increased uptime corresponds to estimated savings of *approximately $1, 200,000/year ($50/MWh wholesale price, 250 MW_e, 4 day savings).*

5) Fuel flexibility. The proposed technology is *complementary with existing strategies for addressing fouling and slagging* (soot blowing, coal blending, load cycling) and needs to be deployed only when sodium levels in feed coal exceed existing plant recommended indices. The flexibility in

[1] L. Allery, J. Rossow, A. Wesbeck, G. Snow, T. McMahon and M. Sylvester, "Demonstrated performance improvements on large lignite-fired boiler with targeted in-furnace injection technology™," 2010. [Online]. Available: https://www.ftek.com/images/ftek/media/en-US/pdfs/TechnicalPapers/TPP-592---Coal-Gen-2010_Leland-Olds_GSnow.pdf. [Accessed 20 February 2019].

deployment of the technology, would result in *sorbent injection costs estimated to be about $250,000/year ($20/ton, injection for 25% of the time)*, that offset a portion of the cost savings.

2.5 Facilities and Resources

Barr: Is a full scale detailed engineering design firm with full infrastructure to support projects including computers, plotters, printer, instrumentation, instrument repair/maintenance/calibration, laboratory space, etc. Multiple software products are licensed such as Chemcad, Mathcad, Autocad, Metsim, flow modeling, etc.

University of North Dakota (UND): Exceptional laboratory and bench-scale equipment and facilities with extensive fabrication experience including design and construction of five different combustion testing platforms are available at the UND. Their Material Characterization Laboratory (MCL) includes multiple equipment for thermal analysis, microscopy, spectrometry and spectroscopy including sample preparation. The College has several relevant process modelling software packages including ASPEN Plus and ANSYS Fluent. Relevant equipment are identified in Section 10.

Host Facility: Milton R. Young Station's (MRY) 250 MW_e Unit 1 is the proposed host site for the field demonstration. Their slagging and fouling challenges were discussed in Section 2.4. The level of sodium in their coal dictates the frequency of cleaning shutdowns with four shutdowns planned annually. MRY monitors its fuel quality using a full stream elemental analyzer and a Coal Tracker Algorithm that will be leveraged during the demonstration project. Flexibility of injection significantly reduces cost. MRY is providing $200,000 worth of in-kind cost share to assist with the demonstration effort. The in-kind cost share will consist of:

1) ***Expert Review and Guidance:*** MRY will support the project by providing a review of test methodology and analysis of data generated.

2) ***Pre-test Data on Baseline Conditions for Unit 1***: MRY will share coal analysis data for 1 to 3 months prior to testing, provide slag and fly ash data analyses, and provide associated mine sediments that would serve as low cost sorbent for laboratory testing.

3) ***Tie-in support/Port addition prior to test:*** MRY offers to install injection ports during one of their planned shutdowns, provide electrical tie-ins for injection equipment, site preparation for equipment location.

4) ***Support during Testing:*** MRY will perform coal, slag and ash sample collection/analyses during field test as needed. Currently, MRY is considering installing a carbon dioxide (CO_2) capture unit. The project, called Project Tundra is currently in the front end engineering design phase and is modelled after the Petra Nova facility in Texas. The technology we propose is expected to help make MRY CO_2 capture-ready.

2.6 Environmental and Economic Impacts during Project

The technology provides the following benefits for facilities burning high alkali fuels:

1) Reduced NOx emissions of about 15% due to increased staging, lower FEGT

2) One percent improvement in heat rate, which corresponds to annual fuel savings of $400,000/year (250 MW_e unit, heat rate of 11,000Btu/KWh, 80% capacity factor, fuel cost $2/MMBtu).

3) Reduced outage time/increased uptime, estimated to be $1,200,000/year (4 days) for a 250 MWe facility at wholesale electricity price of $50/MWh.

4) Fuel flexibility. Facilities will be more tolerant to quality of fuel supplied by mine.

There are some potential environmental and economic risks represented by the testing, but the severity, frequency and mitigation have been considered and described in the PMP in Appendix D. The risks include:

- Injection of the sorbent could cause operational issues and could result in plant downtime.
- Stack testers will be exposed to the elements and industrial site hazards during onsite testing.
- Sorbent handling, preparation and quality screening on-site may result in a stock of unused material, afternoon-hazardous solid waste from cleanout, and miscellaneous solid waste from sampling work that will require disposing.

2.7 Technical and Economic Impacts of Proposed Technology

The technology proposed is compatible with existing strategies for mitigating fouling. It is flexible - facilities only need deploy when fuel quality is poor. Sorbent injection costs are estimated at $250,000/year ($20/ton, injection for 25% of the time, 250 MW_e facility).

In North America, total capacity of applicable lignite-fired power plants is 5.8 GW_e (32.9 million tons/year). The technology is also applicable to facilities firing biomass; they are a similar sized market.

2.8 Project Need

According to the DOE, coal-fueled power plants compete in a marketplace with a growing number of renewable power generation assets, requiring displacement from traditional base-load power generation to flexible generation. Mitigating slagging and fouling issues will reduce operating costs for these facilities and better prepare them for a revenue-constrained environment.

3 Standards of Success

Ash and slag deposits that foul the steam-generation of a boiler are the primary cause for boiler outages. These ash and slagging result from the presence of volatile species in the coal ash that act as a glue for ash deposition and growth. This project will mitigate ash deposition by capturing the volatile species in the boiler through injection of sorbents in the boiler. The impact of mitigating slagging and fouling is significant and expected to:

1) Increase plant revenues due to a reduction in outage time,
2) Reduce overall boiler temperatures due to better heat rate efficiency,
3) Reduce NO_x emissions from lower furnace temperatures,
4) Reduce fuel consumption from improved heat rate,
5) Decrease parasitic power from less fan power (lower pressure drop through convective pass), and
6) Improve fuel flexibility/tolerance for low quality fuels. For a 250 MW facility, we anticipate annual savings of over $2 million dollars.

Budget Period 1 success criteria:

- Candidate sorbents have been successfully screened and a workable model developed that can be used to predict sorbent performance
- A CFD model has been developed that can be used to identify the optimal sorbent injection location to maximize its performance

- A final design package has been prepared that includes detailed input from plant personnel, sorbent suppliers, and technology vendors to ensure the technical and budgetary objectives proposed for Budget Period 2 can be achieved

Budget Period 2 success criteria:

- Equipment at the field test site is successfully installed and operational within the proposed budget and schedule
- Parametric testing demonstrates the effectiveness of the proposed technology and identifies the optimal parameters to maximize the benefits
- Long-term testing demonstrates that the technology is effective over long periods of time and over a wide range of load.

Advancement of the technology to a TRL 7 (system prototype validated in operational environment at full-scale) thus making them ready for commercial demonstration.

4 Background

According to the Department of Energy, coal-fueled power plants compete in a marketplace with a growing number of renewable power generation assets, requiring displacement from traditional base-load power generation to flexible generation. Mitigating slagging and fouling issues will reduce operating costs for these facilities and better prepare them for a revenue-constrained environment.

4.1 Past Industry Experience

Coal containing significant amounts of iron, calcium, sodium (Na) or potassium (K) are known to have low melting points and higher ash-deposition tendencies. This is characteristic of many low-rank coals and international coals. To facilitate combustion of these coals, Babcock & Wilcox developed the Cyclone furnace technology, with high combustion temperatures to ensure melting of the ash. Approximately 70% of the ash is trapped as a molten slag, and about 30% is transported as fly ash into the main boiler section, to manage slagging[2]. Analysis of a cyclone-fired boiler by Benson et al.[3] showed, for the impurities that contribute to ash deposition, *there is partitioning occurring in the cyclone, and higher volatility species such as alkali compounds (Na and K) are released with the fly ash.* Alkali species are major precursors for fouling, due to their low melting temperatures and the stickiness of their compounds. The vaporized alkali condenses (heterogeneously or homogeneously) as a sub-micron particulate as the heat is extracted from the flue gas in the boiler. Four main problems result from this[4]:

1) ***High temperature fouling.*** Occurs with heterogeneous condensation as alkali silicates in regions of the boiler with temperatures above 1050°C.

[2] Babcock & Wilcox. "Cyclone-Furnace Boilers," [Online]. Available: https://www.babcock.com/products/cyclone-furnace. [Accessed 20.02.2019]

[3] S. A. Benson, S. Patwardhan, A. Ruud, A. Freidt and J. Jouri, "Ash Formation and Partitioning in a Cyclone Fired Boiler," in *Impacts of Fuel Quality on Power Production*, Snowbird, Utah, 2014

[4] A. Zbogar, F. Frandsen, P. A. Jensen and P. Glarborg, "Shedding of ash deposits," *Progress in Energy and Combustion Science*, vol. 35, pp. 31-56, 2009.

2) ***Low temperature fouling.*** Occurs with heterogeneous condensation as alkali sulfates in the convective section of the boiler.

3) ***Deactivation of Selective Catalytic Reduction (SCR) catalysts.*** Sub-micron aerosols formed from homogeneous condensation of alkali compounds are known to poison Vanadium-based SCR catalysts[5]. This is the primary reason for the absence of SCR systems on lignite-fired power plants[6].

4) ***Fine Particulate Emission.*** The sub-micron alkali aerosols are captured with only a moderate efficiency (~90%) by ESP. These uncaptured ultra-fine particulate are deleterious for downstream wet treatment systems such as solvent-based CO_2[7] scrubbers.

4.2 Proposed Technology

Fuels with high alkali (Na/K) concentrations, such as North Dakota lignites and certain Powder River Basin (PRB) sub-bituminous coals, create challenges in coal-fired power plants. These include slagging and clinker formation in the radiant zone of the boiler, constrained operation in cyclone-fired boilers (e.g., fuel quality that can be used and limiting air staging, thus increased NOx), fouling of superheat/reheat surfaces leading to lost steam production, economizer fouling resulting in increased ID fan power, increased soot blowing and boiler maintenance costs, and higher stack particulate emissions.

[5] B. K. Olsen, F. Castellino and A. D. Jensen, *Deactivation of SCR Catalysts in biomass fired power plants.* Technical University of Denmark, 2015.

[6] S. B. Benson, J. D. Laumb, C. R. Crocker, J. H. Pavlish, "SCR Catalyst Performance in flue gases derived from subbituminous and lignite coals," *Fuel Processing Technology*, vol. 86, pp. 577-613, 2005

[7] S. Fulk and G. Rochelle, "Quantification of gas and aerosol-phase piperazine emissions by FTIR under variable bench-scale absorber conditions," *Energy Procedia*, vol. 63, pp. 871-883, 2014

4.3 Existing State-of-the-Art for Fouling Mitigation

Current mitigation strategies for fouling are focused on prevention, management and monitoring[8]. Preventive methods consist of coal blending and pre-treatment. These options are considered costly: blending requires access to a compatible low-alkali, higher value coal; pre-treatment requires processing a significant amount of the feed stock. The main management methods consist of:

1) ***The use of soot blowers*** to remove deposits on heat exchange surfaces by blowing jets of high pressure steam on the exchange surfaces to crack and erode away the deposits. Soot blowing effectiveness is dependent on the friability of the ash deposit and governed by its strength and adhesiveness/stickiness. Alkali-based deposits tend to exhibit low friability, reducing blowing effectiveness. Also, coals with high alkali loading exhibit a fast growth rate of the deposits. Soot blowing has very low effectiveness on the back side of the heat exchange surfaces.

2) ***Additive injection in boiler.*** Includes chemical injections for slag management by weakening of the slag crystal. An example is the Targeted in Furnace Injection technology[9]. This method is effective for slag control, but less effective for alkali mitigation and requires additional control strategies such as soot blowing.

3) ***Thermal shock by load cycling.*** This occurs during load cycling where thermal shock between the deposit and water wall results in shedding of the deposit. This method is most effective for friable ash depositions, less effective for alkali-based deposits. Other mitigation strategies exist, such as acoustic or Pulse Detonation, but are still in the experimental phase. Monitoring methods

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[8] M. Hare, M. G. Rasul and S. Moazzem, "A Review on Boiler Deposition/Foulage Prevention and Removal Techniques for Power Plant," *Recent Advances in Energy and Environment*, 2010.
[9] L. Allery, J. Rossow, A. Wesbeck, G. Snow, T. McMahon and M. Sylvester, "Demonstrated performance Improvements on large lignite-fired boiler with targeted in-furnace injection technology™," 2010. [Online]. Available: https://www.ftek.com/images/ftek/media/en-US/pdfs/TechnicalPapers/TPP-592---Coal-Gen-2010_Leland-Olds_GSnow.pdf. [Accessed 20 February 2019].

consist of simulation techniques that try to predict the formation and growth of ash deposits such as slagging indices, internal cameras and ash behavior prediction tools –CFD and AshPro™. These methods do not prevent fouling but are complementary with other mitigation strategies.

4.4 Previous Works of the Proposed Technology

Takuwa and Naruse[10] have shown previously that injection of kaolin ($Al_2O_3.2SiO_2.2H_2O$) is effective in scavenging vaporized alkali to form a solid particulate product (Figure 1). The researchers mixed the kaolin with the coal at kaolin/alkali mole ratio of 5:1 prior to combustion in a drop-tube furnace. The results show a reduction of sodium in the sub-micron (~75%) fraction with a corresponding increase in the super-micron fraction (2-10 µm). Gale and Wendt[11] examined the capture of both Na and Pb by kaolinite in a DFC using natural gas to understand the behavior at low (kaolin/alkali) stoichiometries. They found that (Figure 1) they achieved greater than 90% capture of alkali by kaolin at a molar stoichiometry of 1:1 and close to 65% capture at a stoichiometry of 0.5:1. A more detailed analysis revealed that in addition to the insoluble aluminosilicate product, they also formed aluminates ($Na_2O.\ Al_2O_3$) and silicates, leading to lower kaolin (mass) demand. Xu et al.[12] also performed alkali mitigation tests on high Na Chinese lignite where they focused on the effects of temperature and particle size. The best performance was observed for a kaolin size of 3 microns and at 1000°C (70% Na capture); larger sizes and higher temperatures required a larger dosage of kaolin to achieve similar capture. Recently, Dai et al[13] performed a 10 month long test at a 30 MW_{th} sub-critical PC boiler firing a Chinese lignite. For the test, they blended the coal with a silica additive (4% by weight) and were *able to increase production capacity*

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[10] T. Takuwa and I. Naruse, "Emission control of sodium compounds and their formation mechanisms during coal combustion," *Proceedings of the Combustion Institute*, vol. 31, pp. 2863-2870, 2007

[11] T. K. Gale and J. O. L. Wendt, "Mechanisms and Models Describing Sodium and Lead Scavenging by a Kaolinite Aerosol at High Temperatures," *Aerosol Science and Technology*, vol. 37, pp. 865-876, 2003

[12] L. Xu, J. Liu, Y. Kang, Y. Miao, W. Ren and T. Wang, "Safely Burning High Alkali Coal with Kaolin Additive in Pulverized Fuel Burner," *Energy and Fuels*, vol. 28, pp. 5640-5648, 2014

[13] B.-Q. Dai, X. Wu, A. De Girolamo and L. Zhang, "Inhibition of lignite ash slagging and fouling upon the use of a silica-based additive in an industrial pulverized coal-fired boiler.," *Fuel*, vol. 139, pp. 720-732, 2015

by 10%. Earlier attempts to increase production during normal operation always resulted in significant slagging and fouling and unscheduled shutdowns.

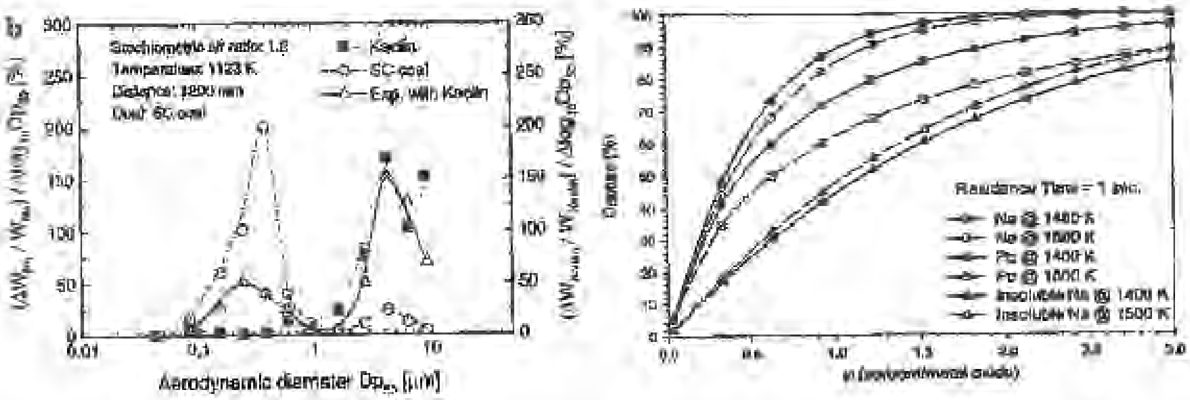

Figure 1. (Left) Naruse and Takuwa results for Na content versus size with/without kaolin injection (Right) Gale and Wendt results for alkali capture with injection of kaolin

4.5 Market Potential

The proposed technology is applicable to all fuels with alkali-based fouling and slagging issues. In North America, this includes lignite-fired power and energy generation plants with a total capacity of 5.8 GW in North America (32.9 million tons/year) as well as high-alkali containing PRB fuels such as Spring Creek and Decker. We have also identified units firing biomass as a major market with a combined firing rate of 42,900 MMBtu/hr.

The total capacity of units firing biomass (42,900 MMBtu/hr) is similar to that of lignite-fired boilers in terms of heating value, but the number of biomass units is much larger. Penetration of this market will be through our team's contacts in the industry and will include initial implementation of alkali mitigation technology through product demonstrations. We can expect to capture 10-20% of the market or about 10 to 15 units.

The overall market for our sorbent injection technology worldwide is larger as it can easily be exported for implementation in foreign markets. Countries firing lignites include Australia, China, Germany, Poland, Turkey, Russia, Greece, Indonesia, Czech Republic and India. The quantity of lignite mined worldwide was about 800 million metric tons in 2015.

For small demonstration tests, the sorbent injection system is modularized, and the sorbent loading process is not considered to be complex or atypical. The injection points considered are anticipated to be a feasible retrofit that can be completed during normal outage times.

5 Qualifications

Barr Engineering Co. has worked on projects for more than 300 power companies, ranging from small municipal utilities to large regional power producers and nonregulated energy developers. Barr brings together engineering and environmental expertise to provide innovative solutions in the face of changing regulations, markets and political climates. Barr offers a wide range of services for power clients from seeking to add a new generation facility or powerline, make improvements to a current facility, meet environmental requirements or help diversify fuel portfolio, Barr can take a project from the first feasibility studies and regulatory negotiations through construction, startup, and closure.

> ***Principal Investigator and Project Manager– Nicole Nguyen, Barr***, is a Project Management Professional responsible for the day-to-day management of the project. Nicole is a licensed chemical engineer from Barr with over a decade of experience working with clients in the power industry, with experience managing projects varying in labor fees over $1 million for power plant projects in multiple states.
>
> ***Contract and Risk Manager - Richard Hardegger, Barr***, will be the Principal for Barr for all tasks. He has applied a chemical engineering background to a 27 year career in environmental consulting for clients in the utility, mining, energy and manufacturing sectors. His experience includes projects for new and modified facilities that required federal and state air permitting, emissions control systems evaluation in support of best available control technology determinations, air dispersion modeling, human health risk assessment, ambient air monitoring, and stack testing.
>
> ***Consultant / Advisor - Bruce Browers, Barr***, will be the Technical Advisor for Barr for all tasks. Bruce has 46 years of coal fired power plant experience covering virtually all types of combustion systems including PC, IGCC, cyclones and stokers. He has conducted significant thermal modeling

studies of several types of power plant configurations including conventional and supercritical systems.

Dr. Steve Benson, Microbeam Technologies, Inc. has over 35 years of experience associated with the impact of major, minor and trace fuel impurities on combustion and gasification system design, reliability and performance. Dr. Benson in his current position at Microbeam has developed tools for combustion and gasification plants (power and syngas production) to manage coal/fuel properties and plant operating conditions. MTI's primary expertise lies in the following:

1) Unique deep understanding of the chemical and physical processes associated with the behavior of ash materials in the boilers of power plants,
2) Extensive experience in determining the forms and modes of occurrence of major, minor, and trace species, in coal and coal related materials,
3) Extensive contacts with coal mines and coal-fired utilities through decades of research related to solving real-world challenges in coal combustion,
4) Extensive databases on coal and ash chemical composition properties,
5) Extensive experience in the development and applications of algorithms to predict plant performance based on coal properties and plant performance, and
6) Existing models that are used to provide information to optimize fuel properties and boiler operations.

The models or tools are currently being augmented with condition-based monitoring combined with machine learning through a project funded by coal companies, utilities, and the DOE in a project entitled "Improving Coal-Fired Plant Performance through Integrated Predictive and Condition-Based Monitoring Tools" (DE-FE00031547). Microbeam has conducted over 1560 projects for clients worldwide and has extensive databases on fuel properties and plant performance and utilizes neural networks and machine learning to extract relevant information that allows for prediction of plant performance based on fuel properties, system design and plant operating parameters.

Dr. Srivats Srinivasachar, Envergex, LLC is a leading world expert in coal combustion, power plant operations, and development of innovative products and solutions for solid-fuel-fired power plants. He is the author of sixteen patents and over sixty publications in this subject area. Dr. Srinivasachar received his doctoral degree in Chemical Engineering at Massachusetts Institute of Technology with a dissertation on coal-water slurry combustion. Subsequently, he joined Physical Sciences, Inc. where his main focus was in developing tools for the power industry to combat ash deposition in boilers, including slagging and fouling. Dr. Srinivasachar has over thirty peer-reviewed publications in areas of mineral matter transformations and ash behavior in coal-fired boilers ranging from fundamental laboratory studies to full-scale commercial applications. Dr. Srinivasachar was the author of Slagging Advisor, a computational tool for coal-fired power plants to evaluate the impact of fuel quality on power plant performance. This tool was commercially used by several coal-fired utility customers to select coals for procurement, taking into consideration both their existing boiler design and operation as well as the fuel properties. Dr. Srinivasachar joined ABB Combustion Engineering (subsequently, ALSTOM Power, Inc. and now GE) in 1993 where he continued the implementation of ash deposition tools for power plants that were switching from high-sulfur bituminous coals to lower sulfur sub-bituminous (PRB) coals and which caused boiler de-rating due to ash deposition. At ABB Combustion Engineering, Dr. Srinivasachar developed additional commercial products for multiple components in coal-fired power plants, including novel coal-firing nozzles, contributing to the development of TFS-2000™ low-NOx firing system for tangentially-fired boilers, developing advanced methods of Ljungstrom air heater operation, and testing methods to improve precipitator performance for high ash resistivity coals. Dr. Srinivasachar has multiple patents related to these subject matters.

UND's Institute for Energy Studies is home to bench-scale facilities and equipment (sampling, combustion testing, and analysis) that will be essential for successful completion of the project.

Dr. Michael Mann is the director of the Institute of Energy Studies at UND, with 38 years of experience in Energy research.

Mr. Junior Nasah, PhD Candidate, UND Institute for Energy Studies is the principle investigator for the UND team. He is the Major Project Manager for UND's Institute for Energy Studies and was UND's lead researcher during development of the proposed technology under SBIR award DE-SC0015737. He will manage UND's activities and be the technical lead for Task 2. Mr. Nasah has experience in operating bench scale coal combustion systems, low pressure particulate impactors, and particulate extractive required for monitoring alkali occurrence from a power plant. Mr. Nasah holds a M.Sc. degree in Chemical Engineering and has worked as a research engineer for 6 years at UND. He has led multiple field sampling exercises at the host facility for the demonstration.

Dr. Gautham Krishnamoorthy brings a multi-year expertise in CFD modelling using FLUENT software package and will lead the modelling effort to identify optimum injection location for sorbent distribution. UND will be offering cost share for the project in the form of tuition waivers and hourly commitment.

Resumes of key personnel can be found in Appendix C.

5.1 Expertise of Team with Developing Similar Technology

The following list provides some of Barr's applicable power plant work:

1) Performed process review, procurement, and oversight of installation, data collection, and testing of dry sorbent injection of different sorbent types and sizes at a coal fired power plant – 2016, confidential client.

2) Provided compliance testing for particulate matter, opacity, and sulfuric acid mist at the main boiler stack. As a qualified AETB (air emission testing body) firm under the ASTM D7036 standard, Barr also provided Part 75 RATA testing for nitrogen oxides and carbon monoxide at two natural gas–fired facilities – 2015, Great River Energy.

3) Evaluated three different technologies to reduce stack vibration, developed screening-level constructed cost estimates for the three options, and provided detailed installation drawings for selected option. 2015 Great River Energy.

4) Provided a variety of engineering services, including pipe stress analysis, heat and material balances to optimize operational efficiency, root-cause analysis, combustion-turbine selection and design. We performed a test burn to uncover potential fatal flaws and determine how to best control the flow rate of biomass being fed to the boiler, which entailed temporarily using the plant's limestone silo and feeders. 2010-2019, Municipal Power Plant in Michigan.

5) Prepared applications to modify environmental permits, provided design engineering support, including reactor process modeling, to optimize burner performance. – 2015, Confidential Client.

During his tenure as Director of the Center for Air Toxic Metals at UND's Energy and Environmental Center Dr. Benson oversaw the research, development and training program on preventing toxic metal (e.g. mercury) emissions. The program spanned the entire development pathway for mercury control on lignite fired system and included multiple field demonstration of enhanced mercury capture sorbents. Dr. Srinivasachar is the inventor and developer of Mer-Cure™, a sorbent-based technology for mercury control. He holds US Patent 6,848,374 on this subject technology, which is assigned to ALSTOM Power

Inc. During his tenure at ALSTOM, he scaled the product through pilot-scale evaluation and commercial-scale testing, including commercial-scale production of sorbents, and led the successful demonstration of this technology at three full-scale plants. In March 2006, Dr. Srinivasachar formed Envergex LLC, with one of its objectives being the commercial-scale supply of enhanced sorbents for mercury control to ALSTOM and others. At Envergex, Dr. Srinivasachar developed a new sorbent product portfolio (ESORB-Hg™), which was supplied and tested successfully at full-scale at seven coal-fired power plants. The mercury control technology elements identified above are very similar to the sorbent injection technology proposed here and the in-depth experience with scaling and demonstrating that technology at several power plants and other industrial facilities will prove to be valuable in this development effort.

6 Value to North Dakota

The focus and purpose of this large and critical government funded study benefits the lignite industry by showing relevance in power generation and to the public. This study educates the industry and public on the properties of lignite as fuel and how emissions can be mitigated. Results from this study could strengthen and provide added flexibility in future, benchmarking, and transformative projects like Project Tundra that propel North Dakota to help pave a future in carbon capture storage and utilization technologies.

The proposed project will take the aerosol mitigation technology from the current TRL of 5 to a TRL of 7. The technology, demonstrated here on lignite from a North Dakota cyclone-fired boiler, has the potential to improve the performance of other high-alkali fuels and other boiler configurations. The improved performance as measured by increased efficiency, reliability and flexibility can be realized at relatively low cost and with minor modifications, thereby making the technology an attractive retrofit to existing plants. The impact of mitigating slagging and fouling is significant and expected to:

1) Increase plant revenues due to a reduction in outage time,
2) Reduce overall boiler temperatures due to better heat rate efficiency,
3) Reduce NO_x emissions from lower furnace temperatures,
4) Reduce in fuel consumption from improved heat rate,
5) Decrease parasitic power from less fan power, and
6) Improve fuel flexibility/tolerance for low quality fuels. For a 250 MW facility, we anticipate annual savings of over $2 million dollars.

The North American market represents about 5800 MWe of capacity firing about 33 million tons of lignite fuel. The majority of this capacity is located in North Dakota. The market for this application will include the implementation of alkali mitigation technology in lignite-fired boilers. We can conservatively expect to capture 20 percent of the market over the longer term, with the potential to reach 50 percent.

7 Management

7.1 Feasibility, Appropriateness, Rationale, and Completeness of the Statement of Project Objectives

The Statement of Project Objectives (SOPO) is discussed in Section 2.2 and 2.3 and is structured into two budget periods. For the first budget period we will screen, benchmark and down-select the clay used for field testing and determine key technology attributes, perform CFD modelling of the host facility's boiler to identify optimum injection locations and develop a detailed design of the injection system for the field test campaign. The results of the detailed design will be a key "go/no go" decision step. In the second budget period, we will perform sorbent injection at the test facility in two campaigns: first, parametric testing, to investigate the effect of technology attributes, followed by an extended testing to determine effect on plant performance metrics at optimum conditions. A TEA will be performed and the TMP updated.

7.2 Adequacy and Completeness of the PMP

The PMP in Appendix B is provided as a separate attachment to this application. The program will capitalize on the extensive experience of key personnel from Barr, MTI, Envergex and UND in management and execution of projects. This section describes:

1) Project organization and structure.
2) A detailed risk management strategy has been clearly defined that identifies the technical, resource and management risks along with their likelihood and impact, and mitigation strategies. The list of risks and mitigation strategies will be continuously updated and addressed during the project.
3) The project milestones/deliverables have been defined and are structured on a task-by-task basis with sufficient flexibility for each task.

4) The project budget and funding profile have been laid out; and,

5) The project timeline and decision points have been identified with a go/no go decision point at the end of the first budget period.

7.3 Clarity, Effectiveness, Adequacy and Availability of the Project Team

The project team is led by Barr and consists of the UND, Envergex LLC., Microbeam Technologies and MU Consulting. Figure 2 illustrates the team's organization.

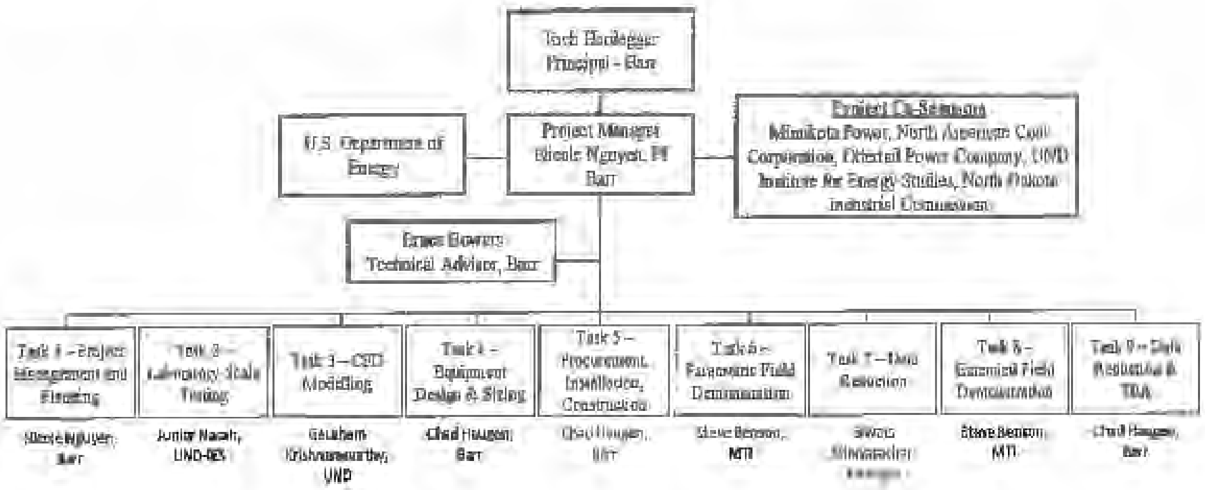

Figure 2. Project Organizational Structure

The periodic and final reports are proposed to be submitted in parallel the DOE schedule, including the following items:

Task/Subtask Number	Deliverable Title	Due Date
1.0	PMP	Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the NETL Project Manager
3.6	WRP	WRP due 30 days after completion of Task 3.6
3.0	Budget Period 1 Final Report	Due 30 days after the completion of Task 3
6.0	Field Demonstration Report 1	Due at the end of Task 6

7.3.1 Briefings/Technical Presentations

Barr will include the LEC/NDIC, and other cost share partners in detailed briefings for presentation to the NETL Project Manager, which will likely occur via WebEx. These briefings will include a presentation to the NETL Project Manager at a project kick-off meeting held within ninety (90) days of the project start date. Annual briefings will also be given by Barr to explain the plans, progress, and results of the technical effort and a final project briefing will be given at the close of the project.

8 Timetable

Barr was notified by the DOE on June 6, 2019 (Appendix E) that the aerosols mitigation proposal was selected for negotiation for funding. Barr submitted a response to the DOE's request for pre-award information on June 20, 2019 and is currently waiting for a draft agreement. Barr anticipates that the project start date will be in the August timeframe.

The project timeline and decision points are identified in the PMP with a go/no go decision point at the end of the first budget period.

Table 2 provides a summary of task timelines. Appendix G provides a MS Project Gantt Chart of the project timeline.

Table 2 Project Timeline

Task / Subtask Award	Start Date	Planned Completion Date	Deliverable	Milestone Marker / Verification Method Award
Task 1 – Project Management and Planning.	9/02/2019	9/02/2022	PMP	Quarterly Reports
Task 2 – Laboratory Scale Testing	9/02/2019	9/31/2020		Down-selection of field testing sorbent (5/01/2020) Establishment of Key Technology Attributes (9/31/2020)
Task 3 – Sorbent Injection Modelling - CFD	2/7/2020	10/15/2020		Identification of optimum injection locations
Task 4 – Equipment Design and Sizing for Field Demonstration	4/13/2020	1/15/2021	Design Report WRP Revised TMP	Go / No Go Decision
Task 5– Procurement, Installation and Construction:	1/18/2021	8/27/2021	Revised Detailed Design Report	Final Vendor Quotation Installation of Injection ports Commissioning of demonstration equipment
Task 6 – Parametric Testing – Field Demonstration:	8/30/2021	9/24/2021		Delivery of Sorbent Completion of parametric tests
Task 7 – Data Reduction and Evaluation of Parametric Testing:	9/27/2021	3/11/2022	Revised Detailed Design Report Revised TMP	Go / No Go Decision
Task 8 – Extended Sorbent Testing:	3/14/2022	4/8/2022		Completion of extended tests
Task 9 – Data Reduction and TEA	4/11/2022	9/02/2022	Final Report Final TEA, Final TMP	

9 Budget

Pending a cost-share award by the NDIC, the project budget is summarized as follows:

DOE Funding: $4,000,000
Cost Share (20%):

NDIC	*$400,000 – Requested; Pending*
Minnkota Power	$200,000 (in kind)
UND	$199,412 (in kind)
Otter Tail Power	$100,000
North American Coal	$100,000
	$999,412

Total: $4,999,412

Budget details are provided as Appendix A. Letters of support for contributions are found in Appendix B.

10 Matching Funds

This application is a request for cost-share support for a DOE-sponsored project (Funding Opportunity Announcement Number DE-FOA-0001989). Interest in the technology has been expressed by:

1) Minnkota Power Cooperative, operator of the proposed demonstration facility, the MRY power station. They have offered $200,000 in-kind support for the field demonstration and if successful will consider the technology for future application.
2) Otter Tail Power Company that operates the Coyote Station has provided $100,000 cash support.
3) North American Coal (NAC) with $100,000 cash support. NAC mining company in ND provides the coal for Coyote Station. Their mine sediments and those from Center Mine, which supplies MRY, could be potential sources of low cost sorbents.
4) University of North Dakota – Institute for Energy Studies will provide $199,412 as in-kind labor and lab facilities support.

11 Tax Liability

Barr does not have an outstanding tax liability owed to the State of North Dakota or any of its political subdivisions.

12 Confidential Information

Confidential information is provided as Appendix F.

13 Bibliography

1. J. Frandsen, "Ash Research from Palm Coast, Florida to Banff, Canada: Entry of Biomass in Modern Power Boilers," Energy and Fuels, vol. 23, pp. 3347-3378, 2009.

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11. T. K. Gale and J. O. L. Wendt, "Mechanisms and Models Describing Sodium and Lead Scavenging by a Kaolinite Aerosol at High Temperatures," Aerosol Science and Technology, vol. 37, pp. 865-876, 2003.

12. L. Xu, J. Liu, Y. Kang, Y. Miao, W. Ren and T. Wang, "Safely Burning High Alkali Coal with Kaolin Additive in Pulverized Fuel Burner," Energy and Fuels, vol. 28, pp. 5640-5648, 2014.

13. B.-Q. Dai, X. Wu, A. De Girolamo and L. Zhang, "Inhibition of lignite ash slagging and fouling upon the use of a silica-based additive in an industrial pulverized coal-fired boiler.," Fuel, vol. 139, pp. 720-732, 2015.

14. S. Srinivasachar, J. Nesah, D. Laudal "Mitigation of Aerosol Emissions from Solvent-based Post Combustion CO2 Capture Systems" 2017. Final Report. DOE Agreement DE-SC0015737

Appendices

Budget summary and budget justification
Letters of support and cost share contributions
Resumes of key personnel
Project Management Plan
DOE Notification Letter for DE-FOA-0001989
Confidential Information
Project Timeline Chart

Appendix A

Budgetary Summary and Budget Justification

Instructions and Summary

Award Number:

Award Recipient:

Date of Submission: 2019-02-28

Form submitted by: Barr Engineering Co.

(May be award recipient or sub-recipient)

Please read the instructions on each worksheet tab before starting. If you have any questions, please ask your DOE contact!

1. If using this form for award application, negotiation, or budget revision, fill out the blank white cells in workbook tabs a. through j. with total project costs. If using this form for invoice submission, fill out tabs a. through j. with total costs for just the proposed invoice and fill out tab k. per the instructions on that tab.
2. Blue colored cells contain instructions, headers, or summary calculations and should not be modified. Only blank white cells should be populated.
3. Enter detailed support for the project costs identified for each Category line item within each worksheet tab to autopopulate the summary tab.
4. The total budget presented on tabs a. through i. must include both Federal (DOE) and Non-Federal (cost share) portions.
5. All costs incurred by the preparer's sub-recipients, vendors, and Federal Research and Development Centers (FFRDCs), should be entered only in section f. Contractual. All other sections are for the costs of the preparer only.
6. Ensure all entered costs are allowable, allocable, and reasonable in accordance with the administrative requirements prescribed in 2 CFR 200, and the applicable cost principles for each entity type: FAR Part 31 for For-Profit entities; and 2 CFR Part 200 Subpart E - Cost Principles for all other non-federal entities.
7. Add rows as needed throughout tabs a. through j. If rows are added, formulas/calculations may need to be adjusted by the preparer. Do not add rows to the Instructions and Summary tab. If your project contains more than three budget periods, consult your DOE contact before adding additional budget period rows or columns.
8. ALL budget period cost categories are rounded to the nearest dollar.

BURDEN DISCLOSURE STATEMENT

Public reporting burden for this collection of information is estimated to average 3 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Office of Information Resources Management Policy, Plans, and Oversight, AD-241-2 - GTN, Paperwork Reduction Project (1910-5162), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, DC 20585; and to the Office of Management and Budget, Paperwork Reduction Project (1910-5162), Washington, DC 20503.

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED

The values in this summary table are from entries made in subsequent tabs, only blank white cells require data entry

Section A - Budget Summary

		Federal	Cost Share	Total Costs	Cost Share %	Proposed Budget Period Dates
	Budget Period 1	$1,125,228	$299,088	$1,424,316	21.00%	Example: 01/01/2014 - 12/31/2014
	Budget Period 2	$2,871,770	$700,324	$3,572,094	19.61%	
	Budget Period 3	$0	$0	$0	0.00%	
	Total	$3,996,998	$999,412	$4,996,410	20.00%	

Section B - Budget Categories

CATEGORY	Budget Period 1	Budget Period 2	Budget Period 3	Total Costs	% of Project	Comments (as needed)
a. Personnel	$185,845	$354,211	$0	$540,056	10.81%	
b. Fringe Benefits	$85,972	$163,858	$0	$249,830	5.00%	
c. Travel	$21,600	$61,800	$0	$83,400	1.67%	
d. Equipment	$0	$96,000	$0	$96,000	1.92%	
e. Supplies	$0	$972,500	$0	$972,500	19.46%	
f. Contractual						
Sub-recipient	$796,851	$990,002	$0	$1,786,853	35.76%	
Vendor	$69,958	$430,000	$0	$499,958	10.01%	
FFRDC	$0	$0	$0	$0	0.00%	
Total Contractual	$866,809	$1,420,002	$0	$2,286,811	45.77%	
g. Construction	$0	$0	$0	$0	0.00%	
h. Other Direct Costs	$0	$0	$0	$0	0.00%	
Total Direct Costs	$1,160,026	$3,068,371	$0	$4,228,397	84.63%	
i. Indirect Charges	$264,290	$503,723	$0	$768,013	15.37%	
Total Costs	$1,424,316	$3,572,094	$0	$4,996,410	100.00%	

Additional Explanation (as needed):

[illegible] Personnel

[illegible]

[illegible]

b. Fringe Benefits

INSTRUCTIONS - PLEASE READ!!!

1. Fill out the table below by position title. If all employees receive the same fringe benefits, you can show "Total Personnel" in the Labor Type column instead of listing out all position titles.
2. The rates and how they are applied should not be averaged to get one fringe cost percentage. Complex calculations should be described/provided in the Additional Explanation section below.
3. The fringe benefit rates should be applied to all positions, regardless of whether those funds will be supported by Federal Share or Recipient Cost Share.
4. Each budget period is rounded to the nearest dollar.

Labor Type	Budget Period 1			Budget Period 2			Budget Period 3			Total Project
	Personnel Costs	Rate	Total	Personnel Costs	Rate	Total	Personnel Costs	Rate	Total	
EXAMPLE!!! Sr. Engineer	$175,000	20%	$35,000	$10,000	20%	$2,000	$10,000	20%	$2,000	$39,000
Total Personnel	185,845	46.26%	$85,972	354,211	46.26%	$163,858			$0	$249,830
			$0			$0			$0	
			$0			$0			$0	$0
			$0			$0			$0	$0
			$0			$0			$0	$0
Total:	$185,845		$85,972	$354,211		$163,858	$0		$0	$249,830

A federally approved fringe benefit rate agreement, or a proposed rate supported and agreed upon by DOE for estimating purposes is required at the time of award negotiation if reimbursement for fringe benefits is requested. Please check (X) one of the options below and provide the requested information if not previously submitted.

_____ **A fringe benefit rate has been negotiated with, or approved by, a federal government agency. A copy of the latest rate agreement is/was included with the project application.***

__X__ **There is not a current federally approved rate agreement negotiated and available.****

*Unless the organization has submitted an indirect rate proposal which encompasses the fringe pool of costs, please provide the organization's benefit package and/or a list of the components/elements that comprise the fringe pool and the cost or percentage of each component/element allocated to the labor costs identified in the Budget Justification.

**When this option is checked, the entity preparing this form shall submit an indirect rate proposal in the format provided in the Sample Rate Proposal at http://www1.eere.energy.gov/financing/resources.html, or a format that provides the same level of information and which will support the rates being proposed for use in the performance of the proposed project.

Additional Explanation (as necessary): See Barr_SupportingRateJustification.pdf for additional information. The full audit report can be provided upon request and execution of a Financial Disclosure Agreement.

c. Travel

[illegible]

1. Identify Foreign and Domestic Travel as separate items. Examples of Purpose of Travel are subrecipient site visits, DOE meetings, project mgmt. meetings, etc. Examples of Basis for Estimating Costs are past trips, travel quotes, GSA rates, etc.
2. All listed travel must be necessary for performance of the Statement of Project Objectives
3. Federal travel regulations are contained within the applicable cost principles for all entity types. Travel costs should remain consistent with travel costs incurred by an organization during normal business operations as a result of the organizations written travel policy. In absence of a written travel policy, organizations must follow the regulations prescribed by the General Services Administration.
4. [illegible]

SOPO Task #	Purpose of Travel	Depart From	Destination	No. of Days	No. of Travelers	Lodging per Traveler	Flight per Traveler	Vehicle per Traveler	Per Diem Per Traveler	Cost per Trip	Basis for Estimating Costs
	Domestic Travel	Budget Period 1									
~~1~~	~~[illegible]~~			~~2~~	~~2~~	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~Current GSA rates~~
1	Team Meetings - In Person - Onsite Team Meeting	Minneapolis, MN	Grand Forks	2	6	$105	$500	$40	$55	$5,400	GSA & estimates of flight/rental car
1	Team Meetings - In Person Period 1 Review Meeting	Minneapolis, MN	Grand Forks	2	6	$105	$500	$40	$55	$5,400	GSA & estimates of flight/rental car
1	Team Meetings - In Person Period 2 Review Meeting	Minneapolis, MN	Grand Forks	2	6	$105	$500	$40	$55	$5,400	GSA & estimates of flight/rental car
1	Team Meetings - Final Report Review	Minneapolis, MN	Grand Forks	2	6	$105	$500	$40	$55	$5,400	GSA & estimates of flight/rental car
	International Travel										
										$0	
	Budget Period 1 Total									$21,600	
	Domestic Travel	Budget Period 2									
1	Team Meetings - In Person	Minneapolis, MN	Grand Forks	[illegible]	3	$105	$500	$40	$55	[illegible]	GSA & estimates of flight/rental car
1	Team Meetings - In Person	Minneapolis, MN	Grand Forks	2	3	$105	$500	$40	$55	$2,700	GSA & estimates of flight/rental car
6	Travel to / From Testing Site	Minneapolis, MN	Center, ND	20	6	$105	$500	$40	$55	$27,000	GSA & estimates of flight/rental car
8	Travel to / From Testing Site	Minneapolis, MN	Center, ND	20	6	$105	$500	$40	$55	$27,000	GSA & estimates of flight/rental car
	International Travel										
										$0	
	Budget Period 2 Total									[illegible]	
	Domestic Travel	Budget Period 3									
										$0	
										$0	
										$0	
										$0	
	International Travel										
										$0	
	Budget Period 3 Total									$0	
	PROJECT TOTAL									$83,400	

Additional Explanation (as needed):

d. Equipment

INSTRUCTIONS - PLEASE READ!!!

1. Equipment means tangible personal property (including information technology systems) having a useful life of more than one year and a per-unit acquisition cost which equals or exceeds the lesser of the capitalization level established by the non-Federal entity for financial statement purposes, or $5,000. Please refer to the applicable Federal regulations in 2 CFR 200 for specific equipment definitions and treatment.
2. List all equipment below, providing a basis of cost (e.g. vendor quotes, catalog prices, prior invoices, etc.). Briefly justify items as they apply to the Statement of Project Objectives. If it is existing equipment, provide logical support for the estimated value shown.
3. During award negotiations, provide a vendor quote for all equipment items over $50,000 in price. If the vendor quote is not an exact price match, provide an explanation in the additional explanation section below. If a vendor quote is not practical, such as for a piece of equipment that is purpose-built, first of its kind, or otherwise not available off the shelf, provide a detailed engineering estimate for how the cost estimate was derived.
4. [illegible]

SOPO Task #	Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
			Budget Period 1			
3.4.5	EXAMPLE!!!: Thermal shock chamber	2	$70,000	$140,000	Vendor Quote - Attached	Reliability testing of PV modules- Task 4.3
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
	Budget Period 1 Total			$0		
			Budget Period 2			
6	Stack Testing Equipment Rental (Unit - Day)	20	$2,000	$40,000		1st testing mobilization
6	Extra Hoses / Splitters (Per 25 FT)	40	$200	$8,000		Hose Cost $200 / 25 ft.
6	Stack Testing Equipment Rental (Unit - Day)	20	$2,000	$40,000		2nd testing mobilization
6	Extra Hoses / Splitters (Per 25 FT)	40	$200	$8,000		Hose Cost $200 / 25 ft.
				$0		
				$0		
				$0		
	Budget Period 2 Total			$96,000		
			Budget Period 3			
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
	Budget Period 3 Total			$0		
	PROJECT TOTAL			$96,000		

Additional Explanation (as needed):

e. Supplies

INSTRUCTIONS - PLEASE READ!!!

1. Supplies are generally defined as an item with an acquisition cost of $5,000 or less and a useful life expectancy of less than one year. Supplies are generally consumed during the project performance. Please refer to the applicable Federal regulations in 2 CFR 200 for specific supplies definitions and treatment. A computing device is a supply if the acquisition cost is less than the lesser of the capitalization level established by the non-Federal entity for financial statement purposes or $5,000, regardless of the length of its useful life.
2. List all proposed supplies below, providing a basis of costs (e.g. vendor quotes, catalog prices, prior invoices, etc.). Briefly justify the need for the Supplies as they apply to the Statement of Project Objectives. Note that Supply items must be direct costs to the project at this budget category, and not duplicative of supply costs included in the indirect pool that is the basis of the indirect rate applied for this project.
3. Multiple supply items valued at $5,000 or less used to assemble an equipment item with a value greater than $5,000 with a useful life of more than one year should be included on the equipment tab. If supply items and costs are ambiguous in nature, contact your DOE representative for proper categorization.
4. Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.
5. Each budget period is rounded to the nearest dollar.

SOPO Task #	General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
			Budget Period 1			
4.0	EXAMPLE!!! Wireless DAS components	10	$360.00	$3,600	Catalog price	For Alpha prototype - Task 2.4
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
	Budget Period 1 Total			$0		
			Budget Period 2			
				$0		
5	Sorbent Supply with Freight (Units in Tons)	2500	$194.50	$486,250	Cost of Sorbent $100/ton, Bara-Kade Special Grind - $94.50/TON	Sorbent needed at 5-10 tons / hour - estimated 300 hours of testing.
6	Sorbent Supply with Freight (Units in Tons)	2500	$194.50	$486,250	Cost of Sorbent $100/ton, Bara-Kade Special Grind - $94.50/TON	Sorbent needed at 5-10 tons / hour - estimated 300 hours of testing.
				$0		
				$0		
				$0		
				$0		
				$0		
	Budget Period 2 Total			$972,500		
			Budget Period 3			
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
				$0		
	Budget Period 3 Total			$0		
	PROJECT TOTAL			$972,500		

Additional Explanation (as needed):

Detailed Budget Justification

f. Contractual

INSTRUCTIONS - PLEASE READ!!!

1. The entity completing this form must provide all costs related to subrecipients, vendors, and FFRDC partners in the applicable boxes below.
2. Subrecipients (partners, sub-awardees): Subrecipients shall submit a Budget Justification describing all project costs and calculations when their total proposed budget exceeds either (1) $100,000 or (2) 50% of total award costs. These subrecipient forms may be completed by either the subrecipients themselves or by the preparer of this form. The budget totals on the subrecipient's forms must match the subrecipient entries below. A subrecipient is a legal entity to which a subaward is made, who has performance measured against whether the objectives of the Federal program are met, is responsible for programmatic decision making, must adhere to applicable Federal program compliance requirements, and uses the Federal funds to carry out a program of the organization. All characteristics may not be present and judgement must be used to determine subrecipient vs. vendor status.
3. Vendors (including contractors): List all vendors and contractors supplying commercial supplies or services used to support the project. For each Vendor cost with total project costs of $250,000 or more, a Vendor quote must be provided. A vendor is a legal entity contracted to provide goods and services within normal business operations, provides similar goods or services to many different purchasers, operates in a competitive environment, provides goods or services that are ancillary to the operation of the Federal program, and is not subject to compliance requirements of the Federal program. All characteristics may not be present and judgement must be used to determine subrecipient vs. vendor status.
4. Federal Funded Research and Development Centers (FFRDCs): FFRDCs must submit a signed Field Work Proposal during award application. The award recipient may allow the FFRDC to provide this information directly to DOE, however project costs must also be provided below.
5. [illegible]

SOPO Task #	Sub-Recipient Name/Organization	Purpose and Basis of Cost	Budget Period 1	Budget Period 2	Budget Period 3	Project Total
2,4	EXAMPLE!!! ABC Corp.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1,2,3,4,5,6,7,8,9	University of North Dakota	Task Lead for Task 8, Cost estimate based on personnel hours, Lab equipment and Supplies	$413,883	$376,187		$790,070
1,2,4,5,6,7,8,9	Microbeam Technologies, Inc.	Task Lead for Task 6,8, Cost estimate based on personnel hours and travel	$144,918	$304,960		$449,878
1,2,3,4,5,6,7,8,9	Envergex, LLC	Task Lead for Task 7, Cost estimate based on personnel hours and travel	$216,872	$282,905		$499,777
2,3,4	MLJ Consulting, LLC	Cost estimate based on personnel hours, Consultant Advisory	$24,000	$24,000		$48,000
						$0
						$0
		Sub-total	$799,651	$990,092	$0	$1,788,853

SOPO Task #	Vendor Name/Organization	Purpose and Basis of Cost	Budget Period 1	Budget Period 2	Budget Period 3	Project Total
	EXAMPLE!!! ABC Corp.	[illegible]	[illegible]	[illegible]		[illegible]
4	United Conveyor Corporation	UCC will provide a VIPER™ Mill Trailer, 2,000 Cu Ft storage silo, hardware Lead Time Reserve Cost	$49,958	$0		$49,958
6,8	United Conveyor Corporation	UCC will provide a VIPER™ Mill Trailer, 2,000 Cu Ft storage silo, hardware, Field Engineer and Process Engineer, all necessary conveying hoses and accessories, including splitters, splitter hoses and lances		$280,000		$280,000
2,3,4,5,6,7,8,9	Minnkota Power Cooperative	750 Hours Strategy Meetings, Installation of parts during testing, Electrical Tie-in connections, Utility Tie-in, Prep Laydown Area, Engineering coordination during field test and sampling, Coal Main analysis, Calibration and Tuning	$50,000	$150,000		$200,000
						$0
						$0
		Sub-total	$99,958	$430,000	$0	$529,958

SOPO Task #	FFRDC Name/Organization	Purpose and Basis of Cost	Budget Period 1	Budget Period 2	Budget Period 3	Project Total
						$0
						$0
		Sub-total	$0	$0	$0	$0

	Total Contractual		$899,609	$1,420,092	$0	$2,288,941

Additional Explanation (as needed):

g. Construction

PLEASE READ!!!

1. Construction, for the purpose of budgeting, is defined as all types of work done on a particular building, including erecting, altering, or remodeling. Construction conducted by the award recipient is entered on this page. Any construction work that is performed by a vendor or subrecipient should be entered under f. Contractual.

2. List all proposed construction below, providing a basis of cost such as engineering estimates, prior construction, etc., and briefly justify its need as it applies to the Statement of Project Objectives.

3. [illegible]

Overall description of construction activities: Example Only!!! - Build wind turbine platform

SOPO Task #	General Description	Cost	Basis of Cost	Justification of need
		Budget Period 1		
3	EXAMPLE ONLY!!! Three days of excavation for platform site	$26,000	Engineering estimate	Site must be prepared for construction of platform.
	Budget Period 1 Total	$0		
		Budget Period 2		
	Budget Period 2 Total	$0		
		Budget Period 3		
	Budget Period 3 Total	$0		
	PROJECT TOTAL	$0		

Additional Explanation (as needed):

h. Other Direct Costs

INSTRUCTIONS - PLEASE READ!!!
1. Other direct costs are direct cost items required for the project which do not fit clearly into other categories. These direct costs must not be included in the indirect costs (for which the indirect rate is being applied for this project). Examples are: tuition, printing costs, etc. which can be directly charged to the project and are not duplicated in indirect costs (overhead costs).
2. Basis of cost are items such as vendor quotes, prior purchases of similar or like items, published price list, etc.
3. Each budget period is rounded to the nearest dollar.

SOPO Task #	General Description and SOPO Task #	Cost	Basis of Cost	Justification of need
		Budget Period 1		
3	EXAMPLE!!!: Grad student support - tasks 1, 2	$15,000	Established UCD costs	Support of graduate students working on project
	Budget Period 1 Total:	$0		
		Budget Period 2		
	Budget Period 2 Total	$0		
		Budget Period 3		
	Budget Period 3 Total	$0		
	PROJECT TOTAL	$0		

Additional Explanation (as needed):

i. Indirect Costs

INSTRUCTIONS - PLEASE READ!!!

1. Fill out the table below to indicate how your indirect costs are calculated. Use the box below to provide additional explanation regarding your indirect rate calculation.
2. The rates and how they are applied should not be averaged to get one indirect cost percentage. Complex calculations or rates that do not do not correspond to the below categories should be described/provided in the Additional Explanation section below. If questions exist, consult with your DOE contact before filling out this section.
3. The indirect rate should be applied to both the Federal Share and Recipient Cost Share.
4. NOTE: A Recipient who elects to employ the 10% de minimis Indirect Cost rate cannot claim resulting costs as a Cost Share contribution, nor can the Recipient claim "unrecovered indirect costs" as a Cost Share contribution. Neither of these costs can be reflected as actual indirect cost rates realized by the organization, and therefore are not verifiable in the Recipient records as required by Federal Regulation (§200.306(b)(1)).
5. [illegible]

	Budget Period 1	Budget Period 2	Budget Period 3	Total	Explanation of BASE
Provide ONLY Applicable Rates:					
Overhead Rate	123.16%	123.16%	0.00%		
General & Administrative (G&A)	19.03%	19.03%	0.00%		
FCCM Rate, if applicable	0.00%	0.00%	0.00%		
OTHER Indirect Rate	0.00%	0.00%	0.00%		
Indirect Costs (As Applicable):					
Overhead Costs	$228,924	$436,317	$0	$665,241	
G&A Costs	$35,366	$67,406	$0	$102,773	
FCCM Costs, if applicable	$0	$0	$0	$0	
OTHER Indirect Costs	$0	$0	$0	$0	
Total indirect costs requested:	$264,290	$503,723	$0	$768,014	

A federally approved indirect rate agreement, or rate proposed (supported and agreed upon by DOE for estimating purposes) is required if reimbursement of indirect costs is requested. Please check (X) one of the options below and provide the requested information if it has not already been provided as requested, or has changed.

______ An indirect rate has been approved or negotiated with a federal government agency. A copy of the latest rate agreement is included with this application, and will be provided electronically to the Contracting Officer for this project.

___X___ There is not a current, federally approved rate agreement negotiated and available*.

*When this option is checked, the entity preparing this form shall submit an indirect rate proposal in the format provided by your DOE contact, or a format that provides the same level of information and which will support the rates being proposed for use in performance of the proposed project. Additionally, any non-Federal entity that has never received a negotiated indirect cost rate, except for those non-Federal entities described in Appendix VII to Part 200—States and Local Government and Indian Tribe Indirect Cost Proposals, paragraph D.1.b, may elect to charge a de minimis rate of 10% of modified total direct costs (MTDC) which may be used indefinitely. As described in §200.403 Factors affecting allowability of costs, costs must be consistently charged as either indirect or direct costs, but may not be double charged or inconsistently charged as both. If chosen, this methodology once elected must be used consistently for all Federal awards until such time as a non-Federal entity chooses to negotiate for a rate, which the non-Federal entity may apply to do at any time.

You must provide an explanation (below or in a separate attachment) and show how your indirect cost rate was applied to this budget in order to come up with the indirect costs show

Additional Explanation (as needed):See Barr_SupportingRateJustification.pdf for additional information, The full audit report can be provided upon request and execution of a Financial Disclosure Agreement

Cost Share

PLEASE READ!!!

1. A detailed presentation of the cash or cash value of all cost share proposed must be provided in the table below. All items in the chart below must be identified within the applicable cost category tabs a. through i. In addition to the detailed presentation of the cash or cash value of all cost share proposed provided in the table below, identify the source organization & amount of each cost share item proposed in the award.
2. Cash Cost Share - encompasses all contributions to the project made by the recipient, subrecipient, or third party (an entity that does not have a role in performing the scope of work) for costs incurred and paid for during the project. This includes when an organization pays for personnel, supplies, equipment, etc. for their own company with organizational resources. If the item or service is reimbursed for, it is cash cost share. All cost share items must be necessary to the performance of the project. Vendors may not provide cost share. Any partial donation of goods or services is considered a discount and is not allowable.
3. In Kind Cost Share - encompasses all contributions to the project made by the recipient, subrecipient, or third party (an entity that does not have a role in performing the scope of work) where a value of the contribution can be readily determined, verified and justified but where no actual cash is transacted in securing the good or service comprising the contribution. In Kind cost share items include volunteer personnel hours, the donation of space or use of equipment, etc. The cash value and calculations thereof for all In Kind cost share items must be justified and explained in the Cost Share Item section below. All cost share items must be necessary to the performance of the project. If questions exist, consult your DOE contact before filling out In Kind cost share in this section. Vendors may not provide cost share. Any partial donation of goods or services is considered a discount and is not allowable.
4. Funds from other Federal sources MAY NOT be counted as cost share. This prohibition includes FFRDC sub-recipients. Non-Federal sources include any source not originally derived from Federal funds. Cost sharing commitment letters from subrecipients and third parties must be provided with the original application.
5. Fee or profit, including foregone fee or profit, are not allowable as project costs (including cost share) under any resulting award. The project may only incur those costs that are allowable and allocable to the project (including cost share) as determined in accordance with the applicable cost principles prescribed in FAR Part 31 for For-Profit entities and 2 CFR Part 200 Subpart E - Cost Principles for all other non-federal entities.
6. NOTE: A Recipient who elects to employ the 10% de minimis indirect Cost rate cannot claim the resulting indirect costs as a Cost Share contribution.
7. NOTE: A Recipient cannot claim "unrecovered indirect costs" as a Cost Share contribution, without prior approval.
8. Each budget period is rounded to the nearest dollar!!!

Organization/Source	Type (Cash or In Kind)	Cost Share Item	Budget Period 1	Budget Period 2	Budget Period 3	Total Project Cost Share
ABC Company EXAMPLE!!!	Cash	Project partner ABC Company will provide 25 PV modules for product development at the cost of $500 per module	$12,500			$12,500
Minnkota Power Cooperative	In-Kind	750 Hours Strategy Meetings, Installation of ports during testing, Electrical Tie-in connections, Utility Tie-In, Prep Laydown Area, Engineering coordination during field test and sampling, Coal /Ash analysis, Calibration and Tuning	$50,000	$150,000		$200,000
Ottertail Power Company	Cash		$25,000	$75,000		$100,000
North American Coal	Cash		$25,000	$75,000		$100,000
NDIC	Cash		$110,000	$290,000		$400,000
UND	Cash	586 hours of Department Director time plus benefits and indirect charges. $98,260 in graduate tuition remission.	$88,088	$110,324		$198,412
						$0
						$0
						$0
						$0
						$0
		Totals	$298,088	$700,324	$0	$998,412

Total Project Cost: $4,986,410

Cost Share Percent of Award: 20.00%

Additional Explanation (as needed):

Applicant Name: 0 Award Number: 0

Budget Information - Non Construction Programs

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1. Budget Period 1				$1,125,228.00	$299,088.00	$1,424,316.00
2. Budget Period 2				$2,871,770.00	$700,324.00	$3,572,094.00
3. Budget Period 3				$0.00	$0.00	$0.00
4.						
5. Totals				$3,996,998.00	$999,412.00	$4,996,410.00

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity: Budget Period 1	Budget Period 2	Budget Period 3		Total (5)
a. Personnel	$185,845.00	$354,211.00	$0.00		$540,056.00
b. Fringe Benefits	$85,972.00	$163,058.00	$0.00		$249,030.00
c. Travel	$21,600.00	$61,800.00	$0.00		$83,400.00
d. Equipment	$0.00	$96,000.00	$0.00		$96,000.00
e. Supplies	$0.00	$972,600.00	$0.00		$972,600.00
f. Contractual	$866,609.00	$1,420,002.00	$0.00		$2,286,611.00
g. Construction	$0.00	$0.00	$0.00		$0.00
h. Other	$0.00	$0.00	$0.00		$0.00
i. Total Direct Charges (sum of 6a-6h)	$1,160,026.00	$3,068,371.00	$0.00		$4,228,397.00
j. Indirect Charges	$264,290.00	$503,723.00	$0.00		$768,013.00
k. Totals (sum of 6i-6j)	$1,424,316.00	$3,572,094.00	$0.00		$4,996,410.00
7. Program Income					$0

Previous Edition Usable

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

Applicant Name: 0 Award Number: 0

Budget Information - Non Construction Programs

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1. Budget Period 1				$1,125,228.00	$299,088.00	$1,424,316.00
2. Budget Period 2				$2,871,770.00	$700,324.00	$3,572,094.00
3. Budget Period 3				$0.00	$0.00	$0.00
4.						
5. Totals				$3,996,998.00	$999,412.00	$4,996,410.00

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity: Budget Period 1	Budget Period 2	Budget Period 3		Total (5)
a. Personnel	$185,845.00	$354,211.00	$0.00		$540,056.00
b. Fringe Benefits	$85,972.00	$163,858.00	$0.00		$249,830.00
c. Travel	$21,600.00	$61,800.00	$0.00		$83,400.00
d. Equipment	$0.00	$96,000.00	$0.00		$96,000.00
e. Supplies	$0.00	$972,500.00	$0.00		$972,500.00
f. Contractual	$866,609.00	$1,420,002.00	$0.00		$2,286,611.00
g. Construction	$0.00	$0.00	$0.00		$0.00
h. Other	$0.00	$0.00	$0.00		$0.00
i. Total Direct Charges (sum of 6a-6h)	$1,160,026.00	$3,068,371.00	$0.00		$4,228,397.00
j. Indirect Charges	$264,290.00	$503,723.00	$0.00		$768,013.00
k. Totals (sum of 6i-6j)	$1,424,316.00	$3,572,094.00	$0.00		$4,996,410.00
7. Program Income					$0

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

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Appendix B

Letters of Support and Cost Share Contributions

Minnkota Power COOPERATIVE
A Touchstone Energy® Cooperative

5301 32nd Avenue South
Grand Forks, ND 58201

Phone 701.795.4000
www.minnkota.com

Mr. John Lee, PE
President and CEO
Barr Engineering Co.
4300 MarketPointe Drive
Minneapolis, MN 55435

Re: Letter of Commercial Support of the proposal entitled "**Mitigation of Alkali Promoted Ash Deposition and Emissions from Coal Combustion**" submitted in response to DE-FOA-0001989 "IMPROVING EFFICIENCY, RELIABILITY, AND FLEXIBILITY OF EXISTING COAL BASED POWER PLANTS"

Dear Mr. Lee:

Minnkota Power Cooperative, Inc. (Minnkota) is pleased to support the proposal from the Barr Engineering Team that includes Envergex, LLC, Microbeam Technologies Inc., University of North Dakota, and MLJ Consulting to develop a transformational technology that controls the formation of alkali aerosols. Controlling and reducing the formation of the alkali vapors in the boiler has the potential to improve plant performance by decreasing slagging and fouling as well as fine particle emissions, but also can provide a step-change reduction in energy penalties.

Minnkota is a not-for-profit electric generation and transmission cooperative headquartered in Grand Forks, ND. Formed in 1940, Minnkota provides wholesale electric energy to 11 member-owner distribution cooperatives located in eastern ND and northwester MN. The primary source of electric generation for the Minnkota member-owners is the Milton R. Young Station (MRYS), a two-unit, lignite coal-fired power plant located near the town of Center, ND. Technologies that manage and reduce the formation of alkali-based liquid phases and fine particles would be transformational for the MRYS, both from an ash deposition standpoint and from a back-end pollution control standpoint. Management of alkali promoted ash deposits and fine particulate will improve operational efficiency and reliability.

In the proposed project, the team's novel concept targets a reduction in the formation of the offending ash deposit bonding materials and fine particulate. The concept involves delivery of specific materials (low-cost sorbents) into the boiler, targeted material preparation (to minimize sorbent quantities), and unique methods of use (to maximize reactivity and alkali vapor capture) to effectively capture vaporized alkali in the boiler. In this approach, the sorbent concentrates the alkali vapor into larger particles minimizing their availability for ash deposit formation and also allowing for effective removal of the larger particles by existing particulate control equipment, such as electrostatic precipitators.

This technology is of specific interest since it not only reduces fouling during operation of a combustion system similar to MRYS, but also can lead to a proactive technology that reduces fine particulate. Minnkota is pleased to provide a total in-kind cost share estimated at $200,000 subject to project award by US Department of Energy and final review. As part of the in-kind cost, we are proposing MRY Unit 1 as a host site for testing of the sorbent injection. Some of the major tasks associated with the in-kind cost share include review and guidance on design, pre-test data gathering to establish a baseline, tie-in support for the on-site testing, and support during testing. Upon successful testing, an economic analysis of a full scale system will drive consideration for future application.

We look forward to working with your team on this project. If you have questions or require additional information, please contact me at 701-794-7234, or at gpfau@minnkota.com.

Sincerely,

Gerry Pfau
Sr. Manager of Project Development

Cc: Dan Laudal
Craig Bleth
Stacey Dahl
Tim Hagerott
Andy Freidt
Dylan Wolf

Coyote Station
6240 13th Street Southwest
PO Box 339
Beulah, North Dakota 58523-0339
701-873-2571
www.otpco.com

Mr. John Lee, PE
President and CEO
Barr Engineering Co.
4300 MarketPointe Drive
Minneapolis, MN 55435

Re: Commercialization Letter of Support of the proposal entitled "Mitigation of Aerosol Impacts on Ash Deposition and Emissions from Coal Combustion" submitted in response to DE-FOA-0001989 "IMPROVING EFFICIENCY, RELIABILITY, AND FLEXIBILITY OF EXISTING COAL BASED POWER PLANTSPLANTS"

Dear Mr. Lee:

As operating agent of Coyote Station[1] Otter Tail Power Company is pleased to support the proposal from the Barr Engineering Team that includes Envergex, LLC, Microbeam Technologies Inc., University of North Dakota, and MLJ Consulting to develop a transformational technology that controls the formation of alkali aerosols. Controlling and reducing the formation of the alkali vapors in the boiler has the potential to improve plant performance by decreasing slagging and fouling as well as fine particle emissions, but also can provide a step-change reduction in energy penalties.

Coyote Station is an approximate 427 megawatt lignite-fired electric generating unit, located near Beulah, North Dakota. The unit is equipped with separated overfire air for nitrogen oxides control, and a spray dryer followed by a fabric filter for sulfur dioxide and particulate emissions control. The Coyote Station owners are interested in this project not only for the potential benefits to reduce CO2 capture cost and energy penalties, but also controlling the formation of the aerosols has the potential to improve plant performance by decreasing boiler slagging and fouling.

In the proposed project, the team's novel concept targets a reduction in the formation of the offending ash deposit bonding materials and fine particulate. The concept involves delivery of specific materials (low-cost sorbents) into the boiler, targeted material preparation (to minimize sorbent quantities), and unique methods of use (to maximize reactivity and alkali vapor capture) to effectively capture vaporized alkali in the boiler. In our approach, the sorbent concentrates the alkali vapor into larger particles minimizing their availability for ash deposit formation and also allowing for effective removal of the larger particles by existing particulate control equipment, such as electrostatic precipitators.

[1] Coyote Station is jointly owned by Otter Tail Power Company, Montana-Dakota Utilities Co., NorthWestern Energy, and Northern Municipal Power Agency.

Coyote Station
6240 13th Street Southwest
PO Box 339
Beulah, North Dakota 58523-0339
701-873-2571
www.otpco.com

OTTER TAIL POWER COMPANY

Coyote Station is pleased to provide a total of $100,000 ($33,333 per year for three years) in cost-share for the project, subject to project award by US Department of Energy and final review. Upon successful testing, we plan to consider using the technology in full scale operation in the future.

If you have questions and require additional information, please contact me at (701) 873- 2571.

Sincerely,

Brad Zimmerman
Coyote Station Plant Manager
Otter Tail Power Company

Carroll
[illegible]
[illegible]
Vice President – Operations
[illegible]

[illegible]
[illegible]

February 19, 2019

Mr. John Lee, PE
President and CEO
Barr Engineering Co.
4300 MarketPointe Drive
Minneapolis, MN 55435

Re: Letter of Commercial Support for the proposal entitled "Mitigation of Alkali Promoted Ash Deposition and Emissions from Coal Combustion" submitted in response to DE-FOA-0001989 "IMPROVING EFFICIENCY, RELIABILITY, AND FLEXIBILITY OF EXISTING COAL BASED POWER PLANTS"

Dear Mr. Lee:

The North American Coal Corporation (NACoal) is pleased to support the proposal from the Barr Engineering Team that includes Envergex, LLC, Microbeam Technologies Inc., University of North Dakota, and MLJ Consulting to develop a transformational technology that controls the formation of alkali aerosols. Controlling and reducing the formation of the alkali vapors in the boiler has the potential to improve plant performance by decreasing slagging and fouling as well as fine particle emissions, but also can provide a step-change reduction in energy penalties.

In the proposed project, the team's novel concept targets a reduction in the formation of the offending ash deposit bonding materials and fine particulate. The concept involves delivery of specific materials (low-cost sorbents) into the boiler, targeted material preparation (to minimize sorbent quantities), and unique methods of use (to maximize reactivity and alkali vapor capture) to effectively capture vaporized alkali in the boiler. In our approach, the sorbent concentrates the alkali vapor into larger particles minimizing their availability for ash deposit formation and also allowing for effective removal of the larger particles by existing particulate control equipment, such as electrostatic precipitators.

This technology is of specific interest to NACoal since we currently have coal mining operations in North Dakota, Mississippi, New Mexico, Texas and Louisiana. Our North Dakota operations, where testing of this technology would be conducted, include Falkirk, Freedom, and Coyote Creek Mines with a total annual production of over 25 million tons annually.

NACoal is pleased to provide a total cost-share of up to $100,000, over the 3-year term of the project, subject to project award by US Department of Energy and final review. Upon successful testing, we plan to consider using the technology in full scale operation in the future.

If you have questions or require additional information, please do not hesitate to contact me.

Regards,

THE NORTH AMERICAN COAL CORPORATION

Carroll L. Dewing

Carroll L. Dewing
Vice President – Operations
5340 Legacy Drive, Building 1, Suite 300, Plano, Texas 75024-3141 • 972-239-2625 • Fax 972-387-1329 • www.nacoal.com

UNIVERSITY OF UND NORTH DAKOTA

INSTITUTE FOR ENERGY STUDIES
COLLEGE OF ENGINEERING AND MINES
COLLABORATIVE ENERGY COMPLEX ROOM 246
2844 CAMPUS ROAD – STOP 8153
GRAND FORKS, NORTH DAKOTA 58202-8153
PHONE (701) 777-3852 FAX (701) 777-4838

February 26, 2019

Nicole Ngyuen
Barr Engineering Co.
4300 MarketPointe Dr.
Minneapolis, MN 55435

RE: Support for proposal entitled "Mitigation of Alkali Impacts on Coal-Fired Boiler and Emissions Control System", submitted in response to the U.S. Department of Energy under Funding Opportunity Number DE-FOA-0001989

Dear Ms. Ngyuen

The University of North Dakota Institute for Energy Studies (IES) is pleased to provide this letter of commitment to Barr Engineering Co. for the subject-line proposal. We are excited to collaborate with Barr Engineering Co. in development of clay additives to help mitigate the impacts of alkali on coal-fired boiler performance. Our early work in this area has been highly successful, and we would like to extend the unique knowledge and capabilities gained from that project into new related applications. The UND team is capable of novel research and design at our state-of-the-art facilities, has strong relationships with Midwest power and oil industry, and has extensive experience with fossil generating systems. We believe that our progressive knowledge of the release of alkali and various techniques to render these alkalis harmless, combined with our experimental and modeling capabilities offers strong value to the project.

The scope of work planned for UND is summarized as follows.

Task 1 – Project Management and Planning. PI Junior Nasah will coordinate activities in order to effectively accomplish the work proposed by UND. He will ensure that project plans, results, and decisions are appropriately documented and project reporting and briefing requirements for UND's portion of the work are satisfied. UND will provide input to the Project Management Plan and Technology Maturation Plan as necessary throughout the project to accurately reflect the current status of the project and the technology maturation.

Task 2 – Laboratory Scale Testing. UND will be the lead on this task.
Subtask Task 2.1 – Feedstock selection, preparation and characterization: This task will involve the following: 1) Procuring the test coals; 2) identifying and procuring up to five different sorbent materials, 3) Characterizing the coals for proximate, ultimate and ash mineral analyses, 4) characterizing the sorbent materials to determine composition, size and morphology, and 5) preparation of the sorbent materials for testing.

Methodology– The target market for the proposed technology is power generation facilities firing high alkali content solid fuels, specifically low rank coals such as lignite and sub-bituminous; and co-firing of biomass. A high sodium coal will be obtained from the field test facility. The solid fuels will be characterized for their proximate, ultimate and chemical composition (sodium and potassium compounds) and then pulverized to the target particle size. The sorbent materials will be procured, crushed and pulverized to the desired particle size distribution. The sorbent materials will consist of commercially available materials and low-cost affordable alternatives. The low cost sorbents are not commercially available, so commercial sorbents will be used as a sorbent performance benchmark. A screening and benchmarking tool for predicting sorbent performance will be developed by comparing morphological (porosity and surface area) and mineral properties of the commercial and low-cost sorbents.

Subtask 2.2: Coal Testing and Analysis: Detailed testing of the fuels will be performed with the sorbents. Prior to testing, modifications of UND's 10 kW down-fired combustor (DFC) to include independent sorbent injection and post combustion temperature flexibility will be performed. The testing to be performed will include baseline pulverized coal combustion operation with measurements of detailed ash particle size distribution and ash composition versus size, specifically vaporizable alkali (Na, K) components. The different sorbent materials will be evaluated for their effectiveness as sorbents for the vapor phase alkali components and for their ability to capture the alkali. From these tests, specific compositions/materials will be down-selected for pilot testing and for performance attributes (loading, particle size) that determine effectiveness.

Methodology – A summary of the test procedure is outlined below:

- Furnace upgrades through addition of an extended combustion zone, automated data acquisition, replacement of refractory walls and an independent sorbent injection system. The extended combustion zone will provide temperature flexibility to better simulate relevant temperature profiles expected in a full scale facility as result of modifications such as combustion staging and low load operation. The sorbent injection system allows for flexible additive addition during runs.
- Baseline pulverized coal combustion testing to determine fate of alkali during combustion in the DFC. In the absence of heat exchange surfaces in the bench scale unit, de-volatilized alkali are expected to condense out as ultra-fine and fine aerosol particulates. Particulate sampling at the exit of the combustor will be conducted with a pre-separator cyclone in series with a Dekati® Low Pressure Impactor (DLPI) – a state-of-the-art 13-stage cascade impactor for measuring gravimetric particle size distribution of very small particles. The cyclone removes a majority of particles larger than 10 micron from the sample gas stream. This allows a sufficient quantity of smaller particles to be collected in the DLPI impactor and minimizes any bounce-off of larger particles which skews the data. The cyclone-DLPI combination size-classifies particles from 10 microns (μm) to 30 nm, and a bulk filter stage enables collection of particles smaller than 30 nm in diameter.
- Fuel-Sorbent testing at one loading rate. During combustion, the sorbent acts a reactive species for "neutralizing" the alkali vapors and segregating them to easy-to-capture particle sizes. The sorbent will be co-fed to the DFC along with each solid fuel/coal at a fixed loading. Previous technology development showed a sorbent-coal loading of 2% providing acceptable performance. This screening step will establish the benchmark parameters for each sorbent. This data will be used in the TEA to evaluate commercial viability of the technology as a function of fuel (lignite, sub-bituminous and biomass) market. A total of 15 tests are planned.
- Extended testing of pilot coal with optimal sorbent. This testing will focus on generating key data for the pilot test campaign. Most viable and commercially available sorbent identified in the previous

step will be subjected to additional parametric testing with a focus on sorbent loading and particle size. A correlation between both factors will be developed to facilitate design and procurement of the pilot-scale test system and sorbent materials. The actual target size of the sorbent as delivered into the boiler system depends on the effectiveness of the pilot scale system, by establishing a performance correlation of particle size and sorbent loading, it will be possible to estimate the amount of sorbent needed for pilot testing once the capability of the test system is confirmed. Three levels of each factor (low medium and high) will be tested for a total of nine runs.

- Analysis of ash samples. Samples collected during testing in the previous steps will be analyzed to determine the fate of sodium, the final chemical nature of the sodium and the quality of the ash generated. Analysis will seek to confirm that the sodium is reporting to ash size fractions that will not contribute towards fouling and verify how the final ash quality is affected. Samples collected on the DLPI stages will be subjected to elemental analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for quantitative data on fate of elements.

Task 3 – Sorbent Injection Modelling - CFD: Modelling using Computational Fluid Dynamics (CFD) will be performed to understand distribution of sorbent in the flue gas stream and identify optimum injection locations. Fluent™ software available at UND will used for modelling. Process conditions (temperatures, gas volumes/flowrates) and design specifications will be obtained from the demonstration facility for this task. Different injection locations will be tested using tracer distribution and mixing models. Investigations will focus on identifying:

- Injection conditions and location to obtain optimal penetration and distribution in the boiler system. Effectiveness of sorbent is dependent on optimal distribution within boiler.
- Boiler temperature profile versus extent of sorbent distribution. Distribution of sorbent needs to occur in boiler location with temperatures at which sorbent performance is maximized.

Task 4 – Equipment Design and Sizing for Field Demonstration: Based on the results of Task 2, scale-up considerations for sorbent preparation, loading and injection will be evaluated for the field demonstration. Additional factors also evaluated will be impact to existing coal-feed systems and down-stream particulate controls systems. This task will require close communication with demonstration facility, equipment suppliers and recipient. UND will provide assistance to Barr Engineering in developing a general process flow diagram and material and energy balances, providing input into the detailed design of injection equipment and the sensitivity analysis, and help finalize technical design with optimized parameters from demonstration site.

Task 5 – Procurement, Installation and Construction: The UND team will provide consultation to Barr Engineering in Task 5 using the experience gained during the bench-testing and the CFD modeling to help with selection of equipment and incorporating the equipment into the Milton R. Young plant.

Task 6 – Parametric Testing – Field Demonstration: This task will consist of the actual sorbent injection test campaign and will focus on evaluating key parameters – effect of grind, effect of feed as a function of load, plant loading (boiler temperature in system), effect of combustion staging and the effect of alkali levels in coal. UND will provide manpower and equipment in support of the sampling team and injection team. Power plant data will be collected real time during testing and injection will be adjusted accordingly to match load. Key data collected form plant during injection will consist of coal feed rate/boiler heat input, plant load (sub-divided into three categories of low, mid and high), inlet/outlet temperature of the heat exchange surfaces (convective pass, economizer, air preheater) where available, steam production rate, inlet/outlet temperature of particulate control devices, soot blowing activity, secondary current and voltage of the ESP to determine any impacts on performance due to ash loading variations. UND has experience in sampling coal, DLPI, Method 5 and opacity measurement including past sampling work at the Milton R. Young Power Plant.

Task 7 – Data Reduction and Evaluation of Parametric Testing: Upon completion of Task 6, the data collected will be reviewed and a complete description of the fate of alkali during the test campaign will be determined along with the impact on fouling mitigation. The UND team will assist in performing the mass balance of the alkali based on analyses of coal samples, slag and ash. This balance will be correlated with plant operating conditions to identify trends. The team will also assist in the development of an updated testing program.

Task 8 – Extended Sorbent Testing: This task will consist of an extended sorbent injection test campaign after identifying optimum parameters from Task 5 and 6. During this test campaign, injection will be varied to match plant load. The UND team will provide similar support as proposed in Task 6 to support the extended testing.

Task 9 – Data Reduction and Techno-Economic Assessment: Upon reduction of the data from the extended injection testing, UND will assist BARR in finalizing the Techno-Economic Assessment (TEA) and Technology Maturation Plan (TMP).

We are very excited to continue our collaborations with Barr and look forward to a successful proposal outcome. The proposed budget for UND for this 3-year project is $790,000 as summarized in our attached budget documents. UND will be providing $199,412 in cost share and is requesting the remaining $590,588 from Department of Energy funds. If there are any questions, please do not hesitate to contact us at the letterhead address, or at the contact information of Mr. Junior Nasah, who will be the PI for UND's scope of work on this project – junior.nasah@und.edu, 701-777-4307.

Sincerely,

Michael P. Mann

Dr. Michael Mann
Executive Director
Institute for Energy Studies
University of North Dakota
michael.mann@und.edu

Jamie Mitzel
Grants and Contracts Officer
Division of Research and Economic Development
University of North Dakota
jamie.mitzel@und.edu

INDUSTRIAL COMMISSION OF NORTH DAKOTA

LIGNITE RESEARCH, DEVELOPMENT AND MARKETING PROGRAM

Governor,
Doug Burgum
Attorney General,
Wayne Stenehjem
Agriculture Commissioner,
Doug Goehring

February 21, 2019

Mr. John Lee, PE
President and CEO
Barr Engineering Co.
4300 Market Pointe Drive
Minneapolis, MN 55435

Re: Support of the proposal entitled "Mitigation of Aerosol Impacts on Ash Deposition and Emissions from Coal Combustion" submitted in response to DE-FOA-0001989 "IMPROVING EFFICIENCY, RELIABILITY, AND FLEXIBILITY OF EXISTING COAL BASED POWER PLANTS"

Dear Mr. Lee:

The Lignite Research Council (LRC) is pleased to support the proposal from the Barr Engineering Team that includes Envergex, LLC, Microbeam Technologies Inc., University of North Dakota, and MLJ Consulting to develop a transformational technology that controls the formation of alkali aerosols. Controlling the formation of the aerosols has the potential to improve plant performance by decreasing slagging and fouling as well as fine particle emissions but also can provide a step-change reduction in energy penalties.

We are highly encouraged by the preliminary work performed by Envergex and the UND team under their previously funded STTR grant. The results of their early work demonstrate potential to mitigate a number of problems associated with the formation of aerosols. The proposed solution appears to be one that can be effectively integrated into the fleet of lignite generating systems in our state. As such, this project is a good fit with the mission of the Lignite Research Council. Your proposed project serves the needs of our members which includes mining companies and major users of lignite to generate electricity, synthetic natural gas, and other byproducts.

We are pleased to see the support this project has received from industry in the State including North American Coal Corporation, Minnkota Power Cooperative, and Otter Tail Power Company. As a part of this project, the NDIC will provide $400,000 in cash cost share to match that provided by your industry partners. The cost share will be provided over the 3-year project duration and is subject to a project award by the US Department of Energy. The cash support will be contingent upon submission of a proposal to the North Dakota Lignite Research Program and subsequent approval by the Lignite Research Council and the North Dakota Industrial Commission. It is understood that this lignite research program funding will provide cost share to federal funding from the U.S. Department of Energy (DOE); therefore, LRC certifies that its cost-share funding will comprise nonfederal dollars and will not be used as federal match on any other project.

We hope that DOE gives careful consideration to this project as we feel that if successful, it will significantly contribute to the development and deployment of a viable method for mitigating the impacts of aerosols emissions. Again, we express our interest in and support of the project and look forward to working with DOE and project co-sponsors and advisors on the this important project.

Sincerely,

Mike Holmes
Director & Technical Advisor
Lignite Research Development and Marketing Program

Appendix C

Resumes of Key Personnel

Richard Hardegger
Vice President, Sr. Environmental Engineer
Barr Engineering Co.

Education and Training

- South Dakota School of Mines & Technology, Chemical Engineering, B.S., 1991

Research and Professional Experience

- Prepared a Prevention of Significant Deterioration (PSD) air permit application for a 99 MW lignite-fired combined-heat-and-power facility that provides process steam to ethanol and malting plants. The project uses a circulating fluidized-bed boiler with spray-dry and baghouse control of acid gases and particulates and selective non-catalytic reduction (SNCR) for NOx control. Three gas- or oil-fired auxiliary boilers provide backup and peaking capacity.
- Prepared environmental approvals for the installation of a 170 MW gas- and oil-fired peaking turbine at an existing RDF-fired power plant. Key regulatory hurdles involved cumulative impacts from air emissions deposition on area lakes and subsequent human-health risks. Work included conducting a study focused on metal and persistent organic-compound emissions from the existing RDF boilers; the study showed that emissions occurred at less than background levels.
- Managed an engineering cost-estimate development for a demonstration-scale solid sorbent-based carbon-capture process for a coal-fired boiler system.
- Managed the preparation of a PSD air permit application for a 1.2 million-ton-per-year integrated steel-making operation. Air emission sources included mining, taconite pellet production, direct reduced iron, electric arc furnaces, and rolling mill. Close proximity of the plant and mining operations to residential properties and to Class I protected areas presented significant challenges to dispersion modeling and health-risk assessment analyses.
- Managed emission-source testing projects for utility, mining, and manufacturing sources. EPA test methods used for criteria and hazardous-air-pollutant (HAP) sampling and analysis.
- Prepared a PSD permit application for a six-unit, gas-fired simple-cycle power plant in southern Minnesota. Key efforts centered on the BACT determination for NOx control.
- Managed EIS preparation for a 1.2 million-ton-per-year integrated steelmaking project that included all aspects from mining iron ore to finished steel. Key issues addressed included air emission impacts on Class I areas of northern Minnesota, ultimate water discharge impacts to the Mississippi River, and modeled impacts on human health and ecology.
- Coordinating preparation of an EAW for a 6 MW anaerobic-digestion-based power project. The project is defined as a fuel conversion facility, which is a mandatory EAW category in Minnesota. The project will be primarily challenged by wastewater discharge limitations, whether as a direct discharge or via the POTW. Potential odor emissions and the impacts of significant new truck traffic are also addressed by the EAW.
- Oversaw ambient air monitoring project in the Alberta oil sands to support identification of odour sources; oversaw annual fugitive greenhouse gas emissions monitoring projects at oil sands and coal mining sites.

- Participated in an air-pathway analysis for air toxics at a used-oil re-refinery site. To obtain air emissions data, the analysis employed flux-chamber testing of HAPs from source material through various stages of a pretreatment system. This information was essential to completion of a risk assessment for material-handling activities related to site remediation.

Synergistic Activities

- Regulatory permitting (air emissions) for coal fired power plants in Minnesota and North Dakota.
- Emissions control options evaluation (BACT reviews) for coal-, gas- and biomass-fired utility units.
- Stack testing projects for combustion emissions from commercial/industrial- and utility-scale units, multiple solid, liquid and gaseous fuels.
- Ambient air monitoring projects in support of compliance for industrial and utility sites.

Nicole Nguyen, PMP, PE
Project Manager, Chemical Engineer
Barr Engineering Co.

Education and Training

- BS, Chemical Engineering, University of Toledo, 2005
- PMP Certification, February 2019

Research and Professional Experience

- *2012-Present: Chemical Engineer, Barr Engineering Co.*

  Work with clients in the power, energy, mining, and fuels industries, serving as a project manager and lead process-design engineer. Tasks include developing detailed cost estimates and performing budgetary feasibility studies, detailed design and procurement for plant betterment work, construction and commissioning support, risk assessments and contract and subcontract management. Relevant project experience includes:

  - Managing boiler house installation project that included procurement of two 1200 horsepower steam boilers and detailed design of a new boiler house.
  - Managing a dry-transfer-system study and detailed design project for a confidential power producer in North Dakota with engineering fees totaling $1 million.
  - Managing preliminary design and budgetary cost estimates for new natural-gas engine systems integrated with coal and gas power plants.
  - Leading multiple cost evaluation studies for bottom-ash and gypsum dewatering that were driven by coal combustion residuals (CCR) regulations and effluent limitations guidelines (ELG).
  - Evaluating environmental control systems and preparing cost estimates for a several power plants, manufacturing, and pharmaceutical facilities.
  - Reviewing process design, managing procurement of plant valves and instrumentation, and authoring functional descriptions of major systems for an anaerobic-digestion power plant in Minnesota.
  - Leading P&ID design and instrumentation and control development for a new activated-carbon production facility.

- *2006-2011: Environmental Process Engineer, Babcock and Wilcox Company*

  Served as lead process wet FGD engineer and single-point-of-contact discipline lead for the $500 million AQCS installation of five units in the eastern U.S. Performed startup, commissioning, and testing as a field process engineer for a 3,400 MW wet FGD system installation project in Michigan. Served as resident engineer onsite at power plant for over 1 year. Performed guarantee testing for multiple wet FGD systems along the eastern U.S.

- *2005-2006: Process Engineer, SSOE Group*

  Served as a process design engineer for a privately owned, ISO 9001–certified, international engineering, procurement, construction, and maintenance (EPCM) firm based in Ohio for part of a year. Responsibilities included working on contracts with solar-panel manufacturing facilities and refineries.

Synergistic Activities

- Provided onsite engineering and oversight for a DSI injection onsite test, which included a one week test, rental testing trailers with onsite milling, and stack and lab testing in 2016.
- Worked with federally funded support teams to conduct a process review and create budgetary cost estimates for rare-earth element extraction system and carbon capture system (CACHYS) 2012-2018.

Bruce Browers
Senior Consultant
Barr Engineering Co.

Education and Training

- Michigan Technological University, Bachelor of Science, Mechanical Engineering, 1972
- University of Minnesota—Duluth, Masters of Business Administration, 1989

Research and Professional Experience

- *2008-Present: Senior Consultant, Barr Engineering Co.* Project/Engineering Manager for complex, large, high-profile capital projects. Project work has entailed:
  - Serving as engineering manager for the Great River Energy coal-drying project; coordinated multiple engineering disciplines, provided project schedules, and developed several construction specifications.
  - Serving as lead mechanical engineer for a new combustion-air-preheating system; developed design criteria for the process along with component specifications.
  - Developing a suite of technology options for compliance with new regulations along with capital and operating conceptual cost estimates for an environmental screening study at a coal-fired power plant.
  - Developing conceptual site arrangements, component specifications, heat/material balances, and conceptual cost estimates for capital and O&M for a carbon-capture-technology study.
  - Developing site arrangement, equipment general arrangements, process flow diagrams, electrical single-line drawings, foundations, and new structures for a biomass fuel-handling retrofit project.
- *2003-2008: President, Browers Consulting LLC.* As a management consultant, performed technical and financial analysis for capital project domestically and internationally, including:
  - Developing market analysis, capital cost, operating cost, business pro-forma cases for a trade development association (TDA) desk study for refined oil products pipeline in Rwanda.
  - Reviewing conceptual designs; developing estimates for capital cost and operating cost; and developing business pro-forma cases for two hydroelectric projects for a TDA definitional mission study in Rwanda.
  - Performing fuel assessment studies, developing preliminary plant design concepts, advising on preliminary PPA terms, and acting as owner's engineer for merchant power development in Uganda. This work for a confidential client was an investigation into the creation of a privately owned power development in a country with government-owned utilities.
  - Reviewing several natural gas, hydro, coal, and renewable projects for potential TDA definitional mission funding in Tanzania. Project work resulted in a grant from the U.S. federal government to underfunded Tanzanian government agencies for the hiring of an American-trained regulator.
  - Reviewing generation technologies that provide estimates of capital cost, operating cost, fuel cost, and total busbar cost.
  - Reviewing technologies that provide estimates of capital cost, operating cost, and total yearly cost of pollution control.

- Conducting technical and feasibility studies for biomass-fueled power plants.
- Serving as an internal owner's engineer, providing technical analysis for site selection, water supply, site arrangement, engineering design criteria, and permitting for a two-phase 1200 MW IGCC project. Also provided steam profile, boiler/turbine size, capital cost, operating cost, total production cost for steam/electricity for a 25 MWe, 150 MWt CHP facility.

- *1977-2003: Department Manager/Senior Engineer, Minnesota Power*. Analyzed plant operations and executed capital projects for the Power Generation Division. Work included:
  - Project managing the acquisition and boiler expansion of a CHP project at a large paper mill. Led the engineering portions of due-diligence efforts related to the purchase of the assets, developed the costs structure for the pro-forma business case; led conceptual development, engineering, permitting, construction, and installation of two gas-fired packaged boilers.
  - Leading a multi-team effort to develop a 250 MW, fluidized bed-coal/biofuel CHP facility to provide steam to a major paper mill and merchant power to wholesale markets. Supervised the work of Pohjolan Voima Oy Engineering and Electrowatt Ekono in Helsinki, Finland and led detail design and permitting efforts.
  - Leading the development of a 175 MW natural-gas-fired peaking facility. As project manager, Bruce negotiated the combustion turbine contract, evaluated and awarded engineering, equipment, and construction contracts. He successfully acquired all permits and land.
- *1972-1977: Power Station Engineer, Dairyland Power Cooperative*. Analyzed plant operations and designed capital projects for the power plant. Developed test procedures for all major equipment, conducted routing equipment tests and recommended changes to operation.

Publications

- "Using Emissions Trading to Optimize Environmental Compliance Costs," EnergyPulse, 2004
- "Four Events Shape IGCC," EnergyPulse, 2004

Synergistic Activities

- Conducted techno/economic analysis for an innovative carbon capture process, including developing integrated power plant heat balances and cost of electricity calculations
- Served as owner's engineer for an integrated coal-gasification combined-cycle power plant.
- Served as engineering manager for the detail engineering of Great River Energy's innovative DryFining process at the Coal Creek Station.
- Conducted techno/economic analyses for energy projects in several east African countries.

Chad Haugen
Senior Process Engineer
Barr Engineering Co.

Education and Training

- University of North Dakota, Chemical Engineering, Bachelor of Science, 2008

Research and Professional Experience

- *2012 to present: Senior Process Engineer, Barr Engineering Co.* Project manager and process design engineer for rare earth leaching from lignite coal and geothermal brines, water/wastewater treatment design for refineries, municipalities, and manufacturing. Conducted system alternatives review for mercury removal from iron pellet furnace exhaust, including reviews of removal using activated carbon and halide injection.
- *2008–2012: Production Engineer, ADM Corn Processing.* Process engineering involving managing and completing projects to improve safety and efficiency for processing corn into different products such as ethanol and corn syrup.
- *Summer, 2007: Engineer Intern, ADM Soybean Processing, Decatur, IL.* Engineering intern working on process improvement projects and safety evaluations.

Synergistic Activities

- Completed energy assessments under the U.S. EPA's boiler maximum achievable control technology (MACT) rule for facilities in the power, refining, and manufacturing industries.
- Developed cost improvement project recommendations to increase efficiency for boilers and process heaters in an effort to reduce greenhouse gas emissions.

Michael D. Mann, PhD
Executive Director, Institute for Energy Studies
Chester Fritz Distinguished Professor, Department of Chemical Engineering
University of North Dakota

Education and Training

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

Research and Professional Experience

2014 –Present: Executive Director, Institute for Energy Studies. Help realize the Institute's goal of developing UND into a premier "Energy University" that "inspires the creation of new knowledge to enable the development of revolutionary energy technologies, train the next generation of energy experts, and establish advanced industries required to make affordable emissions free energy technologies a reality." Responsibilities include identifying key technical and economic barriers to the development of secure, affordable, and reliable energy production technologies; identifying proposal opportunities and develops new relationships with potential partners; and drawing from resources across campus building teams to deliver the research, education, and outreach required to meet the needs of public and private partners.

2009-14: College of Engineering (Associate Dean 2013-14; Associate Dean for Research 2009-13). Provide advice and support to the Dean in issues related research and development within the college and support academic affairs. Responsible for the implementing the college's major research goals, promoting a culture of research in the college, enhancing research opportunities for faculty and students, and providing administrative oversight for proposal submittal and grant accounting.

2008: Interim Dean, UND School of Engineering and Mines. Responsible for all academic and research activities within SEM. In this role he expanded his leadership experience and broadened his overview of the campus wide talents and opportunities for enhancing UND's reputation as a leader in energy research and education.

1999 – Present: UND Department of Chemical Engineering (Professor, 2006-present; Chair 2005-13; Associate Professor, 1999-2006). Developed a reputation as an engaging teacher, excellent researcher, and inspirational leader. Awarded UND's highest honor, the Chester Fritz Distinguished Professorship in 2009 in recognition for his accomplishments in research, teaching, and service. Led the Department to UND's top departmental awards for Excellence in Research in 2005 and 2011 and Excellence in Teaching in 2007. Co-founder of the SUstainable eNergy Research, Infrastructure, and Supporting Education (SUNRISE) group in 2004. SUNRISE now has over 30 faculty participants from 12 different departments and 4 North Dakota Universities with over $20 million in research grants.

1981-99: UND Energy & Environmental Research Center (Sr. Research Mgr, Advanced Processes and Technologies 1994-99; Research Mgr. Combustion Systems 1985-94; Research Engineer 1981-85). Activities evolved from hands on research to the development and marketing of ideas and technology. Involved in a wide range of technology development, including energy production from combustion and gasification, wind, and geothermal resources. Highlights include management of over $15 million in research projects; design, installation, and operation of a 1 MW_{th} CFBC; design, installation, and operation of a 250 lb/hr gasifier; development of small power systems for Alaskan villages; and the development of a small-modular fluid-bed combustion system (0.5 to 5 MW)

Relevant Publications (selected from over 150)

- Michael Mann, Daniel Laudal, and Steve Benson, "Maintaining Coal's Prominence in a Carbon Constrained World", Keynote presentation; 2017 International Conference of Coal Science & Technology, Sept 2017.
- Johannes van der Watt, Daniel Laudal, Gautham Krishnamoorthy, Harry Feilen, Junior Nasah, Michael Mann, Ryder Shalbetter, Teagan Nelson, and Srivats Srinivasachar, "Development of a Spouted Bed Reactor for Chemical Looping Combustion", Journal of Energy Resources Technology, 2018.
- Daniel Laudal, Brittany Rew, Steve Benson and Michael Mann, "Technical and Economic Feasibility Analysis of Integrating Activated Carbon with Heating Plant", 2017 International Pittsburgh Coal Conference, Sept 2017
- Mann, M.D.; Knutson, R.Z.; Erjavec, J.; Jacobson, J.P.; "Modeling Reaction Kinetics for a Transport Gasifier", *Fuel* 83 2004 1643-1650.
- Fix, G; Seames, W.; Sisk, D.; Miller, D.; Benson, S.; Mann, M.; "Studies of Coal-Ash Fine Fragmentation Mode Formation Mechanisms During Combustion"; Fuel Processing and Technology, 2010
- Chenguri Ou, Mo Zhang, and Michael Mann, "Effect of Combustion Temperature on the Emission of Trace Elements under O_2/CO_2 Atmosphere during Coal Combustion", IOP Conference Series Earth and Environmental Science, 2018.
- U.S. Patent Number 6,053,954. Methods to Enhance the Properties of Hydrothermally Treated Fuels, 2000
- Karki, S., Mann, M.; Salehfar, H.; "Substitution and Price Effects of Carbon Tax on CO_2 Emission Reduction from Distributed Energy Sources", *Asian Journal of Energy & Environment"*
- Bandyopahdyay, G., Bagheri, F.M.; Mann, M.D.; "Reduction of Fossil Fuel Emission in US: A Holistic Approach Towards Policy Formulation", *Energy Policy*; 2007, 35 (2) 950-65.
- Sondreal, E.A.; Benson, S.A.; Hurley, J.P.; Mann, M.D.; Pavlish, J.H.; Swanson, M.L.; Weber, G.F.; Zygarlicke, C.J. "Review of Advances in Combustion Technology and Biomass Firing". *Fuel Processing Technology* 2001, 71 (1-3), 7-38.
- Zhao, Y., Mann, M.D, Pavlish, J.P., Mibeck, B.A.F.; Dunham, G.E.; Olson, E.W.; "Application of Gold Catalyst for Mercury Oxidation by Chlorine", *Environmental Science and Technology*; 2006 40: 1603.
- Karki, S; Kulkarni, M.; Mann, M.D.; Salehfar, H.; "Efficiency Improvements through Combined Heat and Power for On-Site Distributed Generation Technologies", *Cogeneration and Distributed Generation Journal*, Vol 22, No 3, 2007, pp 19-34.
- Feng Xiao, Alemayehu Bedane, Julia Zhao, Michael Mann, and Joseph Pignatello, "Thermal Air Oxidation Changes Surface and Adsorptive Properties of Black Carbon (Char/Biochar)", Science of the Total Environment, 2018.

Synergistic Activities

Dr. Mann's principal areas of expertise include multidisciplinary and integrated energy and environmental projects emphasizing a cradle-to-grave approach; development of energy strategies coupling thermodynamics with political, social, and economic factors; selection of optimum utilization processes emphasizing renewable energy and clean coal technologies; and integration of effluent treatment and emission controls.

Major active projects include "Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-ion Battery," "Investigation of Rare Earth Element Extraction from North Dakota Coal Related Feedstocks," and "Supercritical Treatment Technology for Water Purification."

Junior Nasah
Major Projects Manager
University of North Dakota

Education and Training

- University of Buea, Cameron, Chemistry, B.Sc., 2007
- University of North Dakota, Chemical Engineering, M.Sc, 2012
- University of North Dakota, Chemical Engineering, Ph.D., 2020 (Ongoing)

Research and Professional Experience

- *2019-Present: Major Projects Manager, UND Institute for Energy Studies.*

  Primary roles include developing and writing major funding proposals, managing major research projects, coordinating IES research staff and students, and process design/development of innovative solutions to challenges in the energy industry. Primary research areas include aerosol formation, measurement and mitigation, chemical looping combustion, fluidized bed operation and air pollution from fossil fuel combustion.

- *2012-2018: Research Engineer, UND Institute for Energy Studies.*

  Primary role involved developing and managing research projects specifically in pollution control from energy-based sources. Was in charge of test program for measuring occurrence and distribution of alkali-based aerosols during combustion of ND lignite.

- *2010-2012: Graduate Research Assistant, Department of Chemical Engineering, UND.*

  Investigated the effectiveness of tailored sorbents to preferentially adsorb oxidized mercury from flue gas and scrubber waters.

- *2009-2010: Undergraduate Research Assistant, Department of Chemical Engineering, UND.* Investigated the effectiveness of zeolite catalysts in improving the aromatization of short chain hydrocarbons.

Publications

- Srinivasachar, S., **Nasah, J.**, Laudal, D. "Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO2 Capture Systems." US Department of Energy Agreement No. DE-SC0015737, Final Report, April 2017.
- **Nasah, J.**, Jensen, B., Dyrstad-Cincotta, N., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. "Segregation of Unreacted Char from Oxygen Carriers During Chemical Looping Combustion." 5th International Conference on Chemical Looping. September 2018.
- Pei, P., **Nasah, J.**, Solc, J., Korom, S. Laudal, D., Barse, K. "Investigation of the feasibility of underground coal gasification in North Dakota, United States." Energy Conversion and Management. Volume 113, 1 April 2016, pages 95-103
- Pei, P., Barse, K., Gil, A. J., **Nasah, J.** "Waste Heat Recovery in CO2 Compression" International Journal of Greenhouse Gas Control. Volume 30, 2014, pages 86-96.

Synergistic Activities

- Mr Nasah has specific expertise in operation of low-pressure impactors for particulate capturing. His past experience involves using impactors to capture sub-micron ash particulates to determine alkali distribution in gas stream. He has led multiple field-sampling test campaigns involving extractive particulate sampling using low-pressure impactors and bulk filters.
- Mr. Nasah has extensive experience operating UND's coal combustion bench equipment, including a 5 kW bubbling bed combustor and a 10 kW down-fired pulverized coal combustor. He also has experience with analytical equipment such as Flame Atomic Absorption spectrometers (FAA), Inductively Coupled Plasma – Mass Spectrometers (ICP-MS), Carbon Analyzers, Continuous Gas monitors for mercury, sulfur oxides, nitrogen oxides and other gas oxides. Mr. Nasah has experience in sample preparation techniques for analytical equipment, including sample digestion and conditioning.

Gautham Krishnamoorthy
Associate Professor
University of North Dakota

Education and Training

Bangalore University, India	Chemical Engineering	B.E. ChE	1998
University of Utah	Chemical Engineering	M.S. ChE	2002
University of Utah	Chemical Engineering	Ph.D. ChE	2005

Research and Professional Experience

August 2016-present: Ann and Norman Hoffman Associate Professor of National Defense/Energetics, University of North Dakota, Grand Forks, ND

August 2011-July 2016: Ann and Norman Hoffman Assistant Professor of National Defense/Energetics, University of North Dakota, Grand Forks, ND

November, 2009-August 2011: Assistant Professor, University of North Dakota, Grand Forks, ND

2005-2009: Consulting Engineer, ANSYS Inc., Lebanon, NH

Publications Related to Proposed Research

Robert Mota, Gautham Krishnamoorthy, Oyebola Dada and Steven A. Benson, "Hydrogen Rich Syngas Production from Oxy-Steam Gasification of a Lignite Coal – A Design and Optimization Study," Applied Thermal Engineering, http://dx.doi.org/10.1016/j.applthermaleng.2015.06.081

Gautham Krishnamoorthy, Anura Perera, Muhammad Sami, Stefano Orsino, Mehrdad Shahnam and David E. Huckaby, "Radiation Modelling in Oxy-Fuel Combustion Scenarios," International Journal of Computational Fluid Dynamics, vol. 24, Nos. 3-4, pp. 69-82, 2010.

Gautham Krishnamoorthy, Rydell Klosterman and Dylan Shallbetter, "A Radiative Transfer Modeling Methodology in Gas-Liquid Multiphase Flow Simulations," Journal of Engineering, vol. 2014, Article ID 793238, 14 pages, 2014. doi:10.1155/2014/793238.

Gautham Krishnamoorthy and Caitlyn Wolf, "Assessing the Role of Particles in Radiative Heat Transfer during Oxy-Combustion of Coal and Biomass Blends" Journal of Combustion, Volume 2015, Article ID 793683, 15 pages. http://dx.doi.org/10.1155/2015/793683.

Pravin Nakod, Gautham Krishnamoorthy, Muhammad Sami and Stefano Orsino, A Comparative Evaluation of Gray and Non-Gray Radiation Modeling Strategies in Oxy-Coal Combustion Simulations, Applied Thermal Engineering, vol. 54, pp. 422-432, 2013.

Other Related Publications

Gautham Krishnamoorthy, "A Computationally Efficient P1 Radiation Model for Modern Combustion Systems Utilizing Pre-Conditioned Conjugate Gradient Methods," Applied Thermal Engineering. vol. 119 (2017) pp. 197 - 206.

David W. James, Gautham Krishnamoorthy, Steven A. Benson and Wayne S. Seames "Modeling Trace Element Partitioning During Coal Combustion" Fuel Processing Technology, vol. 126, pp. 284 – 297, 2014.

Hassan Abdul-Sater, Gautham Krishnamoorthy and Mario Ditaranto, "Predicting Radiative Heat Transfer in Oxy-Methane Flame Simulations: An Examination of Its Sensitivities to Chemistry and Radiative Property Models" Journal of Combustion, Volume 2015, Article ID 439520, 20 pages. http://dx.doi.org/10.1155/2015/439520

Gautham Krishnamoorthy, "A New Weighted-Sum-of-Gray-Gases Model for CO2-H2O gas mixtures," International Communications in Heat and Mass Transfer, vol. 37, pp. 1182-1186, 2010.

Hassan Abdul-Sater*, Gautham Krishnamoorthy, An Assessment of Radiation Modeling Strategies in Simulations of Laminar to Transitional, Oxy-Methane, Diffusion Flames Applied Thermal Engineering vol. 61, pp. 507-518, 2013.

Synergistic Activities

Specialty Fields: Computational fluid dynamics; combustion modeling; radiative transfer.

Research Productivity: Dr. Krishnamoorthy has been awarded 17 grants as a PI/Co-PI/Major Participant valued at $5,000,000 as a faculty member at UND. Most relevant recent projects: DOE NETL, "Interfacing MFIX with PETSc and HYPRE Linear Solver Libraries," $400,000, 09/15 - 08/18, PI.

Awards: (Student's Choice Award for Teaching), School of Engineering and Mines, University of North Dakota, Grand Forks ND (2012)

Graduate Program Director: Chemical Engineering/Environmental Engineering/Sustainable Energy Engineering Graduate Programs (8/2012 – 7/2018)

Journal Reviewer:

Bioresource Technology, Chemical Engineering Communications, Chemical Engineering Science, Energy and Fuels, Energy, Fuel, Fuel Processing Technology, Green House Gases: Science and Technology, Heat Transfer Engineering, Indoor and Built Environment, Int. J. of Heat and Mass Transfer, Int. J. Hydrogen Energy, Journal of Hazardous Materials, Journal of Powder Technology, Journal of Power Technologies, Journal of Thermal Sciences, Numerical Heat Transfer Part B, Recent Patents on Engineering, The Canadian Journal of Chemical Engineering, Journal of the Energy Institute, Journal of Thermophysics and Heat Transfer

Steven A. Benson, PhD
President
Microbeam Technologies Incorporated

Education and Training

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

Research and Professional Experience

1991–Present: President, Microbeam Technologies Incorporated. Founded Microbeam Technologies Incorporated (MTI), a spin-off company from the University of North Dakota, to conduct service analysis of materials using automated methods aimed at assessing efficiency and reliability problems in renewable and fossil energy conversion systems. MTI has conducted over 1560 analysis projects for industry, government, and research organizations worldwide. Dr. Benson is responsible for technical direction, data interpretation, and proposal preparation. MTI has obtained funding for Phase I and Phase II SBIR projects through the U.S. Department of Energy and National Science Foundation.

2015–2017: Associate Vice President for Research, Energy & Environmental Research Center, University of North Dakota. Responsible for developing and managing projects on the clean and efficient use of fossil and renewable fuels.

2010–2014: Director/Chair, Petroleum Engineering Program and Institute for Energy Studies. Coordinated energy related education and research activities for faculty, research staff, and students.

2008–2017: Professor, University of North Dakota. Taught courses on energy production and associated environmental issues. Conducted research, development, and demonstration projects aimed at solving environmental, efficiency, and reliability problems associated with utilization of fuel resources in refining/combustion/gasification systems, including petroleum coke utilization, transformations of fuel impurities, carbon dioxide separation and capture technologies, advanced analytical techniques, and computer-based models.

1999–2008: Senior Research Manager/Advisor, Energy & Environmental Research Center, University of North Dakota (EERC, UND). Led a group of about 30 highly specialized chemical, mechanical, and civil engineers and scientists in developing and conducting projects and programs on combustion and gasification system performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide.

1994–1999: Associate Director for Research, EERC, UND. Directed and managed programs for integrated energy and environmental systems development; led a team of over 45 scientists, engineers, and technicians.

1989–1991: Assistant Professor of Geological Engineering, Department of Geology and Geological Engineering, UND. Taught courses on fuel geochemistry, fuel/crude behavior in refining, combustion and gasification systems, and analytical methods of materials analysis.

1986–1994: Senior Research Manager, Fuels and Materials Science, EERC, UND. Managed and supervised research on the behavior of inorganic constituents in fuels in combustion and gasification.

1984–1986: Graduate Research Assistant, Fuel Science Program, Department of Materials Science and Engineering, The Pennsylvania State University. Took courses in fuel science, chemical engineering (at UND), and ceramic science and performed independent research leading to a Ph.D. in Fuel Science.

1983–1984: Research Supervisor, Distribution of Inorganics and Geochemistry, Coal Science Division UND Energy Research Center. Managed and supervised research on coal geochemistry.

1977–1983: Research Chemist, Energy Resources Development Administration (ERDA) and U.S. Department of Energy Grand Forks Energy Technology Center, Grand Forks, North Dakota

Selected Publications and Presentations

1. Laudal, D.L., Srinivasachar, S., Feilen, van der Watt, J.G., and Benson, S.A., Development of an advanced oxygen carrier attrition characterization methodology for chemical looping combustion, ASME, In preparation, 2017.
2. Feilen,H., Mann, M. D., Benson, S.A., Laudal, D. L., , Barse,K., van der Watt, J.G., Srinivasachar, S., and Nealson, T., Grewal, N., and Krishnamoorthy, G., Attrition Rate of Oxygen Carriers in Chemical Looping Combustion Systems, Clearwater Conference, June 2017.
3. Benson, S.A., Patwardhan, S, Ruud, A., Freidt, A., Joun, J., Ash Formation and Partitioning in a Cyclone Fired Boiler, Presented at Impacts of Fuel Quality on Power Production Conference, Snowbird Utah, October 26-31, 2014.
4. James, D.W., Krishnamoorthy, G., Benson, S.A., and Seames, W.S., "Modeling trace element partitioning during coal combustion," Fuel Processing Technology, 126 (2014) 284–297
5. Van Dyk, J.C., Waanders, F.B., Benson, S., Laumb, M., and Hack, K., Viscosity Predictions of the slag composition of gasified coal, utilizing FactSage equilibrium modeling, Fuel, 2009, 88, 67-74.
6. Ma, Z.; Iman, F.; Lu, P.; Sears, R.; Vasquez, E.; Yan, L.; Kong, L.; Rokanuzzaman, A.S.; McCollor, D.P.; Benson, S.A. A comprehensive slagging and fouling prediction tool for coal-fired boilers and its validation/application, Fuel Process. Technol. 2007, 88, 1035–1043.
7. Matsuoka, K.; Suzuki, Y.; Eylands, K.E.; Benson, S.A.; Tomita, A. CCSEM Study of Ash-Forming Reactions During Lignite Gasification. *Fuel* **2006**, *85*, 2371–2376.
8. Nowok, J.W.; Hurley, J.P.; Benson, S.A. The Role of Physical Factors in Mass Transport During Sintering of Coal Ashes and Deposit Deformation Near the Temperature of Glass Transformation Fuel Process. Technol. 1998, 56, 89–101.
9. Nowok, J.W.; Hurley, J.P.; Benson, S.A. The Role of Sulfate-Silicate Phase Separation in Sintering Propensities of Coal Fly Ashes at 800°–1000°C. J. Inst. Energy 1996, 69, 12–14.
10. Jones, M.L.; Kalmanovitch, D.P.; Steadman, E.N.; Zygarlicke, C.J.; Benson, S.A. Application of SEM Techniques to the Characterization of Coal and Coal Ash Products. In *Advances in Coal Spectroscopy*; Plenum Publishing Co.: New York, 1992; pp 1–27.

Patents: 4 patents issued and several applications pending
7,574,968: Method and apparatus for capturing gas phase pollutants such as sulfur trioxide
7,628,969: Multifunctional abatement of air pollutants in flue gas
7,981,835: System and method for coproduction of activated carbon and steam/electricity
8,277,542: Method for capturing mercury from flue gas

Synergistic Activities

- Lignite Energy Council, Distinguished Service Award, Research & Development, 1997, 2003, 2005, and 2008. College of Earth and Mineral Science Alumni Achievement Award, Pennsylvania State University, 2002; Science and Technology Award, Impacts of Fuel Impurities Conference, 2014.

- Provided testimony to the United States Senate Committee on the Environment and Public Works on mercury emissions control at coal-fired power plants (2008 and 2005).

Srivats Srinivasachar
President
Envergex LLC

Education and Training

- Boston University, School of Management, Master of Business Administration, 2004
- Massachusetts Institute of Technology, Sc.D. degree in Chemical Engineering, 1986
- Indian Institute of Technology, Bachelor of Technology degree, Chemical Engineering, 1981

Professional experience

Present: President, Envergex LLC

- Supercritical water desalination technology (DOE Phase I STTR) April 2018
- Developing spouted fluid beds for chemical looping (DOE Phase I/II STTR) (April 2017)
- Developing method to evaluate attrition propensity of oxygen carriers for chemical looping – Department of Energy (DOE) (Phase I/II STTR) grant (July 2015)
- Developing method to separate coal conversion products from sorbents/oxygen carriers - US DOE (Phase I/II STTR) grant (June 2015)
- Developed method for mitigation of aerosol emissions from solvent-based CO_2 capture systems (Phase I STTR) grant (June 2016)
- Developing novel materials for capturing CO_2 - US DOE (Phase I/II STTR) grant (Aug. 2014)
- Developed a novel method for capturing CO_2 from flue gas (CACHYS™) - awarded a US Department of Energy grant (June 2010) DOE Phase I STTR; CommercializingCACHYS™ technology; teaming with University of North Dakota on a $3.6 million USDOE program
- Commercial production of high-performance sorbents for mercury control
- Received from the US Patent and Trademarks office registration of trademark for mercury sorbents, ESORB-HG®, in March 2009 (Registration Number: 3589943).
- Manufactured and supplied commercial quantities and successfully demonstrated ESORB-HG® sorbent to several power utility and industrial customers at full scale
- Tested at commercial-scale mercury control technologies for taconite processing plants
- DOE Phase I STTR (June 2007): Method to reduce mercury re-emissions from scrubbers
- Developed a business plan for coal and biomass to liquids venture
- Teamed with UND and utility partner to perform engineering and costing to implement an innovative technology: activated carbon manufacturing integrated into a power plant
- Developed a technical/business strategy to increase manufacturing process energy efficiencies at a major building materials company

1999 – 2006: ALSTOM Power, Inc. and *1993 – 1999: ABB Combustion Engineering, Inc.*

- *Technical Manager, Environmental Control Technology* (March 2003-2006)
  Developed a new product for controlling mercury emissions from coal-fired power plants. Led product development team, successfully scaled-up technology, executed three (3) commercial demonstration projects, and implemented the product at commercial scale.
- *Principal Consulting Engineer, New Product Business Development* (Oct. 1999-March 2003)
  - Multi-business product development for control of SO_2 emissions from power plants
  - Developed concept for combined cement and power plant
- *Environmental Group Leader (Oct. 1997-Sept. 1999)*
- *Senior Consulting Engineer (1994 – 1997)*
  - Project leader on environmental and heat recovery projects
  - Developed high-performance fuel nozzles for boilers to reduce nitric oxide emissions

1986-1993: Physical Sciences Inc.

- *Manager, Environmental Remediation and Resource Utilization (1992-93)*
  Secured and managed an EPA Superfund project to remediate heavy metal-contaminated soils
- *Principal Research Scientist (1986-92)*
  Principal Investigator on a multi-million dollar university-industry project: created test methods and software for electric utilities to evaluate savings with various fuel switching options and predict fuel quality impacts on deposition in coal-fired power plants

Selected Patents

- U.S. Patent 9,121,606, "Method of manufacturing carbon-rich product and co-products"
- U.S. Patent 8,840,706, "Capture of carbon dioxide by hybrid sorption"
- U.S. Patent 8,277,542, "Method of capturing mercury from flue gas"
- U.S. Patent 8,080,088, "Flue gas mercury control"
- U.S. Patent 8,069,797, "Control of Mercury Emissions from Solid Fuel Combustion"
- U.S. Patent 7,981,835, "System and method for coproduction of activated carbon and steam/electricity"
- U.S. Patent 6,848,374, "Control of Mercury Emissions from Solid Fuel Combustion"
- U.S. Patent 6,749,681, "Method of Producing Cement Clinker and Electricity"
- U.S. Patent 6,089,171, "Minimum Recirculation Flame Control Pulverized Solid Fuel Nozzle Tip"
- U.S. Patent 6,089,023, "Steam Generator System Operation"
- U.S. Patent 5,556,447, "Process for treating metal-contaminated materials"

Representative Publications

1. Van der Watt, J., Laudal, D., Feilen, H., Krishnamoorthy, G., Mann, M., Shallbetter, R., Nelson, T. and **Srinivasachar, S.** (2018). Development of a spouted bed reactor for chemical looping combustion. *Journal of Energy Resources Technology*, *140* (11), 112002
2. **Srinivasachar, S.**, Nelson, T., Van der Watt, J., Feilen, H., Laudal, D., & Mann, M. (2018). *Methodology for Attrition Evaluation of Oxygen Carriers in Chemical Looping Systems: Final Scientific/Technical Report-Phase II* (No. DOE-Envergex-PhII-SC0011984). Envergex LLC.
3. Benson, S.A. and **Srinivasachar, S.** "Evaluation of CO_2 Capture from Existing Coal-fired Power Plants by Hybrid Sorption Using Solid Sorbents," 2014 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA http://www.netl.doe.gov/events/conference- proceedings/2014/2014-netl-co2-capture-technology-meeting
4. Benson, S.A., Crocker, C.R., Hanson, S.K., McIntyre, K.A., Just, B.J., Raymond, L.J., Pflughoeft- Hassett, D.F, **Srinivasachar, S.**, Barry, L.T. and Doeling, C.M., "JV Task 115-Activated Carbon Production from North Dakota Lignite – Phase IIA," Final Report, U.S. Department of Energy Cooperative Agreement No. DE-FC26-98FT40321, June 2008
5. Kang, S.K., **Srinivasachar, S.** and Brickett, L.A., " Full-Scale Demonstration of Mer-Cure™ Technology for Mercury Emissions Control in Coal-Fired Boilers, " 31st International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL May 2006
6. Senior, C.L., Bool, L.E., **Srinivasachar, S.**, Pease, B.R. and Porle, K., "Pilot-Scale Study of Trace Element Vaporization and Condensation during Combustion of a Pulverized Sub-bituminous Coal," Fuel Processing Technology, 63(2-3), 149-165, 2000
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8. Boni, A.A. and **Srinivasachar, S.**, "An Overview of Computational Fluid Dynamic Software for Heat Transfer and Combustion Applications," J. Eng. Computing and Applications, 2, pp.12-19, 1987.

Michael L. Jones, PhD
President
MLJ Consulting, LLC

Education and Training

- Ph.D., Physics, University of North Dakota, 1978
- M.S., Physics, University of North Dakota, 1973
- B.S., Physics, Bemidji State University (Minnesota), 1971

Research and Professional Experience

Dr. Jones' principal areas of interest and expertise include management of and technical direction for multidisciplinary science and engineering research teams focused on integrated energy and environmental technologies. Current focus includes minimizing the carbon footprint of energy systems based on lignite coal, including CO_2 separation and sequestration. Minimization of emissions from lignite-based energy conversion systems and development of niche opportunities for use of lignite coal including extraction of rare earth elements.

2017–Present; President, MLJ Consulting LLC. After retiring from the Lignite Energy Council, Dr. Jones formed MLJ Consulting to provide consulting services based on over 39 years working on research and development of energy and environmental technologies with special emphasis on lignite coal.

2009–2016: Vice President R&D, Lignite Energy Council, Responsibilities included identification of critical issues to facilitate the enhanced use of lignite coal. Technologies of interest included combustion, gasification chemical from coal and hydrogen from coal. Provided recommendation to the Lignite Research Council and the North Dakota Industrial Commission on funding of R&D activities to ensure completion of critical project in support of enhanced use of North Dakota lignite. Developed strategies to increase working relationships with research groups around the world including US DOE, EPRI, Canadian lignite coal users and others.

2004–2009: Senior Research Advisor, Energy & Environmental Research Center (EERC), University of North Dakota (UND). Responsibilities included management of and technical direction for multidisciplinary science and engineering research teams focused on a wide range of integrated energy and environmental technologies. Specific program areas of interest included clean and efficient use of low-grade fuels, matching of fuel characteristics to system design and operating parameters, development of advanced power systems based on low-grade fuels, fundamentals of low-grade fuel combustion, ash behavior in low-grade fuel conversion systems, and analysis of inorganic materials in low-grade fuels. Projects emphasized a cradle-to-grave approach from resource assessment to optimum utilization systems to minimization of emissions and waste management featuring by-product utilization.

2004–Present: Adjunct Professor, Physics, UND
1994–2004: Adjunct Assistant Professor, Physics, UND.

1983–2004: Associate Director, Industrial Relations and Technology Commercialization, EERC, UND. Responsibilities included planning, staffing, and technical direction of combustion and gasification research, including projects in combustion chemistry or gasification chemistry, behavior during coal utilization, fluidized-bed combustion, coal–water fuels, SO_x/NO_x removal, and particulate removal and characterization. Special emphasis was given to low-rank coal systems; activities ranged from field testing of full-scale power plants, to pilot-scale studies, to laboratory investigations that examine both fuel and system characteristics and their impacts on overall performance.

1990–1994: Adjunct Professor, Department of Chemical Engineering, The University of Utah, Salt Lake City, Utah.

1979–1983: Grand Forks Energy Technology Center, U.S. Department of Energy, Grand Forks, North Dakota. Responsibilities included technical direction of research and development projects related to combustion technology for low-rank coals, with specific responsibility for fundamental research on pulverized coal combustion. Directed research on new, specialized analytical procedures for determining inorganics and trace elements in coal and materials derived from coal combustion and conversion processes. Instrumentation included methods Auger/ESCA spectrometer, scanning electron microscope, x-ray diffraction, x-ray fluorescence, argon plasma spectrometer, and atomic absorption spectrometer.

Selected Publications and Presentations

Benson, S.A.; Jones, M.L.; Stanislowski, J.J.; Laumb, J.D.; Swanson, M.L.; Galbreath, K.C. Coal Ash Behavior in Reducing Environments (CABRE) III. Presented at the Project Kickoff Meeting, Grand Forks, ND, March 5, 2008.

Jones, M.L. Carbon Capture and Sequestration Technology Overview. Presented at the Clean Coal and Carbon Capture and Sequestration Information Session, Regina, SK, April 17, 2008.

Pavlish, B.M.; Jones, M.L.; Kay, J.P. *Mercury Control Field Testing at Lewis and Clark Station*; Final Report (May 6 – Sept 30, 2007) for Montana–Dakota Utilities Co.; EERC Publication 2008-EERC-04-08; Energy & Environmental Research Center: Grand Forks, ND, April 2008.

Jones, M.L.; Pavlish, B.M.; Benson, S.A. Evaluation of CO_2 Capture Technologies for Lignite-Fired PC Boilers. In *Proceedings of Air Quality VI: Mercury, Trace Elements, SO_3, Particulate Matter, and Greenhouse Gases*; Arlington, VA, Sept 24–27, 2007.

Jones, M.L.; Pavlish, B.M.; Sollom, S.E.; Kay, J.P. *JV Task 107 – Pilot-Scale Emission Control Technology Testing for Constellation Energy*; Final Report (Dec 15, 2006 – June 30, 2007) for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-98FT40321 and Constellation Energy Purchase Order No. 242624; EERC Publication 2007-EERC-07-10; Energy & Environmental Research Center: Grand Forks, ND, July 2007.

Benson, S.A.; Jones, M.L.; Galbreath, K.C. Ash Behavior & Mercury Control in Coal Combustion Short Courses, Denver, CO, Sept 5–7, 2006.

Benson, S.A.; Jones, M.L.; Bryers, R.W. Practical Measures to Minimize Ash Deposition. In *Proceedings of the Engineering Foundation Conference—The Impact of Ash Deposition on Coal Fired Plants*; June 20–25, 1993; Williamson, J.; Wigley, F., Eds.; Taylor & Francis: Solihull, England, 1994; pp 657–678.

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Benson, S.A.; Jones, M.L. Inorganic Transformations, Fouling, and Slagging. In *Fundamentals of Coal Combustion*; Smoot, L.D., Ed.; Elsevier: New York, 1992.

Jones, M.L.; Hurley, J.P. *Project Sodium—Follow-On Work to the Original Evaluation of Sodium Effects in Low-Rank Coal Combustion Systems*; Final Technical Report and Executive Summary for the follow-on work for Project Sodium Sponsors; Energy & Environmental Research Center: Grand Forks, ND, Jan 1992.

Appendix D

Project Management Plan

PROJECT MANAGEMENT PLAN

AOI 2: Power Plant Component Improvement
Subtopic 2A: High Fidelity Field Testing of Technologies

Mitigation of Alkali Promoted Ash Deposition and Emissions from Coal Combustion

February 28, 2019

SUBMITTED UNDER FUNDING OPPORTUNITY ANNOUNCEMENT

DE-FOA-0001989

SUBMITTED BY

Barr Engineering Co.-Prime
University of North Dakota
Microbeam Technologies, Inc.
Envergex, LLC.

PRINCIPAL INVESTIGATORS

Prime Principal Investigator:
Barr Engineering, Co.
Nicole Nguyen
nnguyen@barr.com
(734) 922-4447

University of North Dakota, Junior Nasah: Co-Principal Investigator
Microbeam Technologies, Inc: Co-Principal Investigator
Envergex, LLC, Srivats Srinivasachar: Co-Principal Investigator

SUBMITTED TO

U.S. Department of Energy
National Energy Technology Laboratory

A. Executive Summary

Barr Engineering Co. (Barr) has teamed with the University of North Dakota (UND), Microbeam Technologies Inc. (MTI), Envergex, LLC, and MLJ Consulting to develop a transformational technology that controls the formation of alkali aerosols. Controlling and reducing the formation of alkali vapors in the boiler has the potential to improve plant performance by decreasing slagging and fouling as well as fine particle emissions, and it can provide a step-change reduction in energy penalties.

Project Goals: 1) Demonstrate effectiveness of tailored clay sorbents in mitigating fouling and slagging, 2) Develop a benchmark/screening tool for identifying low cost clay sorbents, and 3) Develop a techno-economic assessment of the sorbent technology including a pathway to commercialization.

Expected Results: Ash and slag deposits that foul the steam-generation surfaces of a boiler are the primary cause for boiler outages. These deposits result from the presence of volatile species in the coal ash that act as a glue for ash deposition and growth. This project will mitigate ash deposition by capturing the volatile species in the boiler through the injection of sorbents in the boiler. The impact of mitigating slagging and fouling is significant and is expected to: 1) increased plant revenues due to a reduction in outage time, 2) reduce boiler temperatures due to better heat rate efficiency, 3) reduce NO_x emissions from lower furnace temperatures and deeper staging, 4) reduce fuel consumption from improved heat rate, 5) decrease parasitic power from less fan power (lower pressure drop through convective pass), and 6) improve fuel flexibility/tolerance for low-quality fuels. For a 250 MW facility, we anticipate these impacts could translate to annual cost savings of over $2 million. .

Table 1: Scope, Schedule, Budget Breakdown

Period 1 – Lab and Pre-Engineering (July 2019-January 2021) (Budget $1,477,993)	
Activity	**Deliverable / Verification**
Task 1 (Period 1): Project Management	Project Management Plan
Task 2: Laboratory Scale Testing	Down-selection of field testing sorbent (5/01/2020) Establishment of Key Technology Attributes (9/31/2020)
Task 3: Sorbent Injection Modelling - CFD	Identification of optimum injection locations
Task 4: Equipment Design and Sizing for Field Demonstration	Design Report Workforce Readiness Plan Revised TMP
Period 2 – Operational Evaluation (January 2021-July 2022) (Budget $3,518,417)	
Activity	**Deliverable**
Task 1 (Period 2): Project Management	Updated Project Management Plan
Task 5: Procurement, Installation and Construction	Final Vendor Quotation Installation of injection ports Commissioning of demonstration equipment
Task 6: Parametric Testing – Field Demonstration	Delivery of Sorbent Completion of parametric tests
Task 7: Data Reduction and Evaluation of Parametric Testing	Revised Test Plan Revised Design Basis Document Budget Period 2 Status Report
Task 8: Extended Sorbent Testing	Completion of extended tests
Task 9: Data Reduction and Techno-Economic Assessment	Final Report Final TEA, Final TMP

B. Project Organization and Structure

i. Organizational Chart (see Figure 1)

The proposed technical team has a long history of conducting large, interdisciplinary and multi-organizational research projects. Additionally, UND and Barr have recently collaborated on multiple projects, including the successfully completed 3-year, $3.6 million effort to evaluate UND's carbon dioxide capture technology, CACHYS™ (DE-FE0007603). Barr will be in the Prime role for this proposal and will manage the overall project.

ii. Roles and Responsibilities of Participants

- *Prime Principal Investigator and Project Manager: Nicole Nguyen, Barr*, is a Project Management Professional responsible for day-to-day project management. She is a licensed chemical engineer with over a decade of experience working with clients in the power industry. Nicole has managed power-plant projects ranging in size from labor fees of $5,000 to over $1 million. She has worked on proprietary R&D projects and feasibility projects funded by the Department of Energy.
- *Contract and Risk Manager (Project Principal): Richard Hardegger, Barr*, has applied a chemical engineering background to a 27-year career in environmental consulting for clients in the utility, mining, energy, and manufacturing sectors. His focus has been air quality monitoring and compliance for coal-, gas-, oil- and biomass-fired utilities and industrial processes. Rich's experience includes projects for new and modified facilities that required federal and state air permitting, emissions control systems evaluation in support of best available control technology determinations, air dispersion modeling, human health risk assessment, ambient air monitoring, and stack testing. Rich was on the UND/Barr team for the DOE-sponsored CACHYS technology evaluation.
- *Technical Consultant/Advisor: Bruce Browers, Barr*, will be Barr's technical advisor for all tasks. He has 46 years of coal-fired power-plant experience with virtually all types of combustion systems including pulverized coal, IGCC, cyclones, and stokers. Bruce has conducted significant thermal modeling studies for several types of power plant configurations including both subcritical and conventional supercritical steam systems. He was on the UND/Barr team for the DOE-sponsored CACHYS technology evaluation and focused on integration of the system into the power block steam cycle.
- *Technical Lead: Chad Haugen, Barr*, will be a task manager for pre-engineering Tasks 4 and 5 and techno-economic evaluation Task 9. He has over 10 years of process engineering and project management experience involving energy assessments, environmental permitting review, process modeling, and process safety review. He worked on the techno-economic evaluation of a rare-earth-element extraction project with the Department of Energy.
- *Co-PI: Steve Benson, Microbeam Technologies*, will serve as a co-principal investigator and will manage the field testing tasks, Tasks 6 and 8. He is a lead developer of the technology, arising from his experience with alkali-related fouling and slagging of coal boilers. Steve has over 35 years of experience related to the impact of major, minor, and trace fuel impurities on combustion and gasification system design, reliability, and performance. In addition, he has participated in development of tools for combustion to optimize coal/fuel properties and plant operating conditions to improve plant operations.
- *Co-PI: Srivats Srinivasachar, Envergex, LLC*, will be a technical advisor and a co-principal investigator. He is a developer of the proposed technology through a Small Business Innovation Research award (SBIR, DE-SC0015737) executed at UND. Srivats will manage the data reduction task, Task 7. He has over 32 years of experience in coal-fired power generation, including 13 years with ABB Combustion Engineering/ALSTOM Power (now GE) where he rose to the position of principal consulting engineer. There he developed commercial technologies related to coal nozzle injection systems, low-NOx firing, ash deposition mitigation, regenerative air heaters, electrostatic precipitators, and mercury and SO2 control.

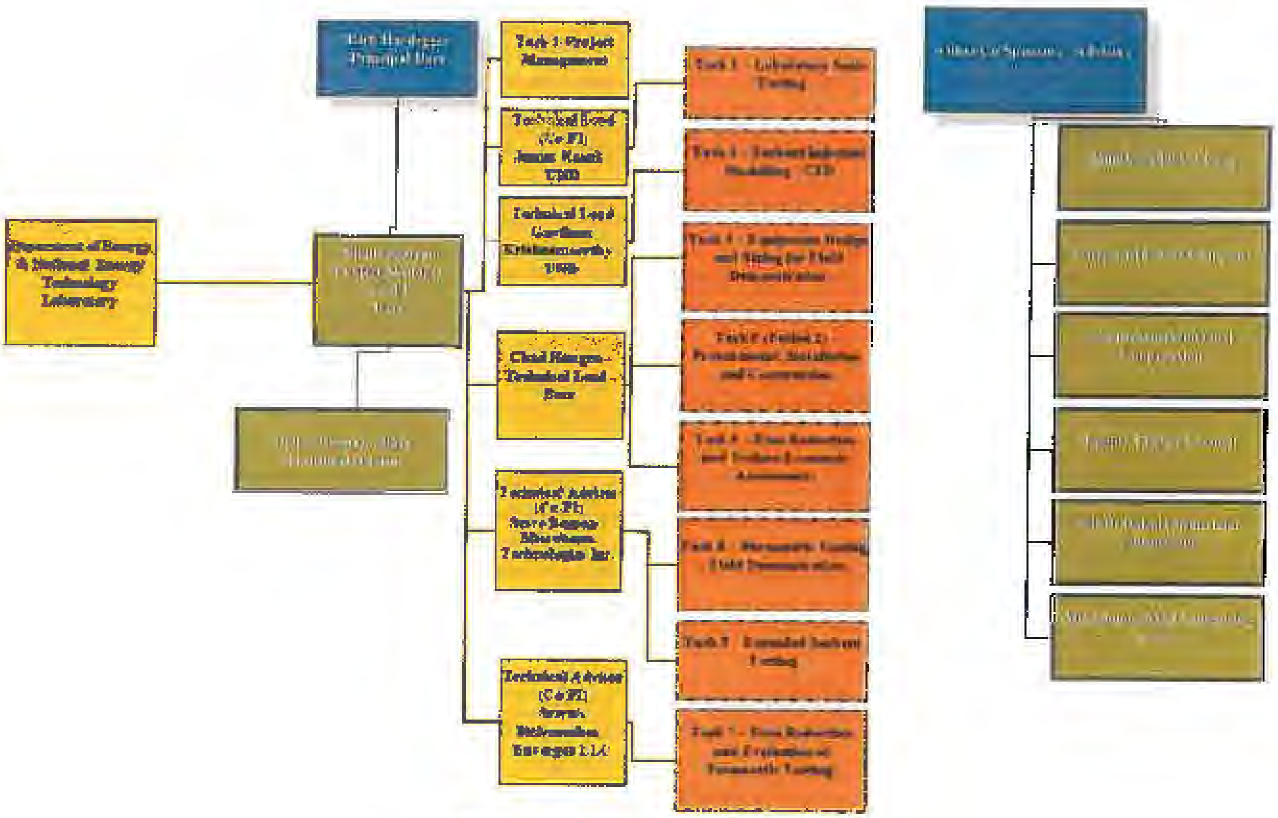

Figure 1: Project Organizational Chart

Roles and Responsibilities of Participants (continued)

- *Co-PI: Junior Nasah, UND*, is principle investigator for the University of North Dakota team. The Major Project Manager for UND's Institute for Energy Studies. Junior was UND's lead researcher during development of the proposed technology under SBIR award DE-SC0015737. He will manage UND's activities and be the technical lead for Task 2. He has experience operating bench-scale coal combustion systems, low-pressure particulate impactors, and particulate extractive sampling from power plants. His other duties involve research on advanced combustion systems, including chemical looping, gasification and energy storage. He led field sampling exercises at the host facility for the demonstration.
- *Consultant/Advisor: Michael Mann, UND*, is Executive Director of UND's Institute for Energy Studies. He has spent his career working with the power-generation industry, and has been a part of many bench-, pilot-, and field-demonstrations, as well as managed multi-institutional projects with budgets exceeding $1 million. He will provide technical advice to the project team and manage the overall resources of the UND team.
- *Technical Lead: Gautham Krishnamoorthy, UND*, is an associate professor of Chemical Engineering and will lead Task 4. He has over 18 years of experience in the areas of heat transfer, reacting flow modeling, and the use of CFD tools to study fuel conversion technologies. From 2005-2009, he was a consulting engineer and heat transfer specialist at ANSYS Inc., where he was at the interface of power generation clientele and software development teams to solicit input and provide feedback on enhancing ANSYS FLUENT's heat transfer modeling capabilities. He is currently a Co-PI on an NSF funded project to study "Deposition of ash and its effect on heat transfer during the oxy-combustion of biomass and biomass-coal blends."
- *Consultant/Advisor: Mike Jones, MLJ Consulting, LLC*, will serve as a technical advisor with MLJ Consulting, LLC for all tasks. Dr. Jones' principal areas of interest and expertise include management of and technical direction for multidisciplinary science and engineering research teams focused on integrated energy and environmental technologies. Current focus includes minimizing the carbon footprint of energy systems based on lignite coal, including CO2 separation and sequestration. Minimization of emissions from lignite-based energy conversion systems and development of niche opportunities for use of lignite coal including extraction of rare earth elements

3. Decision-making and Communication Strategy

The Barr PI will be DOE's primary contact, and she will employ proven communication strategies already used successfully at Barr Engineering Co. to communicate with clients. The Barr PI will set clear expectations that the task leads and co-PI's read and understand the project management plan and use the plan to prepare, execute, monitor and control project activities. The project management plan will be further developed by the Barr PI and will be mutually agreed upon by all co-PIs. As part of the project management plan, a communication plan will be prepared and will include Barr PI led biweekly project meetings and conference calls with co-PI's and task leads to review the project schedule, upcoming milestones/deliverables, deviations from the technical direction originally proposed, and costs and challenges associated with completion of project tasks.

Formal in-person review meetings with co-PI's and sponsors will be led by the Barr PI and held quarterly to promote communication and discussion of progress, accomplishments, up-coming plans, and management of project risks. Visual progress reports showing overall cost, project, and schedule status will be submitted monthly by the Barr PI to the internal task leads/co-PI to allow leads to monitor and control progress of their specific tasks. Barr will manage file sharing sites and webex conferences to for document sharing and conferences.

A change log and issue log will be used to document reported changes and issues of the project. The Barr PI will work with the DOE during development of the Project Management Plan to verify changes are properly logged, reported, and approved per DOE preferred protocol. Meetings with industry sponsors will be held to update them on technical progress and seek input on commercial viability and applicability. As the prime, Barr Engineering will have ultimate decision rights in scope and deliverables, schedule, budget, risk, communication, resources, quality, integration, procurements, and stakeholder engagements.

4. Management Capabilities

Key team members for this project have extensive experience managing projects with similar technical and budgetary scopes. Their individual experience is summarized in the Roles and Responsibility section above and detailed in their resumes. Primary responsibility for overall project management rests with Barr Engineering Co. As a company Barr has an annual expenditure rate of annual revenues of $115MM with project sizes ranging from $1,000 to $5MM. Barr has worked on DOE-supported projects both as a lead and as a subcontractor and Barr team members have worked with the other members of the proposed team. Barr has a proven record of completing projects on time and on budget. In an annual survey of a cross-section of clients, Barr consistently receives high marks for meeting project commitments, including schedule and budget. Clients report that this is one of the top three factors they consider in continuing to work with us and they rate us as better than our competitors in this area.

C. Risk Management Plan

Technical, resource, and management risks will be analyzed continuously and appropriate measures taken to address them. A preliminary list of the perceived risks associated with completing the project is summarized in **Error! Reference source not found.**. This risk register will be maintained and reviewed by task leads throughout the project and will be available to all team members.

Table 3. Technical, Resource and Management Risks

Perceived Risk	Risk Rating: Probability (Low, Med, High)	Impact	Overall	Mitigation/Response Strategy
Financial Risks:				
1 – Participants do not follow through on cost share	Low	High	Low	Selected cost share participants with a solid financial track record; commitment letters obtained; participants are motivated to support a solution to the high-sodium coal fouling problem.
Cost/Schedule Risks:				
1 – Task cost are overrun	Med	Med	Med	Budgets for each participant will be developed before work will begin. Costs will be monitored and adjustments to scope made as the work progresses.
2 – Task schedules are not met	Med	Med	Med	Schedules for each participant will be developed before work will begin. Schedule will be monitored and adjustments to schedule made as the work progresses.
Technical Risks:				
1 – Sorbent options are not fully developed	Low	Med	Med	Previous lab testing has demonstrated a proven concept (sorbent injection reduces aerosol concentration). Additional lab testing is proposed as part of the SOPO to further develop sorbent options.

Perceived Risk	Risk Rating Probability	Impact	Overall	Mitigation/Response Strategy
	(Low, Med, High)			
2 – Plant interconnections may become more complicated than envisioned	Low	Med	Med	The project team has deep experience with various types of plant tests. The types of connections and their potential locations have already been identified during a plant walk down.
3 – Sorbent preparation and delivery to the boiler may become more complicated	Med	Med	Med	The Project Team has contacted multiple vendors and received initial indications that their test trailers can grind and deliver the types and quantities of sorbent required.
4 – Sorbent supply may become more complicated	Med	High	Med	The Project Team has contacted multiple vendors and received initial assurances that supplies will be available.
5- The power plant may experience a catastrophic failure	Low	High	Low	The Milton R. Young Station has demonstrated reliable operation for many years.
6- Injection of the sorbent may cause operating issues	Low	Med	Med	The sorbents are inert materials with similar characteristics to the typical coal combustion residues and will be injected in the furnace after combustion has taken place.
Management, Planning, and Oversight Risks:				
1 – PMP plan is mis-managed	Low	High	Low	The Project Team is composed of senior members of each organization who will lead the activities of their respective organizations. Barr has proposed a very senior and well qualified PMP professional to lead the project.
2 – Project team staff will leave	Med	Med	Med	The Project Team is committed to the work. The Project Team collectively have a bench of staff that can be called upon if necessary.
ES&H Risks:				
1 – Permits/ Permissions from the ND Department of Health will need to be obtained	Low	High	Med	Minnkota Power Cooperative as the plant owner has a good working relationship with the ND Department of Health and will manage the process of obtaining approvals. The short-term tests will have almost no environmental impact. A successful trial is expected to show a reduction in particulate emissions.
External Factor Risks:				
1 – Severe winter weather could affect the test plan	Med	High	Low	The testing plan will be conducted in the spring and fall.

D. Milestone Log

The project milestone log is summarized in Table 4 and includes key milestones by task, planned completion dates, and verification methods. The planned start date for the project is July 1, 2019. The verification methods will include providing data and reports to DOE. In addition, meetings with DOE will be conducted periodically to provide detailed review of findings and determine future directions.

Table 4. Milestone Log

Task / Subtask	Planned Completion Date	Deliverable	Milestone Marker / Verification Method
Award			Award
Task 1 – Project Management and Planning.	7/14/2022	Project Management Plan	Quarterly Reports
Task 2 – Laboratory Scale Testing	9/31/2020		Down-selection of field testing sorbent (5/01/2020) Establishment of Key Technology Attributes (9/31/2020)
Task 3 – Sorbent Injection Modelling - CFD	10/31/2020		Identification of optimum injection locations
Task 4 – Equipment Design and Sizing for Field Demonstration	1/1/2021	Design Report Workforce Readiness Plan Revised TMP	Go / No Go Decision
Task 5– Procurement, Installation and Construction:	3/1/2022	Revised Detailed Design Report	Final Vendor Quotation Installation of injection ports Commissioning of demonstration equipment
Task 6 – Parametric Testing - Field Demonstration:	10/1/2021		Delivery of Sorbent Completion of parametric tests
Task 7 – Data Reduction and Evaluation of Parametric Testing:	3/1/2022	Revised Detailed Design Report Revised TMP	Go / No Go Decision
Task 8 – Extended Sorbent Testing:	5/1/2022		Completion of extended tests
Task 9 – Data Reduction and Techno-Economic Assessment:	7/14/2022	Final Report Final TEA, Final TMP	

E. Funding and Costing Profile

The project funding profile is shown in Table 5

Table 5. Project Funding Profile

	FY 2019		FY 2020		FY 2021		FY 2022		Total	
	DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share
Barr	211,066	50,000	316,599	50,000	1,000,000	225,000	1,132,092	225,000	2,659,757	550,000
UND	128,745	45,000	193,118	45,000	150,000	50,000	128,137	50,000	600,000	190,000
MTI	41,966	20,000	62,950	20,000	100,000	30,000	144,960	30,000	349,876	100,000
Envergex	60,349	32,500	90,523	32,500	100,000	42,662	97,581	42,662	348,453	150,324
MLJ Consulting	7,965	2,044	11,947	2,044	9,000	2,500	10,000	2,500	38,912	9,088
Total ($)	450,091	149,544	675,137	149,544	1,359,000	350,162	1,512,770	350,162	3,996,998	700,324
Total Cost Share %	33%		22%		26%		23%		18%	

	BP1		BP2		Total	
	DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share
Barr	527,665	100,000	2,132,092	450,000	2,659,757	550,000
UND	321,863	90,000	278,137	100,000	600,000	190,000
MTI	104,916	40,000	244,960	60,000	349,876	100,000
Envergex	150,872	65,000	197,581	85,324	348,453	150,324
MLJ Consulting	19,912	4,088	19,000	5,000	38,912	9,088
Total ($)	1,125,228	299,088	2,871,770	700,324	3,996,998	999,412
Total Cost Share %	27%		24%		25%	

F. Project Timeline

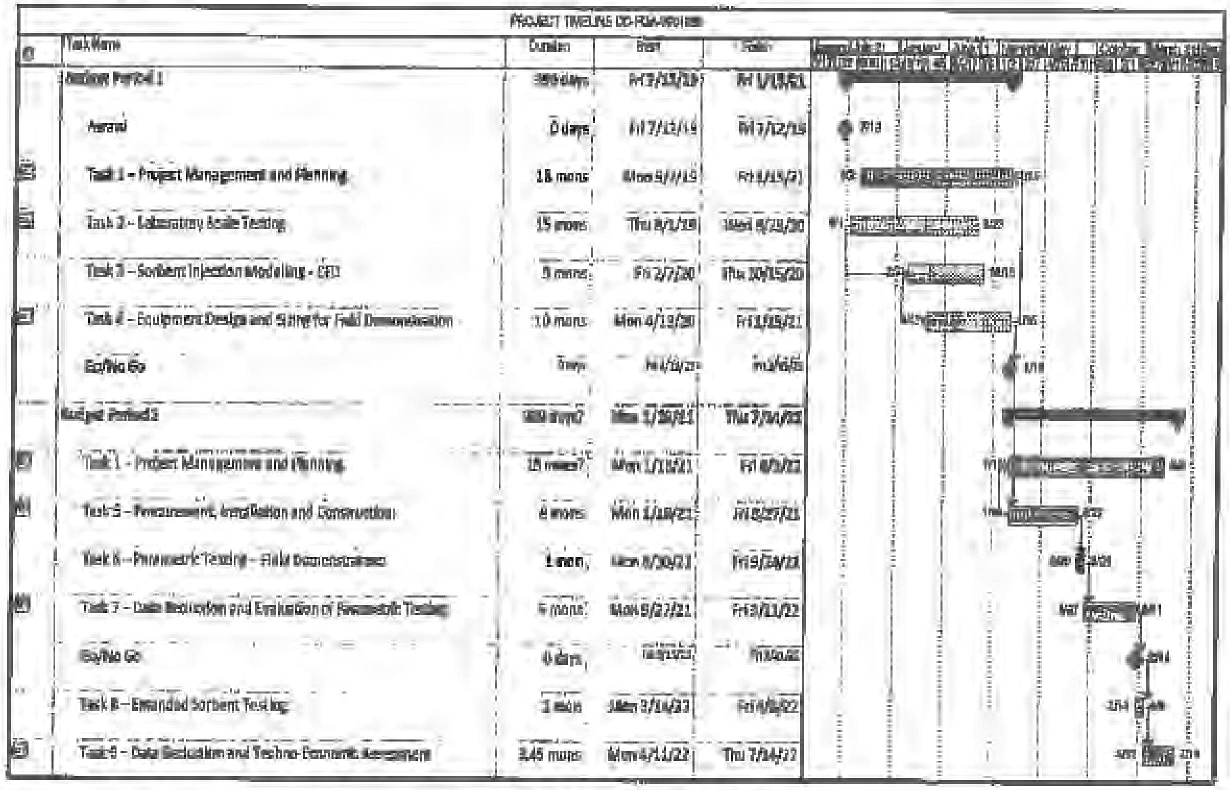

Figure 2. Milestone Schedule

G. Success Criteria at Decision Points

Budget Period 1 success criteria:

- Candidate sorbents have been successfully screened and a workable model developed that can be used to predict sorbent performance
- A CFD model has been developed that can be used to identify the optimal sorbent injection location to maximize its performance
- A final design package has been prepared that includes detailed input from plant personnel, sorbent suppliers, and technology vendors to ensure the technical and budgetary objectives proposed for Budget Period 2 can be achieved

Budget Period 2 success criteria:

- Equipment at the field test site is successfully installed and operational within the proposed budget and schedule
- Parametric testing demonstrates the effectiveness of the proposed technology and identifies the optimal parameters to maximize the benefits
- Long-term testing demonstrates that the technology is effective over long periods of time and over a wide range of load.
- Advancement of the technology to a TRL 7 (system prototype validated in operational environment) thus making them ready for commercial demonstration.

Appendix E

DOE Notification Award Letter (DE-FOA-0001989)

June 6, 2019

SENT VIA ELECTRONIC MAIL

Richard Hardegger
Barr Engineering Co.
4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435-5423
rhardegger@barr.com

SUBJECT: Selection of Application for Negotiation Under Funding Opportunity Announcement Number **DE-FOA-0001989, Improving Efficiency, Reliability, and Flexibility of Existing Coal-Fueled Power Plants**

Dear Mr. Hardegger:

We are pleased to provide this update on your application. The Office of Fossil Energy within the Department of Energy (DOE) has completed its evaluation of your application submitted in response to the subject Funding Opportunity Announcement (FOA). The application below has been recommended by the Office of Fossil Energy for negotiation of a financial award (**Note: This notification does not guarantee Federal Government funding, as an award will only be obligated upon completion of negotiations**):

Application: Mitigation of Aerosol Impacts on Ash Deposition and Emissions from Coal Combustion; Tracking Number:GRANT12803869; Nicole Nguyen

Receipt of this letter does not authorize the applicant 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. Applicants do not receive an award until award negotiations are complete and the Contracting Officer executes the funding agreement. Only an award document signed by the Contracting Officer obligates DOE to support a project.

The award negotiation process may take up to 75 days. The applicant must be responsive during award negotiations (i.e., provide requested documentation) and meet the stated negotiation deadlines. Failure to submit the requested information and forms by the stated due date, or any failure to conduct award negotiations in a timely and responsive manner, may cause DOE to cancel award negotiations and rescind this selection. DOE reserves the right to terminate award negotiations at any time for any reason.

Please complete the following items and submit to DOE no later than June 20, 2019

- Pre-Award Information Sheet (available at https://netl.doe.gov/node/5719)
- Data Management Plan

A Contract Specialist from the Acquisition group will contact you shortly regarding the process of negotiating an award.

Please provide the requested documents to the attention of Amanda Lopez, who is the Contract Specialist from the Acquisition group handling the administrative portion of your application. Ms. Lopez can be reached at 304-285-4220 or Amanda.Lopez@netl.doe.gov. Diane Madden is the NETL Project Manager from the Project Management Division handling the technical portion of your application and can be reached at 412-386-5931 or Diane.Madden@netl.doe.gov

Sincerely,

Jeffrey S. Kooser
Contracting Officer
Finance and Acquisition Center

cc: FOA File
nnguyen@barr.com
Diane.Madden@netl.doe.gov
Amanda.Lopez@netl.doe.gov

Appendix G

Project Timeline Chart

PROJECT TIMELINE DO-FOA-0001989

ID		Task Name	Duration	Start	Finish
1		**Budget Period 1**	**396 days**	**Fri 7/12/19**	**Fri 1/15/21**
2		Award	0 days	Fri 7/12/19	Fri 7/12/19
3		Task 1 – Project Management and Planning.	18 mons	Mon 9/2/19	Fri 1/15/21
4		Task 2 – Laboratory Scale Testing	15 mons	Thu 8/1/19	Wed 9/23/20
5		Task 3 – Sorbent Injection Modelling - CFD	9 mons	Fri 2/7/20	Thu 10/15/20
6		Task 4 – Equipment Design and Sizing for Field Demonstration	10 mons	Mon 4/13/20	Fri 1/15/21
7		Go/No Go	0 days	Fri 1/15/21	Fri 1/15/21
8		**Budget Period 2**	**389 days?**	**Mon 1/18/21**	**Thu 7/14/22**
9		Task 1 – Project Management and Planning.	18 mons?	Mon 1/18/21	Fri 6/3/22
10		Task 5 - Procurement, Installation and Construction:	8 mons	Mon 1/18/21	Fri 8/27/21
11		Task 6 – Parametric Testing – Field Demonstration:	1 mon	Mon 8/30/21	Fri 9/24/21
12		Task 7 – Data Reduction and Evaluation of Parametric Testing:	6 mons	Mon 9/27/21	Fri 3/11/22
13		Go/No Go	0 days	Fri 3/11/22	Fri 3/11/22
14		Task 8 – Extended Sorbent Testing:	1 mon	Mon 3/14/22	Fri 4/8/22
15		Task 9 – Data Reduction and Techno-Economic Assessment:	3.45 mons	Mon 4/11/22	Thu 7/14/22