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April 1, 2022

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

Subject: University of North Dakota request for amendment to Contract FY20-XC-221 “Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks.”

Dear Ms. Fine,

The University of North Dakota Institute for Energy Studies (UND-IES) is very grateful for your support and the support of the Lignite Research, Development and Marketing Program, which has made it possible for us to advance the development of our technology from the laboratory-scale to the pilot-scale. However, due to covid-19 pandemic-related challenges, our team has experienced significant cost and schedule overruns in the construction of our pilot-scale lignite-based rare earth element (REE) extraction facility.

To manage these challenges, in the enclosed proposal, we are respectfully requesting an award amendment to increase the NDIC funding approval by \$175,000 (from \$900,000 to \$1,075,000). This additional funding will be augmented by additional funding from the U.S. Department of Energy (\$405,000) and the lignite industry (\$70,000). These additional funds will enable our project team to successfully complete the full scope of work as originally proposed to NDIC in 2019 and laid out in our existing contract FY20-XC-221.

Our team, including our industry sponsors, are very excited about the commercial potential of our technology and the significant benefits it can provide the North Dakota lignite industry, the State and the Nation. Successful completion of the pilot-scale project will lead to the next steps towards realizing a first-of-a-kind commercial project in North Dakota.

In addition to the enclosed request for amendment, the \$100 application fee has been submitted electronically using ACH. Two hard copies of the proposal will be sent via regular mail. Please let me know if you have any questions or require any additional information to consider this request.

Sincerely,



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**AMENDMENT TO: RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION
AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS**

Submitted to:

**Ms. Karlene Fine
North Dakota Industrial Commission Lignite Research Program
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840**

New Funding Requested: \$175,000

Submitted by:

Institute for Energy Studies
College of Engineering and Mines
University of North Dakota
P.O. Box 8153
Grand Forks, ND 58202

Project Manager:

Nolan Theaker
Phone: 701-777-6298
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A handwritten signature in dark ink, appearing to read 'Nolan Theaker', is positioned above a horizontal line.

Nolan Theaker, Technical Group Manager – Critical Minerals
Institute for Energy Studies

April 1, 2022

**RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE
FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS**

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RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

1. ABSTRACT

Due to cost and schedule overruns outside of the project team's control, a contract amendment to the existing NDIC award # FY20-XC-221 is proposed to increase the total project budget in order to achieve the project objectives originally proposed. A total budget increase of \$650,000 (<10% of original award) is being requested from project sponsors, including NDIC, the Department of Energy (DOE) and lignite industry partners. This budget increase is needed as a result of significant cost increases and schedule changes caused by supply chain and labor disruptions from the covid-19 pandemic, and will be used to successfully complete all aspects of the originally proposed project, as follows:

- construction, commissioning, and operation of UND's pilot-scale facility processing up to 0.5 tonnes per hour of cleaned lignite feed to recover and concentrate rare earth elements (REE) and critical minerals (CM)
- analysis and testing of reliability and possible process control schemes for management of unstable feedstock conditions
- refiner testing and analysis of produced UND concentrates for determination of suitability, impurity constraints, and possible cost effects associated with commercial-scale separation of the REE and/or CM products
- development and analysis of a NI-43-101 formatted Preliminary Economic Assessment of a specified resource and the piloted resource recovery technology, with major gap analysis and analysis of process economics to an AACE Class 4 accuracy

The proposed amendment of \$650,000 includes a request for \$405,000 from the DOE, and the use of an additional \$70,000 committed cost share funds to the project from North American Coal Corporation. **We are requesting \$175,000 in new funding from NDIC (an increase from \$900,000 originally awarded to \$1,075,000).** The proposed project, when completed, will position the project team to pursue commercialization of a technological solution to key challenges facing the supply chains of multiple CM and for continued use and development of the United States' and North Dakota's significant lignite reserves.

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2. PROJECT SUMMARY

The University of North Dakota, maintaining its team of Microbeam Technologies Incorporated (MTI), Barr Engineering Co., Rare Earth Salts (RES), and MLJ Consulting, is proposing an amendment to the existing NDIC award # FY20-XC-221 to enable the completion of the scope for the economical evaluation and demonstration at a pilot-scale of the originally-proposed novel technology for rare earth element (REE) recovery from North Dakota lignite coal and related feedstocks.

As we will describe herein, the covid-19 pandemic has resulted in significant cost overruns associated with construction of the pilot-scale system. These cost overruns and schedule delays have been completely outside the project team's control, as the original proposal was submitted in 2019, without any knowledge of the ultimate impacts that the pandemic would cause. We have attempted to limit these impacts during the course of the project, but we have reached the point where it is clear that additional funding will be required to complete the full scope of the project as originally proposed. While it may be possible to reduce the scope of the project to stay within the original award budget, our team feels strongly that going down this path would be significantly detrimental to our chances of successful commercialization and realizing the benefits to the North Dakota lignite industry. As such, we are respectfully requesting additional funding from the U.S. Department of Energy (DOE), North American Coal Corporation (NAC), and NDIC. This proposal is, therefore, a contract amendment proposal to increase the funding award from NDIC.

This contract amendment proposal follows the requirements of a new proposal to the Lignite Research, Marketing and Development Program as outlined in NDAC 43-03-04 and we also include, as an appendix, our original 2019 proposal to NDIC. Much of the information is the same as originally provided in the 2019 proposal, but we provide supplemental information where appropriate to describe progress to date and specific reasoning for this amendment request. Technical reviewers may also find it useful to review our team's quarterly report submissions, which can be provided by NDIC.

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3. PROJECT DESCRIPTION

3.1 Overall Project Goal

The overall objective of this proposed project is to demonstrate at the pilot scale a high performance, economically viable and environmentally benign technology to recover rare earth elements (REE) from North Dakota (ND) lignite coal feedstocks.

3.2 Project Objectives

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

- Design and construct a pilot-scale system for continuous REE extraction from ND coal feedstocks capable of a minimum 0.25 tons/hr feed rate of physically beneficiated lignite coal based on previous laboratory and bench scale testing at UND.
- Leveraging prior REE project experience, obtain a large sample (~300 tons) of high REE (>300 ppm following coal cleaning) from the Freedom mine in North Dakota for testing in pilot-scale demonstration facility.
- Conduct initial parametric testing of a sample of the Freedom lignite, leveraging bench-scale equipment from previous projects, to cost-effectively identify optimal operating conditions and aid in the design of the pilot-scale system.
- Commission the pilot facility using selected high REE containing coals from various regions in ND.
- Conduct continuous pilot-scale testing utilizing optimal conditions for REE extraction and concentration on at least 100 tons of the >300 ppm REE-containing Freedom lignite.
- Confirm compatibility of REE concentrate generated during pilot-scale testing with commercial-scale REE refining.
- Based on results from the pilot testing campaign utilizing the Freedom lignite, conduct a preliminary Front End Engineering Design (pre-FEED) study on a potential commercial facility, in which an economic feasibility study and workforce assessment will be contained.

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- Work with industry partners to develop a technology roadmap and commercial deployment plan.

3.3 Scope of Work

The original project scope of work may be found in the appended original 2019 proposal. Major accomplishments associated with specific tasks completed to date, as well as future planned testing, will be described in the below task sections.

A. TASKS TO BE PERFORMED

PHASE I:

Task 1.0 - Project Management and Planning

UND shall continue management and direction of the project in accordance with the Project Management Plan, defining specific plans to meet proposed technical, schedule, and budget objectives. Significant deviations that have occurred from the proposed plan have been as a result of major supply chain and labor disruptions beyond the scope of those foreseen, and the project team is considering such supply disruptions and concerns in all future efforts. Continual, periodic briefing of the project via reporting and/or presentations or meetings, as needed/defined, will continue for project participants and sponsors, culminating in a final report and close-out presentation on project activities.

SubTask 1.1 – Project Management Plan

The original Principal Investigator (PI) proposed was Dr. Mike Mann. A previously approved amendment changed the PI to Mr. Nolan Theaker, who will lead the project to completion. A new addition to the team is Dr. Daniel Laudal, the Director of the UND Institute for Energy Studies (IES). Dr. Laudal was one of the original inventors of the foundational technology being used and was the original PI on UND's bench-scale testing project. Dr. Laudal recently rejoined the IES and will assist Mr. Theaker in project management going forward. Our risk management plan also includes addition of risks associated with supply chain availability, price, and schedule of needed items. No other material changes are proposed.

SubTask 1.2 – Technology Maturation Plan

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A technology maturation plan was completed within the first phase of this project, and will be updated prior to project completion with projected costs and timelines required for technology commercialization.

SubTask 1.3 Workforce Readiness Plan

The project team successfully completed the first draft of this plan, and will continue to monitor and update its assessment of workforce availability and development plans throughout the life of the project.

Task 2.0 - Financial Plan for Commercialization

UND has completed preliminary versions of the Financial Plan for Commercialization as per requirements for the Go/No-Go decision passed in 2020. UND will continue to update and analyze possible scenarios for commercialization of the technology, including cost reduction methods (both operating and capital), identification of possible funding mechanisms for preliminary funding support, as well as defining the impact of the technology in the supply chains of the critical minerals (CM) targeted.

The financial plan will consist of a written report with the key assumptions and data used for development being documented in the design basis. The results of the design basis and financial plan will be utilized and refined through subsequent tasks. A final financial plan will be developing using all data and experience gained through execution of the project and will be complete 30 days prior to award completion.

Task 3.0 – Techno-Economic Assessment

UND has developed a preliminary Techno-Economic Assessment (TEA) based on previous testing and analysis of possible feedstocks and reserves. This was updated from prior work (DE-FE0027006), including mass and energy balances, equipment sizing and selection, estimates of reagent and water usage, analysis of waste disposal costs, labor estimate, among others, and will be updated at the conclusion of the project using the knowledge gained from the design and operation of the pilot facility.

The final TEA will include a design estimate with adequate detail to be classified as an Association for the Advancement of Cost Engineering (AACE) Class 4 or better estimate. This estimate is intended to serve as a pre-Front-End Engineering and Design (pre-FEED) level estimate for a future commercial scale

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demonstration project. In order to obtain the AACE Class 4 estimate, Task 3.0 will require the creation of a design basis, process model (including mass and energy balance and process flow diagram), proposed plant general arrangements, equipment specifications, and a Basis of Estimate. Task 3.0 will consist of the engineering documents outlined above for the completion of the cost estimate, the AACE cost estimate, and the full TEA interactive Excel model. This TEA will be included within the scope of the NI-43-101 formatted Preliminary Economic Assessment planned as the Task 5.0 final deliverable.

Task 4.0 – Provide Split Samples

No change or action from original proposal.

Task 5.0 – Feasibility Study

UND completed a Feasibility Study 30 days prior to the Go/No Go decision point in the framework of the Canadian National Instrument 43-101 (NI-43-101), including preliminary cost of processing, reserve estimates, and possible environmental concerns associated with the commercialization of the technology.

Notable findings included:

- A significant lack of drilling and resource characterization work, well below levels commensurate with compliant NI-43-101 documents in proposed reserves
- A deficiency in the understanding of the proposed resource extraction technology's effectiveness with the defined reserve as would be required (via pilot testing of a feedstock) prior to compliance
- A deficiency in the technical assurance in the proposed pathway to final marketable products (refined oxide materials) as a result of a lack of testing of the proposed mixed REE concentrates with commercial refiners.

These deficiencies were considered with the second phase of the project, as well as the other proposed workscope, and methods of addressing these were planned in the ongoing phase (such as with mine testing and drilling, refiner testing of multiple possible forms of proposed concentrates, as well as the development of a rigorous piloting system capable of handling disparate feedstocks for specific reserve testing).

Task 6.0 - Large Sample Collection and Preparation

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A large sample (combined 350 tons of lignite coal) was received and determined by UND to be adequate for the proposed testing of the pilot system within the first budget period.

Subtask 6.1 – Large Sample Planning:

Completed as of 2019.

Subtask 6.2 – Procurement and Preparation:

Procurement of coal was completed within 2020, with final crushing and preparation of coal discussed and planned for the week prior to operation (so as to avoid storage of large volumes of coal fines for prolonged periods of time).

Task 7 – Pilot Plant Design

This task includes the design of the pilot plant, including finalizing site location, sizing and planning of all equipment, necessary environmental controls, and staffing requirements of the plant, and was completed prior to the Go/No-Go decision in 2020.

7.1 – Planning and Conceptual Design of the Pilot Plant

Subtask completed in 2020.

7.2 - Permitting and Logistics Planning

This subtask was largely completed in 2020, with final logistical planning of chemical receipt into the plant for operation completed within 2019.

GO/NO GO DECISION POINT AFTER TASK 7

The Go/No-Go decision point was successfully passed by the project team in September, 2020, with the following milestones identified as the defining metrics for acceptance.

- DOE approval of Technology Readiness Plan, Workforce Readiness Plan, Financial Plan for Commercialization, preliminary Techno-Economic Analysis and Feasibility Study
- All permits have been received and the site approved.
- Verified availability of suitable reserves of coal for pilot testing with proven > 300 ppm REE on a cleaned, whole coal basis.

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- TEA shows scenarios with positive NPV using the global economic assumptions provided by DOE in FOA-0002003.

PHASE II:

Task 8 – Pilot Plant Procurement and Construction

The bulk of the cost and schedule overruns that have necessitated this contract amendment request have originated from this task. The covid-19 pandemic has significantly increased the costs of equipment as compared to what was originally quoted by vendors in early 2019. Supply chain disruptions have also resulted in significantly longer lead times for many major and minor equipment, resulting in challenges in syncing the timing of the construction and increased construction labor costs. We are proposing new funding from DOE to cover the equipment cost increases and new funding from NDIC to cover the labor cost increases.

Subtask 8.1 – Plant Component Procurement

Pilot procurement has been largely completed, with only ancillary items, as needed (such as piping, sheet metal, hoppers for solid storage, etc.), remaining. Significant lead time delays (in some cases increasing by more than 6x – an increase from a 12-week lead time to a 12-month lead time) have significantly delayed the completion of this task, and as such, as much progress on subtask 8.2 as can be reasonably achieved has been pursued while delays in equipment receipt occurred.

In addition, there have been significant increases in costs of equipment associated with the project. As examples: i) increase in instrumentation cost (sensors, housing, and wiring) by over \$75,000 from originally proposed/quoted (as a result of copper wire cost escalation), ii) filter press cost increases from original quoted by \$12,000 each (8 total filter presses installed), and iii) general increases in costs (valve costs increased by up to 20% times >180 valves in the process). Nearly everything that has been purchased to date, from small components to major equipment, has increased in cost compared to early 2019.

Subtask 8.2 – Plant Construction

Construction of the pilot facility, to the limit of the available equipment on-site and delivered, has largely been completed, including the preponderance of plumbing, wiring (both >120V and signal wiring),

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solids handling, chemical feed and addition (both from suppliers and from storage into the process), safety mechanisms and controls. Construction of remaining items will continue as per receipt of final equipment pieces, and is scheduled for completion in June-July, 2022 (final completion pending receipt of long-lead time items). The photograph below shows the pilot plant construction in progress. In the image can be seen two of the large filter presses and several of the process tanks and associated plumbing.



Labor costs for construction have proven higher than anticipated, largely due to inefficiencies generated from exorbitant lead times and/or late deliveries of items. For example, lead times associated with new data acquisition hardware using the existing systems in place is now being guaranteed at an 11-12-month lead time, along with other vendors commonly missing delivery dates by up to 2 months. These delays in delivery of material significantly detract from efficient use of fabrication labor.

Subtask 8.3 – Plant Shakedown Testing

After completion of the continuous pilot plant system, shakedown testing of the integrated system for adequate performance and training for operators will verify total system performance. Preliminary draft procedures for shakedown testing, including coal spiral shakedown and analysis, control PID loop tuning,

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leak and stress-testing of filtration components, and effective process and emergency control utilization are planned.

Task 9 – Bench-Scale Feedstock Testing

This task, divided into the two sections involving the UND bench-scale testing of the lignite feedstock blend and the RES bench-scale testing of the UND concentrates produced, has significantly progressed. UND bench-scale testing of the lignite feedstock blend was completed in 2021, generating more accurate pilot design criterion and anticipated pilot operational parameters (pH, residence times, etc.), with the combined bench-scale concentrates produced sent and received by RES for refiner testing. However, UND's bench-scale system did not produce the quantity of concentrate needed for RES feedstock testing in cells, and as such refiner testing has been thus-far limited to synthetic and/or similar blends to the UND concentrates, without utilizing specific lignite-derived materials.

Upon operation and concentrate production from UND's pilot facility (producing 10+ kg of concentrate planned over the project), suitable quantities of concentrate will be present for refiner testing and analysis, and will be critical in alleviating NI-43-101 deficiencies identified within Task 5.

Task 10 – Pilot Plant Testing of Chosen Feedstock/Feedstock Blend

Subtask 10.1 – Abbreviated Parametric Testing Based on Bench-Scale Data for Chosen Feedstock

Utilizing results from the bench-scale testing, abbreviated parametric tests around highest opportunity ranges identified through bench testing will be conducted. Each unit operation will be tested sequentially. Economically optimal conditions for each prior unit operation will be the feed for further unit operations.

Subtask 10.2 – Continuous Operation Testing on at least 100 tons of chosen feedstock

Utilizing optimum parametric conditions for the chosen feedstock, process at least 100 tons of chosen feedstock to generate a minimum of 10 kg of >2wt% REE concentrate, thereby meeting DOE requirements. It is expected that the testing will generate at least 30 kg of >50wt% REE.

3.4 Anticipated Results

The anticipated results of the proposed project are summarized as follows:

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- Successful demonstration of the proposed technology at a 0.50 ton/hr throughput (on a cleaned coal basis) and production of approximately 30 kg with at least 50 wt% REE on a dry, cation basis.
- Optimization of the REE extraction process and definition of complete flowsheet/unit operations required to achieve the target purity levels
- Completion of a technical and economic feasibility study that will include detailed process flow diagrams, equipment specifications, mass and energy balances, and economic metrics (i.e. capital and operating expenses, rates of return, payback time). A pre Front End Engineering and Design (pre-FEED) for future commercial-scale demonstration project will be delivered.
- Preliminary commercialization strategy to identify the opportunities at existing mines/power plants or justification of a new mine opening. This will include overall process configuration that includes REE extraction as well as byproducts usage/processing and integration within existing facilities or value chains. A business plan for commercializing the technology will be included.
- The project will demonstrate a high performance, economically viable and environmentally benign method for production of REEs from the vast lignite reserves in North Dakota. This will open up new opportunities and increase the value of lignite use. Upon completion of this small pilot-scale test program, the technology will be ready for demonstration-scale and rapid commercialization.

3.5 Facilities and Resources

UND and the project team have maintained and added to the facilities and resources available to the project, most notably the addition of the Drilling and Completions Laboratory and Research Center at the College of Engineering and Mines, where the pilot facility is housed.

3.6 Environmental and Economic Impacts during Project

No additional environmental/economic impacts beyond the original proposal.

3.7 Technical and Economic Impacts of Proposed Technology

Impacts of the technology identified and remain the same as originally proposed.

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- Demonstration of a novel and economically viable method to recover rare earth elements from North Dakota lignite and lignite-related feed stocks
- The properties of lignite coal offer a unique opportunity that results in lower cost REE recovery from coal and coal-related materials than higher rank coals or coal combustion byproducts
- New markets for lignite coal will be created, including new jobs associated with the REE recovery/separation/purification processes
- Successful development of REE recovery technologies for coal will displace imported REEs and REE-based products, resulting in increased economic and national security for the U.S.
- Development of the new resource for REEs will create price stability and promote new REE innovation in the U.S. that will reduce monopolistic control of the REE value chain by China
- A secure domestic source of critical REEs will be available to high importance end uses such as military defense applications, electronics and hybrid/electric vehicles. ND lignite, in particular, has a very favorable distribution of particular REEs that are more valuable, are used in market growth sectors and are currently in scarce supply globally.

Preliminary techno-economic assessments and feasibility studies have demonstrated strong evidence for a cost-effective method of generating a REE-concentrate from ND lignite, significantly enhanced through the sale of multiple byproducts, including CM and upgraded coal products. As a part of the current effort, Barr Engineering is completing an AACE International Class IV - Study or Feasibility with accuracy in the range of about $\pm 30\%$. Results from their analysis summarized in Table 1 show strong economic potential for the process. UND has been working with Valley City State University to host the first small commercialization plant (see letter of interest included with the 2019 proposal). The size of the first plant, 5 ton/hr, matches the current feedrate of their existing steam plant, and provides the opportunity to further process the coal into activated carbon. Under this scenario (Case 1), the high value of the activated carbon makes the project profitable, even at this low feed rate when economies of scale are not yet realized. This site was chosen as potentially serving as the first commercial demonstration as the ability to co-produce

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activated carbon provides buy-down of the economic risk. In addition, there is interest from the North Dakota University System to duplicate the steam/activated carbon/REE plant at other institutions across North Dakota.

Table 1. Summary of Economics of UND REE Process from the Phase 2 TEA.

Case	1	2	3	4	5
Lignite Feed Rate, ton/hr	5*	5	10	21	100
CAPEX	(\$24,200,000)	(\$24,200,000)	(\$27,600,000)	(\$33,700,000)	(\$59,700,000)
OPEX	(\$7,600,000)	(\$7,600,000)	(\$13,000,000)	(\$24,900,000)	(\$106,700,000)
REE and Base Metal Payable Amount per year	\$7,100,000	\$7,100,000	\$14,300,000	\$30,300,000	\$142,800,000
Upgraded Coal Payable Amount per year	\$6,400,000	\$2,800,000	\$5,500,000	\$11,800,000	\$55,500,000
Net Annual Revenue per year	\$5,900,000	\$2,300,000	\$6,800,000	\$17,200,000	\$91,600,000
Simple Payback (years)	4.1	10.5	4.0	2.0	0.7
IRR (10 years)	20%	-3%	20%	50%	153%
ROI (10 years)	12%	-1%	12%	36%	128%
NPV (10 years) @ 15% discount rate	\$4,100,000	-\$13,200,000	\$5,000,000	\$48,600,000	\$377,200,000
IRR (20 years)	24%	7%	24%	51%	153%
ROI (20 years)	18%	4%	19%	44%	141%
NPV (20 years) @ 15% discount rate	\$12,600,000	-\$9,900,000	\$14,700,000	\$73,200,000	\$507,800,000
CAPEX/annual dry ton feed	\$580	\$580	\$330	\$190	\$70
OPEX/annual dry ton feed	\$180	\$180	\$150	\$140	\$130
Net Revenue/annual dry ton feed	\$140	\$60	\$80	\$100	\$110

Assumptions: Feed rates, raw materials, and other costs based upon testing of H-Bed lignite sample; 50% recovery of REE; REE sold as a mixed oxide to be further refined; cost of upgrading mixed oxide to individual REE oxides included in the analysis; REE oxide prices based upon FOA; delivered cost of coal to plant \$25/ton; upgraded coal sold at a 30% premium over the cost of the as-mined coal.

*Scenario based upon integration with Valley City State University; residual coal upgraded to activated carbon.

Realizing that the activated carbon market is relatively small, Cases 2 through 5 are performed assuming the coal by-product will be sold as an upgraded boiler fuel, commanding a 30% premium above the current price of coal (based upon discussion with ND utility and coal mine partners). The economies of scale are evident from this analysis, with the economics improving as the importance of capital cost diminishes with plant size. Under the base assumptions, breakeven at a 15% discount rate would occur at a plant size of 7 ton/hr. UND's plan for full commercial implementation expects plant sizes between 10 and 100 ton/hr, with the optimal range determined as a part of the work scope of this project. Sensitivity analyses were also performed around other critical variables, with the prices received for the REE and upgraded coal being the most important. At a plant size of 21 ton/hr, the plant will breakeven (NPV=0 at 15%) with no recovered cost from the upgraded coal. At this plant size, 21 ton/yr and with the sale of

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upgraded coal, the price received for the REE oxides could be reduced by approximately 40% and the process can still breakeven.

The UND team has also analyzed the importance of the relative abundance of various elements within the feed coal. While the bench-scale work focused on feedstocks of greater than 300 ppm, lignites have been identified with high ratios of heavy-to-light rare earth elements, with the value of the REE sales being more dependent upon the individual elements present, rather than the total REE concentration. For example, the lignite from the Freedom Mine Rider seam proposed for this work has approximately 25% of its REE concentrated in Pr, Nd, Eu, Tb, and Dy, making this a high value feedstock with economics more favorable than those shown in Table 1.

Process supply risks to the process are low, primarily due to the use of commodity chemicals and a feedstock with great abundance and reserves (Harmon-Hansen coal zone). Variability in high-REE feedstocks is a concern for the process, with development of a continuous feedstock monitoring and control scheme envisioned for management of this risk. Additionally, use of sorting equipment, such as PGNAA full-stream elemental analyzers, are being investigated as a method of sorting high-REE feedstocks from as-mined coal, allowing for a higher degree of feedstock control.

Product price risks are of concern for the process, as with the REE industry as a whole, and have been managed in the proposed technology by leveraging byproduct sales, including the upgraded lignite coal product and CM such as Ga, Ge, Co and Al, totaling a larger revenue than combined REE sales. These products have been priced using input from commercial partners and literature mineral commodities values supplied from the U.S. Geological Survey [1]. With the current scale of the byproduct markets, significant price impact from facilities using this technology are unlikely. Additionally, positive NPV's are possible at larger scales using a sale price of only 60% of the contained value, permitting economic operation of a plant even under substantial REE price reduction scenarios.

Market saturation is a concern when introducing a new technology for producing commodity goods. Since the overall economics for the proposed technology is the most sensitive to the selling price of the REE, the impact of producing REE from lignite coal on market penetration has been assessed and is

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summarized in Figure 1. The current total US consumption of 16,000 tons/yr REE is expected to grow. North Dakota has the potential to capture a modest share of that market, while not saturating the market and adversely impacting the price. For example, a small plant (21 ton/hr as used in the example above) only captures 0.8% of the total market. A larger plant designed with a feed rate matched to a 120 MW power plant would capture about 1.25% of the market, while having the potential to generate \$180 to \$360 million per year revenue for coals with REE ranging from 300 to 600 ppm, respectively. Therefore, this process offers the potential for high returns with a low economic/price risk.

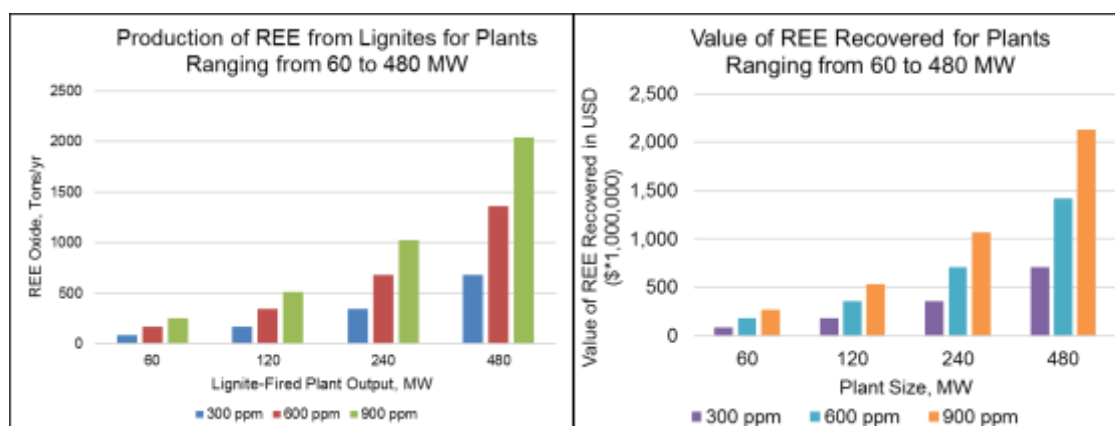


Figure 1. Potential production of REE from ND lignite power plants

Commercialization of the technology from the current technology developers will be conducted through technology licensure to commercial entities, with preference given to the commercial partners on the project. Commercial partners such as coal reserve companies and power utilities have shown interest in licensing of the technology thus far and represent likely candidates for commercialization outlets.

3.8 Project Need

With increasing environmental regulations on fossil-fuel based power and decreasing coal production nationwide, new opportunities for marketable use of lignite coal are required to maintain the existing mining/lignite use infrastructure, jobs and economic impact in the State. The recovery of REEs from ND lignite and related materials has potential to be a significant new industry for the state that will both maintain existing jobs and create new jobs and revenue for the State. The results from previous and current work (see Section 5) are extremely encouraging, and the unique properties of ND lignite coal make recovery of

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REEs a simpler and lower-cost proposition than either higher rank coals or traditional mineral ore-based resources. Additionally, the U.S. is currently 100% import reliant for REEs, and critical end-use applications in growing market sectors require a stable, domestic supply. Under the current conditions, extreme instability/uncertainty exists due to monopolistic control of the entire REE value chain by China. To ensure the national and economic security of the U.S., it is imperative that domestic sources of REEs be identified and processes developed to produce them. This is the focus of the proposed project.

4. STANDARDS OF SUCCESS

The standards of success for the project as originally proposed still are applicable to this amendment, with the addition of:

- Detailed review and analysis of the final completed Feasibility Study in a NI-43-101 format to identify remaining gaps, associated costs and schedules for addressment of gaps, to enable commercial deployment of the proposed technology concept.

5. BACKGROUND INFORMATION

No new background information is provided. We refer technical reviewers to the Background Section provided in the appended original 2019 proposal.

6. QUALIFICATIONS

We are not proposing any new organization team members, as the originally proposed team (from the 2019 proposal) is fully intact. We refer technical reviewers to the Qualifications Section in the attached original 2019 proposal.

The project team and key personnel are exceptionally well qualified to perform this project. While the project team organizations are unchanged from the original proposal, there are new personnel members/roles. The project is now led by Mr. Nolan Theaker, Technical Group Manager – Critical Minerals of the UND Institute for Energy Studies. Mr. Theaker was originally listed as a co-PI in the 2019 proposal, with Dr. Michael Mann as the project's PI. A previously NDIC-approved amendment was issued to make the change to Mr. Theaker as the new PI, who will lead the project to completion. Mr. Theaker has extensive experience in the development of REE/CM extraction, evaluation, and economic assessment projects. He

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served as the co-PI and technical lead for the previous \$3.5M award developing UND's process to the bench-scale, and was instrumental in its success and co-authors two of the patent applications associated with the process.

Dr. Daniel Laudal, Director of the Institute for Energy Studies at UND, will assist Mr. Theaker in project management and will serve as a technical advisor to the project team. Dr. Laudal was previously the lead researcher on the lab-scale project and the PI on the bench-scale project and is one of the co-inventors on the relevant IP associated with this proposal/technology. Dr. Laudal's PhD dissertation was the foundation for UND's REE/CM from lignite research program. Prior to recently rejoining the IES as its new Director, Dr. Laudal was the environmental manager and Project Tundra development manager at Minnkota Power Cooperative. For a period of about two years (2019-2021), Dr. Laudal led Minnkota's efforts on the engineering of the carbon capture plant, the permitting of the geologic storage facility, and initial financing activities. With his unique knowledge and experience in the proposed REE technology and extensive project management experience, Dr. Laudal's addition to the proposed project will provide great benefit.

Other personnel team members as originally provided in the 2019 proposal are unchanged.

7. VALUE TO NORTH DAKOTA

North Dakota produces over 30 million tons of lignite annually. The state's economy is heavily invested in the production and use of lignite. Successful completion of the proposed project will open a new high value commercial opportunity for lignite use. A completely new industry will be realized if successful commercialization of the technology is achieved, providing new opportunities for high-paying jobs and new tax revenues for the State. Several potential commercialization strategies have been conceptualized, each of which will provide tremendous economic impact to the state. Although the proposed project is focused on extraction and concentration of REEs from lignite, additional processing steps will be required to arrive at final REE products. Having a lowest cost source of REE concentrate in the Nation will encourage location of these processors/refiners in North Dakota, further increasing employment and revenue opportunities.

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8. MANAGEMENT

The project structure is designed to facilitate management of the project by task. The task lead and lead individual from each partner organization are listed in Figure 9. UND will be the lead for the project, serving to direct the technical and scientific aspects, managing resources, scheduling and budgets, and be the point of contact between DOE NETL and other project participants/sponsors. Mr. Nolan Theaker will act as the Principal Investigator for this effort. He has co-led multiple other \$1M+ projects, including the previous bench-scale work noted above, and will be assisted by project advisor Dr. Daniel Laudal. Cost management will be coordinated by the Administrative Resource Manager who will be responsible for tracking all costs for each of the project tasks.

Co-PI, Nick Sosalla, assisted by Dr. Dan Palo, Barr, will lead Tasks 2, 3, and 5, which include developing the financial plan, the feasibility study, and the techno-economic analysis. Barr Engineering has been a partner on our previous work and has extensive experience in coal mining and handling, power generation, minerals exploration, and minerals processing and extractive metallurgy. Their experience in the processing of other ores, such as iron, copper, gold, uranium, trona, and sylvinitite provides critical background to the proposed work. They will also provide significant input into the pilot plant design, including permitting, and construction of the plant as these tasks align well with their current portfolio of projects.

Co-PI, Dr. Ryan Winburn will co-lead Task 9. Dr. Winburn is a co-developer of the RES refining process and has ties to the North Dakota lignite industry. Co-PI, Dr. Steve Benson, MTI, was the original PI for the Phase I developmental work and maintained that role for the Phase II efforts before he left UND to focus his attention on MTI, a company he founded. His company will provide advice regarding the process development (Tasks 2, 3, and 5) and analysis and engineering support for Tasks 8, 9, and 10. He will also lead the effort of integrating on-line analysis into the mining process to expedite the use of selective mining techniques, which will enhance commercialization of the process.

MLJ Consulting, and in particular Dr. Mike Jones, will assist the project team related to the market analysis, technical and economic analysis and commercialization plan development efforts. Dr. Jones brings

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tremendous knowledge of, and relationships in the lignite industry in the State and will greatly augment the project. The ND Geological Survey, in particular Mr. Ned Kruger and Mr. Ed Murphy, will provide technical support regarding the geology and geochemistry of ND lignites and in selection of sites for sample collection, critical for the development of the commercialization plan. Under separate efforts, the NDGS has been sampling in Southwestern and Western ND, and has identified several areas that are targets for commercialization.

Project meetings and conference calls with the core project management team will be held on a biweekly basis to conduct project activities, review project timelines, upcoming milestones/deliverables, costs, and challenges associated with the completion of the project tasks. Microsoft Project management tools will be utilized. Project review meetings with sponsors will be held semi-annually to ensure communication and discussion of accomplishments, plans and management of project risks. Intellectual property management and discussions have been initiated. During the course of the project, any new findings will be promptly documented and patent applications to protect the intellectual property filed as necessary. Discussions with potential commercial sponsors have been initiated regarding further development and scale-up of the technology and will be continued on a semi-annual basis as the project progresses.

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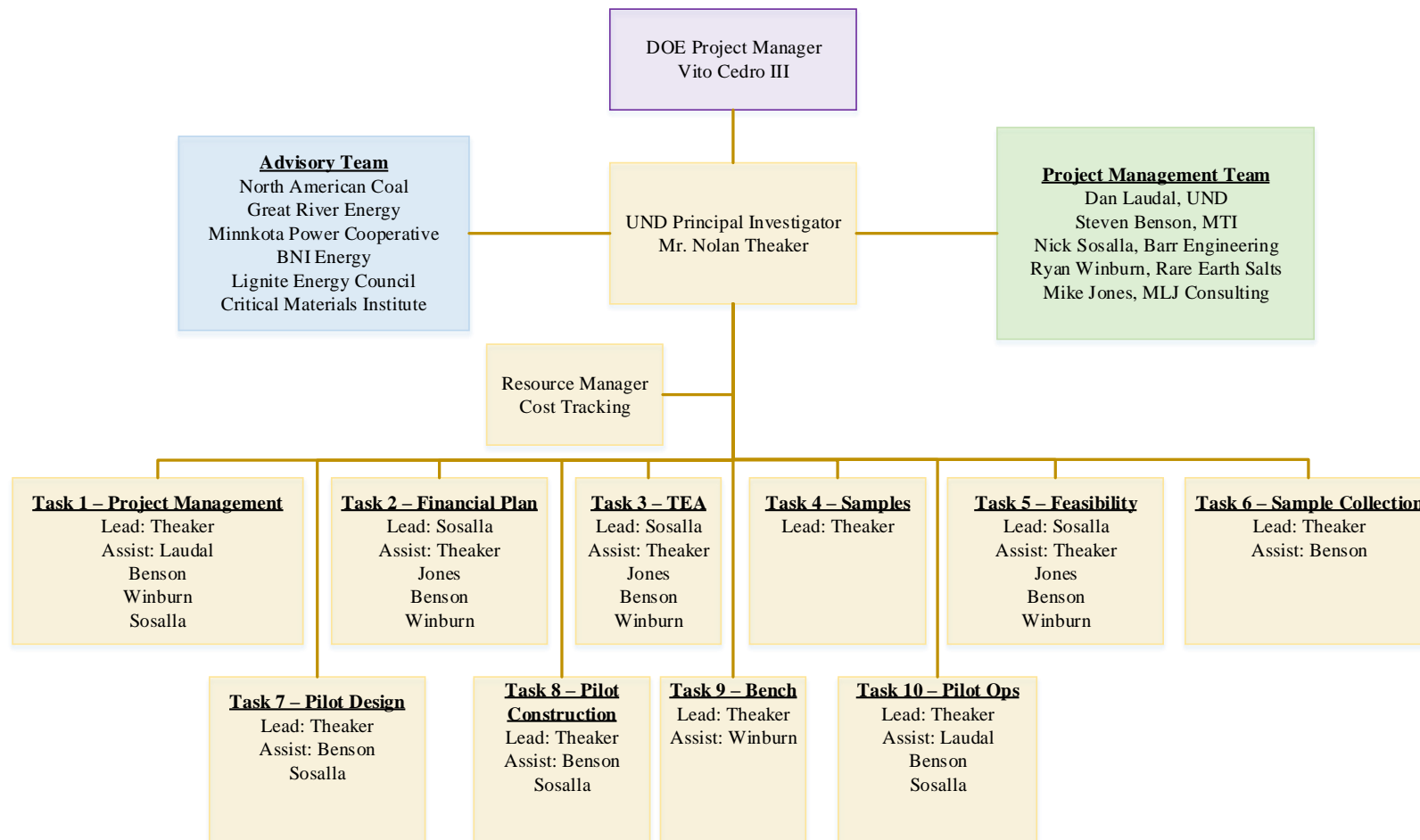


Figure 9. Project Organization

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9. TIMETABLE

The timetable for the project has been extended to June 30th, 2023, with the following Milestone table representing the updated project timeline. The project Gantt chart is displayed in Figure 10. Major milestones and planned completion dates are provided in Table 2.

Table 2 Milestone Log.

Task/ Subtask	Milestone Title & Description	Planned Completion Date	Verification method
1.1	Update project management plan	11/15/2019 As needed thereafter	Plan approved by DOE/NDIC
1.2	Technology Maturation Plan	5/30/2020	TMP approved by DOE/NDIC
1.3	Workforce Readiness Plan	5/30/2020	Plan approved by DOE/NDIC
2.0	Financial plan developed	5/30/2020	Plan approved by DOE/NDIC
3.0	Techno-economic analysis plan complete	5/30/2022	Plan approved by DOE/NDIC
5.0	Feasibility study completed	8/31/2020	Study approved by DOE/NDIC
6.2	Verified availability >300 ppm cleaned coal	5/31/2020	Quarterly Report
7.1	Pilot plant design completed	8/31/2020	Quarterly Report
7.2	Pilot plant construction and operation permits obtained	8/31/2020	Quarterly Report
8.2	Pilot plant construction completed	7/31/2022	Quarterly Report
8.3	Pilot plant fully operational	8/31/2022	Quarterly Report
10.1	Optimal conditions for pilot plant operation determined	10/30/2022	Quarterly Report
10.2	100 tons of coal processed on a continuous basis in the pilot plant	12/31/2022	Quarterly Report
9.0	Refiner suitability testing and produced 99+% pure REE (any, not all) produced	5/31/2023	Quarterly/Final Report
4.0	Split samples provided to DOE	5/31/2023	Sample delivery verified by DOE
1.0	Final report	09/30/2023	Final Report

10. BUDGET

A budget justification is provided as an appendix to this application. The proposed contract amendment requests \$175,000 in new funding from the NDIC. These funds will be augmented by \$405,000 from the DOE and an additional \$70,000 from North American Coal. The NDIC portion of this new \$650,000 will be used to support labor cost associated with Task 8, the pilot system construction. As per the contract requirements, DOE funding will pay all costs associated with major equipment. Therefore, the equipment cost overruns identified in Task 8 will be covered by the \$405,000 from DOE.

11. MATCHING FUNDS

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A breakdown of the funding sources for the proposed amendment is provided in Table 3 North American Coal has already committed \$195,000 of cost share to the project, which is \$70,000 greater than their originally committed support. This increase from North American represents the proposed change in lignite industry support. Evidence of this committed support from North American is provided in an Appendix. As shown in the table, the NDIC investment is still heavily leveraged by DOE and industry funding, with only 15% of new proposed total project cost being provided by NDIC.

At the time of this proposal submission, our team is in the process of requesting a similar contract amendment from the DOE. We have been verbally told that there is funding available from the DOE. However, DOE will need to follow a similar amendment approval process. As such, we anticipate that both the new funding from DOE and the new funding requested from NDIC will be contingent on approval by both funding sponsors.

Table 3. Matching funds breakdown and comparison between the original 2019 proposal and the new requested funding.

Organization	Original Budget	% of Total Cost	Proposed Increase	Proposed Total Budget	% of Total Cost
DOE-NETL	\$4,989,231	76.7%	\$405,000	\$5,389,231	75.3%
NDIC – LRP	\$900,000	13.8%	\$175,000	\$1,075,000	15.0%
Industry Cost Share	\$495,000	7.6%	\$70,000	\$565,000	7.9%
Project Team Cost Share	\$124,300	1.9%	\$0	\$124,300	1.7%
Total Project Budget	\$6,508,531	100%	\$650,000	\$7,158,531	100%

12. TAX LIABILITY

No outstanding tax liabilities to the state of North Dakota

13. REFERENCES

[1] Josso, P., Roberts, S., Teagle, D. A. H., Pourret, O., Herrington, R., Albarran, C. P. dL. "Extraction and Separation of Rare Earth Elements from Hydrothermal Metalliferous Sediments," Minerals Engineering, vol. 118, pp. 106-121, 2018.

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14. APPENDICES

RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

14.1 Budget Justification

Personnel

Personnel costs for the proposed budget amendment, with associated fringe and indirects, account for the entirety of the proposed budget amendment (equipment costs required to be specified through DOE-NETL as per contract requirements). The proposed budget is for an increase in planned pilot construction and operation from June, 2022 through December, 2022, and reflects the extension of personnel salaries to account for this (table below). Note: the salary and fringe anticipated for the research engineers is cumulative (9.61 months spread over both), not multiplicative to the number of engineers.

Title	Salary	Proposed Months	Fringe Rate	Total Project Cost	Basis
Project PI	\$85,809.12	2	40.31%	\$20,066	Actual Salary and Fringe
Project Advisor	\$200,025.00	1	32.08%	\$22,016	Actual Salary and Fringe
Research Engineer (2)	\$74,880.00	9.61	40.07%	\$83,997	Standard Salary and Fringe for Position Rate
Graduate Student	\$24,400.00	6	5.00%	\$12,810	Standard Salary and Fringe for Position Rate
Total Salary and Fringe				\$138,889	

Fringe

Fringe rates are calculated per employee and vary with time, so historical averaged rates are used for the positions. Actual fringe costs may deviate from this estimate within project execution.

Indirect

For the purpose of this amendment, UND's off-campus indirect rate (current definitional position of the pilot facility) of 26.0% has been used. For the proposed budget, all budgeted expenses are used in indirect calculation, for a total indirect budget of \$36,111.

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14.2 Letters of Support and Cost Share Contributions

See the original 2019 proposal for letters of support.

On the following page, we provide the most recent cost share report from North American Coal Corporation, that shows commitment of a total of greater than \$195,000, which is \$70,000 more than their originally proposed committed amount.

INKIND Financial Report

Sponsor: Name North American Coal Corp.	Date July 31 st , 2020
Address: 5340 Legacy Drive	Project Number: DE-FE0031835
Building 1, Suite 300 Plano TX, 75024	Current Billing Period 3 as of June 30th, 2020 Final Report <u> X </u> Yes <u> </u> No <u> </u>

Major Cost Elements	Amount for Current Period	Cumulative Amount from Inception
Personnel	\$31,688.71	\$79,706.29
Supplies	\$46,604.16	\$74,102.90
Travel	-0-	-0-
Equipment	\$13,094.48	\$42,366.20
Indirect Cost	-0-	-0-
Total	\$91,387.35	\$196,175.39

Certification:

By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise. (U.S. Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812.)

Date: July 30, 2020

Signature: 

Title: VP - Engineering & Business Development

UND Approvals:

Michael D. Mann PI Approval 7/30/20 Date

Chassi Herman G&C Officer 7.30.20 Date

RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

14.3 Resumes of Key Personnel

All original project personnel are remaining on the project, with the exception of Dr. Michael Mann. Dr. Mann will be retiring in May, 2022.

Dr. Daniel Laudal is a new key personnel on the project. His resume is provided in the following pages.

Dr. Daniel A. Laudal, Director, Institute for Energy Studies, University of North Dakota (UND)

Education and Training

University of North Dakota	Chemical Engineering	B.S. 2006
University of North Dakota	Chemical Engineering	Ph.D. 2017
University of North Dakota	Master of Public Admin.	Expected 2023

Research and Professional Experience

2021-Present Director, UND Institute for Energy Studies (IES)

Leading the research and academic programs in Energy at the College of Engineering & Mines. Help realize the IES 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 develop 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.

2019-2021 Environmental Manager / Project Tundra Project Manager, Minnkota Power Coop

Led the environmental regulatory compliance and environmental planning efforts for a generation & transmission cooperative serving eastern ND and northwestern MN. As Project Tundra Project Manager, led Minnkota’s development of a world-scale carbon capture and storage project for the Milton R. Young Station, a lignite coal fired power plant in ND. Responsibilities included leading development of the design, permitting and financing of the carbon capture plant and geologic storage facility.

2016-2018 Manager: Major Projects, UND Institute for Energy Studies.

Primary roles included developing and writing funding proposals, managing research projects, coordinating IES research staff and students, and process design/development of innovative solutions to challenges in the energy industry. Principal Investigator or Project Manager or several DOE, State and industry funded projects. Research focused on the following major areas: carbon management for the power industry, production of co-products from coal and associated materials, value-added opportunities/technology development for North Dakota’s energy industries.

2012-2015 Research Engineer, UND Institute for Energy Studies.

Lead researcher or principal investigator on several federal, state and industry funded projects. Work involved early-stage R&D of novel processes and technologies, primarily focusing on laboratory- and bench-scale demonstrations. Areas of focus included chemical looping combustion and post combustion carbon dioxide capture.

2008-2012 Research Engineer, UND Energy & Environmental Research Center.

Research involved design and operation of various lab and pilot-scale gasification, combustion and advanced power systems. Gained invaluable experience with high pressure and high temperature systems and fluidized beds.

2006-2008 Field Engineer, Schlumberger Oilfield Services.

Design, execution and evaluation of well cementing operations in the Williston Basin.

Selected Publications

Laudal, D., Benson, S., Addleman, S., Palo, D. “Leaching behavior of rare earth elements in Fort Union lignite coals of North America.” *International Journal of Coal Geology* 191 (2018) 112-124.

Laudal, D., Benson, S., Addleman, S., Palo, D. “Rare earth elements in North Dakota lignite coal and lignite-related materials.” *ASME Journal of Energy Resources and Technology* 140 (2018).

Park, D., Middleton, A., Smith, R., Deblonde, G., **Laudal, D.**, Theaker, N., Hsu-Kim, H., Jia, Y. "A biosorption-based approach for selective extraction of rare earth elements from coal byproducts." Separation and Purification Technology. Volume 241:116726. June 2020.

Mann, M; **Laudal, D.**; Benson, S. "Maintaining Coal's Prominence in a Carbon Constrained World." Conference Proceedings: 2017 International Conference on Coal Science and Technology and 2017 Australia-China Symposium on Energy. September 25-29, 2017. Beijing, China.

Van der Watt, J.G., **Laudal, D.**, Krishnamoorthy, G., Feilen, H., Mann, M., Shallbetter, R., Nelson, T., Srinivasachar, S. "Development of a spouted bed reactor for chemical looping combustion." Journal of Energy Resources and Technology. 140(11), 112002 (8 pages), November 2018.

Nelson, T., van der Watt, J.G., **Laudal, D.**, Feilen, H., Mann, H., Srinivasachar, S. "Reactive jet and cyclonic attrition analysis of ilmenite in chemical looping combustion systems." International Journal of Greenhouse Gas Control. Volume 91, December 2019, 102837.

Nasah, J., Jensen, B., Dyrstad-Cincotta, N., Gerber, J., **Laudal, D.**, Mann, M., Srinivasachar, S. "Method for separation of coal conversion products from oxygen carriers." International Journal of Greenhouse Gas Control. Volume 88, September 2019, pages 361-370.

Emerson, S., Zhu, T., Davis, T. Peles, A., She, Y., Willigan, R., Vanderspurt, T., Swanson, M., **Laudal, D.** "Liquid Phase Reforming of Woody Biomass to Hydrogen". International Journal of Hydrogen Energy, August 2013.

Benson, S., Srinivasachar, S, **Laudal, D.**, Browers, B. "Evaluation of Carbon Dioxide Capture from Existing Coal Fired Plants by Hybrid Sorption using Solid Sorbents." Final Technical Report. US Department of Energy Award Number: DE-FE0007603. May 2015

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., **Laudal, D.**, Nasah, J., Johnson, S., Ling, K. "Utilization of Aquifer Storage in Flare Gas Reduction." Journal of Natural Gas Science and Engineering. Volume 27, Part 2, November 2015, 1100-1108.

Patents

Laudal, D., Benson, S. "Rare earth element extraction from coal." U.S. Patent No. 10,669,610. March 2017

Theaker, N., **Laudal, D.**, Lucky, C. "Generation of rare earth elements from organically associated leach solutions." Provisional Application 63/112,842. November 2020.

Theaker, N., **Laudal, D.** "Method for leaching rare earth elements and critical minerals from organically associated materials." Provisional Application 63/112,846. November 2020.

Synergistic Activities

Dr. Laudal's technical expertise includes lignite coal and organic materials geochemistry and rare earth element and mineral recovery processes. His doctoral research and dissertation were the foundation for UND's rare earth elements research program. Dr. Laudal also has extensive experience leading large multidisciplinary projects, ranging from early R&D stages all the way through commercial projects.

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14.4 Originally Submitted Proposal



RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

Submitted to:

**Ms. Karlene Fine
North Dakota Industrial Commission Lignite Research Program
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840**

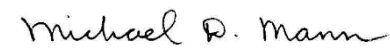
Funding Requested: \$900,000

Submitted by:

Institute for Energy Studies
College of Engineering and Mines
University of North Dakota
P.O. Box 8153
Grand Forks, ND 58202

Project Manager:

Michael D. Mann, Ph.D.
Phone: 701-777-3852
michael.mann@und.edu



Dr. Michael D. Mann, Director
Institute for Energy Studies

July 1, 2019

**RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE
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RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

1. ABSTRACT

The University of North Dakota (UND), led by principal investigator Dr. Michael Mann, in collaboration with Microbeam Technologies Inc. (MTI), Barr Engineering Co., Rare Earth Salts (RES) and MLJ Consulting is proposing to demonstrate at the pilot scale its novel technology for rare earth element recovery from North Dakota lignite coal feedstocks. The objectives of this project include: 1) Confirm coal seams found within active North Dakota mines have elevated REE content (>300 ppm whole coal basis) and collect a large sample (300-500 tons) for further processing, 2) Design and construct a pilot-scale facility for REE extraction and concentration with at least 0.25 tons/hr coal feed, 3) Determine optimal operating conditions using existing bench-scale equipment and utilize these optimized parameters to process at least 100 tons of high REE coal, and 4), verify REE product quality with downstream REE refiners (RES) and reduce potential costs and time-to-market associated with coal-related REE materials. The expected technical and economic impacts are the following: 1) Develop a low-cost, environmentally friendly REE concentrate from North Dakota lignite feedstocks, 2) Verify scalability of the process proven at the bench scale and develop a baseline for future commercial demonstration, and 3) Perform rigorous economic modeling equivalent to a preliminary Front End Engineering Design for evaluation of the technology at a potential commercial demonstration site. The total project costs are \$6,508,555. The request from the U.S. Department of Energy is \$4,989,255 and requires 20% cost share. We have received commitments for \$125,000 from North American Coal Corporation, \$125,000 from Great River Energy, \$125,000 from Minnkota Power Cooperative, \$125,000 from BNI Energy, along with \$34,300 from MTI and \$90,000 from UND. We are requesting \$900,000 from the North Dakota Industrial Commission. The proposed technology provides a possible solution to key challenges facing the coal and critical materials industries in the United States, and is closely relevant to both the Office of Fossil Energy's and the Lignite Energy Council's mission for developing alternative products from coal-based materials.

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2. PROJECT SUMMARY

The University of North Dakota (UND) Institute for Energy Studies (IES) is teaming with Microbeam Technologies Incorporated (MTI), Barr Engineering Co., Rare Earth Salts (RES), and MLJ Consulting to demonstrate at a pilot-scale its novel technology for rare earth element (REE) recovery from North Dakota lignite coal and related feedstocks. The project will be conducted with funding from the U.S. Department of Energy, North American Coal Corporation, Great River Energy, Minnkota Power Cooperative, BNI Energy, MTI and UND. Technical advisory support will also be provided by the Critical Materials Institute and the North Dakota Geological Survey. Valley City State University has expressed interest in hosting the first commercial demonstration.

North Dakota lignite coal has been discovered with REE levels as high as anything ever reported previously for U.S. coals. In lignite coal, the REE are weakly bound as organic complexes, rather than in mineral forms that are typical of higher-rank coals. These organic associations permit simple dilute acid leaching directly from the lignite. The technology is much less complex than most REE mineral processing methods, potentially offering significant cost savings. Finally, the leaching process is also a coal beneficiation process, offering value-added opportunities for the upgraded lignite byproduct. During Phase II, REE oxide concentrates of over 85% were produced from lignites with over 650 ppm REE with favorable economic projections.

The overall objective of this proposed project is to demonstrate at the pilot scale a high performance, economically viable and environmentally benign technology to recover rare earth elements (REE) from North Dakota (ND) lignite coal feedstocks. To meet the project objectives, a two-phase approach is proposed. The technology's profitability and viability will be verified during the first phase through completion of preliminary economic, feasibility, and commercialization studies. Additionally, gathering, preparation, and verification of sufficient REE concentrations in the chosen coal feedstock(s) will be conducted, along with a conceptual design study of the pilot plant, including engineering drawings, to enable rapid construction and develop quotes for all equipment required for continuous operation.

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During the second phase of the project, pilot plant procurement and construction will begin in tandem with bench-scale parametric testing and evaluation of the feedstock chosen. REE concentrates from this bench-scale testing will be delivered to project partner RES, for preliminary lab-work to evaluate optimal process conditions and pathways for rapid refining of the UND REE concentrate into individual rare earth oxides. Upon completion of the construction of the pilot plant and suitable commissioning, pilot plant testing of at least 100 tons of the feedstock will be conducted, with REE concentrates generated during the project sent to RES for downstream refining. Finally, updates will be made to economic, feasibility, and commercialization studies in the form of a pre-Front End Engineering Design (pre-FEED) study to evaluate in detail the performance and economics of a potential commercial plant.

The ultimate significance of this pilot-scale demonstration is the development of an environmentally benign and economically viable technology for REE production from lignite coal resources that will limit dependence on foreign supplies and strengthen the economic and national security of the U.S. Production of rare earth elements and other critical minerals will significantly enhance the value of the North Dakota Feedstocks. This project will enable migration of the technology from its current TRL of 5 to the next scale, TRL 7, and will be a foundation for subsequent full commercial deployment.

3. Project Description

Due to their unique properties, the REE (lanthanide series elements + scandium and yttrium) are essential in energy system components, military applications, and consumer goods. These elements support a market of greater than \$300 billion and employing over 600,000 in the United States [1]. However, the United States is nearly 100% import reliant on REEs, particularly from China, the global leader in REE production and use [2]. The REEs, along with another group of high-value materials of national security to the United States, have been denoted critical materials (CM), and domestic generation of these materials has become a major initiative throughout the United States. Mining of traditional ores domestically, while conducted previously, have significant challenges associated with economics of extraction. Traditional ore resources typically are depleted in the most critical and valuable REEs, resulting in a substantially lower value ore. Of these valuable REE resources, nearly 100% of the global market is produced from a single

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resource in China (ion-adsorbed clays). Projections of this reserve anticipate only 10-20 years remaining of economically extractable reserves [3]. The U.S. considers generation of a domestic REE market a matter of national security, of which coal and coal byproduct resources have been identified as a promising resource for domestic use. The proposed technology is capable of making a disruptive impact on domestic REE markets, in large part due to the novel extraction methodology and substantial lignite reserves in ND.

3.1 Overall Project Goal

The overall objective of this proposed project is to demonstrate at the pilot scale a high performance, economically viable and environmentally benign technology to recover rare earth elements (REE) from North Dakota (ND) lignite coal feedstocks.

3.2 Project Objectives

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

- Design and construct a pilot-scale system for continuous REE extraction from ND coal feedstocks capable of a minimum 0.25 tons/hr feed rate of physically beneficiated lignite coal based on previous laboratory and bench scale testing at UND.
- Leveraging prior REE project experience, obtain a large sample (~300 tons) of high REE (>300 ppm following coal cleaning) from the Freedom mine in North Dakota for testing in pilot-scale demonstration facility.
- Conduct initial parametric testing of a sample of the Freedom lignite, leveraging bench-scale equipment from previous projects, to cost-effectively identify optimal operating conditions and aid in the design of the pilot-scale system.
- Commission the pilot facility using selected high REE containing coals from various regions in ND.
- Conduct continuous pilot-scale testing utilizing optimal conditions for REE extraction and concentration on at least 100 tons of the >300 ppm REE-containing Freedom lignite.
- Confirm compatibility of REE concentrate generated during pilot-scale testing with commercial-

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scale REE refining.

- Based on results from the pilot testing campaign utilizing the Freedom lignite, conduct a preliminary Front End Engineering Design (pre-FEED) study on a potential commercial facility, in which an economic feasibility study and workforce assessment will be contained.
- Work with industry partners to develop a technology roadmap and commercial deployment plan.

3.3 Scope of Work

To meet the project objectives laid out, a two-phase approach is envisioned, with a Go/No-Go decision following the completion of the first. The primary goals of the first phase are to ensure the technology's profitability and viability through completion of preliminary economic, feasibility, and commercialization studies. Additionally, gathering, preparation, and verification of sufficient REE concentrations in the chosen coal feedstock(s) will be conducted, along with a conceptual design study of the pilot plant, including engineering drawings, to enable rapid construction and develop quotes for all equipment required for continuous operation. During the pilot plant design, logistical planning of coal and process chemical requirements storage, feeding, and replenishment will be investigated, with finalized plans for operation completed prior to the Go/No-Go decision.

Following a favorable Go/No-Go decision, pilot plant procurement and construction will begin in tandem to bench-scale parametric testing and evaluation of the feedstock chosen. REE concentrate results from this bench-scale testing will be delivered to project partner Rare Earth Salts (RES), for preliminary lab-work to evaluate viability and optimal process conditions and pathways for rapid refining of more valuable components. Upon completion of the construction of the pilot plant and suitable commissioning, pilot plant testing of at least 100 tons of the feedstock will be conducted, with REE concentrates generated during the project sent to RES for downstream refining. Finally, updates will be made to economic, feasibility, and commercialization studies in the form of a pre-Front End Engineering Design (pre-FEED) study to evaluate in detail the performance and economics of a potential commercial plant.

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A. TASKS TO BE PERFORMED

PHASE I:

Task 1.0 - Project Management and Planning

UND shall manage and direct the project in accordance with a Project Management Plan to meet all technical, schedule and budget objectives and requirements. UND will coordinate activities in order to effectively accomplish the work. UND will ensure that project plans, results, and decisions are appropriately documented, and project reporting and briefing requirements are satisfied. A final report documenting the work performed in the project will be prepared.

SubTask 1.1 – Project Management Plan

UND shall update the Project Management Plan 30 days after award and as necessary throughout the project to accurately reflect the status of the project. Examples of when it may be appropriate to update the Project Management Plan 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 Project Management Plan 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.

SubTask 1.2 – Technology Maturation Plan

UND will develop a Technology Maturation Plan (TMP) that describes the current technology readiness level (TRL) of the proposed technology/technologies, relates the proposed project work to maturation of the proposed technology, and describes known post-project work necessary to further increase the technology TRL level.”

SubTask 1.3 Workforce Readiness Plan

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UND will prepare and maintain a Workforce Readiness Plan (WRP) related to the technology being researched under the project. The Plan must describe the skillset and availability of the workforce needed for future commercialization and deployment of the technology, including whether any related apprenticeships, certificates, certifications, or academic training are currently available. If a workforce with the required skills is not readily available, or if the technology is so new that a trained workforce does not yet exist, UND's plan shall detail how the needed workforce could be developed, for instance, through coordination with educational institutions such as community colleges, technical schools, and universities; company-led in-house training; union training, etc. UND will monitor and update its assessment of workforce availability and development plans throughout the life of the project.

Task 2.0 - Financial Plan for Commercialization

UND will develop and periodically update a Financial Plan for Commercialization. At a minimum, the plan should explain the economic feasibility demonstrated by UND's Excel financial spreadsheet model and include a description of UND's proposed business plan for developing and commercializing their technology to economically produce salable REEs and CMs from U.S. coal and coal-based resources. Information to be included is an explanation of the hurdles and risks for factors such as: supply of process inputs; process and technology development; capital, operating, and maintenance cost; process operation factors; life-cycle environmental, permitting, and other regulatory factors; market demand and quantity/price points for output products; offtake agreements; downstream supply chain for refining products; international demand, supply, competition, and other considerations; etc.

The financial plan will consist of a written report with the key assumptions and data used for development being documented in the design basis. The results of the design basis and financial plan will be utilized and refined through subsequent tasks. A final financial plan will be developing using all data and experience gained through execution of the project and will be complete 30 days prior to award completion.

Task 3.0 – Techno-Economic Assessment

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UND will develop and provide the National Energy Technology Lab and other project sponsors a Techno-Economic Assessment (TEA) based on testing and operation of the REE/CM recovery system. UND will develop a detailed TEA that estimates the cost and performance for scale-up to a commercial demonstration.

The techno-economic analysis produced during DE-FE-27006 will be updated and refined utilizing the feedstock chosen for the process and based upon the results from the previous tasks. During this task, we plan to utilize a commercial demo-scale as the possible site for the TEA and will be determined through assistance and discussion with project partners. Evaluation of the potential of opening an additional mine for targeted REE recovery, in addition to utilization of existing mine's coal seams will be conducted. Included in this study will be the key components of a preliminary commercialization plan, such as resource assessments, plant scale, time to market, market analysis, equipment vendor discussions, identification/discussion with purchasers/refiners of our >2wt% concentrate and initial investment strategies. The technical and economic feasibility study will be performed by project partner Barr Engineering, a qualified Architectural and Engineering (A&E) firm with extensive experience in coal mining and handling, power generation, minerals exploration, and minerals processing and extractive metallurgy.

The TEA will include and be based on a mass and energy balance, which identifies component concentrations and yields associated with each processing step. Conversion factors and units will be identified. A fully functional interactive Excel spreadsheet model with no locked or hidden cells will be included with the TEA. In addition to rare earth element prices supplied by NETL, future market prices for products based upon input from project partners Rare Earth Salts and the Critical Materials Institute will be used for the TEA. Revenue projections will be itemized for each rare earth compound/element and each product other than rare earths. Both capital and operating cost factors will be used to estimate the economic viability. The capital cost estimate will indicate the all-in costs for the facility, including infrastructure from the site fence line, interconnection to existing facilities, equipment costs, construction costs, construction indirect costs, and owner's costs.

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The TEA will include a design estimate with adequate detail to be classified as an Association for the Advancement of Cost Engineering (AACE) Class 3 or better estimate. This estimate is intended to serve as a pre-Front-End Engineering and Design (FEED) level estimate for a future commercial scale demonstration project. In order to obtain the AACE Class 3 estimate, Task 3.0 will require the creation of a design basis, process model (including mass and energy balance and process flow diagram), proposed plant general arrangements, equipment specifications, and a Basis of Estimate. Task 3.0 will consist of the engineering documents outlined above for the completion of the cost estimate, the AACE cost estimate, and the full TEA interactive Excel model.

Task 4.0 – Provide Split Samples

UND will provide NETL with a single sample that reflects the highest achieved REE concentration generated during conduct of project effort. The quantity of material to be provided to NETL shall be no less than 3 grams). Material Safety Data Sheets (MSDS) are required to accompany material supplied to NETL. NETL reserves the right for DOE/NETL employees or agents to witness the sampling and splitting. Results of any analysis arranged by DOE/NETL will be documented in a Publicly Releasable Report accessible on the NETL website.

Task 5.0 – Feasibility Study

UND will develop and provide NETL and other project sponsors a Feasibility Study 30 days prior to the Go/No Go decision point. The Feasibility Study will provide NETL with information on, but not limited to, availability of the proposed feedstock; information on environmental impacts; process flow diagram(s); product yield and concentration; estimated system costs; etc.

At a minimum, the feasibility study should investigate and discuss the following: 1) information developed in the Sampling and Characterization Plan (if applicable) with regard to the available resource and REE and CM grade on a regional or national scale as required for eventual commercial recovery of REEs and CMs from the proposed feedstocks with the proposed technology; 2) expected waste management characterization and proposed processes to minimize or reduce environmental impacts; 3) future advanced manufacturing techniques; 4) a quantified process flow diagram showing REE and CM recovery process

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input and process flows, including feedstocks, reagents and other additives; 5) identification of process recovery, yield, final product concentration for REEs and CMs and other useful materials; 6) mass/water/energy balances; 7) capital, operating and maintenance, and process costs per unit of input and output; 8) the expected market demand and pricing for REEs and CMs and other useful recovered products on a regional basis; 9) a fully functional financial spreadsheet model with no hidden or locked cells (the model should clearly identify assumptions and include instructions for use by DOE); and 10) feasibility study conclusions and recommendations.

Information and conclusions will be evaluated and reported in a format similar to that used for mineral resource reporting according to Canadian National Instrument 43-101 (NI43-101). Task 5.0 will consist of a written feasibility study report containing but not limited to the information provided above as well as the information developed as part of Tasks 2.0 and 3.0.

Task 6.0 - Large Sample Collection and Preparation

Through work conducted through Phase 1 and Phase 2 of the project, in addition to other work conducted at UND, multiple sizable areas of high REE concentration (>300 ppm) have been found, including an active mine of a project sponsor (North American Coal). This task will include the large-sample (>300 tons) collection of coal, and the physical preparation of the coal, including crushing, drying, and coal cleaning. The final product of the coal cleaning process will be taken as the feedstock to the process of >300 ppm, and may be blended with additional higher REE coal (>600 ppm) to evaluate performance.

Subtask 6.1 – Large Sample Planning:

Upon project award, discussions will be held with North American Coal regarding the most effective methods of gathering the large samples for further processing. Mining concerns, particularly involving permitting and selective mining methods, will be re-evaluated for each coal elected for sample extraction. The project team will also work with Great Northern Properties to evaluate the potential use of additional cored samples for testing.

Subtask 6.2 – Procurement and Preparation:

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North American Coal will work with UND to mine and deliver >300 tons of Rider Seam coal (>300 ppm after coal cleaning) for physical processing and coal cleaning. Secondary feedstocks from the Harmon-Hansen seam for blending and alternative testing plans will also be gathered. Coal will be crushed to -10 mesh and screened to prepare for downstream operation.

Task 7 – Pilot Plant Design

This task includes the design of the pilot plant, including finalizing site location, sizing and planning of all equipment, necessary environmental controls, and staffing requirements of the plant.

7.1 – Planning and Conceptual Design of the Pilot Plant

This subtask will consist of the major elements of the Pilot Plant planning, including finalize the location of the plant, final equipment sizing, and plant layout. Sizing will be largely conducted through scale-up parameters associated with the data from the operating bench-scale equipment. Additionally, the plant location will be finalized, along with necessary utility requirements laid out for successful pilot operation. Control requirements for the pilot plant will be addressed and designed during this phase.

7.2 - Permitting and Logistics Planning

This subtask will include obtaining construction and environmental permits for the pilot plant in addition to planning for logistical concerns with continuous pilot plant operation. Wastewater treatment and disposal systems will be developed as per local, state, and federal environmental requirements, along with management with local utilities to ensure effective integration into existing infrastructure.

Logistical concerns, particularly in transport, processing and storage of materials required for seamless pilot plant operation will be explored. Contact with chemical vendors to confirm shipping regularity and total size for the chosen location, in addition to possible bulk chemical and coal storage on/off site.

GO/NO GO DECISION POINT AFTER TASK 7

UND is NOT authorized to proceed beyond Task 7 without the DOE Contracting Officer's written approval of acceptable progress associated with the Go/No Go technical and economic criteria.

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- DOE approval of Technology Readiness Plan, Workforce Readiness Plan, Financial Plan for Commercialization, preliminary Techno-Economic Analysis and Feasibility Study
- All permits have been received and the site approved.
- Verified availability of 300+ tons of coal with proven > 300 ppm REE on a cleaned, whole coal basis.
- TEA shows scenarios with positive NPV using the global economic assumptions provided by DOE in FOA-0002003.

If UND unilaterally decides to continue into the subsequent tasks prior to the DOE Contracting Officer's written approval, all costs are incurred at UND's risk and no DOE funds may be utilized for such costs prior to the DOE Contracting Officer's written approval of the technical Go/No Go criteria.

PHASE II:

Task 8 – Pilot Plant Procurement and Construction

Subtask 8.1 – Plant Component Procurement

The procurement of required pilot plant components will be initiated under this subtask. Multiple vendors have been contacted related to bench-scale procurement with likely scaled versions of equipment available. This task will be initiated upon completion of subtask 7.1 and meeting the criterion for a “Go” decision.

Subtask 8.2 – Plant Construction

This subtask will incorporate multiple aspects of the on-site construction phase of the pilot plant, including fabrication of equipment not chosen from vendors, integration of equipment, development of controls systems, and individual component testing to ensure adequate performance from vendors. The pilot plant will be constructed for continuous and integrated processing of all major unit operations.

Subtask 8.3 – Plant Shakedown Testing

After completion of the continuous pilot plant system, shakedown testing of the integrated system for adequate performance and training for operators will verify total system performance.

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Task 9 – Bench-Scale Feedstock Testing

This task will entail utilization of the bench-scale equipment generated in DE-FE27006 for preliminary parametric testing for optimized operating conditions for the chosen feedstock. This will occur in a semi-continuous nature, where the optimized conditions found for the previous unit operation will be fed into the parametric testing associated with the next unit operation. Final testing of the complete process under optimized conditions will be conducted to ensure expected integrated performance.

The material generated in the testing of the optimized conditions will then be forwarded to Rare Earth Salts (RES) for testing. Initial samples will be tested to ensure the feedstock performs within specifications utilizing the separations technology at RES. Following verification of performance, the remaining material will be used to optimize the flow stream through the RES process flow to maximize the number of REEs separated when moving to the pilot scale operation.

Bench-scale optimization at RES is required for two reasons. First, RES has not had a feedstock with significant Sc and thus the conditions for its separation have not been optimized. Its position in the process flow is well understood, but the conditions and actual process flow in the commercial line are not known at this time and work will need to be done to ensure smooth introduction of the REE concentrate from the coal source. Second, the lead time for some REE in RES's commercial facility can be as long as 30 weeks (or longer) and thus some of the critical REEs may not be separated within the time frame of the grant. Bench-scale work will be undertaken to find conditions in which steps in the process can be 'combined' to give a material that can be fed into downstream lines without issue and thus skipping steps in the process flow. While this is not ideal (hence not S.O.P. in the commercial facility), it will allow for a substantial amount of the critical REEs to be passed forward into the appropriate streams to allow separation within the time-frame of the grant. These conditions need to be determined and optimized at the bench-scale before utilizing them in Task 11.

Task 10 – Pilot Plant Testing of Chosen Feedstock/Feedstock Blend

Subtask 10.1 – Abbreviated Parametric Testing Based on Bench-Scale Data for Chosen Feedstock

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Utilizing results from the bench-scale testing, abbreviated parametric tests around highest opportunity ranges identified through bench testing will be conducted. Each unit operation in use in the pilot plant will be tested sequentially. Economically optimal conditions for each prior unit operation will be the feed for further unit operations.

Subtask 10.2 – Continuous Operation Testing on at least 100 tons of chosen feedstock

Utilizing optimum parametric conditions for the chosen feedstock, process at least 100 tons of chosen feedstock to generate a minimum of 10 kg of >2wt% REE concentrate, thereby meeting DOE requirements. It is expected that the testing will generate at least 30 kg of >50wt% REE.

Task 11 – Down-Stream Refiner Testing and Analysis

11.1 – Blending of REE Concentrate with Existing Refiner Products

Samples of the REE concentrates produced from the pilot plant operation will be analyzed and determined if suitable for integration into current production lines for seamless operation. This will allow for determination if the generated REE concentrate is of sufficient quality to current commercial refiners. From this analysis, determination of possible valuable byproducts or deleterious impurities in the concentrate may be investigated, which will influence possible secondary clean-up activities.

Subtask 11.2 – Separation of REEs at 99+% purity

The REE concentrates will be blended with existing feedstocks at an appropriate place within the process flow to maintain optimal conditions for separation of REE products. The REE concentrates will be mixed and then converted to a chloride salt using RES's patented technology. The REE chloride will then be dissolved in water and subjected to a patented electrowinning process that will provide separated REEs at 99+% purity. The number of REEs separated will depend on time, the amount of material provided from the pilot plant and the concentrations of the individual REEs in the concentrate provided. For a limited number of critical REEs, laboratory scale separations will be utilized when the amount of material is below the threshold for the commercial cells.

The REE concentrate obtained from UND will be integrated into the existing process flow as much as feasibly possible. As mentioned in Task 9, the lead-time for some REE elements within the separation is

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beyond the time-line for the grant work and thus some modifications to the process flow will be made for this project. Additional cells will be procured and implemented within the RES facility to account for the modified process flow and the resulting materials will be reintegrated into the existing process flow at appropriate points. It is assumed that there may be up to four points in the process flow that will need to be modified in order to obtain separated critical REEs (Tb, Dy and the SEG group being the REEs predicted to need modification in their process flow streams).

3.4 Anticipated Results

The anticipated results of the proposed project are summarized as follows:

- Successful demonstration of the proposed technology at a 0.25 ton/hr throughput and production of approximately 30 kg with at least 50wt% REE on a dry basis.
- Optimization of the REE extraction process and definition of complete flowsheet/unit operations required to achieve the target purity levels
- Completion of a technical and economic feasibility study that will include detailed process flow diagrams, equipment specifications, mass and energy balances, and economic metrics (i.e. capital and operating expenses, rates of return, payback time). A pre Front End Engineering and Design (FEED) for future commercial-scale demonstration project will be delivered.
- Preliminary commercialization strategy to identify the opportunities at existing mines/power plants or justification of a new mine opening. This will include overall process configuration that includes REE extraction as well as byproducts usage/processing and integration within existing facilities or value chains. A business plan for commercializing the technology will be included.
- The project will demonstrate a high performance, economically viable and environmentally benign method for production of REEs from the vast lignite reserves in North Dakota. This will open up new opportunities and increase the value of lignite use. Upon completion of this small pilot-scale test program, the technology will be ready for demonstration-scale and rapid commercialization.

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3.5 Facilities and Resources

UND has exceptional existing analytical, laboratory, and fabrication facilities which will be leveraged in the proposed work. Additionally, UND has laboratories and high-bay space necessary for performance of any required laboratory and bench-scale testing. UND has a fully equipped and staffed mechanical/electrical fabrication shop, and has the expertise and experience on larger-scale equipment fabrication and construction to construct the pilot-scale facility proposed. Software licenses for Aspen Plus, METSIM, ChemCad, HSC Chemistry, and additional process and chemical engineering software available to the project to assist technical and pilot design efforts associated with the proposed work.

UND has unique and exceptional analytical, lab, and bench-scale equipment which will be leveraged during the project, along with equipment at project partner RES. Analytical capabilities include an ICP-OES, SEM-EDS, XRF and XRD instruments with experienced and dedicated technicians, allowing substantially faster sample turn-around time and flexibility than possible with the use of external laboratories. UND has unique bench-scale equipment REE extraction plant developed during previous phases of the project, able to process 10-20 kg/hr of coal. Additionally, project partner RES has unique bench, pilot, and commercial-scale equipment for individual separation of REE concentrates which will be leveraged during the project. MTI has a wide array of analytical capabilities and equipment relevant to the coal analysis. MTI has advanced computer-controlled scanning electron microscopy (CCSEM) and associated sample preparation equipment. MTI has software developed to interpret CCSEM mineral analysis and is equipped to perform chemical fractionation, which is essential in determining the association of inorganic elements present in coal. MTI has developed multiple proprietary algorithms for prediction of various performance indicators based on the abundance and association of coal impurities. These algorithms build on MTI's large fuel CCSEM database, technical expertise, and findings from field-testing at mines and plants.

3.6 Environmental and Economic Impacts during Project

The environmental impacts resulting from performance of the proposed work are negligible. Waste streams produced as a part of testing will be disposed of via the existing waste disposal mechanisms

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available at UND, and any hazardous waste (if produced) will be handled according to UND regulations. Preliminary discussions have been held with the City of Grand Forks to verify the viability of the proposed disposal plans. Economic impacts include employment opportunities for UND research staff, students and support staff. This project will train the next generation of engineers/scientists that will benefit the North Dakota labor force.

3.7 Technical and Economic Impacts of Proposed Technology

Major technical and economic impacts are summarized below:

- Demonstration of a novel and economically viable method to recover rare earth elements from North Dakota lignite and lignite-related feed stocks
- The properties of lignite coal offer a unique opportunity that results in lower cost REE recovery from coal and coal-related materials than higher rank coals or coal combustion byproducts
- New markets for lignite coal will be created, including new jobs associated with the REE recovery/separation/purification processes
- Successful development of REE recovery technologies for coal will displace imported REEs and REE-based products, resulting in increased economic and national security for the U.S.
- Development of the new resource for REEs will create price stability and promote new REE innovation in the U.S. that will reduce monopolistic control of the REE value chain by China
- A secure domestic source of critical REEs will be available to high importance end uses such as military defense applications, electronics and hybrid/electric vehicles. ND lignite, in particular, has a very favorable distribution of particular REEs that are more valuable, are used in market growth sectors and are currently in scarce supply globally.

Preliminary techno-economic assessments and feasibility studies have demonstrated strong evidence for a cost-effective method of generating a REE-concentrate from ND lignite, significantly enhanced through the sale of multiple byproducts, including CM and upgraded coal products. As a part of the current effort, Barr Engineering is completing an AACE International Class IV - Study or Feasibility with accuracy

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in the range of about $\pm 30\%$. Results from their analysis summarized in Table 1 show strong economic potential for the process. UND has been working with Valley City State University to host the first small commercialization plant (see letter of interest). The size of the first plant, 5 ton/hr matches the current feedrate of their existing steam plant, and provides the opportunity to further process the coal into activated carbon. Under this scenario (Case 1), the high value of the activated carbon makes the project profitable, even at this low feed rate when economies of scale are not yet realized. This site was chosen as potentially serving as the first commercial demonstration as the ability to co-produce activated carbon provides buy-down of the economic risk. In addition, there is interest from the North Dakota University System to duplicate the steam/activated carbon/REE plant at other institutions across North Dakota.

Table 1. Summary of Economics of UND REE Process from the Phase 2 TEA.

Case	1	2	3	4	5
Lignite Feed Rate, ton/hr	5*	5	10	21	100
CAPEX	(\$24,200,000)	(\$24,200,000)	(\$27,600,000)	(\$33,700,000)	(\$59,700,000)
OPEX	(\$7,600,000)	(\$7,600,000)	(\$13,000,000)	(\$24,900,000)	(\$106,700,000)
REE and Base Metal Payable Amount per year	\$7,100,000	\$7,100,000	\$14,300,000	\$30,300,000	\$142,800,000
Upgraded Coal Payable Amount per year	\$6,400,000	\$2,800,000	\$5,500,000	\$11,800,000	\$55,500,000
Net Annual Revenue per year	\$5,900,000	\$2,300,000	\$6,800,000	\$17,200,000	\$91,600,000
Simple Payback (years)	4.1	10.5	4.0	2.0	0.7
IRR (10 years)	20%	-3%	20%	50%	153%
ROI (10 years)	12%	-1%	12%	36%	128%
NPV (10 years) @15% discount rate	\$4,100,000	-\$13,200,000	\$5,000,000	\$48,600,000	\$377,200,000
IRR (20 years)	24%	7%	24%	51%	153%
ROI (20 years)	18%	4%	19%	44%	141%
NPV (20 years) @15% discount rate	\$12,600,000	-\$9,900,000	\$14,700,000	\$73,200,000	\$507,800,000
CAPEX/annual dry ton feed	\$580	\$580	\$330	\$190	\$70
OPEX/annual dry ton feed	\$180	\$180	\$150	\$140	\$130
Net Revenue/annual dry ton feed	\$140	\$60	\$80	\$100	\$110

Assumptions: Feed rates, raw materials, and other costs based upon testing of H-Bed lignite sample; 50% recovery of REE; REE sold as a mixed oxide to be further refined; cost of upgrading mixed oxide to individual REE oxides included in the analysis; REE oxide prices based upon FOA; delivered cost of coal to plant \$25/ton; upgraded coal sold at a 30% premium over the cost of the as-mined coal.

*Scenario based upon integration with Valley City State University; residual coal upgraded to activated carbon.

Realizing that the activated carbon market is relatively small, Cases 2 through 5 are performed assuming the coal by-product will be sold as an upgraded boiler fuel, commanding a 30% premium above the current price of coal (based upon discussion with ND utility and coal mine partners). The economies of scale are evident from this analysis, with the economics improving as the importance of capital cost diminishes with plant size. Under the base assumptions, breakeven at a 15% discount rate would occur at

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a plant size of 7 ton/hr. UND's plan for full commercial implementation expects plant sizes between 10 and 100 ton/hr, with the optimal range determined as a part of the work scope of this project. Sensitivity analyses were also performed around other critical variables, with the prices received for the REE and upgraded coal being the most important. At a plant size of 21 ton/hr, the plant will breakeven (NPV=0 at 15%) with no recovered cost from the upgraded coal. At this plant size, 21 ton/yr and with the sale of upgraded coal, the price received for the REE oxides could be reduced by approximately 40% and the process can still breakeven.

The UND team has also analyzed the importance of the relative abundance of various elements within the feed coal. While the Phase II work focused on feedstocks of greater than 300 ppm, lignites have been identified with high ratios of heavy-to-light rare earth elements, with the value of the REE sales being more dependent upon the individual elements present, rather than the total REE concentration. For example, the lignite from the Freedom Mine Rider seam proposed for this work has approximately 25% of its REE concentrated in Pr, Nd, Eu, Tb, and Dy, making this a high value feedstock with economics more favorable than those shown in Table 1.

Process supply risks to the process are low, primarily due to the use of commodity chemicals and a feedstock with great abundance and reserves (Harmon-Hansen coal zone). Variability in high-REE feedstocks is a concern for the process, with development of a continuous feedstock monitoring and control scheme envisioned for management of this risk. Additionally, use of sorting equipment, such as PGNAA full-stream elemental analyzers, are being investigated as a method of sorting high-REE feedstocks from as-mined coal, allowing for a higher degree of feedstock control.

Product price risks are of concern for the process, as with the REE industry as a whole, and have been managed in the proposed technology by leveraging byproduct sales, including the upgraded lignite coal product and CM such as Ga, Ge, Co and Al, totaling a larger revenue than combined REE sales. These products have been priced using input from commercial partners and literature mineral commodities values supplied from the U.S. Geological Survey [9]. With the current scale of the byproduct markets, significant price impact from facilities using this technology are unlikely. Additionally, positive NPV's are possible at

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larger scales using a sale price of only 60% of the contained value, permitting economic operation of a plant even under substantial REE price reduction scenarios.

Market saturation is a concern when introducing a new technology for producing commodity goods. Since the overall economics for the proposed technology is the most sensitive to the selling price of the REE, the impact of producing REE from lignite coal on market penetration has been assessed and is summarized in Figures 1. The current total US consumption of 16,000 tons/yr REE is expected to grow. North Dakota has the potential to capture a modest share of that market, while not saturating the market and adversely impacting the price. For example, a small plant (21 ton/hr as used in the example above) only captures 0.8% of the total market. A larger plant designed with a feed rate matched to a 120 MW power plant would capture about 1.25% of the market, while having the potential to generate \$180 to \$360 million per year revenue for coals with REE ranging from 300 to 600 ppm, respectively. Therefore, this process offers the potential for high returns with a low economic/price risk.

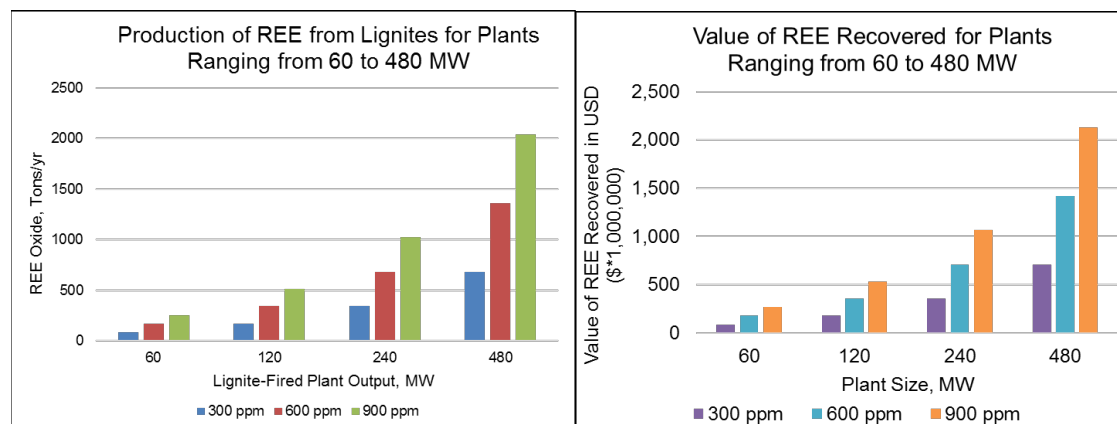


Figure 1. Potential production of REE from ND lignite power plants

Commercialization of the technology from the current technology developers will be conducted through technology licensure to commercial entities, with preference given to the commercial partners on the project. Commercial partners such as coal reserve companies and power utilities have shown significant interest in licensing of the technology thus far and represent likely candidates for commercialization outlets.

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3.8 Project Need

With increasing environmental regulations on fossil-fuel based power and decreasing coal production nationwide, new opportunities for marketable use of lignite coal are required to maintain the existing mining/lignite use infrastructure in the State. The recovery of REEs from ND lignite and related materials has potential to be a significant new industry for the state that will both maintain existing jobs and create new jobs and revenue for the State. The results from current work (described later in this Application) are extremely encouraging, and the unique properties of ND lignite coal make recovery of REEs a simpler and lower-cost proposition than either higher rank coals or traditional mineral ore-based resources. Additionally, the U.S. is currently 100% import reliant for REEs, and critical end-use applications in growing market sectors require a stable, domestic supply. Under the current conditions, extreme instability/uncertainty exists due to monopolistic control of the entire REE value chain by China. To ensure the national and economic security of the U.S., it is imperative that domestic sources of REEs be identified and processes developed to produce them. This is the focus of the proposed project.

4. STANDARDS OF SUCCESS

The standards of success for the outcomes of the proposed work are summarized as follows:

- Successful completion of this project will result in an environmentally benign and technically and economically feasible method to concentrate REEs from coal-related feedstocks.
- Identification of multiple REE- and CM-rich lignite coal deposits in sufficient quantity for commercial production. Ideally, this will be in an existing mine to eliminate mine startup costs, but we will also evaluate the feasibility and scenarios that would encourage/justify the opening of a new mine.
- Demonstration of a process design at the pilot-scale that can economically produce REEs from ND lignite coal and lignite-related materials with a recovery of at least 50wt% (on a dry whole feedstock basis) producing a REE concentrate in the product of at least 50wt%, preferably greater than 80wt% (dry oxide basis).

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- Successful processing of REE concentrate at a commercial rare earth element refining company: ability to direct feed the produced concentrate into an existing commercial process without modification to produce 99%+ REE oxides.
- Development of a commercialization strategy, including a fully functional economic and financial model that integrates synergistically within an existing mine or plant facility, or provides sufficient economic justification for the opening of a new mine as defined by a positive NPV at a 15% discount rate.

5. BACKGROUND INFORMATION

UND has demonstrated the ability to economically recover REE/CM products from ND lignite as evidenced by the bench-scale data presented in this section, showing good promise for commercial deployment

5.1 Proposed Feedstock

The proposed feedstock for the pilot plant testing is from a seam of high total REE (TREE) containing ND lignite coal from the Freedom Mine near Beulah, ND, owned and operated by project partner North American Coal Corporation (NACC). The selection of coal is based upon both the elevated levels (>300 ppm whole coal basis) found across multiple samples of the location, along with the relative ease of large (300 tons) sample collection associated with active mine operations. Previous work in Phase 1 and 2 has also identified other attractive REE-rich coals, particularly within the expansive Harmon-Hansen coal region of Southwestern ND but lack an active mine for large sample gathering. As such, a smaller quantity sample (~10-20 tons) will be gathered from this very high REE content (>600 ppm whole coal basis) site to utilize as a blending coal to evaluate potential blended feed performance. Analysis of the Freedom Mine sample and the high REE H-Bed coal from the Harmon-Hansen region are found in Figure 2.

For reference, we are defining coal samples as those samples with less than 50 wt% ash content, a high value, but gravity-separation mechanisms including air segregation and coal spirals have been demonstrated

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at substantially reducing ash content with modest increases in total REE levels. The feedstock to the proposed REE process will be defined as crushed, cleaned coal following physical separation mechanisms.

The Freedom mine coal samples collected demonstrate a highly attractive distribution of REE associated with the feedstock, primarily due to the relative enrichment of the HREE as compared with traditional reserves. Utilizing a methodology from Seredin and Dai (2012), the coal resource in the Freedom

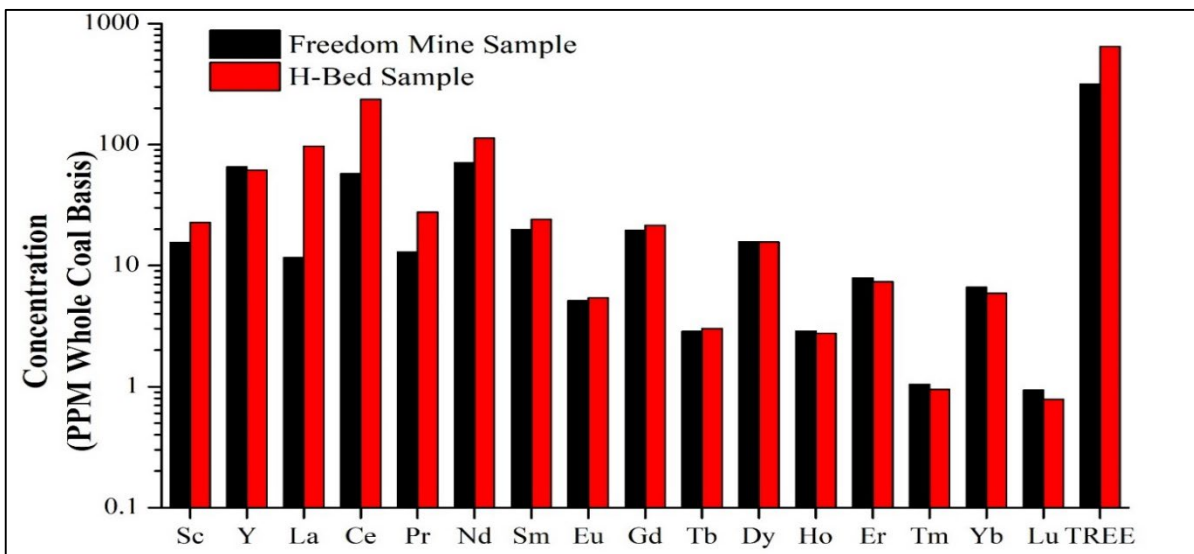


Figure 2. Abundance of REE (dry whole coal basis) and total REE (TREE) in the Freedom Mine lignite sample and the H-bed lignite sample. Y axis on logarithmic scale.

Mine represents a highly promising ore resource, with a C_{out} of greater than 2.5 [4]. Figure 3 illustrates the ratio of REE to the average upper crustal concentration.

Detailed analysis of previous lignite samples, including both samples shown in Figure 2, using ICP-MS, scanning electron microscopy/x-ray microanalysis and chemical fractionation have demonstrated that REE in lignites are predominantly contained with organic coordination complexes. Based upon chemical

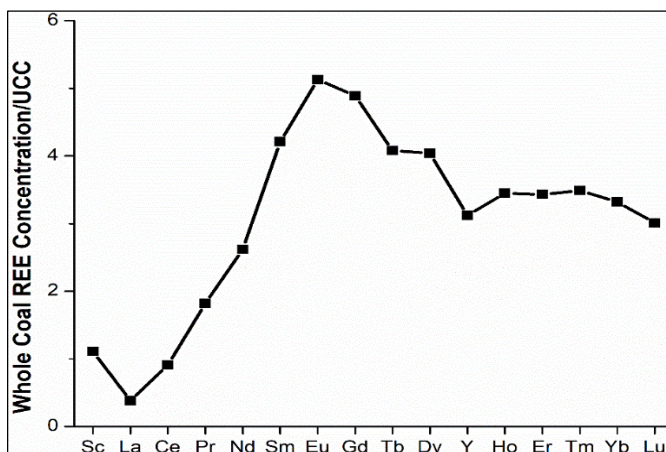


Figure 3. Ratio of REE level in coal to upper crustal concentration (UCC) for Freedom Mine Coal.

fractionation of the coal, 80-95% of the REE contained are estimated to be organically associated, with

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remainders associated with clays, phosphates, and zirconium minerals. The organically-associated REE fraction has been demonstrated to be effectively extracted from the coal using a simple, single-step, dilute acid leaching step. Mineral forms of the REE (5-20%) were not extractable using the same leaching process.

5.2 REE Abundance and Modes of Occurrence

Phase 1 results of REE abundance demonstrated several highly promising seams of ND lignite, particularly in the Harmon-Hansen coal zones as directed by project advisor the ND Geological Survey (NDGS, Table 2). The range of TREE levels varied from 194 to 642 ppm on a dry whole sample basis and represented coals and clay-rich sediments collected from margins of coal seams. These samples were collected from exposed outcroppings of coal seams with thickness approximately 12-18 inches. Sample 6A, 3A, and 6AA represent the entire thicknesses of a coal seam, while 6A-2, and 3C represent samples near margins and the roof or floor of a seam. It consists of multiple coal seams up to 42 feet thick, portions of which have been mined as recently as 1997 at the Gascoyne Mine that produced about 2.5 Million tons/year between 1975 and 1995. For a one-foot-thick REE-rich layer in a seam, the estimated reserves of REE-rich coal would be about 6 billion tons and would correspond to a total REE reserve of 1.8 to 3.7 million tons (pure elemental basis), when using an average TREE of 300 to 600 ppm, respectively. This estimate was prepared using a coal-in-place density of 80 lb/ft³, a value recommended by project co-sponsor North American Coal Corporation (NACC). Although the Harmon-Hansen zone was the target for Phase 2, we believe there to be tremendous reserves of REE-rich lignite coals in the State that could also be exploited, including in multiple active mines. Sample FM-R1 is a sample taken from a selected coal seam in the Freedom Mine and represents to coal selected for the proposed work. *Overall, there is a vast resource of REE-rich lignite coals in the northern great plains of the United States that would be targets for our technology.*

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Table 2. Abundance of REE in samples collected from the Harmon-Hansen coal zone and Freedom Mine

Sample ID	Ash Content (wt%)	Total REE (ppm)	Total REE, ash basis (ppm)	HREE/LREE	Total Critical REE (ppm)
6A-2	36.3	642	1752	0.28	191
6A	20.1	564	2235	0.35	189
6A-1	75.5	449	587	0.28	129
3A	40.5	363	892	0.89	151
3C	60.9	322	525	0.43	104
6AA	47.0	212	449	2.06	94
FM-R1	26.37	402	1526	1.45	245

*HREE/LREE = Σ (Sc, Y, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) / Σ (La, Ce, Pr, Nd, Sm)

Accumulation of REE in ND lignite is believed to have occurred through an infiltrational process, by which REE were introduced through volcanic ash sedimentation to organic, detrital layers. Water-based leaching processes are likely responsible for mobilization of the REE from these ash layers, after which the unique oxygen functional groups associated with the decaying matter were able to stabilize the REE during coalification and compactions processes. *However, due to the “young” nature of lignite coals, mineralization of organically-associated inorganic elements has not yet occurred, offering a unique opportunity for selective and simple extraction. In contrast, hard rock and mineral-based REE resources commonly require near-full chemical digestion of the material to recover the desired materials, a costly and environmentally challenging approach.*

Two methods were used to verify the organic association of REE in coals, a float/sink characterization of lignite and TREE content, and chemical fractionation tests. Coal sourced from the Harmon-Hansen coal zone of 265 ppm was separated using float-sink separation, with TREE content measured in each fraction (Figure 4). From the data, a negative correlation between TREE content and specific gravity may be realized on both a whole coal and ash-basis, with lighter specific gravity fractions representing the lowest-ash cleaned coal sections. This trend follows expected literature results from inferred organic associations with REE in low-rank coals [5] [6] [7]. Chemical fractionation studies were

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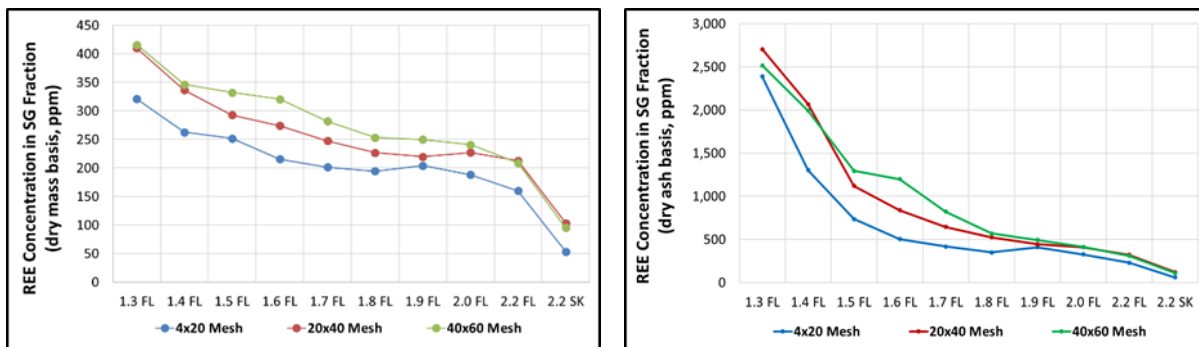


Figure 4. REE abundance in float-sink fractions of Harmon outcrop sample on coal and ash basis (left and right respectively).

conducted for the coals utilized in Phase 2 (H-Bed and Hagel B) and determined to have greater than 80-90% of REEs associated with organic complexes, with the notable exclusion of Sc (Figure 5). However, leaching of Sc was notably more effective during bench-scale processing than in standard chemical fractionation methods

The Freedom Mine, a currently operating mine with substantial reserves for future mining is a promising source of REE, particularly in the highly favorable heavy-to-light ratio (1.45) of the REE contained within the seam (FM-R1 from Table 2).

From the distribution shown in Figure 3, products with

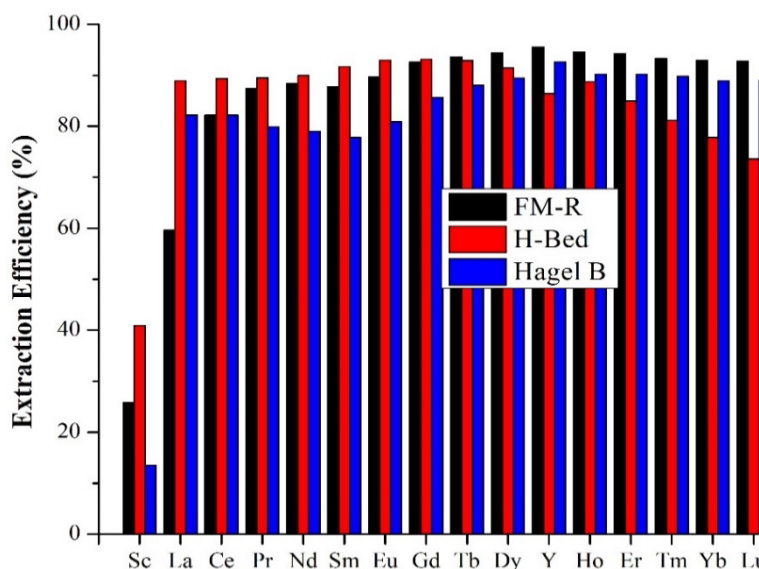


Figure 5. Results of chemical fractionation data on the Freedom Mine Sample (FM-R), along with both coals tested in Phase 2 (H-Bed and Hagel B).

considerable enrichment in magnetic REE and Sc are predicted. Based on laboratory-scale chemical fractionation testing of Freedom Mine coal, 90% of the REE was found to be organically associated, similar to other lignite coals tested in the project, and is therefore expected to have the same REE recovery performance as the H-Bed coal (Figure 5).

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5.3 Proposed Process Flow Diagram and Technology Description

Based on the results obtained in Phase 1 and Phase 2 projects, a process for economic generation of a REE concentrate was developed as shown in Figure 6. The REE products produced in the Phase 2 efforts have shown excellent performance (on REE purity). Products produced have had greater than 80 wt% rare earth oxide (REO) while utilizing low-cost reagents and minimizing potential water use. A summary of each major unit operation follows.

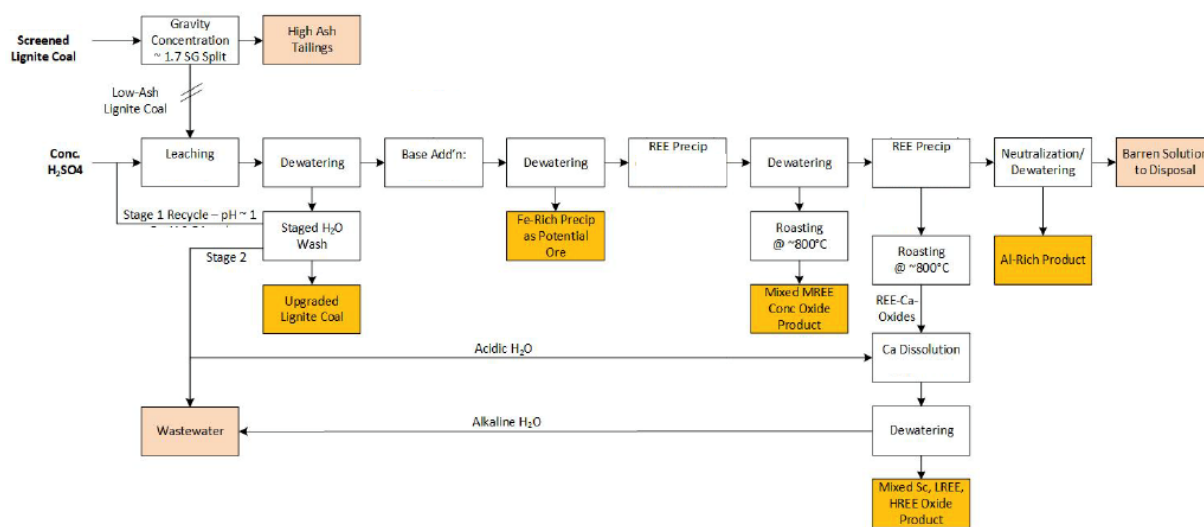


Figure 6. Flow sheet from bench-scale operation of the proposed technology. Products of the process are represented using gold boxes.

Feedstock Mining and Preparation: Selectively mined coal is delivered to the coal cleaning and physical upgrading process. As mentioned previously, REE concentrations vary stratigraphically, and are often concentrated in thin seams or near partings. Laterally, REE concentrations are more consistent (Figure 7). Multiple lateral samples of the Rider seam from the Freedom Mine (Rider 1, 2, and 3 samples), are compared with samples taken of coal beneath the Rider seam. Project partner NACC currently utilizes selective surface mining technologies capable of mining seams as small as 3-6 inches and are interested in deploying these technologies in North Dakota. These mining methods are currently utilized by NACC in mines in the southern US.

Grinding to -10 US Mesh will allow for effective liberation of dense mineral particles to be separated in subsequent coal cleaning steps and to improve mass transfer requirements for liquid penetration into porous

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coal particles. Separation of fines particles will occur following grinding to minimize associated filtration challenges.

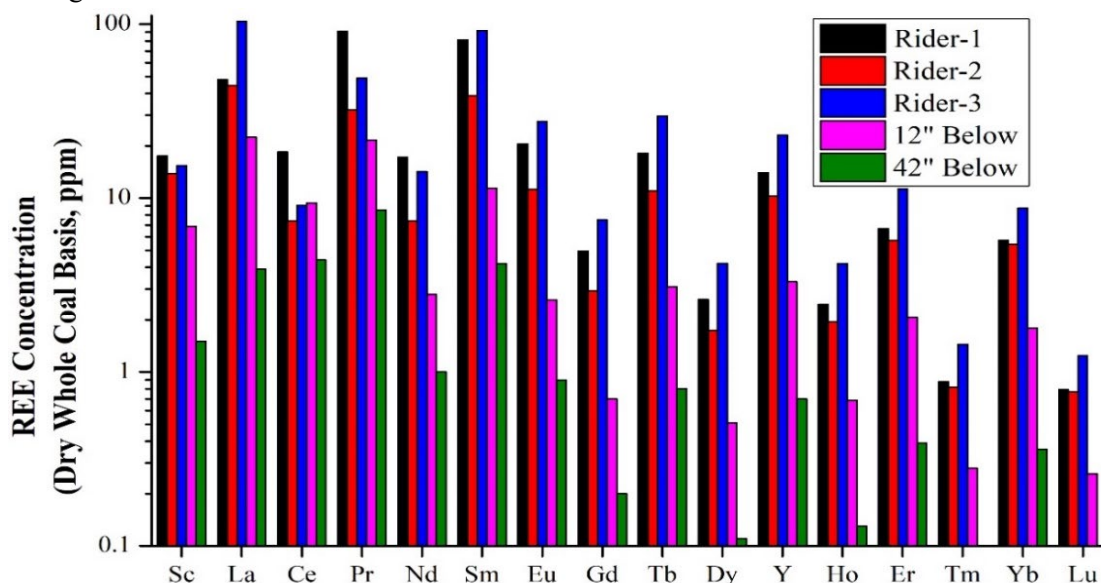


Figure 7. Lateral and stratigraphical distributions of REE from Freedom Mine sampling.

Gravity Separation: This coal-cleaning technique is utilized most often for reduction of ash-forming materials and sulfur by removal of pyritic materials by density. For lignite, the cleaned coal has higher REE levels. The coal cleaning process provides an improved feedstock for the leaching step and reduces the total quantity of material to process, improves REE concentrations in the feed, and cleans the coal for downstream utilization. Phase 1 and Phase 2 results have shown high-ash rejections of greater than 80 wt% ash with minimal REE losses in high REE feedstocks. Likely choices for these technologies include air-based segregation used in *project partner Great River Energy's DryFinishing™ technology*, along with traditional water-based coal spiraling operations.

Dilute Acid Leaching: This leaching step extracts and mobilizes the REEs contained in organic coordination complexes into the pregnant leach solution (PLS) for downstream processing. Leaching is conducted through continuous addition of low-pH and high-REE content wash water from subsequent coal washing steps with small additions of concentrated acid to maintain a solution pH, optimally chosen based upon feedstock variations. *Contact time as small as 45 minutes is all that is required for complete leaching and is conducted under ambient temperature and pressure.* Extraction efficiencies as high as 70% for REE have been found under these conditions for high-REE coals, particularly of the higher-value HREE. Dewatering

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of the coal is conducted through utilization of filter presses to extract clean liquor to be utilized in downstream processes.

Staged washing of the coal is conducted in a counter-current fashion to maximize recovery of acid and REEs contained within pore water of the coal, while also minimizing total plant water use. Ten percent excess water is used for washing to ensure complete acid removal from the coal and to utilize weakly acidic water in downstream processes.

Fe Impurities Removal: This step consists of the addition of base, precipitating a majority of Fe, minimizing a challenging element in downstream REE precipitation. The residence time for the precipitation is roughly 2 hours, occurring at ambient temperature and pressure. The resulting slurry is pumped to a settling tank, where ample residence time is given to allow thickening of the precipitant. Additional deleterious elements, such as a small amount of the NORM (Th, U), report to this product, but in *sufficiently low quantities for safe use/disposal*.

REE-Selective Precipitation: REEs are selectively precipitated in a two-step process. The two-step process utilizes differences in solubility of REE from the primary co-precipitant, Ca, to generate concentration of the REE product and preliminary fractionation of products.

For generation of the final salable products, calcination of the REE products are conducted at 800°C, producing minimal CO₂. The dilute, secondary product is mixed with slightly acidic water, permitting CaO to dissolve selectively and generating a higher-purity REO product.

Aluminum Precipitation: Following the selective precipitation of REE utilizing oxalic acid, the REE-barren liquor contains numerous CM such as Al, Mn, Co, and Ni, with Al being of the highest concentration. Additionally, the liquor requires base addition to adjust the pH to level acceptable for wastewater treatment, allowing low-additional cost generation of an Al-rich product containing additional CM, such as Mn, Mg, Co, and Ni. Residence times for this unit operation are on the order of 2 hours, under ambient pressure and temperature.

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Salable products of the process include: 1) Upgraded lignite coal with reduced ash and alkali, 2) magnetic-REE rich concentrate from REE precipitation #1, 3) Sc and HREE-rich concentrate from REE precipitation #2, 4) Al-rich product containing additional CM, and 5) Ore-grade Fe.

Key benefits of the process are summarized below:

- *Weakly bonded organic associations of REE in ND lignite, with significant enrichment in HREE, presents a unique REE-market opportunity.* The REEs in higher rank coals are primarily associated with mineral-bound materials and represent a more difficult extraction process, which may include acidic or caustic roasting and subsequent leaching. In contrast, REEs associated with lignite are primarily associated with organic matter, permitting a rapid extraction with milder conditions. The extraction process is similar in design to the process currently used for the HREE-rich ion-adsorbed clay deposits of China. Because of the ease of extraction, complex physical beneficiation processes including froth-flotation are not required.
- *Our process utilizes a dilute/mild leaching process of the lignite coal at room temperature.* In comparison, hard rock ores, coal ash, and REEs associated with high rank coals require significantly concentrated acidic or caustic baking at high temperatures to allow for reasonable REE extractions. This is a technically and materially complex approach with significant costs and environmental concerns
- *Use of a mild leaching process allows for extraction tuning to avoid deleterious or problematic elements.* Through control over acidity of the leaching solution, REEs and other target elements may be leached with selectivity, leaving behind mineral components and other potentially stronger-bound materials (Th and U), preventing downstream upcycling and concentrating.
- *Unit operations utilized in the process have been demonstrated at commercial scale in common mining/metallurgical operations.* In the proposed technology, there are no novel equipment configurations or proposed unit operations presenting additional technical barriers to commercialization.

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- *The REE extraction process is also a coal beneficiation process and can provide potential value-added use of the coal to augment economics.* Potential uses of the coal, either combustion or non-combustion mechanisms such as activated carbon production, draw additional value from the higher purity of the carbon product due to lower ash contents. Removal of organically associated ash-forming constituents can be of substantial value to humic-acid derived processes. Also, **as a fuel, there are a number of valuable benefits:**
 - Ash reduction of up to 50% achievable with current process, resulting in a higher heating value
 - Virtually 100% of alkali species are removed (measured below 10 ppm), which can mitigate alkali aerosol-based challenges for CO₂ and NO_x removal technologies
 - Reduced fouling/slagging challenges and associated improved plant reliability
 - Potential reduced burden on sulfur-control devices from removal of pyritic and gypsum during coal cleaning processes
 - Removal of hazardous species pre-combustion, resulting in improved marketability of combustion fly ash and decreased disposal costs

5.4 Results of Previous Phases of Testing

The technical objectives of the previous 2 Phase effort were all met, included:

- Sampling and characterization to evaluate lignite-related feedstocks as a viable REE resource with TREE content greater than the DOE target of 300 ppm on a dry, whole coal elemental basis.
- Development of an economically viable and environmentally benign extraction process for REE from pre-combustion lignite.
- Development of a process for economic recovery of REE from the extractant solution into a salable product for downstream refining.
- Construction and operation of a bench-scale unit (10 kg/hr coal feed) for testing integration of the extraction and concentrating process to generate a greater than 2 wt% REO concentrate. Samples as high as 85 wt% REO were produced

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- Development of a techno-economic assessment of the technology to evaluate economic performance, market impacts, and evaluate potential technology and process gaps required for delivery of a refiner-grade REE concentrate to domestic markets.

Physical Beneficiation for REE Concentration: The unique association of the REE with organic complexes in low rank, specifically ND lignite, allows for some REE concentration through standard coal cleaning techniques, such as wet coal spirals. This was conducted on lignite coals, with a small increase in REE content on a whole coal basis (up to ~ 10%), but great increases on an ash basis (relative to impurities) as high as 250%. Results from coal cleaning operation on TREE and ash content for the H-Bed lignite utilized for testing during the previous Phase 2 project shows substantial ash reductions with a small increase in TREE content, along with an increase in HREE/LREE ratio (Table 3). This, along with preferential leaching of HREE over LREE on previous testing suggests a high organic affinity of the HREE.

Table 3. TREE and ash content of multiple coal spiraling fractions of the H-Bed lignite. Orange highlighting indicates fractions combined to create the upgraded blended coal, highlighted in green.

Sample ID	Mass Fraction (wt% of Feed)	Ash Content (wt%)	Total REE (ppm)	Total REE, ash basis (ppm)	HREE/LREE
Raw Coal	100	35.5	646	1822	0.28
Concentrate	35.6	15.1	657	4357	0.30
Scavenger Concentrate	8.2	19.5	679	3483	0.30
Scavenger Middlings	5.4	47.3	630	1333	0.28
Scavenger Tailings	2.1	59.3	550	927	0.26
Tailings	12.0	70.3	353	502	0.26
Blend	49.2	19.3	658	3881	0.30

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Slurry density of the leaching tank was also viewed as a critical parameter early in the project, with goals to maximize the liquid-to-solid ratio in order to maximize liquid concentrations and minimize water use. Early experiments found that decreasing the liquid-to-solid ratio improved leaching efficiency, but further work determined that the more crucial variable under control was the amount of free acid. Following these experiments, leaching tests with controlled acid concentration through pH found that slurry density had little effect on leaching efficiencies and selectivities, allowing for minimization of water use utilizing a 2:1 liquid-to-dry solid ratio. This ratio was set most on the ability to effectively mix the leaching slurry utilizing the stirred tanks designed for the process. Similarly, utilization of pH control for leaching enabled sharp increases in kinetics of extraction, with near-equilibrium extraction within 45-60 minutes, as illustrated in Figure 8. The rapid leaching kinetics were expected, given the nature of the association of the REE (in weak-acid ion exchange sites).

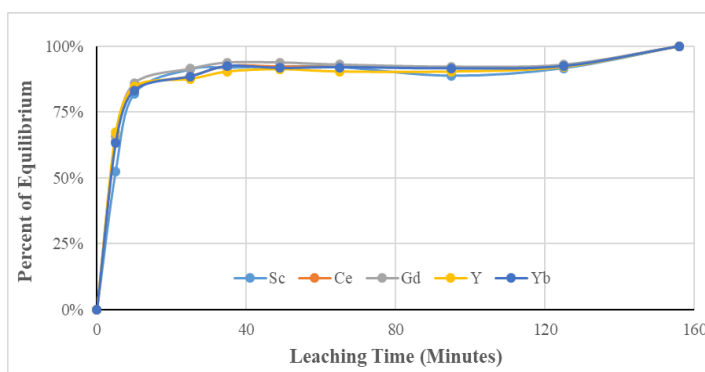


Figure 8. Example kinetics of REE extraction under pH controlled conditions.

Selectivity between elements was achieved using equilibrium extraction efficiencies. For each element, distributions of extraction versus pH were generated to find an optimal cut point for leaching that maximized leaching efficiency of REE and salable products, minimized extraction of hazardous or deleterious materials, and minimized required acid and downstream base costs. Of additional note was the consistent elevated HREE leaching performance as compared with the LREE, a phenomenon likely attributed to differences of ionic radius for the REEs.

Impurity Removal: While leaching steps were selected to minimize impurity ions mobilized as compared to REEs, some unwanted ions were leached. Due to the choice of downstream precipitation, Fe was viewed as a particularly onerous diluent due to complexation with the chosen precipitant. Base addition and precipitation of a Fe-rich precipitant, in the form of jarosite, was identified as a cost-effective removal of Fe and other undesirable diluents. Multiple bases were tested for evaluation of cost, iron removal efficiency,

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and minimal REE loss. The optimal base after these tests and was subsequently subjected to parametric testing for optimal process conditions to minimize REE losses and maximize Fe removal. Additionally, removal of some NORM (Th) reduces additional up-cycling risk upstream during REE precipitation. NORM concentration in this product was sufficiently low as to minimize possible safety and environmental risks. The Fe-rich precipitate is significantly concentrated in Fe (greater than 90 wt% on oxide basis) and has been considered as a potential ore in order to minimize potential waste streams. Dewatering of the Fe-rich precipitate occurs through mechanical separation (centrifuge and settling tank), and polishing removal of pressurized filtration.

REE Precipitation: A cost-effective precipitant for the REEs with few competitive precipitating elements was identified. However, a few elements commonly complex with precipitant, depriving the solution of needed precipitant, necessitating an additional impurity removal step. Calcium presented the largest challenge for co-precipitation and reduction of purity of the REE product, with a liquid concentration an order of magnitude greater than the REE. However, due to substantial differences in solubility between the two precipitation choices (with REE being more insoluble at the conditions of interest), reduced precipitant loadings enabled significant REE precipitation with very minimal Ca co-precipitation. Additionally, slight differences within the REE allowed for significant concentration of the REE around Sm into this product, which further added value of the secondary product.

For near complete REE recovery, higher concentrations of precipitant were required. Additionally, with considerable lanthanide and Y recoveries in the first product, Sc is concentrated into the secondary product, with a concentrating factor against the other REE of 7 to 250. This Sc-rich product is anticipated to be a substantial revenue stream and also contains other valuable CM including Ge and Ga.

Due to the significant Ca impurity associated with the secondary product, a selective dissolution of CaO following calcination is planned. Data from Phase 2 has demonstrated Ca removal efficiencies of greater than 80% with minimal REE loss at elevated pH (possible due to the basic nature of CaO) from the secondary product. Additionally, due to the substantially slower kinetics associated with REO conversion and dissolution as compared with CaO, significant parametric tuning to enhance separations are expected.

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The water used to separate this CaO is the slightly acidic water from coal washing, to enable more effective lime dissolution and minimize REE dissolution.

Aluminum Recovery: Organically-associated aluminum is leached with similar efficiency as the REE and makes up a large portion of the trivalent ions within the previous PLS. Aluminum can be effectively precipitated out of solution through addition of base, a requirement for treatment of wastewater. Further, generation of an Al-rich concentrate can further bolster economics of the process and continue to reduce possible waste streams. Further, the added cost for aluminum recovery is minimal since a significant portion of the cost associated with this step is the pH adjustment, which is a mandatory step in the wastewater treatment.

6. QUALIFICATIONS

The technical team from Phase 2 is intact for the proposed pilot-scale demonstration, and we have added an additional partner in Rare Earth Salts, engaged the Critical Materials Institute, and attracted additional industry sponsors beyond those for Phase 2. UND has a long history of conducting similar large interdisciplinary and multi-organizational research projects. The vast resource of personnel and expertise at UND will be critical in completion of the proposed work. Additionally, UND and Barr Engineering have collaborated on multiple projects recently, including the Phase 1 and 2 REE projects and the successfully completed 3-year \$3.6 million effort to evaluate UND's carbon dioxide capture technology, CACHYST™ (DE-FE0007603). All of the key personnel for this project are exceptionally qualified technically and have a long history of project management experience. Barr Engineering Co. has extensive experience in coal mining and handling, power generation, minerals exploration, and minerals processing and extractive metallurgy. Their experience includes permitting, siting and projecting cash flow for commercial projects. MTI's brings a unique deep understanding of the chemical and physical processes associated with the behavior of ash materials in the boilers of power plants, extensive experience in determining the forms and modes of occurrence of major, minor, and trace species in coal and coal related materials, and contacts with coal mines and coal-fired utilities through decades of research related to solving real-world challenges associated with impurities in fuels and operations of gasification

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and combustion systems. MTI has conducted over 1560 projects on the impacts of fuel properties on plant performance for clients worldwide. *Rare Earth Salts* offers a domestic, commercial refining process, taking the proposed extraction technology through the next step in the value chain. They have experience utilizing a number of REE concentrates in refining processes, including coal-derived materials in previous projects. *MLJ Consulting* brings experience working with the lignite industry in developing value-added products based on the large deposits of North Dakota lignite. Project sponsors serving as project advisors represent the coal mining and utilization industries.

The project team and key personnel are exceptionally well qualified to perform this project. The project is led by Dr. Michael Mann, Executive Director of IES and Distinguished Professor of Chemical Engineering. Dr. Mann has extensive experience in management of large multi-organizational projects of similar scale and scope during his 38+ years' work in the energy field. He is the PI on UND's current \$3.37 million DOE Fossil Energy funded REE project that includes MTI, Barr and MLJ Consulting as project partners. He is the PI on UND's \$2.51 million DOE EERE project focusing on developing a treatment scheme for produced waters from the oil and gas industry. He was also been the PI on a \$2.27 million Department of Defense funded project on lightweight reliable materials for military systems. Previously while at the Energy & Environmental Research Center, he was responsible for the design and installation of their 1 MW_{th} circulating fluid-bed combustion facility and their 1-MW transport gasifier and associated hot-gas cleanup unit. As the Executive Director of IES, he has administrative authority over the UND team and can allocate resources as necessary to accomplish the proposed work.

Co-PI Nicholas Sosalla, Barr Engineering, has gained experience in managing both process engineering and multi-disciplinary projects at Barr Engineering. These projects cover sampling, design, and modeling on mining and processing operations including iron ore, potash, soda ash, and industrial minerals. Nick is Barr's technical lead on process modeling in the current Phase II project and will have access to Barr's network of engineers. He will be assisted by Dr. Dan Palo who has over two decades of process development and deployment experience, including laboratory, pilot, and plant level systems.

Co-PI Dr. Steve Benson, MTI is a world-class expert on the forms and occurrence of major, minor, and

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trace elements including REEs in lignite and other coals. Dr. Benson also conducted extensive work on the development of automated scanning electron microscope analysis of fuels and ash related materials. He has worked extensively with coal beneficiation, combustion, gasification, and air pollution control technologies. Dr. Benson was the PI for the current Phase 1 efforts.

Co-PI Nolan Theaker, UND, has led the current federally funded REE extraction Phase 2 technical effort as a Co-PI on the project, having worked on this and other REE and coal beneficiation projects for the past 2 years. As Co-PI on the previous Phase 2 project, he was instrumental in development of the current process design and operating modes/conditions. His experience in solution chemistry, multi-phase reactions, and separation will be leveraged in the proposed work. He will be assisted by Mr. Harry Feilen, also with UND on the construction activities. Mr. Feilen previously owned a construction company and has been around heavy equipment, both operating and repairing for over 30 years.

Co-PI Ryan Winburn, Rare Earth Salts, Vice-President for Research and Development has been responsible for the continued development and patenting of technologies relating to the conversion and separation of rare earth elements/compounds. In his role he has been responsible for managing all in-house and extramural research activities for his company.

The project will also be supported by Dr. Mike Jones of MLJ Consulting. Dr. Jones recently retired as the Vice President for Research of the Lignite Energy Council in ND, and his knowledge of the ND lignite industry is unsurpassed. Dr. Jones will leverage his relationships and knowledge of the industry and will focus on the commercialization plan development in Phase 2 and in a technical advisory role to ensure the process is developed to best suit the needs of the lignite industry.

7. VALUE TO NORTH DAKOTA

North Dakota produces over 30 million tons of lignite annually. The state's economy is heavily invested in the production and use of lignite. Successful completion of the proposed project will open a new high value commercial opportunity for lignite use. A completely new industry will be realized if successful commercialization of the technology is achieved, providing new opportunities for high-paying jobs and new tax revenues for the State. Several potential commercialization strategies have been conceptualized,

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each of which will provide tremendous economic impact to the state. Although the proposed project is focused on extraction and concentration of REEs from lignite, additional processing steps will be required to arrive at final REE products. Having a lowest cost source of REE concentrate in the Nation will encourage location of these processors/refiners in North Dakota, further increasing employment and revenue opportunities.

8. MANAGEMENT

The project structure is designed to facilitate management of the project by task. The task lead and lead individual from each partner organization are listed in Figure 9. UND will be the lead for the project, serving to direct the technical and scientific aspects, managing resources, scheduling and budgets, and be the point of contact between DOE NETL and other project participants/sponsors. Dr. Michael Mann will be the Principal Investigator (PI) and Program Manager (PM) on the project. He is the current PI for the ongoing Phase II project and has managed a number of larger pilot-plant projects during his career. Cost management will be coordinated by the Administrative Resource Manager who will be responsible for tracking all costs for each of the project tasks.

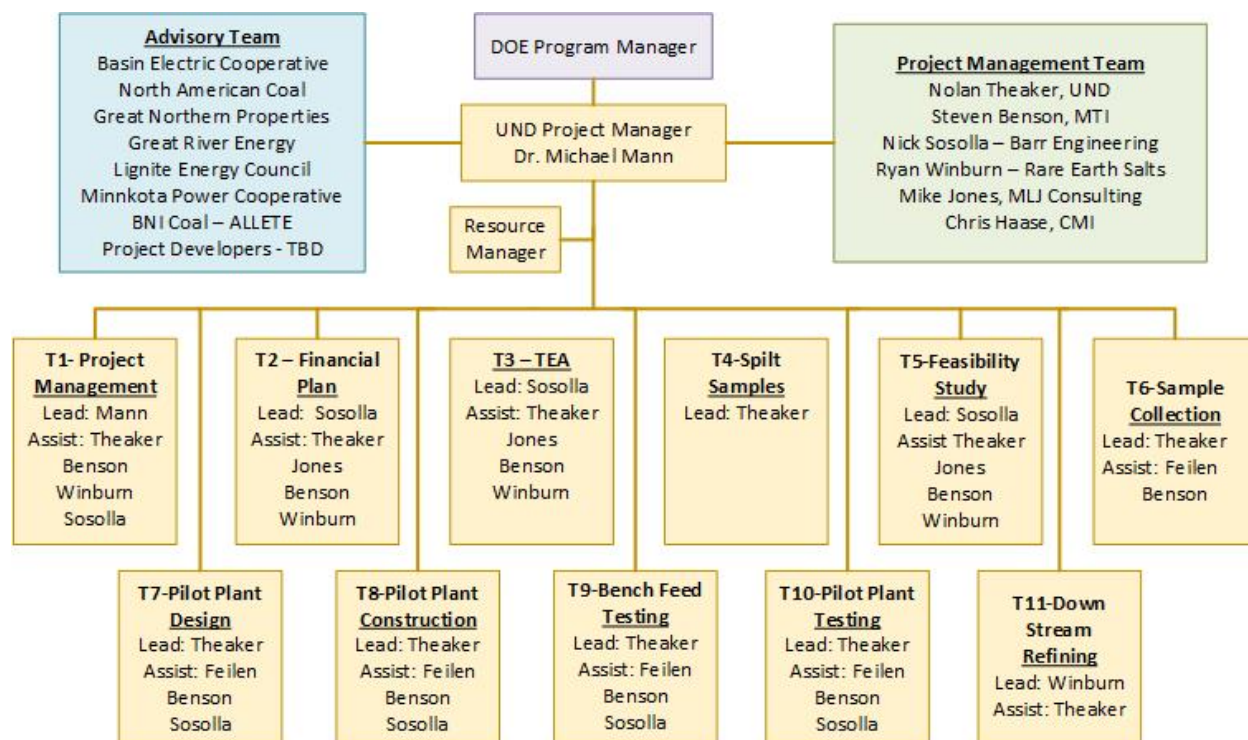


Figure 9. Project Organization

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Co-PI, Nick Sosalla, assisted by Dr. Dan Palo, Barr, will lead Tasks 2, 3, and 5, which include developing the financial plan, the feasibility study, and the techno-economic analysis. Barr Engineering has been a partner on our previous work and has extensive experience in coal mining and handling, power generation, minerals exploration, and minerals processing and extractive metallurgy. Their experience in the processing of other ores, such as iron, copper, gold, uranium, trona, and sylvinitite provides critical background to the proposed work. They will also provide significant input into the pilot plant design, including permitting, and construction of the plant as these tasks align well with their current portfolio of projects.

Co-PI, Nolan Theaker, UND, will be the lead on Tasks 4, and 6-10. These are the primary technical tasks and constitute the bulk of the technical work on the project. Mr. Theaker is the Co-PI and technical lead on our current Phase II project. Co-PI, Dr. Ryan Winburn will lead Task 11. Dr. Winburn is a co-developer of the RES refining process and has ties to the North Dakota lignite industry. Co-PI, Dr. Steve Benson, MTI, was the original PI for the Phase I developmental work and maintained that role for the Phase II efforts before he left UND to focus his attention on MTI, a company he founded. His company will provide advice regarding the process development (Tasks 2, 3, and 5) and analysis and engineering support for Tasks 8, 9, and 10. He will also lead the effort of integrating on-line analysis into the mining process to expedite the use of selective mining techniques, which will enhance commercialization of the process.

MLJ Consulting, and in particular Dr. Mike Jones, will assist the project team related to the market analysis, technical and economic analysis and commercialization plan development efforts. Dr. Jones brings tremendous knowledge of, and relationships in the lignite industry in the State and will greatly augment the project. The ND Geological Survey, in particular Mr. Ned Kruger and Mr. Ed Murphy, will provide technical support regarding the geology and geochemistry of ND lignites and in selection of sites for sample collection, critical for the development of the commercialization plan. Under separate efforts, the NDGS has been sampling in Southwestern and Western ND, and has identified several areas that are targets for commercialization.

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Project meetings and conference calls with the core project management team will be held on a biweekly basis to conduct project activities, review project timelines, upcoming milestones/deliverables, costs, and challenges associated with the completion of the project tasks. Microsoft Project management tools will be utilized. Project review meetings with sponsors will be held semi-annually to ensure communication and discussion of accomplishments, plans and management of project risks. Intellectual property management and discussions have been initiated. During the course of the project, any new findings will be promptly documented and patent applications to protect the intellectual property filed as necessary. Discussions with potential commercial sponsors have been initiated regarding further development and scale-up of the technology and will be continued on a semi-annual basis as the project progresses.

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9. TIMETABLE

DOE has set an aggressive timeline of 30 months for completion of the pilot-scale demonstration, with an estimated start date of October 1, 2019. The project Gantt chart is displayed in Figure 10. Major milestones and planned completion dates are provided in Table 4.

Table 4. Project Timing and Milestones

Task	Timing (months)	Start Date	Stop Date	Deliverable Due
1. Project Management 1.1 – PMP 1.2 – TMP 1.3 – Workforce Readiness	0 - 30	10/1/2019	3/31/2022	10/31/19 11/30/19 and 3/31/22 5/31/20 and 3/31/22
2. Financial Plan Plan developed Update based upon results	0 – 2 LOP	10/1/2019 10/1/2019	11/31/19 2/28/2022	11/31/19 2/28/2022
3. Techno-Economic Analysis	1 - 29	11/1/19	2/28/2022	2/28/2022
4. Provide Split Samples	28 - 29	1/1/2022	2/28/2022	2/28/2022
5. Feasibility Study	0 - 8	10/1/2019	5/31/2020	5/31/2020 (GNG)
6. Large Sample Collection 6.1 – Planning 6.2 – Procure and Prepare	0 – 2 1 - 8	10/1/2019 11/1/2019	11/31/2019 5/31/2019	
7. Pilot Plant Design 7.1 – Design 7.2 – Permitting	0 – 8 0 - 6	10/1/2019 10/1/2019	5/31/2020 3/31/2020	5/31/2020 (GNG) 5/31/2020 (GNG)
GO – NO GO Decision	9			6/15/2019
8. Pilot Plant Construction 8.1 – Procurement 8.2 – Construction 8.3 – Shakedown	10 – 15 10 – 18 18 - 19	7/1/2020 7/1/2020 3/1/2021	12/31/2020 2/28/2021 3/31/2021	
9. Bench-Scale Testing	10 - 16	7/1/2020	1/31/2021	
10. Pilot-Plant Testing 10.1 – Parametric Testing 10.2 – Continuous Operation	19 – 21 22 - 24	4/1/2021 7/1/2021	6/30/2021 9/30/2021	
11. Down-Stream Refining	25 – 27	10/1/2021	12/31/2021	
Final Report	28 - 30	1/1/2022	3/31/2022	3/31/2022

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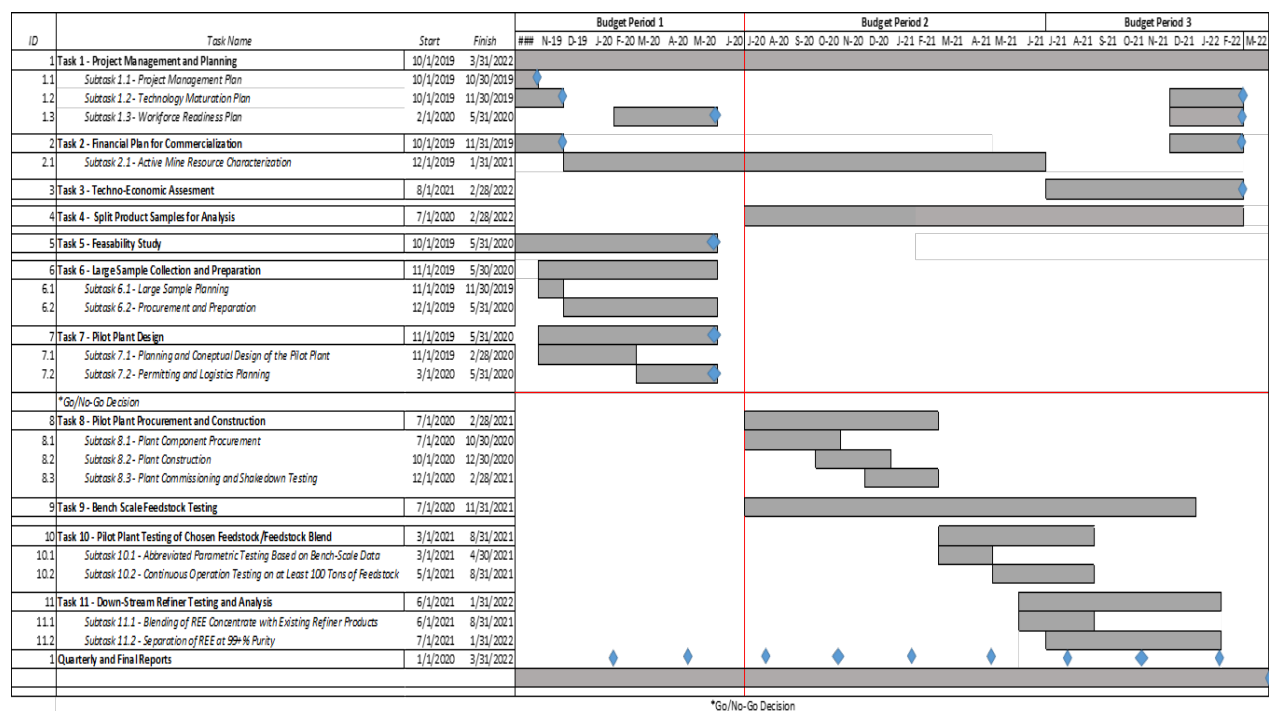


Figure 10. Project Gantt Chart

10. BUDGET

A detailed budget and budget justification are provided as an appendix to this application.

11. MATCHING FUNDS

A breakdown of the funding sources for the project is provided in Table 5.

Table 5. Matching funds and funding breakdown by support source

Support Source	Cash	In-Kind	TOTAL	% of Project
DOE	\$4,989,255		\$4,989,255	76.7
NDIC	\$900,000		\$900,000	13.8
NACC	\$25,000	\$100,000	\$125,000	1.9
GRE	\$0	\$125,000	\$125,000	1.9
MPC	\$75,000	\$75,000	\$125,000	1.9
BNI	\$60,000	\$60,000	\$125,000	1.8
UND	\$0	\$90,000	\$90,000	1.4
MTI	\$0	\$34,300	\$34,300	0.5
TOTAL			\$6,508,555	100

12. TAX LIABILITY

No outstanding tax liabilities to the state of North Dakota

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13. REFERENCES

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14. APPENDICES

RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

BUDGET SUMMARY AND BUDGET JUSTIFICATION

The following table gives the summary of the total project budget and the requested funding for each of the cost share partners and the Department of Energy. To simplify the subcontracting and equipment purchases, those costs have been assigned solely to the Department of Energy. In-kind contributions from project sponsors are listed in the “Other Direct Costs” line and are described in more detail in the section detailing that budget category.

Budget Category	Total Project	DOE	NDIC	NAC	MPC	BNI	GRE	MTI	UND
Personnel	\$774,923	\$383,458	\$263,346	\$14,256	\$28,512	\$34,215	\$0	\$0	\$51,136
Fringe Benefits	\$205,706	\$100,312	\$68,891	\$3,729	\$7,459	\$8,951	\$0	\$0	\$16,364
Travel	\$47,929	\$25,237	\$22,692	\$0	\$0	\$0	\$0	\$0	\$0
Equipment	\$879,800	\$879,800	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Supplies	\$164,000	\$86,353	\$77,647	\$0	\$0	\$0	\$0	\$0	\$0
Subcontracts	\$2,280,995	\$2,280,995	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Other Direct Costs	\$1,334,250	\$702,544	\$214,906	\$100,000	\$75,000	\$60,000	\$125,000	\$34,300	\$22,500
Indirect Cost	\$820,952	\$530,557	\$252,518	\$7,014	\$14,029	\$16,835	\$0	\$0	\$0
Total Cost	\$6,508,555	\$4,989,255	\$900,000	\$125,000	\$125,000	\$120,000	\$125,000	\$34,300	\$90,000
Percent of Total		76.7%	13.8%	1.9%	1.9%	1.8%	1.9%	0.5%	1.4%

Personnel

Salary estimates are based on the scope of work, and the labor rate used for specific personnel is based on their current salary rate. Generic labor categories have also been established with average labor rates. The table below gives the personnel cost breakdown. Any reference to hours worked on this grant is for budgeting purposes only. The University tracks employees’ time based on effort percentage and will not track or report employees time worked on this project in hours. Final numbers may not agree due to rounding.

Personnel	Hours	Cost
Michael Mann, Project Manager	1,205	\$119,443
Nolan Theaker, Co-PI	3,570	\$132,977
Harry Feilen, Operations and Safety	1,500	\$73,159
Research Engineer	4,580	\$170,463
Research Administrator	1,560	\$24,996
Graduate Student	4,820	\$143,461
Undergraduate Student	5,800	\$90,151

Fringe Benefits

Fringe benefits are estimated for proposal purposes only. On award implementation, only the true cost of each individual’s fringe benefit plan will be charged to the project. Fringe benefits are estimated based upon the current rates for each labor category.

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Travel

A breakdown of travel is presented in the table below and includes travel required by DOE to review meetings, sponsor review meetings, sampling field trips, meetings with major equipment vendors and subcontractor and technical conference. Costs have been estimated based on available airfare and lodging rates, conference fees, standard per diems and other UND travel policies. The sampling trips will include travel to mines or power plants or other locations of interest in the state. Sponsor review meetings are anticipated to be located at the respective sponsor facilities. Estimates are broken down as follows:

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
Sample Collection Trips	Grand Forks	Center, ND	4	3	\$375	\$0	\$80	\$210	\$1,995
Sample Collection Trips	Grand Forks	Beulah, ND	4	3	\$375	\$0	\$80	\$210	\$1,995
Sample Collection Trips	Grand Forks	Bowman, ND	10	7	\$950	\$0	\$450	\$550	\$13,650
Equipment vendor site - verify equipment design specs	Grand Forks	TBD	3	1	\$282	\$750	\$120	\$165	\$1,317
Critical Materials Institute	Grand Forks	Ames, IA	2	2	\$188	\$750	\$80	\$110	\$2,256
Rare Earth Salts	Grand Forks	Beatrice, NE	2	2	\$250	\$750	\$80	\$110	\$2,380
Annual project review meeting	Grand Forks	Pittsburgh	2	2	\$250	\$750	\$80	\$140	\$2,440
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$120	\$200	\$1,445
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$120	\$200	\$1,445
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$80	\$200	\$1,405
Annual project review meeting	Grand Forks	Pittsburgh	2	1	\$250	\$750	\$80	\$140	\$1,220
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$80	\$200	\$1,405
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$80	\$200	\$1,405
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$80	\$200	\$1,405
Potential investor sites	Grand Forks	TBD	5	2	\$500	\$750	\$200	\$300	\$3,500
Critical Material Institute	Grand Forks	Ames, IA	2	2	\$188	\$750	\$80	\$110	\$2,256
Rare Earth Salts	Grand Forks	Beatrice, NE	2	2	\$250	\$750	\$80	\$110	\$2,380
Annual project review meeting	Grand Forks	Pittsburgh	2	1	\$250	\$750	\$80	\$140	\$1,220
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$80	\$200	\$1,405
Technical Conference	Grand Forks	TBD	3	1	\$375	\$750	\$80	\$200	\$1,405

Equipment

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of Need
Chemical Processing Tanks	10	\$22,500	\$225,000	Past Project Experience and Vendor Quotes	Required for continuous pilot plant operation in volumes expected
Pumps	20	\$1,800	\$36,000	Past Project Experience and Vendor Quotes	Flow of process streams - includes pumps rated for harsh/thick slurry conditions
Coal Filter Presses	2	\$80,400	\$160,800	Vendor Quote	Required for Filtration of Coal
Settling Tank	1	\$15,000	\$15,000	Found of vendor website	Required for impurity control
Additional Filter Presses	4	\$22,000	\$88,000	Past Project Experience and Vendor Quotes	Required for Filtration of Process Streams
Reverse Osmosis System	1	\$10,000	\$10,000	Past Project Experience and Vendor Quotes	Water purification for feed to process
Instrumentation	1	\$70,000	\$70,000	Past Project Experience	For accurate sensing and process control of each unit op
Electrical Connections	1	\$45,000	\$45,000	Past Project Experience	Connections required for tank motors, data acquisition, sensing requirements, etc
Plumbing/Fittings/Valves	1	\$65,000	\$65,000	Past Project Experience	Integration of pilot plant operations
Data Acquisition	1	\$20,000	\$20,000	Past Project Experience	Data reading and control over process
Fabricated Components	1	\$40,000	\$40,000	Past Project Experience	Additional in-house fabricated equipment for pilot plant operation
Forklift	1	\$15,000	\$15,000	Vendor Price	Required for construction and movement of materials required for operation
HVAC, Water, and Electrical Upgrades	1	\$90,000	\$90,000	Past Project Experience	Possible upgrade requirements for building systems to ensure safe working order for pilot facility
Total Equipment Cost			\$879,800		

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Equipment cost has been estimated based upon our current Phase II bench-scale design experience. The final design of the equipment to be purchased will be completed as part of the proposed work scope. We have vendor quotations for generically similar equipment. Formal quotes will be obtained during the project once the final design specifications have been determined.

Supplies

The bulk of the supplies will be associated with fabrication of the test system and its operation. Therefore, the supplies budget is an estimate based upon experience in building and operating similar scale equipment and anticipated flow-rates of chemicals based upon experience with the current bench-scale equipment.

General Category of Supply	Cost	Basis of Cost	Justification of Need
General office supplies	\$3,000	Experience from past projects	Basic supplies to support projects, including project specific items such as lab notebooks, data storage devices, etc.
Mining equipment	\$2,500	Experience from past projects	Supplies required for collection of H-bed lignite for blending with feedstock
Labware Supplies	\$8,500	Experience from past projects	Miscellaneous lab supplies including glassware, sample bottles, etc
Personal Protective Equipment (Gloves, Labcoats, Respirators, shoe covers, etc)	\$5,000	Experience from past projects	PPE required for safe experimentation and operation of the bench-scale and pilot plant
Tools (Toolbox, wrenches, drills, etc)	\$30,000	Experience from past projects	Tools required for construction and maintenance of the pilot plant at the facility
Trailer for Equipment/Feedstock Transport	\$5,000	Verbal Vendor Quote	Movement of feedstock/fabricated equipment and repair from pilot facility to UND fabrication shop and bench-scale unit
Fabrication Supplies (Welding Rods, tape, cutting wheels, etc)	\$5,000	Experience from past projects	Required supplies for fabrication of equipment and construction of the pilot facility
Chemical Purchase	\$105,000	Derived from Quotes from Chemical Vendors	All chemicals required (acid, base, precipitant) for total bench-scale and pilot scale testing plans
Total	\$164,000		

Fees – Equipment Use and Laboratory Services / Other

This budget line includes several different categories of fees. The project scope of work includes characterization of selected feedstocks. A series of laboratory and analytical tests are required to complete the project. The following table gives a breakdown of these costs, with the basis of costs being established equipment use rates at UND, as well as advertised rates various laboratory service providers. This table also includes the in-kind contributions from our various cost share partners. These costs are highlighted in yellow for ease in differentiating from other project costs.

RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

General Description	Cost	Basis of Cost	Justification
GRE DryFining License	\$50,000	Great River Energy Licensing Fee for Technology	Utilization of DryFining technology for commercialization pathway and processing of material related to the pilot facility
Large Sample Collection and Associated Mining Costs - NACC	\$100,000	Estimated mining costs associated with sample collection	Generation of sample required for pilot processing
Grad student tuition	\$20,000	Current UND graduate tuition rates	Support of graduate students working on project
Aspen liscence	\$2,000	Current cost of education license	Aspen used as basis for design of commercial plant / used to help design pilot plant
Sample Preparation	\$3,750	Standard cost center rates	Sample preparation required (crushing, grinding) for analysis of coal
Analysis - ICPMS, XRFs, SEM, ...	\$10,000	Standard cost center rates	Verificaiton that sample collected meets requirement of >300 ppm / test variability of sample
Minnkota Engineering Support	\$25,000	Cost-Share Commitment	Engineering support as regarding to integration of the technology into existing power station infrastructure
Minnkota Coal Sorting Support	\$25,000	Time/Equipment Required for sample gathering	Coal sorting equipment testing for REE selectivity for pilot commisioning coal sample
BNI Coal Sampling/Engineering Support	\$40,000	Time/Equipment Required for sample gathering and Engineering Time	Coal mining for REE for pilot commisioning coal sample and commercialization potential and evaluation of resource potential
Coal Crushing	\$400,000	Vendor Estimate	Sizing of coal for spiral and downstream operations
Coal Spiraling	\$150,000	Vendor Estimate	Removal of mineral matter for downstream processing
Shipping of Samples	\$500	Experience from past projects	Required for additional analysis
Grad student tuition	\$20,000	Current UND graduate tuition rates	Support of graduate students working on project
Aspen liscence	\$500	Current cost of education license	Aspen used as basis for design of commercial plant / used to help design pilot plant - prorated as usage will be reduced during BP2
Analysis - ICPMS, XRFs, SEM, ...	\$70,000	Standard cost center rates	Analysis required to determine evaluate results of pilot testing
Waste disposal costs	\$30,000	Experience from past projects	Compliant disposal of all wastes/non-storable products during project
Facility Rent/Utilities	\$120,000	Verbal Vendor quote	Space for Pilot Facility
BNI Coal Sampling/Engineering Support	\$20,000	Time/Equipment Required for sample gathering and Engineering Time	Coal mining for REE for evaluation of commercialization and resource potential
Use of GRE Pilot DryFining System	\$50,000	Setup Time/Equipment Costs	Product coal processing and drying to determine viability with process
GRE Engineering Drawing & Support	\$25,000	Engineering Time Costs	Assistance with commercialization and TEA
Grad student tuition	\$20,000	Current UND graduate tuition rates	Support of graduate students working on project
Aspen liscence	\$2,000	Current cost of education license	Aspen used as basis for design of commercial plant / used to help design pilot plant
Analysis - ICPMS, XRFs, SEM, ...	\$25,000	Standard cost center rates	Analysis required to evaluate the pilot scale process and obtain information required to evaluate process effectiveness and use for TEA
Waste disposal costs	\$10,000	Experience from past projects	Compliant disposal of all wastes/non-storable products during project
Facility Rent/Utilities	\$90,000	Verbal Vendor Quote	Space for Pilot Facility
Minnkota Engineering Support	\$25,000	Engineering Time Costs	Assistance with commercialization and TEA
Shipping material to Rare Earth Salts for testing	\$500	Experience from past projects	Shipment of REE concentrates to refiner for processing
Total	\$1,334,250		

Subcontracts

Four subcontracts are included in this budget. The role of each subcontractor is described in the narrative of the proposal. The subcontract amounts are listed here and detailed budgets from each is available upon request.

Sub-Recipient	Role	Cost
Barr Engineering	Partner to lead financial plan development, TEA, and feasibility study and support pilot scale design and operation	\$1,001,860
Microbeam Technologies Inc	Partner to provide support for TEA, and feasibility study, pilot scale design and operation, project management and reporting	\$699,004
Rare Earth Salts	Partner to lead effort in down stream refiner testing and to provide input for financial plan development, TEA and feasibility study	\$498,631
MLJ Consulting	Provide input into development of financial plan, TEA and feasibility study	\$81,500

Indirect Costs

The indirect cost rate included in this proposal is the federally approved rate for UND of 39%. The indirect cost method is the Modified Total Direct Cost method, defined as the total direct cost of the project minus equipment in excess of \$5000, the first \$25,000 of each subcontract in excess of this value, tuition remission, and in-kind cost share contributions.

**RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE
FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS**

14.1 Letters of Support and Cost Share Contributions



LAVERN K. LUND
Vice President – Engineering and Business Development

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

June 7, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled “Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks” submitted in response to DE-FOA-0002003 “Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources”.

Dear Dr. Mann:

North American Coal Corporation (NACoal) is pleased to support the proposal from the University of North Dakota team, that includes Microbeam Technologies Incorporated, Barr Engineering, MLJ Consulting, and Critical Material Institute to scale-up UND’s technology to concentrate rare earth elements from North Dakota lignite.

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

We are highly encouraged by the results of UND’s Phase 1 and 2 projects that both identified locations in North Dakota with coal that is highly enriched in rare earth elements, as well as demonstrated a simple, highly effective, and low-cost extraction technology that takes advantage of unique properties of North Dakota lignite to produce valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour and will utilize NACoal coal mining operations to supply the high-REE coal required for the project.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials. NACoal is pleased to support this project by providing a cash cost share, as well as an in-kind cost share, that will total \$125,000. The in-kind contribution will consist of costs associated with drilling, sampling, and mining of the large coal sample required for testing. The cost share will be provided over the 30-month project duration and is subject to project award by the US Department of Energy, the North Dakota Industrial Commission/Lignite Research Council, and final review.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Very truly yours,

THE NORTH AMERICAN COAL CORPORATION



LaVern K. Lund
Vice President – Engineering and Business Development

June 6, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources".

Dear Dr. Mann:

The BNI Energy Inc. is pleased to support the proposal from the University of North Dakota team, that includes Microbeam Technologies Incorporated, Barr Engineering, MLJ Consulting, and Critical Material Institute to scale-up UND's technology to concentrate rare earth elements from North Dakota lignite.

We are highly encouraged by the results of UND's Phase 1 and 2 projects that both identified locations in North Dakota with coal that is highly enriched in rare earth elements, as well as demonstrated a simple, highly effective and low-cost extraction technology that takes advantage of unique properties of North Dakota lignite, while also producing valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour and will conduct further sampling to further characterize currently mined resources, including in BNI's Center Mine.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials. BNI Energy is pleased to support this project by providing \$60,000 in cash cost share, as well as an estimated \$60,000 in in-kind cost share. The in-kind contribution will consist of costs associated with contributions of professional time to review technical information and advise the project management team, drilling, sampling, and potential mining of commissioning coal for pilot plant operation. The cost share will be provided over the 30-month project duration and is subject to project award by the US Department of Energy, the North Dakota Industrial Commission/Lignite Research Council and final review.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Sincerely,



Wade Boeshans
President and General Manager

BNI ENERGY
1637 Burnt Boat Dr. Bismarck, ND 58503



2875 Third Street SW
Underwood, North Dakota 58576
701-442-3211
greatriverenergy.com

May 29, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering - Executive Director, Institute for Energy Studies
UNIVERSITY OF NORTH DAKOTA
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support for "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources".

Great River Energy is pleased to support the proposal from the University of North Dakota team, that includes Microbeam Technologies Incorporated, Barr Engineering, MLJ Consulting, and Critical Material Institute to scale-up UND's technology to concentrate rare earth elements from North Dakota lignite.

We are encouraged by the results of UND's Phase 1 & 2 projects that identified locations in North Dakota with coal that is highly enriched in rare earth elements, along with the demonstration of a simple, effective and low-cost extraction technology for North Dakota lignite, while also producing valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour and will utilize the GRE's proprietary DryFining™ fuel enhancement process to segregate coal and mineral components and dry the product coal.

Developing low-cost, efficient and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials. GRE is pleased to support this project by providing \$125,000 in in-kind cost share over the 30-month project duration, subject to project award by the US Department of Energy and the NDIC/LRC. The in-kind contribution will include \$50,000 for the DryFining license, \$25,000 for engineering and fabrication drawings on a 5 ton/hour pilot Dryfining unit and \$50,000 for 12-month rental of the 220 lb/hr pilot scale DryFining system setup for supply to the UND team for analysis and testing in its project.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me.

Sincerely,
GREAT RIVER ENERGY

A handwritten signature in cursive script that reads 'David E. Farnsworth'.

David Farnsworth
Manager of Power Generation and Engineering, North Dakota Generation



5301 32nd Avenue South
Grand Forks, ND 58201

Phone 701.795.4000
www.minnkota.com

June 3, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Letter of Commercial Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources"

Dear Mr. Mann:

Minnkota Power Cooperative, Inc. (Minnkota) is pleased to support the proposal from the University of North Dakota team that includes Microbeam Technologies Incorporated, Barr Engineering, MLJ Consulting, and Critical Material Institute to scale-up UND's technology to concentrate rare earth elements from North Dakota lignite.

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 northwestern 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.

We are highly encouraged by the results of UND's Phase 1 and 2 projects that both identified locations in North Dakota with coal that is highly enriched in rare earth elements, as well as demonstrated a simple, highly effective and low-cost extraction technology that takes advantage of unique properties of North Dakota lignite, while also producing valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials. Minnkota is pleased to support this project by providing cash or in-kind cost share up to \$125,000. The in-kind contribution will

include planning assistance, techno-economic assessment support, loading and mining of coal from the Center mine, a potential site location, and engineering support time as it complimentarily helps ongoing company projects or interests. The cost share will be provided over the 30-month project duration and is subject to project award by the US Department of Energy, the North Dakota Industrial Commission/Lignite Research Council, successful completion of the Go/No-Go decision point(s) in the project, support from additional industry participants and final review.

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: Gerad Paul
Dan Laudal
Craig J. Bleth
Dylan Wolf



Great Northern Properties Limited Partnership

1415 Louisiana Street, Suite 2400 • Houston, TX 77002

(713) 751-7500 • Fax (713) 751-7591

Kai Xia

President & CEO

kxia@gnplp.com

Direct: (713) 751-7518

June 6th, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled “Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks” submitted in response to DE-FOA-0002003 “Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources”.

Dear Dr. Mann:

Great Northern Properties wishes to express its interest and potential support for your proposed project to scale-up UND’s technology to concentrate rare earth elements from North Dakota lignite. As an owner of substantial coal deposits in North Dakota and Montana, positive results from your work represent a tremendous opportunity for our company to capture value from those resources.

We have reviewed the results from your previous work and are highly encouraged by the results that both identified locations in North Dakota with coal that is highly enriched in rare earth elements, as well as demonstrated a simple, highly effective and low-cost extraction technology that takes advantage of unique properties of North Dakota lignite, while also producing valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour of coal feed.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials. Great Northern Properties is interested in supporting your project by providing access to our resources, and to support your team to help identify and quantify the commercially viable coal seams. We do have an interest in potentially providing both in-kind and cash contributions to the project, but are currently awaiting final board approval of this request. In-kind contributions would include providing core samples of our most promising reserves to include in your pilot testing and providing input into the development of your commercialization plan. A

decision will be made in time for your July 1st submission to the North Dakota Industrial Commission funded Lignite Energy Council research programs.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Sincerely,

A handwritten signature in black ink, appearing to read "Kai Xia". The signature is fluid and cursive, with the first name "Kai" and last name "Xia" clearly distinguishable.

Kai Xia
President and CEO OF Great Northern Properties L.P.



June 5, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources".

Dear Dr. Mann:

Basin Electric Power Cooperative is pleased to support the proposal from the University of North Dakota team that includes Microbeam Technologies Incorporated, Barr Engineering, MLJ Consulting, and Critical Material Institute to scale-up UND's technology to concentrate rare earth elements from North Dakota lignite.

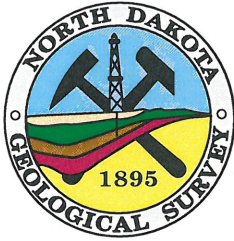
We are encouraged by the results of UND's Phase 1 and 2 projects that both identified locations in North Dakota with coal that is highly enriched in rare earth elements, as well as demonstrated a simple, highly effective and low-cost extraction technology that takes advantage of unique properties of North Dakota lignite, while also producing valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour of coal feed.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials. BEPC is pleased to support this project through its willingness to provide feedstocks from ND lignite reserves.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Sincerely,

Gavin McCollam
Vice President, Engineering & Construction



North Dakota Geological Survey

Edward C. Murphy - State Geologist

Department of Mineral Resources

Lynn D. Helms - Director

North Dakota Industrial Commission

<https://www.dmr.nd.gov/ndgs/>

May 29, 2019

Dr. Michael D. Mann
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources".

Dear Dr. Mann:

The North Dakota Geological Survey (NDGS) is pleased to support the proposal to scale-up UND's technology to concentrate rare earth elements from North Dakota lignite. The University of North Dakota research team includes Microbeam Technologies Incorporated, Barr Engineering, MLJ Consulting, and the Critical Material Institute.

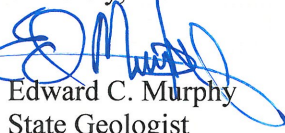
NDGS was an advisor on the UND team's Phase 1 and 2 DOE efforts, we provided samples for analysis and geological insights regarding rare earth enrichment. We are highly encouraged by the results of UND's Phase 1 and 2 projects that both identified locations in North Dakota with coal that is highly enriched in rare earth elements, as well as demonstrated a simple, highly effective and low-cost extraction technology that takes advantage of unique properties of North Dakota lignite, while also producing valuable byproducts. We understand that the UND extraction process is novel and offers numerous benefits over other technologies for REE recovery from coal. In the proposed project, UND will be scaling up its extraction technology to a range of approximately 0.25 tons/hour.

The NDGS is also currently involved in a separate effort to identify coal-related resources in southwestern North Dakota with elevated levels of rare earth elements. We are supportive of this proposal to the extent that it does not duplicate, but rather dovetails with the efforts of our agency in a complimentary fashion. We will be pleased to work closely with the UND project team to identify areas enriched in rare earth elements, provide samples as necessary for testing, procure permits for potential UND sampling, and provide invaluable insight into the geology of the region and North Dakota lignites.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate REE is key to providing additional markets for North Dakota lignite-derived materials.

We look forward to working with the UND team on this exciting opportunity.

Sincerely,



Edward C. Murphy
State Geologist



VALLEY CITY
STATE UNIVERSITY

June 3, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources".

Dear Dr. Mann:

Valley City State University (VCSU) has completed the installation of our new steam heating facility, and, based primarily on the preliminary design and feasibility work that your group did under your Department of Commerce funded grant, we are in the final phase of obtaining funding for integrating an activated carbon plant with our new steam plant as recommended in your work. We hope to be able to initiate construction of the carbon plant in the fall of 2019. Based upon the success of our joint efforts, VCSU is now pleased to support the University of North Dakota as they move into the pilot plant phase of their rare earth element (REE) recovery process. We see promise in integrating UND's new REE recovery process into our activated carbon steam plant.

We understand that REEs provide significant value to our national security, energy independence, environmental future, and economic growth. We are encouraged by the recent work conducted by the UND team and are excited about the opportunity to add a REE recovery process to our integrated activated carbon and steam plant. We would like to continue to work with the UND Team to evaluate the integration of their novel REE recovery process within our steam co-generation plant concept that would produce not only steam for campus heating, but also value-added activated carbon products and REEs produced from North Dakota's vast lignite resources. It is particularly attractive, as we understand that UND's REE recovery process will provide the opportunity to increase the purity and value of the carbon products produced at our facility.

The carbon and REE products will provide revenue streams for the University, which will not only offset costs of steam production, but based on UND's economic analysis, will generate a significant profit that can be used to supplement education and research offerings at VCSU. We are working with UND to develop collaborative science and engineering programs that will educate the next generation of energy experts. We believe that addition of the REE recovery process to our facility will provide additional infrastructure and funding opportunities to expand our research platform and provide additional value to our students, the state and the nation.

We are excited about this first implementation of the next generation of university heating plants at the VCSU campus, and hope that our campus can serve as a pilot, that with success, will encourage subsequent implementation at other facilities within the state. We understand that as a part of your commercialization plan, the next step in scale-up after completing the pilot-scale developing you are now proposing is a small commercial demonstration of approximately 5-10 ton/hour. Our campus is very interesting in serving as a host for this first plant. We believe the concept proposed by the UND team would be beneficial to both VCSU and the state of North Dakota and are excited to help in advancing it to the next stage of development. We look forward to collaborating with UND as they further develop their unique technology.

We wish the UND team success in its current Phase II project with DOE as well as success in securing funding for a subsequent project to scale the technology to the commercial level, of which we will be fully supportive. Please do not hesitate to contact me at the letterhead address or email below for any additional information or with questions.

Sincerely,

A handwritten signature in blue ink, appearing to read "Wesley Wintch", with a stylized, flowing script.

Wesley Wintch – VP for Business Affairs

Valley City State University



Critical Materials Institute

AN ENERGY INNOVATION HUB

Critical Materials Institute
Ames Laboratory
2332 Pammel Dr.
Ames, IA 50011

June 7, 2019

Dr. Michael D. Mann
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Subject: Funding Opportunity Announcement DE-FOA-0002003

Dear Dr. Mann:

I write on behalf of the Critical Materials Institute (CMI) in support of your proposal to the Department of Energy's Office of Fossil Energy Funding Opportunity Announcement, for the Process Scale-Up and Optimization/Efficiency Improvements for Rare Earth Elements (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources. CMI appreciates UND's participation as an Affiliate in CMI's efforts.

Should the University of North Dakota be favorably selected for this FOA, CMI would enthusiastically respond to a collaborative invitation in support of our mission to help alleviate material criticality risks in US energy supply chains. Collaborative efforts like yours that leverage the complementary skills, knowledge, and technology to process leachates produced for the extraction of rare earth elements are very important to future energy security. Concentrates produced from domestic resources and their corresponding processes offer unique opportunities to implement CMI's novel selective separation technologies to increase the economic value of the produced material as a precursor to metal separation and alloying for end-use clean energy applications.

With the potential to deliver vital innovations that enable a viable domestic supply chain for critical materials, we would be humbled to contribute to this important effort for our national interests.

Thank you very much.

Kind regards,

Dr. Chris Haase
Director, Critical Materials Institute

June 7, 2019
Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources."

Dear Dr. Mann:

Barr Engineering Co. (Barr) is pleased to continue its collaboration with the University of North Dakota (UND) and its team of technical and cost share partners in pursuit and execution of the subject project for the U.S. Department of Energy (DOE). Barr is an 800-person, employee-owned engineering design and environmental consulting firm based in Minneapolis, Minnesota, with focus on mining, energy, fuels, and natural resource management.

As you are aware, we have extensive background in coal mining and processing, coal-fired power plant operation and upgrading, mineral processing and extractive metallurgy, techno-economic analysis, performance and oversight of metallurgical testwork, and pilot plant design and operation. Barr's background and strengths in these areas directly complement the capabilities of other team members by providing mineral process engineering, hands-on operational experience, coal and ash handling, and water treatment expertise. We will focus these capabilities on developing processing options and evaluating these options both technically and economically based on sampling, characterization, laboratory results, and pilot plant operation.

With our roots in the upper Midwest of the United States, we are familiar with the lignite resources of North Dakota, and many lignite processors and end users are long-standing clients of ours. Beginning in 2002, we worked on a related project for the DOE intended to develop the next notable improvement in coal-based energy production. For that project, Barr was involved from concept to commercial operation designing the pilot test unit, prototype unit, and commercial units. We also have a successful partnership history with UND, having assisted with the E-CACHYS™ process (2012-2014) focused on carbon capture and sequestration using advanced sorbents. We have also supported the Phase 1 and 2 design and techno-economic analysis of this DOE project. We are also involved in current coal-based DOE research projects related to improved reliability and flexibility of coal power plants (Coal FIRST) and carbon capture technology.

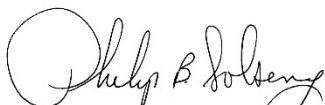
Our relevant, current experience means that the Barr team is well prepared to collaborate with UND toward the successful development of rare earth extraction techniques applied to coal and coal byproducts – now in the pilot-scale phase of development (Phase 3). Based on our discussions with you and the agreed-to scope of work, Barr's estimated budget for the 30-month effort is reflected in our Subaward Budget Justification Form.

For this effort, Mr. Philip Solseng, Vice President and Senior Civil Engineer, and Dr. Daniel Palo, Vice President and Senior Chemical Engineer, will share responsibility as Barr's Principals-in-Charge. Mr. Solseng has decades of experience in the coal mining industry, and Dr. Palo has nearly two decades of experience in applied R&D, having led or contributed to dozens of successful DOE and DoD funded projects. At Barr, the Principal-in-Charge supports the Project Manager from an organizational perspective and ensures quality delivery to the client. The Principal-in-Charge is responsible for all legal and contractual arrangement for the project.

Mr. Nicholas Sosalla, Mineral Process Engineer, will serve as Barr's Project Manager. He is supported by several competent task leaders: Mr. Boyd Eisenbraun – Senior Metallurgical Consultant, Mr. Chad Haugen – Process Engineer, Ms. Nicole Nguyen – Chemical Engineer, Mr. Chase Stevens – Minerals Processing Engineer, and Mr. Richie Kennedy – Mechanical Engineer. This team will lead the efforts in testing support and data analysis, process development, pilot plant design and operation, and economic evaluation. We will also be engaging Mr. Bruce Browers – Senior Mechanical Engineer, and Mr. Richard Hardegger – Vice President and Senior Chemical Engineer as senior consultants on this work. Attached to this letter is Barr's scope of work for this project.

We appreciate the opportunity to propose on this project and look forward to working with you. Please feel free to contact either Philip (952-832-2778, psolseng@barr.com), Dan (801-333-8421, dpalo@barr.com), or Nick (218-262-8644, nsosalla@barr.com) with any questions or concerns.

Best regards,



Philip Solseng, PE, P.Eng.
Project Principal



Dr. Daniel Palo, PhD, PE
Project Principal



Nick Sosalla
Project Manager

Attachment:
Barr's Scope of Work

BARR SCOPE OF WORK

Task 1.0: Project Management and Planning

Barr will assist UND with project management activities, including team coordination, data management, periodic internal and external meetings, and periodic reporting. This task includes participation in the monthly project management meetings (virtual attendance) and providing technical advice as need to support the development of the project. It is anticipated that there will be at least two face-to-face meetings in Grand Forks to discuss details of the project. Barr will also assist in drafting and editing of final report, document management and version control, and drafting and editing of literature submissions and any PR documents.

Task 2.0: Financial Plan for Commercialization

Barr will lead the development of a financial plan for commercialization. The plan will explain the economic feasibility demonstrated by an Excel financial spreadsheet model developed as a part of this effort. A proposed business plan for developing and commercializing the proposed technology to economically produce salable REEs and CMs from U.S. coal and coal-based resources will be developed in conjunction with the project team. Information to be provided includes an explanation of the hurdles and risk factors such as supply of process inputs; process and technology development; capital, operating, and maintenance costs; process operation factors; life-cycle environmental, permitting, and other regulatory factors; market demand and quantity/price points for output products; offtake agreements; downstream supply chain for refining products; international demand, supply, and competition; and other financial and market considerations.

The financial plan will consist of a written report with the key assumptions and data used for development being documented in the design basis. The results of the design basis and financial plan will be utilized and refined through subsequent tasks.

The financial plan will be submitted 60 days after the award of the contract and updated 30 days prior to the end of the award.

Task 3.0: Technical and Economic Analysis

Barr will develop a detailed TEA that estimates the cost and performance for scale-up to a commercial demonstration. The initial TEA will be based on the results generated during the current Phase II project (DE-FE-27006) and updated and refined utilizing the feedstock(s) chosen for the process and based on the input from Task 2, project sponsors, and DOE. The TEA will be updated based on testing and operation of the REE/CM recovery system performed during the proposed project.

The TEA will include and be based on a mass and energy balance which identifies component concentrations and yields associated with each processing step. Conversion factors and units will be identified. A fully functional interactive Excel spreadsheet model with no locked or hidden cells will be included with the TEA. In addition to rare earth element prices supplied by NETL, future market prices for products based on input from project partners Rare Earth Salts and the Critical Materials Institute will be used for the TEA. Revenue projections will be itemized for each rare earth compound/element and each product other than rare earths.

The PFD and mass and energy (M&E) balance used for the TEA will be generated by UND and provided as the input to evaluations of the process. Barr will provide significant input and review of the PFD and M&E balance, as well as the overall design basis document. Both capital and operating cost factors will be used to estimate the economic viability. The capital cost estimate will indicate the all-in costs for the facility, including infrastructure from the site fence line, interconnection to existing facilities, equipment costs, construction costs, construction indirect costs, and owner's costs. The TEA will include a design estimate with adequate detail to be classified as an Association for the Advancement of Cost Engineering International (AACE International, or AACE) Class 3 or better estimate. This estimate is intended to serve as a pre-Front-End Engineering and Design (pre-FEED) level estimate for a future commercial scale demonstration project. The TEA will be performed using the Guidance for Development of Techno-Economic Analysis for DOE/NETL's Feasibility of Recovering Rare Earth Elements Program provided in FOA-0002003.

In order to obtain the AACE Class 3 estimate, Task 3.0 will require the creation of a design basis, process model (including mass and energy balance and process flow diagram), proposed plant general arrangements, equipment specifications, and a Basis of Estimate. Task 3.0 will consist of the engineering documents outlined above for the completion of the cost estimate, the AACE cost estimate, and the full TEA interactive Excel model.

The TEA will be delivered 30 days prior to the end of the award.

Task 5.0: Feasibility Study

Barr will lead the effort for Task 5 with input from the other project partners. The Feasibility Study will provide NETL with information on, but not limited to, availability of the proposed feedstock; information on environmental impacts; process flow diagram(s); product yield and concentration; estimated system costs; etc.

The feasibility study will investigate and discuss the following: 1) information developed in the previous DOE funded projects and input from project sponsors with regard to the available resource and REE and CM grade on a regional scale as required for eventual commercial recovery of REEs and CMs from the proposed feedstocks with the proposed technology; 2) expected waste management characterization and proposed processes to minimize or reduce environmental impacts; 3) future advanced manufacturing techniques; 4) a quantified process flow diagram showing REE and CM recovery process input and process flows, including feedstocks, reagents and other additives (provided by UND team); 5) identification of process recovery, yield, final product concentration for REEs and CMs and other useful materials (provided by UND team); 6) mass/water/energy balances (provided by UND team); 7) capital, operating and maintenance, and process costs per unit of input and output; 8) the expected market demand and pricing for REEs and CMs and other useful recovered products on a regional basis; 9) a fully functional financial spreadsheet model with no hidden or locked cells (the model should clearly identify assumptions and include instructions for use by DOE); and 10) feasibility study conclusions and recommendations.

Information and conclusions will be evaluated and reported in a format similar to that used for mineral resource reporting according to Canadian National Instrument 43-101 (NI43-101).

Task 5.0 will consist of a written feasibility study report containing but not limited to the information provided above, as well as the information developed as part of Tasks 2.0 and 3.0.

The feasibility study will be delivered seven months from the start of the project, allowing time to submit to DOE within 30 days of the go/no go decision point. The study will be performed using guidance provided in Appendix J of DOE-FOA-0002003.

Task 7.0 Pilot Plant Design

UND will lead the design efforts of the pilot plant for a throughput of 500 lb/hr. Barr will assist UND by providing technical input to equipment selection and sizing, procurement, assembly, and startup as needed. Barr will also provide support, as needed, in obtaining the required permits to build and operate the pilot plant including providing engineering drawings based on UND's design that can be used to meet the permitting requirements of the City of Grand Forks.

Task 8.0 Pilot Plant Procurement and Construction

UND will lead the efforts to procure and construct the pilot plant. After completion of the pilot plant, UND will also lead shakedown testing of the system for adequate performance and training of the operators. As part of Task 8.0, Barr will assist UND by providing construction support remotely with reference to the design drawings. Additionally, Barr will assist UND with on-site support of the shakedown testing as needed.

Task 10.0 Pilot Plant Testing of Chosen Feedstock/Feedstock Blend

Utilizing the results of the bench-scale testing, UND will lead pilot plant operation to conduct abbreviated parametric testing followed by continuous operation of the optimum parametric conditions for the chosen feedstock. Barr will support UND during this task by both on- and off-site consultation to troubleshoot unforeseen problems encountered during the pilot plant operation.

June 9, 2019

Dr. Michael D. Mann
University of North Dakota
College of Engineering & Mines
2844 Campus Road Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled “Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks” submitted in response to the Department of Energy under the funding opportunity entitled “Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Elements (REE) and Critical Materials (CM) Recovery from United States Coal based Resources” Funding Opportunity Announcement Number: DE-FOA-0002003.

Dear Dr. Mann:

Microbeam Technologies Incorporated (MTI) is pleased to provide this letter of support to the University of North Dakota (UND) for this collaborative project to demonstrate at the pilot scale a high performance, economically viable and environmentally benign technology to recover rare earth elements (REE) from North Dakota (ND) lignite coal feedstocks.

PHASE I.

Task 1.0 Project Management and Planning – Under this task, MTI will assist UND to coordinate activities in order to effectively accomplish the proposed work. MTI will work with UND and project team members to ensure that project plans, results, and decisions are appropriately documented, and project reporting and briefing requirements are satisfied. MTI will assist in the development the Technology Maturation Plan (TMP) and the Workforce Readiness Plan (WRP).

Task 2.0 - Financial Plan for Commercialization

MTI will provide input into the financial plan for commercialization of UND’s process for REE and CM recovery.

Task 3.0 – Techno-Economic Assessment

MTI will provide input to the project team as it performs the Techno-Economic Assessment (TEA) based on testing and operation of the REE/CM recovery system.

Task 4.0 – Provide Split Samples

MTI will work with UND to analyze and identify a single sample that reflects the highest achieved REE concentration generated during project efforts and will provide the sample to NETL.

Task 5.0 – Feasibility Study

MTI will assist UND and Barr to develop and provide NETL a Feasibility Study 30 days prior to the Go/No Go decision point. The Feasibility Study will provide NETL with information on, but not limited to, availability of the proposed feedstock; information on environmental impacts; process flow diagram(s); product yield and concentration; estimated system costs; etc.

Task 6.0 - Large Sample Collection and Preparation

MTI will work with UND and project sponsors to perform the following: large-sample (>300 tons) collection of coal and the physical preparation of the coal, including crushing, drying, and coal cleaning. The final product of the coal cleaning process will be used as the feedstock for the Pilot testing. The final product of >300 ppm REE may be blended with additional higher REE coal (>600 ppm) to evaluate performance.

Task 7.0 Pilot Plant Design

MTI will provide input into the design of the pilot plant, including the choice of site location, sizing and planning of all equipment, necessary environmental controls, and staffing requirements of the plant.

GO/NO GO DECISION POINT AFTER TASK 7

PHASE II:

Task 8.0 Pilot Plant Procurement and Construction

MTI personnel will assist UND with the procurement, construction, and shakedown testing of the pilot plant.

Task 9.0 Bench-Scale Feedstock Testing

MTI personnel will assist in testing selected coal feedstocks in the bench-scale equipment developed in DE-FE27006 to identify optimized operating conditions for the pilot-scale system.

Task 10.0 Pilot Plant Testing of Chosen Feedstock/Feedstock Blend

MTI personnel will assist in performing parametric and production testing of 100 tons of >300 ppm lignite feedstock to generate a minimum of 10 kg of >2wt% REE concentrate.

MTI is excited to team with UND on this project and looks forward to a successful proposal outcome. The overall budget for the MTI scope of work is \$260,027 for Budget Period 1 and \$438,976 for Budget Period 2. MTI is providing \$34,300 in cost share support. If you have any questions, please do not hesitate to contact me at 701-213-7070 or at sbenson@microbeam.com.

Sincerely,



Steven A. Benson, PhD
President



RARE EARTH SALTS

5331 Element Ave
PO BOX 994
Beatrice, NE 68310
(402) 806-4400

June 7, 2019

Dr. Michael Mann
University of North Dakota
College of Engineering & Mines
2844 Campus Road Stop 8153
Grand Forks, ND 58202-8153

RE: University of North Dakota's (UND) proposal for the Department of Energy (DOE), Office of Fossil Energy (FE), DE-FOA-0002003: "Process Scale-Up and Optimization/Efficiency Improvements for Rare Earth Elements (REE) and Critical Materials (CM) Recovery From United States Coal-Based Resources" Financial Assistance Funding Opportunity Announcement

Dear Dr. Mann,

Rare Earth Salts (RES) is pleased to offer this letter of support for UND's proposal "Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" which is being submitted in response to the Department of Energy (DOE), Office of Fossil Energy (FE), DE-FOA-0002003. As a project team member, we are committed to providing access to our expertise in rare earth processing to work with Battelle to undertake and complete our scope of work:

- Optimization of UND generated rare earth concentrates for use in RES' proprietary separations process
- Process bench-scale and pilot-scale concentrates to separated rare earth oxides
- Support system design and economic evaluation

RES has familiarity working with rare earth elements from coal sources due to past work on DOE projects with Battelle in addition to the nearly 50 other concentrates that we have sourced from all over the globe. We will support this overall project by adjusting and tailoring our process to accept rare earth feedstocks from coal materials with subsidy from the DOE funding. RES will provide full access to its current separation units, our ICP-MS and ICP-OES instruments, and our two senior chemist and technical staff during the project as required. As a result, costs for RES to complete this scope of work is to be approximately \$495,000 and will yield a feedstock that can be incorporated into the RES commercial production feed stream and production of saleable rare earth oxides that are partially from coal sources.

We are pleased to support the University of North Dakota and look forward to working on this project.

Sincerely,

Joseph Brewer
Chief Technology Officer
Rare Earth Salts

MLJ Consulting, LLC
841 Orchard Circle
Grand Forks, ND 58201
701-739-1419
Jones_ml2003@yahoo.com

June 10, 2019

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0002003 "Process Scale-up and Optimization/Efficiency Improvements for Rare Earth Element (REE) and Critical Materials (CM) Recovery from United States Coal-Based Resources".

Dear Dr. Mann:

MLJ Consulting is pleased to provide support for the above project to the University of North Dakota. It has been rewarding to see your technology develop over the past couple of years, and I am happy to help as you continue your development of a high-performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

I understand I would be part of your project management team where I expect to present the viewpoint of various industrial constituents of the state who may be eventual providers of raw material for your process, potential hosts for commercial sites, and/or investors in the technology. I will also provide help for your Tasks 2, 3, and 5, supporting the development of the financial plan, techno-economic assessment and feasibility study. My role in these activities will primarily be to assist with the development and refinement of strategic partnerships as this activity moves through the development phase, and we focus on demonstrating the commercial viability of this project. Please find attached a budget for \$81,500 for these consulting services.

I am looking forward to helping you fully develop and commercialize your process.

Sincerely,

A handwritten signature in black ink that reads "Michael Jones". The signature is fluid and cursive, with the first name "Michael" and the last name "Jones" clearly legible.

Michael L. Jones, PhD.
President

Budget for MLJ Consulting in support of the proposal by the Institute for Energy Studies at UND entitled “Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks”

Year one

- Personnel- 170 Hours @\$175/ hour = \$29,750
- Travel \$1000
- Total year one \$30,750

Year Two

- Personnel 170 hours @\$175/ hour = \$29,750
- Travel \$1000
- Total year two \$30,750

Year Three

- Personnel 100 hours @\$175/hour = \$17,500
- Travel \$2500
- Total year Three \$20,000

Total budget \$81,500

**RARE EARTH ELEMENT EXTRACTION AND CONCENTRATION AT PILOT-SCALE
FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS**

14.2 Resumes of Key Personnel

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 SUsustainable 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)

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.
- 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 Qu, Mo Zhang, and Michael Mann, “Effect of Combustion Temperature on the Emission of Trace Elements under O₂/CO₂ 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 CO₂ Emission Reduction from Distributed Energy Sources”, *Asian Journal of Energy & Environment*”
- Bandyopadhyay, 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)950-965.
- 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.
- 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.

PH.D. ADVISEES: Eduardo Hernandez Pacheco, 2004, Intel; Yongxin Zhao, 2005, ARCADIS, Shankar Karki, 2006, Electric Power Research Institute; Kevin Harrison, 2006, National Renewable Energy Laboratory; Rhonda Hill, 2007, Clipper Energy; Gopal Bandyopadhyay, 2007, Pacific Northwest National Laboratory; Philip Hutton, 2009, Energy & Environmental Research Center; Nilesh Dale, 2009, Bhanuaben Patel, 2010; Taehee Han, 2010, Nissan; Christian Biaku, 2010; Ryan Knutson, 2011; Udhe Corp of America; Kirtipal Barse, 2014, UND; Stacy Bjorgaard, 2015 UND. Jivan Thakare, 2016, Energy & Environmental Research Center; Daniel Laudal, 2017, UND. **M.S.** over 30 students.

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.

Organized and coordinated training program for 32 Eastern Europeans utilizing trainers from 9 different companies; trained Polish power industry personnel on use of model for estimating the cost of clean coal technologies; coordinated two workshops on implementing small, remote power systems in Alaska; co-coordinator of Least-Cost Power workshop in Prague, the Czech Republic.

Developed and Implemented new degree programs: Sustainable Energy Engineering MS, Sustainable Energy Engineering BS Concentration, Energy Systems Engineering MS, Environmental Engineering MS and Certificate, Chemical Engineering PhD, Engineering PhD in Energy Engineering and Environmental Engineering.

Nolan L. Theaker

Research Engineer, Institute for Energy Studies
University of North Dakota, Grand Forks, ND 58202

Education and Training

University of Louisville
University of Louisville

Chemical Engineering
Chemical Engineering

B.S. 2016
M.Eng. 2017

Research and Professional Experience

2017-Present Research Engineer, UND Institute for Energy Studies.

Responsibilities include high-level innovative research to solve challenges in the energy industry and development of novel concepts for submission of funding proposals. Developed into a major technical role in a project involving extraction and purification of rare earth elements from coal and coal-associated feedstocks. Lead theoretical and experimental investigations and designs into process pathways and process optimization for improving commercial viability. Coordinated and conducted efforts associated with downstream rare earth element concentration operations that have resulted in the development of final process flow diagrams. Performed modeling of chemical equilibrium systems for utilization in solution chemistry and chemical reaction conditions. Key contributor to multiple proposals involving REE extraction and/or concentration from multiple feedstocks with innovative ideas for significant cost reductions. Currently leading the day-to-day technology development aspects of UND's technology to recover REE from lignite coal, including design and operation of UND's bench-scale test system, data analysis and reporting, and overall technology optimization.

2016-2017 Research Assistant, University of Louisville Conn Center.

Research involved design and operation of multi-stage electrochemical reactor scheme for efficient production of fuels from CO₂. Performed analysis and characterization of electrodes and product samples for evaluation of performance and degradation mechanics. Developed nano-functionalized electrocatalysts for improvements in activity and selectivity for targeted reactions in two phase reaction systems. Gained invaluable experience in heterogeneous catalyst chemistry and surface reactions, metal-based catalyst characterization, and deactivation pathways under carbon-based reducing conditions.

2014-2015 Coop Engineer, University of Kentucky CAER.

Research involved improvement and operation of a DOE bench-scale CO₂ capture unit in multiple reaction conditions. Evaluation and comparison of catalyst performance in a holistic view for CO₂ capture was conducted, including novel organic and enzymatic catalysts. Conducted characterization of catalyst degradation and deactivation mechanisms and experiments to improve cyclic lifetimes in harsh process conditions.

Publications/Presentations

Theaker, N., Strain, J. M., Kumar, B., Brian, J. P., Kumari, S., & Spurgeon, J. M. (2018). Heterogeneously Catalyzed Two-Step Cascade Electrochemical Reduction of CO₂ to Ethanol. *Electrochimica Acta*, 274, 1-8. doi:10.1016/j.electacta.

Holden, J.; **Theaker, N.**; Rew, B.; Lucky, C.; Laudal, D.; Benson, S. Investigation of a Combined Leaching and Thermal Decomposition Approach to Determine Modes of Occurrence of rare earth elements in North Dakota Lignite Coal. *in prep.*

Theaker, N.; Rew, B.; Lucky, C.; Addleman, R. S.; Laudal, D.; Benson, S. Flow Sheet for the Recovery of a REE Concentrate from Lignite Coal. *in prep.*

Rew, B.; Shallbetter, R.; **Theaker, N.**; Addleman, R. S.; Laudal, D.; Benson, S. Development and Optimization of a Leaching Process for Recovery of rare earth elements from North Dakota Lignite Coal. *in prep.*

Rew, B.; Kotwal, A.; **Theaker, N.**; Addleman, R. S.; Laudal, D.; Benson, S. Investigation into the Reverse Ion-Exchange Capability of Lignite Coal. *in prep.*

Laudal, D., Benson, S., **Theaker, N.** Investigation of rare earth element extraction from North Dakota Coal-Related Feed Stocks. 2018 NETL Rare Earth Elements Review Meeting. April 10, 2018. Pittsburgh, PA.

Laudal, D., Benson, S., **Theaker, N.**, Rew, B. Examination of an REE-rich lignite by combined density separations and leaching. 2018 Clearwater Clean Energy Conference. June 6, 2018. Clearwater, FL.

Rew, B., **Theaker, N.**, Laudal, D., Holden, J. Determination of rare earth element modes of occurrence in lignite coal. 2018 AIChE Conference. November 1, 2018. Pittsburgh, PA

Theaker, N., Laudal, D., Benson, S., Rew, B., Lucky, C. Bench-scale testing update – recovery of rare earth elements from lignite coal. 2019 SME Annual Conference. February, 2019. Denver, CO. *in prep.*

Synergistic Activities

Mr. Theaker's principal areas of expertise include hydrometallurgical separations for dilute mineral extraction and solution chemistry. Additionally, he has experience in multi-phase reactions systems with a focus into solid-fluid interactions. He has specifically performed research and equipment designs at levels from proof-of-concept research to bench scale testing. Mr. Theaker has experience working in multiple multi-disciplinary teams and research projects.

Mr. Theaker has recently been an integral part of the rare earth element extraction and concentration project funded through the Department of Energy NETL, with significant chemical and physical developmental work, in addition to economic optimization studies for the project. His expertise in multi-phase reaction systems and his significant work into the extraction and hydrometallurgical separations of critical materials is directly applicable to the current project.

Harry M. Feilen

Manager of Operations & Safety, Institute for Energy Studies
University of North Dakota, Grand Forks, ND 58202

Education and Training

University of North Dakota	Energy Engineering	Pursuing PhD – Dec 2019
University of North Dakota	Mechanical Engineering	M.S. - 2015
University of Mary	Mechanical Engineering	B.S. – 2014
University of Mary	Management	B.S. – 2011
Marine Corps Military Police Academy		1989

Research and Professional Experience

2016 – Present Manager of Operations & Safety / Research Engineer, UND Institute for Energy Studies

Responsibilities include management of all operational issues within the research department at the Institute for Energy Studies, along with management of full-time and student employees. Ensure deliverables and timelines are met for currently funded projects, including governmental and private grants. Maintain safety protocols and ensure a safe working environment for all engineers/scientists in the department and college. Maintain and upgrade existing fabrication and lab equipment and ensure proper training and use. Directs major fabrication projects and ensures safe manufacture, operation, and decommissioning of all equipment developed. Manage and collaborate with other UND departments for laboratory safety, management and construction of new equipment, and effective use of college and departmental resources. Developed and fabricated numerous DOE bench-scale (TRL 5) equipment, including equipment for REE recovery from coal-related resources.

2010-2016 – Research/Mechanical Engineer, UND Institute for Energy Studies

Conducted research including development, management, fabrication and operation of numerous coal combustion, CO₂ capture, and chemical looping attrition projects, totaling greater than \$4,000,000 in total research costs. Constructed, maintained, and instructed additional engineers in operation of DOE bench-scale equipment for post-combustion CO₂ capture of flows in excess of 800 lbs/hr of sorbent material. Developed first-of-a-kind equipment for testing and evaluation of chemical looping combustion oxygen carrier attrition testing under high-temperature, reacting conditions. Managed subcontractors and other UND departments as needed for effective completion of project goals. Designed, fabricated, and commissioned equipment for 20+ graduate student projects comprising total funding in excess of \$10,000,000. Developed proposals for federal, state, and private funding sources for additional research projects and new major research areas. Mentored and educated undergraduate and graduate students and full-time junior engineers.

2003-2010 – Project Manager, Opp Construction

Managed multiple contracting projects, including a \$5,000,000 remodel of the Grand Cities Mall (Grand Forks, ND). Designed retail, housing, and industrial layouts with owners of properties, meeting all city, state, and federal construction requirements. Consulted with architects and city inspectors to locate “has built” plumbing and electrical lines, load bearing walls, and additional structural integrity challenges. Scheduled and complied with all city inspections to ensure full compliance of all municipal and state codes for construction. Managed and developed contractual agreements for crew members and subcontractors, and ensured timely completion of projects.

1999-2003 – Community Service Officer, Grand Forks Police Department

Maintained records, warrants for arrest, and other duties as assigned in a law-enforcement environment. Ensured security of general public and office staff in the court room. Maintained proper order and discipline was adhered to during all court proceedings.

1997-1999 – Owner of Ace Investigations/Partner of Nordic Unlimited Construction

Developed and maintained daily operations at a private investigation firm and a general construction company. Conducted background checks, interviews, and sworn legal affidavits for Ace Investigations. Remodeled commercial spaces, residential buildings, and constructed new structures in compliance with all city, state, and federal codes in a safe and timely manner. Hired and managed subcontractors on numerous projects for specific work required.

1989-1997 – United States Marine, United States Marine Corps

Managed Accident Investigations Division of Barstow, CA reporting directly to Provost Marshal of the Marine Corps Logistic Base, Barstow, CA. Conducted investigations and traffic surveys to gather data regarding road speeds, traffic load, and parking lot layout. Developed and approved drawings for roads, parking lots, and buildings for remodel and construction. Conducted investigations on traffic accidents regarding military property and personnel. Maintained best practice policies and procedures in a law enforcement department. Mentored junior Marines to further their careers and personal goals. Fulfilled military police duties while deployed to the Persian Gulf War.

STEVEN A. BENSON, PH.D.
President
Microbeam Technologies Incorporated
Grand Forks, ND 58203

Areas of Expertise

Dr. Benson's principal area of interest and expertise is on the development and management of complex multidisciplinary research and development programs that are focused on solving challenges associated with efficient and environmentally acceptable generation of energy.

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. Dr. Benson 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 began operations in 1992 and 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.
2015 – 2017	Associate Vice President for Research, Energy & Environmental Research Center, University of North Dakota -- Dr. Benson is 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 – coordinate energy related education and research activities that involve faculty, research staff, and students.
2008 – 2017	Professor, University of North Dakota -- Dr. Benson is responsible for teaching courses on energy production and associated environmental issues. Dr. Benson conducts research, development, and demonstration projects aimed at solving environmental, efficiency, and reliability problems associated with the utilization of fuel resources in refining/combustion/gasification systems that include: 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) -- Dr. Benson is responsible for leading a group of about 30 highly specialized group of chemical, mechanical and civil engineers along with scientists whose aim is to develop and conduct 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 -- Dr. Benson was responsible for the direction and management of programs related to integrated energy and environmental systems development. Dr. Benson led a team of over 45 scientists, engineers, and technicians.
1989 – 1991	Assistant Professor of Geological Engineering, Department of Geology and Geological Engineering, UND -- Dr. Benson was responsible for teaching 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 -- Dr. Benson was responsible for management and supervision of 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, Mr. Benson took course work 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 -- He was responsible for management and supervision of 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. A., Benson, S.A., Palo, D., and Addleman, R.S., Rare Earth Elements in North Dakota Lignite Coal and Lignite-Related Materials, ASME, J. Energy Resour. Technol 140(6), 062205 (Apr 09, 2018) (9 pages).
2. Laudal, D. A., Benson, S.A., Addleman, R.S., and Palo, D., Leaching behavior of rare earth elements in Fort Union lignite coals of North America, International Journal of Coal Geology, Volume 191, 15 April 2018, Pages 112-124.
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. 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. 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
6. 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.
7. 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.
8. 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.
9. 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.
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 – Mercury emissions control at coal fired power plants - 2008 and 2005.

Ryan S. Winburn, Ph.D.
5331 Element Ave, Beatrice, NE 68310
ryan.winburn@rareearthsalts.com

Professional Preparation

1996-1999 Ph. D., Analytical Chemistry with Inorganic Emphasis; North Dakota State University, Fargo, ND
1991-1995 M. S., Physical Chemistry; University of North Dakota, Grand Forks, ND
1987-1991 B. S., Chemistry, American Chemical Society certified; University of Wisconsin-Eau Claire, Eau Claire, WI

Appointments

2013 – Vice President for Research and Development, Rare Earth Salts
Supervise and participate in a small research group focused on the conversion and separation of rare earth elements/compounds. Prepare patent applications and budgets for the group.
2000 - Owner/CEO, Ryan Winburn Consulting
2006-2013 Chairperson, Division of Science, Minot State University
1999-2013 Assistant Professor of Chemistry, Minot State University
1998-1999 Graduate Teaching/Research Fellow, North Dakota State University
1996-1998 Teaching/Research Assistant, North Dakota State University
1995 Adjunct Professor, University of Minnesota-Crookston, Crookston, MN
1991-1995 Teaching/Research Assistant, University of North Dakota
1991 Laboratory Technician, University of Wisconsin-Eau Claire

Research Interests

Rare Earth Elements. Extraction and separation of the rare earth elements, either as pure metals or as pure compounds. Use of rare earth elements as catalysts. Solid state reactions involving rare earth elements.
X-ray Diffraction. Application of the Rietveld method to complex mixtures (such as mine tailings, combustion by-products, etc.) for quantitative phase analysis. Application of the Rietveld method for the determination of substitution in solid solutions. Determination of reaction mechanisms in solids using XRD. Structure solution using the Rietveld method.

Research Achievements

Vice President of Research and Development (2013-present)

Develop techniques for the conversion and separation of rare earth materials

- Developed novel separation technique for the rare earth elements
- Investigated existing methodologies for conversion of rare earth oxides and oxalates into other rare earth compounds for use in separations
- Investigate selective and specific reactions involving rare earth elements

CEO/Owner Ryan Winburn Consulting

Certify SRMs for X-ray Analysis

- Worked with a team of scientists on the certification of SRMs 676 (Alumina powder), 676a (Alumina Powder) and 674b (Quantitative Powder Diffraction Standard).

Provide training in quantitative analysis using X-ray diffraction

Government Contracts (through Ryan Winburn Consulting)

“Certification of NIST SRMs 676 and 674b and 676a for Quantitative Analysis via Powder Diffraction Techniques”
Funded by NIST, June 2001-May 2002, \$24,900.

“Certification of NIST SRMs 676 and 67b for Quantitative Analysis via Powder Diffraction Techniques” Funded by NIST, June 2000-May 2001, \$24,900.

Selected Publications

1. "Rietveld Quantitative X-Ray Diffraction of NIST Fly Ash Standard Reference Materials" R.S. Winburn, D.G. Grier, G.J. McCarthy, and R.B. Peterson, *Powd. Diff.* **2000**, 15, 163

2. "Quantification of Ferrite Spinel and Hematite in Fly Ash Magnetically Enriched Fractions" R.S. Winburn, S.L. Lerach, G.J. McCarthy, D.G. Grier and J.D. Cathcart, *Adv. X-Ray Anal.*, **2000**, 43, 350.
3. "Factors Influencing Quantitative Results for Coal Combustion By-Products Using the Rietveld Method" R.M. Gonzalez, T.D. Lorbiecke, B.W. McIntyre, J.D. Cathcart, M. Brownfield, and R.S. Winburn, *Adv. X-Ray Anal.*, **2002**, 45, 188.

Patents

1. Method for extraction and separation of rare earth elements. PCT/US2015/045423. Joseph R. Brewer; Ryan S. Winburn. Filed on August 15, 2014.

Selected Presentations

1. Invited Talk, "Rietveld Quantitative X-Ray Diffraction on Complex Mixtures – What Can We Do?" presented at the Denver X-Ray Conference, Colorado Springs, CO, 2002.
1. Poster "Certification of SRM Materials for Crystallinity – SRM 676, SRM 676a and SRM 674b" presented at the Denver X-Ray Conference, Denver, CO, 2003.
2. Poster "X-Ray Diffraction Study of the Formation of Brownmillerite" presented at the Denver X-Ray Conference, Steamboat Springs, CO, 2004.* Winner of Best Poster Honors.

SRM Certificates

Standard Reference Material 676 Alumina Internal Standard for Quantitative Analysis by X-Ray Powder Diffraction, 20 September 2005, J.P. Cline, R.S. Winburn, R.B. Von Dreele, A. Huq, P.W. Stephens, S. B. Schiller, H-k. Liu, and J.J. Filliben,, National Institute of Standards and Technology, Gaithersburg, MD 20899.

Standard Reference Material 674b X-Ray Diffraction Intensity Set for Quantitative Analysis by X-Ray Powder Diffraction, 21 September 2005, J.P. Cline, R.S. Winburn, R.B. Von Dreele, J.J. Filliben, and I. Aviles, National Institute of Standards and Technology, Gaithersburg, MD 20899.

Standard Reference Material 676a Alumina Internal Standard for Quantitative Analysis by X-Ray Powder Diffraction, 28 January 2008, J.P. Cline, R.S. Winburn, R.B. Von Dreele, P.W. Stephens, J.J. Filliben, et al., National Institute of Standards and Technology, Gaithersburg, MD 20899.

Professional Memberships

American Chemical Society, International X-Ray Analysis Society (IXAS), Materials Research Society

Professional Activities

Vice President, Minot State University Chapter, Sigma Xi, 2000-2001; President, Minot State University Chapter, Sigma Xi, 2001-2002.

Research Collaborators and Graduate Advisors

Dr. Mark Hoffmann, University of North Dakota (Master's Thesis Advisor)
 Dr. Gregory McCarthy, North Dakota State University (Doctoral Advisor)
 Dr. James P. Cline, National Institute of Standards and Technology
 Dr. Robert von Dreele, Los Alamos/Argonne National Laboratories
 Dr. Peter Stephens, State University of New York, Stonybrook and Brookhaven National Laboratory
 James D. Cathcart, United States Geological Survey, Denver, CO.
 Dr. Christopher Beachy, Southeastern Louisiana University, Hammond, LA

Joseph Reese Brewer

5331 Element Avenue, Beatrice, NE 68310
joseph.brewer@rareearthsalts.com

Professional Preparations

University of Alabama-Tuscaloosa	Postdoc	Electrical Engineering	2010-11
University of Nebraska-Lincoln	Ph.D.	Inorganic Chemistry	2010
University of Nebraska-Lincoln	M.S.	Chemistry	2007
Minot State University	B.S.	Chemistry	2004

Professional Appointments

2012-Present	Chief Executive/Technical Officer, Rare Earth Salts, LLC.
2010-2012	Chief Technology Officer, Rare Earth Solar, LLC.
2010-2011	Postdoctoral Researcher, University of Alabama, Tuscaloosa, AL
2010-2010	Postdoctoral Researcher, University of Nebraska-Lincoln, Lincoln, NE
2004-2005	Laboratory Technician, Johns Manville Technical Center

Research Achievements

Chief Technology Officer (2013-present, Rare Earth Salts)

Develop novel processes for the extraction and separation of rare earth elements from low grade rare earth ore bodies.

- Developed low cost green chemistry extraction process for the recovery of rare earths from low grade rare earth ore bodies.
- Developed low cost green chemistry extraction process for the recovery of rare earths from recycled compact fluorescent light bulbs and recycled magnets.
- Developed unique leach chemical regeneration techniques to decrease environmental impact of acid pit storage ponds.
- Co-developed unique cost-effective separations process for individual separation of rare earth elements utilizing a small chemical footprint and benign processing conditions.

Chief Technology Officer (2011-present, Rare Earth Solar)

Develop deposition methods for the commercialization of rare-earth element based photovoltaics

- Developed new sputter deposition process for the in-situ synthesis of low cost highly textured rare-earth chalcogenide based *p* and *n*-type layers for photovoltaic devices.
- Determined process conditions to alter *p* and *n*-type layer electronic properties from metallic to semiconducting while maintaining crystal structure.

Graduate Research Assistant (2005-2010)

Advisor: Dr. "Barry" Chin Li Cheung, Department of Chemistry, University of Nebraska-Lincoln

Advanced the chemical synthesis of rare-earth (RE = Y, La, Ce, Pr, Nd, Sm, Gd, Tb, Dy, Ho) compounds

- Developed new general chemical vapor deposition (CVD) synthetic schemes to fabricate single-crystalline rare-earth hexaboride nanostructures with well-controlled diameters and shapes (nanowires, nanopencils and nanoobelisks).
- Developed a new synthetic methodology for the rapid growth of highly textured (100) rare-earth nitride thin films by CVD
- Developed a new CVD synthesis strategy for the stoichiometry controlled growth of crystalline rare-earth sulfide nanomaterials and thin films

Publications

- 1) Zhou, Y.; Lawrence, N. J.; Wang, L.; Kong, L.; Wu, T.-S.; Liu, J.; Gao, Y.; Brewer, J. R.; Lawrence, V. K.; Sabirianov, R. F.; Soo, Y.-L.; Zeng, X. C.; Dowben, P. A.; Mei, W. N.; Cheung, C. L., Resonant Photoemission Observations and DFT Study of s-d Hybridization in Catalytically Active Gold Clusters on Ceria nanorods. *Angewandte Chemie* **2013**, 52 (27), 6936-6939. DOI: 10.1002/anie.201301383
- 2) Marin, C. M.; Wang, L.; Brewer, J. R.; Mei, W. N.; Cheung, C. L., Crystalline alpha-Sm₂S₃ Nanowires: Structure and Optical Properties of an Unusual Intrinsically Degenerate Semiconductor. *Journal of Alloys and Compounds* **2013**, 563, 293-299. DOI:10.1016/j.jallcom.2013.02.082
- 3) Gernhart, Z. C.; Jacobberger, R. M.; Wang, L.; Brewer, J. R.; Dar, M. A.; Diercks, D. R.; Mei, W. N.; Cheung, C. L., Existence of Erbium Hexaboride Nanowires. *Journal of the American Ceramic Society* **2012**, 28, 3992-3996. DOI:10.111/j.1551-2916.2012.05427.x
- 4) Jacobberger, R. M.; Brewer, J. R.; Cheung, C. L., Vertical Growth of Metallic Hexaboride Nanowires and their Field Emission Properties. *World Journal of Engineering* **2011**, 18(suppl.), 509-510.
- 5) Brewer, J. R.; Jacobberger, R. M.; Diercks, D. R.; Cheung, C. L., Rare Earth Hexaboride Nanowires: General Synthetic Design and Analysis Using Atom Probe Tomography. *Chemistry of Materials* **2011**, 23 (10), 2606-2610.
- 6) Lawrence, N. J.; Brewer, J. R.; Wang, L.; Wu, T.-S.; Wells-Kingsbury, J.; Ihrig, M. M.; Wang, G.; Soo, Y.-L.; Mei, W.-N.; Cheung, C. L., Defect Engineering in Cubic Cerium Oxide Nanostructures for Catalytic Oxidation. *Nano Letters* **2011**, 11 (7), 2666-2671.
- 7) Brewer, J. R.; Gernhart, Z.; Liu, H.-Y.; Cheung, C. L., Growth of [100]-Textured Gadolinium Nitride Films by CVD. *Chemical Vapor Deposition* **2010**, 16 (7-9), 216-219.
- 8) Wang, G.; Brewer, J. R.; Chan, J. Y.; Diercks, D. R.; Cheung, C. L., Morphological Evolution of neodymium Boride Nanostructured Growth by Chemical Vapor Deposition. *J. Phys. Chem. C* **2009**, 113, 10446-10451.
- 9) Deo, N.; Brewer, J. R.; Reinhardt, C. E.; Nikolic, R. J.; Cheung, C. L., Conformal Filling of Silicon Micropillar Platform with ¹⁰Boron. *J. Vac. Sci. Technol. B* **2008**, 26 (4), 1309-1314.
- 10) Wang, G.; Brewer, J. R.; Namavar, F.; Sabirianov, R. F.; Haider, H.; Garvin, K. L.; Cheung, C. L., Structural Study of Titanium Oxide Films Synthesized by Ion Beam-Assisted Deposition. *Scanning* **2008**, 30 (2), 59-64.
- 11) Namavar, F.; Wang, G.; Cheung, C. L.; Sabirianov, R. F.; Zeng, X. C.; Mei, W.; Bai, J.; Brewer, J. R.; Haider, H.; Garvin, K. L., Thermal Stability of Nanostructurally Stabilized Zirconium Oxide. *Nanotechnology*, **2007**, 18, 415702-

Patents

- 1) *Crystalline nanostructures*. US 8,247,070 B2. CL Cheung; JR Brewer; N Deo. Filed on Oct 30, 2007.
- 2) *Rare earth sulfide thin films*. PCT/US2011/031454. CL Cheung; JR Brewer. Filed on April 6, 2011.
- 3) *Cerium oxide having high catalytic performance*. PCT/US2011/031467. CL Cheung; NJ Lawrence; JR Brewer; G Wang. Filed on April 6, 2011
- 4) *Method for rare earth and actinide element recovery, extraction and separations from natural and recycled resources*. PCT/US2012/61717916. JR Brewer; NJ Lawrence. Filed on October 24, 2012.
- 5) *Method for extraction and separation of rare earth elements*. PCT/US2015/045423. Joseph R Brewer; Ryan S. Winburn. Filed on August 15, 2014.

Collaborators and Co-Editors:

Alf Bjorseth (Scatec Corporation), Paloma Magistrati (Bergald Miljoradgivere), Henning Reier Nilsen (Scatec Corporation), David R. Diercks (Colorado School of Mines), Natale J. Ianno (University of Nebraska-Lincoln), Chin Li Cheung (University of Nebraska-Lincoln), Josh Magnum (Mustang Solar and Mustang Vacuum Systems), John Kutch (Thorium Energy Alliance), Rich Martens (University of Alabama-Tuscaloosa)

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 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.

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.; Stanislawski, 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 CO₂ Capture Technologies for Lignite-Fired PC Boilers. In *Proceedings of Air Quality VI: Mercury, Trace Elements, SO₃, 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.

Benson, S.A.; Jones, M.L.; Harb, J.N. Ash Formation and Deposition. In *Fundamentals of Coal Combustion for Clean and Efficient Use*; Smoot, L.D., Ed.; Coal Science and Technology 20 Series; Elsevier: Amsterdam, 1993; Chapter 4, pp 299–373.

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.

Experience Dr. Daniel Palo is a professional engineer with a PhD in chemical engineering and over 20 years of experience in process design, plant improvement, project management, and research and development for processes that involve minerals, chemicals, fuels, and manufactured products. Dan serves as a Vice President within Barr's Engineering & Design business unit, where he provides project and programmatic leadership in the areas of mineral and chemical processing. In addition, Dr. Palo provides engineering and management services on projects for local, national, and international clients who work in the mineral, chemical, and fuel process industries.

Examples of Dan's work experience include:

- Providing process engineering services for scoping, pre-feasibility, and feasibility studies for mineral processing clients
- Conducting technical evaluations and pilot plant testing for new and existing processes
- Modeling and optimizing equipment, sub-processes, and whole plants using METSIM and/or CHEMCAD software
- Coordinating vendor trials for new equipment installations and upgrades
- Providing plant layout, equipment specification, cost estimation, and project oversight for various mineral and chemical process applications
- Building and coordinating teams that conduct advanced research and development in mineral processing, energy, and fuels
- Conducting third-party reviews and due-diligence for mining and other processing projects

Dan's experience in mineral processing has included projects in coal, iron, soda ash, potash, borates, salt, manganese, rare earths, and copper. This includes all forms of metallurgical work such as beneficiation, leaching, crystallization, solvent extraction, magnetic separation, and product sizing and finishing.

Dan's work in chemical and material processing has included projects in manufacturing of glass, activated carbon, synthetic fuels, solar fuels, and hydrogen.

Prior to Barr, Dan worked in a variety of positions and roles at Pacific Northwest National Laboratory (PNNL), including:

- Serving as Deputy Co-Director and Senior Research and Development Leader for the Microproducts Breakthrough Institute (MBI) at PNNL. His duties included:
 - Providing business development and outreach around key programs for DOE and DoD
 - Providing project management and technical research services in the fuel and energy space
- Serving as Research Engineer and Senior Research Engineer at PNNL

Education	PhD, Chemical Engineering, University of Connecticut, 1999 BS, Chemical Engineering, University of Minnesota-Duluth, 1994
Registration	Registered Professional Engineer (Chemical): CA, CO, MI, MN, NM, NV, TX, UT, WY
Affiliations	Society for Mining Metallurgy & Exploration; Officer in MN and CA Sections 2015-present
Honors	R&D100 Award, 2014; Battelle Key Contributor Award: 2000, 2001, 2002, 2007 PNNL Top-30 Inventor Award: 2004
Publications	30+ peer-reviewed publications related to microchannel chemical processing, solar thermal energy systems, portable power systems, mineral extraction, hydrocarbon processing, nanomaterials, and supercritical fluid applications
Presentations	More than 20 technical presentations (several invited) at national and international conference venues
Patents	Five issued US patents in the areas of solar thermochemical energy systems, microchannel process technology, hydrocarbon processing, and hydrogen production

Experience Nick has over seven years of experience working on a variety of mineral processing and chemical engineering projects including design, mass and energy balance calculations, process modeling, and capital and operating expense estimates. He has served clients in the mining and mineral processing industries for iron ore, trona/soda ash, and industrial sands as well as industrial manufacturing clients. Nick has a BS degree in chemical engineering and gained work experience during two internships at a mining and mineral processing operation on Minnesota's Iron Range.

Examples of his work experience include:

- Reviewing P&IDs of a soda ash plant and trona mine while on site and modeling the entire facility from ore to final product within a process simulation modeling software.
- Dynamically modeling various portions of a potash operation in Saskatchewan to minimize losses and increase production capabilities and performing economic analysis to provide capital cost, operating cost, and payback period estimates.
- Evaluating multiple potash operations in Saskatoon to identify upgrades and practices required to meet fine-particle-sized dust-emissions regulations.
- Sampling and modeling of concentrator production lines to provide an updated mass balance for an iron ore operation in Minnesota.
- Sampling and process modeling of concentrator and agglomerator production to provide an iron, silica, and mercury mass balance for an iron ore operation in Minnesota.
- Providing preliminary design for the addition of a thickening system to a Canadian iron ore operation to improve tailings basin management.
- Providing preliminary design services including mass balance, energy balance, capital expense, and operating expense calculations for a proprietary chemical process for a confidential client in Ohio.
- Assisting with development of pilot plant testing for reclaimed iron ore processing and analysis of the produced data for a confidential client in Minnesota.
- Analyzing the existing operations of a hydroseparator system to aid in determining its effects on downstream tailings basin management.
- Assessing and documenting the entire process flow for two frac sand processing facilities as a part of a due diligence review.

Prior to Barr, Nick gained work experience:

- Interning in a mineral processing facility's analytical laboratory where he performed analytical experiments to ensure production output met required quality standards and performed testing to statistically analyze the performance of laboratory equipment.
- Interning in chemical engineering for a mining and mineral processing facility where he designed experiments to optimize process machinery efficiency; created

mathematical models to aid in process stability and control; and helped monitor, control, and maintain the taconite pellet creation process and process machinery.

Education	BS, Chemical Engineering, University of Minnesota-Twin Cities, 2011
Affiliations	Society of Mining, Metallurgy and Exploration (SME)
Software	METSIM, CHEMCAD

Experience Since joining the firm in 1972, Philip Solseng has served as principal-in-charge and design engineer for geotechnical engineering projects involving dams, foundations, excavations, slope stability, waste piles, and reclamation. He has direct and extensive experience in geotechnical investigation and analysis, design, plans and specifications, and construction review. He has provided expert testimony, technical reports, and professional presentations related to geotechnical, structural, soils, and groundwater issues. Highlights of his experience include:

- Responsible for planning and designing tailing basins. Experience emphasizes studies and designs for dams built on foundations with stability and seepage problems, including tailing dams in Minnesota, Missouri, and Wyoming. Also provided permit assistance and construction quality control.
- Evaluated and designed corrective measures for landslides and slope failures.
- Analyzed, designed, and prepared plans and specifications for reclamation and stabilization of open-pit mines and stockpiles.
- Designed and prepared plans and specifications for landfills and many projects involving the investigation and cleanup of soil and groundwater contamination.
- Investigated and analyzed groundwater systems for seepage control, waste contamination, and water supply. Designed seepage control measures involving filters, drains, relief wells, cutoffs and blankets. Developed dewatering methods for deep excavations and construction.
- Conducted investigations and evaluations of many earth and concrete dams and their foundations, including subsurface exploration testing, instrumentation, and analysis for stability, seepage, and settlement.
- Conducted dam safety analyses under programs by the MSHA, FERC, Nuclear Regulatory Commission, U.S. Army Corps of Engineers, and the states of Minnesota and Missouri.
- Planned and evaluated field and laboratory testing programs that included vane shear, borehole shear, triaxial shear, cone penetration, permeability, and consolidation tests; also planned and evaluated instrumentation programs involving inclinometers, settlement gauges, horizontal-movement gauges, and various piezometers.
- Provided expert testimony and technical reports related to geotechnical, structural, soils, and groundwater issues, including roadway construction.
- Served as principal in charge and project manager of projects for Minnkota Power Cooperative since 1990. These projects include permitting and designing the leachate collection system for the Horseshoe Pit Disposal Area and the Butterfly Pond. Other projects included designing the flue-gas desulfurization landfill cells and their liners and inspection and repairs to the Nelson Lake Dam.

Highlights of his experience related to railroads include:

- Duluth, Winnipeg & Pacific Railway railroad embankment design across 50 feet of Muskeg. Design resulted in significant savings over other options including bridges.

- Duluth, Winnipeg & Pacific Railway railroad embankment repair for unstable slope caused by groundwater.
- Confidential client: Trench design along railroad within 10 feet of track. Design accounted for vibrations and dynamic loading from train traffic and its effect on stability. Special trench box design and construction procedures were specified.
- Confidential client: Design of pipes and horizontal drilling through railroad embankments. This included detailed analysis for subsidence.

Education BS, Civil Engineering, North Dakota State University, 1970

Registration Professional Engineer: Colorado, Michigan, Minnesota, Missouri, Montana, North Dakota, Wisconsin, and Wyoming, U.S.A., and Alberta and Saskatchewan, Canada

Affiliations American Society of Civil Engineers
Minnesota Society of Professional Engineers
National Society of Professional Engineers
Minnesota Geotechnical Society
Society of American Military Engineers
Society of Mining Engineers, Inc.

Presentations "Wellner-Hageman Flood Control Project." Coauthor. Annual Water Resource Conference, 1991.
"Lake Marie Dam Evaluation and Repair." Coauthor. ASDSO Annual Conference. 1989.
"Tailing Dam Design and Construction Over Muskeg." Coauthor. Pan-American Conference on Soil Mechanics and Foundation Engineering. June 1983.
"Staged Construction of 160-Foot-High Tailings Dam Over Organic Soils." Coauthor. Soil Mechanics and Foundation Engineering Conference. February 1981.

Experience As a minerals processing consultant, Boyd offers over 26 years of experience, which includes 16 years working for mining companies where he served as a metallurgist, project team engineer, section manager, plant superintendent, and senior operations engineer. Boyd has managed several capital projects, including a biofuel plant expansion. He has held executive roles in operations, regulatory compliance, and process optimization, and has supervised plant operations and maintenance. Boyd's project work with Barr includes:

- Serving as project manager and senior process expert for plant operations and optimization projects. Work involved laboratory and pilot-plant test work, regulatory compliance assistance, and documentation projects.
- Serving as project manager at a gold mine. Work included plant ventilation and air flow evaluation.
- Performing flocculation review for tailings long-term design and optimization project.
- Serving as a team member for a northern Minnesota iron ore recovery project that included pilot-plant testing, demonstration plant design, and facility scale-up.
- Performing silica sand plant tailings thickener evaluation and process improvements.
- Serving as a team member to develop metallurgical section of 43-101 for a rare earth deposit in Canada.
- Conducting oils sands review and evaluation of process tailings systems.
- Working on trona mine development and evaluation of alternative options for long-term tailings deposition methods.
- Working with Barr staff in conducting a pilot-plant test study at a facility in Venezuela. Assisted in the draft and final report associated with this test work, including recommendation with additional testing. This study was designed to confirm the proposed process flow sheet for the hard ore concentrator.
- Conducting a process audit and failure mode analysis for the process associated with the operation of the friable ore concentrator currently under construction in Venezuela. This document will be used during plant startup in 2014.
- Working on several, process safety management (PSM) projects to review and update existing programs for industrial facilities.

From 2012 through 2013, Boyd served as SR Process Engineer for Uranium One Americas and Uranerz Energy. In this role, he oversaw all areas of solution mining performance, resin loading performance, ion exchange performance, and process precipitation of uranium.

From 2002 to 2009, Boyd served as technical manager at POET Bio-Refining in Glenville, Minnesota. In this role, he oversaw plant operations, production goals, and laboratory operation.

Prior to his work at POET, Boyd worked at EVTAC Mining Company, where he held several positions in engineering and management.

From 1991 to 1995, Boyd worked at Phelps Dodge Mining Company. He served as a metallurgist in the concentrator and hydrometallurgical divisions.

Boyd served as a metallurgical engineer at Climax Molybdenum Company from 1989 to 1991.

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|----------------------|---|
| Education | BS, Metallurgical Engineering, South Dakota School of Mines and Technology, 1988
Minnesota Management Academy, University of Minnesota, 1998 |
| Certification | ISO 9001 Certification 1997 |
| Publications | 2002 Duluth SME-Magnetic Iron Recovery Improvements at EVTAC |

Experience Chase Stevens recently joined Barr with over six years of operational and process optimization experience in copper, gold, and molybdenum mining. His work includes developing and operating several bench- and pilot-scale minerals-processing systems, developing and commissioning advanced process-control strategies, focusing on Lean Six Sigma principles, and analyzing big data and SQL resources to deliver actionable conclusions. During a metallurgical internship at the Freeport-McMoran Bagdad Mine in Arizona, Chase gained experience with leaching, solvent extraction (SX), and electrowinning (EW) processes on the hydrometallurgical side of the operation.

His work prior to joining Barr includes:

- Serving as a process engineer for IM Flash in Utah for one year. His work in this high-volume manufacturing environment entailed:
 - Acting as shift chemical vapor deposition (CVD) engineer solving issues and assisting technicians.
 - Developing a new metric from existing data to identify tool operation issues before product could be manufactured outside of specification.
 - Developing reports and dashboards in SQL and SSRS to help shift teams manage inventory of critical tool qualification supplies.
 - Working with interdisciplinary teams quickly to quarantine and find the root cause of product failures when needed.
- Serving as a process engineer at Calumet Electronics Corporation in Michigan for one year where his experience included:
 - Overseeing production volume and quality of circuit boards used for space, aerospace, and medical applications. Debottlenecked process to increase maximum production throughput by over 20 percent.
 - Following military and industrial certification requirements and regulations.
 - Refurbishing and commissioning a previously used SES line, including extensive testing to optimize operations. Developed and validated a theoretical model of process operation for optimization.
 - Developing and implementing visual KPI dashboards for real-time plant performance statistics, including SQL queries to gather and deliver data, eliminating the need for manual data input.
- Serving as a metallurgist and process control engineer at KGHM's Robinson Mine in Nevada for six years where his experience included:
 - Managing an "expert control" project to add advanced process control systems to the mill. The grind expert increased grinding throughput by 2 percent. Added machine vision (froth cameras) on top of flotation cells to measure froth velocity, color, bubble size, and mineral loading. Information was used to optimize operation, leading the froth camera project to increase recovery by 2 percent.
 - Managing a large-scale, three-year software and hardware upgrade for the DCS.

- Overseeing mill DCS/SCADA system (Emerson Ovation), including programming logic and tuning, installing, and modifying hardware and I/O for the system; administering software and hardware on the mill network; and maintaining connections for five separate systems to read and write information on the mill network.
- Managing startup of the FLSmidth SuperCell (600L) project, which included testing bench- and pilot-scale units to confirm additional recovery potential. Developed economics to justify multimillion-dollar capital expense. Was involved with programming, testing, and commissioning control and interlock system for the new equipment.
- Measuring and analyzing real-time daily, monthly, and yearly statistics on every unit operation, including rebuilding site metallurgical accounting tool for ease of use, reducing daily reporting time from hours to one minute.
- Developing statistical models to forecast metal production for the mine site. Used the models and mine engineering inputs to determine life-of-mine economics and metal production budget.
- Auditing pilot plant operations in Chile.
- Participating in weekly safety audits throughout the site.

Education	BS, Chemical Engineering, Michigan Technological University, 2011 Minor in Minerals Processing
Training	Six Sigma Green Belt and Lean Concepts
Software	MS Visio, MS Project, Minitab, JMP, AutoCAD, R Studio, VBA, SQL, PowerBI, OSISoft PI, MathCAD, Aspen, Unisim, Caspeo simulation software, JKTech simulation software
Presentations	Improved Copper and Gold Recovery at KGHM International's Robinson Mine, ExpoMin Mexico 2015; Acapulco, Mexico.

Experience Chad has more than eight years of experience in process and production engineering, process safety management, energy assessments and process hazard analysis. His services include process startup and troubleshooting along with writing standard operating procedures for existing and new systems. He has worked on a variety of projects involving mine tailings management and design, wastewater treatment system design, and process safety. He also assists with National Pollutant Discharge Elimination System (NPDES) permit applications, including wastewater discharge limit calculations and analysis, and is skilled in developing piping and instrument diagrams. He is a certified energy auditor and completes energy assessments under the U.S. EPA's boiler maximum achievable control technology (MACT) rule. His work at Barr has included:

- Completing boiler MACT energy assessments for facilities in the power, refining, and manufacturing industries.
- Designing and conducting pilot studies for groundwater remediation projects.
- Developing capital cost estimates for feasibility studies relating to wastewater treatment systems for the mining and manufacturing industries.
- Assisting with client NPDES permit applications, including completing wastewater discharge-limit calculations and analyses.
- Providing process-safety and process-hazard analysis reviews, as well as reviewing and developing standard operating procedures (SOPs) for new processes, including a pyrolysis system.
- Serving as a member of an oil-refinery wastewater-treatment design team.
- Developing piping and instrument diagrams (P&IDs).
- Project manager for municipality process optimization projects.
- Water treatment plant design and capital cost estimations.
- Serving on design teams for mining clients and assisting with:
 - Water and mass balances
 - Debottlenecking projects
 - Development of P&IDs and process flow diagrams
 - Wastewater studies

Before joining Barr, Chad served as a production engineer and shift supervisor for Archer Daniels Midland's corn processing division, where his work involved:

- Process engineering in the utilities and corn refinery departments.
- Managing and completing projects to improve safety and efficiency with water/wastewater treatment in corn processing, which included working with reverse osmosis and water softening systems and biological wastewater treatment systems.
- Directing wastewater treatment pilot studies to implement new technologies.

- Troubleshooting flash dryer systems to increase reliability and efficiency.
- Assisting with plant safety by acting as chair of the confined-space safety committee and serving as a member of the plant-site Code Blue and HAZMAT teams.

Education BS, Chemical Engineering, University of North Dakota, 2008

Experience

Nicole Nguyen is a process engineer with over nine years of experience working with clients in the power, energy, and fuels industries. She has worked as an environmental process engineer, start-up and commissioning field engineer, project manager, and lead process-design engineer. Nicole has experience as project manager and task lead in detailed design for power projects, and developing detailed cost estimates and performing budgetary feasibility studies for power, mining, and fuels projects. She has been involved with equipment procurement and selection, contract management, process and controls design, and commissioning. Nicole's relevant project experience includes:

- 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 the pre-design study for a pretreatment reverse osmosis system for a power plant in Michigan.
- 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).
- Conducting a process and mechanical design review of a carbon capture system and advising on flue-gas desulfurization (FGD) for air quality control of power plants at a research facility in the Midwest.
- 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 an activated-carbon production facility.
- Working with the Department of Energy and other federally funded support teams to create budgetary cost estimates for rare-earth element extraction systems for power-plant coal byproducts.
- Preparing procurement specification and budgetary cost estimates for new natural-gas engine systems integrated with coal and gas power plants.
- Developing electrical and automation check-out procedures for a confidential client's compressor station start-up.
- Performing a third-party review of commissioning for a boiler feedwater pump system for a confidential client.

Before joining Barr, Nicole's experience included:

- Working as an environmental process-design engineer for a manufacturer of original equipment for major boiler and environmental systems. For over four years there her experience included:
 - Serving 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.

- Working as a field process engineer for a 3,400 MW wet FGD system installation and start-up project in Michigan to troubleshoot distributed control systems (DCS), PLC, electrical, process, and mechanical related start-up; commissioning; and operating issues in the field.
- Performing guarantee testing for multiple wet FGD systems along the eastern U.S.
- Serving as a process design engineer for SSOE, 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.

Education BS, Chemical Engineering, University of Toledo, 2005

Registration Professional Engineer: Michigan, Ohio, and North Dakota
Project Management Professional (Project Management Institute)
National Council of Examiners for Engineering and Surveying (NCEES) record

Software AFT Arrow and AFT Fathom, ASPEN, AutoCAD, CHEMCAD, MATLAB/Simulink, PIPE-FLO, PI/Proficy, Plant-4D, Product Lifecycle Management (PLM), Emerson Ovation DCS, ABB 800xA DCS

Affiliations Society of Women in Engineering (SWE)
International Society of Automation (ISA)
Advancing Women in Energy (AWE)

Experience

Richie has over five years of experience in mechanical design, project management, and engineering tasks such as equipment and plant layout, material handling system design, process modeling, dust collection system design, and piping design for mining, mineral processing, power, pipeline, forest products, manufacturing, industrial sands, and governmental agency projects. Examples of his work experience include:

- Designing process flow diagrams, creating a high-level site arrangement, and developing a constructed capital cost estimate for new crushing and screening facilities as part of a feasibility study at Carmeuse Lime & Stone's Calcite Operation in Rogers City, Michigan.
- Managing the detailed design of a new slurry pump and pipeline in the agglomerator at U. S. Steel – Minntac.
- Conducting a feasibility study for pneumatic handling systems, material storage, and screw feeders for a binder addition project at a local taconite processing facility.
- Managing a concentrate recovery feasibility study for U. S. Steel - Minntac.
- Conducting a pipe abrasion study and developing a cost estimate for pipe material alternatives at Rio Tinto Borate's Borax Mine in Boron, California.
- Evaluating a trona ore crushing facility for upgrade projects necessary to increase overall production at Ciner Wyoming's soda ash mine in Green River, Wyoming.
- Managing the civil, electrical, mechanical, and structural balance of plant design for the installation of a new fly ash handling system at Minnesota Power's Hibbard Renewable Energy Center. Richie also provided onsite construction observation and support.
- Managing and assisting with the design of a maintenance bracket for changing cooler wheels at U. S. Steel – Minntac.
- Designing the process water piping system for a U.S. Silica sand plant.
- Assisting with a dust collection audit of the transfer house and fines crusher at a confidential iron mining client's facility.
- Conducting a water flow study as part of a plant-wide water balance at Minnesota Power's Laskin Energy Center.
- Assisting with boiler ash discharge water sampling as part of the ash pond decommissioning at Minnesota Power's Boswell Energy Center.
- Providing a hydraulic power unit layout, designing the hydraulic piping system, and providing construction observation for a new truck dumper installation at Minnesota Power's Hibbard Renewable Energy Center.
- Designing a piping system and flowmeter stations for the new city potable water system and providing construction observation at Minnesota Power's Hibbard Renewable Energy Center.

- Assisting with purchase specifications for lubrication oil skids for six hydro turbines and one hydraulic power unit for a high-pressure hydraulic system at Minnesota Power's Thomson Hydroelectric Power Station.
- Assisting with a purchase specification for an oily water filter system and designing the piping for a spill prevention system at Minnesota Power's Thomson Hydroelectric Power Station.
- Designing a piping system for the plant compressed air system at Minnesota Power's Thomson Hydroelectric Power Station.
- Designing steam piping modifications for #7 and #8 boiler economizers at Minnesota Power's Rapids Energy Center.
- Providing equipment and piping layout for a fire pump house for Enbridge Energy.
- Assisting with an HVAC study to make system upgrade recommendations in the agglomerator at U. S. Steel – Minntac.
- Managing the design of a platform to access an expansion joint in the waste-gas scrubber ductwork for U. S. Steel – Keetac.
- Designing a packing seal for an up-ramp shaft for a Disney waterpark ride.
- Conducting an airflow study on a dust collection system and designing fan and ductwork modifications based on the results of the airflow study for U. S. Steel.
- Assisting with rail load-out chute installation project at a northern Minnesota iron mining operation.
- Designing material handling chutework for conveyor transition points for a U.S. Silica sand plant.
- Designing ductwork for a fluid bed dryer plant for a U.S. Silica sand plant.
- Providing mechanical equipment layout for a fluid bed dryer plant at a U.S. Silica sand plant.
- Developing screw conveyor purchase specifications, providing mechanical equipment layout, and designing chutework for a screen replacement project for Dakota Gasification Company at its Great Plains Synfuels plant in Bismarck, North Dakota.
- Assisting with multiple pipeline design and layout projects for Enbridge Energy.
- Providing OCI Wyoming (now Ciner) with a preliminary design for a new silo and conveyors for a new rail load-out system at its facility in Green River, Wyoming.

Education BS in Engineering (mechanical engineering emphasis), Minnesota State University, Mankato, Minnesota - Iron Range Engineering, Virginia, Minnesota (2012)

AS in Engineering, Itasca Community College, Grand Rapids, MN (2010)

Registration Professional Engineer: Minnesota

Certification MSHA

Software AutoCAD, CADWorx, SolidWorks, AFT Fathom, METSIM

Experience Bruce Browsers has 40 years of experience in engineering, operations, development, and construction of electric generation facilities specializing in power generation and process-steam industries. He also has 20 years of experience in the design and construction of combined heat and power plants.

Before joining Barr in 2008, Bruce served as president of Browsers Consulting for five years. He specialized in assessing the feasibility of prospective U.S. power industry investment in developing nations, including Tanzania. From 1977 to 2003, he served in managerial roles at Minnesota Power. His project experience at Barr includes:

- Serving as engineering manager for the Great River Energy coal-drying project. In this role, he coordinated the various engineering disciplines providing project schedules and the development of several construction specifications.
- Serving as lead mechanical engineer for a new, combustion-air-preheating system where he 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.
- Performing analysis of a potential hydropower facility purchase.
- 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.

His experience as president of Browsers Consulting includes:

- 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. Bruce conducted this work in Tanzania, and his 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. Bruce provided technical analysis for site selection, water supply, site arrangement, engineering design criteria, and permitting for a two-phase 1200 MW IGCC project. He 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.

Bruce served as manager of generation development at Minnesota Power from 1998 to 2003. During this time, his experience included:

- Project managing the acquisition and boiler expansion of a CHP project at a large paper mill. Bruce led the engineering portions of due-diligence efforts related to the purchase of the assets, and he developed the costs structure for the pro-forma business case. He led the conceptual development, engineering, permitting, construction, and installation of two gas-fired packaged boilers.
- Leading a multi-team effort to develop this 250 MW CHP bed-coal/biofuel-to provide steam to a major paper mill and merchant power to wholesale markets. He supervised the work of Pohjolan Voima Oy Engineering and Electrowatt Ekono in Helsinki, Finland. Bruce also led detail design and permitting efforts for this project.
- 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.

Bruce served in several other capacities at Minnesota Power, including as manager of fuels between 1994 and 1998 and as manager of engineering for independent power projects between 1992 and 1994. His experience with the company extends to 1977.

Prior to joining Minnesota Power, Bruce served as a results engineer for the Dairyland Power Cooperative from 1972-1977.

Education MBA, University of Minnesota at Duluth, 1989

BS, Mechanical Engineering, Michigan Technological University, 1972

Publications "Using Emissions Trading to Optimize Environmental Compliance Costs," EnergyPulse, 2004

"Four Events Shape IGCC," EnergyPulse, 2004

Experience Rich has more than 25 years of experience managing projects involving air emissions permitting, environmental review, environmental compliance auditing, and waste remediation. His work at Barr has included:

- Managing New Source Review (NSR) applicability determinations and complex project permitting at industrial facilities for clients in the utility, food-processing, steelmaking, and mining and ore-processing industries.
- Directing environmental review projects.
- Managing environmental compliance audits of industrial facilities.
- Performing best available control technology (BACT) reviews for combustion sources.
- Leading emission-source testing projects.

Rich's project experience in specific areas includes:

Air Quality

- Preparing 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 NO_x control. Three gas- or oil-fired auxiliary boilers provide backup and peaking capacity.
- Managing 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.
- Managing engineering cost-estimate development for demonstration-scale solid sorbent-based carbon-capture process for coal-fired boiler system.
- Preparing engineering cost estimates for air-pollution-control equipment, including thermal oxidizers, electrostatic precipitators, scrubbers, baghouses, cyclones, and injection systems for NO_x, SO₂, and mercury emissions control.
- Providing permitting assistance to a three-facility dairy operation with waste-to-energy systems based on anaerobic digestion of manure and biogas-fired engines to generate about 2 MW of power. Air permitting and compliance aspects included PSD applicability determination, coordination of NSPS compliance testing, modeling against short-term ambient standards, Title V permit application, and permit negotiation support.
- Providing on-site assistance to the environmental staff of a large utility to facilitate the expediting of numerous air-permit modification applications. The modifications included adding new equipment, increasing equipment capacity, and conducting test burns of alternative fuels.

- Preparing an emission inventory and Minnesota registration permit application for a barley malting facility. Emission sources included grain handling, combustion, and malt-handling equipment.
- Preparing Title V air permit applications for 17 power generation facilities: coal-burning power plants, gas-turbine peaking stations, refuse-derived fuel (RDF) plants, and engine generators.
- Conducting an air emission inventory for a metal fabrication facility that included foundry, heat-treating, machining, plating, painting, welding, and miscellaneous support operations. Inventoried 1,100 sources for their respective criteria and HAP emissions before preparing a Title V permit application.
- Preparing construction permit applications for five turbine-driven natural gas compressors. The new compressors were part of a natural-gas pipeline expansion project that required permits to be issued in time for contracts for gas to be honored.

Environmental Review

- Coordinating the 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.
- Coordinating the preparation of an EAW for a animal-feed drying process fired by packaging materials separated from off-specification food products. Initial determinations aligned the process with those of a solid-waste combustor. While still under dispute, the determination triggers the EAW requirement for new waste combustors in Minnesota. A beneficial-use determination for the solid fuel material is being sought in parallel.

Education BS, Chemical Engineering, South Dakota School of Mines and Technology, 1991
 BS, Dairy Manufacturing, South Dakota State University, 1980

Registrations Environmental Engineer: Minnesota, Michigan; Alberta

Memberships Association of Professional Engineers and Geoscientists of Alberta (APEGA)
 Air & Waste Management Association
 Minnesota Society of Professional Engineers
 Institute of Professional Environmental Practice

Training 40-Hour Hazardous Waste Operations Worker Training, 1992