UNIVERSITY OF UND NORTH DAKOTA

INSTITUTE FOR ENERGY STUDIES
COLLEGE OF ENGINEERING AND MINES
UPSON II ROOM 366
243 CENTENNIAL DRIVE – STOP 8153
GRAND FORKS, NORTH DAKOTA 58202-8153
PHONE (701) 777-3852 FAX (701) 777-4838

April 1, 2017

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Re: Proposal entitled "Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks"

Dear Ms. Fine:

The University of North Dakota Institute for Energy Studies is preparing as response to the Phase II opportunity under U.S. Department of Energy DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recovery Rare Earth Elements (REEs) from Domestic Coal and Coal Byproducts". In the Phase II project, UND will continue its successful collaboration with Barr Engineering and Pacific Northwest National Laboratory. In Phase I, the project team both identified locations in the State with lignite-related materials that had very high levels of REE, as well as a novel extraction technology that takes advantage of the unique properties of North Dakota lignite coal in an extremely simple, highly effective and low cost process.

Great River Energy and North American Coal Corporation will continue their support of the UND team by providing funding in the amount of $90,000 each. Great Northern Properties will be joining the team for Phase II and will provide $60,000. The attached proposal requests $280,000 from the North Dakota Industrial Commission for the 18 month project. The total value of the project is $3,437,500.

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

Sincerely,

Steven A. Benson, Ph.D.
Professor, Institute for Energy Studies
Associate VP for Research, EERC

c.enc
Mike Holmes, Lignite Energy Council

INSTITUTE FOR ENERGY STUDIES
THE UNIVERSITY OF NORTH DAKOTA

INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION 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: $280,000

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:

Steven A. Benson, Ph.D.
Phone: 701-777-5177
Fax: (701)777-3773
steve.benson@engr.und.edu

Dr. Steven A. Benson, Associate Vice President for Research, EERC and Professor
Institute for Energy Studies

Dr. Barry I. Milavetz, Assoc. VP for Research and Economic Development
Research Development & Compliance

April 1, 2017

PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

NOTE FOR TECHNICAL REVIEWERS

This document is the public version of the application. The document intended for technical review is an entirely confidential version that has been submitted separately. Due to the large amount of confidential information required to fully describe the proposed project, we felt it necessary to include a fully confidential version to maintain flow and prevent the need for continuous reference to a confidential appendix.

PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

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PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

1. ABSTRACT

Rare earth elements consist of the lanthanide series of elements on the periodic table and are crucial materials in an incredible array of consumer goods, energy system components and military defense applications. However, the global production and entire value chain for rare earth elements is dominated by China, with the U.S. being currently 100% import reliant for these critical materials. Traditional mineral ores, however, have several challenges. Chief among these is that the content of the most critical and valuable of the rare earths are deficient, making mining uneconomical. Further, the supply of these most critical rare earths is nearly 100% produced in China from a single resource that is only projected to last another 10 to 20 years. The U.S. currently considers the rare earths market an issue of national security, given the supply risks and the importance of their end uses to both energy applications and military defense applications. Therefore, given the complete import reliance and dwindling Chinese reserves, it is imperative that alternative domestic sources of rare earths be identified and methods developed to produce them. Recently, coal and coal byproducts have been identified as one of these promising alternative resources.

The proposed Phase II project will be a continuation of a Phase I effort lead by the University of North Dakota Institute for Energy studies, with technical partners Barr Engineering and Pacific Northwest National Laboratory investigating the feasibility of recovering rare earth elements from North Dakota lignite and lignite-related feedstocks. The Phase I work identified locations in North Dakota with coal-related feedstocks having exceptionally high rare earths content. Further the project team developed a simple, highly effective and low-cost method to concentrate the REEs in the lignite feedstocks using a novel technology that takes advantage of the unique properties of lignite that make for much simpler and lower cost processing than other coal feedstocks. This Phase II work will scale-up the technology and demonstrate it at a scale of 10-20 kg/hr and evaluate the economics for a commercial-scale rare earths concentrating facility in North Dakota.

PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

2. PROJECT SUMMARY

In recent years, due to their recognition as crucial materials for a huge variety of important end use applications such as military defense, wind turbines, hybrid/electric vehicles, electronics and many others, the secure supply of rare earth elements (REE) and REE-based products is considered an issue of national security. China, in part due to its deposits of a unique REE resource (ion-adsorbed clays) that combines high quantities of the more valuable heavy REE, as well as simple and low cost extraction, dominates the global supply market. In 2010, China established new quotas on exports of REEs, which resulted in huge increases in REE prices peaking in 2011 due to an expected supply shortage for critical applications such as in permanent magnets used in wind turbines and motors in hybrid/electric vehicles. As a result, production at the California-based Mountain Pass Mine (Molycorp, Inc.) was re-started after several years of dormancy. However, after peaking in price in 2011, prices have dropped substantially to slightly above 2010 levels, challenging the profitability of non-China based production which consists mainly of hard rock carbonatite deposits that are deficient in the more valuable heavy REE. Some researchers have noted that *mining of the Mountain Pass and similar resources will neither mitigate the crisis in REE resources nor eliminate the shortage of the most critical REE, but will only result in overproduction of excessive cerium.*

According to the USGS 2017 Mineral Commodity Summary report, China accounted for about 83% of the total global REE supply in 2016, down from about 95% prior to 2010. Meanwhile, the US production was zero, with the Mountain Pass mine having declared bankruptcy and closing operations in the last quarter of 2015. *The U.S. is currently 100% import reliant for REEs*. Although still dominating global supply of the heavy REE, researchers have estimated that the Chinese ion-adsorbed clays resource will only last another 10-20 years. The Chinese clays represents essentially the entire global supply of the most critical of the REEs. *Due to its limited supply, and because the Chinese clay resource is rich in the most critical REE, while most other traditional resources are deficient in these less common and more valuable elements, it is imperative that new domestic sources of REEs, especially the most critical REE, be identified and processes be developed to produce them. Coal and coal byproducts have recently been* *identified as one of these potential new resources for REEs. This proposed work is aimed at development of a novel technology to separate and concentrate REEs in North Dakota lignite coal and lignite-related materials.*

This proposed Phase II project is a continuation of a nearly complete Phase I project that responded to the U.S. Department of Energy funding opportunity announcement "DE-FOA-0001202: Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recovery Rare Earth Elements from Domestic Coal and Coal Byproducts." The goals of the FOA were to identify U.S. coal-related feedstocks with rare earth element (REE) content of at least 300 parts per million and to develop technologies to concentrate the REEs in the selected feedstocks to a concentration of at least two percent by weight, such that the product could be a suitable replacement for traditional mineral ore resources.

In Phase I of the project, the UND team collected samples from North American Coal Corporation's Falkirk Mine and Great River Energy's Coal Creek Station Power plant and DryFining™ lignite drying system. Samples were also collected from an outcropping of the Harmon-Hansen coal zone in southwestern North Dakota. Phase I feedstock characterization included determination of the bulk chemical composition, including rare earth elements, as well as the rare earth modes of occurrence. It was found that certain locations within certain coal seams were most concentrated in the REEs and that the primary modes of occurrence appear to be organic associations and some mineral forms such as clays, phosphates and carbonates. Very high REE levels were detected in several feedstocks. A novel REE extraction technique was developed at the laboratory-scale in Phase I that, due to the unique bonding of REEs in lignite, results in a very high recovery at about 70-90% in a very simple and low-cost and environmentally benign process. An initial technical and economic feasibility assessment showed that the developed technology was highly profitable when combined with an existing coal conversion facility.

In the proposed Phase II work, the REE extraction technology will be scaled-up to the small pilot-scale with a feedstock throughput of about 10-20 kg/hr and extensive parametric testing will be completed to optimize the process and determine performance for a range of feedstocks. Production testing will be completed at optimized conditions to produce a total of about five pounds of the REE concentrate product. Finally, an updated technical and economic feasibility assessment will be performed with Barr Engineering to identify the anticipated commercial-scale application and determine overall economics of the process based on the Phase II testing results.

3. PROJECT DESCRIPTION

3.1 Overall Project Goal

The overall goal of the proposed Phase II project is to demonstrate at a bench-scale (10 to 20 kg/hr) a high performance, economically viable, and environmentally benign technology to recover rare earth elements (REE) from North Dakota lignite coal or lignite-related feed stocks.

3.2 Project Objectives

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

- Based on the design of a bench-scale system developed in Phase I, construct a bench-scale system with a throughput of 10 to 20 kg/hr to produce a mixed REE stream of >2% by weight.
- Obtain large samples of coal containing >300ppm ash basis REE for testing
- Conduct parametric testing of the bench-scale system in order to determine optimum conditions required to recover REE
- Produce approximately 50 gallons of mixed REE concentrate solution that would be suitable for evaluation by a processing/purification company.
- Update the technical and economic analysis of the REE recovery process conducted in Phase I with the result obtained in Phase II.
- Identify opportunities for commercialization at existing mines/plants in North Dakota and/or build the commercially feasible case for opening a new mine in an area with most favorable REE content

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3.3 Scope of Work

Task 1 – Project Management & Planning

This will include coordination and planning of the project with DOE/NETL and all other project participants. Project budget, scope, schedule and risks will be continuously monitored and updated as the project progresses. Presentations will be made at DOE project review meetings, and as required by DOE or other project sponsors.

Task 2 – Bench-scale Test System Construction

This task will include construction of the bench-scale test system designed in the Phase I project. Complete details regarding the process design are contained in the discussion of Phase I results in the Background Section of this application. We expect to size the system for approximately 10-20 kg/hr feedstock throughput for batch or semi-batch operations to involve testing of REE extraction and impurities removal steps. The system will include a high degree of flexibility to allow testing of a wide range of configurations, chemistries and process conditions. The system will be constructed with modularity in mind, such that it can be transported and tested at a field or mine site if necessary. The system will be fully instrumented and real-time data acquisition will be utilized to monitor and control the system.

Task 3 – Sampling, Analysis and Large Sample Collection

Based on the results of Phase I, we have identified some target locations in the State that contained elevated levels of REEs. However, additional sampling is needed. In this task, we will sample from multiple coal seams from multiple mines and coal zones. This may include collection of drill core samples or face samples or other sampling methods available. We will work closely with project sponsors, mine operators, resource owners and the NDGS to identify locations for sampling. Analysis in this task will mainly include measurement of total REE content via inductively coupled plasma mass spectrometry (ICP-MS), but will also include some laboratory concentration testing. Based on the results, we will select at least two locations for large sampling, on the order of about 1000-2000 kg from each that will be shipped to UND for subsequent testing in Tasks 4/5.

Task 4 – Bench-scale Parametric Testing

The Phase I project has identified some of the conditions that effectively concentrate REEs and other target elements from ND lignite-related feedstocks. However, additional parametric testing is needed to tune the chemistry and conditions to maximize selectivity to REEs and optimize the process. This task will also investigate and optimize methods for impurities removal both before and after the primary REE separation step. Analysis under this task will include ICP-MS to determine concentration and distribution of REEs and target elements in the solid and liquid samples.

Task 5 – Bench-scale Production Testing

Based on the results of Task 4, production tests will be completed over longer duration at optimized conditions. We anticipate producing approximately five pounds of 2 wt% mixed REE concentrate product that would be suitable for evaluation by a separation/refining company. This task will also identify impact of feedstock consistency on overall process performance. Analysis under this task will include ICP-MS to determine concentration and distribution of REEs at each step in the process.

Task 6 –Technical and Economic Feasibility Study and Preliminary Commercialization Plan

Based on the results from previous tasks, the economic feasibility study completed in the Phase I project will be updated and refined with the increased process definition obtained from the Phase II testing. Phase I of the project used the Valley City State University combined heat and power plant concept as the model for the economics evaluation. However, in this task, we aim to identify and model a larger-scale commercial operation that would either be incorporated within an existing mine, or justify the opening of a new mine in a location with a more favorable REE content/distribution. We will work with project partners/supporters in development of the economic model.

PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

Task 7 – Final Report

A final report will be compiled that will detail all work completed during the project and present discussion, conclusions and recommendations for future work.

3.5 Anticipated Results

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

- Successful demonstration of the proposed technology at a 10 to 20 kg/hr throughput and production of approximately five pounds of mixed REE concentrate with at least 2wt% REE on a dry basis, or approximately 30-50 grams of pure REE contained.
- Optimization of the REE concentration 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).
- 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 concentration as well as byproducts usage/processing and integration within existing facilities or value chains.
- The project, if successful, 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 bench-scale test program, the technology will be ready for pilot-scale and rapid commercialization.

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3.6 Facilities and Resources

The University of North Dakota has exceptional laboratory-, bench- and pilot-scale testing facilities as well as world-class analytical laboratories that will be leveraged in the proposed work. A summary of the key facilities and resources to be utilized in this work is provided below. The exceptional analytical facilities at the UND Energy & Environmental Research Center will be utilized in this work.

Scanning Electron Microscopes

FEI Quanta 650 FEG SEM: Field emission SEM capable of obtaining high-resolution data from almost any sample material. This system was purchased in 2014. The instrument is operable in both high and low vacuum modes. The x-ray microanalysis system consists of an energy dispersive Bruker QUANTAX 200 x-ray detector. The system is equipped with backscattered and secondary electron imaging. The backscattered imaging allows for discerning materials based on atomic number. The presence of higher atomic number materials increases the brightness and allows for easy identification and subsequent analysis. The instrument is able to achieve 1-3 nm resolution. The imaging software package allows for performing analysis of mineral association with coal and other minerals.

Hitachi Scanning Electron Microscope with an Energy Dispersive System (SEM/EDS). The SEM is equipped with backscattered and secondary electron detectors for imaging and is automated with energy dispersive x-ray detectors for chemical composition analysis. The system can perform computer controlled scanning electron microscopy (CCSEM) of particles to determine the size, composition (major, minor, trace elements), and mineral typing. The system is also equipped to perform included/excluded analysis that provides information on association of minerals with coal particles or gangue materials. The system is also a good tool for examining the microstructure of the laser clad specimen, for examining the integrity at the clad/substrate interface, for determining microstructure of the laser melted surfaces, and for studying corrosion properties. This instrument allows samples to be viewed at a high magnification and to acquire information about the coating thickness, porosity, adhesion, microstructure analysis, and elemental composition.

X-ray Fluorescence Spectrometers

Rigaku Supermini 200 XRF: This XRF is a wavelength dispersive bench-top XRF able to provide low ppm detection limits for major, minor, and trace elements. The instrument is equipped with a 12 sample autosampler and can analyze either solids or liquids. The software allows rapid analysis of known and unknown samples. The system provides the ability to perform quantitative analysis and qualitative survey scans to identify the presence of elements.

Bruker Tracer IV Geo handheld XRF: The Tracer IV Geo is equipped with a large area silicon drift detector as well as a vacuum system for the analysis of lighter elements. This portable instrument can be taken to field sites. The flexibility of the system also allows for analysis of bulk samples (e.g., coal core samples, clays and other sediments for major elements) in the field without any sample preparation.

X-ray Diffraction

The Rigaku SmartLab is a fully automated XRD that utilizes cross-beam optics (CBO) enabling fast and easy changing of the incident X-rays by substituting selection slits. The instrument can operate in either Bragg-Brentano or parallel beam focusing methods. The flexible design allows for analysis of samples ranging from loose powder to large pieces of sample. The instrument is equipped with both a scintillation acquisition. A Ka1 system with a monochromator is also available for high intensity measurements. The system is equipped with a CCD camera for imaging of specific areas on a sample and has a variety of stages allowing analysis of a wide array of sample types and applications. Once the x-ray diffraction pattern is obtained it is analyzed to determine the crystalline phases present. The system can also be used to perform quantitative XRD analysis.

Inductively Coupled Plasma – Mass Spectrometry (ICP-MS)

UND has two ICP-MS systems available. Both are the Thermo Electron iCAP SQ Quadrupole models from Fisher Scientific. The ICP-MS measures trace and major element analysis at the sub- part per trillion levels. Samples are prepared by a standard digestion method. To ensure total digestion and recovery of the trace elements, the sample is first ashed and then mixed with a borate fluxing agent (lithium metaborate and lithium tetraborate) and heated to 1000° – 1100 °C to form a glass bead. The bead is then dissolved in dilute acid and brought to a known volume with reagent water. The solution is analyzed by ICP-MS and results are reported on a µg/g (ppmw) or a dry whole sample basis and ash basis. Detection limits and standard reference materials available are included as an Appendix to this application.

Sample Preparation

To take advantage of the above equipment, UND has a fully-equipped sample preparation lab, with all of the necessary capabilities for the sample preparation requirements contained in the proposed work.

Other Resources/Facilities

UND also has a fully-equipped mechanical and electrical fabrication shop, with a full list of capabilities that include welding and machining as well as mechanical and electrical installation services. The shop is staffed by experienced personnel with the training and availability to perform the necessary work proposed. UND's office areas are equipped with all of the necessary software and computing requirements to complete the scope of work. UND keeps licenses to process modeling software programs Aspen Plus® and ChemCad, and has personnel with extensive experience in their use.

New Equipment Proposed

In addition to the above existing equipment and facilities, the proposed project involves the purchase of new equipment for the bench-scale test system to be constructed in this project. The system will include gravity separation equipment, magnetic separation equipment and mixing tanks, along with instrumentation and data acquisition, as well as accessory items such as filters and pumps that will be required for the test system.

3.7 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 available at UND, and all hazardous waste will be handled according to UND regulations. 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.

3.8 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
- 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.

3.9 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 of the Phase I project (described later in this Application) are extremely encouraging, and the unique properties of ND lignite 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 REE-rich lignite or lignite-related deposits in sufficient quantity for commercial production. Some target areas have been identified in the Phase I project, but additional sampling is required. 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 at the bench-scale (10-20 kg/hr throughput) of our novel technology to concentrate REEs to a target concentration of 2 percent by weight

- Development of a process design that can economically produce REEs from ND lignite and lignite-related materials.
- Development of a commercialization strategy that integrates synergistically within an existing mine or plant facility, or provides sufficient economic justification for the opening of a new mine

5. BACKGROUND INFORMATION

5.1 Introduction

Rare earth elements (REEs) includes the lanthanide series of elements with atomic numbers from 57-71. This includes the elements lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Yttrium (Y) and Scandium (Sc) are often included in the group because of their similar properties. Promethium (Pm) is the only radioactive REE and has a short half-life, and thus no natural occurrences are known to exist. The location of these elements on the periodic table is shown in Figure 1. The rare earth elements are classified as light (LREE) and heavy (HREE). The LREE include La to Eu. The HREE include Gd to Lu, Sc and Y.

According to the U.S. Department of Energy National Energy Technology Laboratory (DOE NETL) [1], REEs provide significant value to our national security, energy independence, environmental future, and economic growth. REEs are utilized in a suite of high importance end-uses, such as cell phones, hybrid vehicles, magnets, computer components, catalysts and many others. The unique magnetic properties of REEs, in particular, makes them crucial materials for the growing renewable energy and electric automotive markets. REEs are used in the strongest permanent magnets currently known, and are used in generators for wind turbines and in motors for hybrid/electric vehicles. These same types of magnets, as well as other critical REE-based products are used in a host of military defense applications, as well.

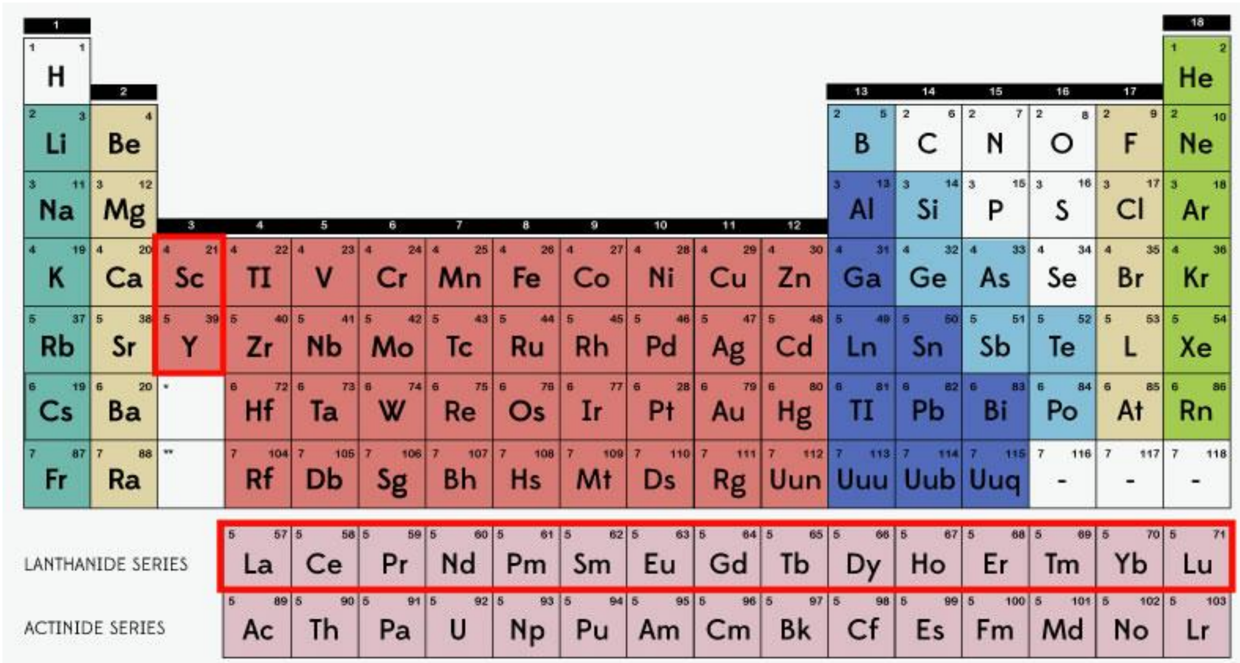


Figure 1. Rare earth elements on the period table - identified by dark red boxes

Recently, due to their recognition as essential materials for today's modern economy, several groups have performed strategic or critical materials assessments that included evaluation of REEs. An example is the recent study by the U.S. Department of Energy [2], in which mineral commodities were evaluated for their criticality based on a combination of their supply risk and their importance to energy applications. This analysis was completed over a 5 year and 15 year outlook and is shown in Figure 2. From this analysis, the only elements deemed critical are some of the REEs, namely Dy, Nd, Tb, Eu and Y. Other sources have included Er in the list of critical REEs [3]. In the short term assessment, Ce and La were also deemed near-critical. This analysis shows that REEs are some of the most critical mineral commodities and securing long-term domestic supply sources is crucial to the economic and national security of the U.S. To that end, Representative Duncan Hunter (R-CA) in March 2017 introduced the Materials Essential to American Leadership and Security (METALS) Act which would create loan facilities aimed at encouraging U.S.-based companies to get back into mining REEs and producing REE-based products. In his address to congress, Rep. Hunter stated:

The U.S. must no longer be wholly dependent on foreign sources of strategic and critical materials. The risk of this dependence on national security is too great, and it urgently demands that we re-establish our depleted domestic industrial base.

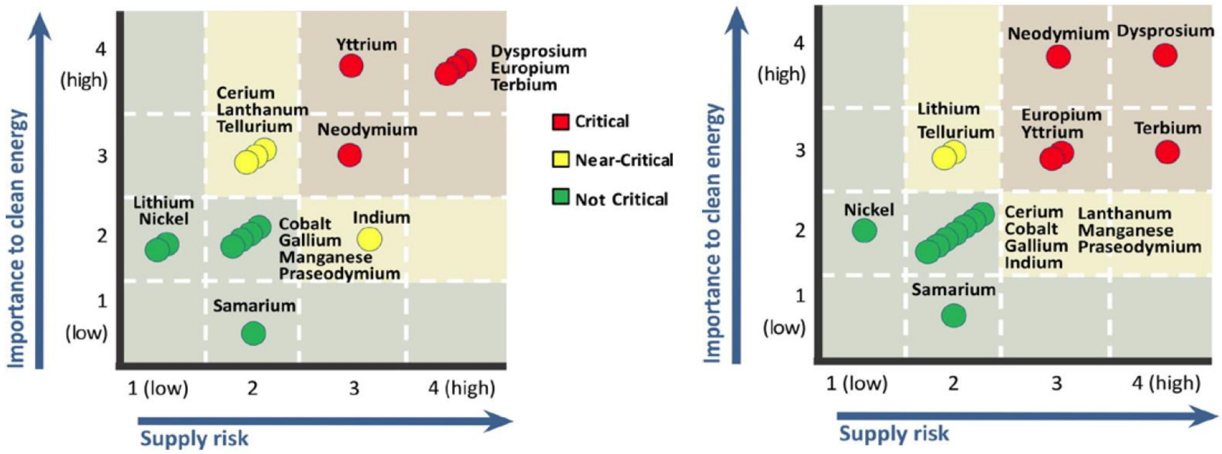


Figure 2. U.S. DOE Criticality Matrix - short-term (5 year – left) and medium-term (15 year – right)

China, in part due to its deposits of a unique REE resource (ion-adsorbed clays) that combines high quantities of HREE and critical REE, as well as simple and low cost extraction, dominates the global supply market. In 2010, China established new quotas on exports of REEs, which resulted in huge increases in REE prices peaking in 2011 due to an expected supply shortage for critical applications such as in permanent magnets used in wind turbines and motors in hybrid/electric vehicles. As a result, production at the California-based Mountain Pass Mine (Molycorp, Inc.) was re-started after several years of dormancy. However, after peaking in price in 2011, prices have dropped substantially to slightly above 2010 levels, challenging the profitability of non-China based production which consists mainly of hard rock carbonatite deposits, that are deficient in critical REE and HREE. Seredin and Dai (2012) [3] have noted that *mining of the Mountain Pass and similar resources will neither mitigate the crisis in REE resources nor eliminate the shortage of the most critical REE, but will only result in overproduction of excessive Ce.* This disparity in REE distribution is illustrated in Figure 3 showing the breakdown of REE content in the carbonatite Mountain Pass mine ore and the Chinese ion-adsorbed clays (also called lateritic ore).

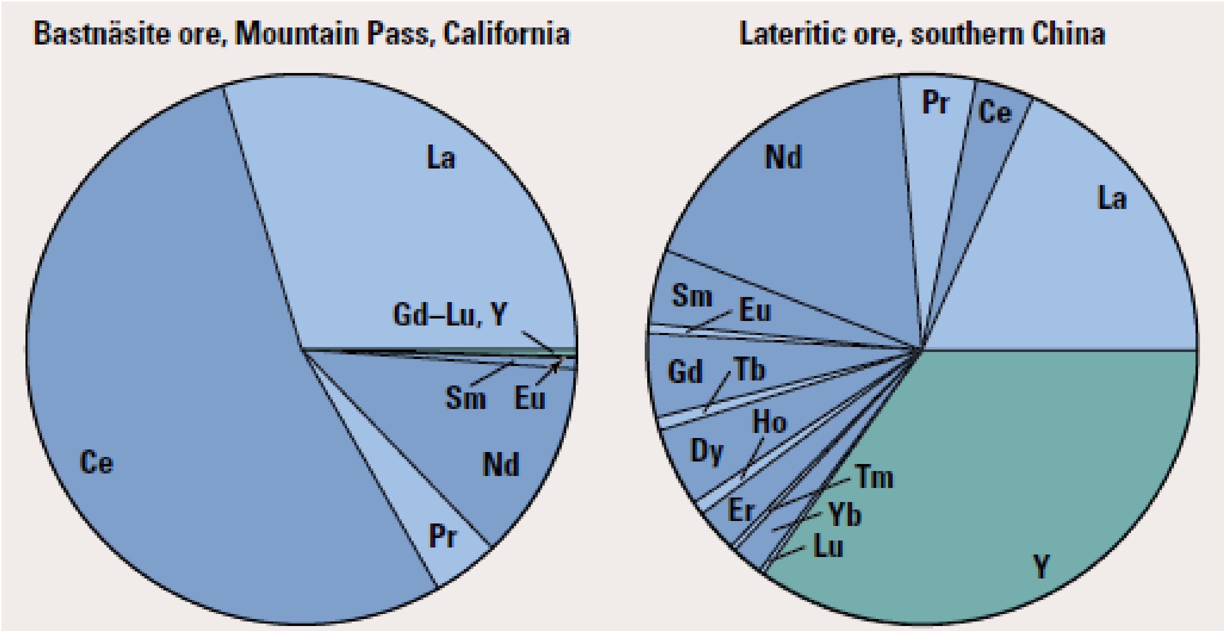


Figure 3. Comparison of the REE distribution in the Mountain Pass ore and the Chinese ion-adsorbed clay deposit

According to the USGS 2017 Mineral Commodity Summary report [4], China accounted for about 83% of the total global REE supply in 2016, down from about 95% prior to 2010. Meanwhile, the US production was zero, with the Mountain Pass mine having declared bankruptcy and closing operations in the last quarter of 2015. *The U.S. is currently 100% import reliant for REEs*. Although still dominating global supply of HREE, Chegwidden and Kingsnorth (2011) [5] have estimated that the Chinese ion-adsorbed clays resource will only last another 15-20 years, with remaining reserves estimated at 3-12 kt [6], [7]. The Chinese clays represents essentially the entire global supply of HREE and most of the critical REE [8]. Further, the bulk of Chinese reserves and production is from a carbonatite-type deposit (Bayan Obo) that contains only trace amounts of HREE (98.7% LREE), and supplies roughly 80% of the global LREE demand [9]. *Due to its limited supply, and because the Chinese clay resource is rich in HREE and critical REE, while most other traditional resources are deficient in these less common and more valuable elements, it is imperative that new domestic sources of REEs, especially the HREE and critical REE, be identified and processes be developed to produce them. Coal and coal byproducts have recently been identified as one of these potential* *new resources for REEs. This proposed work is aimed at development of a novel technology to separate and concentrate REEs in North Dakota lignite coal and lignite-related materials.*

5.2 Rare Earth Elements in Coal and Coal Byproducts – Alternative REE Resources

Leonardo Technologies, Inc (2012) [8] performed a detailed assessment of the prospects of coal and coal byproducts as alternative resources for REE production in the U.S. and found that "unintended production" of REE associated with coal mining exceeds 40,000 tons annually, of that the HREE may exceed 10,000 tons annually. They estimated that total recoverable reserves of REE in coal may exceed 2 million tons for the major coalbeds and formations in the U.S.

In particular, a major advantage of REEs found in coal-related materials is the relatively high proportion of the more valuable critical and heavy REE compared to traditional mineral ore deposits, such as Mountain Pass mine and Bayan Obo in China. This is shown in Figure 4 [8], which compares various coal formation REE distributions to Earth's crustal averages, the Mountain Pass carbonatite ore and the Chinese ion-adsorbed clay resource (Chinese lateritic REE ore). This data shows that coals are enriched above crustal averages, and although the content of the LREE in coal is significantly lower than the carbonatite ore, the content of less common, more critical and higher value HREE in coal exceeds that of the carbonatite, with similar concentrations as the Chinese clay (current global source of HREE). Of particular note is the Fort Union coal, which has the highest concentration of the heaviest REEs.

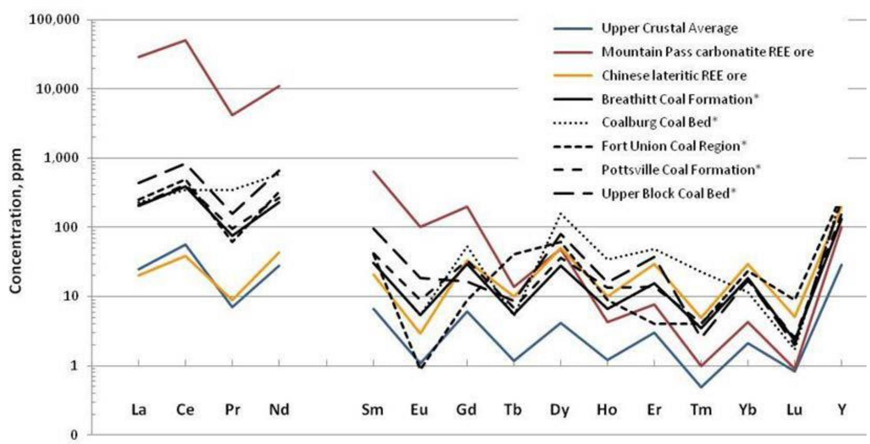


Figure 4. Comparison of REE concentration of various resources, including multiple U.S. coal formations

A similar analysis method was developed by Seredin and Dai (2012) [3], in which they grouped global coal deposits according to their relative content of the critical REE, as shown in Figure 5. Here the X-axis represents the ratio of critical (Nd, Eu, Tb, Dy, Y, Er) to excessive REE (Ce, Ho, Tm, Yb, Lu), and the Y-axis represents percentage of critical REE in the total REE. Moving to the right and up in the figure represents a more favorable/promising distribution of the REE skewed towards the more valuable critical REE. The authors conclude that coal represents a more promising source of REE than traditional carbonatite ore deposits, such as Mountain Pass. Also superimposed on this figure, are two samples of North Dakota lignite coal, which fit nicely into the 'promising' category in cluster II.

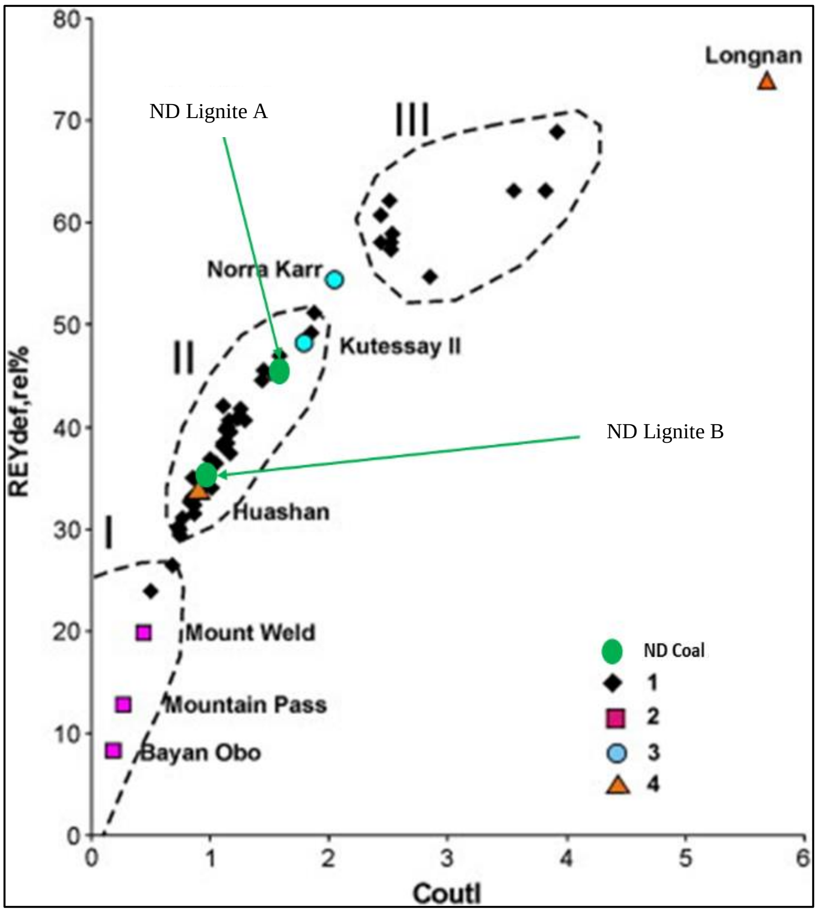


Figure 5. Classification of REE-rich coal by outlook for individual REE distribution in comparison with selected deposits of conventional types. 1 - REE-rich coals; 2 - carbonatite deposits; 3 - hydrothermal deposits; 4 - weather crust elution-deposited (ion-adsorbed) deposits. Clusters of REE-rich coal distinguished by outlook for REE distribution (numerals in figure): I – unpromising, II – promising, and III – highly promising [3].

The USGS Coal Quality Database has also been used as a source for initial assessment of coal producing regions. Figure 6 [8] displays graphically the data in the database for total REE concentration. Several of the prominent coal producing regions in the U.S. are shown to be enriched in REE, including the Fort Union coal in North Dakota and surrounding region.

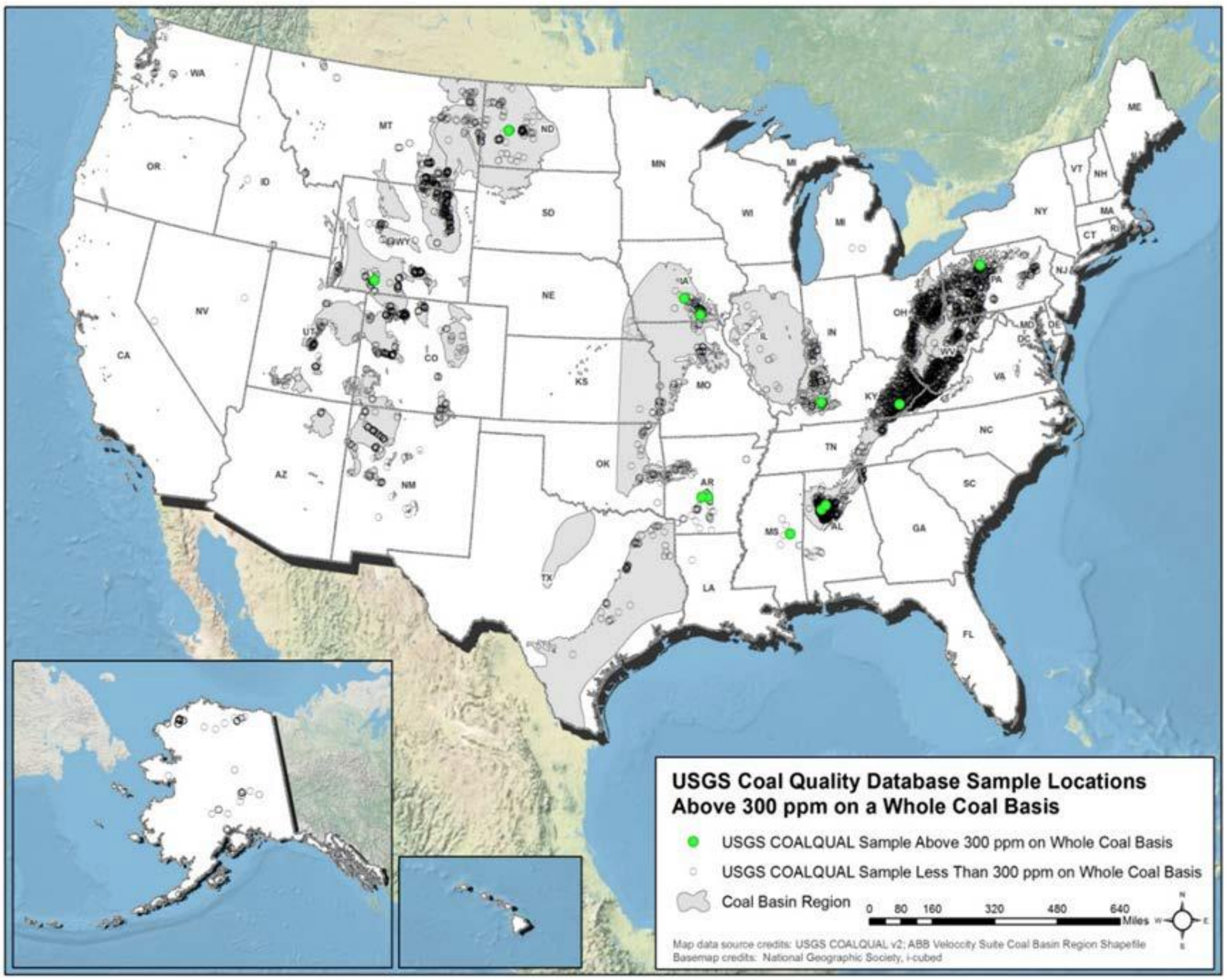


Figure 6. USGS Coal Quality Database and coal formations of interest with elevated levels of REE [8].

5.2.1 REE Associations in Coal

The abundance and association of the REE in coal is controlled by the type of REE-containing source materials. Source materials can be derived from minerals and volcanic ash (detrital origin) that are accumulated with the organic materials in a swamp [10], [11], [12]. During the coal formation process the REE-containing volcanic ash and minerals are exposed to the influence of ground water and other processes that can result in the transfer of the REE to the organic fraction or to new authigenic minerals. This process can result in the enrichment of REE in selected layers in the coal bearing stratigraphic sequences. REEs in coal can be mineral-bound within a range of mineral forms, can be ionically bound to clays, or organically associated as ion exchangeable cations or as organic complexes. *To effectively develop separation, extraction and concentrating technologies for REE from coal and coal byproducts, it is critical that the modes of REE occurrence in the feedstock be elucidated.* A very brief review of some relevant literature is presented below that discusses some of the common REE associations in coal.

Very fine-grained REE-bearing minerals are commonly found in coals and authigenic minerals are typically more abundant than detrital minerals in high REE content coals. These can be discrete minerals contained in the organic matrix, or as minerals associated with clay minerals. Often, the REE in clay-bound minerals are enriched or contained only within the partings of the coal or margins of the seam. Seredin and Dai (2012) [3] have categorized the main genetic types of high REE accumulation in coals as shown in Table 1.

Table 1. Main genetic clasifications of REE accumulation in coal [3]

Type	**REE Content in Ash, %**	**Associated Elements**
Terrigenous	0.1–0.4	Al, Ga, Ba, Sr,
Tuffaceous	0.1–0.5	Zr, Hf, Nb, Ta, Ga
Infiltrational	0.1–1.2	U, Mo, Se, Re
Hydrothermal	0.1–1.5	As, Sb, Hg, Ag, Au, *etc*.

Many low-rank subbituminous and lignite coals contain a high proportion of REE associated with the organic fraction as ions attached to carboxylic acid groups or as coordination complexes or adsorbed onto the organic matter. Hower and others (2016) [13] note that HREE generally have higher affinity to organic matter and form more stable organic complexes than LREE. Ezansky [14] evaluated a Bulgarian lignite coal and found that REE cations bound to –COOH and –OH groups replaced the alkali cations. Other studies have indicated correlations of REE content with ash content and specific gravity fraction, with highest REE content in the low ash and low density fractions, which were considered to be inferred organic associations [13].

5.3 Technical Summary of the Phase I Project

The U.S. DOE NETL has recently initiated a large research program [1] aimed at identifying coal and coal-related resources for REE and technologies to recover the REE. The University of North Dakota Institute for Energy Studies (UND IES) was awarded one of these initial Phase I projects (DE-FE0027006) in March 2016, and will be complete in August 2017. The North Dakota Industrial Commission, along with Great River Energy and North American Coal Corporation were supporters of this Phase I project. The funding request in this proposal is to support a subsequent Phase II project. DOE's overall objective for these initial projects was to develop high performance, economically viable, and environmentally benign concentrating technologies for coal-related feedstocks to REE concentration of 2% by weight. The projects were to focus on the up-front aspects of mining and physical beneficiation processes to form a synthetic REE-rich ore that could replace traditional REE mineral ore resources. The goals of the Phase I UND project are summarized below:

- Identify North Dakota lignite and lignite-related feedstocks with total REE content of greater than 300 ppm
- Identify and evaluate methods to concentrate the REEs to a target of 2 wt.%
- Perform a technical and economic feasibility analysis of a commercial concentration facility
- Develop the design of a bench-scale (small pilot-scale) test system to be constructed and tested in a subsequent Phase II project.

The following sections summarize the key Phase I project results.

5.3.1 Sampling and Characterization Results

Sampling was primarily at the Falkirk Mine and the Coal Creek Station power plant, both located near Underwood, ND. Sampling from the mine included: i) roof sediments, ii) coal, iii) partings, and iv) floor sediments. Samples were collected either from available drill cores, from faces of exposed seams or from drill cuttings from horizontal planes of exposed seams. Feedstocks from the Coal Creek Station included: inlet coal, bottom ash, fly ash, and streams associated with the Great River Energy (GRE) DryFining™ lignite drying/beneficiation process, including the air jig rejects, feeder outlet and coal dryer fines. The sampling locations from the plant are depicted in Figure 7. As originally proposed to DOE, the target feedstock was the mineral rich reject stream from the DryFining™ process (air jig outlet), which was shown to have high levels of REE in initial analysis (later determined to be non-quantitative analysis method). However, the results obtained during Phase I using a refined/accurate analysis method (ICP-MS) indicated relatively low REE content in the Coal Creek Station sample locations, as shown by the results presented in Table 2. Because the content of REE in these streams did not meet DOE's target threshold of 300 ppm, the focus was subsequently switched to identifying 'hot spots' in the Falkirk Mine with higher REE levels. However, an important, but unexpected finding from this, was that the ash basis REE content of the fly ash (and the feed coal) is significantly higher than the mineral-rich reject stream.

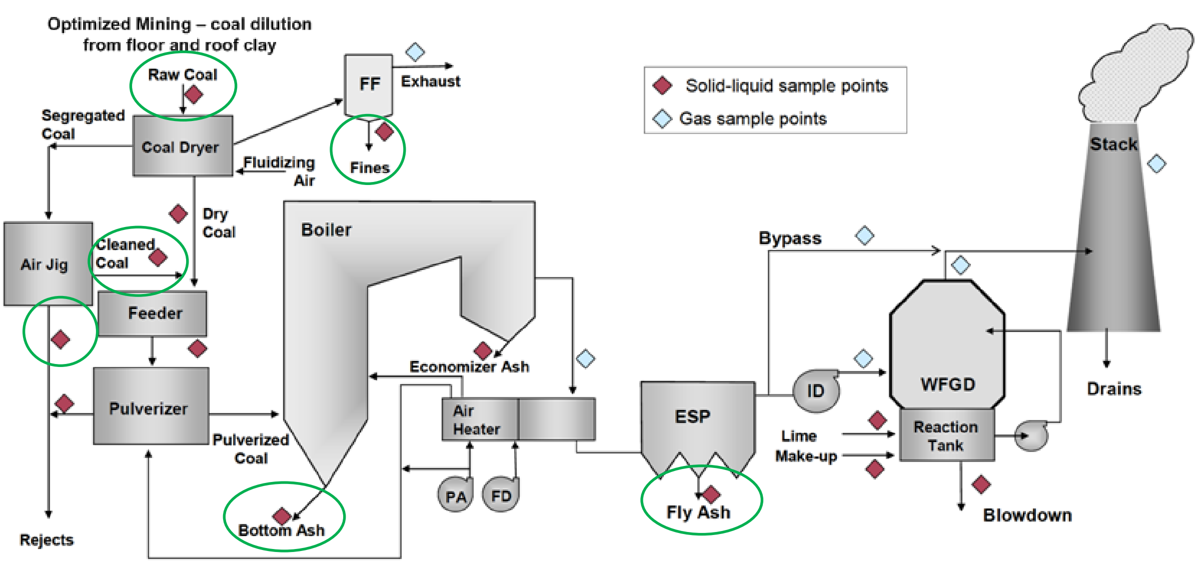


Figure 7. Sampling locations at coal creek station - samples collected at locations circled in green

Table 2. Average REE content in Coal Creek Station samples

Sample Location	Average total REEs – dry whole sample basis, ppm	Average total REEs – dry ash basis, ppm
air jig rejects	36	105
coal dryer dust collector	66	199
Fly ash	240	240
Clean coal to feeder	25	234

As noted above, a range of samples was collected from the Falkirk Mine in multiple locations. The REE content (ash) basis in the mine stratigraphic sequence is shown in Figure 8. The roof and floor sediments from the mine typically ranged from about 100 to 180 ppm REE content, also below DOE's minimum threshold. However, in certain locations within each of the coal seams sampled (Hagel A, B Rider, and Hagel B), there were locations with ash basis REE content exceeding the 300 ppm target. This is consistent with the observation from the Coal Creek Station samples, in which the coal fly ash had a higher REE content than the mineral-rich reject stream.

In addition to samples from the Falkirk Mine and the Coal Creek Station, a few samples were gathered from other locations in the state. Two of these (one coal sample and one high ash roof sediment sample) were supplied by the North Dakota Geological Survey (NDGS), which were collected from an outcropping of the Harmon-Hansen coal zone in Slope County, ND (Figure 9). These samples proved to have exceptionally high levels of REE. Figure 10 displays a comparison of the Harmon-Hansen coal to the Hagel B seam. To better illustrate the exceptionally high REE content in this sample, Figure 11 shows a breakdown of all of the samples in the USGS CoalQual Database nationwide for the major coal producing regions. The Hagel B sample is about average nationwide. Only about 3% of samples in the national database have REE content above 200 ppm (dry whole coal basis). The Harmon-Hanson coal sample had an REE content of 560 ppm (dry whole coal basis), or 2300 ppm (ash basis), values that are well in excess of the DOE target of 300 ppm. Additionally, the high ash roof sediments had a whole sample REE content of 450 ppm, or an ash basis content of about 595 ppm. A note regarding the CoalQual database is that, in general, North Dakota is underrepresented (only 16 samples with complete REE analysis and 180 overall) compared to the quantity of complete REE analysis samples available from other coal producing regions. However, data for samples with partially complete REE analysis suggests potential for several samples exceeding the 200 ppm level.

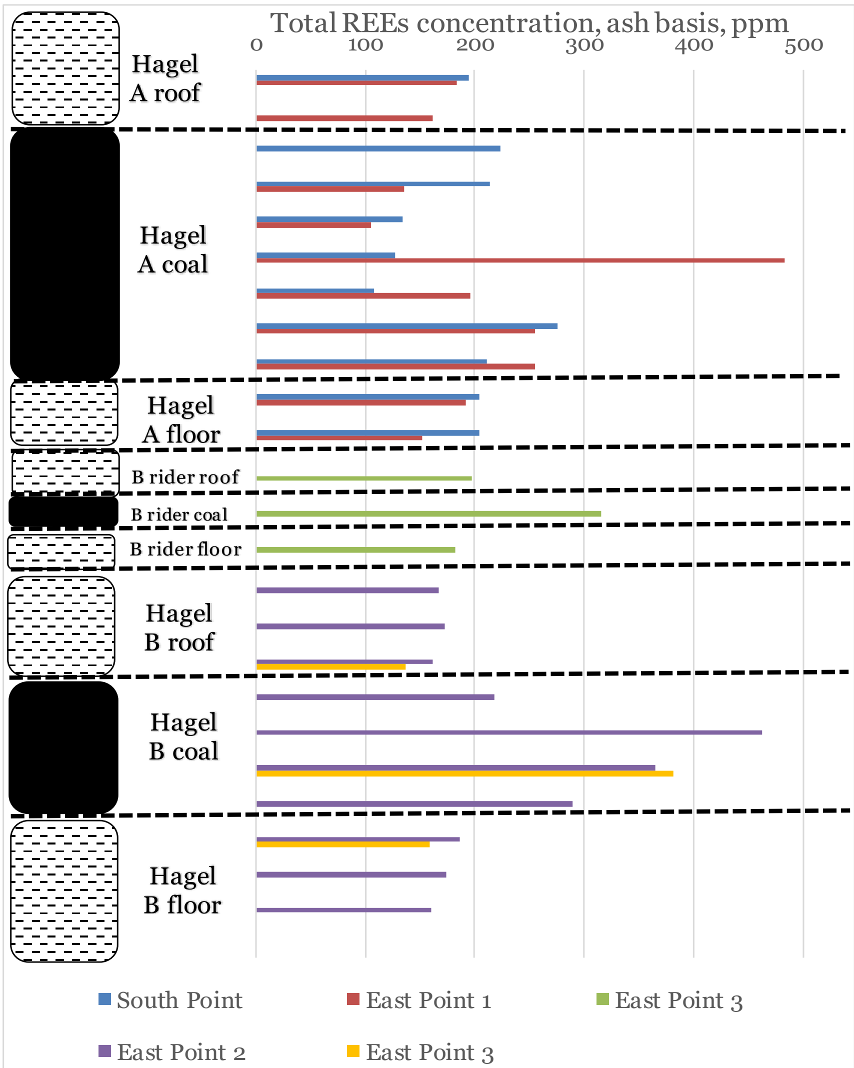


Figure 8. REE content in the Falkirk Mine stratigraphic sequence (ash basis)

Figure 9. Outcropping of the Harmon-Hansen coal zone in Slope County, ND

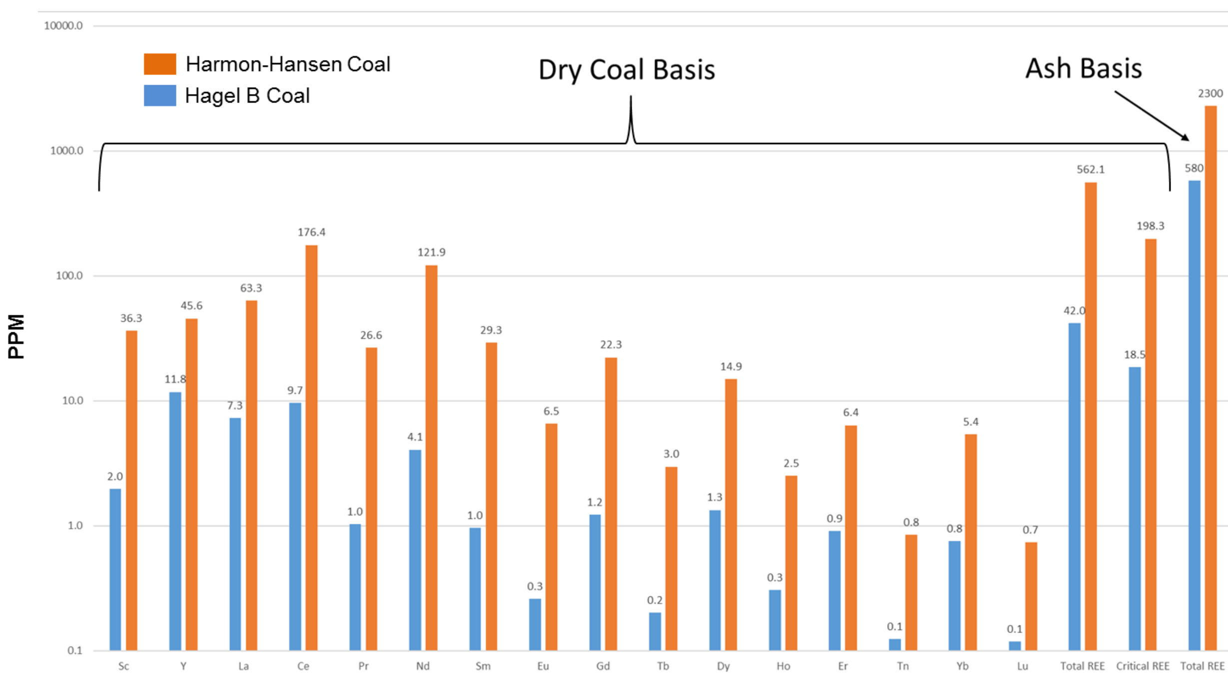


Figure 10. Comparison of the REE content in two ND lignite samples

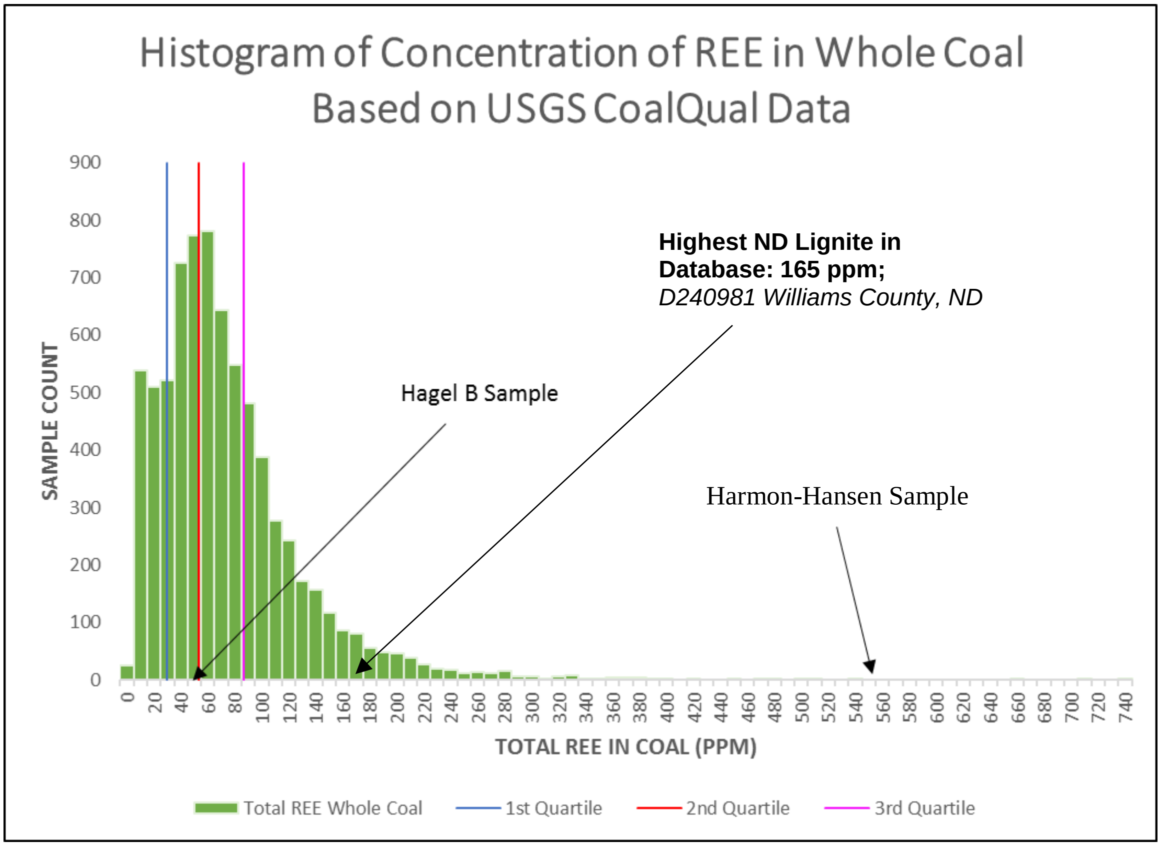


Figure 11. Comparison of ND lignite coal samples to samples available nationally in the USGS CoalQual Database

To identify the modes of occurrence of the REEs in the various samples, the analytical procedures shown in Table 3 were utilized. Inductively coupled plasma mass spectrometry (ICP-MS) is the standard method by which REE abundance is determined and was the workhorse analytical method used in Phase I. However, a large amount of work was also done using scanning electron microscopy (SEM) to elucidate the REE modes of occurrence in the lignite and related samples. For example, Figure 12 displays some of the computer controlled SEM (CCSEM) results for roof and floor sediments from the mine that were aimed at identifying mineral and elemental associations and size of REE-rich mineral grains. For the sediments, the REEs appear to be mainly associated with carbonates, phosphates and clays and are present in very fine mineral grains, almost exclusively less than 4 microns. SEM with x-ray microanalysis was also conducted on several raw coal samples. For raw coal, the REE-bearing minerals were very difficult to detect. In most samples, no REEs were found, with La and Ce found in a couple of samples. An example is shown in Figure

13 with the accompanying table. Here, the REEs appear to be associated with zirconium, phosphorous and iron.

Table 3. Analytical methods used to determine REE content and characterize samples

Category	Equipment	Function
Bulk chemical composition	ASTM standard analysis	Proximate analysis; Ultimate analysis; Ash composition
	X-ray Fluorescence	Bulk chemistry; major, minor and trace element
	Inductive Coupled Plasma-Mass Spectrometry	Abundance of trace elements including REE
Forms of REE	Scanning Electron Microscopy	Morphological analysis – imaging and chemical composition of minerals
		CCSEM – chemical composition, size and associations (included or excluded relative to coal particles)
	Chemical Fractionation	Quantitatively determine the modes of occurrence of the inorganic elements

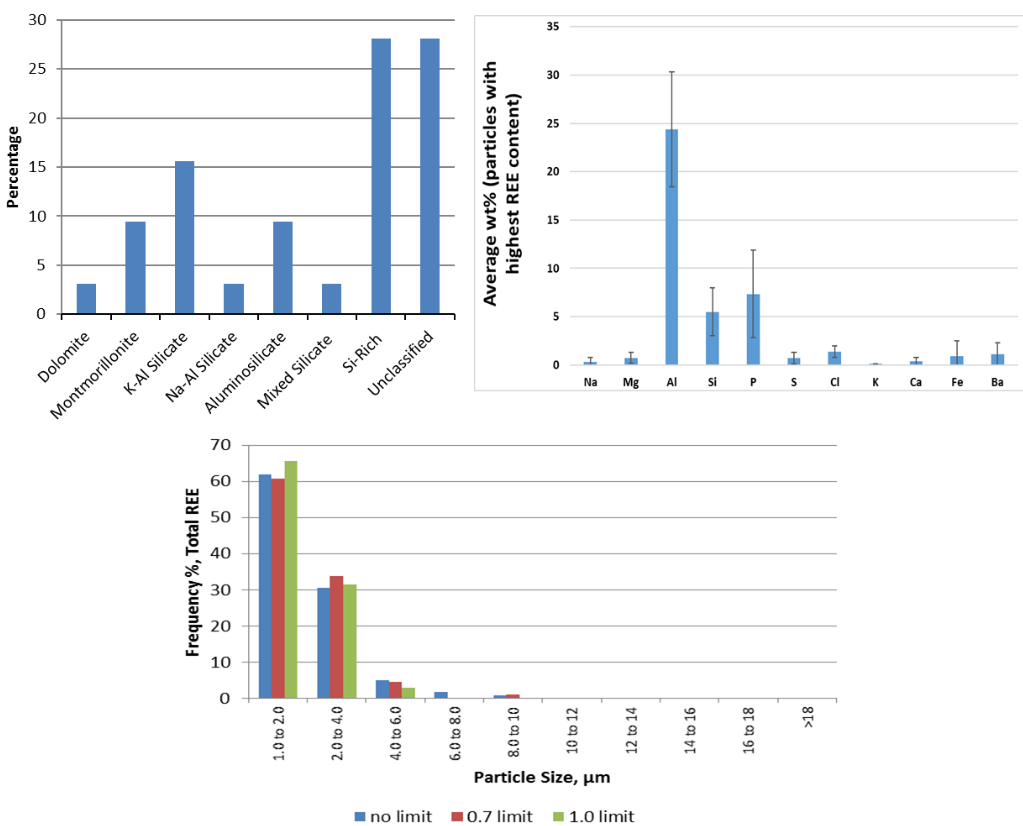
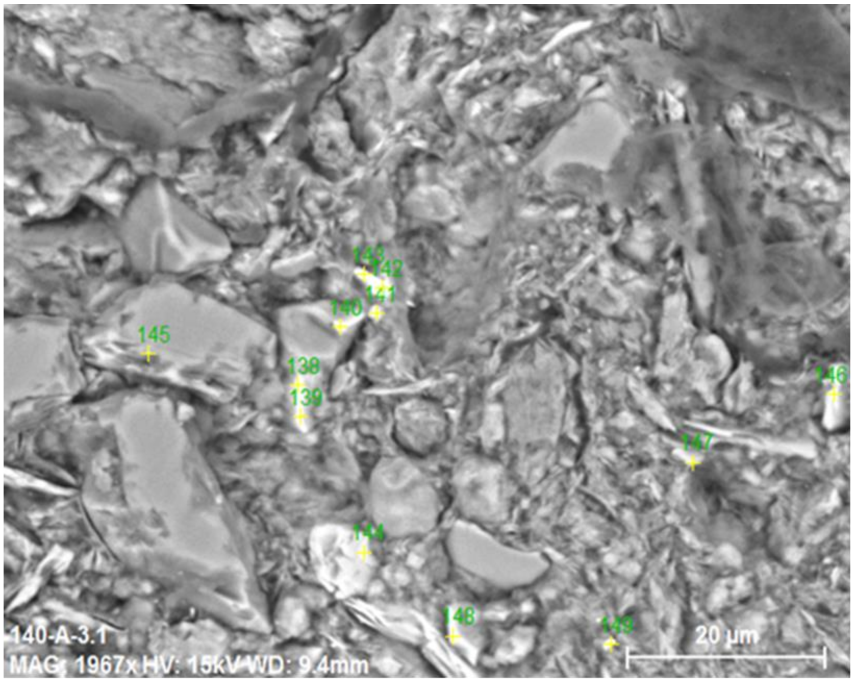


Figure 12. CCSEM results for roof/floor sediments from the mine. Top left - mineral associations of REE-bearing grains. Top Right - elemental associations of REE-bearing grains. Bottom - size of REE-bearing mineral grains



Norm. mass percent (%)

Spectrum	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Y	Zr	Nb	La	Ce
138	56.29	1.69	8.05	2.40	16.81	0.00	0.00	0.98	4.85	1.15	2.90	3.60	0.00	0.00	0.00	0.00	1.27
139	53.62	2.16	9.79	2.61	16.38	0.00	0.00	1.15	4.95	1.21	3.39	3.04	0.00	0.00	0.00	0.00	1.70
140	56.64	30.68	0.39	0.58	4.02	0.00	0.00	0.80	0.55	2.65	0.07	3.48	0.00	0.00	0.00	0.00	0.13
141	64.92	4.93	3.87	2.56	4.59	0.00	0.00	0.10	0.62	1.22	0.63	15.87	0.00	0.00	0.00	0.00	0.70
142	15.14	0.10	0.04	3.26	5.03	13.43	0.01	0.03	0.05	0.18	0.00	0.88	0.00	5.54	0.00	17.88	38.42
143	28.45	0.14	0.02	2.43	6.09	11.22	0.00	0.03	0.14	0.06	0.00	0.63	0.00	4.72	0.00	14.48	31.60
144	36.64	1.33	3.56	3.38	6.24	0.00	0.00	0.06	0.19	0.62	0.00	37.01	0.00	0.00	0.00	4.68	6.29
145	31.75	6.26	2.40	3.17	26.67	0.00	0.00	21.58	2.04	2.73	0.68	[illegible]	0.00	0.00	0.00	0.00	0.58
146	18.57	7.62	4.18	4.92	9.00	0.00	0.00	0.00	1.27	0.88	0.00	40.20	0.00	0.00	0.00	5.77	7.59
147	50.26	0.88	3.15	2.17	27.79	0.00	0.00	1.18	2.25	1.96	0.31	9.46	0.00	0.00	0.00	0.06	0.54
148	60.29	1.29	2.39	1.12	2.20	0.00	0.00	21.41	2.01	0.78	0.24	7.21	0.00	0.00	0.00	0.34	0.71
149	50.78	0.00	4.75	2.79	6.37	0.00	0.00	2.91	3.05	3.70	0.50	23.92	0.00	0.00	0.00	0.39	0.83
Mean value:	43.61	4.76	3.55	2.62	10.93	2.05	0.00	4.19	1.83	1.43	0.73	12.29	0.00	0.85	0.00	3.63	7.53
Sigma:	16.83	8.55	3.00	1.10	8.87	4.82	0.00	8.13	1.72	1.11	1.16	14.08	0.00	2.00	0.00	6.23	13.14
Sigma mean:	4.86	2.47	0.86	0.32	2.56	1.39	0.00	2.35	0.50	0.32	0.34	4.06	0.00	0.58	0.00	1.80	3.79

Figure 13. SEM results for raw coal sample showing REE-bearing minerals associated with P, Zr and Fe

As noted previously, low-rank coals may have a significant portion of the REE content associated with the organic matrix. This would make detection via SEM methods difficult. To further understand the modes of REE occurrence in the raw lignite coal, a series of Chemical Fractionation [15] tests was performed. Based on these results, combined with our literature review (some of which was discussed previously), we believe that REEs in North Dakota lignite are primarily associated with the organic matrix as ion exchangeable cations, coordination complexes or adsorbed. There is also likely some association with phosphate/ carbonate minerals and potentially some ionic bonding with the clay minerals.

In summary, sampling was conducted on a range of ND lignite and lignite-related materials. The results indicated highest concentration of REEs exist in certain locations within certain coal seams. There is a lower content in the associated roof/floor sediments. The blending practices at large utility-scale, such as with Coal Creek Station results in a diluted REE content at the plant. We believe selective mining will be needed to target the REE-rich zones to separate and stockpile the coal with highest REE content. Chemical Fractionation tests and detailed literature review have identified that the majority of the REEs in ND lignite are likely organically associated.

5.3.2 Laboratory-scale REE Concentration Testing

A novel technology that combined extreme simplicity and high performance has been developed to recover REEs from ND lignite-related feedstocks. These specifics are currently considered confidential, as patent applications are currently being filed. Complete details can be found in the separately attached Confidential Version of this application. However, in the below sections, we highlight some of the key results. Figure 14 displays the recovery efficiency of REEs from the feedstocks selected for additional evaluation in Phase I. The results show that for one of the feedstocks, the recovery is very high across the board, at about 90%, with a slightly lower recovery for scandium. The other feedstock had lower efficiency, but importantly showed good selectivity to the more valuable HREE and critical REE. Our testing also showed that several other high value elements, such as gallium and germanium are recovered into the concentrate (Table 4), and have a large positive impact on overall economics.

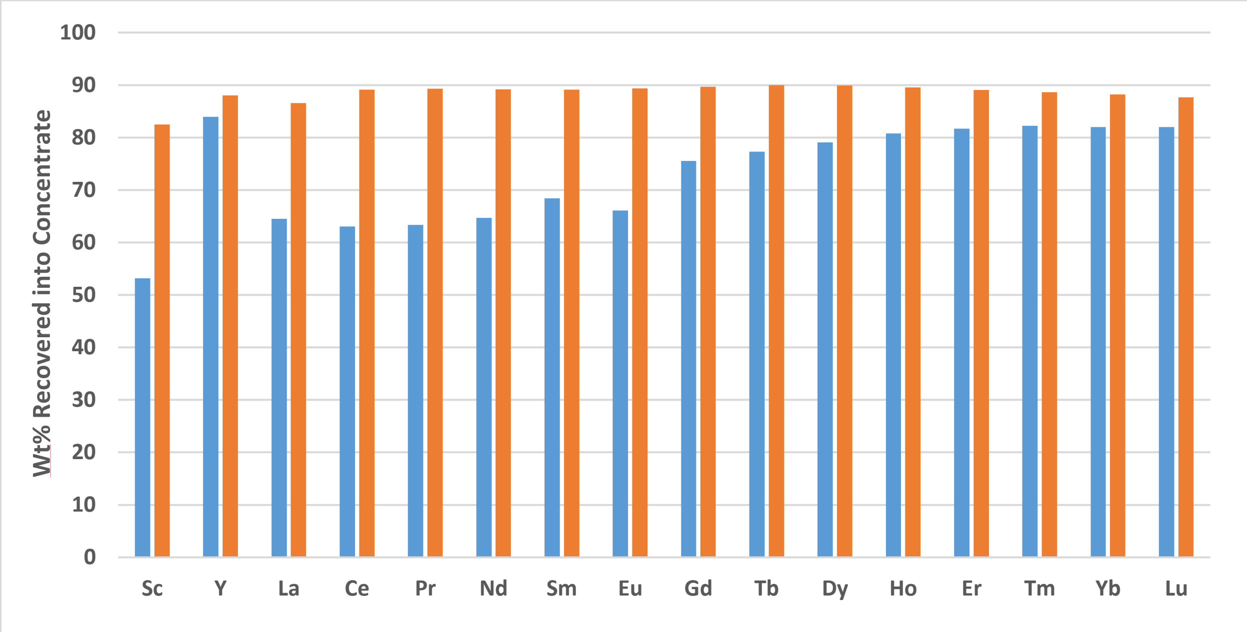


Figure 14. REE recovery results for two selected feedstocks

Table 4. Additional high value elements recovered with REEs into the concentrate

Element	% Recovered with REEs
Co	97.9
Cu	34.9
Ga	76.5
Ge	71.1
V	82.4
Li	17.9
Ni	92.9
Zn	84.7
Mn	60.3
Pb	34.1
Ti	18.0
P	58.4

5.3.3 Technical and Economic Feasibility Analysis (TEA)

Based on the results of the Phase I project, Barr Engineering was contracted to perform a Technical and Economic Feasibility Analysis of the UND REE concentration process. Due to the confidential nature of the flowsheets and overall process design, complete details are located in the Confidential Version of the application separately attached. However, due to the process simplicity, high recovery rates, as well as value-added opportunities to generate revenue from byproducts, the overall economic metrics are highly attractive, even at the relatively small scale evaluating in this study. The economics of the concentrating facility are provided below for a facility with a production of about 10 tons/year of REEs (pure oxide basis):

- Capital Costs: $28.3 Million
- Annual Operating Costs: $4.7 Million
- Net Annual Revenue: $9.8 Million
- Simple Payback: 2.9 Years
- 20 Year Internal Rate of Return: 35%
- 20 Year Net Present Value (@15% Hurdle Rate): $32.6 Million

6. QUALIFICATIONS

The project team and key personnel are exceptionally well qualified to perform this project. The project is led by ***Dr. Steve Benson,*** IES Professor and Associate Vice President for Research at the EERC, who will be the Project Manager. Dr. Benson is a world class expert on the forms and occurrence of major, minor, and 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 also worked extensively with coal beneficiation, combustion, gasification, and air pollution control technologies. Dr. Benson is also the Project Manager for UND's current Phase I project on REE recovery from ND lignite feedstocks.

Mr. Daniel Laudal, Manager: Major Projects at UND IES, is currently the lead researcher on UND's Phase I project, and will continue that role in Phase II. Mr. Laudal is currently also completing his Ph.D. in Chemical Engineering at UND, with graduation in May 2017. His dissertation topic is extraction of REEs from coal and coal byproducts which is based on the work conducted in Phase I of this project. Mr. Laudal also has extensive experience in fuels analysis/characterization, coal conversion systems, chemical process design, feasibility studies and mineral processing.

PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

Dr. Michael Mann is the Executive Director of IES and is responsible for coordination of all projects within IES. Dr. Mann has more than three decades of experience in the energy field, and has been involved in a wide range of technology development, including extensive experience in the North Dakota lignite and power generation industries. Dr. Mann will work with the project team to ensure that all personnel, equipment and other resources are available to efficiently conduct the project.

The UND expertise will be augmented Barr Engineering Company. ***Dr. Daniel Palo*** from Barr has nearly two decades of process development and deployment experience, including laboratory, pilot, and plant level systems. His work in the mineral processing industry focuses on extractive metallurgy and process development for various minerals, and he was part of a separate DOE project focused on the extraction of REE from geothermal waters. Dr. Palo will be assisted by ***Mr. Boyd Eisenbraun***, a Metallurgical Engineer with over 25 years of experience in plant operations for various minerals, including copper, uranium, and iron. Dr. Palo and Barr Engineering will lead the work associated with the technical and economic feasibility study.

The project is enhanced by ***R. Shane Addleman*** from Pacific Northwest National Laboratory (PNNL), a surface scientist whose work is focused on methods to capture and recover trace constitutes in a variety of materials. His comprehensive knowledge of the chemistry of REEs and trace elements found in coal will be key in effectively optimizing/tuning separation methods. PNNL will provide its expertise in an advisory role in the project.

UND and Barr Engineering have a history of collaborating on large research projects, having recently successfully completed a 3-year $3.6 Million effort to evaluate UND’s carbon dioxide capture technology, CACHYS™ (DE-FE0007603). Dr. Benson and Dr. Michael Mann, Executive Director of IES, have a long history of managing large research projects and large interdisciplinary and multi-organizational projects. The resumes of key personnel are attached as an Appendix to this application.

PHASE II - INVESTIGATION OF RARE EARTH ELEMENT EXTRACTION FROM NORTH DAKOTA COAL-RELATED FEEDSTOCKS

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. 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 concentration of REEs from lignite-related materials, additional processing steps will be required to arrive at final REE products. Having a source of REE concentrate in the State will encourage location of these processors/refiners in North Dakota, further increasing employment and revenue opportunities.

8. MANAGEMENT

The team assembled to perform the proposed work includes UND Institute for Energy Studies (IES), Energy & Environmental Research Center (EERC), Barr Engineering and Pacific Northwest National Laboratory (PNNL), with advisory support from the North Dakota Geological Survey and MLJ Consulting. The team brings together the expertise required to effectively perform the proposed work to investigate the feasibility of concentrating rare earth elements from coal-related feedstocks in North Dakota. The project is led by Dr. Steve Benson, who will be the Project Manager. Dr. Benson will be the contact person for the University of North Dakota and will be responsible for managing resources and project schedule and will coordinate meetings and conference calls with the NETL and other project co-sponsors as well as communications with project participants. Mr. Dan Laudal will be the lead researcher on the project and will lead the day-to-day research tasks and coordination of IES research staff. Dr. Michael Mann, Executive Director of the Institute for Energy Studies, is responsible for coordination of all projects within the IES. Dr. Mann will work with the project team to ensure all personnel, equipment, and other resources are available to efficiently conduct the project. Dr. Dan Palo from Barr Engineering will lead the work associated with the technical and economic feasibility study. PNNL will provide its expertise in an advisory role in the selection and identification of promising REE concentrating/extraction methods. The project team assembled for Phase II is the same team currently completing the Phase I effort, and it has been a very successful collaboration. The key personnel for this effort all have a long history of leading large interdisciplinary and multi-organizational research projects.

Project activities are divided by task, with the tasks to be implemented and completed under the direction of each task leader. Figure 15 shows the management structure for the project, which is designed on a task-by-task basis with the task leaders and key personnel for each task identified. Cost management will be coordinated by the Administrative Resource Manager who will be responsible for tracking all costs for each of the project tasks.

Project meetings and conference calls will be held, at least, on a weekly 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 also be held on a monthly or quarterly basis to ensure communication and discussion of accomplishments, plans and management of project risks.

Intellectual property management and discussions have been initiated. Patents for the extraction process have already been filed. 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 regular basis as the project progresses.

9. TIMETABLE

DOE has set an aggressive timeline of 18 months for completion of the Phase II program, with an estimated start date of September 1, 2017. The project Gantt chart is displayed in Figure 16. Major milestones and planned completion dates are provided below.

1. Procurement of at least two 1000-2000 kg large samples of REE-rich feedstock (Month 5)

2. Complete bench-scale construction and shakedown testing (Month 5)

3. Optimize process and identify complete flowsheet to produce 2 wt% REE concentrate (Month 12)

4. Identify modeling scope for TEA (Month 12)

5. Identify commercialization strategy at existing facility or justification for new mine (Month 17)

6. Completion of all work proposed (Month 18)

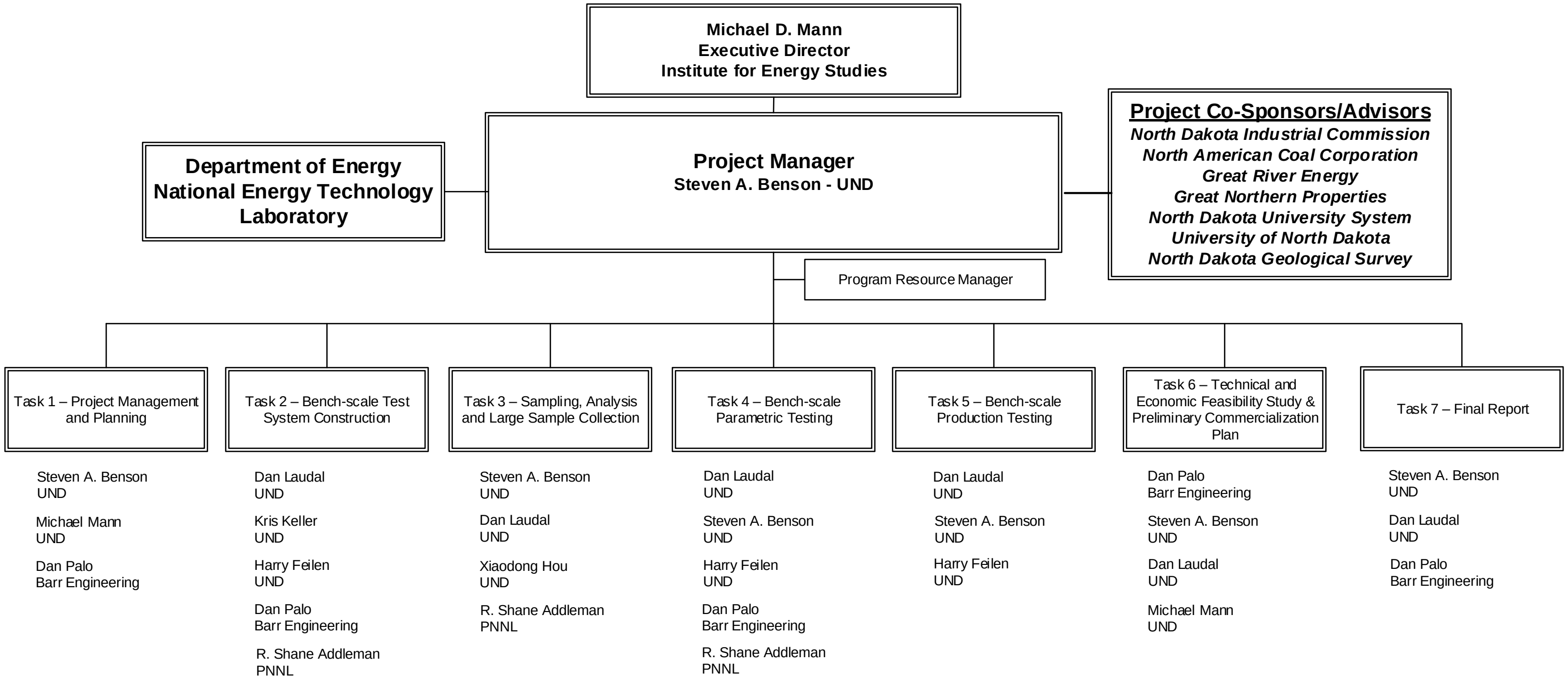


Figure 15. Project management structure by task

ID	Task Name	Start	Finish
1	Task 1 – Project Management & Planning	9/1/2017	2/28/2019
2	Task 2 – Bench-scale Test System Construction	9/1/2017	1/31/2018
3	Task 3 – Sampling, Analysis and Large Sample Collection	9/1/2017	1/31/2018
4	Task 4 – Bench-scale Parametric Testing	2/1/2018	8/31/2018
5	Task 5 – Bench-scale Production Testing	9/3/2018	10/31/2018
6	Task 6 – Technical and Economic Feasibility Study & Preliminary Commercialization Plan	9/3/2018	1/31/2019
7	Task 7 – Final Report	12/3/2018	2/28/2019

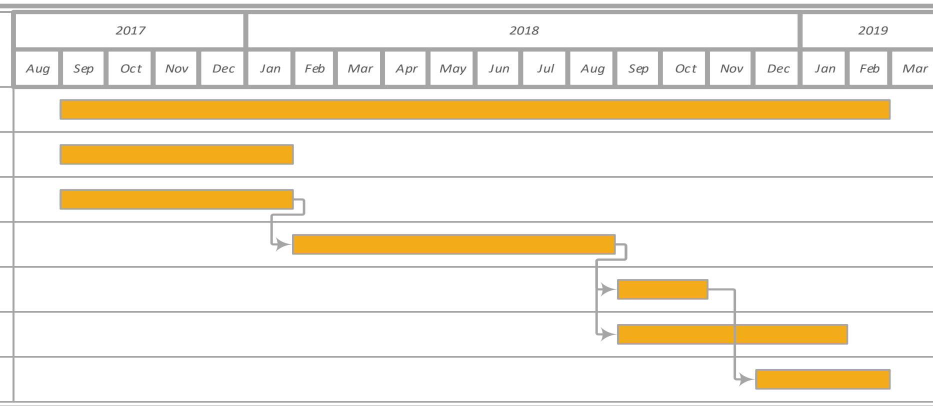


Figure 16. Project timeline

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. Currently garnered matching funds for the NDIC portion include North American Coal Corporation (NACC), Great River Energy (GRE) and Great Northern Properties (GNP). NACC and GRE will each provide $70,000 in cash and $20,000 in-kind support. GNP will provide $60,000 in cash. We recognize that the $280,000 requested from NDIC is not fully matched by the industry sponsors at this time. However, we are currently in discussion with multiple other interested parties, and expect to be able to acquire additional industry support prior to submission of the DOE application on May 31, 2017. Additional cost share support will be provided by UND and the NDUS, as shown in the table.

Table 5. Matching funds and funding breakdown by support source

Support Source	Cash	In-Kind	TOTAL	% of Project
DOE	2,750,000		2,750,000	80.0
NDIC	280,000		280,000	8.1
NACC	70,000	20,000	90,000	2.6
GRE	70,000	20,000	90,000	2.6
GNP	60,000		60,000	1.7
UND			67,500	2.0
NDUS			100,000	2.9
TOTAL			**3,437,500**	**100**

12. TAX LIABILITY

No outstanding tax liabilities to the state of North Dakota

13. CONFIDENTIAL INFORMATION

This is the public version of the application and contains no confidential information. A separately attached document contains the entire application in a confidential form that is to be used only for review purposes. The separate document is clearly marked confidential.

14. APPENDICES

A. References

B. Budget summary and budget justification

C. Letters of support and cost share contributions

D. Additional facilities and equipment documentation

E. Resumes of key personnel

APPENDIX A: REFERENCES

[1] U.S. Department of Energy National Energy Technology Laboratory, "Rare Earth Elements From Coal and Coal By-Products," 2017. [Online]. Available: https://www.netl.doe.gov/research/coal/rare-earth-elements.

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[13] J. C. Hower, E. J. Granite, D. B. Mayfield, A. S. Lewis and R. B. Finkelman, "Notes on Contributions to the Science of Rare Earth Element Enrichment in Coal and Coal Combustion Byproducts," *Minerals,* vol. 6, no. 32, 2012.

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APPENDIX B: BUDGET SUMMARY AND BUDGET JUSTIFICATION

BUDGET SUMMARY

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. With the exception of the equipment purchase, which will all be under the DOE share, we have assumed an even distribution of the cost share funds across all budget line items. The overall cost share is 20% to match the 80% DOE share. The NDIC share is about 8.1% of the total budget.

Budget Category	Total Project	DOE Share	NDIC Share	NACC Share	GNP Share	GRE Share	UND Share	NDUS Share
Personnel	1,034,769	860,873	96,418	24,104	20,661	24,104	8,609	0
Fringe Benefits	345,409	287,362	32,185	8,046	6,897	8,046	2,874	0
TOTAL PERSONNEL	1,380,179	1,148,235	128,602	32,151	27,558	32,151	11,482	0
Travel	32,200	26,789	3,000	750	643	750	268	0
Supplies	30,000	24,958	2,795	699	599	699	250	0
Fees - Equipment Use & Lab Services	315,535	262,508	29,401	7,350	6,300	7,350	2,625	0
Fees - Subcontracts								
a.) Barr Engineering	300,000	249,584	27,953	6,988	5,990	6,988	2,496	0
b.) PNNL	100,000	83,195	9,318	2,329	1,997	2,329	832	0
c.) MLJ Consulting	25,000	20,799	2,329	582	499	582	208	0
d) In-kind Support	182,500	0	0	20,000	0	20,000	42,500	100,000
TOTAL OPERATING	985,235	667,833	74,797	38,699	16,028	38,699	49,178	100,000
Equipment > $5,000	250,000	250,000	0	0	0	0	0	0
TOTAL DIRECT COST	2,615,414	2,066,068	203,400	70,850	43,586	70,850	60,661	100,000
INDIRECT COST	822,086	683,932	76,600	19,150	16,414	19,150	6,839	0
TOTAL COST	3,437,500	2,750,000	280,000	90,000	60,000	90,000	67,500	100,000
% of Total Project Cost	100	80.0	8.1	2.6	1.7	2.6	2.0	2.9

BUDGET JUSTIFICATION

The following sections detail the justification for each of the budget line items.

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 employee’s time on the basis of 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	Role	Rate	Hours	Total Project
Steve Benson	Project Manager	85.81	1500	128,715
Dan Laudal	Lead Researcher	40.87	2000	81,740
Michael Mann	Senior Management	92.23	450	41,504
Harry Feilen	Operations Manager	40.87	2000	81,740
Xiaodong Hou	Laboratory Manager	28.52	1000	28,520
Research Engineer	Research Support	36.06	8218	296,351
Research Technician	Research Support	22	9000	198,000
Resource Manager	Administrative	22	100	2,200
Graduate Student	Research Support	20	5500	110,000
Undergraduate Student	Research Support	12	5500	66,000
TOTAL				**1,034,769**

Fringe Benefits

Fringe benefits are estimated fro proposal purposed only. On award implementation, only the true cost of each individual’s fringe benefit plan will be charged to the project. Fringe benefits are figured as follows:

- Project Manager – 63%
- Graduate and Undergraduate Students – 5%
- All other personnel – 35%

Travel

Several trips are planned during the project. These include travel to three conferences, one kickoff and one review meeting with DOE in Pittsburgh, six sponsor review meetings and four sampling trips. Costs have been estimated based on available airfare and lodging rates, conference fees, standard per diems and other UND travel policy. 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	Destination	No. Days	No. Travelers	Cost per Traveller	# of trips	Cost per Trip
Conferences	ex. Clearwater, Fl	5	1	5000	3	15000
Kickoff Mtg	Pittsburg, PA	2	2	1700	1	3400
Review Mtg	Pittsburg, PA	2	2	1700	1	3400
Sponsors Mtg.	Bismarck, ND	1	1	600	6	3600
Sampling	Underwood, ND	1	1	1700	4	6800

Equipment and Supplies

These categories have only been estimated currently. The design of the equipment to be purchased is currently being completed as part of the ongoing DOE Phase I program. As such, we do not yet have the information necessary to specify equipment and obtain vendor quotations. Similarly, the bulk of the supplies will be associated with testing and fabrication of the test system. Therefore, the supplies budget is not yet finalized. If awarded by NDIC, these budget items will be finalized prior to contract agreements.

Fees – Equipment Use and Laboratory Services

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 a various laboratory service providers.

Analysis Method	$/Sample	No. Samples	Total Cost
ICP-MS	680	400	272,000
Sample Preparation	75	80	6,000
SEM	103	25	2,575
Proximate/Ultimate	103	30	3,090
XRF	103	100	10,300
Chemical Fractionation	249	30	7,470
Float Sink	470	30	14,100

Fees – Subcontracts

Three subcontracts are included in this budget. However, these are currently only estimates. Upon submission of the DOE Phase II application on May 31, 2017, these numbers will be finalized and will be supplied to NDIC. The scope of work for each of the subcontracts needs to be finalized before settling on a budget.

Estimates are as follows:

- Barr Engineering: $300,000
- Pacific Northwest National Laboratories: $100,000
- MLJ Consulting: $25,000

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, and in-kind cost share contributions.

APPENDIX C: LETTERS OF SUPPORT FROM COST SHARE PARTNERS AND PROJECT PARTICIPANTS

CARROLL L. DEWING
Vice President – Operations

Direct Dial: (972) 448-5486
E-mail: carroll.dewing@nacoal.com

March 31, 2017

Dr. Steven A. Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

The North American Coal Corporation is pleased to support the proposal from the University of North Dakota team, that includes Barr Engineering and Pacific Norwest National Laboratory, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

We are highly encouraged by the results of UND's Phase I project 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 10 kg/hr and will investigate coals from North American Coal Corporation mines and other resource holdings in the State.

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. The North American Coal Corporation is pleased to support this project by providing $70,000 in cash cost share, as well as an estimated $20,000 in in-kind cost share. The in-kind contribution will include cost of drilling, sampling and coal preparation for supply to the UND team for analysis and testing in its project. The cost share will be provided over the 18-month Phase II project duration. Both the cash cost share and the in-kind cost share are 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.

Regards,

THE NORTH AMERICAN COAL CORPORATION

Carroll L Dewing

Carroll L. Dewing
Vice President – Operations

1611 East Century Avenue
Bismarck, North Dakota 58503
701-250-2176
greatriverenergy.com

April 1, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from

North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

The Great River Energy is pleased to support the proposal from the University of North Dakota team, that includes Barr Engineering and Pacific Norwest National Laboratory, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

We are highly encouraged by the results of UND's Phase I project 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 10 kg/hr and will investigate coals from the GRE DryFining™ process.

1611 East Century Avenue
Bismarck, North Dakota 58503
701-250-2176
greatriverenergy.com

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. GRE is pleased to support this project by providing $70,000 in cash cost share, as well as an estimated $20,000 in in-kind cost share. The in-kind contribution will include sampling from the Coal Creek Station, sample analysis, participation in project meetings, project advising and travel. The cost share will be provided over the 18-month Phase II 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,

John Bauer

John Bauer
Director, North Dakota Generation
Great River Energy

Great Northern Properties Limited Partnership

1415 Louisiana Street, Suite 2400 • Houston, TX 77002
(713) 751-7500 • Fax (713) 751-7591

Charles H. Kerr
President & CEO

ckerr@gnplp.com
Direct: (713) 751-7590

March 28, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

The Great Northern Properties Limited Partnership ("GNP") is pleased to support the proposal from the University of North Dakota team, that includes Barr Engineering and Pacific Norwest National Laboratory, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

We are highly encouraged by the results of UND's Phase I project 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 10 kg/hr and will investigate coals from GNP's resource holdings in the State.

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. GNP is pleased to support this project by providing $60,000 in cash cost share. The cost share will be provided over the 18-month Phase II 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,

Charles H. Kerr

NORTH DAKOTA UNIVERSITY SYSTEM
ACCESS. INNOVATION. EXCELLENCE.

NORTH DAKOTA UNIVERSITY SYSTEM
Facility Planning Department
4349 James Ray Drive
P.O. Box 13597
Grand Forks, ND 58202-3597
701-777-4270

April 1, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

The North Dakota University System (NDUS) is pleased to support the proposal from the University of North Dakota team, that includes Barr Engineering and Pacific Norwest National Laboratory, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

We are highly encouraged by the results of UND's Phase I project 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 are also very excited about the opportunity to integrate rare earth element recovery within the next generation of NDUS campus heating plants, as the Phase I project showed that the economics of such a concept appear very appealing. 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 10 kg/hr.

To support the above project, the NDUS will commit up to $100,000 over the 18-month project in the form of in-kind support. The NDUS has been working closely with the UND team recently in the development of designs for the next generation of NDUS steam heating plants for the state university campuses which are all aging and in need of replacement in the near future. The in-kind support for this project will be in the form of costs associated with NDUS personnel participation in the project in an advisory role as well as in evaluation of potential opportunities for installation of the technology at the NDUS campuses. We will work closely with the UND team in Task 6 of the project to evaluate commercial or demonstration-scale options for one or more of the NDUS campuses.

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 (701) 777-4270

Sincerely,

R Tonder

Rick Tonder
Director of Facility Planning

UNIVERSITY OF UND NORTH DAKOTA

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

April 1, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

This letter confirms the University of North Dakota College of Engineering and Mines' commitment to support your proposed efforts in response to DE-FOA-0001202. I have been impressed by the work you have completed during Phase I of this project, and the recognition your work has brought to our college. I am also pleased by the amount of industry support you have been able to raise to help support the proposed Phase II work.

To show our support of this project, the college is willing to provide up to $67,500 in cost share to the project. The actual contribution may vary as needed to ensure your project can meet the required 20% cost share.

If you have questions, please contact me at 701-777-3412 or rewini@engr.und.edu.

Sincerely

Hesham El Rewini, Ph.D., P.E.
Dean, College of Engineering and Mines

resourceful. naturally.
engineering and environmental consultants
BARR

1 April 2017

Dr. Steven Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

Barr Engineering Co. is pleased to collaborate with the University of North Dakota (UND) and its team of technical and cost share partners in pursuit and execution of Phase II the subject project for the U.S. Department of Energy (DOE). Barr is a 750-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, and mineral processing and extractive metallurgy. Barr's background and strengths in these areas complement the capabilities of other team members by providing mineral process engineering expertise to be focused on developing processing options, evaluating these options both technically and economically based on sample characterization results, and scaling up the technology for commercial application.

With our roots in the upper Midwest of the United States, we are familiar with the lignite resources of North Dakota, and many of these lignite processors and end users are long-standing clients of ours. Because of this, as well as our presence in North Dakota and Minnesota, we are excited to continue our partnership with you and your team, building off of the successes of the Phase 1 effort and moving this technology towards commercial application in North Dakota for the betterment of the state, the region, and the country.

We appreciate the opportunity to co-propose on Phase II of this project and look forward to working with you. Please feel free to contact Dr. Daniel Palo (218-262-8661, dpalo@barr.com) with any questions or concerns.

Best regards,

Philip B. Solseng

DRPZ

Philip B. Solseng
Vice President

Pacific Northwest
NATIONAL LABORATORY

902 Battelle Boulevard
P.O. Box 999,
Richland, WA 99352
www.pnnl.gov

April 1, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

Pacific Northwest National Laboratory (PNNL) is pleased to support the proposal from the University of North Dakota team that also includes Barr Engineering, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

PNNL will contribute is expertise in the areas of rare earth element chemistry and hydrometallurgy and will work with the UND team to effectively develop extraction methods that are both efficient and environmentally benign. We have been very encouraged by the results of the Phase I project, on which PNNL has collaborated with the UND team, and we are looking forward to continuing this exciting and highly promising work.

If you have questions or require additional information, please do not hesitate to contact Dr. Addleman by phone or email.

Sincerely,

R. Shane Addleman, PhD
Sr. Research Scientist, Program Manager
Pacific Northwest National Laboratory
(509) 375-6824 raymond.addleman@pnnl.gov

April 1, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

MLJ Consulting is pleased to support the proposal from the University of North Dakota team that also includes Barr Engineering and Pacific Northwest National Laboratory, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite. We are encouraged by the promising results of UND's Phase I project that both identified locations in the State with very high rare earth elements content and also demonstrated a simple, highly effective and low-cost extraction method that takes advantage of unique properties of lignite that make REE recovery a simpler proposition than other types of coal feedstocks.

My role in the project will be to assist with development and refinement of strategic partnerships as this activity moves through the development phase, and we focus on demonstrating the commercial viability of the proposed activity.

If you have questions or require additional information, please do not hesitate to contact Michael Jones at 701-739-1419 or jones_ml2003@yahoo.com.

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Sincerely,

Michael Jones

Michael Jones
President, MLJ Consulting.
701-738-1419
Jones_ml2003@yahoo.com

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/

April 3, 2017

Dr. Steve Benson
Professor, Institute for Energy Studies
Associate Vice President for Research, EERC
University of North Dakota
15 N. 23rd St, Stop 9018
Grand Forks, ND 58202

Re: Support of the proposal entitled "Phase II – Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks" submitted in response to DE-FOA-0001202 "Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements from Domestic Coal and Coal Byproducts."

Dear Dr. Benson:

The North Dakota Geological Survey (NDGS) is pleased to support the proposal from the University of North Dakota team, that includes Barr Engineering and Pacific Norwest National Laboratory, to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite.

NDGS was an advisor on the UND team's Phase I DOE effort providing samples for analysis as well as geological insights regarding rare earth enrichment occurrences in North Dakota lignites. We are encouraged by the results of UND's Phase I project that 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 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 10 kg/hr.

The NDGS is also currently involved in an 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, as well as to assist in understanding the geology of North Dakota lignites that will be invaluable in development of extraction methods.

Developing low cost, highly efficient, and environmentally benign technologies to separate and concentrate rare earth elements 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. Please contact me if you have any questions regarding our support of this proposal.

Sincerely,

Edward C. Murphy
State Geologist

APPENDIX D: ADDITIONAL FACILITIES DOCUMENTATION

Table D1.Rare Earth Element Detection Limits in µg/g (dry basis) with UND ICP-MS.

Element	Symbol	ICP–MS
Cerium	Ce	0.05
Dysprosium	Dy	0.01
Erbium	Er	0.01
Europium	Eu	0.005
Gadolinium	Gd	0.05
Holmium	Ho	0.01
Lanthanum	La	0.01
Lutetium	Lu	0.01
Neodymium	Nd	0.05
Praseodymium	Pr	0.01
Samarium	Sm	0.05
Terbium	Tb	0.02
Thulium	Tm	0.01
Yttrium	Y	0.05
Ytterbium	Yb	0.01

Table D2. Rare Earth Data for Standard Reference Materials

		CANSPEX 57	CANSPEX 58						
		bituminous	bituminous	bituminous	low rank bituminous		Montana	San Joaquin	Buffalo River
		coal	coal	coal	coal	Rock	soil	soil	sediment
Element	**symbol**	**2684b**	**2685b**	**2682b**	**SRM 18**	**GBW-07111**	**2711**	**2709**	**2704**
Cerium	Ce	12	18	10	22	112	69	42	72
Dysprosium	Dy					3.2	5.6	3.5	6
Erbium	Er					1.57			
Europium	Eu	0.23	0.36	0.17		1.91	1.1	0.9	1.3
Gadolinium	Gd					5.09			
Holmium	Ho					0.6	1	0.54	
Lanthanum	La	6.7	10	5.2	10	60.5	40	23	29
Lutetium	Lu					0.24	31	19	
Neodymium	Nd					48.1			
Praseodymium	Pr					13.2			
Samarium	Sm	1.1	1.7	0.78	2	7.74	5.9	3.8	6.7
Terbium	Tb				0.3	0.68			
Thulium	Tm					0.26			
Yttrium	Y				12	15.5	25	18	
Ytterbium	Yb					1.56	2.7	1.6	2.8

Table D3. Rare Earth Data for Standard Reference Materials.

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		bituminous	low rank bituminous	sub-bituminous	bituminous	bituminous	bituminous coal
-		**coal**	**coal**	**coal**	**coal**	**coal**	**coal fly ash**
name	**symbol**	**1632c**	**SRM 19**	**1635**	**1632b**	**1632d**	**1633b**
Cerium	Ce	11.9	56	3.6	9	11.7	190
Dysprosium	Dy					0.9	17
Erbium	Er						
Europium	Eu	0.1238	0.7	0.06	0.17	0.217	4.1
Gadolinium	Gd						13
Holmium	Ho					6	3.5
Lanthanum	La				5.1		94
Neodymium	Nd						85
Praseodymium	Pr						
Samarium	Sm	1.078	4.9		0.87	1	20
terbium	Tb		0.7				2.6
Thulium	Tm						
Yttrium	Y	4	20				
Ytterbium	Yb		2				7.6

Table D4. CanmetMINING (Natural Resources Canada) REE-1 Standard Reference Material

Element	Units	Mean	Within-lab Standard Deviation	Between-labs Standard Deviation	95% Confidence Interval of Mean
Al [a]	%	3.59	0.04	0.12	0.06
As [a]	µg/g	124	5	20	12
Ba [a]	µg/g	100.1	4.5	9.4	4.3
Ca [a]	%	2.30	0.03	0.10	0.05
Ce [b]	µg/g	3960	70	150	70
Co [a]	µg/g	1.58	0.15	0.21	0.13
Cr no AD [b]	µg/g	277	9	35	19
Cs [a]	µg/g	1.07	0.05	0.14	0.08
Cu	µg/g	79.7	2.5	7.6	4.4
Dy [a]	µg/g	847	16	41	19
Er	µg/g	701	13	58	26
Eu [a]	µg/g	23.5	0.6	1.7	0.8
Gd [a]	µg/g	433	10	21	10
Hf [a]	µg/g	479	9	26	14
Ho	µg/g	208	4	21	9
K [a]	%	3.09	0.04	0.13	0.06
La [a]	µg/g	1661	28	72	32
Na [a]	%	1.445	0.021	0.077	0.034
Nb [a]	µg/g	4050	90	350	150
Nd [a]	µg/g	1456	25	53	25
Ni	µg/g	24.7	1.7	3.2	2.0
P [a]	%	0.0261	0.0024	0.0053	0.0033
Pb	µg/g	1137	26	99	46
Pr [a]	µg/g	435	8	18	8
Rb [a]	µg/g	1047	24	47	26
Si [a]	%	31.36	0.16	0.38	0.22
Sm [a]	µg/g	381	8	18	8
Sn [a]	µg/g	498	12	52	25
Sr [a]	µg/g	129	3	13	6
Tb [a]	µg/g	106.2	2.0	9.6	4.4
Th [a]	µg/g	719	19	56	26
Tm [a]	µg/g	106.0	2.1	5.8	2.9
U [a]	µg/g	137	3	10	5
Y [b]	µg/g	5480	100	280	130
Yb [a]	µg/g	678	11	50	22
Zr no AD [b]	%	1.91	0.03	0.15	0.07

a either no sets were received using digestion by two acids (hydrochloric and nitric) and/or by three acids (hydrochloric, nitric and hydrofluoric) or the set(s) by either of these methods was/were declared method outlier(s) based on statistical tests

b the data includes sets by digestion using four acids (hydrochloric, nitric, hydrofluoric and perchloric) in a closed vessel, various types of fusions, pressed powder pellet and/or instrumental neutron activation analysis based on statistical tests or the selection of methods by the laboratories

Table D5. Canmet MINING (Natural Resources Canada) REE-2 Standard Reference Material

Analyte	Units	Mean	Within-lab Standard Deviation	Between-labs Standard Deviation	95% Confidence Interval of Mean
Al [a]	%	0.761	0.015	0.049	0.020
Ba [b]	%	5.02	0.08	0.29	0.15
Ca [a]	%	13.68	0.16	0.37	0.16
Ce [a]	µg/g	9610	140	360	160
Co [a]	µg/g	7.71	0.31	0.51	0.27
Dy [a]	µg/g	69.2	1.4	1.6	0.8
Er [a]	µg/g	14.0	0.4	1.6	2.1
Eu [a]	µg/g	96.6	1.7	5.8	2.5
Fe [a]	%	12.14	0.17	0.42	0.17
Ho [a]	µg/g	7.87	0.20	0.56	0.25
La (total) [b]	µg/g	5130	80	110	50
Li [a]	µg/g	9.61	0.54	0.59	0.43
Loss on ignition [c]	%	31.38	0.07	0.19	0.11
Mg (total) [b]	%	6.26	0.06	0.21	0.10
Mn (total) [b]	%	1.316	0.015	0.051	0.024
Nd [a]	µg/g	3660	60	170	70
P [a]	%	0.461	0.006	0.024	0.011
Pr [a]	µg/g	1075	22	52	26
Rb [a]	µg/g	1.22	0.17	0.24	0.13
S(total) [d]	%	1.745	0.041	0.092	0.057
Sc [a]	µg/g	57.5	1.1	3.6	2.0
Si (total) [b]	%	1.377	0.020	0.053	0.030
Sm [a]	µg/g	410	6	16	7
Sn [a]	µg/g	24.1	1.0	3.3	1.5
Sr [a]	µg/g	2300	40	210	80
Ta [a]	µg/g	1.17	0.11	0.25	0.15
Tb [a]	µg/g	20.3	0.4	1.4	0.7
Th [a]	µg/g	737	12	34	14
Ti [b]	%	0.1969	0.0048	0.0096	0.0049
Tm [a]	µg/g	1.383	0.042	0.044	0.022
U [a]	µg/g	3.73	0.13	0.27	0.12
W [a]	µg/g	9.9	0.6	1.3	0.9
Y [a]	µg/g	176	3	13	6

a the data generally includes sets by digestion using four acids (hydrochloric, nitric, hydrofluoric and perchloric); various fusions; and for some elements, fused pellet, fusion or pressed powder pellet followed by x-ray fluorescence; and instrumental neutron activation analysis

b the data generally includes sets by various fusions, and fused pellet or fusion followed by x-ray fluorescence

c the data is based on samples of 0.8 to 2 grams ignited for 0.5 to 4 hours at 650 to 1050°C

d the data generally includes sets by combustion followed by infrared spectroscopy and various fusions

APPENDIX E: RESUMES OF KEY PERSONNEL

STEVEN A. BENSON
Associate VP for Research, EERC
Professor, University of North Dakota

Areas of Expertise

Dr. Benson's principal areas of interest and expertise include development and management of complex multidisciplinary education and research programs that are focused on educating the next generation energy experts and solving environmental and energy problems. These programs include: 1) technologies to improve the performance of fuel resource recovery, refining, conversion and environmental control systems; 2) transformations and control of fuel impurities in combustion and gasification systems; 3) carbon dioxide separation and capture technologies, 4) advanced analytical techniques to measure the chemical and physical transformations of inorganic species in gases; 5) computer-based models to predict the emissions and fate of pollutants from combustion and gasification systems; 6) advanced materials for power systems; 7) impacts of power system emissions on the environment; 8) national and international conferences and training programs; and 8) state and national environmental policy.

Education and Training

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

Research and Professional Experience

2015 – Present	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 student.
2008 – Present	Professor, University of North Dakota (Part time) -- 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.
1991 – Present	President, Microbeam Technologies Incorporated (MTI) -- Dr. Benson is the founder of MTI whose mission is to conduct service analysis and consulting associated with efficient and clean combustion and gasification of fossil and renewable fuels. MTI began operations in 1992 and has conducted over 1500 projects for industry, government, and research organizations. MTI has extensive databases of fuel, fireside deposits, fly ash, and corrosion project that totals approximately 10,000 samples.

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 Relevant Publications and Presentations

1. Laudal, D.,Benson, S.A., Recovery of Rare Earth Elements from North Dakota Lignite Coal and Related Feedstocks, Clearwater Clean Energy Conference, Cleawater Florida, 2017
2. 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.
3. 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\
4. 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 Processing Technology 88 (2007) 1035–1043.
5. 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.
6. Benson, S.A. and Laumb, M.L. Advances in Predicting Ash Behavior in Western Coal Fired Power Plants. In *Proceedings of the Symposium on Western Fuels: 20th International Conference on Lignite, Brown, and Subbituminous Coals Workshops*; Denver, CO, Oct 23, 2006.
7. Benson, S.A.; Zygarlicke, C.J.; Steadman, E.N.; Karner, F.R. Geochemistry and Mineralogy of Fort Union Lignites. In Geology and Utilization of Fort Union Lignites; Finkelman, R.B.; Tewalt, S.J.; Daly, D.J., Eds.; Environmental and Coal Associates: Reston, VA, 1992; pp 111–120.
8. Benson, S.A.; Falcone, S.K.; Karner, F.R. Elemental Distribution and Association with Inorganic and Organic Components in Two North Dakota Lignites. Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem. 1984, 29 (4), 36–47.
9. Benson, S.A.; Zygarlicke, C.J.; Karner, F.R. Distribution of Detrital, Authigenic, and Absorbed Inorganic Constituents in Lignite from the Beulah Mine, North Dakota. In Proceedings of the Rocky Mountain Coal Symposium; Haughton, R.L.; Clausen, E.N., Eds.; N.D. Geological Society, Report No. NB84-1; 1984; pp 22–27.

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

Daniel A. Laudal

Principal Areas of Expertise

Mr. Laudal's principal areas of expertise include fuels characterization, rare earth element recovery processes, advanced power generation systems and emissions control. He has specifically focused on process and equipment design and has worked with numerous types of lab, bench and pilot-scale systems. Mr. Laudal has more than nine years of experience working in large multidisciplinary and multi-organizational research projects.

Education and Training

University of North Dakota	Chemical Engineering	B.S. 2006
Pursuing Ph.D in Chemical Engineering	(Graduation expected May 2017)	

Research and Professional Experience

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

Primary roles include developing and writing major funding proposals, managing major research projects, coordinating IES research staff and students, and process design/development of innovative solutions to challenges in the energy industry. Primary research areas include recovery of rare earth elements from coal and coal byproducts, chemical looping combustion, post-combustion CO_2 capture, novel gas/solid contacting reactor designs, and development of novel designs for the aging fleet of North Dakota University System steam generation plants.

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

Research areas included CO_2 capture, advanced fuel conversion systems and natural gas processing. Work included concept development, process design and testing of innovative solid-sorbent based technologies. Principal Investigator on multiple projects and key contributor on several successful research proposals

Lead research engineer on multiple projects relating to Chemical Looping Combustion (CLC) Technology. Developed concepts for innovative methods to characterize both the physical attrition and reactivity of oxygen carriers for CLC. Co-developer of a unique technology for segregation of oxygen carriers and fuel combustion products (ash, unburned char) in CLC, a significant challenge in advancing the technology. Developing new oxygen carrier compositions and optimizing process conditions to maximize fuel conversion and increase carrier durability.

Lead research engineer developing UND's CACHYS™ technology for post-combustion CO_2 capture. Led the design, construction and testing of the small pilot-scale slipstream test system installed at the UND steam plant. Doctoral research is focusing on the next-generation CACHYS™ technology, with multiple innovative concepts to improve performance and lower costs.

Co-inventor and lead developer of a novel sorbent-based technology for capture and processing of associated natural gas for reduction of gas flaring from oil fields.

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. Lead researcher on a project aimed at developing a process for the production of hydrogen by catalytic hydrolysis of biomass. 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. Lead a team of 3-5 operators in performing various types of cement and work-over operations. Lead cement lab operator – designed, tested and validated cement compositions for each job.

Publications/Reports

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.

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

Benson, S., Srinivasachar, S., **Laudal, D**. "CO_2 Capture Using Hybrid Sorption with Solid Sorbents (CACHYS™)". Thirteenth Annual Conference on Carbon Capture, Utilization & Storage. April 2014.

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.

Swanson, M., Sondreal, E., **Laudal, D.**, Hajicek, D., Henderson, A., Pavlish, B. "JV Task-129 Advanced Conversion Test – Bulgarian Lignite" US Department of Energy Cooperative Agreement No. DE-FC26-98FT40321. June 2009.

Swanson, M., **Laudal, D**. "Subtask 7.4 – Powder River Basin Subbituminous Coal-Biomass Cogasification Testing in a Tranport Reactor." US Department of Energy Cooperative Agreement No. DE-FC26-98FT40320. May 2009

Swanson, M., **Laudal, D**. "Advanced High-Temperature, High-Pressure Transport Reactor Gasification" Period of 2005-2008. US Department of Energy Cooperative Agreement No. DE-FC26-05NT42605. December 2008.

Synergistic Activities

Introduction to Mineral Processing Short Course – Colorado School of Mines

- Completed 2.0 Continuing Education Units – July, 2016

Currently serving as a new faculty mentor in the UND Alice T. Clark program

- Focusing on grant-writing and research

Proposal Reviewer

- University Coalition for Fossil Energy Research

Michael D. Mann

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:

The goal of the Institute for Energy Studies is for UND to become a premier "Energy University" that "inspires the creation of new knowledge that enables the development of revolutionary energy technologies, trains the next generation of energy experts, and establishes 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 2013-24; 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 implementation of the college's major research goals and initiatives stated in the college's strategic plan, 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. Support the Dean by monitoring the academic procedures and policies of the college, participating in curricular matters including the development of new programs of study, and providing support to the academic units for accreditation processes and reports.

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 of Chemical Engineering to UND's top departmental awards for Excellence in Research in 2005 and Excellence in Teaching in 2007. Co-founder of the SUstainable eNergy Research, Infrastructure, and Supporting Education (SUNRISE) group in 2004. SUNRISE now has over 30 faculty participants from 12 different departments and 4 North Dakota Universities with over $20 million in research grants.

1981-99: UND Energy & Environmental Research Center (Sr. Research Mgr, Advanced Processes and Technologies 1994-99; Research Mgr, Combustion Systems 1985-94; Research Engineer 1981-85):

Activities evolved from hands on research to the development and marketing of ideas and technology. Involved in a wide range of technology development, including energy production from combustion and gasification, wind, and geothermal resources. Activity was focused on system integration and life-cycle effects. 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; manager for project for the 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)

1. Hussain, M.; Mann, M.D.; Swanson, M.L.; Musich, M.; "Testing of Lithium Silicate and Hydrotalcite as Sorbents for CO_2 Removal from Coal Gasifiction", *in* Proceedings of the 24th Annual International Pittsburgh Coal Conference, Johannesburg, South Africa, September, 2007.
2. Karki, S., Mann, M.; Salehfar, H.; "Substitution and Price Effects of Carbon Tax on CO_2 Emission Reduction from Distributed Energy Sources", *Asian Journal of Energy & Environment"*
3. Bandyopahdyay, G.; Bagheri, F.M.; Mann, M.D.; "Reduction of Fossil Fuel Emission in US: A Holistic Approach Towards Policy Formulation" , *Energy Policy*; 2007, 35 (2) 950-965.
4. Hrdlicka, J.A., Seames, W.S., Mann, M.D., Muggli, D.S., and Horabik, C.A., "Mercury oxidation in flue gas using gold and palladium catalysts on fabric filters", *Engineering Science and Technology*, (2008), 42 (17), pp. 6677-6682.
5. Nel, M.V.; Mann, M.D.; Folkedahl, B.; Timpe, R.; "Comparison of Sodium Chloride Removal Abilities of Kaolin Clay and Calcined Bauxite as Possible Sorbents for Gasification", *in* Proceedings of the 24th Annual International Pittsburgh Coal Conference, Johannesburg, South Africa, September, 2007.
6. Zhao, Y., Mann, M.D, Pavlish, J.P., Mibeck, B.A.F.; Dunham, G.E.; Olson, E.W.; "Application of Gold Catalyst for Mercury Oxidation by Chlorine", *Environmental Science and Technology*; 2006 40: 1603.
7. 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.
8. Pavlish, J.P.; Sondreal, E.A.; Mann, M.D.; Olson, E.S.; Galbreath, K.C.; Laudal, D.L.; Benson, S.A. "A Status Review of Mercury Control Options for Coal-Fired Power Plants" *Fuel Process. Technol.* 2003, 82: 89-165
9. 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.
10. Mann, M.D.; Knutson, R.Z.; Erjavec, J.; Jacobson, J.P.; "Modeling Reaction Kinetics for a Transport Gasifier", *Fuel* 83 **2004** 1643-1650.

SYNERGISTIC ACTIVITIES

1. *Specialty Fields:* The development of multidisciplinary and integrated energy and environmental projects emphasizing a cradle-to-grave approach, i.e., 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.
2. Member UND President's Council on Environmental Stewardship and Sustainability – lead role in the Campus Greenhouse Gas Inventory and development of UND's Climate Sustainability Plan.
3. Awards and Honors: Recipient of NSF Career Award, 2001: *Thermoeconomic Modeling as a Tool for Advancing the Electric Power Industry*; The Department of Chemical Engineering was the recipient of the 2005 and 2011 Fellows of the University Award of Excellence in Research and the 2007 Fellows of the University Award of Excellence in Teaching; UND Foundation Thomas J. Clifford Faculty Achievement Award for Individual Excellence in Research, 2006

a. Education and Training

BS, Chemical Engineering, University of Minnesota-Duluth, 1994

PhD, Chemical Engineering, University of Connecticut, 1999

b. Research and Professional Experience

As a **Senior Process Engineer** with Barr Engineering Company **since 2011**, Dan provides engineering and management services on projects related to mineral, chemical, and other process technologies. This includes process engineering services for scoping and pre-feasibility studies for mineral processing clients; conducting process evaluation 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, and providing plant layout, equipment specification, cost estimation, and project oversight for various mineral and chemical process applications.

As **Deputy Co-Director** and **Senior Research and Development Leader** for the Microproducts Breakthrough Institute (MBI) and Pacific Northwest National Laboratory (PNNL) from **2005 to 2011** and as **Research Engineer** for the Chemical and Biological Process Development Group from **1999 to 2005**, Dan led large and small R&D efforts focused on energy, chemical, and material processing systems; managed facility operation and upgrades; and coordinated PNNL and inter-institutional laboratories, funding, and staff.

As a **Graduate Research Assistant** in the chemical engineering department of University of Connecticut from **1995 to 1999**, Dan focused on utilization of supercritical CO_2 ($scCO_2$) as a benign solvent. This work included the design and fabrication of windowed high-pressure reactors; design, synthesis, and demonstration of novel $scCO_2$-soluble catalysts; synthesis of conductive and functionalized polymers; and chelation of heavy metals from waste water using $scCO_2$.

As a **Process Engineer** on the product management team at Lake Superior Paper Industries (currently New Page Corp.) from **1994 to 1995**, Dan provided process engineering services including designing a laboratory quality assurance program, developing a print quality testing procedure, conducting routine troubleshooting and calibration of process and laboratory equipment, and providing technical assistance to operators and laboratory personnel in sampling and testing.

c. Publications

RA Dagle, JA Lizarazo-Adarme, V Lebarbier Dagle, MJ Gray, JF White, DL King, DR Palo, *Syngas conversion to gasoline-range hydrocarbons over Pd/ZnO/Al2O3 and ZSM-5 composite catalyst system*; Fuel Processing Technology 2014, 123, 65-74

Vanessa M. Lebarbier, Robert A. Dagle, Libor Kovarik, Jair A. Lizarazo-Adarme, David L. King, Daniel R. Palo, *Synthesis of Methanol and Dimethyl Ether from Syngas over Pd/Zno/Al2O3 Catalysts*; Catal. Sci. Technol., 2012, 2, 2116-2127.

Zhu, Y.; Jones, S.B.; Biddy, M.J.; Dagle, R.A.; Palo, D.R. *Single-step syngas-to-distillates (S2D) process based on biomass-derived syngas – A techno-economic analysis*; Bioresource Technology, 2012, 117, 341.

Dagle, R. A.; Platon, A.; Palo, D. R.; Datye, A. K.; Vohs, J. M.; Wang, Y. PdZnAl *Catalysts for the Reactions of Water-Gas-Shift, Methanol Steam Reforming, and Reverse-Water-Gas-Shift*; Appl. Catal. A, 2008, 342(1-2), 63.

Palo, D. R.; Dagle, R. A.; Holladay, J. D. *Methanol Steam Reforming for Hydrogen Production*, Chem. Rev., 2007, 107, 3992.

Dagle, R. A.; Wang, Y.; Xia, G. G.; Strohm, J. J.; Holladay, J. D.; Palo, D. R. *Selective CO Methanation Catalysts for Fuel Processing Applications*; Appl. Catal. A, 2007, 326(2), 213.

Palo, D. R.; Stenkamp, V. S.; Dagle, R. A.; Jovanovic, G. N. *Industrial Applications of Microchannel Process Technology in the United States*; In Applied Micro and Nano Systems, Vol. 5 (AMN5); Wiley VCH, 2006, N. Kockman, Ed.

Palo, D. R.; Holladay, J. D.; Dagle, R. A.; Chin, Y.-H. *Integrated Methanol Fuel Processors for Portable Fuel Cell Systems. In Microreactor Technology and Process Intensification*; ACS Symposium Series, 2005, Y. Wang and J. Holladay, Eds., vol. 914, pp. 209-223.

Palo, D. R.; Erkey, C. *The Effect of Fluorinated Ligands on Rhodium Catalyzed Homogeneous Hydroformylation in Supercritical Carbon Dioxide*; Organometallics 2000, 19, 81.

Palo, D. R.; Erkey, C. *Kinetics of the Homogeneous Catalytic Hydroformylation of 1-Octene in Supercritical Carbon Dioxide with HRh*(CO)[P(p-CF3C6H4)3]3; Ind. Eng. Chem. Res. 1999, 38, 3786.

d. Patents, copyrights, and software systems

Daniel R. Palo, Jamelyn D. Holladay, Robert A. Dagle, Robert T. Rozmiarek, Compact Integrated Combustion Reactors, Systems and Methods of Conducting Integrated Combustion Reactions, US Pat. 8,696,771, 2014.

Jamelyn D. Holladay, Yong Wang, Jianli Hu, Ya-Huei Chin, Robert A. Dagle, Guanguang Xia, Eddie G. Baker, Daniel R. Palo, Max R. Phelps, Heon Jung, Alcohol Steam Reforming Catalysts and Methods of Alcohol Steam Reforming, US Pat. 7,208,136; 2007.

Jamelyn D. Holladay, Yong Wang, Jianli Hu, Ya-Huei Chin, Robert A. Dagle, Guanguang Xia, Eddie G. Baker, Daniel R. Palo, Max R. Phelps, Heon Jung, Alcohol Steam Reforming Catalysts and Methods of Alcohol Steam Reforming, US Pat. 7,563,390; 2009.

Jamelyn D. Holladay, Yong Wang, Jianli Hu, Ya-Huei Chin, Robert A. Dagle, Guanguang Xia, Eddie G. Baker, Daniel R. Palo, Max Phelps, Heon Jung Microcombustors, Microreformers, and Methods Involving Combusting or Reforming Fluid US Pat. 7,585,472; 2009.

Robert S. Wegeng, Daniel R. Palo, Steven D. Leith, Paul H. Humble, Shankar Krishnan, Robert A. Dagle Solar Thermochemical Reactor System for Concentrated Solar Energy Capture and Storage, U.S. Application No. 13/559,127; Filed July 26, 2012.

e. Synergistic Activities

Engineers Club of Northern Minnesota

Society for Mining Metallurgy & Exploration (SME)

a. Education and Training

BS, Metallurgical Engineering, South Dakota School of Mines and Technology, 1988

Minnesota Management Academy, University of Minnesota, 1998

b. Research and Professional Experience

As a **Senior Minerals Processing Consultant** with Barr Engineering Company from **2009 to 2012** and since **2014**, Boyd provides consulting, engineering, and management services on projects related to mineral processing and metallurgy for clients in the gold, iron ore, rare earth, trona, silica sand, and oil sands industries. This includes providing consulting services for scoping and pre-feasibility studies; providing laboratory and pilot-plant test work and regulatory compliance assistance for plant operations and optimization projects; designing demonstration plants and facility scale-ups; and evaluating and developing long-term tailings process improvements, thickening, and deposition.

As **SR Process Engineer** for Uranium One Americas and Uranerz Energy from **2012 to 2014**, Boyd oversaw all areas of solution mining performance, resin loading performance, ion exchange performance, and process precipitation of uranium. This included setting up metallurgical balance from the mine data through dried uranium yellow cake; preparing capital estimates for new filter press, dryer, and precipitation circuit; providing training on proper sample techniques and storage for lab analysis; and setting up flocculant systems for plant operations.

As a **Technical Manager** for POET Bio-Refining from **2002 to 2009**, Boyd oversaw plant operations, production goals, and laboratory operation including environmental safety, compliance with regulations (city, county, state, federal) and inspectors, operations and lab management, plant capital requests, annual insurance inspections, downtime schedule for major outages items, and OSHA-mandated PSM program. He assisted with upgrading existing process and optimizing process-flow changes at the plant, managed a $25 million plant process expansion and milling project, assisted with plant startups and commissioning of other POET facilities, and assisted with operational functionality of a thermal oxidizer and heat recovery system.

As an **Engineer** and **Manager** for EVTAC Mining Company from **1995 to 2002**, Boyd provided process engineering and management services including safety, union relations, railroad and mine schedules, grinding media overview, annual production budgets and operating goals, and ISO 9001 quality system implementation.

As a **Metallurgist** in the concentrator and hydrometallurgical divisions for Phelps Dodge Mining Company from **1991 to 1995**, Boyd worked with plant engineering, operations, and laboratory teams to make modifications to concentrator flotation cells, to manage plant sampling systems, to develop regression analysis, to install particle-size monitors into the cleaner system, to improve reagent scheme, to improve solids settling rates on tailings thickener systems, to assist with overall mine plan and stockpile haulage schedules, and to attain optimal water balances.

As a **Metallurgical Engineer** for Climax Molybdenum Company from **1989 to 1991**, Boyd assisted with installation of analyzers, control systems for SAG mill and flotation circuits, pilot plant studies for a rhenium recovery project and a pyrite-byproduct recovery circuit, replacement of a cleaner flotation system, and evaluation of new filter system for the filter plant.

c. Publications

Eisenbraun, B. J., *Magnetic Iron Recovery Improvements at EVTAC*, SME-Minnesota Section, Duluth, 2002.

d. Synergistic Activities

Society for Mining Metallurgy & Exploration (SME) - Registered Member

Canadian Mining/Metallurgical Association - Registered Member

Association for Iron and Steel Technology – Registered Member