Lignite Resource Evaluation for Advanced Utilization Opportunities

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Contents

Abstract

The goal of this project is to characterize the lignite resources in existing coal mines to provide information on critical elements (including rare earths), waste coal materials, and associated sediments that are critical to the future utilization of the lignite resources. The lignite resources have the potential to provide critical elements essential to advanced electronic devices, materials for the building industry, and provide a resource that can produce power cleanly and efficiently. Past methods to track resource properties in mines have been limited to the standard method utilized to assess thermal coal to produce power and syngas. Currently there is an insufficient understanding of the critical mineral abundance and associations to be able to determine the true resource. The aim of this project is work with North American Coal Company to collect drill core samples for characterization to determine the abundance and mode of occurrence of critical minerals in major and minor seams as well as in the associated clay and shale materials. The drill core samples will be scanned onsite as well as analyzed in the laboratory. The onsite system, TruScan™, will be tested for its ability to image and provide elemental analysis and density of the cores in the field. The primary deliverables will include data on the abundance and distribution of critical minerals in the coal and related sediments and the feasibility of the use of the TruScan™ to analyze core samples in the field. The project team includes Microbeam Technologies Incorporated (lead), North American Coal Corporation (NACC), and Boart Longyear Company, with analytical consultants including Activation Laboratories Ltd. and Minnesota Valley Testing Laboratories. The project team is requesting funding in the amount of $1,238,994.18. This is a three-year project with a proposed timeline of January 1, 2023, to December 31, 2025.

Project Summary

The overall goal of the project is to characterize lignite coal-bearing sequences to determine abundance and association of REE-CM that can be used optimize the recovery of rare earth elements and other critical elements (REE-CM) extraction and concentrating processes. In this project, Microbeam and Boart Longyear will work with NACC to collect drill core samples from Falkirk and Freedom mines to analyze the samples and determine the abundance and modes of occurrence of REE-CM in major, minor coal seams (waste coal), and associated sediments. This information will be used to provide insight into the potential for lignite materials to be an economic source of REE-CM. In order to meet the objectives of the project, a multiyear project is envisioned. The workplan involves the following tasks that include:

- Project Management and Reporting – This task will involve the coordination of all project-related activities that include tracking project progress and milestones, management of sub-contractors and analysis laboratories, and the preparation of reports.
- Sample Selection and Procurement – Microbeam will work closely with NACC to identify optimum areas for drill core collection, sampling, and analysis. The drill cores sediments sampled will include all clay/shale, minor coal seams, partings, and coal specific lithotypes.
- Sample Characterization – The collected samples will be analyzed to determine the abundance and modes of occurrence or REE-CM and selected elements considered critical, properties of coal considered important for building materials production, and floor and roof mineral/phase abundance for modeling and utilization.
- Resource Evaluation and Geological Modeling – The data from the analysis performed will be used to conduct an evaluation of the resource and to improve the resource predictive methods.
- Field Analysis Methods Testing and Correlation Development – Microbeam's predictive algorithms for REE-CM content from portable X-Ray Fluorescence (pXRF) measurements and/or

prompt gamma neutron activation analysis (PGNAA) will be utilized. The specific technology of interest to this project is Boart Longyear's TruScan™ technology that has the potential to provide on-site elemental analysis and photography of core samples.

The primary deliverables will include data on the distribution of REE-CM abundance and associations, evaluation of the potential critical mineral for feedstock for recovery, and the feasibility of using onsite analysis technology for measurement of critical minerals. This information can be used in the future as a guide for resource exploration and selective mining for REE-CM-rich coals.

Project Description

Overall Project Goal

The overall goal of the project is to characterize lignite coal-bearing sequences to determine abundance and association of REE-CM that can be used to optimize the recovery REE-CM extraction and concentrating processes. The aim of this project is to work with NACC to collect drill core samples from Falkirk and Freedom mines and to analyze the samples to determine the abundance and modes of occurrence of critical minerals in major, minor coal seams (waste coal), and associated sediments.

Project Objectives

To meet the goal, the following objectives have been identified:

- Identification of promising regions that have high levels of REE-CM contents
- Perform survey analysis of each core sample to identify potential high REE-CM content
- Characterize selected samples
    - to determine the abundance and forms of REEs and CM
    - to determine the mineral/phase components present in the associated sediments for use in modeling

- Develop a summary of the associations and modes of occurrence for the REE-CM content, waste coal quality, and associated sediments.

Scope of Work

This project will analyze drill core samples from the NACC Falkirk and Freedom mines. Between 25-75 cores will be drilled at each mine for each year. Selected drill cores will be procured for sampling and will be submitted for detailed analysis as described in this proposal. The data will be used in geologic modeling to assess the resource and aid in possible selective mining of coals and associated sediments that are rich in REE-CM. In addition, the application of an on-site core imaging and elemental analysis system will be evaluated for its ability to measure REE-CM.

Task 1. Project Management and Reporting

In order to achieve the goal of the project, Microbeam and NACC will work together to ensure the project is conducted on-time and within budget. Progress meetings will be held on a regular basis and results of testing will be reported in the form of power point presentations. Reports will be submitted on a quarterly basis, including a final report.

Task 2. Year 2022 Drill Core Analysis

NACC conducts drilling as part of their mine planning efforts every summer. These tasks took place during the months of July and August of 2022. As part of the proposed project, the team will evaluate those cores upon the start of the project in 2023.

Subtask 2.1 Sample Selection and Procurement

Microbeam will review the drill cores collected by NACC in 2022. A select number of samples will be procured to be analyzed in Subtask 2.2. In order to fully understand the resource, Microbeam will carefully sample the cores that include the thin as well as thick seams, the interface between the seams and roof and floor materials, and the associated sediments.

Subtask 2.2 Sample Characterization

Core samples will be processed by describing the various stratigraphic components and samples will be selected for analysis. The selected samples will ground, split and submitted for analysis at Microbeam and other laboratories. Selected intact core samples will be sent to Boart Longyear for initial analysis using TruScan^{TM} technology.

The cores/samples collected in Subtask 2.1 will be submitted for analysis, including:

- Proximate, ultimate, and ash composition will be used to determine basic coal properties.
- ICP-MS will be used to determine abundance of REE-CM (at a minimum the list of elements given in Table 1.).
- Partial chemical fractionation will be performed to determine mode of occurrence and extractability of the REE-CM.
- SEM combined with x-ray microanalysis will be used to provide information on the mineralogy of selected promising samples.

From these analyses, Microbeam will examine relationships between elemental composition, REE-CM abundance, mineralogy, and associations. The team will look to identify indicators of high REE-CM concentrations to help in further understanding the depositional environment associated with the accumulation of the REE-CM in coal.

Table 1. REE and CM selected for analysis.

Rare Earth Elements and Critical Minerals	
Element	**Abbreviation**
Scandium	Sc
Lanthanum	La
Cerium	Ce
Praseodymium	Pr
Neodymium	Nd
Promethium	Pm
Samarium	Sm
Europium	Eu
Gadolinium	Gd
Terbium	Tb
Dysprosium	Dy
Holmium	Ho
Erbium	Er
Thulium	Tm
Ytterbium	Yb
Lutetium	Lu
Thorium	Th
Uranium	U
Gallium	Ga
Germanium	Ge

Subtask 2.3 Resource Evaluation and Geological Modeling

The REE-CM results from the sample characterization will be used to develop a geological model that will describe the distribution of REE-CM in each mine. The software that will be utilized is the Maptek's Vulcan GeoModeller software. This model will be used to provide an initial evaluation of the overall REE-CM resource from the area being explored. Specific results from the analysis and geological models may not be able to be made public, however, indicators and general results can be reported from the models. The models will help in understanding change in distributions over distances and throughout seams.

Subtask 2.4 Field Analysis Methods Testing and Correlation Development

Microbeam developed predictive algorithms for REE content from portable X-Ray Fluorescence (pXRF) measurements in a project sponsored by the North Dakota Industrial Commission (NDIC) under contract FY18-LXXXIII-213. In continuation of that effort, Microbeam has used that technology to predict REE content in coal for various projects. Microbeam recently contacted Boart Longyear Company to discuss the potential opportunity for integrating the REE predictive algorithms into their TruScan™ technology.

TruScan™ is a technology that provides on-site elemental analysis and photography of core samples using XRF and high-resolution cameras. The equipment is encompassed in a portable trailer that can be transported to drilling sites so that analysis can be conducted and delivered in near-real-time.

Boart Longyear conducted initial analysis of drill cores previously collected and analyzed for REE-CM by Microbeam. These results have been reviewed and the REE-CM predictive algorithms have been applied to the results. Initial results show promise that the algorithms can be applied to the TruScan™ technology.

The integration of these technologies would provide low-cost, quick response REE-CM contents of core samples. The current cost of analysis is expensive and having this information will help guide exploration efforts including number of samples required for analysis and direction of drilling plans.

In 2023, Microbeam will work with Boart Longyear company to develop this technology further. The results from this subtask will be used in drill planning and will be tested and demonstrated on-site in subsequent years of this project.

Task 3. Year 2023 Drilling and Analysis

In Task 2, the work outlined will have been conducted after the drilling efforts of NACC. In Task 3, Microbeam will work with NACC to guide the drilling efforts and conduct analysis, data evaluation, and interpretation tasks in parallel to the drilling.

Subtask 3.1 Drilling Planning

Microbeam and NACC will utilize the characterization and modeling results from Task 2 to guide the drill planning in 2023. While NACC will conduct drilling to guide their future coal mining efforts, drilling locations will also be included to enable the evaluation of the REE-CM resource. Drilling locations will be determined to explore new coal seams, continue to develop resource of known coal seams, and reevaluate certain locations that may have resulted in some questions from previous analysis of REE-CM. Separate drill plans will be developed for Freedom and Falkirk mines.

Coal seams for evaluation will be selected during drill planning as well. Thin seams that may not have been of interest for thermal use were not selected for sampling and analysis during normal drill planning. However, based on previous sampling efforts, evidence of high REE-CM concentrations has been observed in some of these thin seams so they will be of interest for this project. As a result, it will be important to identify these locations so that samples can be collected during drilling.

Subtask 3.2 Drilling

NACC will conduct core drilling based on the plan developed in Subtask 3.1. It is expected that NACC will select between 25-75 core sites depending on the mine.

The TruScan^{TM} equipment will be deployed with the drilling efforts to conduct onsite analysis of select core samples. For this task, the team will use this opportunity for determining sampling, handling, and analysis best practices in addition to general XRF analysis. Boart Longyear will consider managing moisture content, structure/integrity of the coal cores, and calibration and standardization of TruScan^{TM} equipment.

Subtask 3.3 Sample Selection and Procurement

Sample selection and procurement will be conducted during the drilling efforts and will be split into two efforts:

- TruScan^{TM} sample evaluation – cores will be selected for analysis on the TruScan^{TM} equipment to obtain continuous imaging and chemical analysis of the entire core. As the method is nondestructive, cores will be returned to NACC after imaging and compositional analysis.

- Laboratory analysis – samples will be selected based on key features (seam margins, partings, thin seams) from the cores to be submitted for laboratory analysis at Activation Laboratories Ltd., MVTL, and Microbeam. Sample selection and collection will be conducted in parallel with drilling as samples are available.

Subtask 3.4 Sample Characterization

The cores selected for TruScan™ evaluation will be analyzed on-site or sent to their laboratory as needed. The TruScan™ requires calibration but samples from 2022 will be able to be used for the efforts in 2023. This will allow the equipment to operate on-site and provide near-real-time data during drilling. The cores will be returned to NACC upon completion of the characterization.

The samples selected for laboratory analysis in Subtask 3.3 will undergo analyses including:

- Proximate, ultimate, ash composition will be performed to determine basic coal properties
- ICP-MS analysis will be used to determine the abundance of REE-CM (list of elements given in Table 1)
- Partial chemical fractionation will be used to determine mode of occurrence and extractability of the critical minerals
- SEM combined with x-ray microanalysis will be used to provide information on the mineralogy of selected promising samples.

Subtask 3.5 Resource Evaluation and Geological Modeling

The geological models and resource evaluation information developed in Subtask 2.2 will be further expanded with the drilling and analysis conducted in 2023. If new seams or sections are observed in 2023, models will be updated to incorporate new seams, and further evaluation will be performed for the total resource.

Subtask 3.6 Field Analysis Methods Testing and Correlation Development

The results from the laboratory analysis will be compared to the core analysis conducted on-site using TruScan™ during the drilling. This will allow for testing of the REE predictive algorithms and further improvement of the algorithm with new data.

Task 4. Year 2024 Drilling and Analysis

In 2024, the efforts will work on further development of the resource by extending the sampling area but also conducting more drilling in the previously analyzed locations, where available.

The TruScan™ and REE predictive algorithm work in 2024 will focus on validation of the algorithms to allow for use in making real-time decisions in the field.

Subtask 4.1 Drill Planning

Similar to 2023, Microbeam and NACC will utilize the characterization and modeling results from Task 3 to guide the drill planning in 2024. While NACC will conduct drilling to understand their future coal mining efforts, drilling locations will included for the evaluation of the REE-CM resource. Drilling locations will be selected to explore new coal seams, to continue to evaluate the resource of known coal seams, and to reevaluate certain locations that may have resulted in some questions from previous sampling and analysis effort.

Subtask 4.2 Drilling

NACC will conduct core drilling based on the plan developed in Subtask 4.1. It is expected that NACC will drill 25-75 cores between each mine.

The TruScan™ equipment will be deployed with the drilling efforts to conduct onsite analysis of select core samples.

Subtask 4.3 Sample Selection and Procurement

Sample selection will be conducted in the same approach as 2023. Sample selection and procurement will be conducted during the drilling efforts and will be split into two efforts:

- TruScan™ sample evaluation – cores will be selected for analysis on the TruScan™ equipment, which will provide continuous imaging and chemical composition for the entire core. As the method is nondestructive, cores will be returned to NACC after evaluation.
- Laboratory analysis – samples will be selected from the cores based on analysis performed with the TruScan™ and will be submitted for laboratory analysis of the properties of the cored materials at Activation Laboratories Ltd., MVTL, and Microbeam.

Subtask 4.4 Sample Characterization

The cores selected for TruScan™ evaluation will be analyzed on-site or sent to their laboratory as needed. The cores will be given back to NACC upon completion of analysis.

The samples selected for laboratory analysis in Subtask 4.3 subject to analyses include:

- Core samples will be processed by describing the various stratigraphic components and samples will be selected for analysis.
- Proximate, ultimate, ash composition will be performed to determine basic coal properties
- ICP-MS analysis will be used to determine the abundance of REE-CM (list of elements given in Table 1)
- Partial chemical fractionation will be used to determine mode of occurrence and extractability of the critical minerals
- SEM combined with x-ray microanalysis will be used to provide information on the mineralogy of selected promising samples.

Subtask 4.5 Resource Evaluation and Geological Modeling

A geological model and resource evaluation will be performed based on all the sample characterizations conducted during the project. While the model will not be disclosed publicly, the model will be used to help identify key identifiers for REE-CM.

Subtask 4.6 TruScan™ Correlation Validation

As discussed in Subtask 4.4, the TruScan™ will be used on-site, and the results will be used to provide estimates of REE-CM content in the cores being analyzed. The results will be validated based on the laboratory analysis. Based on the results, additional refinement of the TruScan™ technology will be conducted in this subtask.

Task 5. Year 2025 Drilling and Analysis

In 2025, the efforts will work on further development of the resource by extending the sampling area and by conducting additional drilling in the previously analyzed locations where possible.

The TruScan™ and REE predictive algorithm work in 2025 will focus on validation of the algorithms to allow for use in making real-time decisions in the field associated with further drilling required to characterize the resource.

Subtask 5.1 Drill Planning

Similar to 2023 and 2024, Microbeam and NACC will utilize the characterization and modeling results from Task 4 to guide the drill planning in 2025. While NACC will conduct drilling to understand their future coal mining efforts, drilling locations will be included for the evaluation of the REE-CM resource. Drilling locations will be identified to explore new coal seams that include thin coal seams currently considered waste, continue to develop resources of known coal seams, and reevaluate selected locations that may have resulted in some questions from previous sampling and analysis characterizations.

Subtask 5.2 Drilling

NACC will conduct core drilling based on the plan developed in Subtask 5.1. It is expected that NACC will drill 25-75 cores between each mine.

The TruScan^{TM} equipment will be deployed with the drilling efforts to conduct onsite analysis for selected core samples.

Subtask 5.3 Sample Selection and Procurement

Sample selection will be conducted in the same approach as 2023 and 2024. Sample selection and procurement will be conducted during the drilling efforts and will be split into two efforts:

- TruScan^{TM} sample evaluation – cores will be selected for analysis on the TruScan^{TM} equipment. As the method is nondestructive, cores will be returned to NACC after evaluation.
- Laboratory analysis – a number of samples will be selected from the cores to be submitted for laboratory analysis at Activation Laboratories Ltd., MVTL, and Microbeam. Sample selection, collection and analysis will be conducted in parallel with drilling as samples are available.

Subtask 5.4 Sample Characterization

The cores selected for TruScan^{TM} evaluation will be analyzed on-site. The cores will be given back to NACC upon completion of the characterization.

The samples selected for laboratory analysis in Subtask 5.3 will be submitted for analysis, including:

- Core samples will be processed by describing the various stratigraphic components and samples will be selected for analysis.
- Proximate, ultimate, ash composition will be used determine basic coal properties.
- ICP-MS will be used to determine abundance of REE-CM in selected samples.

- Measure modes of occurrence (extractability) and mineralogy (SEM) will be performed on selected, promising samples.

Subtask 5.5 Resource Evaluation and Geological Modeling

A final geological model will be utilized that incorporates all data collected to provide an evaluation of the REE-CM resource.

Subtask 5.6 TruScan™ Correlation Validation

As discussed in Subtask 5.4, the TruScan™ will be used on-site, and the results will be used to provide estimates of REE-CM content in the cores collected and analyzed in the laboratory. The TruScan™ results will be validated based on the laboratory analysis. Depending on the results, further development may be conducted at this step.

Anticipated Results

Microbeam has collected and analyzed samples from NACC mines in previous projects. Those results have shown distributions of REE-CM content ranging from 40-300 ppm (dry coal basis) at the Falkirk Mine and 15-365 ppm (dry coal basis) at the Freedom mine. As a result, the project team expects to see a consistent range of REE throughout the coal seams with the potential for high concentrations in certain seams and at the margins of seams. This range will allow the team to be able to compare high REE-CM coals with low REE coals to better understand the depositional environment characteristics.

Microbeam was able to develop REE-CM predictive algorithms with accurate results in the previously discussed NDIC funded project (Benson et al 2021). In addition, Microbeam was able to develop similar algorithms for prompt gamma neutron activation (PGNA) analyzers and dual gamma attenuation (DGA) analyzers through a Department of Energy (DOE) funded study (DE-SC0021837) (Benson et al 2022). Based on the promising results found in those projects, Microbeam expects to be able to develop algorithms to be integrated into the Boart Longyear TruScan^{TM} equipment. The partnership of these technologies could lead to faster and cheaper exploration for REE-CM in coal.

The sampling efforts will also include the thin seams and other associated sediments to determine the abundance of REE-CM materials in coals that would otherwise be discarded with the overburden. The composition of waste coal and its ability to be used in alternative carbon ore applications will vary from seam to seam. However, the variation is not expected to be extreme and is expected to be applicable for multiple purposes.

Facilities

Algorithms for REE Assessments (Patents pending)

Microbeam has developed an algorithm that predicts REE content of a coal sample based on the trace element readings from a pXRF. This algorithm provides an estimate of total REEs, heavy REEs, light REEs, and individual REE content. This method was developed using ND lignite coal from seams across the state. This technology will be used to assist in the down-selection of core samples for additional analysis. Using a pXRF to provide an initial REE measurement is an inexpensive and time-effective way to make decisions of what samples should be sent for further analysis, reducing overall costs for expensive analysis methods on samples that may not need to be further assessed.

Microbeam developed prototype REE-CM predictive algorithms for total REE and individual elemental concentrations in bituminous and lignite coals using data derived from full stream elemental analyzers equipped with prompt gamma neutron activation analysis (PGNAA) and dual gamma attenuation (DGA) analysis. The predictions were enhanced using neural network predictions. The mean absolute error (MAE) for measuring TREE was 0.05 for bituminous and 0.02 for lignite coal using PGNAA spectral algorithms. The MAE for the DGA algorithm to estimate TREE was 0.11 for bituminous and 0.07 for lignite.

Automated Scanning Electron Microscope and X-ray Microanalysis

Microbeam's scanning electron microscopes (SEM) equipped with x-ray microanalysis systems provide key information for the mineral component of the coals and associated sediments. These methods have been utilized at Microbeam for the past 30 years and are a key component of our testing and analysis of fuels and flux as well as ash and slag-related materials produced in gasification and combustion systems. Microbeam databases of fuel minerals, fly ash, and other samples consist of over 16,000 samples. The system includes advanced imaging, stage automation, x-ray microanalysis, and image analysis capabilities. The SEMs are completely automated and can size and analyze thousands of particles and perform phase identification and classification. The datasets from the SEM are utilized in a suite of post processing tools that allows for interpretation phases (minerals) present in fuels of ash and slag behavior processes and provides key data for predicting ash/slag formation and behavior.

Computer controlled scanning electron microscopy (CCSEM) – CCSEM is used to determine the size, composition, abundance, and association of mineral grains in prepared coal, biomass, and petroleum coke samples. The information derived from this analysis is used to assess the behavior of the mineral grains during combustion or gasification. Examples where CCSEM is used to determine the impacts of fuel properties include system component wear, slag flow, slagging deposit, fouling of heat exchangers, fine particle collection, and ash handling. In addition, the CCSEM methods has been used to identify REE-CM rich minerals and ash-related materials.

SEM morphological analysis – Morphological analysis is used to obtain high-magnification images and chemical compositions of selected features of minerals in coal and associated sediments. Backscattered electron and secondary electron imaging are used to provide images of REE-CM-rich samples. REE-CM-rich minerals have been observed in lignite, fly ash, slag, and fouling deposits.

Chemical fractionation analysis – Chemical fractionation is used to determine the modes of occurrence or forms of inorganic elements based on solubility in water, ammonium acetate, and hydrochloric acid (Benson and Holm, 1985). The procedure involves a sequential extraction procedure using water, 1M ammonium acetate, and 1M HCl. The water extracts water-soluble minerals, such as NaCl. The ammonium acetate extracts ion-exchangeable elements attached to carboxylic acid groups or hydroxide groups, and the HCl extracts elements associated as organic coordination complexes or acid-soluble minerals such as carbonates, oxides, and sulfates. The unleached residual elements are associated with silicates, aluminosilicates, sulfides, and insoluble oxides. In this chemical fractionation method, the HCl step was used to determine the overall extractability of the REE-CM and major inorganic components associated as water soluble, organic salts, and organic coordination complexes. The residual material is analyzed to determine the unextractable elements.

Boart Longyear TruScan™ Core Analysis System

Boart Longyear has an office in Salt Lake City, UT, where some of the TruScan™ trailers are located. The TruScan™ is a portable XRF system for drill cores. Figure 1 shows an example of the TruScan™ technology in operation at a drilling site. The team will send samples to the Boart labs in Salt Lake City and the TruScan™ equipment will be deployed to North Dakota during drilling activities.

Figure 1. TruScan™ technology in operation at a drill site (TruScan™ 2022).

Minnesota Valley Testing Laboratories

MVTL is a standard laboratory that conducts a wide range of analytical methods for energy technologies (among other industries). MVTL will be utilized in this project to conduct ash composition and proximate/ultimate analyses. The MVTL site that will be conducting analysis for this project is located in Bismarck, ND. This is a laboratory that Microbeam has worked with for many years on various projects.

Activation Laboratories Ltd.

Activation Laboratories is a standard analytical laboratory that conducts a wide variety of analyses for many different industries. Activation Laboratories will be utilized in this project to conduct ICP-MS analysis. The site that will be conducting ICP-MS analysis for this project is located in Ancaster, Ontario, Canada. This is a laboratory that NACC has worked with to obtain ICP-MS analysis of coal and related materials for REE-CM and was able to provide the most economical pricing for this type of analysis.

Standards of Success

This project has a couple of objectives that can be accomplished with the same compositional analysis. Each objective will have an individual standard of success.

- REE-CM Key Indicators – the standard for success for this objective will be to identify key indicators that will allow for estimations of REE-CM concentrations based on current databases available.
- REE-CM Predictive Algorithm (TruScan™) – the standard for success for this objective will be to integrate Microbeam's REE-CM predictive algorithms with Boart Longyear's TruScan™ technology to show accurate estimations of REE concentrations within coal drill cores. This technology will provide real time information that allows to guiding drilling efforts and can reduce costs of analysis.
- Carbon Ore Characterization – the standard for success for this objective will be providing an evaluation of the coal's ability to be used for alternative products. In addition, this project will provide an estimated resource based on the characteristics of the coal.
- Mapping the REE-CM-rich coal materials in seams and associated sediments in the mine will provide key information needed to evaluate the resource and will provide information that can be used for selective mining.

Background

Advanced Uses of Lignite Carbon Ore

Lignite carbon ore has unique properties that include an organic structure that has the ability to house inorganic elements in its organic framework. Elements such as rare earth elements are associated as organic complexes. These elements are extractable with weak acids. Selected lignite coals have high levels of these elements and are typically enriched in heavy rare earth elements. The organic framework is also unique in its ability to chemically react with binders or bonding agents allowing for the production of building materials such as bricks. The properties of the associated sediments provide clues to the origin of critical minerals and also play a role in optimizing the efficient operation of combustion- and gasification-based energy conversion systems. The application of methods to analyze the inorganic composition of the coal include pXRF and PGNAA can be used to measure and sort REE-CM-rich feedstocks.

Carbon Ore as a Source of Critical Minerals

Currently, the uses for critical minerals (CM) are increasing and many of the sources and markets are controlled by entities outside of the US. CM are utilized in a suite of high importance end-uses, such as cell phones, hybrid and electric vehicles, magnets, computer components, catalysts, and many others. Lack of a domestic source of REE-CM has a significant impact on the US's national security, energy independence, environmental future, and economic growth. The Department of Energy continues to release funding opportunities related to the development of the REE-CM domestic supply chain. However, those resources are focused on waste resources (mine waste, fly/bottom ash, acid mine drainage, etc.) with limited resource evaluation funding. It is crucial to evaluate the resources of active mines in addition to these waste resources and to develop a deeper understanding of the indicators that will help ND identify other potential resources throughout the state.

Rare earth elements (REEs) are part of the group of elements that are considered critical minerals (CM). The REEs include a group of elements with atomic numbers from 57-71. These include 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. The rare earth elements are classified as light (LREE) and heavy (HREE). The LREEs include La to Eu. The HREEs include Gd to Lu, and Y. In addition to the REEs, the critical minerals include aluminum (bauxite), antimony, arsenic, barite, beryllium, bismuth, cesium, chromium, cobalt, fluorspar, gallium, germanium, graphite (natural), hafnium, helium, indium, lithium, magnesium, manganese, niobium, platinum group metals, potash, rhenium, rubidium, scandium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium (DOI 2018).

Ekmann (2012) conducted a prospective analysis of REE + Y in coals and coal byproducts and found that the levels of REEs were enriched above crustal average in some coal beds and formations. Ekmann also estimated that the "unintended" production of REEs from coal mining was greater than 40,000 tons in 2010. Although recovery of REEs from coal presents several challenges, namely the variability of REE concentrations throughout the seam, it also offers several advantages compared to traditional recovery from mineral resources. Feedstocks such as coal, coal refuse, coal ash, and acid mine drainage have been identified as potential high REE-CM-bearing materials.

REE-CM Associations in Coal

The abundance and association of the REE in coal is controlled by the type of REE-containing source materials. Seredin and Dai (2012) have categorized the main genetic types of high REE (including Yttrium) (REE+Y) accumulation in coals as shown in Table 2. Source materials can be derived from minerals and volcanic ash (detrital origin) that are accumulated with the organic materials in a swamp (Bouska and Pesek, 1999; Dai et al., 2011a and 2011b). 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 REEs to the organic fraction or to new authigenic minerals. This process can result in the enrichment of REEs in selected layers in the coal-bearing stratigraphic sequences.

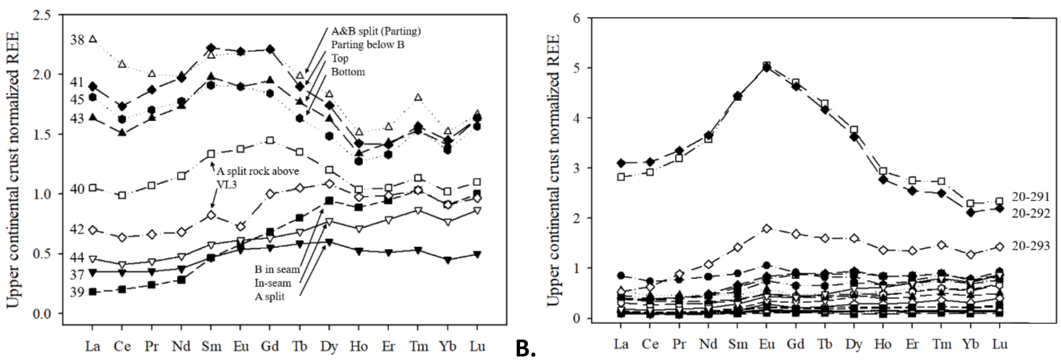
Table 2. The main genetic types of high REE+Y accumulation in coals. After Seredin and Dai [2012].

Type	REO* Content in Ash, %	Associated Elements	Typical Example
Terrigenous	0.1–0.4	Al, Ga, Ba, Sr,	Jungar, China [Dai et al., 2006, 2008]
Tuffaceous	0.1–0.5	Zr, Hf, Nb, Ta, Ga	Dean, USA [Mardon and Hower, 2004]
Infiltrational	0.1–1.2	U, Mo, Se, Re, Ge	Aduunchulun, Mongolia [Arbuzov and Mashen'kin, 2007]
Hydrothermal	0.1–1.5	As, Sb, Hg, Ag, Au, *etc*.	Rettikhovka, Russia [Seredin, 2004]

*REO, oxides of rare earth elements and yttrium.

Seredin and Dai (2012) described four modes of incorporation of REY into coals (Table 2). A fifth mechanism is the organic association, something not necessarily considered in bituminous and higher rank coals but is a real phenomenon in low-rank coals (Eskenazy et al., 1986; Benson and Laudal, 2017). The element enrichment is not confined to the REE, as a number of other critical elements are associated with the enrichment mechanisms.

The Fire Clay coal is the premier coal based REE resource in the eastern US (Hower et al., 1999, 2016a, 2020; Mardon and Hower, 2004). The Upper continental crust normalized have L-type (light REE enrichment) distributions with a strong LREE enrichment. The upper continental crust normalized plot (Figure 2) for the lignite coal indicate that they have both L-type (light REE enrichment) and H-type (heavy REE enrichment) distributions. Most of the lignite coals had H-type distributions (Benson et al., 2022). For any samples, it must be emphasized that multiple influences changed the chemistry of the coal. The thickness of the strata is an important consideration in the interpretation of the UCC distributions, the L-type vs H-type differentiation, and any other primary or derived parameter.



A. **B.**

Figure 2. Upper continental crust normalized REE distribution for the bituminous (A) and lignite (B) samples analyzed (Benson et al., 2022).

REE Predictive Algorithms and Boart Longyear TruScan^{TM}

Microbeam has developed predictive algorithms for individual REE and CM content as well as total concentrations. These algorithms were initially developed for pXRF as part of a NDIC funded project (FY18-LXXXIII-213) (Benson et al., 2021). Results from that project showed that the Microbeam team was able to make accurate predictions of REE concentrations from the pXRF. Those results are shown in Figure 3.

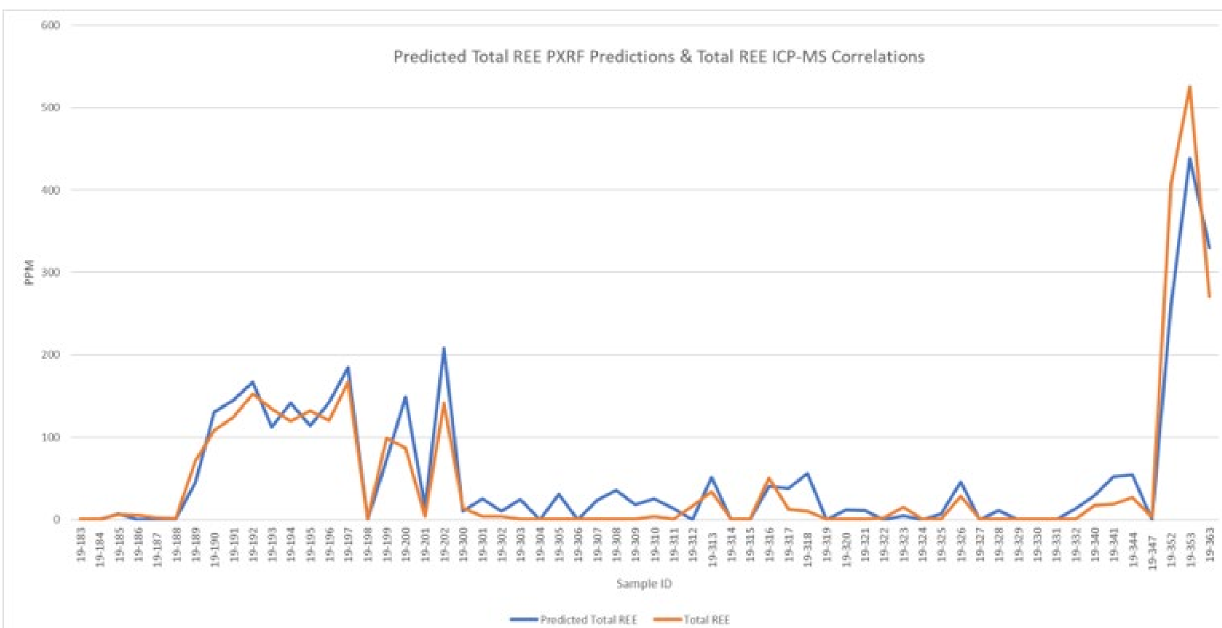


Figure 3. Results of REE predictive algorithms from pXRF spectra.

The main objective of the pXRF project was to determine the feasibility of using the pXRF to predict REE concentrations, however, the team used learnings from the pXRF to develop preliminary algorithms for full stream elemental analyzers (FSEA). The predictive algorithms were incorporated into a previously developed software Microbeam had developed to track coal quality at power plants that utilizes FSEA spectra. These efforts were able to show that the predictive algorithms could be developed for FSEA and a small business innovation research (SBIR) award, funded by the Department of Energy (DOE), was given to Microbeam to further develop the technology (DE-SC0021837) (Benson et al., 2022). The initial FSEA results are shown in Figure 4.

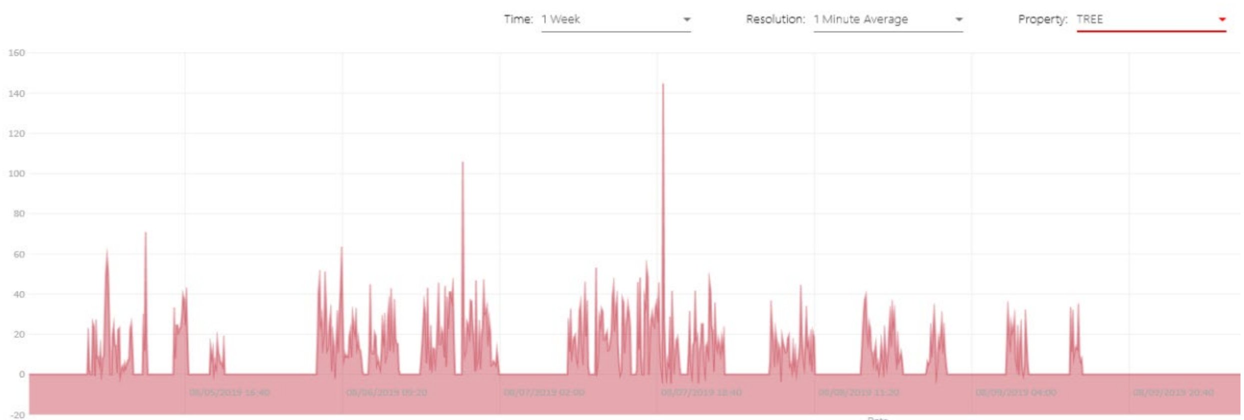


Figure 4. REE predictive algorithm results incorporated into Microbeam's coal quality software.

The DOE project analyzed both lignite and subbituminous samples and developed predictive algorithms for total REE and individual elements. The results for heavy REE are shown in figure 5.

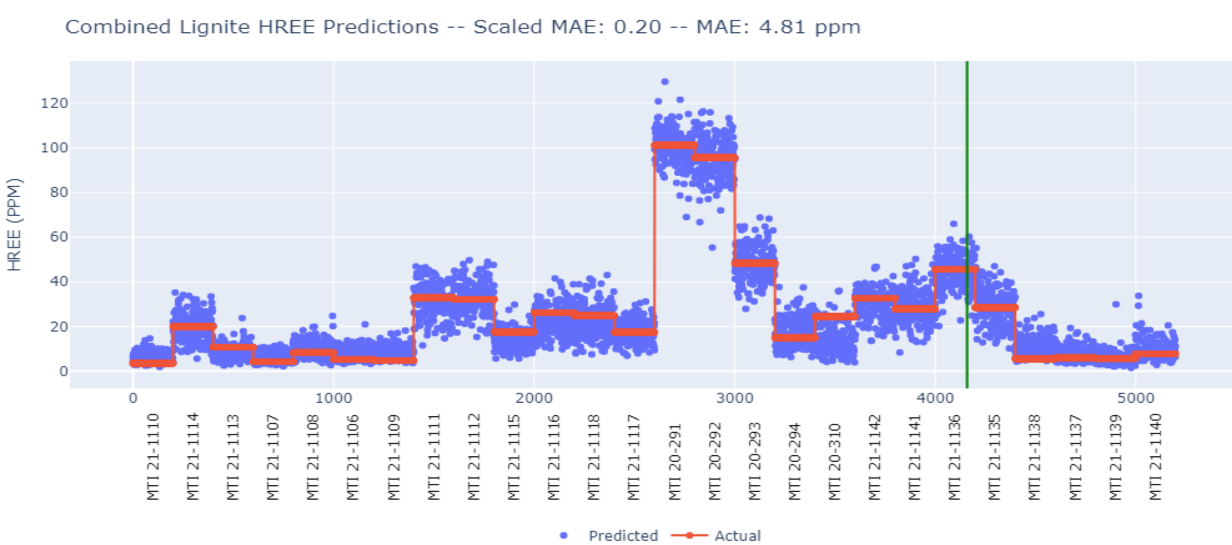


Figure 5. Example of predictive algorithm results for FSEA system.

Table 3 shows the mean average error (MAE) for the numerous algorithms developed for the individual elements and total REE. The FSEA is a combination of a prompt gamma neutron activation analyzer (PGNAA) in series with a dual gamma attenuation (DG) sensor. The PGNAA is comprised of two sources (PGNAA 1 and PGNAA 2). Algorithms were developed for each analyzer as well as the sensors in series (FSEA as a whole) and Table 3 shows the MAE for each of those algorithms.

Table 3. Scaled MAE for each trained network.

	Bituminous				**Lignite**				**Combined**
Element	**DGA**	**PGNAA 1**	**PGNAA 2**	**Combined**	**DGA**	**PGNAA 1**	**PGNAA 2**	**Combined**	**-**
Cerium	0.09	0.05	0.04	0.05	0.06	0.02	0.03	0.02	0.05
Dysprosium	0.15	0.07	0.05	0.05	0.06	0.05	0.03	0.02	0.04
Erbium	0.13	0.05	0.04	0.04	0.07	0.04	0.04	0.03	0.06
Europium	0.12	0.06	0.05	0.05	0.06	0.02	0.02	0.02	0.04
Gadolinium	0.12	0.08	0.05	0.07	0.06	0.02	0.03	0.02	0.04
Gallium	0.09	0.05	0.05	0.04	0.10	0.04	0.06	0.04	0.04
Germanium	0.09	0.06	0.05	0.06	0.12	0.07	0.07	0.06	0.09
Holmium	0.13	0.06	0.04	0.05	0.07	0.04	0.03	0.03	0.05
Lanthanum	0.08	0.05	0.05	0.04	0.07	0.02	0.03	0.02	0.05
Lutetium	0.12	0.05	0.03	0.09	0.08	0.04	0.05	0.05	0.05
Molybdenum	0.15	0.12	0.08	0.13	0.08	0.05	0.05	0.06	0.09
Neodymium	0.11	0.06	0.04	0.05	0.06	0.02	0.02	0.02	0.04
Praseodymium	0.09	0.05	0.04	0.05	0.06	0.02	0.03	0.02	0.05
Samarium	0.12	0.07	0.05	0.04	0.07	0.02	0.02	0.02	0.04
Scandium	0.10	0.05	0.04	0.05	0.12	0.07	0.06	0.06	0.05
Terbium	0.16	0.08	0.05	0.05	0.06	0.03	0.02	0.03	0.04
Thulium	0.12	0.08	0.04	0.04	0.07	0.05	0.04	0.04	0.05
Ytterbium	0.14	0.09	0.10	0.04	0.08	0.07	0.05	0.04	0.07
Yttrium	0.11	0.06	0.07	0.05	0.08	0.05	0.04	0.05	0.05
LREE	0.09	0.05	0.04	0.04	0.06	0.02	0.03	0.02	0.05
HREE	0.11	0.11	0.04	0.05	0.07	0.04	0.04	0.04	0.06
TREE	0.11	0.05	0.04	0.05	0.07	0.02	0.03	0.02	0.05
Average	**0.12**	**0.07**	**0.05**	**0.05**	**0.07**	**0.04**	**0.04**	**0.03**	**0.05**

The approach used to develop these algorithms was used with the TruScan^{TM} technology to determine if it would be a feasible endeavor. Initial results were limited to a few samples but have shown promising results. Cores that had been previously analyzed for REE and CM content were submitted to Boart Longyear and analyzed with minimal guidance. Figures 6 and 7 show an example of initial results. Currently, when core samples are subjected to REE-CM analysis, sections of the seams are taken and submitted to a lab for ICP-MS analysis. The analysis provides one measurement value for that sample which is most likely an average of the concentration of that section based on the sample preparation processes. For example, sample 1 in Figure 6 is from a 1-foot section of coal seam. As a result, the ICP-MS value is an average of the REE content for that full length. The TruScan^{TM} technology is able to take measurements at smaller increments (nearly continuous) and can highlight the variability within that section. For sample 1, the ICP-MS analysis showed a concentration of 60.96 ppm and the average of all of the TruScan^{TM} data points is 56.5 ppm. Those values are similar, which shows that the technology is feasible. However, it can be seen that the REE content appears to vary throughout the length of that sample and appears to be above 200 ppm at one end. This detail is lost in some sampling efforts. Sample 2 is a 4.8 inch sample and shows similar results.

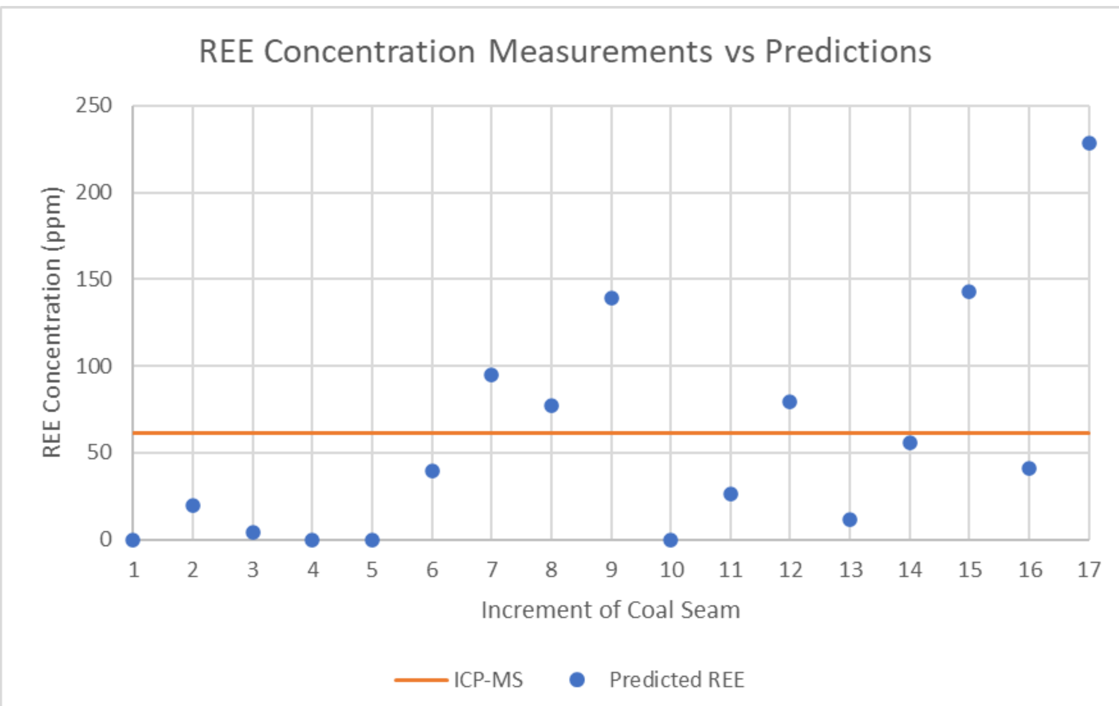


Figure 6. Predicted total REE results from TruScan^{TM} XRF spectra (sample 1).

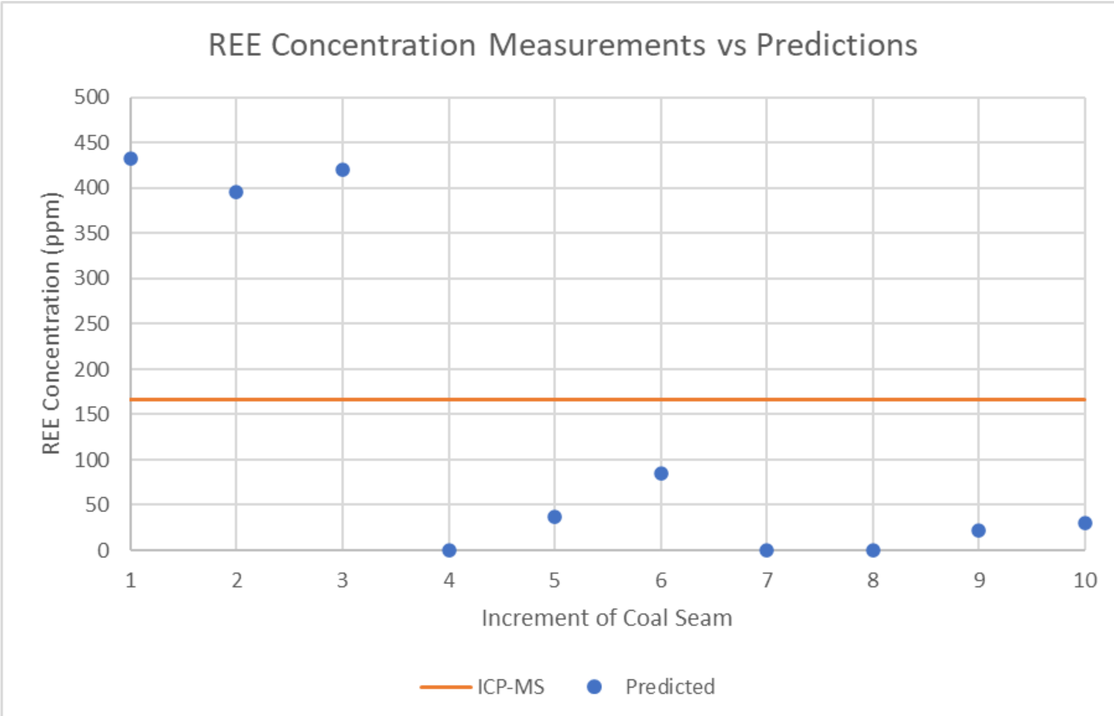


Figure 7. Predicted total REE results from TruScan™ XRF spectra (sample 2).

In addition to the detailed analysis that this technology can provide, this data can be collected in the field, at the drill site, within hours of collecting the drill core. Submitting samples for ICP-MS analysis can take multiple weeks to get results and is an expensive analytical method. This on-site data collection method could reduce costs of exploration through reduced analytical costs as well as providing near-immediate feedback to the team so that the team is able to make quick decisions of where to conduct on-going drilling.

Qualifications

Mr. Alex Benson, Sr. Project Manager, will be responsible for managing the project. Mr. Benson has focused his attention on REE-CM measurement and recovery from coal. He has extensive experience with the High REE-CM-containing coals in the Williston Basin and has worked with the ND Geological survey to obtain larger quantities of samples for testing. Mr. Benson also brings experience in moving technologies from R&D to production as well as in the management and supervision of large teams.

Dr. Steve Benson, Microbeam President, is a world class expert on the forms and occurrence of major, minor, and trace elements including REE and CM in coal and associated materials. Dr. Benson also conducted extensive work on the development of automated scanning electron microscope analysis of fuels and ash-related materials. He has worked extensively with coal beneficiation, combustion, gasification, and air pollution control technologies. Dr. Benson was the PI for the Phase 1 DOE funded efforts on REE in ND. He manages the Microbeam team that consists of highly talented and trained engineers (chemical, mechanical, and electrical), chemists, data scientists, and biologist who have conducted over 1600 projects worldwide on the association and behavior of major, minor and trace elements in coal, biomass, petroleum, and wastes and their fate in and impact on energy conversion systems. This information, combined with Microbeam's expertise associated with the ability to determine the abundance and forms of REE-CM in coal and ash-related materials, make Microbeam uniquely qualified to lead this effort and to successfully achieve the objectives of the project.

Mr. Eric Kolb, Research Engineer, has extensive experience with the extraction of REE and CM from coal. Eric has been designing and constructing a pilot REE processing facility over the past two years. He was involved in the development of the handheld XRF REE predictive algorithms. Eric has also been involved in drilling efforts related to REE resource exploration.

Mr. John Newcomb, Associate Research Engineer, has experience with collecting, analyzing, and modeling samples for REE concentrations. John has conducted sample collection during reconnaissance and drilling efforts for exploration. He has conducted analysis that has continued the development of the REE predictive algorithms and used analytical results to develop resource estimations and models. John has experience with reservoir modeling/simulation along with well bore modeling with cross sections.

Mr. Seth Thoelke, Computer Scientist, has experience in developing predictive algorithms using neural networks and machine learning. He created algorithms for total REE, heavy REE, light REE, and individual REE concentrations for XRF and full stream elemental analyzers (FSEA).

Mr. Shaun O'Brien, Geoscientist Manager, conducts global oversight on training and development of geoscientists within Boart Longyear. His responsibilities include providing technical guidance and operational support to operations and clients, especially with respect to the TruScan™ technology. In his previous role as a Geoscientist, Shaun combined geological inferences, geochemical analysis, and spectral interrogation to develop matrix-matched calibrations for the TruScan™ XRF core analysis system.

Value to North Dakota

There are three main opportunities that this project can provide for North Dakota:

1. A domestic resource of REE-CM - Currently, the United States is nearly 100% reliant on imports of REEs. The market is dominated by China (both industrially and politically). China has over 80% of the total mining and concentrating market, restricting new entities from joining the market. 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. Developing a domestic source will provide an increase in jobs in the recovery, separation, and utilization of REE-CM in advanced products, such as magnets.
2. Lower cost, more time efficient method for resource exploration – the development of REE-CM algorithms for the use with XRF that can be combined with the TruScan™ technology will allow for exploration efforts for REE-CM to be completed faster and cheaper. This will help in evaluating the overall REE-CM resource in ND as well as provide information to the mine that can be used to selectively mine.

3. A resource of materials that includes a clean coal byproduct after the removal of REE-CM and other organically associated elements such as sodium. The cleaned coal has properties that enable it to be an excellent feedstock for the production of building material, pitch, and advanced carbon products.

Management

Microbeam will manage execution of the project to meet the objectives and timelines discussed in this proposal. NACC will lead the mine planning and drilling activities. Figure 8 shows the organizational chart for this project. MTI will oversee the project and will manage the project schedule. Mr. Alex Benson is the PI on the project and will coordinate the efforts with the assistance of other team members. MTI uses the management software Smartsheet to manage projects. Using this software, the team will be able to oversee project action items, owners, and due dates. The team will meet on a biweekly basis or as-needed to review action items. In these meetings, the team will discuss what is needed to keep the project on track and how to work through any issues that arise that may affect the overall project timeline.

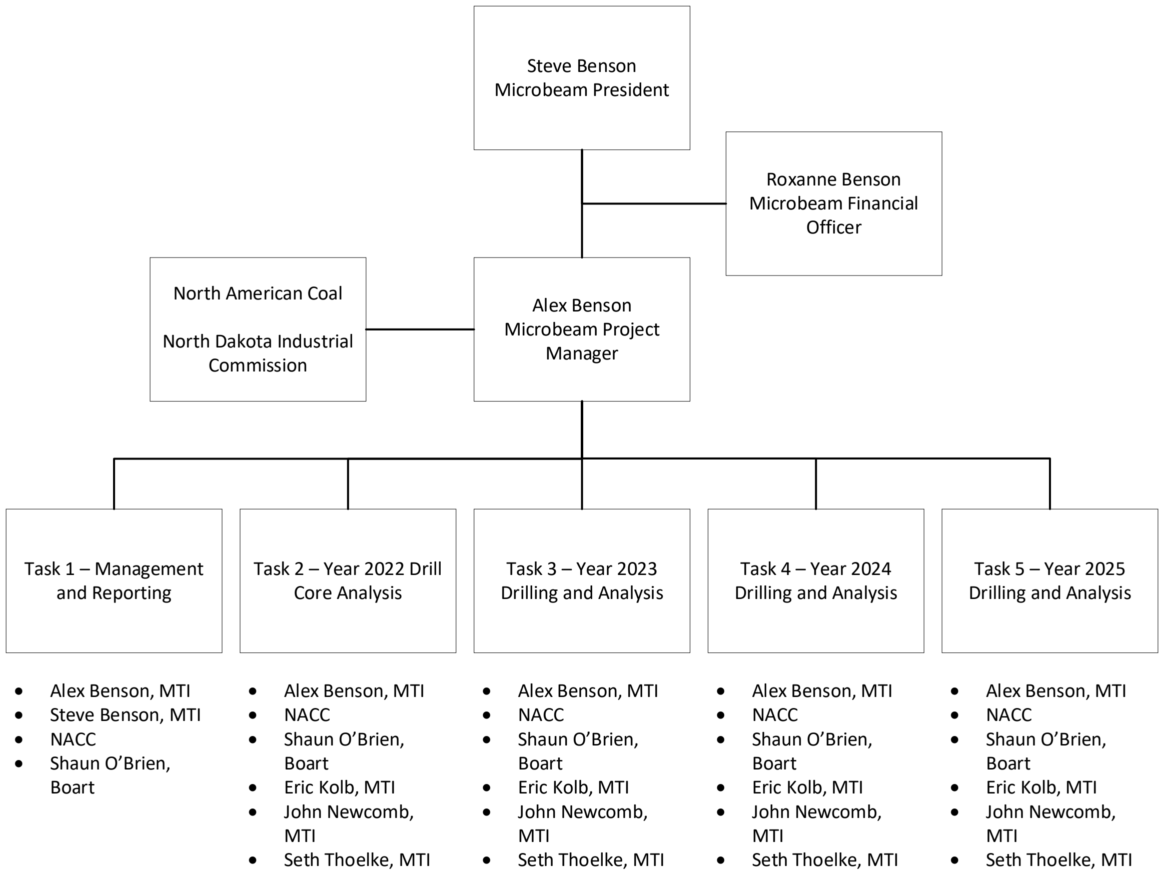


Figure 8. Organizational and management structure.

Timetable

The team is proposing a 3-year project. The timeline is given in Figure 9.

	Task Name	Start	Finish
1	Task 1. Project Management and Reporting	01/02/23	12/31/25
2	Task 2. Year 2022 Analysis	01/16/23	04/28/23
3	Subtask 2.1 Sample Selection and Procurement	01/16/23	02/17/23
4	Subtask 2.2 Sample Characterization (Clay, REE, Waste Coal)	02/20/23	04/07/23
5	Subtask 2.3 Resource Evaluation and Geological Modeling	03/20/23	04/28/23
6	Subtask 2.4 TruScan Correlation Development	01/30/23	04/07/23
7	Task 3. Year 2023 Drilling & Analysis	04/10/23	04/30/24
8	Subtask 3.1 Drill Planning	05/01/23	06/30/23
9	Subtask 3.2 Drilling	07/03/23	09/29/23
10	Subtask 3.3 Sample Selection and Procurement	07/17/23	10/16/23
11	Subtask 3.4 Sample Characterization (Clay, REE, Waste Coal)	08/07/23	01/05/24
12	Subtask 3.5 Resource Evaluation and Geological Modeling	09/04/23	02/16/24
13	Subtask 3.6 TruScan Correlation Testing and Improvement	04/10/23	04/30/24
14	Task 4. Year 2024 Drilling & Analysis	05/01/24	04/30/25
15	Subtask 4.1 Drill Planning	05/01/24	07/02/24
16	Subtask 4.2 Drilling	07/03/24	09/30/24
17	Subtask 4.3 Sample Selection and Procurement	07/17/24	10/15/24
18	Subtask 4.4 Sample Characterization (Clay, REE, Waste Coal)	08/07/24	01/07/25
19	Subtask 4.5 Resource Evaluation and Geological Modeling	09/04/24	02/18/25
20	Subtask 4.6 TruScan Correlation and Validation	05/01/24	04/30/25
21	Task 5. Year 2025 Drilling & Analysis	05/01/25	12/05/25
22	Subtask 4.1 Drill Planning	05/01/25	06/27/25
23	Subtask 4.2 Drilling	06/30/25	09/30/25
24	Subtask 4.3 Sample Selection and Procurement	07/14/25	10/10/25
25	Subtask 4.4 Sample Characterization (Clay, REE, Waste Coal)	08/04/25	12/05/25
26	Subtask 4.5 Resource Evaluation and Geological Modeling	09/01/25	12/05/25
27	Subtask 4.6 TruScan Correlation and Validation	05/01/25	12/03/25

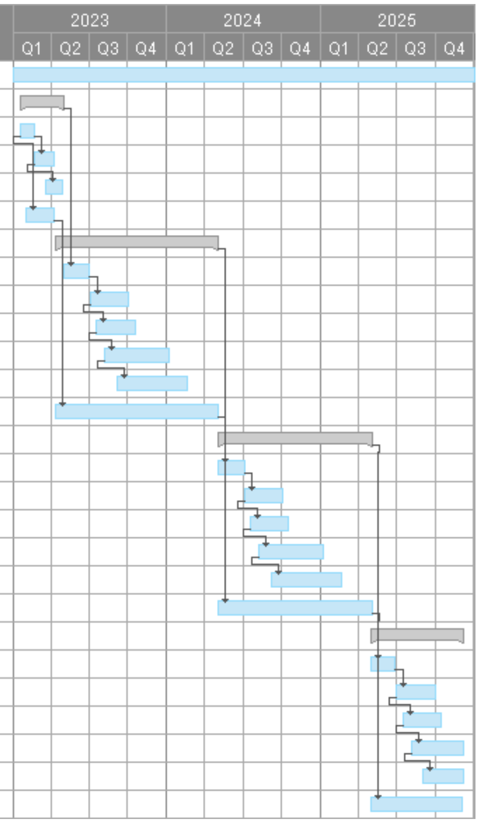


Figure 9. Project timeline.

Budget

The overall project is summarized in Table 4. The budget includes the purchase of Maptek Vulcan GeoModeller software for $60,617 to be used for modeling of the REE-CM, sediment, and carbon ore resources.

Budget Period 1 include Tasks 1, 2, and 3 (January 2023 through April 2024) and Budget Period 2 includes Tasks 1, 4, and 5 (May 2024 through December 2025).

Table 4. Overall project budget including cost share.

Total Project Budget:	BP 1 (Tasks 1, 2, and 3)	BP 2 (Tasks 1, 4, and 5)	Total
A&B. Total Salaries	$ 135,089.03	$ 176,439.48	$ 311,528.51
Total Fringe Benefits	$ 42,728.66	$ 55,807.81	$ 98,536.47
Total Salaries & Fringe Benfits	$ 177,817.69	$ 232,247.29	$ 410,064.98
C. Software	$ 60,616.31	$ -	$ 60,616.31
D. Travel	$ 6,063.50	$ 5,949.00	$ 12,012.50
E. Participant/Trainee Support Costs	$ -	$ -	$ -
F1. Supplies	$ 1,000.00	$ 2,000.00	$ 3,000.00
F3. Consultants	$ -	$ -	$ -
F5. Subawards	$ 16,100.00	$ 53,200.00	$ 69,300.00
F8. Other: Analysis	$ 142,662.92	$ 231,497.03	$ 374,159.95
G. Total Direct Costs	$ 404,260.42	$ 524,893.31	$ 929,153.73
H. Indirect costs			
Labor Overhead of Direct Cost	$ 55,372.43	$ 72,321.81	$ 127,694.23
General & Administrative	$ 74,647.30	$ 107,498.91	$ 182,146.21
Total Indirect Costs	$ 130,019.73	$ 179,820.71	$ 309,840.44
I. Total Direct and Indirect Costs	$ 534,280.15	$ 704,714.03	$ 1,238,994.18
J. Fee	$ -	$ -	$ -
K. Total Costs & Fee	$ 534,280.15	$ 704,714.03	$ 1,238,994.18
Cost Share: NACC/Boart/MTI	$ 409,000.00	$ 830,000.00	$ 1,239,000.00
Total Project Costs	$ 943,280.15	$ 1,534,714.03	$ 2,477,994.18

Table 5 lists the planned number of samples to be analyzed as part of this project. Throughout the project, the team will select sections of the drill cores that include coal seams and surrounding clay and sediments. Depending on the seam thickness, a number of samples will be taken from that seam to be analyzed. Specific to REE-CM, the seams will be divided into subsections so that the variation throughout the depth of the seam can be analyzed. The sections within the coal seams will be subject to

TruScan™ analysis, which will provide continuous analysis across the full length of the seam. The seam thickness will also impact the number of samples that are submitted for CCSEM, morphology, proximate/ultimate, partial chemical fractionation, and ash composition. The quantities given in Table 5 are based on initial conversations within the team and previous core analysis efforts.

Table 5. List of analysis and number of samples.

	Budget Period 1			Budget Period 2		
	Task 1 - Management and Reporting	Task 2 - 2022 Drilling Analysis	Task 3 - 2023 Drilling & Analysis	Task 4 - 2024 Drilling & Analysis	Task 5 - 2025 Drilling & Analysis	Total
Sample Preparation	0	55	210	220	220	**705**
CCSEM	0	5	10	20	20	**55**
Morphology	0	30	80	80	80	**270**
Proximate/Ultimate	0	25	50	50	50	**175**
ICP-MS	0	50	200	200	200	**650**
Partial Chemical Fractionation	0	2	3	3	3	**11**
Ash Composition	0	25	50	50	50	**175**

Matching Funds

The total matching funds for this project is $1,239,000.

North American Coal Corporation is providing matching funds in the form of inkind costs of $1,200,000. The inkind cost will include drilling efforts, supplying samples for analysis, engineering, and geological modeling.

Boart Longyear is providing matching funds in the form of inkind costs of $27,000. The inkind costs will include analysis of samples on the TruScan™ system at their laboratory.

Microbeam Technologies Inc. is providing matching funds in the form of inkind costs of $12,000. The inkind costs will include analysis of the samples at the MTI laboratory to evaluate modes of occurrence and extractability of various elements from the coal.

Tax Liability

None

Confidential Information

No confidential information is included in this proposal.

Appendices

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Resumes

Alex Benson
Sr. Project Manager
Microbeam Technologies Incorporated
Grand Forks, ND 58202

Areas of Expertise

Alex Benson's principal areas of interest and expertise is in project management and technology commercialization. Alex manages and conducts projects for government and industry clients on rare earth and critical minerals along with energy conversion system performance.

Education and Training

University of St. Thomas	Mechanical Engineering	B.S. 2011

Professional Experience

2019 – Present Sr. Project Manager, Microbeam Technologies Incorporated. Alex Benson is responsible for the management of multiple commercial projects and subcontracts on Department of Energy projects. He develops project plans and manages resources to meet deadlines and financial commitments. He has created commercialization plans for a DOE sponsored Rare Earth Element extraction from coal project. Alex also interprets analysis results and uses computer-based models to predict fuel performance for multiple fuel types. Mr. Benson also prepares proposals and writes reports for clients.

2017 – 2019 Sr. Research Engineer (part-time), Microbeam Technologies Incorporated. Alex Benson analyzed datasets using statistical methods to determine potential relationships and correlations between fuel properties and plant parameters. Worked with computer scientists to develop neural networks based on observed correlations.

2017 – 2019 Manufacturing Manager, Medtronic – Minimally Invasive Technology Group. Alex Benson managed manufacturing operations of a medical device manufacturing plant with an annual budgeted Cost of Production of $360M. He was responsible for managing a three-shift manufacturing team of 7 production supervisors and 350+ production personnel. He managed manufacturing build plans to meet financial commitments and demand requirements for 134 SKUs, including developing production capacity, growth, and expansion plans to meet customer demand. He was responsible for ensuring his production team met demand while providing products that meet stringent FDA standards.

2016 – 2017 Sr. Product Engineer, Medtronic – Minimally Invasive Technology Group. Alex Benson lead commercialization activities for new product launches related to manufacturing build plans, engineering line design and validation to meet FDA quality requirements, and production personnel training. He implemented process improvements of new manufacturing lines to improve output, yield, and efficiency, using statistical analysis and six sigma tools.

2015 – 2016 Sr. Manufacturing Engineer, Medtronic Energy and Component Center. Alex Benson was responsible for providing 24-hour engineering support of lithium ion battery manufacturing lines. He managed a cross-functional team through the commercialization of new lithium ion battery manufacturing lines, leading yield and efficiency improvements through product design and equipment improvement projects.

2012 – 2015 Manufacturing Engineer, American Medical Systems. Alex Benson oversaw multiple medical device manufacturing lines, managing yield, efficiency, and other process improvement projects. He was a member of a team to develop and commercialize a novel antimicrobial coating process for implantable medical devices.

Selected Publications/Patent Applications

Steven Benson, Shuchita Patwardhan, David Stadem, James Langfeld, Alex Benson, and Travis Desell, "Application of Condition Based Monitoring and Neural Networks to Predict the Impact of Ash Deposition on Plant Performance," Accepted for publication.

Benson A, Benson S, Fuka M, Kolb E., inventors. Microbeam Technologies Inc., assignee. System And Method For Predicting Abundance Of Rare Earth Elements With Handheld X-Ray Fluorescence. United States of America 63/148,292. 2021 February 11.

Synergistic Activities

1. "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks"(DE-FE0031835). Subcontract to the University of North Dakota.
2. "North Dakota Rare Earth and Critical Element Resource Evaluation" (FY21-XCV-235) – North Dakota Industrial Commission funded research project.
3. "Production of Germanium and Gallium Concentrates for Industrial Process" (DE-FE0032124)
4. "Conceptual Design of a One Ton Per Day Rare Earth Oxide Extraction and Concentration Plant from Low-Rank Coal Resources" (89243320RFE000032). Subcontract to University of North Dakota.
5. "Development of of Low-Cost Rare Earth Element Analysis and Sorting Method" - North Dakota Industrial Commission funded research project. Developing an REE predictive algorithm to be used with pXRF and PGNAA to assist in the exploration, identification, and sorting of REE in coal.

Steven A. Benson, Ph.D.
President
Microbeam Technologies Incorporated
Grand Forks, ND 58202

Areas of Expertise

Dr. Benson's principal areas of interest and expertise include development and management of complex multidisciplinary programs that are focused on solving environmental and energy problems.

Education and Training

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

Research and Professional Experience

1991 – Present President, Microbeam Technologies Incorporated. Dr. Benson founded Microbeam Technologies Incorporated (MTI), a spin-off company from the University of North Dakota to conduct service analysis of materials using automated methods aimed at assessing efficiency and reliability problems in renewable and fossil energy conversion systems. MTI began operations in 1992 and has conducted over 1600 projects for industry, government, and research organizations worldwide. Since 2017, Dr. Benson has been working exclusively at MTI and is responsible for technical direction, data interpretation and proposal preparation.

2015 – 2017 Associate Vice President for Research, Energy & Environmental Research Center, University of North Dakota – Dr. Benson was responsible for assisting EERC in developing and managing projects on the clean and efficient use of fossil and renewable fuels.

2008 – 2017 Chair/Professor/Director – Petroleum Engineering, Chemical Engineering, and Institute for Energy Studies at the University of North Dakota. Dr. Benson was responsible for teaching courses on energy production and associated environmental issues. In addition, Dr. Benson developed and managed projects and conducted research, development, and demonstration projects on 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 was responsible for leading a group of about 30 highly specialized group of chemical, mechanical and civil engineers along with scientists whose aim was 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.

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 – Mr. Benson was responsible for management and supervision of research on coal geochemistry.

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

Selected Publications and Presentations – Dr. Benson is author and co-author of over 200 publications

1. Desell, T., ElSaid, A., Lyu, Z., Stadem, D., Patwardhan, S., Benson, S., Long term predictions of coal fired power plant data using evolved recurrent neural networks. at -Automatisierungstechnik, 68(2), 130-139, 2020.
2. Laudal, D. A., Benson, S.A., Palo, D., and Addleman, R.S., Rare Earth Elements in North Dakota Lignite Coal and Lignite-Related Materials, ASME, J. Energy Resour. Technol 140(6), 062205 (Apr 09, 2018) (9 pages).
3. Laudal, D. A., Benson, S.A., Addleman, R.S., and Palo, D., Leaching behavior of rare earth elements in Fort Union lignite coals of North America, International Journal of Coal Geology, Volume 191, 15 April 2018, Pages 112-124.
4. 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.
5. James, D.W., Krishnamoorthy, G., Benson, S.A., and Seames, W.S., "Modeling trace element partitioning during coal combustion," Fuel Processing Technology, 126 (2014) 284-297\
6. 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.
7. Matsuoka, K.; Suzuki, Y.; Eylands, K.E.; Benson, S.A.; Tomita, A. CCSEM Study of Ash-Forming Reactions During Lignite Gasification. Fuel 2006, 85, 2371–2376.
8. Yan, L.; Jensen, R.R.; Laumb, J.D.; Benson, S.A. Predicting Ash Particle-Size and Composition Distribution from Coal Biomass Cofiring. Presented at the Engineering Foundation Conference Power Production in the 21st Century: Impacts of Fuel Quality and Operations, Snowbird, UT, Oct 28–Nov 2, 2001.
9. Trace Element Transformations in Coal Fired Power Systems, Special Issue of Fuel Process. Technol.; Benson, S.A.; Steadman, E.N.; Mehta, A.K.; Schmidt, C.E., Eds.; Elsevier Science Publishers: Amsterdam, 1994; Vol. 39, Nos. 1–3, 492 p.
10. Inorganic Transformations and Ash Deposition During Combustion; Benson, S.A., Ed.; American Society of Mechanical Engineers: New York, 1992.

Patents

- 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
- 10,669,610 – Rare earth element extraction from coal

Awards

- Lignite Energy Council, Distinguished Service Award, Research & Development, 1997
- GEMS Award, College of Earth and Mineral Sciences, Pennsylvania State University, 2002
- Lignite Energy Council, Distinguished Service Award, Research & Development, 2003
- Lignite Energy Council, Distinguished Service Award, Government Action Program (Regulatory), 2005
- Lignite Energy Council, Distinguished Service Award, Research & Development, 2008
- UND Spirit Award for Teaching and Research, 2013
- Science and Technology Award, Impacts of Fuel Impurities Conference, 2014.

Eric Kolb
Research Engineer: Lead for Engineering Design/Construction/Operations Projects
Microbeam Technologies Incorporated
Grand Forks, ND 58202

Areas of Expertise

Eric's principal area of interest and expertise includes development, design, and fabrication of engineering problems focused on solving energy and critical mineral resources.

Education and Training

University of North Dakota	Mechanical Engineering	B.S. 2020

Professional Experience

2021 – Present Research Engineer, Microbeam Technologies Incorporated. Eric Kolb's primary focus is design, fabrication, and operating a rare earth element extraction plant at a pilot scale. Responsibilities and skills included pipe fitting, plumbing, welding, carpentry, HVAC, and operations of large equipment. Other work includes developing methods for analyzing coal for REE and developing predictive algorithms. Also, when needed, works on other projects focused on environmental and energy technology that need design, construction, and operations. Eric has experience working with North Dakota geology conducting a resource evaluation gathering cores.

2020 – 2021 Associate Research Engineer, Microbeam Technologies Incorporated. Eric worked on design developing and manufacturing a rare earth element extraction plant at pilot scale. Also worked on other projects conducting laboratory experiments, data interpretation, and providing design experience.

2019 – 2020 Intern, Microbeam Technologies incorporated. Eric Kolb worked on various projects with power systems and gasification technology. Conducted various laboratory experiments for projects gathering data and doing data interpretation. Also, operated and maintained the laboratory and scanning electron microscope.

Publications

Benson A, Benson S, Fuka M, Kolb E. Development of Low-Cost Rare Earth Element Analysis and Sorting Methods. [revised 2021 January]. [Print]. 2017 July. Other: Contract No. FY18LXXXIII-213

Patents

Benson A, Benson S, Fuka M, Kolb E., inventors. Microbeam Technologies Inc., assignee. System And Method For Predicting Abundance Of Rare Earth Elements With Handheld X-Ray Fluorescence. United States of America 63/148,292. 2021 February 11.

Synergistic Activities

1. SME Fundamentals of minerals and metallurgical processing class (SME Member).
2. "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks"(DE-FE0031835). Subcontract to the University of North Dakota.
3. “North Dakota Rare Earth and Critical Element Resource Evaluation” (FY21-XCV-235) – North Dakota Industrial Commission funded research project.
4. “Production of Germanium and Gallium Concentrates for Industrial Process” (DE-FE0032124)
5. "Conceptual Design of a One Ton Per Day Rare Earth Oxide Extraction and Concentration Plant from Low-Rank Coal Resources" (89243320RFE000032). Subcontract to University of North Dakota.
6. "Development of of Low-Cost Rare Earth Element Analysis and Sorting Method" - North Dakota Industrial Commission funded research project. Developing an REE predictive algorithm to be used with pXRF and PGNAA to assist in the exploration, identification, and sorting of REE in coal.

John Newcomb
Associate Engineer
Microbeam Technologies Incorporated
Grand Forks, ND 58202

Areas of Expertise

John Newcomb’s principal area of interest and expertise is in measurement and recovery of rare earth and critical minerals associated in carbon ore, wastes, and ash materials. He has experience in various methods of measurement including x-ray fluorescence, inductively coupled plasma/mass spectroscopy, SEM, chemical fractionation, neutron activation, and gamma ray attenuation. John has experience in exploration activities related to REE and oil and gas drilling. He has experience with log analysis software CMG, Petra, Techlog, and CMG.

Education and Training

University of North Dakota	Petroleum Engineering	B.S. 2016

Professional Experience

2021 – Present Associate Research Engineer, Microbeam Technologies Incorporated. John Newcomb is responsible for REE sample collection, preparation, and analysis. He has experience with handheld XRF analysis. John has studied REE and lithology and mineral relationships. He also has experience in REE pilot plant design and construction. He has skills in fabrication, welding, and pipe fitting. John has been involved in REE resource evaluations including experience in core drilling and collection and logging core samples, including those from coal outcrops.

Synergistic Activities

1. SME Fundamentals of minerals and metallurgical processing class (SME Member).
2. "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks"(DE-FE0031835). Subcontract to the University of North Dakota.
3. "North Dakota Rare Earth and Critical Element Resource Evaluation" (FY21-XCV-235) – North Dakota Industrial Commission funded research project.
4. "Development of Sorting Algorithm for Critical Mineral-Rich Coal Resource Feedstocks for use in Full-Stream Analyzers" (DE-SC0021837)

Seth Thoelke
Computer Scientist
Microbeam Technologies Incorporated
Grand Forks, ND 58202

Areas of Expertise

Seth Thoelke's principal area of interest and expertise is in developing tools and software for the purpose of simplifying existing processes and enabling new processes related to power plant management, analysis of sensor data, and fuel composition prediction and analysis.

Education and Training

University of North Dakota	Computer Science	B.S. 2020
University of North Dakota	Honors	B.A. 2020

Professional Experience

2022 – Present Computer Scientist, Microbeam Technologies Incorporated. Seth is responsible for software development and management, neural network training, data analysis, and report writing and editing. In this role, he has also helped conduct field tests at power plants, collecting coal, slag, and ash samples for analysis. He has trained neural networks in past projects to accurately predict rare earth/critical material contents from raw sensor data.

2021 – 2022 Associate Computer Scientist, Microbeam Technologies Incorporated. Involved in software development and management, neural network training, data analysis, report writing and editing, SEM operation, and lab sample prep.

2019 – 2020 Web Developer, Project Rebel. Designed and implemented 2 long-term web development projects alongside a development team. Was responsible for interfacing with clients to determine needs and develop responsive websites to specification. Trained new intern in the existing product codebase and front-end development concepts.

Publications

1. Lyu Z, Patwardhan S, Stadem D, Langfeld J, Benson S, Thoelke S, Desell T. Neuroevolution of recurrent neural networks for time series forecasting of coal-fired power plant operating parameters. The Genetic and Evolutionary Computation Conference (GECCO 2021). 2021 July 10.

Synergistic Activities

1. Developed neural network algorithm to predict various rare earth elements based on composition data and PGNAA/DGA analysis spectra.
2. Involved with late-stage development, installation, and maintenance of coal tracking (CT) and combustion system performance indices (CSPI) software to optimize performance at a full-scale power plant.
3. “North Dakota Rare Earth and Critical Element Resource Evaluation” (FY21-XCV-235) – North Dakota Industrial Commission funded research project.
4. “Development of Sorting Algorithm for Critical Mineral-Rich Coal Resource Feedstocks for use in Full-Stream Analyzers” (DE-SC0021837)

Shaun O’Brien
TruScan™ Geoscientist Manager
Boart Longyear Australia Pty Ltd
Adelaide, South Australia, Australia

Education and Training

University of Adelaide	Honours Geology	B.S. 2016
University of Adelaide	Mineral Geoscience	B.S. 2015
Flinders University	Education (Biology & Earth Science)	B.E./B.S 2008

Professional Experience

2022 – Present Geoscientist Manager, Boart Longyear. Shaun is a key management, technical, and operational resource in the management, staffing, and support of TruScan™ technology. Responsibilities include global oversight on training and development of Geoscientists within Boart Longyear, provide technical guidance and operational support to operations and clients, and to support integration of sensor technology and process controls.

2018 – 2022 Geoscientist, Boart Longyear, Shaun's primary role was to combine geological inferences, geochemical analysis, and spectral interrogation to develop matrix-matched calibrations for the TruScan^{TM} XRF core analysis system. Another essential element of the role is the operational supervision of TruScan^{TM} projects to ensure the quality, integrity, and timeliness of TruScan^{TM} data is maintained, from various sites across Australia.

2016 – 2018 Graduate Mine Geologist, Glencore Mount Isa Mines, Shaun's responsibilities included assisting with diamond drilling operations, contribute to geological interpretation by mapping underground development for structure, lithology, alteration and sulphide minerals, liaise with operational and scheduling personnel, validate resource model through regular inspections of mining activities and make logical geological interpretations to inform the model. Shaun oversaw a measurable improvement in diamond drill core handling and presentation standards through developing and delivering rig-side training and workshops to in-house drilling department and contractors, implemented gyroscopic down hole tools to mitigate high magnetic response in drilling, including facilitating training of drillers at the rig-side for the collection and quality assurance of survey data.

2014 – 2016 Teacher, DECD, South Aust & Horizon Teachers, London.

2010 – 2012 Field Assistant, Zonge Engineering and Research Organisation, Shaun would maintain and ensure the safe operation of survey equipment for a variety of electrical geophysical surveys, including IP, EM, CSAMT.

North American Coal Corporation Letter of Support (PENDING FINAL SIGNATURE)