

Lignite Research, Development and
Marketing Program

North Dakota Industrial Commission

Application

Project Title: DEMONSTRATION OF REE-CM
EXPLORATION AND CHARACTERIZATION
TECHNOLOGIES FOR ND LIGNITE

Applicant: Microbeam Technologies
Incorporated

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ABSTRACT

Objective:

The overall objective is to demonstrate critical mineral (CM) including rare earth element (REE) exploration technologies and characterize the Center Mine coal resource for available REE-CM.

The two technologies that will be demonstrated are Microbeam's RapidREE™ and XREE™ technologies. These are methods for estimating REE-CM concentrations in the field using commercial analytical equipment that do not currently provide this information. The RapidREE™ technology utilizes standard downhole logging tools while the XREE™ technology utilizes drill core XRF scanning equipment. Both methods can be used in the field and provide REE-CM estimations in a short period of time (within 24 hours of sample collection).

Expected Results

This project is expected to provide a further understanding of the REE-CM accumulation mechanisms and associations of REE-CM in ND lignite resources. This project will also demonstrate two technologies that can improve REE-CM exploration efforts. The results of this project will demonstrate the measurable improvement of utilizing these technologies for REE-CM exploration.

Duration

The duration of the project will be 32 months.

Total Project Cost

The total project cost is \$1,956,105. The project team is requesting \$971,225 from NDIC and will be providing \$984,880 in matching funds.

Participants

Microbeam Technologies Inc. – Microbeam Technologies Inc. will be the project lead for this project. With over 30 years of experience in the fuel quality and plant performance industry, Microbeam has a strong understanding of the associations of minerals and elements (such as REE, Ge, and Ga) in ND lignite. Microbeam has conducted over 1700 projects and analyzed over 16,000 samples that have supported the development of advanced technologies for the detection, separation, and extraction of REE, Ge, and Ga from lignite-based sources.

BNI Energy – BNI Energy is the Project Sponsor and is providing a majority of the matching funds as part of this project. BNI Coal, a subsidiary of BNI Energy, operates the Center Mine in Center, ND, which provides coal to the Milton R. Young Power Plant and provides energy to customers in North Dakota and Minnesota. BNI is interested in being a host site for the demonstration of Microbeam's RapidREE™ and XREE™ technologies and using these technologies to better understand the REE-CM in their lignite resources.

PROJECT SUMMARY

Lignite resources have the potential to be a source for critical elements, also known as critical minerals (CM), that include rare earth elements (REE). These elements are essential in the production 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 U.S. national security and economic growth. The assessment of the abundance and form of the REE-CM combined with the development of rapid and accurate methods to assess and recover REE-CM from lignite coal are key components for the growth of a REE-CM industry in North Dakota.

PROJECT DESCRIPTION

Objectives

The overall objective of this project is to demonstrate near real time methods to measure REE-CM contents during exploration, enhancing and excelling resource identification and recovery and to determine the abundance and distribution of REE-CM in Center Mine Lignite coal seams and associated sediments.

The specific objectives include:

- Work with BNI to identify samples for detailed analysis to determine the abundance and form of REE-CM in the coals mined.
- Review the stratigraphy and identify any materials that can be used to identify geologic processes that contribute to the accumulation/enrichment of REE-CM including rare earth elements in Center Mine Lignite.
- Work with BNI to identify locations for drilling to obtain samples of the coal bearing strata.
- Plan sampling and on-site REE measurements using down-hole e-logging tools enhanced with RapidREE™.
- Perform onsite core analysis with non-destructive Veracio TruScan™ core imaging and composition analysis system combined with Microbeam's XREE™ technology to predict REE-CM abundance continuously across the coal seams and associate sediments.
- Obtain core samples using standard methods (ICP-MS, INAA, and others) to determine the abundance of REE-CM.
- Compare the results of standard methods with XREE™ and RapidREE™ predictive methods. The XREE™ technology includes rare earth elements and germanium and gallium. The RapidREE™ technology is aimed at measuring REE.
- Optimization of the XREE™ and RapidREE™ technology will be enhanced (trained) using additional data obtained early in the project followed by validation in the final project year.

Methodology

Drill Planning and Field Sampling – The project will leverage Center mine’s existing annual drilling program to minimize incremental cost while maximizing geological coverage. Drillhole selection will combine grid-based drilling for regional continuity with targeted holes designed to capture under-sampled seams, seam margins, and areas with potential REE–CM enrichment.

Sampling will focus on:

- Major and minor coal seams
- Seam roof and floor sediments
- Intra-seam partings and rider seams

Drill cores will be collected and logged for lithology, seam name, depth, and relative seam position (top, middle, bottom). Selected grab or split samples from the mine’s routine sampling program will supplement spatial coverage. Coal seams will be sub-sampled at finer resolution near seam tops and bottoms, where enrichment is often observed, and composited in more uniform mid-seam intervals.

On-Site Core Scanning and Geophysical Logging – Each drillhole will be supported by standard geophysical logging (e.g., density, natural gamma, advanced tools) to confirm seam depths and boundaries. Microbeam’s RapidREE™ technology will be used to predict CM abundance using e-logging data¹. Drill cores will be scanned on site using a portable or trailer-mounted core scanning system capable of acquiring high-resolution imagery and continuous X-ray fluorescence (XRF) spectra. XRF spectral intensity data are processed using the XREE™ algorithms to predict the abundance of REE.

Mineralogical Characterization – A subset of samples spanning low to high REE-CM concentrations will be analyzed using advanced scanning electron microscopy techniques, including morphology analysis, computer-controlled SEM (CCSEM), and phase mapping. These analyses will quantify mineral types, size distributions, and abundance, and identify REE-CM host phases such as organic matter, aluminosilicates, sulfides, and accessory minerals. This information assists in establishing the modes of occurrence of REE–CMs and informs interpretation of geochemical trends and extraction pathways.

Predictive Algorithm Development and Validation – The algorithm will be trained and validated using matched XRF and laboratory datasets. Performance will be evaluated using standard error metrics to ensure robustness and generalizability. While some analytes (e.g., Ge) may be better suited to qualitative or screening-level prediction, the model will reliably identify high-value zones that warrant targeted sampling and further evaluation.

Real-Time Data Integration and Reporting – A user-facing workflow will be employed to rapidly process geophysical and XRF data, generate predicted REE-CM profiles, and visualize results by drillhole, seam, or

¹ Microbeam Technologies Inc. (2025). Final Scientific/Technical Report: Subsurface Characterization of Critical Minerals Using Down Hole Logging Equipment. Prepared for the U.S. Department of Energy, Office of Science, Award No. DE-SC0025054. Principal Investigator: Eric Kolb. Grand Forks, ND.

element. This capability allows same-day or next-day feedback during drilling campaigns, enabling adaptive sampling strategies and early identification of promising intervals.

Three-Dimensional Geological Modeling – Microbeam uses Maptek Vulcan to develop three-dimensional geological models that can be used to visualize individual REE-CM concentrations and calculated parameters (i.e. total REE, heavy/light ratio, etc.). These models use data from the drill cores to interpolate concentrations between the cores and estimate the overall resource grades. Well-developed models can be used to make estimations of total resource available based on grade.

For this project, the elements of focus when discussing REE-CM for analysis and modeling are included in Table 1.

Table 1. List of REE-CM to be included in the proposed project.

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

Scope of Work

The scope of work is designed to meet the project objectives.

Task 1. Management and Reporting

The project will be managed and directed by the PI to meet all technical, schedule and budget objectives. Regular internal project status meetings will be held to coordinate activities to accomplish the work. In addition, the PI will ensure that project plans, results, and decisions are documented, and project reporting requirements are met.

Task 2. Year 2025 Drill Core Analysis

BNI conducts annual drilling for purposes of planning future mining activities. This task will utilize the data and samples from the 2025 drilling activities to prepare for 2026 drilling. These drilling activities include collecting samples that are submitted to external laboratories for major and minor elemental analysis.

Subtask 2.1 Sample Selection and Procurement

Microbeam will review the samples that BNI has available from the 2025 drilling campaign. The physical samples are from the top, middle, and bottom portions of the currently mined seams and from locations throughout the permitted area of the mine. In addition to the physical samples, Microbeam will work with BNI to review the analysis data for these samples and e-logs from drillholes from which the samples were collected.

All of the BNI samples from 2025 will be sent to Microbeam, however, not all of the samples will be submitted for analyses as discussed in Subtask 2.2. Samples selected for analysis will be based on locations of the sample (drillhole locations and locations in the seam), compositional data, and e-log data.

Subtask 2.2 Sample Characterization

The samples submitted to Microbeam in Subtask 2.1 will not require sample preparation as all of the samples were sent to outside laboratory for BNI's standard mine planning analyses and underwent their standard sample preparation steps. Microbeam will conduct analysis as outlined in Table 2.

Table 2. Analysis methods for 2025 samples.

Analysis Method	Laboratory	All/Select Samples	Purpose
RapidREE™	Microbeam	All e-logs	Estimate REE-CM concentrations throughout the depth of the drill hole
X-Ray Fluorescence (XRF)	Microbeam	All	Provide ash composition and preliminary REE-CM screening
Scanning Electron Microscopy (SEM)	Microbeam	Select	Provide information on mineralogy
Trace Element Analysis (Various Methods)	ActLabs	Select	Provide REE-CM concentrations and other trace elements

Microbeam will make predictions of the REE-CM concentrations in the seams based on all of the e-logs collected from the 2025 drilling campaign using the RapidREE™ technology. Microbeam will also conduct XRF analysis for all samples collected in 2025. The XRF analysis will provide ash composition data and will be used as a secondary REE-CM screening method to the RapidREE™ estimations. Based on the results from the RapidREE™ and XRF analyses, a select number of samples will be submitted for SEM and trace element analysis.

Subtask 2.3 Resource Evaluation and Geological Modeling

Microbeam uses Maptek Vulcan software to develop 3D geological models. These models are used to visualize large datasets of information to identify trends and areas of interest based on compositional data. The models are also useful in estimating the resources available as they can calculate the tonnage of material based on a cutoff grade and volume of material.

The results from the XRF and trace element analysis will be used to develop the initial geological model of REE-CM distributions. As the RapidREE™ estimations are validated, that data can also be incorporated into the databases used in the geological models.

Subtask 2.4 Correlation Development

The initial REE-CM estimations made with RapidREE™ technology will be made based on the correlations developed by Microbeam in a previous Department of Energy funded project. The results from the trace element analysis will provide validation of the REE-CM concentrations. The RapidREE™ algorithms will be further trained using additional REE-CM data obtained.

Task 3. Year 2026 Drilling and Analysis

Task 3 will concentrate on a focused exploration based on initial information from Task 2, development of the RapidREE™ technology, demonstration of the XREE™ technology, and improvement of the geological model.

Subtask 3.1 Drill Planning

The 2026 drill planning will include BNI's scheduled mine planning drilling with focused exploration in certain areas based on the 2025 data. As part of the drill planning, the project team will develop a plan for the Veracio TruScan™ deployment and the field test in which the Microbeam team will participate in a weeklong trip to collect drill core samples during BNI's drilling campaign.

The drill core sampling locations will be determined based on regions that showed high REE-CM concentrations, regions that may not have been significantly sampled in 2025, and locations that may have access to seams that weren't previously sampled (or are able to be accessed often).

Subtask 3.2 Drilling

The 2026 drilling will be executed according to the plan developed in Subtask 3.2. BNI will lead the drilling activities including coordinating with the drilling and downhole logging contractors. Microbeam will work with Veracio and the downhole logging contractors to select additional downhole tools such as 9057 - Multi Parameter Neutron Logging Tool to execute on the planned testing and demonstration of the RapidREE™ and XREE™ technologies.

The objective for Microbeam with respect to the RapidREE™ technology during the 2026 field test will be to work with the downhole logging contractors to determine the best methods for integration of the RapidREE™ technology and the e-logging equipment. Generally, the Microbeam team will be provided with the LAS files from the e-logging equipment at the end of the drilling campaign and then will make estimations of the REE-CM concentrations at that time. The goal of the technology is to provide REE-CM estimations in near real-time so Microbeam will need to understand what opportunities there are to get LAS data sooner and how the RapidREE™ technology can be deployed in the field.

The objective for Microbeam with respect to the XREE™ technology during the 2026 field test will be to demonstrate the technology's ability to provide REE-CM estimations within 24 hours of scanning the drill cores.

Subtask 3.3 Sample Selection and Procurement

The drillholes of interest in which drill cores will be collected will be determined in the drill planning and then those drill cores will be collected during the drilling field test. In addition to the drill cores, BNI will be collecting their normal samples from the other drilling locations. These samples will be "grab" samples from the top, middle, and bottoms of the seams intersected during drilling.

The drill planning process will have identified seams and locations of interest so those regions will be selected for further sampling. In addition to those samples, Microbeam will review the REE-CM estimations made using the RapidREE™ and XREE™ technologies and identify samples that will be important for validation and demonstration of those technologies. This will include locations that show high, medium, and low concentrations of REE-CM so that the technologies can be proven over the full range of REE-CM concentrations.

Once a final list of samples is selected, Microbeam will work with BNI to procure the required samples that will be submitted for detailed characterization in Subtask 3.4.

Subtask 3.4 Sample Characterization

Selected samples will be prepared for analysis by grinding and splitting the samples. Microbeam will conduct these activities and submit them to the appropriate laboratory as outlined in Subtask 2.2. In addition to that analysis, Microbeam and/or BNI will submit samples to MVTL for standard analyses such proximate and ultimate analysis. As a result, the planned analysis in this class includes:

- Proximate and ultimate analysis

- Ash composition
- Minerology
- Trace element analysis

Subtask 3.5 Resource Evaluation and Geological Modeling

As the compositional data is received from Subtask 3.4, Microbeam will update the geological model in Maptek Vulcan. Models will be developed for total REE concentration and individual elements.

Subtask 3.6 XREE™ and RapidREE™ Data Validation

The compositional data will be compared to the estimations made by both the RapidREE™ and XREE™ technologies during the field test. Both technologies are developed using neural networks and machine learning methodologies so the algorithms will improve with additional data.

The RapidREE™ technology is still in the development stage so it is expected that the algorithms will need further development compared to the XREE™.

The XREE™ technology development will focus on improvement of the user interface and integration with the TruScan™.

Task 4. Year 2027 Drilling and Analysis

A Go/No-Go decision will be planned at the beginning of each calendar year. This decision will be made between Microbeam, BNI, and NDIC/LRC. The criteria to be considered for the Go/No-Go decision will include:

- Availability of funding (from any entity)
- Project progressing a satisfactory way

In 2027, the team will focus on further utilization of the RapidREE™ and XREE™ technologies during the exploration activities. Microbeam will look to improve on the useability of the XREE™ technology during field tests through improved efficiencies with the TruScan™. Microbeam will look to demonstrate improved algorithms for the RapidREE™ technology and improved integration with the e-logging tools.

Subtask 4.1 Drill Planning

The 2027 drilling plan will continue to focus on areas with limited data and regions of interest based on the 2025 and 2026 data. The project team will develop a plan for the Veracio TruScan™ deployment and the field test in which the Microbeam team will participate in a weeklong (potentially two-week) trip to collect drill core samples during BNI's drilling campaign.

Subtask 4.2 Drilling

The 2027 drilling will execute on the plan developed in Subtask 4.2. BNI will lead the drilling activities including coordinating with the drilling and downhole logging contractors. Microbeam will work with Veracio and the downhole logging contractors to execute on the planned testing and demonstration of the RapidREE™ and XREE™ technologies.

The objective for Microbeam with respect to the RapidREE™ technology during the 2027 field test will be to work with the downhole logging contractors to validate the improved algorithms from 2026 and evaluate the identified improvement opportunities for integration of RapidREE™ with the e-logging software/tools.

The objective for Microbeam with respect to the XREE™ technology during the 2027 field test will be to measure the improvements that it can provide for exploration of REE-CM. This information will be used in the development of the technical and economic assessment of the technology for commercial applications.

Subtask 4.3 Sample Selection and Procurement

The drillholes of interest in which drill cores will be collected will be determined in the drill planning and then those drill cores will be collected during the drilling field test. In addition to the drill cores, BNI will be collecting their normal samples from the other drilling locations. These samples will be “grab” samples from the top, middle, and bottoms of the seams intersected during drilling.

The drill planning process will identify seams and locations of interest for selection for further sampling. In addition to samples collected, Microbeam will review the REE-CM estimations made using the RapidREE™ and XREE™ technologies and identify samples that will be important for validation and demonstration of those technologies. This will include locations that show high, medium, and low concentrations of REE-CM so that the technologies can be proven throughout the full range of REE-CM concentrations.

Once a final list of samples is selected, Microbeam will work with BNI to procure the required samples that will be submitted for detailed characterization in Subtask 4.4.

Subtask 4.4 Sample Characterization

Selected samples will be prepared for analysis by grinding and splitting the samples. Microbeam will conduct these activities and submit them to the appropriate laboratory as outlined in Subtask 2.2. In addition to that analysis, Microbeam and/or BNI will submit samples to MVTL for standard analyses such proximate and ultimate analysis. As a result, the planned analysis in this task includes:

- Proximate and ultimate analysis
- Ash composition
- Minerology
- Trace element analysis

Subtask 4.5 Resource Evaluation and Geological Modeling

As the compositional data is received from Subtask 4.4, Microbeam will update the geological model in Maptek Vulcan. With these updates, Microbeam will be able to begin making resource evaluation estimates based on the modeling. Microbeam will also work with BNI to identify what improvements would be beneficial for their mining activities and how the models can be improved.

Subtask 4.6 XREE™ and RapidREE™ Data Validation

The compositional data will be compared to the estimations made by both the RapidREE™ and XREE™ technologies during the field test.

Microbeam will validate the estimations made by the RapidREE™ technology in 2027 and begin to demonstrate the commercial opportunity for this technology.

The XREE™ technology development will focus on the technical and economic evaluation of the technology based on improvements in efficiency and cost for analysis and turnaround time.

Task 5. Year 2028 Drilling and Analysis

A Go/No-Go decision will be planned at the beginning of each calendar year. This decision will be made between Microbeam, BNI, and NDIC/LRC. The criteria to be considered for the Go/No-Go decision will include:

- Availability of funding (from any entity)
- Project progressing a satisfactory way

In 2028, the team will focus on demonstrating the commercial viability of the RapidREE™ technology and validation of the estimated technical and economic benefits of the XREE™ technology.

Subtask 5.1 Drill Planning

The 2028 drilling plan will continue to focus on areas with limited data and regions of interest based on the previous years' data. The project team will develop a plan for the Veracio TruScan™ deployment and the field test in which the Microbeam team will participate in a weeklong (potentially two-week) trip to collect drill core samples during BNI's drilling campaign.

Subtask 5.2 Drilling

The 2028 drilling will execute on the plan developed in Subtask 5.2. BNI will lead the drilling activities including coordinating with the drilling and downhole logging contractors. Microbeam will work with Veracio and the downhole logging contractors to execute on the planned testing and demonstration of the RapidREE™ and XREE™ technologies.

The objective for Microbeam with respect to the RapidREE™ technology during the 2028 field test will be to continue the demonstration the feasibility of the technology and to work with the downhole logging contractor to determine opportunities for integration of RapidREE™ with the e-logging data reporting in the field. This would provide a faster turnaround time for the results.

The objective for Microbeam with respect to the XREE™ technology during the 2028 field test will be to validate the estimated technical and economical benefits of the XREE™ technology by demonstrating improvements in analysis costs and turnaround of accurate results.

Subtask 5.3 Sample Selection and Procurement

The drillholes of interest in which drill cores will be collected will be determined in the drill planning and then those drill cores will be collected during the drilling field test. In addition to the drill cores, BNI will be collecting their normal samples from the other drilling locations. These samples will be “grab” samples from the top, middle, and bottoms of the seams intersected during drilling.

The drill planning process will have identified seams and locations of interest so those regions will be selected for further sampling. In addition to those samples, Microbeam will review the REE-CM estimations made using the RapidREE™ and XREE™ technologies and identify samples that will be important for validation and demonstration of those technologies. This will include locations that show high, medium, and low concentrations of REE-CM so that the technologies can be proven throughout the full range of REE-CM concentrations.

Once a final list of samples is selected, Microbeam will work with BNI to procure the required samples that will be submitted for detailed characterization in Subtask 5.4.

Subtask 5.4 Sample Characterization

Selected samples will be prepared for analysis by grinding and splitting the samples. Microbeam will conduct these activities and submit them to the appropriate laboratory as outlined in Subtask 2.2. In addition to that analysis, Microbeam and/or BNI will submit samples to MVTL for standard analyses such proximate and ultimate analysis. As a result, the planned analysis in this task includes:

- Proximate and ultimate analysis
- Ash composition
- Minerology
- Trace element analysis

Subtask 5.5 Resource Evaluation and Geological Modeling

As the compositional data is received from Subtask 5.4, Microbeam will update the geological model in Maptek Vulcan. With these updates, Microbeam will improve on the resource evaluation estimates based on the modeling. Microbeam will implement the improvement opportunities identified by BNI in Subtask 4.5.

Subtask 5.6 XREE™ and RapidREE™ Data Validation

The compositional data will be compared to the estimations made by both the RapidREE™ and XREE™ technologies during the field test.

Microbeam will look to validate the estimations made by the RapidREE™ technology in 2028 and demonstrate its technical and economic feasibility.

The XREE™ technology development will focus on the evaluation of how the technology performed with respect to the technical and economic evaluation.

Anticipated Results

The anticipated outcome of this project is a mine-scale assessment of the abundance, distribution, and modes of occurrence of rare earth elements and other critical minerals within active lignite mining operations. The project is expected to identify REE–CM enrichment patterns within coal seams and associated sediments, including stratigraphic controls, seam-margin effects, and mineralogical or organic host relationships that influence recoverability. These results will establish a technical basis for evaluating the resource potential of lignite as a domestic source of critical minerals, reducing uncertainty associated with site-specific variability and supporting more accurate estimates of recoverable REE–CM resources in North Dakota coal deposits.

In addition, the project is expected to demonstrate the effectiveness of rapid, field-deployable analysis methods integrated with predictive modeling to guide sampling and evaluation in near real time. Validated predictive tools will enable operators to identify high-value CM intervals during routine drilling, reducing analytical cost and cycle time while improving decision-making for selective sampling and resource delineation. Collectively, these results will support the development of a scalable and transferable methodology for continued CM assessment across North Dakota lignite mines, strengthening the technical foundation necessary for future recovery, processing, and commercialization efforts.

Facilities

MTI has a nearly 4,000 ft² shop floor that provides space for collection, storage, and preparation of samples. This space also contains an area for laying out drill core samples and sample preparation.

Resources

The project will leverage existing mining, drilling, and analytical resources at BNI Energy's Center Mine, including routine mine planning drill programs, downhole geophysical logging, and established sample handling practices. These existing operations provide cost effective access to drill cores, geologic data, and field infrastructure without requiring new facilities or modifications to mining activities.

Microbeam Technologies will utilize its existing analytical and computational resources, including AI based predictive algorithms (RapidREE™ and XREE™), XRF instrumentation, automated scanning electron

microscopy (SEM/CCSEM), mineralogical and geochemical databases, and geological modeling software. Additional support will be provided through established partnerships with commercial laboratories (e.g., MVTL and ActLabs) and technology providers such as Veracio for TruScan™ core scanning. Collectively, these existing resources ensure the project can be executed efficiently, reliably, and at low incremental cost.

Techniques to Be Used, Their Availability and Capability

Algorithms for REE Assessments

Microbeam has developed predictive algorithms for REE-CM concentrations for various analytical equipment – including XRF, downhole logging tools, prompt gamma neutron activation (PGNA), and dual gamma attenuation (DGA). These algorithms provide estimates of total REEs, heavy REEs, light REEs, and individual REE content. There are two specific technologies that will be used in this project – RapidREE™ and XREE™.

The RapidREE™ technology was developed in a Small Business Innovation Research grant funded by the Department of Energy (DOE). This technology utilized four downhole logging tools as outlined in Table 3. The tools selected were based on common usage, sources used to obtain measurements, and properties measured. This technology allows for the estimation of REE-CM content without the collection of samples.

Table 3. Tools used in development of RapidREE™ and properties measured by each tool.

Name of Tool	Properties Measured
Compensated Density-Photo Electric Logging Tool	Natural Gamma
	Density
	Photoelectric
	Guard Resistivity
	Caliper
Multiparameter E-Log Neutron Logging Tool	Natural Gamma
	Normal Resistivity
	Neutron-Neutron
	Spontaneous Potential
	Tool Orientation
	Tool (X-Y-Z) Movement
	Temperature
Spectral Gamma Logging Tool (often referred to as the K-U-T tool)	Total Gamma
	Potassium (Percent)
	Uranium (PPM)
	Thorium (PPM)
Compensated Density Logging Tool (most commonly used in e-logging)	Spectral Window
	Natural Gamma
	Density
	Guard Resistivity
	Caliper
	Porosity

The XREE™ technology was developed in a previous NDIC funded project (FY22-101-247) using ND lignite coal. This technology will be used to assist in the down-selection of core samples for additional analysis. Using the TruScan™ XRF in partnership with Microbeam's XREE™ provides initial REE-CM measurements in near real-time with accuracy. This reduces overall costs for expensive analysis methods on samples that may not need to be further assessed.

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 method 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 in lignite coal based on solubility in water, ammonium acetate, and hydrochloric acid. 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.

Veracio TruScan™ Core Analysis System

Veracio 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 TruScan™ equipment will be deployed to North Dakota during drilling activities.



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

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 proximate and 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 Microbeam has worked with in previous projects to obtain ICP-MS analysis of coal and related materials for REE-CM and Actlabs was able to provide the most economical pricing for this type of analysis.

Environmental and Economic Impacts while Project is Underway

Environmental impacts during the project will be minimal, since all work is integrated into existing mining operations and routine drilling efforts. It does not require new land disturbance, permitting changes, or additional emissions beyond current practices.

Economically the project will support highly skilled technical and analytical jobs and channel expenditures to labs and service providers in ND. The project will not disrupt mining operations.

Ultimate Technological and Economic Impacts

This project will demonstrate and validate next generation, field deployable technologies for rapid identification and characterization of rare earth elements and other critical minerals (REE CM) within North Dakota lignite. By integrating routine drilling, downhole logging, core scanning, and AI based predictive methods, the project significantly reduces the time, cost, and uncertainty associated with critical mineral exploration. The resulting workflow enables near real time identification of REE CM enriched zones and provides a scalable, transferable framework applicable across North Dakota mines and other U.S. coal basins.

Economically, the project positions North Dakota lignite as a multi value resource that supports future critical mineral recovery, processing, and commercialization while preserving existing mining jobs and creating new opportunities in advanced materials and resource development. At the national level, successful demonstration strengthens domestic critical mineral supply chains, reduces reliance on foreign sources, and supports U.S. energy security, manufacturing competitiveness, and national defense priorities.

Why the Project is Needed

The United States remains highly dependent on foreign sources for rare earth elements and other critical minerals necessary for energy technologies, advanced manufacturing, and national defense, while North Dakota lignite represents a large, under characterized domestic resource with demonstrated potential. This project is needed to overcome the lack of rapid, cost effective, mine compatible tools for assessing critical minerals during routine mining and exploration. By enabling near real time characterization and reducing uncertainty and cost, the project addresses a key barrier to domestic critical mineral development while enhancing the long-term value of North Dakota Lignite.

STANDARDS OF SUCCESS

1. Establishing reliable data on CM abundance, stratigraphic distribution, and modes of occurrence across coal seams and associated sediments, sufficient to distinguish high-value intervals from background material. Success will be demonstrated by integrating laboratory geochemistry, mineralogical characterization, and geological context into a consistent dataset that reduces uncertainty relative to prior exploration efforts and supports informed evaluation of recoverable critical mineral resources.
2. Demonstrating the ability of rapid, field-deployable measurement and predictive capabilities that are compatible with routine mine drilling programs. This includes validating on-site or near real-time

measurement methods and AI-based predictive tools that can reliably identify REE–CM-enriched intervals during drilling or core handling, with accuracy sufficient to guide selective sampling and reduce analytical cost and turnaround time. Meeting this standard will show that REE–CM assessment can be conducted efficiently at scale and integrated into ongoing mine operations without disrupting production.

3. Finally, the project will succeed if it creates clear value pathways for North Dakota lignite resources by producing results that are applicable to future recovery, processing, and commercialization studies. This includes demonstrating that the methodology can be replicated across multiple lignite operations, providing actionable data to industry stakeholders, and establishing a technical foundation for subsequent extraction, beneficiation, or utilization projects. Collectively, these outcomes will advance NDIC program goals by enhancing the long-term economic value of lignite, strengthening domestic critical mineral supply potential, and supporting technology development within North Dakota.

BACKGROUND

Geologic Setting

North Dakota lignite deposits occur primarily within the Fort Union Group, formed in Paleocene freshwater swamp and fluvial environments. These settings are characterized by thick, laterally extensive coal seams interbedded with clay-rich roof and floor sediments, providing favorable conditions for the uptake and retention of rare earth elements and associated critical minerals. Stratigraphic controls, including seam boundaries, partings, and underlying or overlying sediments, influence elemental enrichment through detrital input, groundwater infiltration, and post-depositional weathering processes. Understanding seam architecture, depositional environment, and post-depositional alteration is essential for predicting REE–CM distribution at the mine scale.

The North Dakota Geological Survey (NDGS) has conducted a comprehensive, multi-year investigation into the geologic factors controlling the occurrence, distribution, and enrichment of rare earth elements (REEs) and other critical minerals (CMs) in North Dakota. Since 2015, NDGS has systematically collected and analyzed thousands of lignite, organic-rich mudstone, and associated sediment samples across the Williston Basin, creating one of the most detailed coal-hosted critical-mineral datasets in North America. The NDGS focused on coal bearing sequences outside of the mines of ND. They found elevated CM concentrations are commonly associated with Paleocene units of the Fort Union Group, particularly in lignites underlying kaolinite-rich paleosols and weathered stratigraphic intervals such as the Bear Den Member of the Golden Valley Formation and the Rhame Bed of the Slope Formation. These horizons formed during intervals of warm, humid climate, where intense chemical weathering leached trace elements from overlying sediments and concentrated them in underlying organic-rich strata².

² North Dakota Geological Survey (NDGS), 2015–2025. Rare earth elements and other critical minerals in North Dakota lignite and associated sediments. North Dakota Department of Mineral Resources, Bismarck, ND. Reports of Investigation, Open File Reports, and public data releases.

Chemical and Physical Properties of Critical Minerals

Rare earth elements and selected critical minerals in lignite typically occur in low-temperature, weakly bound forms compared to hard-rock deposits. REEs are commonly associated with organic functional groups within the coal matrix or sorbed to fine-grained clay minerals, while elements such as Ge and Ga may exhibit mixed organophilic, lithophilic, and chalcophilic behavior. These associations result in relatively high chemical accessibility, allowing potential extraction using mild leaching or ion-exchange processes³. Physical properties such as particle size, mineral surface area, and degree of coal oxidation further influence the mobility, concentration, and recoverability of REE–CMs.

CM, Trace Element, Mineral, and Lignite Properties Measurement

Exploration-focused measurement approaches emphasize integration with routine mine drilling to minimize cost while maximizing data value. Drill core sampling, combined with consistent logging of seam position and lithology, provides the foundation for evaluating REE–CM distribution. Laboratory analyses including trace-element geochemistry, coal quality testing, and mineralogical characterization establish benchmark concentrations and modes of occurrence⁴. These methods support calibration and validation of rapid field-based measurements and ensure that exploration data are representative and defensible.

Statistical analysis including Principal Component Analysis (PCA) and Cluster Analysis (example shown in Figure 2), are used to interpret geochemical relationships and mineralogical patterns within the samples. PCA was applied to evaluate how rare earth elements (REEs) and critical minerals (CMs) are associated with trace elements and mineral phases. This analysis allowed the team to identify dominant factors that control REE distribution and to understand how different geochemical signatures group together.

³ Laudal DA, Benson SA, Addleman RS, Palo D. (2018) Leaching behavior of rare earth elements in Fort Union lignite coals of North America. *International Journal of Coal Geology*. 2018 April; 191:112.

⁴ Benson, A., Benson, S., Kolb, E., Anderson, L., Stadem, D., Kunwar, B., and Amberg, E. (2026). Lignite Resource Evaluation for Advanced Utilization Opportunities. Final Report prepared for the North Dakota Industrial Commission, Lignite Research Program, under Contract No. FY22 101 247. Microbeam Technologies Incorporated, Grand Forks, North Dakota.

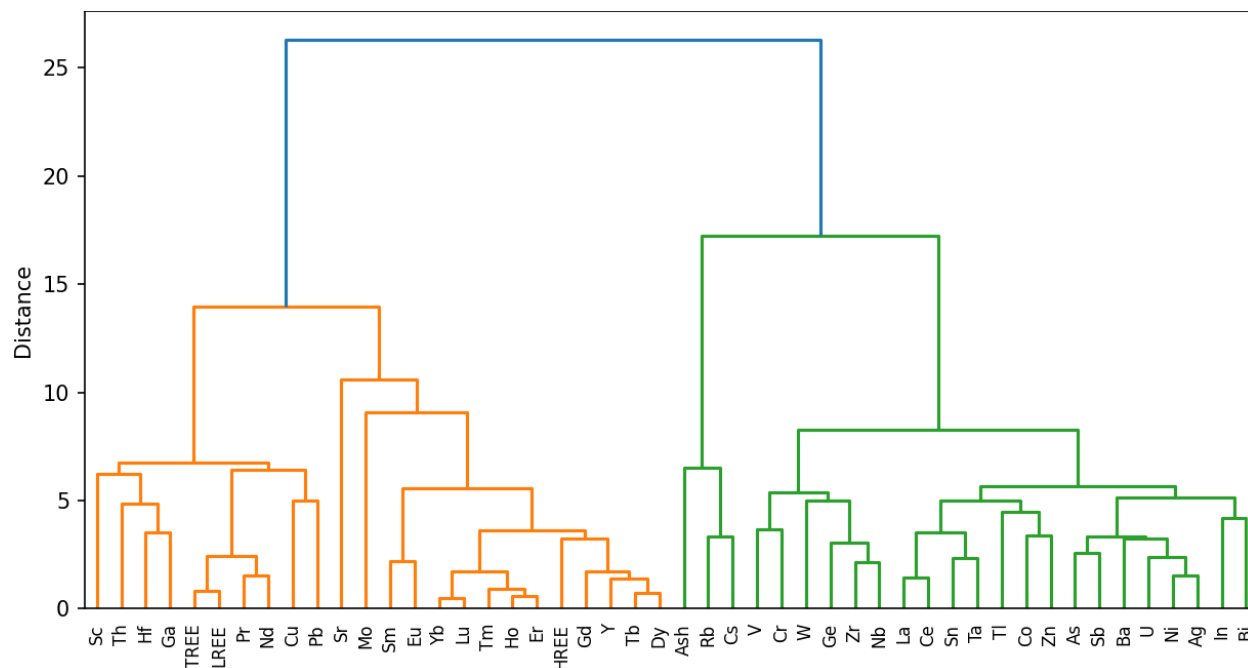


Figure 2. Dendrogram showing relationships between ash-basis trace elements for an entire database (938 samples total).

Distribution and Enrichment Patterns

REE–CM enrichment in lignite commonly exhibits systematic vertical and lateral trends within coal seams. Concentrations are frequently elevated at seam tops and bottoms due to groundwater interaction, mineralized roof or floor materials, and organic adsorption processes, producing distinct seam-margin enrichment profiles. Lateral variability reflects changes in sediment input, hydrologic pathways, and coal facies.

Three dominant enrichment modes have been observed for REE–CM in ND that include: detrital or volcanic ash-associated enrichment of light REEs, organic-associated enrichment of heavy REEs, and localized enrichment of critical minerals such as Ge in pyrite-rich or organically-rich zones. Identifying these patterns is critical for selective sampling and resource delineation enrichment types depending on the relative abundance of light (LREE- La, Ce, Pr, Nd), middle (MREE- Sm, Eu, Gd, Tb, Dy), and heavy (HREE - Ho, Er, Tm, Yb, Lu) rare earth elements. The enrichment is calculated based on the ratio of the REE element concentration to the Upper Continental Crust (UCC)⁵ concentration. The REE/UCC >1 represents enrichment and REE/UCC <1 show a depletion. Rare earth element patterns for enrichment of REE elements were established by Seredin and Dai⁶ (L-type for enrichment of LREE, M-type for enrichment of MREE, and H-type for HREE).

⁵ Rudnick, R.L., and Gao, S., 2003. Composition of the continental crust. In: *Treatise on Geochemistry, Volume 3: The Crust*, Elsevier, Oxford, pp. 1–64.

⁶ Seredin, V.V., and Dai, S. (2012). Coal deposits as potential alternative sources for lanthanides and yttrium. *International Journal of Coal Geology*, 94, 67–93.

Examples of the REE type distributions observed for selected lignite coals are shown in Figure 3 and show all three types of REE enrichment exist in the ND Lignite mines⁴. Germanium and gallium are also of interest in this effort and the trends for Ge and Ga in the various REE enrichment patterns are included in Table 4.

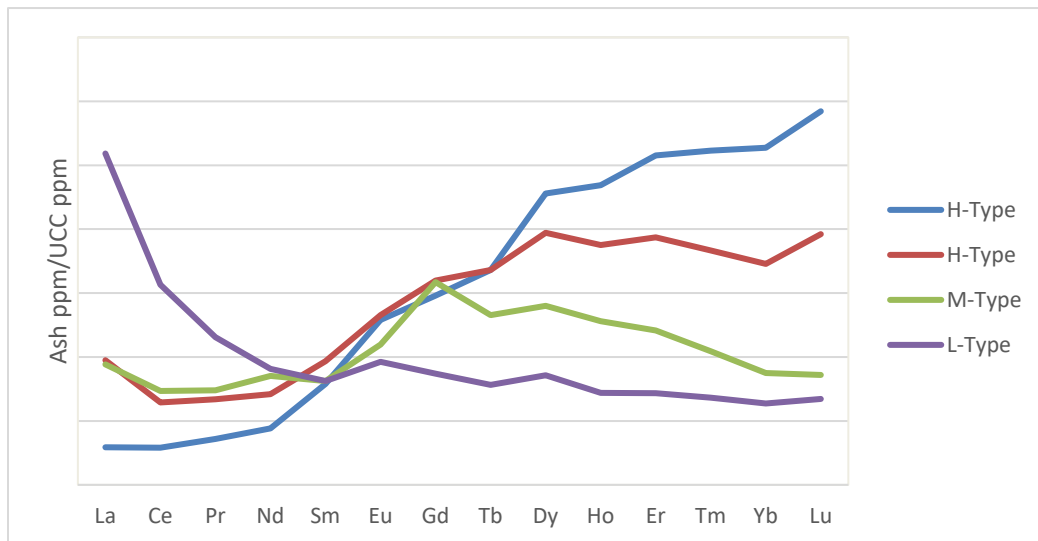


Figure 3. Example of REE-type distributions observed for ND Lignite.

Table 4. REE Distribution Types in Freshwater Lignite Settings (Fort Union Region).

REE Type	Enrichment Pattern	Source Material	Depositional Environment	Typical Mineral/Host Sites	Ge Trend	Ga Trend
L-type (LREE-enriched)	High La, Ce, Nd	Silica-rich detrital input (granitic), volcanic ash	Freshwater swamp, oxidizing zones	Detrital monazite, zircon	Low to moderate (Ge prefers reducing conditions, less stable here)	High (Ga substitutes for Al)
M-type (MREE-enriched)	Elevated Sm, Eu, Gd, Dy	Volcanic ash alteration, minor hydrothermal fluids	Lacustrine or volcanic ash-influenced peat	Organic matter, volcanic glass, feldspar	Moderate (if hydrothermal fluids present)	Moderate to high (Ga linked to volcanic ash-derived materials)
H-type (HREE-enriched)	High Dy–Lu, Y (if present)	Hydrothermal input or fine-grained detrital zircon	Reducing swamp, organic-rich zones	Organic matter (humic acids), resistant zircon	High (Ge strongly complexed by organic matter and locally incorporated in pyrite under reducing conditions)	Low to moderate (Ga less favored in reducing organic-rich settings)

CCSEM analysis was used to quantify the mineral makeup of coal and sediment samples. The mineralogical composition reflects a mixture of silica-rich materials, aluminosilicate phases, sulfide minerals, and minor sulfate minerals together indicating complex depositional and post depositional processes typical of coal-bearing formations. Table 5 summarizes the general findings between mineral type and enrichment type and potential host site for the REE and other elements.

Table 5. Summary of Minerals, Organic Component, REE Host Sites, and Associated Elements in ND Lignites.

Component	Occurrence / Association	REE Enrichment Type	REE Host Role & Associated Elements
Quartz	Detrital input; roof/floor sediments	L-Type (LREE-enriched)	Generally inert
Aluminosilicate Si-rich	Weathered volcanic ash	L-Type	Adsorbs LREE; associated with Ga
K-AlSilicate	sediments	L-Type	Hosts LREE; Ga substitution
Mixed Sediments	Roof/floor sediments; altered ash	M-Type	High surface area; adsorbs LREE & HREE
Pyrite Pyrrhotite	Coal and blackjack layers	H-Type	Associated with Ge; trace As, Sb
Barite	Roof sediments and rider coals	M-Type	Hydrothermal indicator; minor REE
Gypsum	Localized oxidation zones	Epigenetic	No significant REE hosting
Organic/Humic Acids	Coal matrix; reducing zones	H-Type	Major host for HREE; strongly binds Dy–Lu, Y; associated with Ge; trace U, V, Mo

On-Site CM Measurement

On-site near real-time measurement technologies enable rapid assessment of REE–CM variability during active drilling campaigns. Downhole logging tools and portable analytical systems, such as core scanning XRF platforms, allow continuous acquisition of elemental information directly from drill holes and intact drill cores. These measurements provide immediate insight into elemental trends throughout the depth of the seam, enabling identification of high- and low-value intervals without waiting for laboratory turnaround. On-site measurements significantly reduce decision-making lag and improve sampling efficiency.

Downhole geophysical sensors complement surface and core-based measurements by providing continuous depth-resolved information on density, gamma response, and lithologic changes. These tools help confirm seam boundaries, identify zones of increased mineral matter or radioactivity, and support correlation between physical properties and REE–CM concentrations. Integration of downhole data with geochemical measurements improves confidence in seam-scale interpretations and enhances predictive modeling.

Down hole LAS data from four e-logging tools from three holes where core samples were collected and analyzed to determine the REE-CM contents were used to train the RapidREE™ algorithm to predict individual REE and total REE¹. Figure 4 illustrates the performance of the RapidREE™ total REE content prediction as a function of depth for a hole that was not used in training. The RapidREE™ algorithm trained for use with the advanced probe performed the best, achieving a mean absolute error below 30% of the mean value for each parameter. The relatively low error rates, when compared to the natural variability

in the data, suggest that the algorithm provides reliable predictions. This supports its use as a screening tool for identifying promising REE-CM resources in log data.

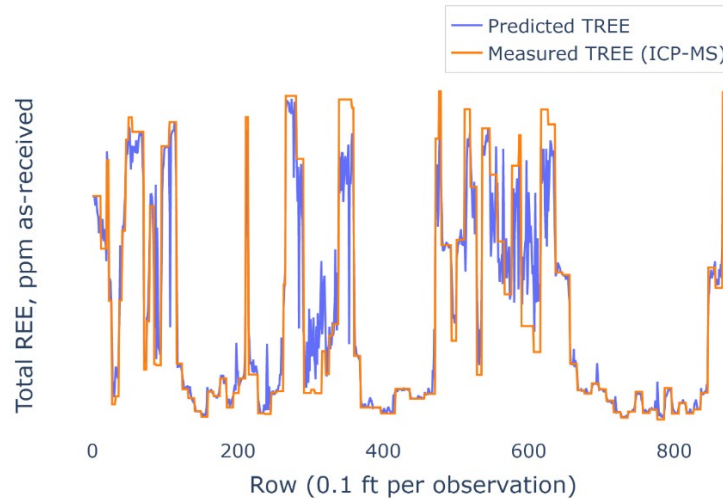


Figure 4. Predicted (blue) vs. measured (orange) TREE for entire dataset for the hole. Algorithm used: v1.5, trained on Train-Test Split dataset #4.

Application of AI-Based Predictive Methods for Near Real-Time Measurement

Artificial intelligence and machine-learning methods provide a powerful framework for converting raw sensor data into quantitative REE–CM estimates. Predictive models trained on paired laboratory analyses and field measurements can leverage spectral XRF data, downhole responses, and seam position information to estimate REE–CM concentrations in near real time. These AI-based methods enable rapid screening for high-value zones, reduce analytical costs, and support adaptive sampling strategies during drilling. When continuously updated with new data, predictive models become increasingly robust and transferable across mines, supporting scalable resource evaluation.

The XREE™, based on XRF core scanning data, results for estimated vs. measured total REE (TREE+Sc+Y) are shown in Figure 5 and Ge and Ga are shown in Figure 6 for an example lignite coal seam. TREE is concentrated at the top and bottom of the seam. Trends in high and low levels of TREE are detected by the algorithm, demonstrating its ability to detect REE-rich coal and sediments in ND lignites.

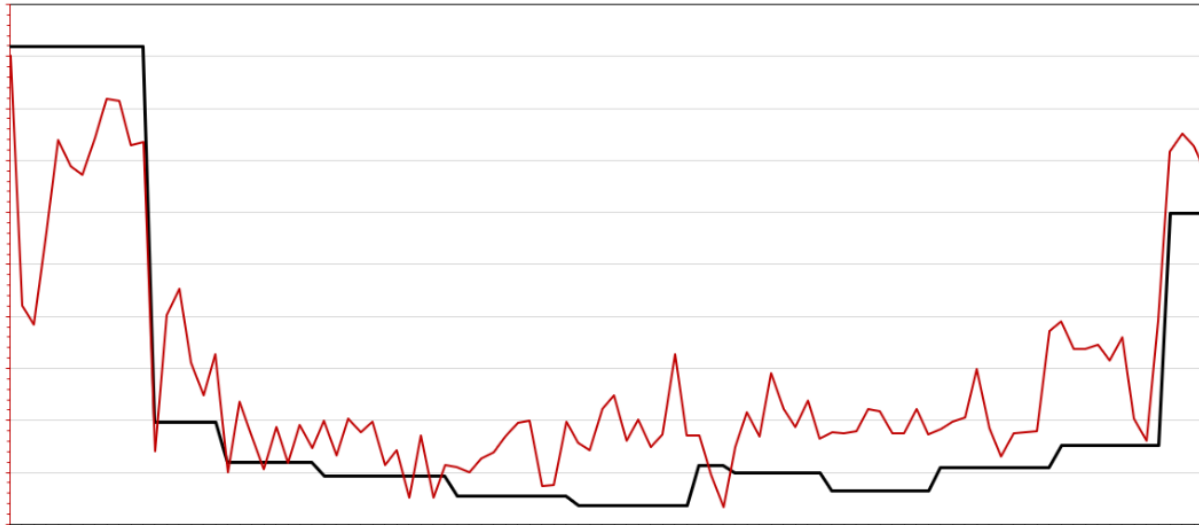


Figure 5. Estimated (red; XREE™) vs. Measured (black; ICP-MS lab analysis) results for TREE+Sc+Y (ppm, coal basis) on one example coal seam from the training dataset.

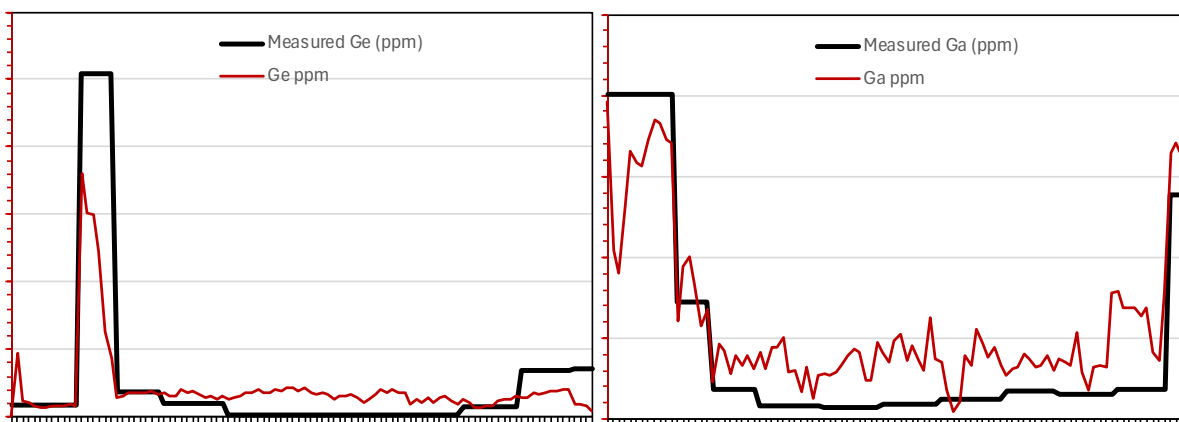


Figure 6. Estimated (red; XREE™ 3.4) vs. Measured (black; ICP-MS lab analysis) results for Ge (left) and Ga (right) on one example coal seam. Units in ppm, coal basis.

Three-Dimensional Geological Modeling – Maptek Vulcan

Geological modeling is a common practice in visualizing analytical data and estimating ore resources in all ore mining industries, including the coal industry. However, modeling of REE-CM in coal resources poses a challenge due to the variation (both within a single seam from top to bottom and horizontally and from seam to seam) and due to the number of elements that make up total REE/CM concentration estimates. Geological modeling for coal seams is fairly straightforward to the simple geology of the seam (relatively long, flat seams) and is modeled based on a few parameters.

Microbeam’s previously funded NDIC project “Lignite Resource Evaluation for Advanced Utilization Opportunities” (FY22-101-247) utilized laboratory data to develop geological models for individual element concentrations and calculated values (total REE, heavy/light ratio) for ND lignite seams. These models helped in visualizing the data from seam to seam and throughout a larger lignite resource. Figure 7 shows an example of seams highlighted by different colors within a drill core and Figure 8 shows an

example of a 3D geological model for total REE concentration based on a single seam from multiple drill holes.

These models were only developed using trace element analytical data from a laboratory. While the sampling and analysis in that project was a large effort, it is still limited based on the increments in which samples can be collected and budgets for analysis. In this project, the team will look to use the results from RapidREE™ and XREE™ to provide more data (both in granularity and by providing estimates from regions not sampled) and integrated it into the geological model.

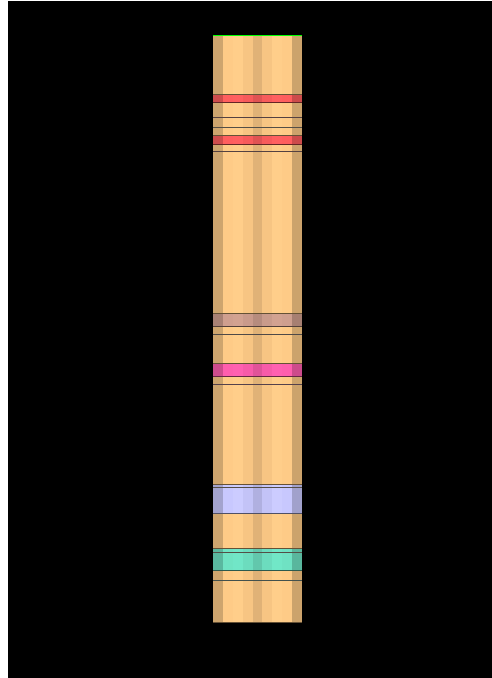


Figure 7. Example of drill core model showing variation of REE content throughout.

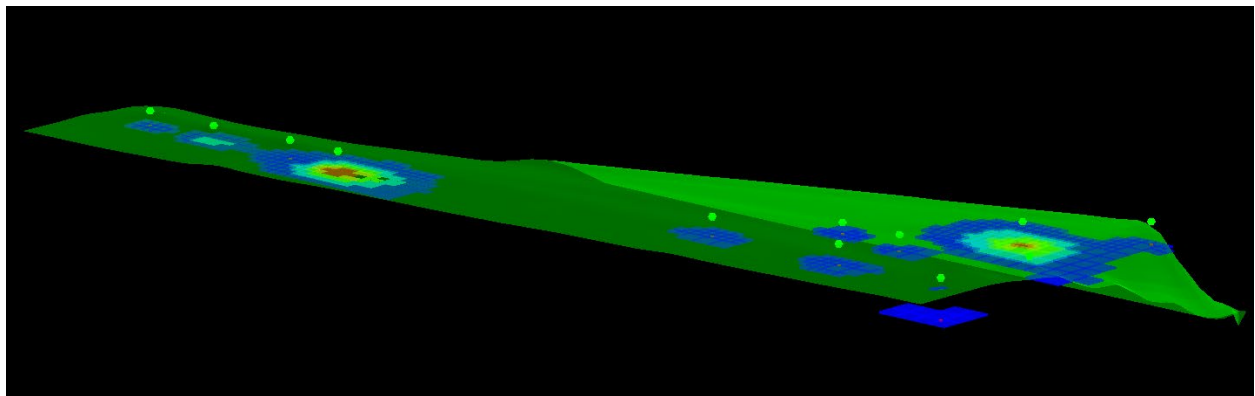


Figure 8. Isometric view of TREE estimations with the surface layer overlaid in green.

QUALIFICATIONS

Project Participants

Microbeam Technologies Inc.

Microbeam Technologies Incorporated (Microbeam) is a U.S. small business that has been in business for over 30 years with extensive experience conducting research, development, and technical service projects for industry and government clients focused on the occurrence, characterization, and recovery of critical minerals (CM), including rare earth elements (REE), germanium (Ge), and gallium (Ga), from coal and other mineral-bearing feedstocks. Microbeam has completed more than 1,700 projects related to critical mineral exploration and recovery, advancement of fuel property and critical mineral measurement technologies, and improvement of energy conversion system performance and reliability. This body of work has provided Microbeam with a deep understanding of the form, fate, and behavior of fuel-associated inorganic components and has led to the development of novel methods to identify, characterize, and concentrate critical minerals derived from coal and coal-associated materials. This experience directly supports the proposed demonstration of REE-CM exploration technologies and characterization of the Center Mine coal resource. The following is a summary of selected related projects.

Critical Mineral Recovery Projects

- *Rare Earth Element Recovery from Lignite:* Microbeam has served as a subrecipient on multiple University of North Dakota (UND)-led projects that resulted in the development, construction, and operation of a mixed REE concentrating pilot facility funded by the U.S. Department of Energy (DOE) and the North Dakota lignite industry. The VP CTO (past President) of Microbeam is a co-inventor of a patented REE extraction process from lignite coal.
- *Germanium and Gallium recovery from REE concentrates – Phase 1:* Microbeam has also led and supported the development of processes to separate and concentrate germanium and gallium from mixed rare earth element concentrates (MREC), building on earlier NSF SBIR Phase I and Phase II projects focused on germanium recovery from gasifier ash. This work culminated in a conceptual process design, including detailed process flow diagrams, for the recovery of Ge and Ga from MREC. In addition, Microbeam developed a pyrometallurgical process to vaporize, selectively condense, and concentrate Ge and Ga.
- *Critical Mineral Commercial Plant Design:* As a subrecipient on a DOE-funded Front-End Engineering and Design (FEED) study, Microbeam evaluated the integration of Ge and Ga recovery concepts into a 1–3 tonne/day mixed REE production facility designed to recover and refine REE and critical minerals from North Dakota lignite mine wastes.
- *Germanium Production from Coal Ash Phase I:* Microbeam completed an Army SBIR funded project focused on the development and evaluation of a pyrometallurgical process for the recovery of germanium from coal fly ash. The effort included feedstock characterization, thermochemical modeling, process simulation, and laboratory scale testing, and demonstrated the ability to produce germanium concentrates from domestically sourced coal ash, supporting coal derived materials as a viable non-traditional source of this critical mineral.

- *Germanium Production from Coal Ash Phase II:* Microbeam is executing an Army SBIR Phase II project to demonstrate a bench scale pyrometallurgical process for recovering germanium (Ge) from North Dakota lignite derived coal ash. This builds on the Phase I results and shows the potential to produce greater than 60% Ge concentrates, supporting coal ash as a viable domestic source of this critical mineral.

Critical Mineral Measurement and Predictive Tools

- *Critical Mineral Predictive Algorithms for Cross-Belt Analyzers:* Microbeam has developed and patented advanced REE-CM predictive algorithms (U.S. Patent No. 11,733,184) based on spectral fingerprinting derived from prompt gamma neutron activation analysis and dual gamma attenuation (PGNAA-DGA) applied to lignite and bituminous coals. These technologies, funded by NDIC and DOE SBIR programs, enable rapid, mine-scale estimation of REE-CM content and directly support the exploration and characterization objectives of the proposed project.
- *Sorting and Tracking Technology:* Through US DOE and Industry funding, Microbeam led a team who developed feedstock tracking, sorting, and blending technologies that utilized full-belt analysis using PGNAA-DGA to improve plant performance and enabled identification and segregation of high- and low-critical-mineral lignite coals. These efforts, supported by DOE Condition-Based Monitoring and Multigamma Attenuation programs, resulted in a filed patent application for sensing and tracking technology (US 12,189,355 B2).
- *Critical Mineral Predictive Algorithms for Downhole Logging Tools:* Under a U.S. Department of Energy award, MTI developed RapidREE™, a machine-learning-based capability that integrates downhole logging data with geochemical datasets to provide real-time and near-real-time predictions of REEs and critical minerals, including yttrium, germanium, and gallium. Field testing at multiple North Dakota coal sites demonstrated strong predictive performance (mean absolute errors ~20–30%) relative to laboratory ICP-MS analyses and outperformed lithology-based approaches. By reducing reliance on extensive core sampling and accelerating resource evaluation, RapidREE™ enables scalable deployment for domestic critical mineral development in North Dakota and beyond.

Resource Evaluation Projects

- *CM Resource Evaluation and Predictive Tool Applications:* The completed NDIC-Industry funded project (FY22-101-247) demonstrated that North Dakota lignite contains economically meaningful concentrations of rare earth elements (REEs) and critical minerals, particularly germanium and gallium, with characteristic enrichment at coal seam tops and bottoms and strong associations with organic matter and specific mineral phases. More than 1,200 samples from operating mines were analyzed and integrated with advanced statistical methods, 3D geological modeling, and Microbeam's XREE™ predictive algorithms coupled with Veracio TruScan™ XRF, enabling near real-time, field-deployable estimation of REE-CM content in drill cores. These tools significantly reduce exploration cost and cycle time while supporting selective sampling and resource delineation.

Collectively, this experience demonstrates Microbeam’s technical qualifications, proven execution capability, and direct relevance to the proposed project objectives related to REE-CM exploration technology demonstration and lignite-hosted critical mineral resource characterization. This proposed project at BNI Energy’s Center Mine will apply and refine this proven workflow at a major lignite operation not yet fully characterized, filling a critical regional data gap, improving predictive model robustness, and advancing mine-specific resource evaluation and utilization strategies for REE-CM recovery and associated value-added applications.

BNI Energy

BNI Energy is the Project Sponsor and providing a majority of the matching funds as part of this project. BNI Coal, a subsidiary of BNI Energy, operates the Center Mine in Center, ND, that provides coal to the Milton R. Young Power Plant that provides energy to customers in North Dakota and Minnesota. BNI is interested in being a host site for the demonstration of Microbeam’s RapidREE™ and XREE™ technologies and using these technologies to better understand the REE-CM in their lignite resources.

Vendors/Contractors

This project does not have any subawards. Microbeam has budgeted to involve the following groups as vendors and/or contractors.

- **Veracio** – Vercio is a subsidiary of Boart Longyear that develops technologies, such as the TruScan™ (drill core scanning XRF system), to improve the speed and reliability of data for drilling and drill core scanning applications. Microbeam worked with them in the NDIC sponsored project “Lignite Resource Evaluation for Advanced Utilization Opportunities”, contract number FY22-101-247, to develop the XREE™ technology that will be demonstrated in this project. Their role in the project will be to conduct their standard drill core analysis and provide the results to Microbeam.
- **Drilling Contractor** (To Be Determined) – BNI’s standard practice for drilling is to submit a request for updated pricing or bids for each year’s drilling activities. This process is currently underway, but the decision on the drilling contractor for this year has not been finalized at the time of this submittal. As this is something that generally occurs each year, there is the possibility that this contractor may change each year. Microbeam’s RapidREE™ technology is meant to be able to be applied to standard downhole logging tools so the vendor should not impact this process. In addition, Microbeam has budgeted to rent alternative downhole logging tools that were evaluated in a previous Department of Energy (DOE) project (DE-SC0025054). These tools can be operated by most licensed drilling companies.
- **Minnesota Valley Testing Laboratories (MVTL)** – MVTL conducts standard analyses such as proximate, ultimate, ash composition, and many other methods. They have a laboratory in Bismarck, ND, that is commonly used by groups in the ND energy industry. MVTL will be utilized to conduct proximate and ultimate analysis for BNI and Microbeam during this project.
- **Activation Laboratories (ActLabs)** – ActLabs is a large analytical company that has a number of laboratories in Canada (along with other locations throughout the world). ActLabs has been used by Microbeam and other ND industry and academic groups for trace element (including REE, Ge, and Ga) analysis. While there are a number of

laboratories in the region that have the capabilities to conduct trace element analysis, ActLabs' prices are significantly lower and provide results for a wider range of elements than other regional laboratories. Microbeam utilized ActLabs in the previous NDIC sponsored project "Lignite Resource Evaluation for Advanced Utilization Opportunities", contract number FY22-101-247.

Key personnel

Alex Benson, Mr. Benson will be Principal Investigator for this project. Mr. Benson is currently the Chief Operating Officer at Microbeam. He has a B.S. degree in Mechanical Engineering from the University of St. Thomas. Mr. Benson has over 6 years of experience conducting projects associated with critical minerals. Currently he leads multiple commercial projects associated with REE/CM resource evaluation, detection, measurement, and extraction from carbon-ore and associated waste materials. He was the project PI (DE-SC0021837) and is one of the inventors on a US patent held by Microbeam for algorithms used with handheld XRF and PGNAA-DGA for REE/CM measurements and of a US patent for Ge and Ga separation from ash materials and mixed rare earth element concentrates. He is currently the lead Project Manager on the DOE and Industry funded project (DE-FE0032522) to produce germanium and gallium from REE concentrates. Mr. Benson has over seven years of manufacturing engineering, project management and commercialization experience in the medical device manufacturing industry. He led engineering activities for new product launches and capacity expansion projects.

Dr. David Stadem, Dr. Stadem is a Sr. Research Scientist at MTI and will lead the development of the REE-CM predictive algorithms through statistical and neural network development. Dr. Stadem has developed algorithms to estimate REE-CM concentrations in coal in real time using on-belt analyzers utilizing Am-241, Cs-137, and other gamma-ray analysis systems. His past research has investigated the physical and chemical properties of coal that interact with gamma rays to produce dual-gamma attenuation spectra. He is currently validating REE-CM predictive algorithms for full stream elemental analyzers that analyze coal on a full-scale power plant. He has developed software for real-time monitoring of coal properties that enables online decision-making including sorting and blending operations.

Logan Anderson, Mr. Anderson is an Associate Research Engineer at MTI with experience in developing coding for the development of REE-CM predictive algorithms. This includes on-belt, full stream elemental analyzers as well as drill core scanning technology. He has conducted field testing related to resource evaluations and REE-CM predictive algorithms. Mr. Anderson has used the data from resource evaluations to develop resource models using Maptrek Vulcan software. This experience will be used in the development of the algorithms and resource modeling in this project along with the integration of the algorithms into the commercial e-logging probe software.

Eric Kolb, Mr. Kolb, Research Engineer and Shop Manager at MTI, has a B.S. degree from UND in Mechanical Engineering. Mr. Kolb worked with UND on the design, construction, and operation of UND's pilot-scale REE and CM processing plant (DE-FE0031835). His experience associated with the UND system will provide important information that will facilitate integrating the Ge and Ga recovery process into the UND MREC production process. Mr. Kolb has experience in performing analysis using electron

microscopes as well as performing tests using the metals recovery unit and other high temperature equipment at Microbeam.

Dr. Steve Benson, Dr. Benson, Microbeam's Chief Technical Officer, has a BS in Chemistry from Minnesota State University and a Ph.D. in Fuel Science from Pennsylvania State University. Dr. Benson's role in this project will be to assist and advise the Principal Investigator. Prior to joining Microbeam full time in 2017 he held faculty and research positions at the UND. He was PI on the DOE and industry funded project (FOA 1202, DE-FE0027006) to develop technologies to recover REE from coal and coal byproducts as well as the current DOE and industry funded project (DE-FE0032522) to produce germanium and gallium from REE concentrates. He has over 45 years of experience in fuel analysis, fuel properties, combustion, gasification, ash transformations, pollution control, and critical mineral recovery. In addition, Dr. Benson has developed and managed numerous complex multidisciplinary research, development and commercialization projects associated with the utilization of coal funded by US DOE and industry. Dr. Benson is one of the inventors on a US patent held by UND for the extraction of REE/CM from lignite and associated materials, one of the inventors on a US patent held by MTI for algorithms used with handheld XRF and PGNAA-DGA for measuring REE-CM, and one of the inventors of a patent for the process of producing separated Ge and Ga concentrates from ash materials and mixed rare earth element concentrates.

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 RapidREE™ and XREE™ technologies 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 operators that can be used to selectively mine.
3. A resource model will improve the identification of REE-CM-rich regions so mines can focus their exploration and selective mining activities. In addition, this will highlight the findings related to modes of occurrence and deposition characteristics as it will highlight areas that should be compared (high vs low REE-CM concentrated regions).

MANAGEMENT

Microbeam will manage execution of the project to meet the objectives and timelines discussed in this proposal. BNI will lead the mine planning and drilling activities. Figure 9 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.

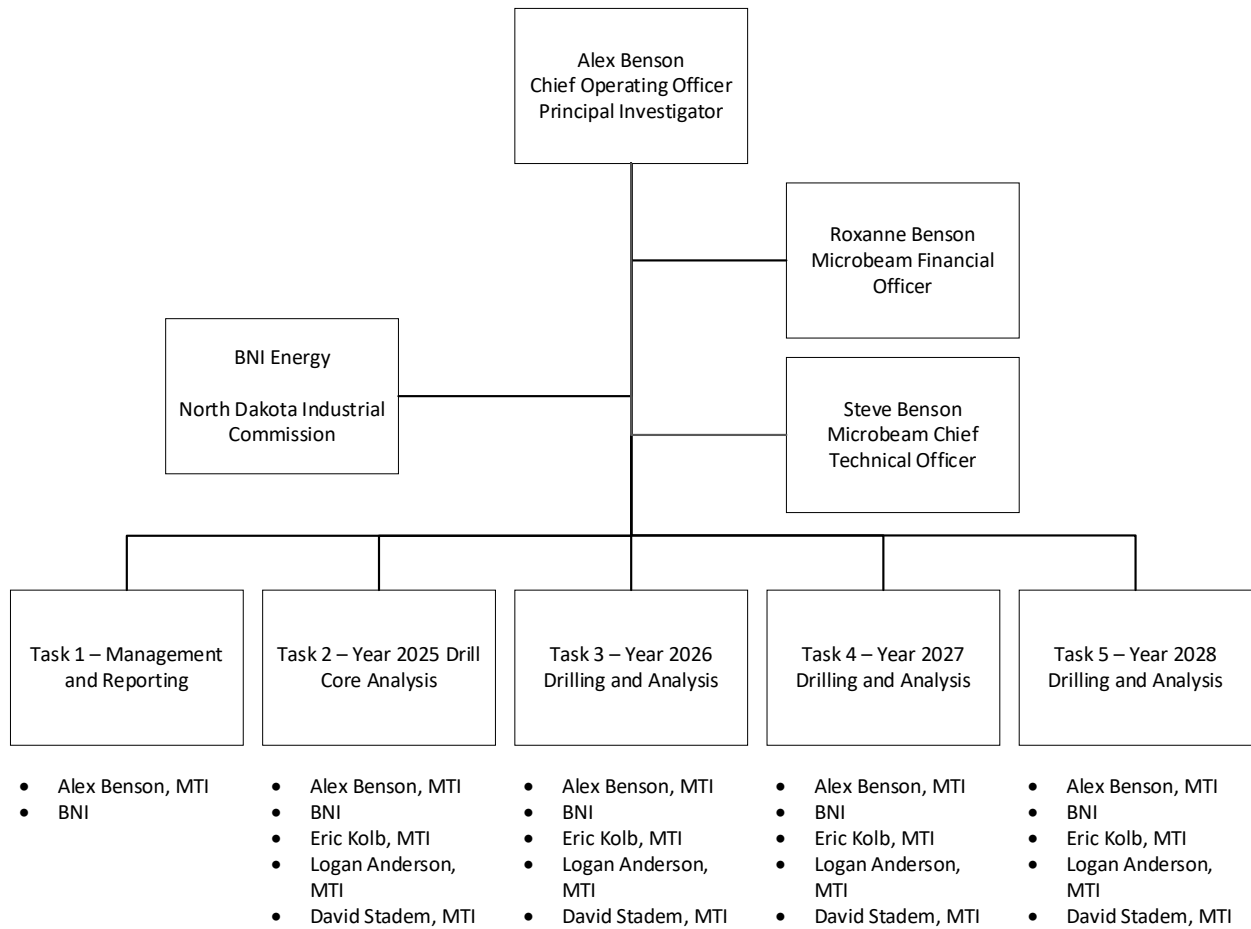


Figure 9. Organizational and management structure.

BUDGET

Table 6 shows a summary of the total project budget broken down by category. The total request of NDIC is \$971,225. The total project budget is \$1,956,105. The funds being requested from NDIC will cover the Total Direct and Indirect Costs.

The cost share budget (\$984,880) is discussed in the Matching Funds section of this proposal.

Table 6. Project budget detail.

Total Project Budget:	
Total Salaries	\$ 230,748
Total Fringe Benefits	\$ 76,193
Total Salaries & Fringe Benefits	\$ 306,941
Software License	\$ 16,279
Travel	\$ 8,543
Supplies	\$ 1,952
Consultants	\$ 86,250
Subawards	\$ -
Other: Analysis	\$ 280,305
Total Direct Costs	\$ 700,270
Indirect costs	
Labor Overhead of Direct Cost	\$ 103,408
General & Administrative	\$ 167,547
Total Indirect Costs	\$ 270,955
Total Direct and Indirect Costs	\$ 971,225
Cost Share	\$ 984,880
Total Project Costs	\$ 1,956,105

The personnel costs were developed based on previous exploration and technology development projects that Microbeam has conducted, including previously funded NDIC project FY22-101-247. This estimation was done based on the scale of the drilling activities, the number of samples expected to be collected based on the drilling, time required for sample procurement and preparation, and time associated with data interpretation, algorithm development and validation, and resource model development.

The software license will cover the cost of the Maptek Vulcan software licensing for this project over the next three years. The software license includes software updates, access to training and troubleshooting videos, and product support from Maptek personnel. In project FY22-101-247, the Maptek license expired in the last year of the project and it created a number of challenges related to modeling a resource that is not commonly modeled. Microbeam required assistance from Maptek personnel when addressing these challenges and when the software license expired, our assistance was very limited and created delays in the development of the models and identifying software irregularities.

The travel costs are associated with three, one-week field tests (1 per year) at the Center Mine. Microbeam's costs for travel include mileage in traveling to Center, ND, hotels during the field test, and per diem. Based on previous projects, two people are required per field test.

The supplies are associated with costs for annual field tests. This includes sampling materials (core boxes, bags, labels, etc.) and storage containers to maintain the quality of the sample.

The consultants' costs are for Veracio and the selected drilling contractor. Veracio provided Microbeam costs based on drilling depths, travel and accommodation costs, mobilization and demobilization, and base operating costs. Microbeam developed the total budget estimate for Veracio based on the field test plans for each year. Veracio's efforts will provide data for the XREE™ technology activities of this project.

The selected drilling contractor budget is associated with renting additional downhole logging tools and the costs for conducting the logging with the additional tools. Standard downhole logging will be part of BNI's cost share. The e-logs for the standard logging and additional logging tools will provide data for the RapidREE™ technology activities of this project. This estimation was based on Microbeam's previous RapidREE™ development project in which rates were provided by a drilling contractor.

The analysis costs cover internal and external (ActLabs and MVTL) analysis for this project. The analysis is used to validate the RapidREE™ and XREE™ estimations, develop the resource model, and develop the understanding of the modes of occurrence for the REE-CM in the lignite resource.

If less funding is available than the amount requested, the primary impacts would be a reduction in analysis and impacts on the resource modeling activities. A reduction in analysis would reduce the analysis budget (including sample preparation) and personnel budget as there would be fewer samples to review and select for analysis and less data to interpret. The resource modeling would be impacted as the software license may only be pursued for a limited period of time and the project team would delay modeling for that period of time. This would result in a less accurate model.

MATCHING FUNDS

Matching funds will be provided by BNI Energy and Microbeam Technologies. The total matching funds will be \$984,880.

BNI Energy will provide a total of \$866,890 in matching funds over the three-year project in the form of in-kind contributions. This will include costs for drilling, downhole logging, sampling, personnel time, and analysis associated with the activities outlined in this project.

Microbeam Technologies Inc. will provide a total of \$117,990 in matching funds over the three-year project in the form of in-kind contributions. This will include sample preparation and analysis costs for benchtop XRF and SEM morphologies. The XRF system that Microbeam has is more accurate than the XRF used in the Veracio TruScan™ system and has been validated using external laboratory comparisons. As a result, Microbeam's XRF will be used to conduct ash composition analysis and REE-CM measurement. It is not calibrated for all REE but can be used to validate some REE values and be used to assist in the selection of samples submitted for trace element analysis. The SEM morphological analysis helps in the understanding of the REE-CM modes of occurrence. This information is helpful for understanding the deposition mechanisms for the REE-CM in the lignite but can also be used in the algorithm development process as recognizing indicators of high REE-CM concentrations.

Indirect costs will be included in the matching funds from BNI Energy and Microbeam Technologies Inc but will not be the primary matching cost.

This project is a continuation of other projects (DOE/DOW and industry funded) that led to the initial development of the RapidREE™ and XREE™ technologies and further supports the many REE and critical mineral projects related to ND lignite.

TAX LIABILITY

Refer to signed Tax Liability affidavit submitted with this proposal through the NDIC Grants Management System.

CONFIDENTIAL INFORMATION

There is no confidential information included in this proposal. Throughout the proposed project, confidential information will not be disclosed in quarterly status reports or final reports. The reports will be submitted with information to provide substantial details on the progress of the project in meeting the goals and objectives without disclosing sensitive information.

Information considered confidential for this project:

- Specific locations of drill holes
- Specific seam names
- Specific REE-CM concentrations in the lignite reserves
- Estimated resource values
- Methods for algorithm development