



October 15, 2025

State of North Dakota
The Industrial Commission
Clean Sustainable Energy Authority Program
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Re: The Forge Project: Rare Earths and Critical Materials Integration – Application for Grant Funding

Dear Members of the North Dakota Industrial Commission and the Clean Sustainable Energy Authority:

Ore Spring Materials, LLC (“Ore Spring”) is pleased to submit this application for grant and loan funding under the Clean Sustainable Energy Authority (CSEA) program for *The Forge Project: Rare Earths and Critical Materials Integration*. This project represents a unique opportunity to expand North Dakota’s lignite innovation platform by integrating rare earth element (REE) recovery and critical mineral production with AmeriCarbon’s advanced carbon manufacturing operations.

Ore Spring Materials is an affiliate of AmeriCarbon Enterprises, LLC, focused on developing new pathways for value-added utilization of lignite resources. Through this initiative, Ore Spring will collaborate with NACCO Industries, Inc., the University of North Dakota (UND), Microbeam Technologies, Inc., and AmeriCarbon Forge, LLC to demonstrate the recovery of REEs and other critical materials from concentrated ash and residue streams produced by AmeriCarbon’s Eco-Pitch™ process. This innovative approach builds directly upon UND’s ongoing lignite-based REE research and leverages AmeriCarbon’s commercial technology platform to accelerate deployment at industrial scale.

When fully implemented, the REE Integration Project will:

- ✓ Establish a domestic source of rare earth elements and critical minerals derived from North Dakota lignite and associated byproducts;
- ✓ Complement The Forge Project by utilizing its ash and carbon residues as a feedstock for REE extraction, creating a closed-loop, zero-waste manufacturing ecosystem; and
- ✓ Strengthen North Dakota’s leadership in the critical materials, clean energy, and advanced manufacturing sectors.

Ore Spring Materials, LLC is committed to advancing this initiative in close collaboration with UND, Microbeam, AmeriCarbon, and the State of North Dakota. The total program is expected to operate on a timeline that is in coordination with The Forge Project and represents a vital step toward establishing a vertically integrated supply chain for both carbon and critical materials within the state.



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Morgantown, WV 26501

This transmittal letter sets forth a binding commitment on behalf of Ore Spring Materials, LLC to complete the project as described in the accompanying application if the North Dakota Industrial Commission approves the requested funding under the CSEA program.

We appreciate the Commission's consideration and continued leadership in fostering innovation in lignite-based energy, materials science, and sustainable industrial development.

Sincerely,

Ore Spring Materials, LLC
by AmeriCarbon Enterprises, LLC, its Manager



Greg Henthorn
Chief Business Officer

APPLICATION CHECKLIST

Use this checklist as a tool to ensure that you have all of the components of the application package. Please note, this checklist is for your use only and does not need to be included in the package.

<input type="checkbox"/>	Application
<input type="checkbox"/>	Transmittal Letter
<input type="checkbox"/>	Tax Liability Statement
<input type="checkbox"/>	Letters of Support (If Applicable)
<input type="checkbox"/>	Confidentiality Request
<input type="checkbox"/>	Business Plan (Appendix)
<input type="checkbox"/>	Historical Financial Statements (3 years) (Appendix)
<input type="checkbox"/>	Budgeted Projections (Appendix)
<input type="checkbox"/>	Loan/Loan Guarantee Application (if Applicable, Appendix)
<input type="checkbox"/>	Other Appendices (If Applicable)

When the package is completed, send an electronic version to ndicgrants@nd.gov

For more information on the application process please visit:

<https://www.ndic.nd.gov/grant-programs/csea/clean-sustainable-energy-authority-applicant-information>

Questions can be addressed to the Industrial Commission at 701-328-3722.

Clean Sustainable Energy Authority

North Dakota Industrial Commission

Application

Project Title:

The Forge Project: Rare Earths and Critical Materials Integration

Applicant:

Ore Spring Materials, LLC

Date of Application:

October 15, 2025

Amount of Request

Grant: \$2,250,000

Loan: N/A

Total Amount of Proposed Project:

\$4,500,000

Duration of Project:

2 years

Point of Contact (POC):

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ABSTRACT

Objective:

The objective of *The Forge Project: Rare Earths and Critical Materials Integration* is to demonstrate and advance the integration of AmeriCarbon's Eco-Pitch™ carbon manufacturing process with rare earth element (REE) and critical mineral (CM) recovery technologies developed by the University of North Dakota (UND) and Microbeam Technologies, Inc. (Microbeam). The project aims to establish a scalable, co-located platform in North Dakota that converts lignite-derived and related feedstocks into engineered carbon materials while simultaneously recovering REEs, germanium (Ge), gallium (Ga), and other critical minerals from process by-products.

This integration will (1) optimize AmeriCarbon's liquefaction process to utilize diverse feedstocks—including upgraded lignite, humins, and humic acid residues from UND's REE processing—tailoring pitch compositions to customer-specific performance requirements; (2) develop a pathway to use AmeriCarbon's carbon process ash as a high-value CM-bearing feedstock for Microbeam's Ge/Ga recovery system; and (3) define the engineering and economic framework for commercial-scale deployment at the Forge site in McLean County, ND.

Through this effort, the project will advance North Dakota's leadership in lignite-based innovation by demonstrating a fully integrated carbon-plus-critical-minerals manufacturing ecosystem—linking clean carbon production, REE-CM extraction, and high-purity metal refining. The outcome will be a validated process model, optimized feedstock strategy, and techno-economic foundation for an industrial complex that strengthens domestic supply chains for both advanced carbon materials and strategic minerals.

Expected Results:

The Forge Project will deliver a validated and integrated process framework that unites AmeriCarbon's Eco-Pitch™ manufacturing, UND's rare-earth extraction technologies, and Microbeam's germanium and gallium recovery system into a cohesive, North Dakota-based production platform.

The project is expected to:

- ✓ Demonstrate feedstock integration and optimization—confirming the technical viability of using upgraded lignite, humins, and humic-acid residues (individually and in blended configurations) as feedstocks for AmeriCarbon's carbon liquefaction process, yielding targeted pitch formulations for downstream customers in energy and materials sectors.
- ✓ Quantify and enhance by-product value recovery—producing empirical data on the concentration, separation, recovery, and refinement potential of REEs and critical minerals (Ge, Ga, and Sb) from AmeriCarbon's ash and residue streams using Microbeam's pyrometallurgical and hydrometallurgical processes.
- ✓ Validate carbon purity and product performance—through demineralization and purification studies conducted with UND to achieve premium carbon qualities suitable for graphite, anode, and advanced binder applications.

- ✓ Develop an integrated process and site design—including mass and energy balances, flow diagrams, and infrastructure layouts defining how REE-CM extraction, ash utilization, and carbon manufacturing can be co-located at AmeriCarbon’s commercial plant in McLean County.
- ✓ Produce a techno-economic and commercialization analysis—quantifying capital and operating costs, product revenue streams, and economic multipliers for North Dakota, while identifying a practical path to commercial deployment.

Collectively, these outcomes will advance the technology readiness and economic feasibility of an industrial system that transforms lignite and its by-products into high-value carbon and critical mineral commodities. Successful execution will position North Dakota as a national model for clean-energy resource integration—linking carbon manufacturing, REE-CM recovery, and critical-materials supply-chain development within one regional industrial ecosystem.

Duration:

2 years.

Total Project Cost:

\$4.5 million (\$2.25 million from CSEA grant program, and \$2.25 million in matching)

Participants:

The proposed project is being led by Ore Spring Materials, LLC, an AmeriCarbon affiliate formed to coordinate integration of advanced carbon and critical mineral technologies. AmeriCarbon Forge, LLC—a joint venture between AmeriCarbon Enterprises and NACCO Natural Resources—will serve as the commercial host entity and provide the process and infrastructure platform for pilot validation and future deployment at the Falkirk site in McLean County, North Dakota.

The University of North Dakota (UND) College of Engineering & Mines will participate in the project along with its demonstrated rare earth element (REE) extraction and beneficiation technology, leveraging pilot-scale systems developed under DOE- and NDIC-supported programs to supply upgraded lignite and humins as optimized feedstocks and to conduct purification and demineralization studies. Microbeam Technologies, Inc. (Microbeam) will apply its patented vaporization and selective condensation process to AmeriCarbon’s ash residues and UND’s mixed rare earth concentrates to recover germanium, gallium, and other critical minerals. As a subcontractor to AmeriCarbon, Worley Group will provide engineering and integration support, developing process flow diagrams and site-level integration studies for co-located operations.

These participants bring a strong combination of industrial capability, engineering depth, and technology readiness. Together, they form a comprehensive team capable of demonstrating a fully integrated carbon and critical materials production ecosystem that aligns with CSEA’s mission to advance sustainable, value-added energy and materials manufacturing in North Dakota.

PROJECT DESCRIPTION

Objectives:

Project FORGE

Carbon & Rare Earth Metal Critical Materials

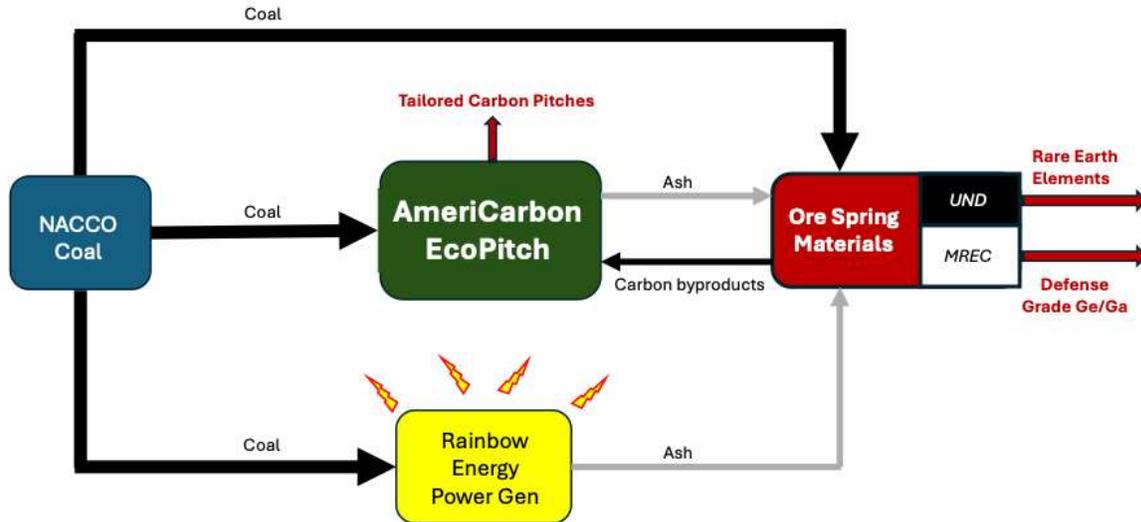


Figure 1. The Forge Project: Rare Earths and Critical Materials Integration.

The overarching objective of *The Forge Project: Rare Earths and Critical Materials Integration* is to develop, demonstrate, and engineer a fully integrated process that combines AmeriCarbon’s carbon liquefaction and pitch manufacturing technology with the rare earth and critical mineral recovery systems pioneered by UND and Microbeam. This integrated system will establish the technical and economic basis for a new lignite-based manufacturing industry in North Dakota that simultaneously produces high-value carbon materials and rare earth/critical mineral products from regional resources and process by-products.

Specifically, the proposed project will:

- ✓ Integrate and optimize feedstock utilization — Demonstrate the use of upgraded lignite, humins, and humic-acid residues from UND’s rare earth extraction process as alternative or blended feedstocks for AmeriCarbon’s Eco-Pitch™ process. This effort will refine process parameters to tailor pitch compositions for distinct industrial applications while maximizing yield and carbon efficiency.
- ✓ Develop and evaluate by-product valorization pathways — Characterize and optimize AmeriCarbon’s process residues and ashes for use as feedstock in Microbeam’s Ge/Ga recovery technology, enabling recovery of high-purity germanium, gallium, and other strategic minerals.

- ✓ Advance purification and demineralization techniques — Conduct joint studies with UND, Worley Group, and prospective customers to enhance removal of ash, sulfur, and metallic impurities from carbon and feedstock streams to achieve ultra-high-purity carbon suitable for advanced materials markets.
- ✓ Perform process integration and engineering design — Engage Worley Group to develop process flow diagrams (PFDs), material and energy balances, and site-integration studies that define how the carbon manufacturing, REE extraction, and critical mineral recovery systems can be co-located and operated synergistically at AmeriCarbon’s Forge site in McLean County, ND.
- ✓ Conduct techno-economic assessment and commercialization planning — Quantify the technical performance, cost structure, and economic impacts of the integrated system, including potential product revenues, co-product credits, and state-level economic multipliers.

The successful completion of these objectives will demonstrate a scalable, North Dakota–based model for the co-production of engineered carbon and critical materials—advancing national supply chain resilience while creating new markets and industrial opportunities within the state’s lignite resource base.

Methodology:

The Forge Project will be executed through a structured series of technical and engineering tasks designed to integrate AmeriCarbon’s Eco-Pitch™ manufacturing process with the rare earth and critical mineral recovery systems developed by UND and Microbeam Technologies. The following Statement of Work outlines the major work activities, responsible organizations, and corresponding budget allocations that collectively define the technical pathway for the project. This work structure provides the framework for coordination, data sharing, and process optimization across all participants.

The Forge Project will be an industrial manufacturing complex in North Dakota to produce critical materials such as carbon and REE-CM to address national and global vulnerabilities and shortfalls in the United States with severe economic and geopolitical strategic consequences caused by the current offshore supply of these materials. Central to the Forge Project is the planned joint venture (AmeriCarbon Forge, LLC) between AmeriCarbon and NACCO to build a lignite coal-to-carbon pitch/materials plant in McClean County, North Dakota. The establishment of this groundbreaking facility provides the basis for an integrated platform for critical materials manufacturing.

The REE manufacturing/production capability is being initiated by Ore Springs LLC, an AmeriCarbon and NACCO affiliate, to bring production of these critical elements derived from lignite coals and by-product streams from AmeriCarbon’s proprietary carbon pitch technology. Integration of these capabilities provide a unique and optimized opportunity that is a key basis of the Forge Project.

Under this proposed work scope being submitted by Ore Spring Materials, LLC, process integration efforts will be undertaken by the key participants to define the necessary optimization between the feedstock inputs and product/by-product outputs of the pitch production (AmeriCarbon) and REE-CM production (Ore Spring / UND / Microbeam).

Project Tasks

Task 1: Project Management:

This task encompasses all project management activities necessary to ensure the successful execution of the project in compliance with CSEA's contractual, technical, and administrative requirements. The Project Management team will provide overall leadership, coordination, and integration of technical, financial, and reporting activities across all project tasks. Responsibilities include tracking schedule and budget performance, managing risk and deliverables, maintaining communication with CSEA program management, and ensuring that project milestones are met in accordance with the approved Work Scope.

The task will also include coordination of subcontractor and partner activities, preparation of project management documentation, and oversight of quality assurance and safety compliance as applicable to R&D operations.

Estimated budget: \$100,000

Task 2: Preliminary Process and Site Integration Assessment

Based on the current design basis for each of the critical material technologies, a process integration and site layout study will be conducted. This will provide the starting point for the integration and optimization studies defined for the various technology efforts in Tasks 3-5. Critical parameters such as material mass and energy requirements will be conducted along with site utility, infrastructure process flow and acreage requirements will be defined. Outputs from Tasks 3-5 will be used to update final assessment study.

Estimated budget: \$100,000

Task 3: Pitch Integration & Optimization Studies

AmeriCarbon's proprietary Eco-Pitch process produces a unique by-product ash that has favorable characteristics that make separation/purification of REEs and CMs simpler, lower energy and more environmentally friendly than power plant derived ash or other post combustion sources. AmeriCarbon will conduct optimization studies to produce tailored ash that will then be evaluated by both the UND REE technology and Microbeam technologies to determine the maximal integration opportunities. AmeriCarbon will also conduct an extensive matrix effort to process and evaluate both lignite coals and the by-product carbon streams from the UND REE process (upgraded lignite by-product ore/carbons, humins and humic acid). This work will be conducted in AmeriCarbon's multi-ton, multi-million-dollar pilot facility to ensure the results can be directly scaled to the commercial plant being built at the North Dakota Project Forge site. Various chemical

and physical processing will be involved in the evaluation studies. This task will help ensure the process integration ties with the REE-CM recovery/production process are adequately defined to allow complete successful site process integration opportunities. The iterative and synergistic nature of process integration across tasks 3-5 are important to understand and optimizing for the successful overall integration of lignite coal, tailored carbon pitch (EcoPitch) and REE-CM production for Project Forge.

Estimated budget: \$2,975,000

Task 4: REE Process Integration & Optimization Studies

The University of North Dakota (UND) has developed extensive intellectual property for the separation and recovery of REE's in North Dakota lignite coal and demonstrated both at the laboratory and pilot scale. This task will be focused on producing various by-product variants to be tested as potential feedstock for AmeriCarbon's Eco-Pitch manufacturing plant. The iterative approach will allow both REE and pitch process unit operations to be optimized for both product quality and by-product integration. Data will be generated at both the laboratory and pilot scale. Demonstration of carbon products (such as graphite, carbon anodes, batteries) made from the novel pitches will be conducted at the bench-scale to validate the process integration approach at Project Forge.

Estimated budget: \$800,000

Task 5: Ge/Ga Process Integration & Optimization Studies

Microbeam's Ge/Ga pyrometallurgical process specifically focuses on concentration of gallium, germanium and antimony and is significant for important electronics and defense critical applications. Microbeam will test the various ash by-products from the AmeriCarbon Eco-Pitch process which will be uniquely produced in varying chemistries/specifications depending on the product/by-products being utilized (from lignite coal mines and by-product use from the UND REE process).

Estimated budget: \$300,000

Task 6: Technoeconomic Assessment

A study will be conducted to evaluate the optimization impact of the REE-CM integration of Project Forge on the baseline economics of the planned AmeriCarbon Forge pitch manufacturing plant. Input will be based on existing AmeriCarbon techno-economics and results from Tasks 3-5. This will also contain preliminary markets and plant economics for the REE integrated process/plant integration at the site.

Estimated budget: \$150,000

Task 7: Technology Development and Commercialization Path

Based on the deliverables of the preceding tasks, a gap analysis approach will be taken to identify a technology development and/or commercialization path leading to a complete integrated commercial lignite pitch and REE plant at the Project Forge site located in North Dakota.

\$75,000

Total project budget:

Task 1: \$100,000
Task 2: \$100,000
Task 3: \$2,975,000
Task 4: \$800,000
Task 5: \$300,000
Task 6: \$150,000
Task 7: \$75,000

Total: \$4,500,000

Anticipated Results:

The Forge Project will generate both technical and strategic outcomes that validate the feasibility and economic potential of integrating AmeriCarbon’s carbon liquefaction process with UND’s and Microbeam’s critical-materials recovery technologies. Completion of the project will result in a process integration framework, validated technical data packages, and an engineering and economic foundation to support commercial-scale implementation at the planned Forge manufacturing complex in McLean County, North Dakota.

Key anticipated results include:

1. Validated Feedstock and Process Integration
 - Demonstrated use of upgraded lignite, humins, and humic-acid residues as optimized or blended feedstocks for AmeriCarbon’s Eco-Pitch™ process.
 - Quantitative data defining yield, composition, and carbon conversion efficiency for each feedstock scenario.
 - Confirmed compatibility of these materials with existing pilot operations and projected commercial-scale plant parameters.
2. Improved Product Quality and Purity
 - Demonstrated reduction of ash and mineral impurities through optimized demineralization and purification processes.

- Production of ultra-high-purity carbon materials suitable for advanced applications such as synthetic graphite, carbon anodes, and binder pitches.
3. By-Product Value Recovery
- Characterization of REE, Ge, Ga, and Sb concentrations in AmeriCarbon’s process residues and UND’s by-product streams.
 - Bench-scale verification of Microbeam’s vaporization and selective-condensation process using these materials, achieving target Ge/Ga purities above 90% oxide basis.
 - Data supporting downstream refining to 99.999%-purity metals for evaluation by industrial offtakers.
4. Engineering and Economic Integration Framework
- Development of process flow diagrams, material and energy balances, and preliminary site layouts illustrating how carbon and critical-mineral systems can be co-located.
 - Definition of shared utilities, waste management, and by-product handling schemes to enable an integrated commercial facility.
 - Completion of a techno-economic assessment (TEA) quantifying capital and operating costs, product revenue potential, and overall economic contribution to North Dakota.
5. Technology Development and Commercialization Pathway
- Identification of remaining technical gaps and a stepwise plan toward full commercialization, including pilot-to-plant scale-up milestones.
 - Defined roles for industrial, academic, and engineering partners in the next development phase.
 - Comprehensive dataset and engineering documentation suitable for inclusion in future CSEA and DOE funding applications supporting scale-up.

Collectively, these outcomes will establish a first-of-its-kind lignite-based carbon and critical-materials manufacturing model. The project will demonstrate how North Dakota’s lignite resources can underpin a new clean-energy and strategic-materials industry—producing value-added carbon, recovering critical minerals, and enabling supply-chain resilience for the nation while diversifying the state’s energy economy.

Facilities:

Proposed Commercial Plant Site

AmeriCarbon and its partners have identified a strategic location for the Forge Project site near Underwood, North Dakota (Figure 2).



Figure 2. Planned location of the Forge Project near Underwood, North Dakota, outlined in blue.

The proposed site is situated near the following:

- Falkirk Mine, a significant lignite coal mining operation, and in proximity to key industrial infrastructures;
- *Rainbow Energy Center's Coal Creek Station*. This is North Dakota's largest power plant, known for its efficiency and substantial electricity generation capacity; and
- *Blue Flint Ethanol Plant*. Located just east of the Coal Creek Station, this facility has been operational for over a decade, producing ethanol and contributing to the region's biofuel industry.

The proximity to these facilities offers potential synergies, such as shared infrastructure and services, which can enhance operational efficiency and sustainability.

Pilot Plant: Foundation for Commercial Design

AmeriCarbon operates the only known multi-ton-per-day coal liquefaction and pitch manufacturing pilot facility in the United States. The pilot plant incorporates AmeriCarbon's patented Liquid Carbon Process (Eco-Pitch™), which converts domestic coals—including lignite—into engineered coal tar pitch and advanced carbon materials.

Key systems include:

- A continuous liquefaction reactor train with precision temperature and residence-time control;
- Real-time analytical instrumentation for viscosity, softening point, and product composition;
- Integrated ash-handling and residue collection systems designed for by-product sampling and characterization; and
- Utilities and controls suitable for rapid parameter adjustments during feedstock blending trials.

This facility provides the platform for conducting feedstock and process optimization under Task 3 (Pitch Integration & Optimization Studies), enabling direct scale-up to AmeriCarbon Forge, LLC's planned commercial plant in McLean County, North Dakota.



Figure 3. AmeriCarbon's Research and Pilot Demonstration Facility in Morgantown, West Virginia.

AmeriCarbon's pilot plant is significant for the following reasons:

- *Process Validation.* The pilot plant has been instrumental in validating the technical feasibility of the Eco-Pitch production process, ensuring that each stage operates seamlessly and efficiently.
- *Data Collection for Scale-Up.* Comprehensive data gathered from pilot operations have been pivotal in informing the scale-up process, facilitating a tenfold increase in production capacity for the commercial plant.

- *Risk Mitigation.* Operating the pilot plant has allowed AmeriCarbon to identify and address potential challenges in a controlled environment, significantly reducing risks associated with scaling up to commercial production.



Figure 4. AmeriCarbon’s pilot scale unit operations that underpin the LCP process.



Figure 5. AmeriCarbon’s pilot scale and research equipment.

University of North Dakota – College of Engineering & Mines Research Facilities

UND’s College of Engineering & Mines Research Institute houses extensive laboratory and pilot infrastructure dedicated to rare earth element (REE) and critical mineral recovery from lignite and associated materials. These include:

- ✓ A fully integrated pilot-scale REE extraction system capable of processing up to 500 kilograms per hour of lignite mine waste feedstock, producing mixed rare earth concentrates (MREC) and upgraded lignite co-products;

- ✓ The Advanced Materials Characterization Laboratory (AMCL), equipped with scanning electron microscopy (SEM-EDS), X-ray fluorescence (XRF), X-ray diffraction (XRD), inductively coupled plasma–mass spectrometry (ICP-MS), and thermal analysis instrumentation;
- ✓ A bench-scale purification and graphitization laboratory, supporting the development of ultra-high-purity carbons for anode and specialty applications; and
- ✓ Process modeling and engineering design software (Aspen Plus, COMSOL Multiphysics, MATLAB, and SimaPro) used for techno-economic and life-cycle analyses.

These facilities support Task 4 (REE Process Integration & Optimization Studies) and provide the test bed for refining demineralization, purification, and carbon-quality improvement studies.

Microbeam Technologies, Inc. – Grand Forks, ND and Minnetonka, MN

Microbeam operates analytical and pilot-scale systems focused on critical mineral recovery and advanced materials analysis. Its Grand Forks facility houses:

- ✓ Two automated scanning electron microscopes (CCSEM) with X-ray microanalysis for mineralogical and compositional mapping;
- ✓ Laboratory and bench-scale pyrometallurgical and hydrometallurgical reactors for germanium, gallium, and antimony vaporization, selective condensation, and refining; and
- ✓ A pilot bench system designed to process mixed rare earth concentrates (MREC) and produce Ge/Ga concentrates at rates of up to 5–10 kg/h.
- ✓ Thermochemical equilibrium modeling software (FactSage) to predict critical mineral vapor-liquid-solid transformations and interactions that is crucial in optimizing process conditions for pyrometallurgical applications.

Microbeam’s Grand Forks and Minnetonka locations include computational modeling, analytical equipment, a metals recovery and high-temperature testing facility, as well as a 7,000-square-foot shop and laboratory area for constructing and operating process equipment. These facilities will support Task 5 (Ge/Ga Process Integration & Optimization Studies) and provide analytical support across all project activities.

Worley Group Facilities

Worley Group will provide engineering design, process integration, and site planning services under Task 2 (Preliminary Process and Site Integration Assessment). The firm’s regional engineering offices and process modeling capabilities will be used to generate process flow diagrams (PFDs), mass and energy balances, and site layout studies defining how the integrated systems can be co-located and scaled at the Forge site.

Resources:

The successful execution of *The Forge Project: Rare Earths and Critical Materials Integration* will rely on a coordinated set of technical, analytical, and organizational resources contributed by AmeriCarbon, Ore Spring Materials, the University of North Dakota (UND), Microbeam Technologies, and Worley Group. These resources form the backbone of the project's ability to execute the technical scope and achieve the anticipated outcomes.

Technical and Engineering Resources

AmeriCarbon Enterprises, LLC / AmeriCarbon Forge, LLC. AmeriCarbon brings the nation's only multi-ton-per-day coal liquefaction pilot facility and a world-class technical team with experience in carbon product manufacturing, feedstock optimization, and process integration. The AmeriCarbon pilot facility will serve as the platform for Task 3 (Pitch Integration and Optimization Studies), providing real-world process data on temperature control, residence time, and yield performance across various feedstock configurations.

AmeriCarbon's engagement of Worley Group provides direct access to multidisciplinary engineering resources for process modeling, mass and energy balance development, and site integration design. Worley's engineering and construction teams have extensive experience in advanced materials, refining, and energy-infrastructure projects in North Dakota and globally.

Academic and Research Resources

University of North Dakota (UND) – College of Engineering & Mines Research Institute. UND contributes a fully operational pilot-scale rare earth element (REE) extraction facility capable of processing up to 500 kilograms per hour of lignite feedstock, producing upgraded lignite and mixed rare earth concentrates. The facility, coupled with UND's Advanced Materials Characterization Laboratory (AMCL), provides comprehensive analytical capabilities (SEM/EDS, XRF, XRD, ICP-MS, and thermal analysis).

UND's team has extensive experience in rare earth and critical mineral recovery, feedstock purification, and techno-economic modeling. Their existing DOE- and NDIC-supported programs provide validated process data and a mature platform for integration with AmeriCarbon's carbon liquefaction technology.

UND's REE extraction process produces several products, including a unique upgraded lignite carbon ore ("upgraded LCO"). REE/CM processing uses lignite that would be otherwise unsuitable for thermal applications (high ash and low heating value) and significantly upgrades it by 1) reducing mineral matter using physical separations and 2) removing the organically associated inorganic elements through dilute mineral acid extraction. UND's prior technology development has identified that our REE/CM process has promising economic potential; however, a major component (~50%) of projected revenues from a commercial facility is from the upgraded LCO, even under the low-value use as a combustion blending fuel. This highlights the magnitude of the potential economic benefit of, instead, manufacturing value-added carbon products.

Industrial Research and Critical Mineral Recovery Resources

Microbeam Technologies, Inc. Microbeam brings to the project a unique combination of analytical, metallurgical, and process-development capabilities. Its Grand Forks and Minnetonka facilities are equipped with equilibrium thermodynamics modeling, high-temperature furnaces, condensation systems, and metals-recovery benches designed to process mixed rare earth concentrates (MREC) and coal-derived ash into germanium (Ge) and gallium (Ga) products. These resources will be directly utilized under Task 5 (Ge/Ga Process Integration and Optimization Studies).

Microbeam's expertise in mineralogical analysis (SEM, XRF, and ICP-MS) and its patented vaporization and selective-condensation process will enable accurate assessment of REE and CM recovery from AmeriCarbon's by-product ash streams.

Data, Intellectual Property, and Prior Research Assets

The proposed project builds upon substantial intellectual property and data portfolios developed by the participants:

- ✓ **AmeriCarbon** AmeriCarbon holds proprietary intellectual property related to its Eco-Pitch production technology. The data from its pilot plant operations provide invaluable insights into the performance, efficiency, and scalability of the process. This proprietary data will be used to inform the commercial design and ensure that all process parameters are optimized for large-scale production. Further, AmeriCarbon holds five patents in the United States and Canada: US# 11667852, 10301549, 9845431, 9534176; and CA# 3120884.
- ✓ **UND** holds patents and pending applications covering the extraction of rare earths and critical minerals from lignite mine wastes and organically associated materials, and maintains several years of pilot-scale performance data validated under DOE projects.
- ✓ **Microbeam** holds patents and pending applications for its REE-predictive analysis algorithms (US# 11733184) and for the process of producing high-purity Ge and Ga from mixed rare earth concentrates and coal-derived ash (US# 12031195).

These collective IP and data resources form a strong foundation for the integrated process modeling and techno-economic evaluation that will be undertaken in this project.

Techniques to Be Used, Their Availability and Capability:

The Forge Project: Rare Earths and Critical Materials Integration will employ a suite of bench, pilot-, and engineering-scale techniques to validate the integrated process for carbon production and critical mineral recovery. All techniques are established and available within the existing facilities of AmeriCarbon, the University of North Dakota (UND), Microbeam Technologies, and Worley Group. Together, these techniques provide the ability to conduct process development, performance optimization, and economic evaluation at a level sufficient to inform commercial-scale design.

1. Feedstock Evaluation and Liquefaction (AmeriCarbon)

AmeriCarbon will utilize its Liquid Carbon Process (Eco-Pitch™) pilot plant and associated laboratory equipment to process and evaluate various feedstocks including run-of-mine lignite, upgraded lignite, humins, and humic acid residues supplied by UND. Techniques include:

- Controlled liquefaction testing. Continuous pilot-scale runs under variable residence time, temperature, and pressure conditions to determine yield and quality of resulting pitches.
- Analytical characterization. Viscosity, softening point, quinoline insolubles, toluene insolubles, elemental analysis, and ash content to assess performance and reproducibility.
- By-product handling and sampling. Automated collection and compositional mapping of ash and carbon residues for mineralogical and REE/CM content analysis.
- Blending and process-optimization matrix. Systematic blending of multiple feedstocks to identify optimal ratios for yield, purity, and pitch specification control.

All techniques are established within AmeriCarbon's operating pilot plant and have been used to generate validated process data for scale-up to commercial operations.

2. Rare Earth Element (REE) and Carbon Co-Product Processing (UND)

The UND College of Engineering & Mines Research Institute will apply a proven set of hydrometallurgical and beneficiation techniques used in its DOE- and NDIC-funded REE extraction programs. These include:

- Mild-acid leaching of lignite-based feedstocks to extract REEs and critical minerals from organically associated matrices while retaining the carbon structure for subsequent use by AmeriCarbon.
- Solid-liquid separation and washing to recover the upgraded carbon material with near-zero sodium and low-ash content.
- Two-stage oxalate precipitation and calcination to generate mixed rare earth concentrates (MREC) with ≥ 75 wt% REE purity on an oxide basis.
- Advanced purification and demineralization using bench-scale chemical treatment and filtration to produce high-purity carbon suitable for anode and binder applications.
- Bench-scale graphitization and electrochemical testing of resulting carbon materials (coin and 18650-cell evaluations).

All techniques are operational within UND's 500 kg/h pilot-scale REE extraction facility and Advanced Materials Characterization Laboratory (AMCL), which houses full analytical capabilities (SEM/EDS, XRF, XRD, ICP-MS, and TGA). These facilities have already achieved Technology Readiness Level (TRL) 6 for REE extraction from North Dakota lignite.

3. Critical Mineral (Ge/Ga/Sb) Recovery and Refining (Microbeam Technologies)

Microbeam will apply its patented vaporization and selective-condensation process to recover germanium (Ge), gallium (Ga), and antimony (Sb) from AmeriCarbon and UND by-product streams. The process combines pyrometallurgical techniques, including:

- High-temperature vaporization of MREC and ash feedstocks in controlled-atmosphere furnaces to release Ge and Ga vapors.
- Selective condensation and particulate capture to recover Ge- and Ga-rich oxides as discrete concentrates.
- Direct metallization and refining via chlorination, hydrolysis, and electrowinning steps to achieve high-purity ($\geq 99.999\%$) Ge and Ga metals.
- Analytical validation using SEM/EDS, XRF, ICP-MS, and XRD to confirm product purity and recovery yield.

Microbeam's bench-scale system (5–10 kg/h feed rate) is supported through DOE-, DoD, and NDIC-supported projects. These techniques will be used to confirm recovery factors, product specifications, and by-product recycling potential.

4. Process Integration and Engineering (AmeriCarbon and Worley Group)

Worley Group will apply process modeling, simulation, and site-integration techniques to develop a unified design framework that combines carbon manufacturing and REE/CM recovery. Methods include:

- Process flow diagram (PFD) and piping & instrumentation diagram (P&ID) development using Aspen Plus and AutoCAD Plant 3D.
- Mass and energy balance modeling based on empirical data from Tasks 3–5.
- Utility and infrastructure integration modeling for power, water, and material handling systems.
- Plot-plan and layout design to support co-location at the Forge site, including environmental, utility, and logistics interfaces.

Worley has extensive experience delivering front-end engineering design (FEED) and techno-economic analysis (TEA) studies for lignite, refining, and advanced-materials facilities throughout North Dakota and other U.S. industrial regions.

5. Analytical and Data Management Techniques

Cross-partner data will be standardized and validated using the following techniques:

- Statistical design of experiments (DOE) and response-surface modeling for optimization across feedstock blends and process parameters.

- Standardized analytical protocols for REE/CM assays and carbon purity (using ICP-MS, XRF, and SEM-EDS) to ensure comparability between institutions.
- Digital data management and integration via shared cloud-based project folders, ensuring traceability of raw data, analytical results, and reports.

These methods ensure technical consistency, reproducibility, and defensible data quality across all project activities.

Collectively, these techniques span the full technology chain—from feedstock characterization through carbon and mineral production, to process modeling and techno-economic evaluation. Each is already established, available, and fully capable of achieving the project’s technical objectives, providing a strong foundation for future scale-up and commercial implementation at the Forge site.

Environmental and Economic Impacts while Project is Underway:

The proposed project will be executed as a research, development, and engineering program, utilizing existing pilot and laboratory facilities at AmeriCarbon, the University of North Dakota (UND), and Microbeam Technologies. As such, environmental impacts during the project are expected to be minimal, localized, and fully manageable within standard institutional safety and environmental procedures.

Environmental Impacts

Limited Material and Energy Use. Pilot- and bench-scale testing will use small quantities of lignite, upgraded carbon feedstocks, and process residues. No large-scale excavation, construction, or waste disposal is planned. Energy and water use will remain within normal laboratory operations.

Waste and Effluent Management.

- Liquefaction residues, process ash, and small volumes of spent reagents generated at AmeriCarbon and UND will be managed under existing facility permits and standard operating procedures.
- Any acid or solvent streams from UND’s REE extraction and purification work will be neutralized and disposed of through UND’s hazardous waste program in compliance with state and federal regulations.
- Gaseous emissions from Microbeam’s high-temperature testing will be captured through particulate control and ventilation systems; no uncontrolled emissions are expected.

Environmental Health and Safety (EHS) Compliance. All partner facilities maintain active EHS programs that include staff training, chemical hygiene plans, and hazardous waste management protocols. No new permitting actions or environmental assessments are anticipated during this phase of work.

No Adverse Community or Ecological Effects. Work will occur entirely within existing industrial or research facilities in Grand Forks, Morgantown, Minnetonka, and other controlled laboratory environments. No fieldwork or disturbance of natural land, water, or habitat will occur during the project.

Economic Impacts

Direct Employment and Workforce Development. The project will support a skilled multidisciplinary workforce of engineers, scientists, and technicians across AmeriCarbon, UND, and Microbeam. Temporary project-specific employment will include graduate and undergraduate researchers at UND, contract engineers, and technical support personnel.

Local and Regional Spending. Project expenditures will include laboratory supplies, analytical services, and engineering support procured within North Dakota and neighboring states. UND's research operations and the project's overall planned activities will direct a substantial portion of spending to local vendors, utilities, and service providers.

Capacity Building for Future Industry. Beyond the immediate project, this work expands North Dakota's industrial base in high-value carbon and critical-mineral technologies. It strengthens institutional and workforce capacity for future phases involving pilot expansion and commercial deployment at the Forge site.

In summary, during the project's execution period, environmental impacts will be negligible and confined to controlled laboratory activities, while economic impacts will be positive, centered on job creation, technical workforce training, and procurement within North Dakota's research and industrial ecosystem. The project thus aligns with CSEA's mission to support clean and sustainable energy innovation with responsible environmental stewardship.

Ultimate Technological and Economic Impacts:

The Forge Project: Rare Earths and Critical Materials Integration will demonstrate the technical and economic viability of an integrated system that transforms North Dakota lignite and process by-products into high-value carbon materials and critical minerals. The project will validate an entirely new model of resource utilization — one that combines advanced carbon manufacturing, rare earth element (REE) extraction, and critical mineral recovery within a single industrial ecosystem. The long-term impacts extend well beyond this research phase, establishing a foundation for new industries, jobs, and supply chains centered in North Dakota.

Technological Impacts

The project will advance a first-of-its-kind integration of carbon and critical-material technologies, combining three complementary innovations:

1. AmeriCarbon's Eco-Pitch™ Liquefaction Process, which converts lignite, upgraded lignite, and humic-based materials into tailored binder and impregnating pitches for high-value applications in synthetic graphite, battery anodes, and carbon composites;

2. UND’s Rare Earth Extraction and Carbon Upgrading Process, which isolates REEs from lignite mine wastes and humic materials, producing upgraded carbon feedstocks with low ash and high purity suitable for conversion into premium carbon products; and
3. Microbeam’s Germanium and Gallium Recovery Process, which separates and refines critical minerals from AmeriCarbon and UND process residues using proprietary vaporization and selective-condensation techniques.

Together, these systems create a closed-loop process chain that captures value from every portion of the lignite resource—carbon, rare earths, and trace metals—while minimizing waste.

Technologically, the project will demonstrate:

- Integration at the process-engineering level, enabling simultaneous production of high-purity carbon materials and REE/CM concentrates within a single facility footprint;
- Improved environmental performance, including lower energy consumption and reduced waste generation compared with traditional REE and carbon manufacturing methods;
- Scalability and replicability, with data and designs directly transferable to commercial-scale deployment at AmeriCarbon Forge in McLean County, ND, and to future projects across other lignite-producing regions; and
- Alignment with national strategic goals, including the *2025 Executive Order on Increasing American Mineral Production*, which prioritizes domestic manufacturing of critical materials essential to defense, energy, and advanced manufacturing sectors.

By establishing the technical basis for co-locating carbon, REE, and critical-mineral production, the Forge Project will showcase a new generation of resource-integrated manufacturing capable of supporting the United States’ long-term industrial and supply-chain resilience.

Economic Impacts and Value to North Dakota

The Forge Project’s long-term economic impacts will be transformative for North Dakota, positioning the state as a center of excellence for critical-materials and advanced-carbon production.

Key economic impacts include:

- ✓ Creation of a New Industrial Platform. The integration of carbon manufacturing and REE/CM recovery represents the foundation of a new high-value industry in North Dakota—one that leverages the state’s lignite resources not for combustion, but for advanced manufacturing and critical-materials production.
- ✓ Expansion of Domestic Supply Chains. By enabling U.S.-based production of coal-tar-pitch equivalents, synthetic graphite precursors, and REE/CM products such as germanium and gallium, the project supports national energy security, defense readiness, and industrial competitiveness.

- ✓ Workforce Development and Technology Transfer. The project will train a new generation of engineers, scientists, and technicians in advanced carbon and critical-material processing, creating transferable expertise for future commercial plants. UND's participation ensures educational integration, internships, and hands-on experience for students in chemical and materials engineering.
- ✓ Regional Economic Growth. The Forge Project will strengthen the economic base of McLean County and surrounding areas by anchoring future construction, operations, and supply-chain activities. The commercial facility enabled by this research will attract suppliers, create high-wage technical jobs, and generate significant secondary economic activity in logistics, maintenance, and services.
- ✓ Diversification and Resource Valorization. Transforming lignite into carbon and mineral products redefines the economic potential of North Dakota's coal reserves—converting a low-cost energy resource into a feedstock for the aerospace, energy storage, semiconductor, and defense industries.

In the long term, the Forge Project will catalyze a new materials manufacturing corridor within the state—anchored by the AmeriCarbon Forge commercial complex and sustained by ongoing partnerships with UND, Microbeam, and the North Dakota Industrial Commission. This vertically integrated system will advance national clean-energy and materials goals while providing durable, high-value employment and long-term economic diversification for North Dakota.

Why the Project is Needed:

The Forge Project: Rare Earths and Critical Materials Integration is needed to close a critical gap between research-stage technologies for rare earth element (REE) and critical mineral recovery and the commercial-scale carbon manufacturing system now being advanced in North Dakota through AmeriCarbon Forge, LLC. This project represents the essential integration phase—aligning the technical, engineering, and operational interfaces that will enable these complementary processes to function as one unified manufacturing platform.

For decades, the United States has been almost entirely dependent on foreign sources for two strategic material streams—coal-tar pitch (used for graphite, anodes, and carbon composites) and rare earth elements and critical minerals (used in electronics, defense, and clean-energy technologies). China currently dominates both supply chains. This dependence poses serious risks to national security, economic competitiveness, and the resilience of U.S. manufacturing.

The Forge Project directly addresses these vulnerabilities by creating a North Dakota-based integrated production system that converts lignite and process by-products into high-value carbon materials and co-recovered critical minerals such as germanium, gallium, and REEs. Through coordinated development by AmeriCarbon, UND, and Microbeam Technologies, the proposed project will establish the technical and engineering basis for co-locating these processes at the AmeriCarbon Forge site in McLean County.

Germanium (Ge) and Gallium (Ga) are essential materials for advancing energy efficiency and sustainability across a wide range of technologies, including quantum processors, photonic circuits, and high-speed electronic devices. Ge enables low-power, high-speed transistors, single-

photon detectors, and quantum dots for integrated sensing and computing, while Ga—especially in the form of gallium nitride (GaN)—powers efficient LEDs, RF amplifiers, and power electronics that reduce energy consumption in data centers, electric vehicles, and renewable energy systems. The lack of readily available Ge and Ga is limiting the US ability to produce high efficiency electronic products for infrared optics, thermal imaging systems, satellite solar panels, emerging quantum computing, and photonics platforms.

Addressing National and State Priorities

1. Energy and Materials Security. The project will strengthen domestic supply chains by enabling U.S. production of two categories of critical inputs: (i) advanced carbon materials and (ii) REEs and associated critical minerals. Integration of AmeriCarbon’s Eco-Pitch™ process with UND’s REE extraction and Microbeam’s Ge/Ga recovery technologies directly supports the U.S. Department of Energy’s Critical Materials Initiative and the 2025 *Executive Order on Increasing American Mineral Production*.
2. Environmental Performance and Resource Optimization. The integration of these processes creates a closed-loop system that minimizes waste and maximizes value from North Dakota lignite. AmeriCarbon’s low-temperature, non-combustion carbon process reduces greenhouse-gas emissions by more than 90% compared with conventional pitch manufacturing. UND’s extraction process converts lignite mine waste into upgraded carbon feedstock, while Microbeam’s technologies recover high-purity metals from process residues. Together, they form an environmentally responsible pathway to critical-materials production with minimal incremental footprint.
3. Economic Diversification and Industrial Development in North Dakota. The proposed project will accelerate North Dakota’s transition from traditional coal utilization toward advanced materials manufacturing. It will position McLean County and the broader lignite region as a national hub for carbon, rare earth, and critical-mineral industries, supporting high-wage technical employment, new capital investment, and supply-chain growth in engineering, logistics, and materials processing.

Why This Project Is Needed Now

The underlying technologies—AmeriCarbon’s Eco-Pitch™ process, UND’s REE extraction platform, and Microbeam’s Ge/Ga separation system—have each reached pilot or early demonstration scale. However, they have not yet been integrated into a shared industrial framework. Without this integration, opportunities for efficiency, by-product valorization, and shared infrastructure would remain unrealized, limiting both economic and environmental benefits.

This project provides the bridge between discrete technology readiness and industrial integration, delivering the data, engineering, and techno-economic foundation required for full-scale implementation at the Forge Project site.

Strategic Outcomes

The Forge Project: Rare Earths and Critical Materials Integration is needed to:

- ✓ Demonstrate process compatibility and optimized material flow among the three technology systems;
- ✓ Establish engineering, economic, and environmental parameters for integrated production;
- ✓ Enable CSEA and the State of North Dakota to evaluate a scalable model for carbon and critical-mineral manufacturing; and
- ✓ Position North Dakota as a national leader in clean, secure, and sustainable materials production.

In short, *The Forge Project* is the integration step that transforms years of parallel research into a unified, commercially viable system. It advances CSEA’s mission by creating a model for clean energy and materials innovation that enhances national security, drives regional economic diversification, and redefines the role of lignite in a modern, low-carbon industrial economy.

STANDARDS OF SUCCESS

The success of *The Forge Project: Rare Earths and Critical Materials Integration* will be measured by its ability to demonstrate, document, and de-risk the technical, economic, and environmental viability of integrating AmeriCarbon’s carbon manufacturing process with the rare earth and critical mineral recovery technologies developed by UND and Microbeam Technologies.

The project will define and validate the framework for a fully integrated carbon and critical-materials manufacturing platform in North Dakota—one that enhances the value of lignite, strengthens domestic supply chains, and positions the state as a leader in sustainable energy and materials innovation.

Key Metrics for Success

1. Technical Integration and Performance

- Successful completion of pilot- and bench-scale testing demonstrating compatibility among AmeriCarbon, UND, and Microbeam process streams.
- Verified ability to process multiple feedstocks—lignite, upgraded lignite, humins, and humic-acid residues—within AmeriCarbon’s Eco-Pitch™ system to produce high-quality carbon pitches with defined customer specifications.

- Demonstrated recovery of germanium, gallium, and other critical minerals from AmeriCarbon and UND process residues, achieving purity levels suitable for downstream refining and potential commercial use.
- Delivery of a comprehensive **process integration model** including mass and energy balances, process flow diagrams (PFDs), and site-integration layouts validated by Worley Group.
- Completion of a **Techno-Economic Assessment (TEA)** showing clear economic potential for integrated production and co-location at the AmeriCarbon Forge site.

2. Environmental and Sustainability Outcomes

- Quantified reduction in process waste and greenhouse-gas intensity relative to conventional carbon and mineral processing.
- Documented lifecycle environmental benefits through data from the integrated process, emphasizing closed-loop material use and minimized waste generation.
- Establishment of an operational baseline to support future environmental permitting and sustainability certification for the commercial Forge facility.

3. Economic and Workforce Development Value

- Demonstrated economic viability and readiness for scale-up, providing the technical and economic foundation for subsequent CSEA and private-sector investment.
- Support of North Dakota-based engineering, research, and laboratory employment throughout the project period, including workforce participation by UND graduate and undergraduate students.
- Creation of an actionable roadmap for commercial deployment, enabling future job creation and local manufacturing investment in McLean County and across the state.

4. Advancement of Research, Development, and Technology Commercialization

- Advancement of three distinct technology families—carbon liquefaction, REE extraction, and Ge/Ga recovery—to a higher level of integration readiness.
- Development of a replicable model for industrial symbiosis that can be applied to other lignite regions or industrial sites in North Dakota.
- Generation of publishable, transferable technical data that can be leveraged by the public and private sectors to support future innovation and commercialization.

Alignment with CSEA Mission and Program Objectives

The Forge Project directly advances the mission of the Clean Sustainable Energy Authority by:

- ✓ Enhancing the **sustainability and value** of North Dakota’s lignite resource through clean manufacturing technologies;

- ✓ Supporting **energy and materials security** by establishing the foundation for domestic production of critical materials;
- ✓ Promoting **environmental stewardship** through substantial reductions in greenhouse-gas and waste outputs; and
- ✓ Driving **economic diversification** through new industries, jobs, and technical capabilities based in the state.

Benchmarks for Long-Term Success

While the proposed project focuses on integration and optimization, its longer-term success will be measured by its ability to catalyze future developments, including:

- Commercial Deployment. Successful transition of the integrated process to full-scale operation at the AmeriCarbon Forge site by 2027.
- Expansion of Advanced Manufacturing. Attraction of additional carbon, rare earth, and critical-mineral manufacturing facilities within North Dakota over the next decade.
- Sustained Economic Impact. Creation of durable, high-wage employment in engineering, manufacturing, and materials processing, supported by a North Dakota–based supply chain.

By meeting these standards of success, *The Forge Project* will deliver measurable technical achievements, clear economic and environmental benefits, and a validated framework for commercial implementation. The results will strengthen North Dakota’s leadership in clean, sustainable materials production and help establish a resilient, domestic supply chain for advanced carbon and critical-mineral industries.

BACKGROUND/QUALIFICATIONS

The Forge Project builds on more than a decade of development in lignite-based carbon manufacturing, rare earth element (REE) extraction, and critical mineral recovery technologies that have been pioneered independently by AmeriCarbon Enterprises, the University of North Dakota (UND), and Microbeam Technologies, Inc. This project represents the convergence of those technology paths into a unified industrial platform for the State of North Dakota.

Project Origins and Context

Ore Spring Materials, LLC was established to manage and coordinate the integration of AmeriCarbon’s coal-to-carbon pitch manufacturing process with emerging REE and critical-mineral recovery technologies developed by UND and Microbeam. The combined system—referred to as *The Forge Project: Rare Earths and Critical Materials Integration*—advances a vision of full-resource utilization: converting lignite and related by-products into high-value carbon materials, rare earth elements, and critical minerals, while minimizing waste and environmental impact.

This integration builds on a series of NDIC- and DOE-funded projects that have demonstrated both the technical feasibility and economic promise of these constituent technologies. The current project, submitted to the Clean Sustainable Energy Authority (CSEA), focuses on the next step—process integration, optimization, and engineering design—to prepare for commercial-scale deployment at the AmeriCarbon Forge site in McLean County.

Background of Key Project Participants

AmeriCarbon Enterprises, LLC / AmeriCarbon Forge, LLC

AmeriCarbon has developed the patented Liquid Carbon Process (LCP), a proprietary technology that converts coal, including lignite, into high-performance binder and impregnating pitches (Eco-Pitch™). The process eliminates dependence on imported coal-tar pitch and reduces greenhouse-gas emissions by over 90% compared to conventional coking-oven processes.

AmeriCarbon operates a 12,000-square-foot pilot facility in Morgantown, West Virginia—the only known coal liquefaction–based pitch production facility in the world. Over multiple NDIC-supported projects, AmeriCarbon has:

- ✓ Demonstrated successful conversion of North Dakota lignite into coal tar pitch meeting industrial specifications;
- ✓ Completed FEL-2 engineering through Worley Parsons, verifying commercial feasibility;
- ✓ Advanced FEL-3 design for the McLean County plant through a series of NDIC- and AmeriCarbon-funded efforts; and
- ✓ Launched a reactor optimization project to maximize conversion efficiency and throughput of lignite feedstocks.

These projects collectively establish AmeriCarbon as the nation’s leader in lignite-to-carbon process development. Its expertise in pilot-to-commercial scale-up, system engineering, and process integration underpins The Forge Project’s carbon manufacturing and feedstock optimization components.

University of North Dakota (UND) – College of Engineering & Mines Research Institute

UND has spent the past decade pioneering rare earth and critical mineral recovery from lignite and related materials, with support from both the U.S. Department of Energy (DOE) and the North Dakota Industrial Commission (NDIC). The university’s patented REE extraction process uses mild acid leaching and selective precipitation to produce Mixed Rare Earth Concentrates (MREC) while generating a valuable upgraded carbon by-product suitable for further conversion into high-value pitch products.

Key UND milestones include:

- ✓ Design, construction, and operation of a 500 kg/hr continuous pilot-scale REE extraction facility—the first of its kind using lignite mine waste feedstocks;

- ✓ Development of integrated purification, calcination, and ion-exchange processes capable of producing MREC with ≥ 75 wt% REE purity on an oxide basis;
- ✓ Partnership with DOE, Rare Earth Salts, Barr Engineering, and other industrial collaborators in completing a Front-End Engineering and Design (FEED) efforts for a demonstration facility; and
- ✓ Advancement of intellectual property protecting both the leaching process and organically associated critical-mineral recovery techniques.

UND's technologies form the front-end beneficiation and purification component of The Forge Project, providing high-purity carbon feedstocks and process data essential to optimizing AmeriCarbon's Eco-Pitch™ system.

Microbeam Technologies, Inc.

Microbeam Technologies, based in Grand Forks, North Dakota, and Minnetonka, Minnesota, is an applied research and development firm specializing in fuel characterization, ash behavior, and critical-mineral recovery from coal and carbonaceous feedstocks.

Microbeam's relevant experience includes:

- ✓ Development of a proprietary vaporization and selective-condensation process for germanium (Ge) and gallium (Ga) recovery from mixed REE concentrates (MREC) derived from UND's process;
- ✓ Successful bench-scale validation of this system under a DOE/NDIC-funded project (Award DE-FE0032522), achieving > 90 wt% purity of Ge/Ga concentrates;
- ✓ Operation of advanced analytical laboratories equipped with scanning electron microscopy, and X-ray fluorescence (XRF) for mineralogical and compositional mapping; and
- ✓ Longstanding collaboration with UND on REE characterization and process optimization.

Microbeam's role in The Forge Project is to lead the critical-mineral recovery and refinement tasks, evaluating AmeriCarbon's ash by-products as feedstocks for Ge/Ga separation and contributing process data to the integrated economic model.

Worley Group

Worley is a global engineering, procurement, and construction (EPC) firm with decades of experience in front-end engineering design (FEED) and industrial process integration. Through previous collaborations with AmeriCarbon and UND, Worley has developed process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), and mass/energy balances for lignite-based carbon and REE facilities in North Dakota.

In The Forge Project, Worley will serve as the engineering integration lead, responsible for:

- Process modeling and mass/energy balance integration across the AmeriCarbon, UND, and Microbeam systems;
- Preliminary site layout and utility interface studies for the Forge site in McLean County; and
- Development of an engineering framework supporting future FEL-3 design and permitting.

Project Team Qualifications

The Forge Project team unites industrial operators, academic researchers, and engineering professionals with unmatched expertise in carbon manufacturing, REE extraction, and mineral recovery.

Technical Leadership

- **David Berry**, CEO of AmeriCarbon, brings more than three decades of DOE and DoD R&D experience in hydrocarbon conversion and advanced materials production, with multiple patents in carbon and liquid-phase processing.
- **Dr. Chetan Tambe**, Senior Engineer at AmeriCarbon, Dr. Tambe specializes in energy-efficient carbon product manufacturing from coal. Prior to joining AmeriCarbon, he worked as a Research Scientist at Cardolite Corporation (PA) on hydrogenation technology scale-up and research collaborations. He holds a Ph.D. from Michigan State University focused on sustainable biobased materials, and his academic work includes multiple peer-reviewed publications, a book chapter, and five patents.
- **Steve Mascaro**, Senior Process Engineer at AmeriCarbon, Steve brings over 25 years of process engineering experience, with a focus on pilot plant optimization. At AmeriCarbon, he leads efforts to optimize reactor performance and scale-up operations. Before joining AmeriCarbon, Steve worked at the U.S. Department of Energy's National Energy Technology Laboratory (NETL), leading pilot research in coal-gas desulfurization, catalyst development, and technical project reviews. He began his career at Aristech Chemical, where he held roles in process engineering, utilities, quality management, and oversaw the expansion of polypropylene capacity with Jacobs Engineering. He holds a B.S. in Chemical Engineering from West Virginia University.
- **Nolan Theaker**, Senior Research Manager with UND CPER, will be UND's principal investigator. Mr. Theaker has been the technical driver for UND's technology development and resource characterization efforts related to REE/CM since he joined UND in 2017. He is widely recognized within the DOE and the research community as a leading expert on REE/CM technologies. Mr. Theaker was the PI on UND's REE/CM pilot demonstration project (DE-FE0031835), as the technical lead on UND's recent FEED project (DE-FE0032295), holds two patents for UND's lignite-based extractive metallurgy process, and has been named as key personnel on two CORE-CM projects: Williston Basin and Gulf Coast.
- **Nic Dyrstad-Cincotta**, Research Operations Manager with UND CPER, is a mechanical and design engineer with over 10 years of experience in technology demonstration and scale-up. Nic was responsible for leading the design, construction and commissioning of

UND's existing REE/CM pilot facility and is one of its lead operations engineers. Nic is also an expert in process instrumentation and controls, having led the design, installation and programming of the REE/CM pilot's National Instruments LabVIEW PLC system and many of CPER's other R&D systems. Nic is also UND CPER's safety officer, responsible for maintaining the safety of our research spaces and operations.

- **Dr. Xiaodong Hou**, Research Associate Professor with UND CPER, is a material chemist with 16 years of experience synthesizing and characterizing advanced materials. He has over 45 peer-reviewed publications in chemistry materials and holds six patents. Dr. Hou has led multiple projects related to advanced carbon materials from lignite for LIBs, including DE-FE0031984 and DE-FE0032139. He will lead activities associated with proof-of-concept prototype product demonstrations for hard carbon anodes and collaborate with Vorbeck on demonstration of UPHA conversion into graphene products.
- **Dr. Dan Laudal**, Executive Director of the UND CEM Research Institute, is an expert on lignite coal, carbon products, and REE/CM technologies. His PhD research was the foundation for UND's technology development related to REE/CM from lignite. He was the Project Director on UND's FEED study project (DE-FE0032295) and in his nearly 20 years in the energy industry has been involved in a wide array of projects ranging from proof-of-concept to world-scale project development. He will support project management and serve as a technical advisor.
- **Dr. Steven Benson**, President of Microbeam Technologies, has over 45 years of experience in fuel chemistry, ash transformations, and critical-mineral recovery, with multiple issued patents and prior DOE project leadership.
- **Alex Benson**, Chief Operating Officer of Microbeam Technologies, leads Microbeam's projects related to the separation and recovery of Ge and Ga from coal-derived byproducts. He is the PI on DOE-NETL and DOD funded projects demonstrating and scaling this technology. He has also led multiple NDIC funded REE-CM resource evaluation efforts in ND (new and current resource developments). Mr. Benson also has experience in new product development, commercialization and operations management of greater than \$300M production facilities.
- **Art Lucas**, Senior Process Engineer at Worley, leads engineering integration and techno-economic analyses, supported by Worley's global process modeling resources.

Summary of Capabilities

The team's combined resources and expertise uniquely position North Dakota to pioneer an integrated carbon-and-critical-materials manufacturing platform. Each participant contributes complementary capabilities:

- AmeriCarbon provides pilot-to-commercial scale process experience and proprietary carbon-conversion data.
- UND supplies validated REE extraction and purification technology and advanced analytical infrastructure.

- Microbeam contributes metallurgical and analytical expertise in Ge/Ga recovery and characterization.
- Worley integrates these systems into a cohesive engineering and economic framework ready for scale-up.

Together, these organizations represent a fully capable and field-proven team that has already demonstrated success in DOE and NDIC-funded programs. Their collective qualifications ensure that The Forge Project will deliver credible, data-driven results that advance North Dakota's leadership in sustainable, value-added energy and materials manufacturing.

MANAGEMENT

Management Approach and Oversight

The Forge Project will be managed through a collaborative project management framework led by Ore Spring Materials, LLC, with technical execution carried out by AmeriCarbon Enterprises, LLC, the University of North Dakota (UND), Microbeam Technologies, Inc., and Worley Group. Ore Spring will serve as the project integrator and administrative lead, responsible for coordination, schedule adherence, and reporting to the Clean Sustainable Energy Authority (CSEA). Governance will be provided by a Project Steering Committee comprising representatives from Ore Spring, AmeriCarbon, UND, Microbeam, and Worley. The Steering Committee will convene monthly to review progress, technical results, budget performance, and risk management. Day-to-day authority resides with the Project Director (Dave Berry, AmeriCarbon) and designated technical leads from each partner organization. Project management will follow established best practices for research program execution, including structured work breakdown, milestone tracking, and risk-based decision gating.

Organization and Responsibilities

Ore Spring Materials, LLC (Project Lead)

- Owns project scope, schedule, and budget.
- Manages partner coordination, reporting, and communications with CSEA and NDIC.
- Oversees compliance, risk management, and quality assurance.
- Maintains the Project Management Plan (PMP), change control procedures, and reporting cadence.

AmeriCarbon (Carbon Manufacturing Lead)

- Leads Task 3 (Pitch Integration & Optimization Studies) and contributes to overall integration design.
- Provides pilot plant operations, data collection, and process optimization for feedstock blending.

- Supplies process performance and material balance data to inform Worley’s engineering integration models.

University of North Dakota (REE Integration Lead)

- Leads Task 4 (REE Process Integration & Optimization Studies) and contributes to feedstock and purification research.
- Provides upgraded lignite, humins, and humic-acid residues as test feedstocks.
- Conducts bench- and pilot-scale validation of demineralization, purification, and carbon-quality improvements.

Microbeam Technologies, Inc. (Critical Mineral Recovery Lead)

- Leads Task 5 (Ge/Ga Process Integration & Optimization Studies).
- Conducts bench-scale vaporization, condensation, and refining trials on AmeriCarbon and UND by-product streams.
- Provides mineralogical and compositional analysis to support the techno-economic assessment.

Worley Group (Engineering and Integration Lead, subcontractor to AmeriCarbon)

- Leads Task 2 (Preliminary Process and Site Integration Assessment) and contributes to system modeling, process flow diagrams (PFDs), and mass/energy balance integration.
- Supports development of the Techno-Economic Assessment (Task 6) and future FEL-3 readiness.

Execution Controls and Reporting Cadence

The Project Management Office (PMO), under Ore Spring, will implement an integrated control and reporting system that emphasizes technical performance, schedule adherence, and accountability. Monthly Progress Reports will summarize technical milestones, budget-to-actual performance, safety metrics, and partner activities. Quarterly Steering Committee Reviews will validate milestone completion and address corrective actions where required. Change Control (MOC) procedures will govern scope and budget modifications, ensuring transparent communication and documented decision-making. A shared risk register will be maintained and reviewed monthly, with proactive mitigation measures documented for technical, financial, and schedule risks.

Safety, Quality, and Environmental Management

All partner facilities operate under established environmental, health, and safety (EHS) programs compliant with federal, state, and institutional requirements. UND’s chemical hygiene plan and AmeriCarbon’s pilot plant safety procedures will guide laboratory and pilot operations. Quality assurance (QA/QC) procedures will include cross-laboratory data verification, analytical

calibration, and review of deliverables by the Project Director and Steering Committee prior to submission to CSEA.

Evaluation Points (Stage Gates & Milestones)

Gate / Milestone	Primary Deliverable / Evidence	Decision / KPI
G1 – Project Initiation	Approved Project Management Plan; Partner Agreements Executed	Schedule and communication plan validated; risk log initialized
M1 – Feedstock and Baseline Testing Complete	Pilot-scale test results (AmeriCarbon & UND)	Feedstock performance validated; preliminary yield and quality data established
M2 – REE and Critical Mineral Recovery Trials Complete	Bench-scale Ge/Ga recovery results; REE and ash analyses	Demonstrated process compatibility and recovery factors
G2 – Integration Design Review	Preliminary mass & energy balances; draft process flow diagrams (Worley)	Engineering and data readiness for techno-economic analysis confirmed
M3 – Techno-Economic Assessment Complete	Draft TEA report integrating data from Tasks 3–5	Commercial potential, cost structure, and ND economic impacts validated
G3 – Final Project Review / Closeout	Final report submitted to CSEA; validated integration framework	Project objectives met; commercial integration pathway defined

Stakeholder Engagement and Communication

Ore Spring will maintain continuous engagement with CSEA, NDIC, and local stakeholders throughout the project. Communication will include monthly technical and financial reports, semi-annual technical briefings, and public outreach via UND’s research communications and AmeriCarbon’s stakeholder network to highlight North Dakota’s leadership in critical-materials innovation.

Summary

This management framework ensures that The Forge Project is executed on schedule, within scope, and in full compliance with CSEA program objectives. The integrated approach—combining industrial, academic, and engineering expertise under coordinated project management—provides the structure necessary to achieve technical success, transparent reporting, and measurable outcomes that support North Dakota’s clean energy and materials strategy.

TIMETABLE

The Forge Project: Rare Earths and Critical Materials Integration is planned as a 24-month project commencing upon award authorization by the Clean Sustainable Energy Authority (CSEA). The schedule outlined below provides the target start and completion dates for major project activities, including key technical milestones and reporting deliverables.

Task / Activity	Description	Start Date	Completion Date	Deliverable / Reporting Milestone
Project Initiation and Management Setup	Execute partner subcontracts, finalize Project Management Plan (PMP), and convene kickoff meeting.	Month 1	Month 2	Project Kickoff Meeting; Project Management Plan submitted to CSEA.
Task 1 – Project Management (Ongoing)	Continuous coordination, reporting, and oversight throughout all project phases.	Month 1	Month 24	Monthly progress reports; quarterly steering committee reviews; risk register updates.
Task 2 – Preliminary Process and Site Integration Assessment	Worley conducts initial process integration, baseline data review, and site layout study.	Month 2	Month 6	Preliminary Process Integration Summary; included in Q2 Report.
Task 3 – Pitch Integration & Optimization Studies (AmeriCarbon)	Pilot-scale testing using lignite, upgraded lignite, humins, and blended feedstocks. Generate process data on yields, ash content, and	Month 3	Month 14	Interim Technical Report #1 (Month 9); Pilot Test Data Package #1 (Month 14).

	pitch composition.			
Task 4 – REE Process Integration & Optimization Studies (UND)	Produce upgraded carbon by-products and REE-rich residues; conduct purification and demineralization testing; validate product quality.	Month 4	Month 15	Interim Technical Report #2 (Month 12); Data Summary for Integration Model (Month 15).
Task 5 – Ge/Ga Process Integration & Optimization (Microbeam)	Bench-scale testing of AmeriCarbon and UND residues; validate selective vaporization and condensation for Ge/Ga recovery.	Month 6	Month 18	Interim Technical Report #3 (Month 18); Analytical Results Package.
Task 6 – Techno-Economic Assessment (TEA)	Integrate process data into unified engineering and economic model; evaluate commercial potential for Forge site co-location.	Month 16	Month 21	Draft TEA and Integration Report (Month 21).
Task 7 – Technology Development and Commercialization Pathway	Identify remaining technical gaps; develop roadmap for pilot-to-commercial transition and follow-on funding.	Month 20	Month 23	Final Technical Report (Month 23) summarizing integration readiness.

Project Closeout	Submit final reports and documentation; conduct project review with CSEA and partners.	Month 24	Month 24	Final Report and Presentation to CSEA; Project Completion Certification.
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Reporting Cadence

- Monthly Progress Reports — Submitted to CSEA within 10 days of month end; include technical updates, budget status, schedule performance, and safety metrics.
- Quarterly Reports — Summarize progress toward milestones, major findings, and planned next steps; Months 3, 6, 9, 12, 15, 18, 21.
- Interim Technical Reports — Issued at completion of major tasks (Tasks 3–5) and submitted to CSEA within 30 days of task completion.
- Final Report and Presentation — Delivered at Month 24, summarizing results, integration framework, and recommendations for commercial implementation at the Forge site.

Overall Schedule Summary

Phase	Duration	Key Milestones
Phase 1 – Project Initiation and Integration Setup	Months 1–3	Kickoff meeting; PMP approved; partner agreements executed.
Phase 2 – Feedstock, REE, and Mineral Optimization	Months 3–18	Completion of pilot- and bench-scale testing (AmeriCarbon, UND, Microbeam).
Phase 3 – Integration, Analysis, and TEA	Months 16–21	Completion of engineering and economic modeling; draft integration report.
Phase 4 – Commercialization Planning and Closeout	Months 21–24	Final report, stakeholder review, and project closeout with CSEA.

This timetable provides a clear framework to manage technical progress, coordinate partner activities, and ensure timely reporting to CSEA. The phased schedule aligns with the project’s integration objectives and ensures that technical deliverables and data are available in time to support engineering, economic, and commercialization evaluations.

BUDGET

Please use the table below to provide an **itemized list** of the project’s capital costs; direct operating costs, including salaries; and indirect costs; and an explanation of which of these costs will be supported by the financial assistance and in what amount. The budget should identify all other committed and prospective funding sources and the amount of funding from each source. **Please feel free to add columns and rows as needed.** Higher priority will be given to projects with a high degree of matching private industry investment.

Project Associated Expense	NDIC Grant	NDIC Loan	Applicant’s Share (Cash)	Other Project Sponsor’s Share	Total
Project budget	\$2,250,000		\$2,250,000		\$5,000,000
Total	\$2,250,000		\$2,250,000		\$5,000,000

Please use the space below to justify project expenses and discuss whether the project’s objectives will be unattainable or delayed if less funding is available than requested.

CONFIDENTIAL INFORMATION

A person or entity may file a request with the Commission to have material(s) designated as confidential. By law, the request is confidential. The request for confidentiality should be strictly limited to information that meets the criteria to be identified as trade secrets or commercial, financial, or proprietary information. The Commission shall examine the request and determine whether the information meets the criteria. Until such time as the Commission meets and reviews the request for confidentiality, the portions of the application for which confidentiality is being requested shall be held, on a provisional basis, as confidential.

If the confidentiality request is denied, the Commission shall notify the requester and the requester may ask for the return of the information and the request within 10 days of the notice. If no return is sought, the information and request are public record.

Note: Information wished to be considered as confidential should be placed in separate appendices along with the confidentiality request. The appendices must be clearly labeled as confidential. If you plan to request confidentiality for **reports** if the proposal is successful, a request must still be provided.

To request confidentiality, please use the template available at <http://www.nd.gov/ndic/CSEA-app-doc-infopage.htm>.

PATENTS/RIGHTS TO TECHNICAL DATA

Each participating organization — AmeriCarbon Enterprises, LLC, the University of North Dakota (UND), and Microbeam Technologies, Inc. — brings its own background intellectual property (IP), expertise, and technical data to this project. All such background IP, including pre-existing inventions, know-how, research results, and proprietary methods, will remain the sole property of the originating organization.

Any new data, methods, or intellectual property developed during the course of this project will be governed by mutually agreed terms among the parties and in accordance with applicable North Dakota Industrial Commission (NDIC) and Clean Sustainable Energy Authority (CSEA) policies. Ownership of project-generated IP will be determined based on the nature and level of contribution, with appropriate rights to use the resulting data for research, development, and commercialization as permitted under program guidelines..

STATE PROGRAMS AND INCENTIVES

Ore Spring Materials, LLC is a newly formed entity and has not received any state funding to date. Ore Spring’s affiliate, AmeriCarbon Products, LLC, has been the recipient of the following contracts through the Lignite Research Council and funded by the North Dakota Industrial Commission:

NDIC Contract Number	Title	Term of Contract	NDIC Share
Contract No. FY22-XCVII-241	North Dakota Lignite Coal-Based Pitch for Production of High Value Carbon Product	January 2022 through June 2023	\$550,000.00
Contract No. FY23-102-251	Engineering Design and Feasibility Analysis for Commercial Graphite and Asphalt Manufacturing from Lignite Derived Carbon Pitch	July 2023 through June 2025	\$700,000.00
Contract No. FY24-104-258	Lignite Conversion Reactor Optimization for Commercial Carbon Pitch Manufacturing	July 2024 through January 2026	\$743,800.00
Contract No. FY25-107-264	Commercial Plant Design Optimization: Lignite to Critical Carbon Materials	May 2025 through July 2026	\$1,499,653

PUBLICATIONS - Selected

1. Ping Wang, Bret Howard, Nicholas Means, Dushyant Shekhawat, David Berry. "Coal chemical-looping with oxygen uncoupled (CLOU) using a Cu-based oxygen carrier derived from natural minerals". *Energies* 2019, 12, 1453, doi:10.3390/en12081453.
2. Daniel J Haynes, Dushyant Shekhawat, David A Berry, Amitava Roy, James J. Spivey, Effect of calcination temperature on the steam reforming activity of Ni substituted pyrochlore catalysts, Jun 2018 to *Applied Catalysis: A: Gen.*
3. Ping Wang, Nicholas Means, Bret Howard, Dushyant Shekhawat, and David Berry, The Reactivity of CuO Oxygen Carrier and Coal in Chemical-Looping with Oxygen Uncoupled (CLOU) and In-situ Gasification Chemical-Looping Combustion (iG-CLC), *Fuel* 217 (2018) 642-649.
4. M.W. Smith, D.A. Berry, D. Shekhawat, D.J. Haynes, J.J. Spivey, Partial oxidation of liquid hydrocarbons in the presence of oxygen-conducting supports: Effect of catalyst layer deposition, *Fuel*, 89 (2010) 1193-1201.
5. D.J. Haynes, A. Campos, M.W. Smith, D.A. Berry, D. Shekhawat, J.J. Spivey, Reducing the deactivation of Ni-metal during the catalytic partial oxidation of a surrogate diesel fuel mixture, *Catal Today*, 154 (2010) 210-216.
6. D. Shekhawat, D. A. Berry, H. W. Pennline, E. Granite, J. J. Spivey, Special Issue: Advanced Fossil Energy Utilization, *Fuel*, Volume 89, Issue 6, January 1, 2010.
7. Maria D. Salazar-Villalpando, D. A. Berry and A. Cugini, Role of Lattice Oxygen in the Partial Oxidation of Methane over Rh/Supported Ceria Catalysts. *Isotopic Studies, Solid State Ionics*, December 2009.
8. M. Salazar, D. A. Berry and T. H. Gardner, "Partial Oxidation of Methane over Rh/Supported-Ceria Catalysts: Effect of Catalyst Reducibility and Redox Cycles", Published, *International Journal of Hydrogen Energy*, 33/11, (2008), 2695-2703
9. Shadle, L.J., Berry, D.A., and Syamlal, M., "Coal Gasification", *Encyclopedia of Chemical Technology, Concise, 5th Edition (ISBN 978-0-470-04748-4)*. , John Wiley & Sons, Inc., NY, NY, May 2007.
10. Turton, R.A., Berry, D.A., Gardner, T.G., and Miltz, A., "The Evaluation of Zinc Oxide Sorbents in a Pilot-Scale Reactor: Sulfidation Kinetics and Reactor Modeling", *Industrial Engineering and Chemistry, Ind. Eng. Chem. Res.* 2004, 43, 1235-1243

PATENTS - Selected

1. U.S. Patent # 9,935,318 SOFC Cathode with Oxygen Reducing Layer, (2018)
2. U.S. Patent 9,598,644 Method of CO and/or CO₂ hydrogenation to higher hydrocarbons using doped mixed metal oxides, (2017).
3. U. S. Patent 9,562,203 Methane-rich syngas production from hydrocarbon fuels using multi-functional catalyst/capture agent, (2017).
4. U.S. Patent 9,126,833 Process for continuous synthesis of mixed oxide powders, (2015).
5. U.S. Patent 8,486,301 Method for designing a reforming and/or combustion catalysts system, (2013).
6. U.S. Patent # 7,442,353 "Heat Recirculating Reformer for Fluid Stream Pollutant Removal, (2008).

SYNERGISTIC ACTIVITIES

- Editorial Board Member, "Catalysis Today", January 2006-2009.
- Distinguished Visiting Scientist, Oak Ridge National Laboratory, April 2002.
- Research Management Board Member, Army Core Technology Program (CTP) for Power Systems, June 2005 / 2006.