MICROBEAM
TECHNOLOGIES, INC.
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September 28, 2021

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

Dear Ms. Fine:

Subject: Proposed Project entitled "Development of Novel Sintered Coal Building Materials"

Microbeam Technologies Incorporated (MTI) is pleased to submit this proposal for consideration for co-funding during the October 1, 2021 Grant Round. The proposal is aimed at developing a process to produce building materials from lignite coals. The project proposal was submitted to the Department of Energy in response to Funding Opportunity DE-FOA-0002438 titled "Design, R&D, Validation and Fabrication of a Prototype Carbon Based Building". The project was selected by the DOE for an award and the project period of performance is from October 1, 2021 to September 30, 2022.

The project team, including the University of North Dakota (UND) and North American Coal Corporation (NACC), will work together to perform the work outlined in the attached detailed proposal. The total cost of the project is $649,407. We are requesting funding from the North Dakota Industrial Commission (NDIC) for $62,500, and will have cost share from NACC for $42,500, MTI for $10,200, and UND for $16,505. The remaining budget of $517,702 will be covered by federal funding from the Department of Energy (DOE) award DE-FE0032083.

Initial testing by MTI and UND have produced a novel sintered lignite material, and this sintered coal building material (SCBM) can be used for various applications such as insulation, joists/studs, tiles, and architectural block. This project has the potential to provide profitable opportunities for the coal industry, and for the US, to produce jobs and effectively utilize one of the nation's most widely available natural resources, North Dakota Lignite.

Please let me know if you have any question or comments. We will send a check for $100 for the application fee.

Sincerely,

Steven A. Benson, PhD
President

c/enc. Mike Holmes, LEC

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Development of Novel Sintered Coal Building Materials

Submitted to:

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

Submitted by:

Microbeam Technologies Incorporated
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Principal Investigator:

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9/28/2021

Total Project Costs: $649,407

NDIC Amount Requested: $62,500

Table of Contents

1.0 ABSTRACT

Microbeam Technologies Incorporated (MTI), project lead, the University of North Dakota (UND), and North American Coal Corporation (NACC) will work together to produce value-added products from lignite coal for use in the fabrication of a prototype carbon-based building. The production of building materials from lignite has the potential for high volume use of coal that is essential for coal industry growth and stability. ND is also home to the single largest deposit of lignite amounting to approximately 351 billion tons. Novel ways of valorizing this important resource have the potential to create wealth and consequently aid in job growth.

MTI and UND are developing a method for producing high-value carbon-based building materials by using a flexible manufacturing process that can be adapted into either a batch or continuous manufacturing process. The manufacturing process involves the sintering of coal and additive particulates at low temperatures, between 300°C and 500°C, with a reactive liquid phase. The reactive liquid phase produces a chemical interaction between the coal and additives that significantly enhances the strength and density of the composite material. The sintered coal building materials (SCBM) technology has been used to produce sintered lignite and additive composites (LIG2) at UND and MTI laboratories, and preliminary analysis shows great opportunity for the technology to be scaled up to the pilot scale and eventually the commercial level. These materials show great potential to be used in masonry brick veneer applications; moreover, by modifying the composition, expanded applications such as high-value carbon foams can also be targeted. Therefore, the SCBM technology has the potential to be optimized for use in various applications of building construction such as insulation, joists/studs, tiles, and architectural block.

The duration of the project is projected to be 12 months, and the total cost of the project is $649,407. Cost share will be received from NACC for $42,500, MTI for $10,200, and UND for $16,505. The remaining budget, $517,702, will be funded by the Department of Energy (DOE) through award DE-FE0032083. The NDIC share of the proposed project is $62,500.

2.0 PROJECT SUMMARY

The objective of this proposed project is to develop value-added products from coal for use in the fabrication of a prototype carbon-based building. The production of building materials from coal has the potential for high volume use of coal that is essential for coal industry growth and stability. Of specific concern to the coal industry is the lower cost of alternative sources of energy, of which the contribution of coal towards US power is projected to decrease to 13% in 2050 as compared to 24% today[1]. These developments resulted in the possible closure of the Coal Creek Station in North Dakota (ND) and the loss of 260 jobs[2]. ND is also home to the single largest deposit of lignite amounting to approximately 351 billion tons[3]. Novel ways of valorizing this important resource have the potential to create wealth and consequently aid in job growth.

Microbeam Technologies Incorporated (MTI) and the University of North Dakota (UND) are developing a method for producing high-value carbon-based building materials by using a flexible manufacturing process that can be adapted into either a batch or continuous manufacturing process. The manufacturing process involves sintering of coal and additive particulates at low temperatures, between 300 and 500 °C, with a reactive liquid phase. The reactive liquid phase produces a chemical interaction between the coal and additives and thereby significantly enhancing the strength and density of the composite material. The sintered coal building materials (SCBM) technology has been used to produce sintered lignite composites (LIG2) at UND and MTI laboratories, and preliminary analysis shows great opportunity for the technology to be scaled up to the pilot scale and eventually the commercial level. Using hypothesis driven microstructure design methodology, the team has shown the ability to tailor the properties of the coal-matrix composites (e.g., density, porosity, strength), while also retaining the composite's carbon

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[1] Natter, Ari. "White House still promoting coal, exploring 'alternative uses." The Detroit News, Bloomberg, February 2020, https://www.detroitnews.com/story/news/politics/2020/02/07/white-house-still-promoting-coal-exploring-alternative-uses/41155909/.

[2] Frangoul, Anmar. "North Dakota's largest power plant looks set to close as the owner bets on wind energy." Business News Sustainable Energy, CNBC, May 2020, https://www.cnbc.com/2020/05/11/north-dakotas-largest-power-plant-set-to-close-as-owner-bets-on-wind.html.

[3] Murphy, Ed. "Mineral Resources of North Dakota: Coal." North Dakota Geological Survey, North Dakota Industrial Commission, .https://www.dmr.nd.gov/ndgs/mineral/nd_coalnew.asp

contents to be greater than 70 wt.% carbon with more than 51 wt.% of the carbon from coal. These materials show great potential to be used in masonry brick and veneer applications; moreover, by modifying the composition, expanded applications such as high-value carbon foams can also be targeted. Therefore, with this manufacturing flexibility, SCBM technology has the potential to be optimized for use in various applications of building construction such as insulation, joists/studs, tiles, and architectural block.

This project will also demonstrate the technical and economic feasibility of SCBM technology to produce building materials by using a flexible manufacturing process that utilizes lignite and various additives as main feedstocks. MTI and UND will identify and procure feedstock materials, conduct testing to determine conditions required to produce materials of optimum properties and performance, provide a list of SCBM candidates for code qualification and incorporation into building structures within ten years, complete a technical and economic assessment (TEA) of the SCBM process, perform a gap analysis of the material to gain market traction, develop a conceptual design of a building, and perform a Life Cycle Analysis (LCA) to show the feasibility of LIG2 as compared to current building materials.

3.0 PROJECT DESCRIPTION

3.1 Detailed Project Description

This technology is based on sintering of lignite coal particles with various additive particulates at temperatures ranging from 300 to 500 °C in an inert atmosphere. The additive particles are low-cost and readily available in ND. During the heating process of the green body, the lignite and additive particles interact. The interaction of the pyrolyzed coal and additive particulates can be characterized as sintering with a reactive liquid phase. The reactive liquid phase is derived mainly from the additive particulates that enhance the sintering and bonding between the particles resulting in a dense material. The microstructures of the polished cross-sections show that chemical reactions have occurred between the additive particles and coal particles and the degree of densification, strength development, and pore formation, are related to the lignite-to-additive ratio and sintering temperature. Laboratory compressive strength measurements show this technology can produce coal composites with strengths exceeding the ASTM physical requirements for various types of bricks[4] (e.g., C62 Building Brick, C216 Facing Brick, C1088 Thin Veneer Brick, and A82 Fired Masonry Brick). These laboratory results, combined with the manufacturing flexibility and simplicity of SCBM's, make the technology a promising and viable method for producing carbon-based building materials and stimulating the job market.

3.2 Project Objectives

The objective of this proposed research project is to develop and establish a method to produce low-temperature LIG2 products using SCBM technology. The proposed work outlines a pathway to proving the technology, determining a high-throughput method of producing coal-based building materials, and achieving a high-fidelity analog to commercially relevant processes. Within the scope of work, MTI and UND will identify feedstock materials (coal and otherwise), optimize material development and performance, develop process flow diagrams for the SCBM process, complete an initial technical and economic assessment (TEA), and a life cycle assessment (LCA) of the potential high-value LIG2 building material products. Development of a scalable process for manufacturing LIG2 products is a goal of this phase.

3.3 Methodology

This work is aimed at achieving the following objectives, in addition to project management and reporting: i) identifying and procuring coal and non-coal feedstock materials, and determining the optimum feedstock blend and conditions, ii) characterizing the microstructure and physical properties of the LIG2 products, including the use of ASTM standard methods of evaluation, iii) determining the technical and economic feasibility of LIG2 production in a batch and/or continuous production facility, and (iv) identifying candidate LIG2 products which have the potential to be commercialized in 10 years timeframe. A qualitative LCA and American Association for Costing Engineers (AACE) Class 5 TEA will be

[4] "Specifications for and Classification of Brick," The Brick Industry Association, Oct-2007. Available: https://www.gobrick.com/docs/default-source/read-research-documents/technicalnotes/9a-specifications-for-and-classification-of-brick.pdf.

conducted for this work, with estimates on potential market capacity for these products, as well as anticipated coal use.

Task 1.0 – Project Management and Planning

MTI shall manage and direct the project in accordance with a Project Management Plan to meet all technical, schedule and budget objectives and requirements. MTI will coordinate activities in order to effectively accomplish the work. MTI will ensure that project plans, results, and decisions are appropriately documented, and project reporting and briefing requirements are satisfied. MTI is committed to conducting a kickoff meeting at the beginning of the project and quarterly progress reports and review meetings with the DOE NETL program manager and project participants.

MTI shall develop a Technology Maturation Plan (TMP) that describes the current technology readiness level (TRL) of the proposed technology/technologies, relates the proposed project work to maturation of the proposed technology, describes the expected TRL at the end of the project, and describes any known post-project research and development necessary to further mature the technology. MTI will prepare and maintain a Workforce Readiness Plan related to the technology being investigated under the project. The Workforce Readiness Plan will describe the skillset and availability of the workforce needed for future commercialization and deployment of the technology, including whether any related apprenticeships, certificates, certifications, or academic training are currently available. MTI will monitor and update its assessment of workforce availability and development plans throughout the life of the project.

Task 2.0 – Feed Stock Procurement

Samples of run-of-mine lignite and "cleaned" lignite coal will be gathered and analyzed for technical feasibility in LIG2 production. In addition, different sources of potential additives will be identified, and samples will be gathered. Data on lignite and additive composition, cost, and available supply will be obtained for an assessment of the economic feasibility of the LIG2 product.

Task 3.0 – Scale Up and Production of Building Materials

This task will involve the bench-scale production of selected LIG2 products (e.g. standard brick, brick veneer, CMU, and insulation block) from the chosen feedstock blends noted previously in Task 2.0.

Equipment available at UND and MTI, along with a larger hydraulic press for cold pressing materials will be configured for LIG2 composite sample production. LIG2 sample analysis protocol will be established to determine the chemical and physical properties. Necessary supplementary laboratory equipment and materials will also be procured as part of this task.

Testing and analysis of potential lignite coal and additive sources will be performed to identify the optimum composition and processing conditions for LIG2 production. Parametric testing and analysis based on hypothesis driven microstructure design of these products will be completed to establish that the desired properties were achieved in small quantity production of LIG2. The microstructure of all the test batch LIG2 samples will be analyzed by using the scanning electron microscope (SEM) to assess the degree of sintering and reaction of the coal particles with the additives. The test batch LIG2 samples will be characterized to determine selected mechanical properties (e.g. density, porosity, hardness, compressive strength) for defining the manufacturing, microstructure, and processing space of these compositions. The composition and fabrication conditions of the LIG2 products will then be tailored to achieve desired properties of targeted building products (e.g. standard brick, brick veneer, architectural block, insulation).

Following optimization of LIG2 compositions and fabrication conditions, larger quantities (~5-10 blocks/day) of LIG2 products will be manufactured. These samples will be produced at relevant scales and aspects similar to a commercial product, and these samples will be used to validate the repeatability of the manufacturing process and for product testing and analysis. This step is critical in order to transition the technology from the laboratory-scale to a bench-scale and ultimately to a pilot-scale.

Figure 1 depicts the process flow of the flexible SCBM process in a block flow format. In the preparation process area, the additive and coal will be dried, ground, sieved, and slurried. In the pressing/casting process area, pressing will be accomplished by compacting with a hydraulic press and subsequent removal from the mold. To perform casting, the mixed coal/additive stream will be cast into their desired shapes through the use of vibrating tables and/or 3D printing to create precise mold designs. Once the preforms/casts are prepared, they will be dried and sintered in a furnace/kiln using inert gas at the optimal process conditions. After sintering, the products will be sent into post-processing, in which the processes will vary depending on the LIG2 product.

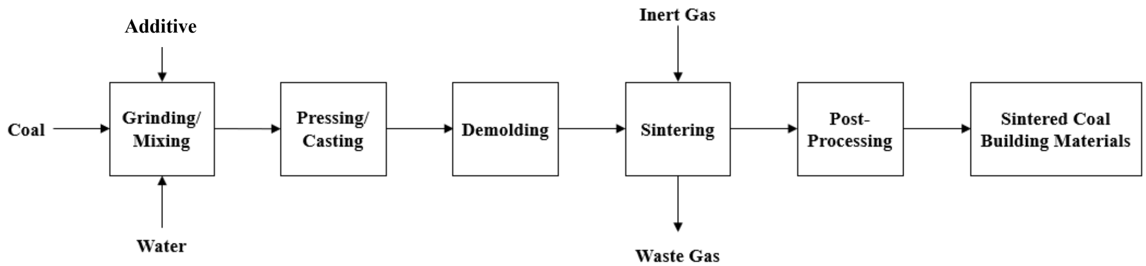

Figure 1: Block flow diagram of flexible SCBM process.

After establishing the manufacturing, microstructure, and processing space of SCBM technology, UND and MTI will identify a list of applications in which LIG2 products have the potential to be commercialized within 10 years. Evaluations of the SCBM technology will be focused on building materials. This will be inexorably linked to the TEA and LCA associated in Task 5, with promising potential applications and preliminary production pathways identified within the scope of this work.

Task 4.0 – Product Testing and Analysis

MTI will work with UND to develop a testing protocol for the batch and large quantity LIG2 products. The products will be analyzed to determine the density, porosity (He pycnometry analysis), tensile strength, compressive strength, flexural strength, hardness, wear, wettability, thermal conductivity, and thermal expansion. In addition, UND will perform FTIR (Fourier Transform InfraRed Spectroscopy) and/or Raman Spectroscopy analysis to understand the chemistry of the sintered carbonaceous compacts.

LIG2 products will be comprehensively analyzed by using MTI's SEM using image analysis to determine the degree of sintering and reactions between coal and additive. Novel microstructures and chemical compositions of the coal-matrix composites will be examined and mechanisms contributing to bonding and mechanical behavior of LIG2 will be identified. In addition, UND will perform X-ray tomography and phase analysis. Upon completion of Task 3.0, durability analyses including microbial growth, oxidation, thermal conductivity, water and moisture absorption will be performed. A detailed list of LIG2 product candidates for code qualification and incorporation into building structures within ten years will be generated.

Task 5.0 – Technology and Impact Assessment

The SCBM technology will be evaluated on the technical and economic potential, including the development of an equivalent mass/energy balance of a commercial LIG2 production facility. Factors of consideration are raw materials, waste, products produced, energy in products, energy in waste, energy losses to surroundings, and unit production time. In the TEA, MTI and UND will consider the principal process economics drivers such as materials price, resource composition and properties, product yields, environmental considerations, and reasonable operating and maintenance expenses. The TEA will account for the major variables affecting both capital (CAPEX) and operating (OPEX) expenses associated with production of the targeted building products. The estimated cost for the proposed process will be considered a Class 5 estimate, as described by the AACE International Cost Estimate Classification System, with an expected accuracy range of 20% to 50% (low) and +30% to +100% (high).

A technology gap analysis, which will feed critical information about additional required R&D for scale-up and/or commercialization of the technology, will be completed. A competitive landscape of different products will be developed, and major roadblocks to market of LIG2 products will be identified, addressing both technical and non-technical gaps. A conceptual design will be developed for a prototype carbon-based building using LIG2 products, fabricated by SCBM technology. This design will detail the mechanisms for integration of LIG2 with traditional building materials into a building structure. A LCA of the LIG2 products will be completed, encompassing both direct and indirect effects from a cradle-grave approach, greenhouse gas emissions and abatement, land use effects, and other potential environmental effects against existing conventional building materials.

3.4 Anticipated Results

As far as MTI and UND investigators are aware, this is a groundbreaking technology that proves that lignite coal particulates can be sintered at relatively low temperatures (range of 300-500°C) to produce a high strength building material. Based on available information, current technologies use coal particles as aggregates by bonding them in polymers or by converting them into ceramics. Comparatively, the versatility of the project team's microstructure-based design technology is demonstrated by the customizability of the (a) microstructure, (b) porosity, (c) wettability, (d) strength, and (e) fire resistance of the composites. Thus, this technology provides a unique platform that can be used to target three different types of building materials: a) low strength foams, b) medium strength products, and c) high-strength premium products. The primary product of the SCBM technology will be producing LIG2 standard bricks, brick veneer, CMU's, and insulation. Furthermore, the appearance of these materials can be modified to add aesthetic value to these products.

3.5 Facilities and Resources

Microbeam Analytical and Testing Labs – MTI has a wide array of analytical capabilities and equipment relevant to materials testing and analysis. MTI has available high temperature furnaces, advanced computer-controlled scanning electron microscopy (CCSEM) equipped with an x-ray microanalysis system, and associated sample preparation equipment. MTI's scanning electron microscopes (SEMs) are its central component of analysis of fuels and additive materials. CCSEM is used to determine the size, composition, abundance, and association of mineral grains in prepared coal, biomass, and petroleum coke samples. Morphological analysis is used to obtain high-magnification images and chemical compositions of selected features of samples. Backscattered electron imaging provides discrimination of features based on atomic number.

University of North Dakota Laboratories and Facilities – UND has a wide array of analytical capabilities and equipment relevant to the material analysis. UND's primary expertise lies in fundamental research and technology development of materials which can be applied in demanding applications. UND will purchase a cold press, muffle furnace for brick production, sieve shaker, vibratory mill, oven, and jar mill valued at $70,101 for scaling up the process. Additional resources and equipment that are available at

UND for this project include: high-temperature furnaces, grinding and polishing equipment, and a Shimadzu universal testing machine.

3.6 Environmental and Economic Impacts

The low sintering temperatures of SCBM-derived LIG2 products is expected to produce low levels of volatile tars and gases, minimizing the production of greenhouse gases. During testing, these constituents will be captured and analyzed to determine the potential of producing harmful materials released during manufacturing. Furthermore, no significant waste is expected to be produced from this process. All of the input materials will be used in the final product, less the material removed during finishing. The waste produced during the manufacturing process can be burned as fuel and used to provide heat to the process. Moreover, the SCBM process is able to effectively valorize waste products, such as rare earth element (REE) extracted coal, to make beneficial and useful building products. Preliminary laboratory tests show that approximately 70 wt.% of the input material (dry basis) used remains in the final product. Overall, the manufacturing process is an environmentally friendly, green process.

It is anticipated that the commercial development of this technology will result in the establishment of a manufacturing plant near or around existing North Dakota lignite mines. Commercialization of this technology will create and support jobs in the mining and manufacturing industry. It is expected that these jobs will grow the local rural communities and assist those communities harmed by economic distress from impacts to the energy sector, such as those that would be hurt by the closing of ND mine and power plant[5]. In addition, the SCBM technology can be co-located with a REE recovery process. The coal after REE recovery has shown the potential to produce higher quality products as compared to run-of-mine coal.

[5] Great River Energy Newsroom. "Plant closure, renewable plans detailed at industry event." October, 14, 2020.

3.7 Relevance and Outcomes/Impacts

This technology will create value-added products from coal, in particular, high-value carbon-based building materials, by using a low-temperature manufacturing process. These coal-derived products have tailorable material properties and are greater than 70 wt.% carbon with more than 51 wt.% carbon from coal. The LIG2 products, developed using SCBM technology, can be used for various applications such as insulation, masonry brick, tiles, and architectural block. Three main types of products can be produced from this technology: a) low strength foams, b) medium strength products, and c) high-strength premium products. In addition to mechanical properties, the appearance of these materials can be modified to add aesthetic value to these products.

The market outlook for the proposed technology is promising and there is a large market potential for the targeted products of this technology. The global building materials market is expected to grow at a compound annual growth rate (CAGR) of 10.86%, and its valuation is expected to increase from USD 9,146.27 Million in 2018 to USD 18,829.49 Million by the end of 2025[6]. The global forecast market size for dimension stone is $5.22 billion by 2022[7]. The US brick market is valued at $6.2 billion USD[8], and the global brick market produced around 2,100 billion units in 2018 and is expected to grow at a CAGR of more than 3% from 2019-2027[9]. The global claddings (including brick veneer) market was valued at $166,026 million in 2015 and is expected to garner $262,381 million by 2022 growing at a CAGR of 6.7%[10].

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[6] Cision® PR Newswire, "The Global Building Materials Market", April 2020. https://www.prnewswire.com/news-releases/the-global-building-materials-market-is-expected-to-grow-from-usd-9-146-27-million-in-2018-to-usd-18-829-49-million-by-the-end-of-2025-at-a-compound-annual-growth-rate-cagr-of-10-86-301035750.html.

[7] The Business Research Company, "Dimension Stone Mining Global Market Report 2020." January 2020, https://www.thebusinessresearchcompany.com/report/dimension-stone-mining-global-market-report..

[8] IBISWorld, "Clay Brick & Product Manufacturing in the US Market Size 2005-2026".

[9] Transparency Market Research, "Global Concrete Block and Brick Manufacturing Market Estimated to Surpass 2700 Billion Units by 2027: Transparency Market Research", February 2020.

[10] "Claddings Market by Component Type (Walls, Roofs, Windows & doors, Staircase), Material Type (Masonry & concrete, Brick & stone, Stucco & EIFS, Fiber cement, Metal, Vinyl, Wood) - Global Opportunity Analysis and Industry Forecast, 2014-2022," Allied Market Research, Mar-2017. https://www.alliedmarketresearch.com/claddings-market.

There is an urgent need to design novel materials that offer competitive alternatives to currently available building materials[11]. Initial data show that LIG2 products have physical properties that can be used for residential and commercial building products that include architectural blocks, tiles, insulation, and structural and non-structural products. Selected competitive products, such as architectural block and carbon foams, have compressive strengths of 11.7 Mpa[12] and 16.0 kPa[13], respectively. Current technologies that utilize coal to produce building materials have targeted the rooftile market and are not suitable for load-bearing applications (Table 1). Furthermore, they do not possess tailorable or high-performance properties as exhibited by the proprietary SCBM technology, which has shown compressive strengths >25 Mpa.

Table 1: Competing building materials formed by coal-based products.

Company	Technology	Application
X-MAT, Semplastics[14]	Coal is bonded with polymer derived ceramic	Rooftiles
Ohio University[15]	Coal is bonded with polyethylene	Construction Composites

SCBM technology combines abundantly available lignite coal with additive. The United States can produce over 1 billion dry tons of additive per year. The valuation of the additive is anticipated to be $40-60 per dry ton. According to a UN study[17], rapid population growth will lead to a demand of 5 million housing units per year. Usage of locally available resources, like coal and additive, as precursors for building materials can potentially fill this market gap and can create additional revenue streams.

An economic model was created to evaluate initial commercialization options for the SCBM process. The capital and operational costs were provided based on previous estimations that UND has done for a plant of similar size. The reference plant processes coal and additive feed rate at about 0.5 tons/hr (dry basis). For the application of producing standard brick veneer (7-5/8" x 2-1/4" x 1/2") using SCBM

[11] National Academy of Engineering, "Restore and improve urban infrastructure." NAE Grand Challenges for Engineering, http://www.engineeringchallenges.org/14607.aspx
[12] ASTM C90: Standard Specification for Loadbearing Concrete Masonry Units
[13] "CFOAM® Carbon Foam Typical Properties," CFoam. https://www.cfoam.com/spec-sheets/.
[14] Roofing, "Fireproof, Eco-Friendly Roof Tiles." January 2019, http://www.roofingmagazine.com/fireproof-eco-friendly-roof-tiles/.
[15] *ACS Sustainable Chem. Eng.* 2019, 7, 19, 16870–16878
[17] UN Habitat, "Global housing demand at critical levels", July 2008, https://mirror.unhabitat.org/content.asp?cid=5809&catid=206&typeid=6

technology, that equates to about 550,000 bricks per month. The model was based on the following additional assumptions: 51%/49% (by weight) blend between lignite and additive, 55% yield, manufacturing a standard brick veneer. Based on the given volume and estimated capital operational expenses, a brick veneer manufactured with this process would be $1.08 to break even. A standard brick veneer of similar size from Lowe's is about $1.26. If these bricks were sold at the same retail value as current brick veneers on the market ($1.26), it is expected that this technology could result in about $7.7M in initial annual sales.

The proposed LIG2 products (standard brick, brick veneer, architectural block, and insulation) are anticipated to have a greener lifecycle analysis as compared with current standard concrete materials and/or polymeric insulation, both in terms of greenhouse gas impact as well as potential disposal/recyclable avenues. Formation of the new material requires low-temperature sintering (300-500°C) and avoids any clinkering process, substantially reducing both energy and CO_2 impacts versus limestone-based cements. Further, LIG2 products are anticipated to be recyclable in a similar aspect as concrete with grinding and re-binding, with final end of life use of the coal-based material as a potential fuel in certain burner types, mitigating landfilling problems and utilizing the C/H-based fuel energy within the original coal.

4.0 STANDARDS OF SUCCESS

The primary standards of success for this project will be the demonstration of the ability to sinter coal composites to produce value-added carbon products and high strength building materials, demonstrating the ability to produce the materials in a continuous or batch process, and a technical and economic analysis showing the potential of LIG2 products to be profitable for the coal industry. In particular, this success measure will be achieved by meeting the following objectives in addition to project management and reporting: i) identifying and procuring coal and non-coal feedstock materials, and determining the optimum feedstock blend and conditions, ii) characterizing the microstructure and physical properties of the LIG2 products, including by use of ASTM standard methods of evaluation, iii) determining the technical and economic feasibility of LIG2 production in a batch and/or continuous production facility, and (iv) identifying candidate LIG2 products which have the potential to be commercialized in 10 years timeframe. A qualitative LCA and American Association for Costing Engineers (AACE) Class 5 TEA will be conducted for this work, with estimates on potential market capacity for these products, as well as anticipated coal use.

5.0 BACKGROUND

Based on initial testing conducted by UND and MTI, it was hypothesized that through modification of the lignite-to-additive ratios and sintering temperatures, the properties of the LIG2 product could be tailored from a dense highly sintered material to a porous foam as illustrated in Figure 2. This hypothesis was proved by UND and MTI through a microstructure-based materials manufacturing approach for fabricating ultra-high-performance carbon-based structures for building materials applications using a thermal treatment process. Additionally, prior UND testing has shown that the use of additives in composites can produce materials with over 25 Mpa compressive strength (concrete compressive strengths range from 15–30 Mpa depending on grade). These results show that the SCBM technology has the potential to also be used with additives that are readily available in ND. Figure 2a shows a highly sintered dense matrix that is bonded by additive particulates reacting with lignite particles. Figure 2b shows the microstructure that has been engineered by adding different types of pore-formers (chemical additives) and/or changing the ratio of lignite-to-additive particulates and sintering temperature. Figure 2c shows the use of chemical ceramic materials that can be added to enhance the structure formed during sintering.

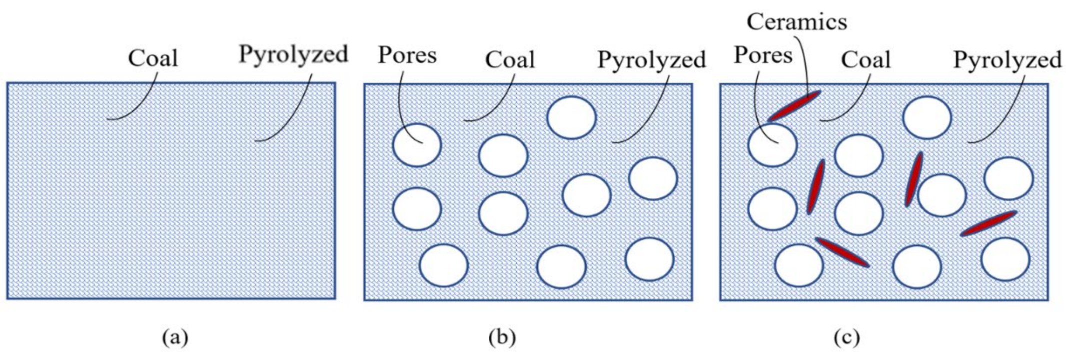

Figure 2: Schematics of microstructure of (a) pyrolyzed additive bonded coal, (b) tailored foams, and (c) tailored foams reinforced in-situ derived ceramics.

5.1 TRL-4 Validation of the Technology

Laboratory-scale testing and analysis has been performed by MTI and UND on ND lignite and additive blends. Lignite coal used was obtained from North American Coal Corporation’s Coyote Creek Mine and organically associated inorganic and rare earth element (REE) extracted lignite coal was obtained from UND’s DOE project (“Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks” DE-FE0027006), henceforth referred to as cleaned coal.

Figures 3-6 show initial results of the sample densification and microstructure study. Backscattered electron imaging (BEI) was performed on polished cross-sections of the sintered products. The BEI imaging allows for the ability to discern the darker lower atomic number additive particles from the brighter higher atomic number coal. It is clear that the addition of additives (<50wt.%) increases the bonding and sintering of the product (Figs. 3-6). Additionally, using this technology, samples with greater than 50 wt.% additive material are able to easily produce low strength carbon foams (Fig. 6). The results show that the coal-additive composites densify after heating with increased additive content (<50 wt.%). Figure 7 shows that additive particulates are effective in sintering coal compacts at 500˚C or higher temperatures. The as-received coal compacts without additive particulates (Figs. 7a and d) are riddled with cracks, whereas the addition of additives resulted in sintering and bonding of the coal particulates (Figs. 7e and f). Figure 8 shows SEM images of cleaned coal-additive composites pyrolyzed at 500˚C. On detailed inspection of the Figs. 8a and 8c, it can be observed that the edges of cleaned coal particles are rounded, which indicates that coal is “reactively bonded” with the additives at 500˚C.

Figure 3: 100wt.% coal sintered at 900°C.

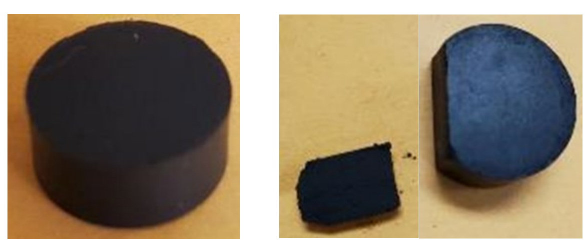

Figure 4: High strength compacts - cleaned-coal(50wt.%)-additive(50wt.%) coal sintered at 500°C.

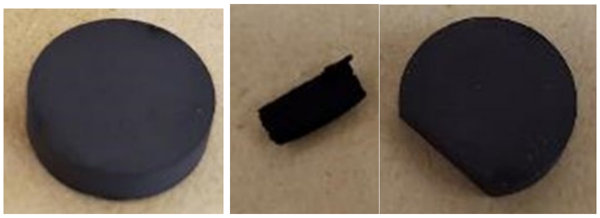

Figure 5: Medium strength compacts - coal(50wt.%)-additive (50wt.%) coal sintered at 900°C.

Figure 6: Low strength compacts - coal(10wt.%)-additive (90wt.%) coal sintered at 900°C.

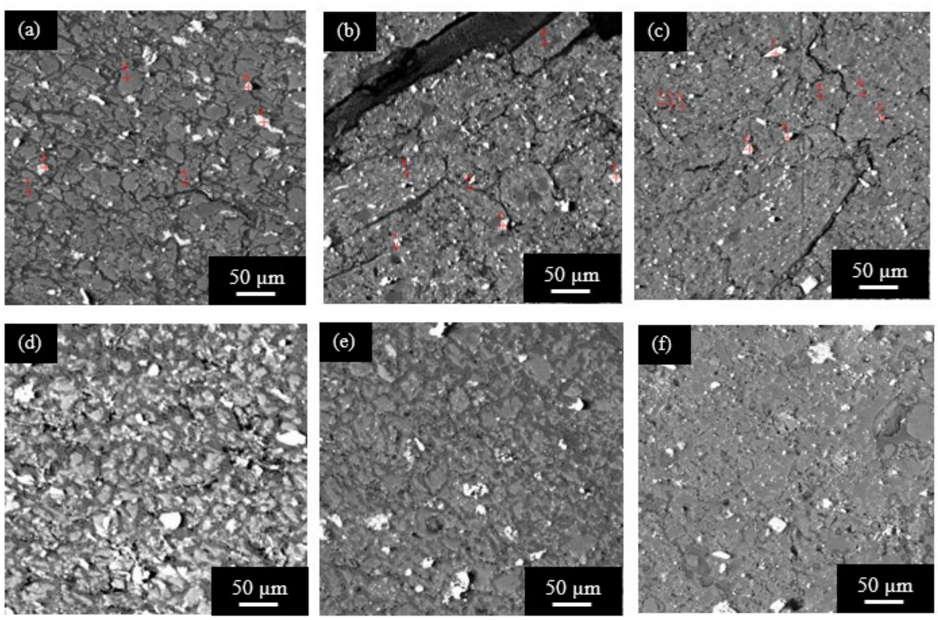

Figure 7: SEM micrographs of (a) 100wt.% coal, (b) coal (90wt.%)-additive(10wt.%), (c) coal(75wt.%)-additive (25wt.%) sintered at 500˚C, and (d) 100wt.% coal, (e) coal(75wt.%)-additive (25wt.%), and (f) coal(50wt.%)-additive (50wt.%) sintered at 900˚C in Ar environment.

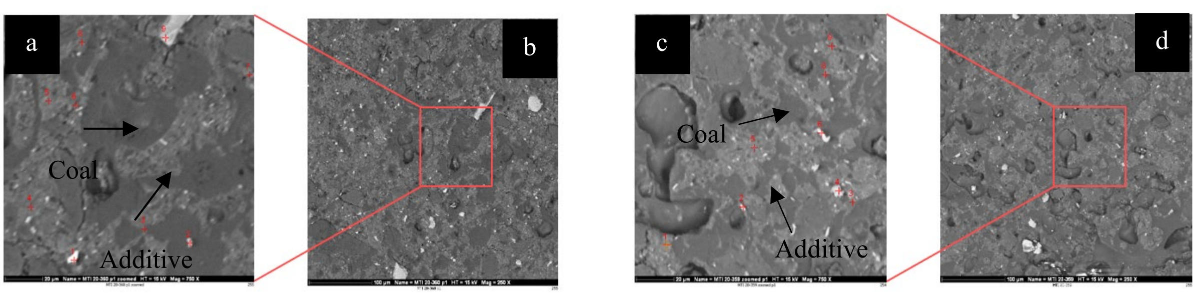

Figure 8: SEM micrographs of (a-b) Cleaned coal (50 wt.%)-additive (50 wt.%), (c-d) coal (75 wt.%)-additive (25 wt.%) after sintering at 500˚C in Ar environment.

Preliminary ignition tests were also performed on the coal-additive composites by heating in a muffle furnace in air. All of the compositions were stable at room temperature in these tests, and in some cases, it was observed that the addition of additive particulates increased the ignition temperature.

Figures 9a and b show the density and mechanical behavior of the cold-pressed and sintered samples in the temperature of 300-500°C. Both the cleaned coal and run-of-mine coal (Coyote Station) premixed with additive particulates had <1.2 g/cc density and showed >27 Mpa compressive strength which is comparable to Portland cement after 28 days of curing and residential concrete[21,22]. Structural lightweight concretes have densities in the range of 1.4-1.8 g/cc with a strength requirement of >17 Mpa for structural applications. This study shows that SCBM-based materials have the adequate strength to compete with masonry bricks (15-20 Mpa) and lightweight concrete masonry unit (CMU) (≈13.7 Mpa) based materials. Figures 9c and 9d shows density and compressive strength of hot-pressed samples. By using this processing technology, LIG2 products can be designed in the strength range of 10-15 Mpa. Comparatively, Figs. 9e and 9f show the density and compressive strength of pre-cast samples. By using this technology, composites can be designed with <1 g/cc density which make them potential candidates for the insulation market. These compositions can potentially compete with nonstructural lightweight concrete (NSLWC) in insulation and lower density requirement categories[23].

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[21] NRMCA, "CIP 36 - Structural Lightweight Concrete," Concrete in Practice, 2016. [Online]. Available: https://centralconcrete.com/wp-content/themes/centralconcrete/images/cip/36pr.pdf.
[22] "Portland Cement Compressive Strength," Pavement Interactive. Available: https://pavementinteractive.org/reference-desk/testing/cement-tests/portland-cement-compressive-strength/.
[23] "Compressive Strength of Lightweight Concrete", Saman Hedjazi, DOI: 10.5772/intechopen.88057

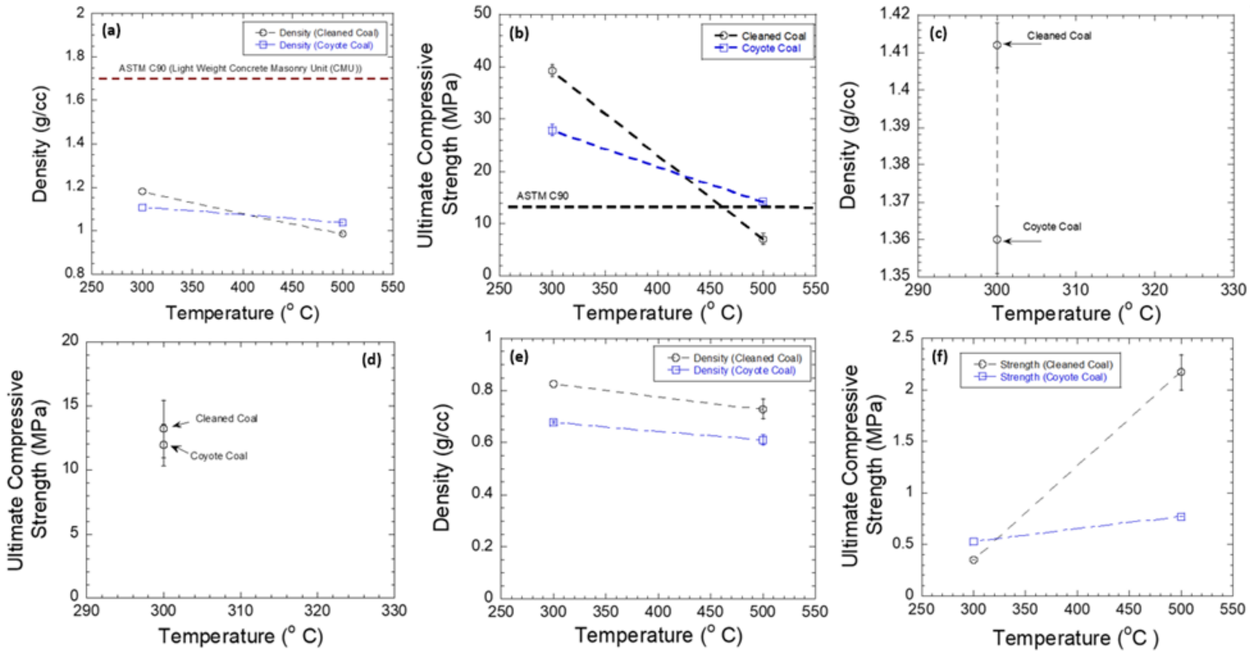

Figure 9: Plot of (a) density, and (b) compressive strength of cold-pressed and sintered product; (c) density, and (d) compressive strength of hot-pressed product; (e) density, and (f) compressive strength of pre-cast product. The baseline composition is 51 wt% coal-49 wt% additive composition; Cleaned Coal refers to coal after the removal of organically associated and rare earths elements.

These results show that LIG2 products meet and exceed ASTM strength requirements, as well as current building materials' strengths, and that LIG2 properties can indeed be tailored with respect to composition, temperature, and manufacturing method. The yield of product (dry basis) has been as high as 70% for low temperature sintering at 300 °F. Moreover, these results further showcase the fact that UND and MTI have demonstrated the feasibility of the SCBM technology in the laboratory scale as TRL-4.

6.0 QUALIFICATIONS

This program capitalizes on the expertise of MTI and UND. The team brings together the unique expertise required to incorporate the ability to develop the method for production of low-temperature sintered coal building materials. Microbeam personnel have a deep understanding of the behavior of lignite and UND has experience in the properties of the additives and manufacturing. UND and Microbeam possess the required capabilities to test the compositions and validate the technology. Resumes for the key participants are included in the Appendix (Section 14.2).

MTI's primary expertise lies in the following: Microbeam currently has a staff of fifteen people who have backgrounds in fuel science, engineering (mechanical, chemical, electrical, petroleum), computer/data science, chemistry, biology, and business (accounting). This multidisciplinary team works together to develop innovative solutions to plant performance and reliability issues. Since 1992, Microbeam has performed nearly 1600 projects providing advanced analysis of coal, biomass, petroleum coke, fly ash, slag, ceramics, metals, and other materials and has done consulting for researchers, the refining industry, the power industry, boiler manufacturers, coal companies, and government. Microbeam's financial and accounting system meets all the requirements to perform projects funded by the US Department of Energy. Microbeam's project management team has extensive experience in managing US DOE and commercial projects.

UND's primary expertise lies in the following*:* Dr. Gupta's research group has expertise in a) fundamental research and technology development of materials which can be applied in demanding applications, b) design of materials by microstructure design of high performance and construction materials, c) comprehensive materials characterization for targeted product development, d) transfer of technology from lab-scale to pilot-scale by coordinating with different collaborators and industry, and e) IP development.

Mr. Matt Fuka, Principal Investigator (PI) from MTI on this project, will lead the project effort. Mr. Fuka, Sr. Research Engineer at MTI, has a B.S. and M.S in Mechanical Engineering with Materials and Manufacturing concentration from the University of North Dakota (UND). He performs materials research and development and focuses on chemical and physical properties of materials and their behavior during processing. Mr. Fuka oversees commercial projects, leads technical material analysis and interpretation of experimental results, and has over seven years of materials-related research experience.

Mr. Alex Benson, Project Manager at MTI, has experience in leading multiple projects related to fuel analysis and REE in coal, sediments, and ash. Mr. Benson has a B.S. in Mechanical Engineering from the University of St. Thomas. Mr. Benson has led projects for MTI related to the REE extraction from coal-related feedstocks, REE analysis and sorting methods, and other projects related to the improvement of power plant combustion processes. Mr. Benson will hold a project management role for MTI in managing project timeline and budget as well as assist in engineering related activities.

Dr. Steve Benson, President of MTI, has strong expertise in fuel analysis, fuel properties, combustion, gasification, ash transformations, and pollution control. Dr. Benson and MTI have performed numerous projects for many coal-fired power-plants and will bring expertise in the areas of SEM, coal chemical composition analysis, and chemical reactions between coal and added constituents. Dr. Benson works with clients worldwide to address opportunities and challenges associated with the utilization of fossil and renewable fuels. Dr. Benson will assist the PI for MTI in managing the scope of work.

Dr. Surojit Gupta, Associate Professor of Mechanical Engineering at UND, will be the PI from UND. Dr. Gupta has 19 years of experience in fundamental research, technology development, and commercialization in materials-related technologies. Dr. Gupta has published extensively in designing of novel materials and has over 50 peer reviewed publications with an h-index of 25, and 5 patents (4 granted and 1 pending). Dr. Gupta was a lead inventor of green technology platform of Solidia Technologies. Dr. Gupta has successfully collaborated with highly reputed companies like Aerospace Division of Honeywell International, Environmental Division of Corning, and CTL at various capacities.

Mr. Nolan Theaker, Research Engineer at the UND Institute for Energy Studies, brings specialized expertise and knowledge of the cleaned coal precursor material, as well as other mining and mineralogy knowledge associated with lignite materials. Mr. Theaker currently leads the work conducted by UND utilizing lignites as a feedstock for REE and other CM (DE-FE0031835) and will provide the cleaned coal feedstock as needed for the project (production of >5 tons/day available). Mr. Theaker has conducted numerous economic studies associated with coal mining, processing, and conversion for high-value carbon-based product applications, and will leverage this experience in assisting the team in these areas.

The North American Coal Corporation (NACC) and its affiliated companies operate surface mines that supply coal primarily to power generation companies and provide other value-added services to natural resource companies. The NACC operates 10 surface coal mines and equipment in 15 limestone quarries, delivering more than 30 million tons of coal and 30 million cubic yards of limestone in 2017. NACC operates more draglines than anyone else in the U.S. (over 40), and controls 161,000 surface acres, 1.9 billion tons of coal and 24,000 acres of oil and gas reserves.

7.0 VALUE TO NORTH DAKOTA

Commercialization of this project will provide value to North Dakota in several ways that include: 1) utilization of lignite resource, 2) production of valuable LIG2 products, and 3) high paying jobs. It is anticipated that commercial development of this technology will result in the establishment of a manufacturing plant near or around existing North Dakota lignite mines (i.e. Beulah, Underwood, and Center, ND). Commercialization of this technology will create and support jobs in the mining and manufacturing industry. In addition, the SCBM technology can be co-located with a rare-earth element and critical mineral recovery process. The coal after REE recovery has shown the potential to produce higher quality products as compared to run-of-mine coal.

These jobs will be located near or around rural communities. Furthermore, the technology and proposed process are environmentally friendly and are able to effectively valorize coal while minimizing the release of emissions. Thus, the proposed process is able to provide new environmentally friendly jobs. The nature of jobs produced will be able to pull from an existing labor force of those from mining, manufacturing, and production. Additionally, the University of North Dakota (UND) and North Dakota State University (NDSU) offer ABET accredited engineering programs and Master of Business Administration (MBA) programs that would provide high-skill employees for the plants as needed.

8.0 MANAGEMENT

The management structure for the project is shown in Figure 10, which is designed on a task-by-task basis with the task leaders and key/essential personnel for each task identified. The team brings together the unique expertise required to develop building products from coal. Mr. Matt Fuka will be the Principal Investigator (PI) from MTI and Dr. Surojit Gupta will be the Principal Investigator from UND on this project. Mr. Fuka will work closely with Dr. Gupta and Dr. Benson to conduct technical research activities and will work closely with DOE and project participants to ensure regular communication is maintained throughout the project. Mr. Fuka will coordinate with Dr. Gupta, Dr. Benson, Mr. Alex Benson, and Mr. Nolan Theaker to complete a TEA of the LIG2 product. Mr. Fuka has provided technical direction and management of commercial projects funded by US and international clients associated with the high temperature sintering process. Mr. Fuka has also participated in multiple DOE funded projects. Mr. Fuka will be supported by Dr. Benson who has managed numerous DOE and industry projects similar in complexity and size to this proposed project.

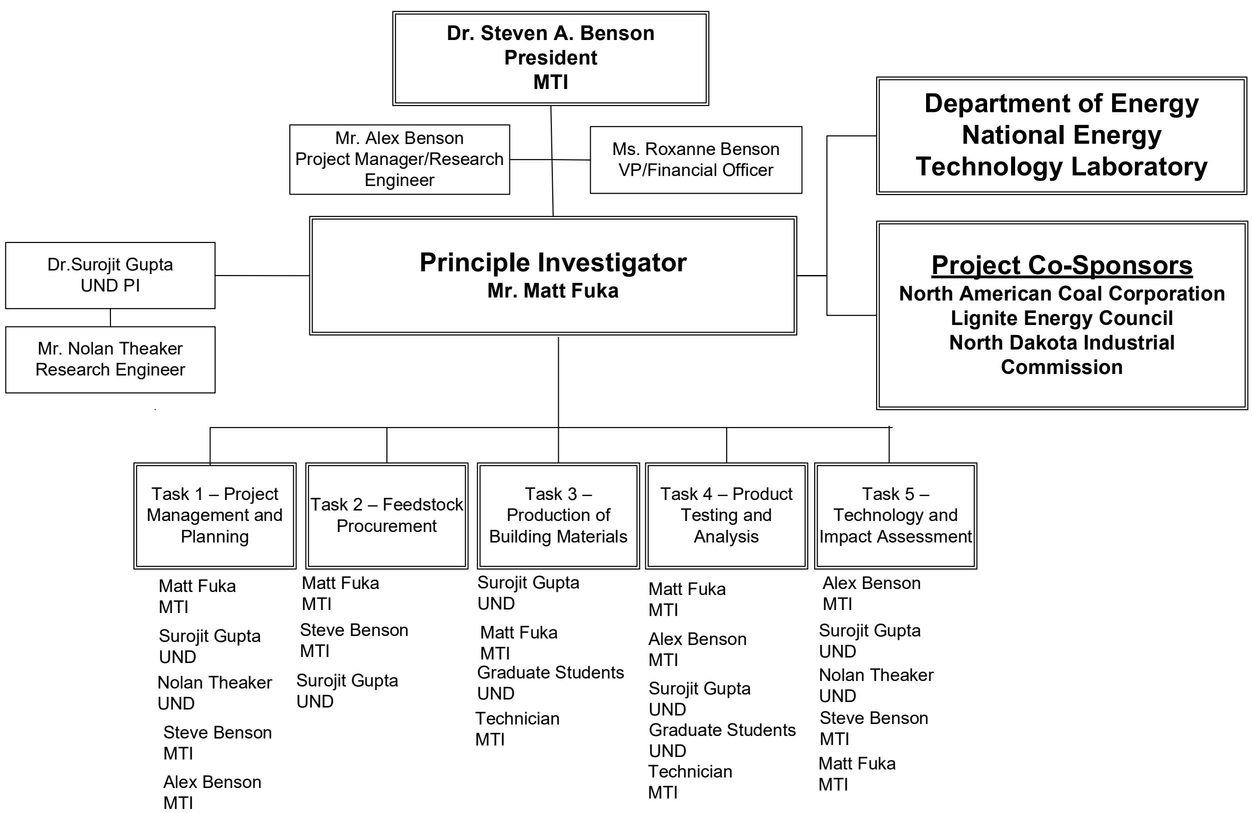

Figure 10. Project management structure.

MTI and UND are committed to successful completion of this project within the allotted time period. Mr. Fuka, MTI PI, is committed to spend 35% of his time throughout the duration of the project. Mr. Fuka will utilize expertise of other scientists, engineers, and technicians at MTI who have time available on the project. Mr. Fuka will work closely with Dr. Gupta, Dr. Benson, and other project collaborators to ensure timely successful completion of the objectives in this project.

Management risks are mitigated through planned communications with regularly scheduled meetings and conference calls, use of Project Management software tools, and budget projecting and tracking measures currently in place at MTI. Microbeam utilizes several project management tools that include Smartsheet and Jira. Jira is used to track personnel time and Smartsheet is used to track project schedule. Smartsheet is a software used to track project progression, assignment of tasks, allocation of resources, and adherence to project timeline. Information from Jira on personnel time for each project is utilized by Quickbooks to track spending and is used for invoicing. Scheduling and meeting milestones are an integral part of the communications strategy.

9.0 TIMETABLE

The project is expected to take 12 months to complete. The timeline and deliverables are shown in Table 2.

Table 2. Proposed project timeline and milestones.

Task/Subtask Name	Start Date	End Date	2021			2022									
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Task 1 - Project Management and Reporting	10/1/2021	9/30/2022													
Milestones															
Kickoff Meeting		11/1/2021													
Final Report		9/30/2022													
Task 2 - Feedstock Procurement	10/1/2021	12/31/2021													
Milestones															
Feedstock Procurement Protocol		12/31/2021													
Task 3 - Production of Building Materials	11/1/2021	7/31/2022													
Subtask 3.1 - Equipment Set-up	11/1/2021	12/1/2021													
Subtask 3.2 - Optimization of Processing Conditions	12/1/2021	4/30/2022													
Subtask 3.3 - Production of Testing Quantities	5/1/2022	7/31/2022													
Milestones															
Identification of Optimum Processing Conditions		4/30/2022													
Task 4 - Product Testing and Analysis	12/1/2021	7/31/2022													
Subtask 4.1 - Phase Analysis and Mechanical Testing	1/1/2022	4/30/2022													
Subtask 4.2 - Scanning Electron Microscopy (SEM) Analysis	2/1/2022	5/31/2022													
Subtask 4.3 - Durability Analysis	4/1/2022	7/31/2022													
Milestones															
SCBM Testing and Analysis Report		7/31/2022													
Task 5 - Technical and Economic Assessment	4/1/2022	9/30/2022													
Subtask 5.1 - Process Flow Diagrams	4/1/2022	5/31/2022													
Subtask 5.2 - Mass and Energy Balance	6/1/2022	7/31/2022													
Subtask 5.3 - Costs	7/1/2022	8/31/2022													
Subtask 5.4 - Technology Gap Analysis	8/1/2022	9/30/2022													
Milestones															
Preliminary Technical and Economic Assessment		9/30/2022													

10.0 BUDGET

The overall project and UND subrecipient budgets are summarized in Tables 3 and 4, respectively. The budget includes all cost share, personnel, fringe benefits, travel, supplies, equipment, and indirect costs. The UND budget includes the purchase of a 100 ton electric hydraulic press ($8,900), a vibratory disc mill ($21,000), and a laboratory furnace ($17,025) to be used during the project to produce LIG2 products. The NDIC budget is summarized in Table 5 and will support microstructural sample analysis required for the microstructural features of the materials.

Table 3. Overall Project Budget.

Section A - Budget Summary				
		Federal	Cost Share	Total Costs
	Budget Period 1	$517,702	$131,705	$649,407
	Budget Period 2	$0	$0	$0
	Budget Period 3	$0	$0	$0
	Total	$517,702	$131,705	$649,407
Section B - Budget Categories				
CATEGORY	**Budget Period 1**	**Budget Period 2**	**Budget Period 3**	**Total Costs**
a. Personnel	$120,618	$0	$0	$120,618
b. Fringe Benefits	$25,173	$0	$0	$25,173
c. Travel	$9,772	$0	$0	$9,772
d. Equipment	$2,146	$0	$0	$2,146
e. Supplies	$3,537	$0	$0	$3,537
f. Contractual				
Sub-recipient	$229,461	$0	$0	$229,461
Vendor	$0	$0	$0	$0
FFRDC	$0	$0	$0	$0
Total Contractual	$229,461	$0	$0	$229,461
g. Construction	$0	$0	$0	$0
h. Other Direct Costs	$168,799	$0	$0	$168,799
Total Direct Costs	$559,506	$0	$0	$559,506
i. Indirect Charges	$89,901	$0	$0	$89,901
Total Costs	$649,407	$0	$0	$649,407

Table 4. UND subrecipient budget and cost share.

Section A - Budget Summary		Federal	Cost Share	Total Costs	Cost Share %
	Budget Period 1	$229,461	$16,505	$245,966	6.71%
	Budget Period 2	$0	$0	$0	0.00%
	Budget Period 3	$0	$0	$0	0.00%
	Total	$229,461	$16,505	$245,966	6.71%
Section B - Budget Categories					
CATEGORY	Budget Period 1	Budget Period 2	Budget Period 3	Total Costs	% of Project
a. Personnel	$61,122	$0	$0	$61,122	24.85%
b. Fringe Benefits	$4,449	$0	$0	$4,449	1.81%
c. Travel	$3,224	$0	$0	$3,224	1.31%
d. Equipment	$70,101	$0	$0	$70,101	28.50%
e. Supplies	$24,041	$0	$0	$24,041	9.77%
f. Contractual					
Sub-recipient	$9,385	$0	$0	$9,385	3.82%
Vendor	$0	$0	$0	$0	0.00%
FFRDC	$0	$0	$0	$0	0.00%
Total Contractual	$9,385	$0	$0	$9,385	3.82%
g. Construction	$0	$0	$0	$0	0.00%
h. Other Direct Costs	$29,770	$0	$0	$29,770	12.10%
Total Direct Costs	$202,092	$0	$0	$202,092	82.16%
i. Indirect Charges	$43,874	$0	$0	$43,874	17.84%
Total Costs	$245,966	$0	$0	$245,966	100.00%

Table 5. Summary of NDIC budget for sample analysis.

NDIC Cost Share		Task 2		Task 3		Task 4					G&A	Total
Period 1:	Rates	# of samples	Total $	# of samples	Total $	# of samples	Total $	Totals	Totals		24.01%	Pd 1
Sample Prep	$ 69	$ 9	$ 619	$ 40	$ 2,751	$ 32	$ 2,201	$ 81	$ 5,572	$ 5,572		
Morphology	$ 242	$ 8	$ 1,935	$ 40	$ 9,677	$ 32	$ 7,741	$ 80	$ 19,354	$ 19,354		
CCSEM	$ 661	$ 2	$ 1,322	$ 8	$ 5,290	$ 8	$ 5,290	$ 18	$ 11,902	$ 11,902		
Sintering	$ 798	$ 2	$ 1,597	$ 8	$ 6,387	$ 7	$ 5,588	$ 17	$ 13,571	$ 13,571		
Totals		$ 21	$ 5,474	$ 96	$ 24,105	$ 79	$ 20,821	$ 196	$ 50,399	$ 50,399	$ 12,101	$ 62,500

11.0 MATCHING FUNDS

Other committed sources and amounts of funding in addition to the $62,500 requested from NDIC are identified in Table 6. North American Coal Corporation will provide in-kind support in the form of coals from their North Dakota mines for use in the technical and economic analysis. Microbeam will provide a portion of the analysis required for the testing and UND will provide tuition costs for graduate students and time for the UND PI.

Table 6. Other committed sources and amounts of funding for proposed project.

Organization/Source	Type (Cash or In Kind)	Total Project Cost Share
Microbeam Technologies Inc.	Cash	**$10,200**
University of North Dakota	In Kind/Cash	**$16,505**
North American Coal Co.	In Kind	**$42,500**
Total		**$69,205**

12.0 TAX LIABILITY

None

13.0 CONFIDENTIAL INFORMATION

None

14.0 APPENDICIES

14.1 Resumes

MATT FUKA

Education and Training

University of North Dakota	Mechanical Engineering	M.S. 2018
University of North Dakota	Mechanical Engineering	B.S. 2015

Research and Professional Experience

2018 – Present Research Engineer, Microbeam Technologies, Inc.
Mr. Fuka currently provides technical direction and management of commercial projects funded by US and international clients associated with the high temperature behavior of materials in combustion and gasification systems. He identifies measures to improve performance and reliability of boilers/gasifiers based on an understanding of the chemical physical processes occurring in the plant and laboratory-derived experimental data. Mr. Fuka is also an active contributor in multiple DOE funded projects. The main areas where Mr. Fuka works include scanning electron microscopy (SEM) and x-ray microanalysis, laboratory-scale ash deposition/sintering/corrosion process testing, physical property of materials (strength, density, thermal conductivity), and thermochemical equilibrium modeling. Mr. Fuka also prepares technical reports and communicates results of work with clients.

2018 Research Assistant, Microbeam Technologies, Inc.
Mr. Fuka prepared and analyzed samples using SEM/x-ray microanalysis for commercial and government clients. He also conducted and analyzed data from laboratory sintering and high temperature viscosity testing.

2016 – 2018 Graduate Research/Teaching Assistant, University of North Dakota
Synthesize and characterize novel ternary boride and carbide powders via pressureless reaction. Conduct and analyze mechanical performance and tribology tests on ternary boride and carbide reinforced composites, and bioplastics. Fabricate, conduct and analyze compressive strengths of sintered fly ash-based composites for proppant design.

2015 – 2016 Design Engineer, Odra Street Sweepers
Improve design of the mechanical, electrical and hydraulic systems on the Broom Badger street sweeper.

Selected Publications/Patent Application

- Q. Tran, M. Fuka, M. Dey, S. Gupta, "Synthesis and Characterization of Novel Ti_3SiC_2 Reinforced Ni-Matrix Multilayered Composites based Solid Lubricants", Lubricants: Wear and Corrosion Resistant Coatings 2019, 7(12), 110; DOI: https://doi.org/10.3390/lubricants7120110.
- D. Stadem, S. Patwardhan, M. Fuka, J. Langfeld, A. Benson, and S. Benson, "Condition Based Monitoring and Predicting Ash Behavior in Coal Fired Boilers–III–Coal Properties Optimization", Proceedings of 36th Annual International Pittsburgh Coal Conference (2019 PCC).
- M. Fuka. "Synthesis and Characterization of Novel Ternary Borides (MoAlB) and Their Composites", The University of North Dakota, ProQuest Dissertations Publishing, 2018. 10814246.
- M. Dey, M. Fuka, F. AlAnazi, and S. Gupta, "Synthesis and Characterization of Novel Ni-Ti_3SiC_2 Composites", Proceedings of 42nd Int'l Conf & Expo on Advanced Ceramics & Composites (ICACC 2018).
- M. F. Riyad, M. Fuka, R. Lofthus, Q. Li, N. M. Patel, and S. Gupta "Novel Engineered Cementitious Materials by Using Class C Fly Ash as a Cementitious Phase", Ceramics Transaction, Materials Science & Technology (MS&T) 2015.

SUROJIT GUPTA

Education and Training:

University of Calcutta	Ceramic Engineering	B.S. 2001 (First Class with Honors)
Drexel University	Materials Science and Engineering	Ph.D. 2001-2006
The Pennsylvania State University	Materials Science and Engineering	Postdoctoral 2006-2008
University of Massachusetts, Amherst	MBA	2013-2017

Research and Professional Experience:
2019-present: Associate Professor, University of North Dakota, Grand Forks, North Dakota
2012-2018: Assistant Professor, University of North Dakota, Grand Forks, North Dakota
2014: Adjunct Professor in Henan Polytechnic Institute, China
2008 - 2012: Research Assistant, Rutgers University, Piscataway, New Jersey
2006- 2008: Postdoctoral Fellow, The Pennsylvania State University, State College, Pennsylvania
2001-2006: Research Fellow, Drexel University, Philadelphia, PA

Industrial Positions/Collaboration:
2008-2012: Technical collaborator with Solidia Technologies (formerly CCS Materials)
2009-2012: CTL Group, Skokie, IL 60077-1030
2006–2008: Environmental Materials Division, Corning Incorporated.

2007-2008: Consultant for EPCOS, Austria.
2003-2006: Aerospace Division of Honeywell International.
2003-2006: 3one2, NJ (a startup company).

Publications Related to Proposed Research (h-index 25 and over 1300 citations)

1. "Novel MAB Phase-based nanolaminates suit high performance applications", Surojit Gupta and Maharshi Dey, Advanced Materials & Processes 177, 22-26 (2019).
2. "Synthesis and characterization of novel polymer matrix composites reinforced with max phases (Ti_3SiC_2, Ti_3AlC_2, and Cr_2AlC) or MoAlB by fused deposition modeling", K Hall, M Dey, C Matzke, S Gupta, International Journal of Ceramic Engineering & Science 1 (3), 144-154 (2019).
3. "Synthesis and Characterization of Novel Ti_3SiC_2 Reinforced Ni-Matrix Multilayered Composite-Based Solid Lubricants", Q Tran, M Fuka, M Dey, S Gupta, Lubricants 7 (12), 110 (2019).
4. "On the Synthesis and Characterization of Poly Lactic Acid (PLA), Polyhydroxyalkanoate (PHA), Cellulose Acetate (CA), and Their Engineered Blends by Solvent Casting", Saud Abu Aldam, Maharshi Dey, Sabah Javaid, Yun Ji, and Surojit Gupta, Journal of Materials Engineering and Performance (Accepted).
5. "Beneficial usage of recycled polymer particulates for designing novel 3D printed composites", R. Dunnigan, J. Clemens, M. N. Cavalli, N. Kaabouch, and S. Gupta, Prog Addit Manuf (2018) 3: 33. https://doi.org/10.1007/s40964-018-0046-2
6. "Ternary carbide and nitride materials having tribological applications and methods of making same", S. Gupta, T. Palanisamy, M.W. Barsoum and C.W. Li, (U.S Patent 7,553,564 BA, June 30, 2009).

Synergistic Activities

- Chair, Engineering Ceramics Division, American Ceramics Society
- Associate Editor (guest) of Journal of Materials Engineering and Performance and Japanese Journal of the Ceramics Society for Special Issues (2019).
- Volume Editor of Ceramics Proceedings published by the American Ceramics Society (2017).
- Adjunct Professor, Henan Polytechnic University, China (2014).
- Lifetime member of ASM International, American Ceramics Society (ACerS), and Indian Institute of Metals (IIM).
- Member-at-large of Red River Chapter of American Chemical Society (ACS).

ALEX BENSON

Education and Training

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

Professional Experience

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

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

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

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

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

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

2007 – 2012 Lab Assistant (part-time), Microbeam Technologies Incorporated. Alex Benson prepared ash, coal, metal, and other samples for SEM analysis. Alex also developed sample porosity and stress test process including equipment design and manufacturing and developing standard procedures for completing these tests.

Selected Publications and Presentations

Steven Benson, Shuchita Patwardhan, David Stadem, James Langfeld, Alex Benson, and Travis Desell, "Application of Condition Based Monitoring and Neural Networks to Predict the Impact of Ash Deposition on Plant Performance," Accepted for publication, Conference postponed to 2021.

Synergistic Activities

Continued Education (CE)/Professional Development Hour (PDH) Classes Completed:

- Combined Cycle Power Plant Fundamentals (EUCI)
- Heat Recovery Steam Generator (HRSG) Fundamentals (EUCI)
- A Comparison of the New SEC Regulation S-K 1300 on Modernization of Property Disclosures for Mining Registrants to Canadian National Instrument 43-101 (SME)

STEVEN A. BENSON

Education and Training:

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

Research and Professional Experience:

1991 – Present President, Microbeam Technologies Incorporated. Dr. Benson founded Microbeam Technologies Incorporated (MTI), a spin-off company from the University of North Dakota to conduct service analysis of materials using automated methods aimed at

	assessing efficiency and reliability problems in renewable and fossil energy conversion systems. Dr. Benson is responsible for technical direction, data interpretation and proposal preparation.
2015 – 2017	Associate Vice President for Research, Energy & Environmental Research Center, University of North Dakota -- Dr. Benson was responsible for developing and managing projects on the clean and efficient use of fossil and renewable fuels.
2008 – 2015	Professor, Chemical Engineering; Chair, Petroleum Engineering; and Director, Institute for Energy Studies – coordinated energy related education and research activities that involve faculty, research staff, and students.
1986 – 2008	Associate Director for Research/Senior Research Manager, EERC, UND -- Dr. Benson was responsible for the direction and management of programs related to integrated energy and environmental systems development.
1984—1986	Graduate Research Assistant, Fuel Science Program, Pennsylvania State University.
1983 – 1984	Research Supervisor, Distribution of Inorganics and Geochemistry, Coal Science Division, UND Energy Research Center -- He was responsible for management and supervision of research on coal geochemistry.
1977 – 1983	Research Chemist, Energy Resources Development Administration (ERDA) and U.S. Department of Energy Grand Forks Energy Technology Center, Grand Forks, North Dakota.

Selected Publications:

1. Laudal, D. and Benson, S.; Rare Earth Extraction from Coal; US Patent 10,669,620 B2; June 2, 2020.
2. Laudal, D. A., Benson, S.A., Addleman, R.S., and Palo, D., Leaching behavior of rare earth elements in Fort Union lignite coals of North America, International Journal of Coal Geology, Volume 191, 15 April 2018, Pages 112-124.

Synergistic Activities:

- American Chemical Society (ACS) -- Member, Executive Committee, Energy and Fuels Division – 2004– 2009 – Participated on the Executive Committee involved in the coordination and direction of division activities, including outreach, programming, finances, and publications. Chair of Energy and Fuels Division 2004-2005.
- Lignite Energy Council, Distinguished Service Award, Research & Development, 1997, 2003, 2005, and 2008.
- College of Earth and Mineral Science Alumni Achievement Award, Pennsylvania State University, 2002.
- Science and Technology Award, Impacts of Fuel Impurities Conference, 2014.

Nolan L. Theaker

Education and Training:

University of Louisville	Chemical Engineering	B.S. 2016
University of Louisville	Chemical Engineering	M.Eng. 2017
University of North Dakota	Chemical Engineering	Pursuing PhD

Research and Professional Experience:

2017-Present	Research Engineer, UND Institute for Energy Studies. Responsibilities include high-level innovative research and development of novel concepts for submission of funding proposals. Coordinated and led efforts associated with downstream rare earth element concentration operations that have resulted in the development of final process flow diagrams. Key contributor to multiple proposals involving REE extraction and/or

	concentration from multiple feedstocks. Proposed efforts associated with coal conversion and value improvement using chemical/thermal methods. Key contributor on proposals and projects for CO2 capture and/or utilization from coal combustion flue gases. Currently co-PI on pilot-scale REE work (DE-FE31835), and leading day-to-day research activities on the project.
2016-2017	Research Assistant, University of Louisville Conn Center. Research involved design and operation of multi-stage electrochemical reactor scheme for efficient production of fuels from CO2. Developed nano-functionalized electrocatalysts for improvements in activity and selectivity for targeted reactions in two phase reaction systems.
2014-2015	Co-op Engineer, University of Kentucky CAER. Research involved improvement and operation of a DOE bench-scale CO2 capture unit in multiple reaction conditions. Evaluation and comparison of catalyst performance in a holistic view for CO2 capture was conducted, including novel organic and enzymatic catalysts.

Publications/Presentations:

1. Theaker, N., Strain, J. M., Kumar, B., Brian, J. P., Kumari, S., & Spurgeon, J. M. (2018). Heterogeneously Catalyzed Two-Ctep Cascade Electrochemical Reduction of CO2 to Ethanol. Electrochimica Acta, 274, 1-8. doi:10.1016/j.electacta.
2. Park, D., Middleton, A., Smith, R., Laudal, D., Theaker, N., Hsu-Kim, H., Jiao, Y. A Biosorption-based approach for the selective extraction of REEs from coal byproducts. Separation and Purification Technology. 2020.
3. Mann, M; Theaker, N; Benson, S; Palo, D. "Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks – Final Report". Submitted March 31, 2020.
4. Theaker, N., Rew, B., Laudal, D., Mann, M. Investigation of rare earth element extraction from North Dakota Coal-Related Feed Stocks. 2019 NETL Annual Crosscutting Projects Review Meeting. April 9th, 2019. Pittsburgh, PA.
5. Zygarlicke, C; Folkedahl, B; Feole, I; Kurz, B; Theaker, N; Benson, S; Hower, J; Eble, C. "Rare-Earth Elements (REEs) in U.S. Coal-Based Resources: Sampling, Characterization, and Round-Robin Interlaboratory Study – Final Report". Submitted September 30th, 2019.

Patents/Applications:

- Theaker, Nolan; Laudal, Dan. 2020. Method for Leaching Rare Earth Elements and Critical Minerals from Organically Associated Materials. USA. 63/112,846A, filed Nov. 12, 2020.
- Theaker, Nolan; Laudal, Dan; Lucky, Christine. 2020. Generation of Rare Earth Elements from Organically-Associated Leach Solutions. USA. 63/112,842A, filed Nov. 12, 2020.

Synergistic Activities:

Mr. Theaker's principal area of research interest includes energy, fuels, and alternative critical material research. These include developing alternative uses and sources of fuels and valuable materials, both carbon and mineral based.

14.2 North American Coal Corporation Letter of Support

14.3 University of North Dakota Letter of Commitment

14.4 Microbeam Letter of Commitment

14.5 DOE Award Letter

CARROLL L. DEWING
Vice President – Operations

Telephone: 701-323-3392
E-Mail: carroll.dewing@nacoal.com

January 25, 2021

Dr. Steven A. Benson
President
Microbeam Technologies Inc.
4200 James Ray Drive, Ste 193
Grand Forks, ND 58202

Re: Support of the proposal entitled "Development of Novel Sintered Coal Building Materials" submitted in response to the Department of Energy Funding Opportunity DE-FOA-0002438 titled "Design, R&D, Validation and Fabrication of a Prototype Carbon Based Building".

Dear Dr. Benson:

The North American Coal Corporation (NACoal) is pleased to support the proposal from Microbeam Technologies Incorporated and the University of North Dakota (UND) to develop a process to produce building material from lignite coals.

This project builds on initial testing conducted by Microbeam and UND to produce sintered coal materials using a novel process. We understand that the sintered coal building materials (SCBM) can be used for various applications such as insulation, joists/studs, tiles, and architectural block. Furthermore, these materials have great potential to be used for expanded applications as high-value carbon foams.

This technology is of specific interest to NACoal since it currently has mining operations in North Dakota, New Mexico, Mississippi, Texas and Louisiana, and also provides dragline mining services for independently owned limerock quarries in Florida. North Dakota operations include Falkirk Mine, Freedom Mine, and Coyote Creek Mine with a total annual production of over 25 million tons annually in North Dakota.

NACoal will work closely with the Microbeam team in the testing and development of the technology by providing access to coal samples, and coal mine database information on lignite properties. NACoal will also advise the team on the feasibility of the use of lignite to produce SCBM. NACoal will provide $42,500 in cash equivalent cost share in the form of analysis of lignite coals that have the potential to be used in the SCBM process. The data will provide information on the variability of the lignite properties that impact product yield and quality.

We believe that, if successful, this technology has the potential to provide profitable opportunities for the coal industry, and for the US, to produce jobs and effectively utilize one of the nation's most widely available natural resources.

If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Very truly yours,
THE NORTH AMERICAN COAL CORPORATION

Carroll L Dewing

Carroll L. Dewing
Vice President – Operations

DEPARTMENT OF MECHANICAL ENGINEERING
UPSON II ROOM 266
243 CENTENNIAL DRIVE STOP 8359
GRAND FORKS, NORTH DAKOTA 58202-8359
PHONE (701) 777-2180
https://engineering.und.edu/academics/mechanical/

January 26, 2021

Dr. Surojit Gupta
Mechanical Engineering Stop 8359
University of North Dakota
Grand Forks, ND 58202-8359

RE: Cost share support for DE-FOA-0002438 – Design, R&D, Validation, and Fabrication of a Prototype Carbon-Based Building

Dear Dr. Gupta:

The Department of Mechanical Engineering is happy to support your proposal entitled "**Development of Novel Sintered Coal Building Materials.**" This proposal is in close alignment with the goals of the department, and supports the university's One UND Strategic Plan, more specifically its Energy and Environmental Sustainability Grand Challenge.

The department will specifically support your proposed effort by providing tuition support for graduate student(s) supported from this project. In addition, the department will allocate a portion of your academic salary to this effort. The estimated value of this cost share is $16,505.

I wish you the best of luck with your proposed efforts. Your proposed project indicates a good fit with the DOE program.

Sincerely,

Clement Tang, PhD
Associate & Chair of Mechanical Engineering
University of North Dakota

Michael D. Mann
Associate Dean for Research
College of Engineering and Mines

MICROBEAM
TECHNOLOGIES, INC.

www.microbeam.com

January 28, 2021

Department of Energy
Office of Fossil Energy

RE: Description of cost share support for the proposed project entitled "Development of Novel Sintered Coal Building Materials" submitted in response to the Department of Energy Funding Opportunity DE-FOA-0002438 titled "Design, R&D, Validation and Fabrication of a Prototype Carbon Based Building".

To whom it may concern:

Microbeam Technologies is pleased to provide cost share support for the proposal entitled "Development of Novel Sintered Coal Building Materials". Microbeam will specifically support the proposed effort by conducting porosity analysis on 34 samples which will provide physical property measurements for the project. The value of the analysis is $10,200.

The cash cost share received from North Dakota Industrial Commission ($62,500) will be used to perform testing, microstructural characterization and composition analysis for the project that will entail sample preparation, sintering testing, morphology analysis, CCSEM image analysis, ash content measurement, and ash composition analysis. These efforts will be conducted by Microbeam.

Microbeam is looking forward to teaming with DOE and other project sponsors to make this project a success.

Sincerely,

Steven A. Benson, PhD
President
Microbeam Technologies Inc.

Shipping:
4200 James Ray Drive, Ste 193
Grand Forks, ND 58202-6090

Mailing:
PO Box 5
Victoria, MN 55386-0005

Phone: 701-757-6200
Fax: 701-738-4899
info@microbeam.com

May 12, 2021

SENT VIA ELECTRONIC MAIL

Microbeam Technologies, Inc.
Ms. Roxanne B. Benson
4200 James Ray Drive, Suite 193
Grand Forks, ND 58202-6090
rbenson@microbeam.com

SUBJECT: Selection of Application for Negotiation Under Funding Opportunity Announcement Number DE-FOA-0002438, titled "Design, R&D, Validation, and Fabrication of a Prototype Carbon-Based Building"

Dear Ms. Benson:

We are pleased to provide this update on your application. The Office of Fossil Energy within the Department of Energy (DOE) has completed its evaluation of your application submitted in response to the subject Funding Opportunity Announcement (FOA). The application below has been recommended by the Office of Fossil Energy for negotiation of a financial award (**Note: This notification does not guarantee Federal Government funding, as funding will only be obligated upon completion of successful negotiations**.)

Please note:

1) **The Office of Fossil Energy has determined that awards selected under this FOA will be for Phase I only and there will be no competitive down-select for Phase II. DOE may or may not issue separate FOAs in future years to pursue the Phase II and Phase III Prototype Carbon-Based Building work.**

2) **The Office of Fossil Energy has determined that awards selected under this FOA will be required to incorporate additional tasks into the Statement of Project Objectives (SOPO) including Summary of Environmental Justice Considerations, Summary of Economic Revitalization and Job Creation Outcomes, and Environmental, Safety, and Health Analysis for Products Proposed to be Manufactured under the award (included herein as Attachments). Please see the revised SOPO template and guidance for the additional tasks attached to this letter. Changes to the Statement of Project Objectives may require adjustments to the application budget which may require revisions and will be addressed in the negotiation phase, prior to award.**

   Should this change result in your organization not wishing to execute a Phase I project, please email me to indicate your desire to withdraw from this FOA.

Application Title: *"Development of Novel Sintered Coal Building Materials";*
Principal Investigator*:* Mr. Matt Fuka;
Application Number*:* 13277359.
Receipt of this letter does not authorize the applicant to commence with performance of the project. DOE makes no commitment to issue an award and assumes no financial obligation with the issuance of this letter. Applicants do not receive an award until award negotiations are complete and the Contracting Officer executes the funding agreement. Only an award document signed by the Contracting Officer obligates DOE to support a project.

You are required to refrain from any press release or social media regarding this notification until after DOE issues their Press Release; you will be notified when the Press Release is issued.

The award negotiation process may take up to 90 days. The applicant must be responsive during award negotiations (i.e., provide requested documentation) and meet the stated negotiation deadlines. Failure to submit the requested information and forms by the stated due date, or any failure to conduct award negotiations in a timely and responsive manner, may cause DOE to cancel award negotiations and rescind this selection. DOE reserves the right to terminate award negotiations at any time for any reason.

Please complete the Pre-Award Information Sheet (available at https://netl.doe.gov/node/5719) and submit it to DOE no later than May 26, 2021.

Please complete the revision of the SOPO with the additional tasks and an update to the Budget Justification file with the additional project costs and submit it to DOE no later than May 26, 2021.

Please provide the requested documents to the attention of Patrick Mayle, who is the Contract Specialist from the Acquisition group handling the administrative portion of your application. Mr. Funk can be reached at Patrick.Mayle@netl.doe.gov. Barbara Carney is the NETL Project Manager from the Project Management Division handling the technical portion of your application and can be reached at Barbara.Carney@netl.doe.gov.

Sincerely,

Janet S. Laukaitis
Contracting Officer
Finance and Acquisition Center

Enclosures: Statement of Project Objectives template
Additional Requirements document to support Statement of Project Objective tasks

cc: FOA File
Matt Fuka, Principal Investigator, mfuka@microbeam.com
Janet S. Laukaitis, Contracting Officer, Janet.Laukaitis@netl.doe.gov
Barbara Carney, Project Manager, Barbara.Carney@netl.doe.gov
Patrick Mayle, Contract Specialist, Patrick.Mayle@netl.doe.gov

ASSISTANCE AGREEMENT

1. Award No. DE-FE0032083

2. Modification No.

3. Effective Date 09/20/2021

4. CFDA No. 81.089

5. Awarded To
MICROBEAM TECHNOLOGIES INCORPORATED
Attn: ROXANNE BENSON
P.O. BOX 5
Victoria MN 553860005

6. Sponsoring Office
Fossil Energy and Carbon Management
FECM-1
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington DC 20585

7. Period of Performance
10/01/2021
through
09/30/2022

8. Type of Agreement
☐ Grant
☒ Cooperative Agreement
☐ Other

9. Authority
See Page 2

10. Purchase Request or Funding Document No.
21FE003976

11. Remittance Address
MICROBEAM TECHNOLOGIES INCORPORATED
Attn: Roxanne Benson
P.O. BOX 5
Victoria MN 553860005

12. Total Amount
Govt. Share: $517,702.00
Cost Share : $131,705.00
Total : $649,407.00

13. Funds Obligated
This action: $517,702.00
Total : $517,702.00

14. Principal Investigator

15. Program Manager
Mark K. Render II
Phone: 304-285-1621

16. Administrator
U.S. DOE/NETL
NATIONAL ENERGY TECH LAB
3610 Collins Ferry Road
PO Box 880
Morgantown WV 26507-0880

17. Submit Payment Requests To
VIPERS
https://vipers.doe.gov
Any questions, please contact
by call/email 855-384-7377 or
ViperSupport@hq.doe.gov

18. Paying Office
VIPERS
https://vipers.doe.gov
Any questions, please contact
by call/email 855-384-7377 or
ViperSupport@hq.doe.gov

19. Submit Reports To
See Attachment 3

20. Accounting and Appropriation Data
00150-2021-31-232425-25500-1611271-0000000-0000000-0000000

21. Research Title and/or Description of Project
Development of Novel Sintered Carbon-Ore Building Materials

For the Recipient		For the United States of America	
22. Signature of Person Authorized to Sign		25. Signature of Grants/Agreements Officer Signature on File	
23. Name and Title	24. Date Signed	26. Name of Officer Janet S. Laukaitis	27. Date Signed