Renewable Energy Program

North Dakota Industrial Commission

Application

Project Title: Novel process for biocoal production with CO_2 mineralization to achieve negative carbon emissions

Applicant: Envergex LLC

Principal Investigator: Dr. Srivats Srinivasachar

Date of Application: 08/01/2022

Amount of Request: $174,830

Total Amount of Proposed Project: $349,825

Duration of Project: 18 months

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ABSTRACT

Objective: The overall objective is to demonstrate the technical and economic viability of a novel technology to upgrade high-moisture waste biomass materials into high quality, renewable biocoal (solid fuel) and capture (sequester) the associated CO_2 emissions into a solid mineralized product, resulting in multiple valuable products and negative overall CO_2 footprint. Biomass energy with carbon capture and storage (BECCS) is one of the few technological methods available currently to achieve negative CO_2 emissions. Traditionally, BECCS contemplates CO_2 storage in deep geologic reservoirs; but this approach to storage requires large volumes of CO_2 and the correct geology to be feasible given existing federal incentives. Our proposed BECCS approach, with our mineralization technology, obviates the need for geologic storage, making it attractive for smaller-scale applications that are common to agriculture/biomass processing industries. To achieve the project objective, we will perform a laboratory experimental study of both the biocoal and CO_2 mineralization approaches, followed by a performance and value characterization of our products for end-use markets: **1)** biocoal as a fossil fuel replacement for combustion/gasification systems (heat, power, chemicals), **2)** CO_2 mineralization product as a substitute cementitious material and soil amendment. We will complete the project with a preliminary techno-economic assessment to prepare for future scale-up and development.

Expected Results: We anticipate this project will be the foundation for further investment towards commercialization in North Dakota. Specifically, we expect to demonstrate, at the laboratory-scale, the performance/cost improvements that are made possible by our novel approach: **1)** our biocoal production process can enable cost-effective upgrading of high-moisture waste biomass materials, and **2)** our unique CO_2 mineralization approach can offer sufficient reaction rates to make it applicable to point-source CO_2 capture. The technology, once commercialized, will provide significant benefit to the North Dakota renewable energy and agriculture industries to reduce CO_2 emissions, minimize and monetize current wastes, and access new revenue streams (CO_2 tax credits/offsets).

Duration: 18 months, with a tentative start date of October 1, 2022

Total Project Cost: We are requesting \$174,830 from the Renewable Energy Program. Cost share of \$174,846 will be provided by the U.S. Department of Agriculture (USDA). Total project cost is \$349,676.

Participants: Envergex LLC is the project lead. The University of North Dakota will be a subcontractor to Envergex. Project supporters include American Crystal Sugar Company, Red River Biorefinery and ADM Enderlin Oilseeds Plant.

PROJECT DESCRIPTION

Objectives: The overall objective of this project is to demonstrate the technical and economic viability of a novel technology to upgrade high-moisture waste biomass materials into high quality, renewable biocoal (solid fuel) and capture (sequester) the associated CO_2 emissions into a solid mineralized product. Biomass energy with carbon capture and storage (BECCS) is one of the few technological methods available currently to achieve negative CO_2 emissions. Traditionally, BECCS contemplates CO_2 storage in deep geologic reservoirs; this approach to storage requires large volumes of CO_2 and the correct geology to be feasible given existing federal incentives. Our proposed BECCS approach, with our mineralization technology, obviates the need for geologic storage, making it attractive for smaller-scale applications that are common to the agriculture/biomass processing industries. The overall technology concept is founded in our team's previous technology development and builds on the literature. To demonstrate the technical and economic viability, we will address the following specific technical objectives:

- Demonstrate production of renewable biocoal, a high-quality solid fuel for combustion or gasification systems, using our novel process and multiple high-moisture waste biomass materials derived from ND.
- Demonstrate a unique CO_2 mineralization (CO2M) technology, with drastically increased reaction rates compared to state-of-the-art, to capture and permanently sequester the CO_2 generated during biomass conversion.
- Evaluate the performance/quality of our products for commercial applications: **1)** The biocoal will have use in combustion/gasification systems (heat, power, chemicals). **2)** Our CO2M process creates a carbonated solid residue with unique chemical/physical properties that are valuable for cement additives and soil amendment.
- Evaluate the overall technical and economic viability with a preliminary techno-economic analysis (TEA).

Methodology: Our proposed technology is summarized in Figure 1 and below (full details in Confidential Appendix).

Hydrothermal Carbonization (HTC) for Biocoal Production: HTC is the process by which a high moisture organic material (i.e., pressed sugar beet pulp, water treatment sludge) is treated under an oxygen-free environment at elevated temperature (~180-250°C) and pressure sufficient to ensure water remains in the liquid state (10-40 bar). Under these conditions, decomposition of various organic compounds present in the raw biomass (i.e., decarboxylation) occurs, resulting in a hydrophobic (easily, non-thermally dewatered) and carbon-rich biocoal with lower O/C and H/C ratios. HTC is an ideal process to upgrade high moisture biomass, as the dewatering does not require vaporizing the moisture, resulting in a large energy savings. HTC is well-established in the literature and there are commercial technologies available. However, key challenges with high capital and operating costs need to be addressed to enable wide deployment. We employ a ***unique enhancement to reduce energy requirements and processing time (smaller equipment) to overcome these challenges.***

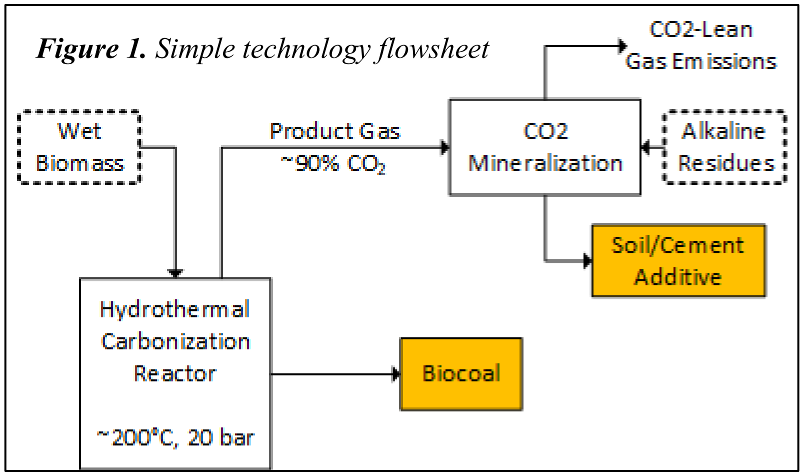


Figure 1. *Simple technology flowsheet*

The products resulting from HTC are a biocoal/liquid slurry and a CO_2-rich exhaust gas (~90% by volume, but post oxidation – thermal or catalytic – of reduced species can be included, if necessary). The slurry can be dewatered simply (due to hydrophobic nature of the biocoal), with the solid biocoal ready for additional drying (if needed) and final use. The liquid stream will contain primarily water with various dissolved organic compounds and inorganic compounds leached from the biomass. The liquid stream can be a feedstock for anaerobic digestion to break down the dissolved organics into renewable natural gas (biogas). We can also oxidize the dissolved organics via wet air oxidation to create heat for the HTC reactor operation, while breaking down the organics into additional CO_2 for the mineralization process step. Beneficial utilization (anaerobic digestion, oxidation) of the dissolved organics will also reduce/eliminate downstream treatment costs. The inorganics contained in the liquid stream may also include plant nutrients, such as phosphorous (P), which could be recovered via adsorption if desired. The soil/cement additive produced from the CO2M step of our process is an ideal such adsorbent, but there are also commercially available options.

CO_2 Mineralization (CO2M): To enable carbon-negative operation of the biocoal process, we integrate a unique and facile method of CO_2 capture/storage. Our approach leverages the carbonation capacity of alkaline residues, which include abundant waste (low or negative cost) materials such as coal/biomass ash, iron and steelmaking (ISM) slag, and natural alkaline silicate minerals (i.e., olivine). While CO2M via alkaline materials is a widely researched topic, there are key challenges associated with slow kinetics and mass transfer of CO_2 to the reactive particle surfaces. ***We have discovered a transformational approach that increases reaction rates by several orders of magnitude***, from geologic time scales in the natural environment (i.e. alkaline silicate weathering) down to minutes/seconds. This exciting advancement makes our approach applicable to point-source CO_2 capture where fast reactions are needed.

The products from CO2M are CO_2-lean exhaust gas and a solid carbonated alkaline residue with unique chemical/physical properties that make it a valuable substitute cementitious material (SCM) and soil amendment.

Scope of Work: As we will discuss in complete detail in the Confidential Appendix, the proposed technology is founded in our own previous technology development and builds on the literature. Yet, to demonstrate the technical and economic viability, there are still key questions that must be answered with experimentation, process modeling and economic analysis: **1)** How effective is our novel HTC process enhancement in reducing energy requirements and equipment size? **2)** What CO2M reaction rate increases are possible and is our approach a viable option for point-source CO_2 capture? **3)** What are the properties and potential value of our products for end-use markets? **4)** What are the optimum performance parameters and overall process configuration? **5)** Based on the project results, is the process economically viable? To answer these questions, we will perform the following set of tasks over the 18-month project.

We note: *The funding requested from NDIC-REP will be used for tasks related to the HTC process and biocoal production. The cost-share funding related to the CO2M process development has been awarded by the USDA SBIR program. The two process elements (biocoal production by HTC* *and* *CO2M) are complementary as shown in Figure 1; the associated tasks for their development are distinct and do not overlap as described below.*

Task 1 – Laboratory testing equipment construction and sample procurement: Both the HTC and CO2M processes can be tested using the same equipment setup, which is fully described in the Confidential Appendix. The core system is available from multiple equipment vendors, with additions to include a multi-flow gas delivery system and multi-gas analytical system. Because of the unique process enhancements we propose for both the HTC and CO2M processes, we will require the procurement of new equipment. Funding for the acquisition of the equipment will be obtained from the USDA project, while the modifications for use for the HTC testing will be funded by the NDIC-REP funding.

We will procure multiple samples of biomass (NDIC-REP funds) and alkaline residues (USDA funds) for testing. ACSC will provide pressed beet pulp for HTC testing and spent lime and coal ash for CO2M testing. We have also reached out to the city of Grand Forks municipal water treatment plant, who is willing to provide samples of waste activated sludge for HTC testing. We also have access to SO_2 scrubber waste (lime, calcium sulfate/sulfite particles) and coal fly ash from power plants in the region, including Otter Tail Power Company's Coyote Station (ND) and Big

Stone Plant (SD). We may also consider procuring natural alkaline silicate minerals, such as wollastonite or olivine for CO2M testing. We will determine the samples' chemical/physical properties (XRD, XRF, proximate/ultimate analysis).

Task 2 – Experimental evaluation of HTC process: (NDIC-REP funds) This task will focus on biocoal production from biomass and characterization of the gas, liquid and solid products. We will evaluate the impact of varying process conditions. Final products will be analyzed to determine composition, heat content and partitioning of inorganic/organic species. We aim to maximize biocoal yield and quality and minimize processing time and energy requirements.

Target test temperatures will range from ~180-250°C at corresponding saturation pressures to prevent vaporization of the biomass moisture (10-40 bar). ***Batch testing*** will employ autogenous pressurizing. Vaporization of water during the heat-up cycle will pressurize the vessel. We will evaluate pressure, temperature, CO_2 concentration, H_2O/dry biomass ratio, and parameters specific to our HTC enhancement approach (see Confidential Appendix). ***Continuous testing*** will use mass flow controllers (MFC), a water pump, and boiler to produce the steam/CO_2 composition of interest. A backpressure regulator installed post reactor will maintain gas pressure during testing. An optional condenser will be installed downstream of the test unit for capturing condensable gases. A continuous gas analyzer or sample bags (analysis via gas chromatography) will be used to evaluate composition of effluent gases.

This task will also include characterization of the gas and liquid effluents. Specifically, we will determine the composition of the CO_2-rich effluent, and based on the results will determine whether post-oxidation is required to fully oxidize reduced species. This analysis will inform the type of oxidation that would be appropriate for commercial application. The liquid effluent (after biocoal dewatering) will contain dissolved organics and inorganics. We will perform total organic carbon tests to identify oxygen demand, which will inform wet air oxidation needs (to decompose the organics) and the suitability of this stream for anaerobic digestion to produce biogas. For the inorganics, we will determine total dissolved solids, and will use ICP-OES or ICP-MS to determine inorganic species concentrations. This will inform the viability of plant nutrients recovery (P) and downstream treatment needs.

Task 3 – Experimental evaluation of CO2M process: (USDA funds) This task will focus on the carbonation of alkaline residues using CO_2-containing gas streams that would represent biomass conversion processes, including the HTC process proposed as shown in Figure 1 previously. The same test setup as Task 2 will be used. Alkaline residues will be subjected to varying CO_2 concentration and pressure, humidity, and temperature. Additional parameters specific to our unique CO2M approach are further discussed in the Confidential Appendix. The residue will then be evaluated for extent of mineralization. The testing objective is to maximize the extent of CO2M, minimize the duration of the reaction, and determine the appropriate gas-solid contacting regime for process scale-up.

Task 4 – Product characterization and market analysis: This task includes two subtasks, focusing separately on the products of HTC and CO2M. ***Subtask 4.1*** – *Biocoal product characterization and valuation:* (NDIC-REP funds) This subtask will primarily focus on the combustion properties of the biocoal. Proximate/ultimate analysis and heating value will be determined. We will also perform ash composition analysis (XRF) to evaluate impact of the biocoal inorganics on a combustion/gasification system (i.e., slagging/fouling). Based on the results, we will evaluate the potential market and value. ***Subtask 4.2*** – *CO2M product characterization and valuation:* (USDA funds) This subtask will evaluate the properties of the carbonated alkaline residue for use as SCM and soil amendment. Our novel CO2M technology imparts unique chemical/physical properties on the carbonated residue (see Confidential Appendix for additional details).

Task 5 – Process modeling and initial techno-economic analysis (TEA): (NDIC-REP funds) Based on the results from previous tasks, we will develop an Aspen Plus process model to determine the overall mass and energy balances for a commercial-scale facility. We will also perform a high-level TEA, equivalent to an AACE Class V cost estimate. This information will be the foundation for future scale-up.

Anticipated Results: This project will be the foundation for future scale-up and commercialization. We anticipate to demonstrate: **1)** our HTC process enhancements can offer significant cost savings and performance improvement, **2)** our unique CO2M approach can offer sufficient reaction rates to make it applicable to point-source CO_2 capture, and **3)** that our technology can offer significant benefits to the ND renewable energy and agriculture industries.

Facilities, Resources & Techniques to be Used: UND has world-class labs, fabrication facilities and analytical capabilities that will be available to this project. The only new equipment needed is the test setup described in Task 2, which will be purchased by Envergex and installed at UND using USDA funding. All of the analytical work will be done using existing equipment at UND. UND also has an active license to Aspen Plus which is required for Task 5.

Environmental & Economic Impacts While the Project is Underway: Environmental impacts are negligible. Economic impacts include employment and training opportunities for Envergex and UND research faculty, staff and students. The project will provide funding for at least one Ph.D. student.

Ultimate Technological and Economic Impacts: This project will facilitate development of a low-cost and carbon-negative biocoal production process with multiple valuable byproducts. The process will **1)** upgrade/monetize low value biomass in an environmentally friendly and carbon-negative approach to create a high-quality renewable biocoal, and **2)** monetize waste alkaline residues by upgrading via CO2M to generate valuable cement additives and soil amendment. The proposed process is applicable to small-scale biomass conversion and CO_2 emission sources, as it provides a low-cost and viable method for CO_2 sequestration where traditional capture, compression and geologic storage of CO_2 is not economically viable or geographically/geologically available. We will also enable new revenue sources for agriculture/biomass processors in the form of carbon sequestration tax credits and carbon offsets markets.

Why the Project is Needed: The proposed project addresses three key challenges facing the energy and agriculture sectors: 1) CO_2 emissions, 2) waste disposal/minimization, and 3) degrading soil health. We discuss these challenges (and associated opportunities) in the following sections to provide the context and motivation for our proposed solution.

1) CO_2 Emissions from Biomass Conversion: Carbon capture and geologic storage is viewed by many to be a critical tool to address climate change. However, limited availability of suitable geology, as well as the large-scale at which this has to be conducted to be economical, preclude its applicability to small, distributed CO_2 emission sources common to the biomass products manufacturing industry. Biomass processing releases significant CO_2 to the atmosphere. One example is the manufacturing of bio-ethanol. We have ***received a letter of support from Red River Biorefinery in Grand Forks, ND, which makes low-carbon ethanol.*** CO_2 emissions result from fermentation and combustion of fuels for steam production. While the use of biomass is in itself mostly carbon neutral, sequestering at least a portion of the CO_2 emissions can create negative overall emissions. In the case of ethanol facilities, many companies are actively working to reduce their carbon intensity to enable access to the low carbon fuel markets, such as in California. Another opportunity for monetizing CO_2 reductions is the nascent, yet growing, carbon offsets market (McKinsey & Company, 2021). The 45Q federal tax credit program for CO_2 capture and storage is yet another revenue opportunity. Capturing and sequestering the CO_2 generated from biomass conversion is one way to realize these opportunities.

Ex-situ CO2M is emerging as a viable method for CO_2 capture, wherein alkaline material can be reacted with CO_2 to yield carbonates as products (Ho et. al., 2019), eliminating need for deep geologic disposal. Weathering reactions via carbonation of common alkaline silicate minerals (i.e., olivine), while thermodynamically favorable, have significant kinetic limitations making them traditionally impractical for point-source CO_2 capture. ***To make ex-situ CO_2 capture feasible via CO2M, significant increases in reaction rates are needed, low-to-zero cost raw materials should be used, and we must create products that have market value*** (i.e., they must not be landfilled at a cost).

2) _Waste Disposal/Minimization:_ Both the energy and agriculture sectors produce large quantities of wastes that present environmental challenges but also an economic opportunity. For example, we have received a ***letter of support from American Crystal Sugar Company (ACSC),*** the world's largest processor of sugar beets. ACSC, in its ND and MN processing facilities, creates waste materials that are currently landfilled, including: 1) partially carbonated lime, at 400,000 tons/year, and 2) ash from their boilers, at 40,000 tons/year. Both the carbonated lime and ash contain alkaline materials that would be useful for CO2M reactions. ACSC also produces about 150,000-200,000 tons/year of pressed beet pulp, a high moisture (70-80wt%) byproduct that essentially has no market today, but is an excellent option for HTC treatment. ACSC is extremely interested in a process that could create value from these byproducts.

Another large source of waste biomass is municipal water treatment waste activated sludge (WAS), with about 14 million tons/year generated in the U.S., of which about 50% is beneficially used. The City of Grand Forks, ND currently landfills its WAS, and will provide samples for testing. While the volume of high-moisture waste biomass is large in ND and in the U.S., upgrading is significantly hampered by the very ***large energy requirements to vaporize the moisture. HTC is one method that can address this challenge, but capital costs remain high due to the high-pressure equipment needed. Advances in HTC treatments are needed to reduce equipment size and cost.***

We have also ***received strong interest from ADM (Enderlin Oilseeds Plant in Fargo, ND, letter attached)*** who landfill the ash from their biomass combustion boilers, which has a very large fraction of alkali and alkaline earth elements (K, Ca, Mg) with capacity for CO2M. Other sources of Ca/Mg-rich waste materials include coal ash. A significant fraction of the US coal ash produced today cannot be used for cement due to high levels of unburnt carbon or lime-derived solids (scrubber ash). Such materials (~30 million tpy in 2019) would still be viable for CO2M. Waste materials with capacity for CO2M are abundant, but there are significant mass transfer and kinetic limitations that create reaction rates that are traditionally too slow for point-source CO_2 capture. ***Novel methods/materials are needed to increase reaction rates.*** Other sources of alkaline silicates are rock minerals such as wollastonite and olivine.

3) Degrading Agricultural Soil Quality: A key goal of the USDA funding (our proposed cost share) is development of materials to increase soil carbon (SC) and soil health. Degrading soil quality is an issue globally. About 80% of the total global carbon is tied up in soils (Lal, 2008). Due to degradation, soils today in many parts of the world have significantly reduced SC, resulting in more atmospheric CO_2. Increasing SC is a viable approach to addressing climate goals.

Basile-Doelsch et al. (2020) synthesize the mechanisms underlying carbon storage in soil. Organic matter reaches the soil through the roots of plants or in the form of litter decomposition via unharvested aboveground plant parts. The optimal substrate property which promotes efficient incorporation into the mineral-associated organic matter (MAOM) pool is either via in vivo microbial turnover or via direct sorption (Figure 2). From Figure 2, in microbially dense areas (yellow), low molecular weight (LMW) C substrates (i.e., sugars) that are biosynthesized with high carbon-use efficiency (CUE) form microbial-derived MAOM (pentagons), whereas LMW C substrates with low CUE (i.e., oxalic acid) are largely lost as CO_2 via respiration. As a result of microbiome respiration, concentrations of CO_2 in the root zone can range from several thousand ppm to as high 5%, which is 1-2 orders of magnitude higher than atmospheric concentrations. ***If this respired CO_2 could be captured and retained in the soil, then it would increase the SC.***

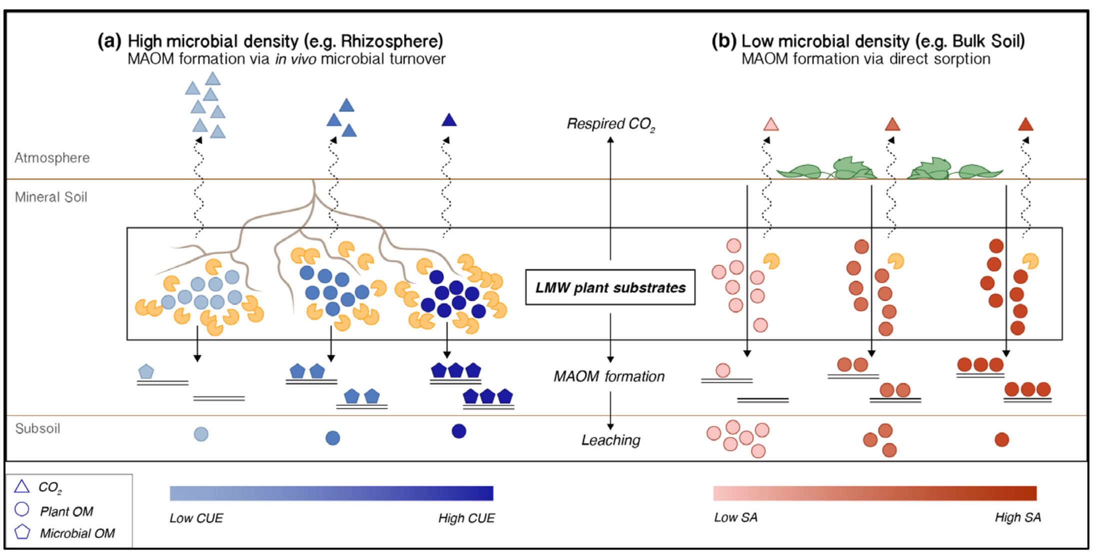


***Figure 2**. Mechanisms of soil organic matter formation (Sokol et al. 2019)*

Continuing from Figure 2, in soil with low microbial density, organic compounds with low sorption affinity to soil components are largely lost via leaching. However, ***if soil particulates/amendments present a strong affinity to the LMW plant substrates, these would be retained within the soil strata to form MAOM. It would be ideal to deploy SA that can capture the respired CO_2 and act as strong adsorbent for a range of LMW C substrates.***

<u>*Summary of the Project Need*</u>: Our proposed technology addresses: **1)** The energy and agriculture sectors produce

huge quantities of waste that represent economic and environmental liabilities. New processes are needed to create value from these materials. **2)** Waste biomass often contains high moisture, making thermal upgrading processes costly. Advances are needed to enable monetization of these low-value materials. **3)** Alkaline waste materials, such as biomass ash, coal ash, and various alkaline silicate minerals, have large carbonation capacity. However, mass transfer and kinetic limitations make these materials unfeasible for point-source CO_2 capture/sequestration. Advances are required to increase reaction rates. **4)** Biomass conversion to products, including bioenergy, releases a substantial portion of the C back into the atmosphere as CO_2. This CO_2 should be captured/sequestered to enable carbon negative processes. **5)** Soil Carbon (SC) is reducing worldwide. New technologies/soil amendments are needed to reverse this trend. CO2M should result in soil amendment products that have affinity to organic plant decomposition products, to sequester additional carbon in the soil and increase SC content.

STANDARDS OF SUCCESS

The standards of success are as follows: **1)** Demonstrate an ability to reduce equipment size (processing time) for HTC treatment by at least 20% using our novel HTC enhancement approach. **2)** Demonstrate CO2M reactions, under conditions consistent with gas-phase HTC effluent, that achieve 50% extent of mineralization in less than 10 minutes of gas/solid contact time. **3)** Create products and byproducts that are cost- and performance-competitive with existing alternatives (coal replacement, substitute cementitious materials, soil amendment). **4)** Determine the overall process performance and configuration and initial mass and energy balances to serve as the foundation for future scale-up.

BACKGROUND/QUALIFICATIONS

The proposed team has a long history of collaboration on large, interdisciplinary and multi-organizational R&D projects. Envergex and the Institute for Energy Studies (IES) at UND have partnered on numerous projects in the last 15 years, many of which include low-carbon technologies relevant to the proposed work. Of specific relevance, is the team's decade-long collaboration to develop the CACHYS™ technology platform for CO_2 capture. The proposed CO2M technology is an extension of the CACHYS™ platform, relying on multiple key principles, as disclosed in U.S. Patent 8,840,706. A brief background of each of the proposed key personnel is provided below (see Appendix 4 for resumes).

Dr. Srivats Srinivasachar is the President of Envergex LLC and will be the principal investigator (PI) on this project. Dr. Srinivasachar holds 15 patents and has over 50 publications, several of these related to pollution control technology.

He is a world-renowned expert on the subjects of coal combustion, gasification, pulverized coal and fluidized bed boilers, CO_2 capture, and mercury control. He is the inventor and developer of the CACHYS™ technology for CO_2 capture using hybrid sorption and Mer-Cure™ technology for mercury control. **Mr. Junior Nasah** is the Major Projects Manager at UND-IES and brings expertise in the areas of gas-solid reactions, analytical equipment and CO_2 capture. Mr. Nasah will lead UND's scope of work and will be supported by **Dr. Dan Laudal**, the Director of UND-IES. Dr. Laudal brings expertise in CO_2 capture and storage and thermal conversion processes. He was previously the Project Manager for Minnkota Power Cooperative's Project Tundra, a world-scale CCS project currently in development in ND. The team is also augmented by the expertise of **Dr. Brian Darby**, Associate Professor of Biology at UND, with expertise in soil ecology and ecological genomics. His current work involves understanding the role of microbes and micro-invertebrates in soil health. Dr. Darby will assist the team in understanding the properties of the CO2M products for soil amendment.

MANAGEMENT

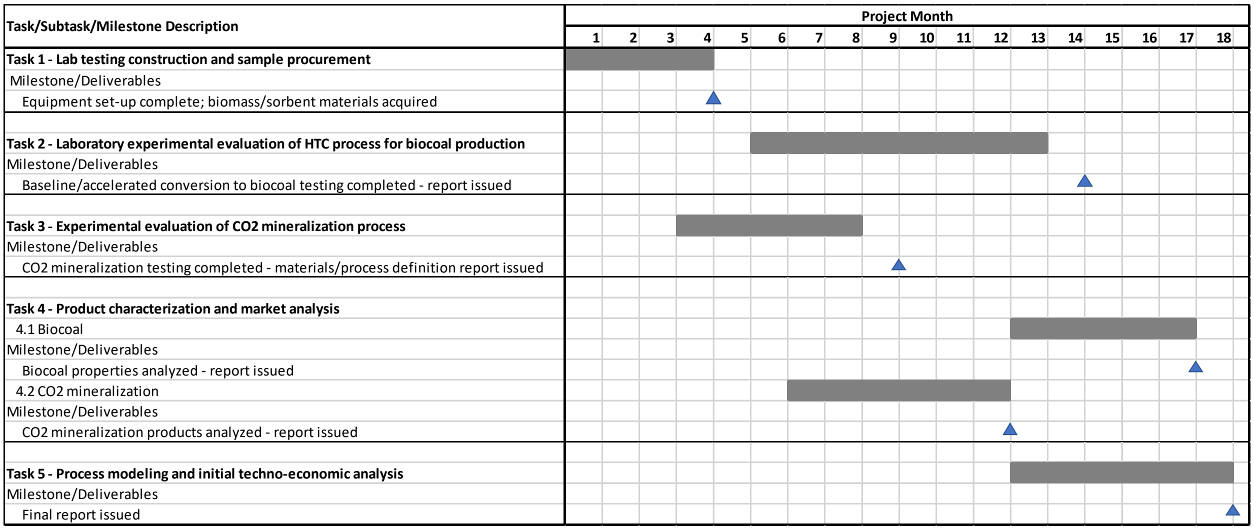
Dr. Srivats Srinivasachar will serve as the project PI and the contact person for Envergex LLC and will be responsible for coordination of all project activities. He will be involved in all the tasks providing technical direction and will lead Tasks 3 and 5 related to CO2M. Mr. Junior Nasah will lead UND's scope of work and will lead Tasks 1, 2 and 4 related to experimental activities and biocoal production. He will be supported by Dr. Dan Laudal, ensuring all personnel, equipment, and other resources from UND are made available to conduct the project efficiently and to meet the project goals. Once awarded, the following items will be addressed throughout the duration of the project: **1)** Monitor project scope, schedule, cost, and risk; **2)** Update project plans periodically to reflect changes in scope, schedule, and cost/risk; **3)** Provide quarterly technical reports, initiate and conduct stakeholder meetings, and present at conferences as required. The key personnel from Envergex and UND have a long history of successful collaboration on projects of similar scope. This experience will be leveraged to execute this project efficiently.

TIMETABLE

The project has a duration of 18 months, tentatively starting October 1, 2022 with the timetable as shown below.

BUDGET

The amount of **$174,830** (50% of project cost) is requested from NDIC-REP. Matching cost share will be provided from the USDA Small Business Innovation Research Program (USDA SBIR) awarded to Envergex. The overall project budget breakdown is provided in the following table. See Appendix 1 for budget notes.



Budget Category	Envergex (USDA)	Envergex (ND-REP)	Envergex (Total)	UND (USDA)	UND (ND-REP)	UND (Total)
Personnel (w/ Fringe)	68,546	64,567	133,113	35,694	58,527	94,221
Operating	3,200	3,200	6,400	5,398	3,433	8,830
Equipment	12,998	-	12,998	-	-	-
Indirect Costs	32,312	19,699	52,011	16,848	25,404	42,251
TOTAL	**117,056**	**87,466**	**204,522**	**57,940**	**87,364**	**145,303**

TAX LIABILITY

Envergex LLC does not have an outstanding tax liability owed to the State of ND or any of its political subdivisions.

CONFIDENTIAL INFORMATION

Confidential information is provided in Appendix 2.

PATENTS AND RIGHTS TO TECHNICAL DATA

Existing Intellectual Property (IP) developed under previous projects is the basis for certain features of the proposed technology. Any new IP developed under the proposed project will be protected in accordance with relevant clauses.

STATE PROGRAMS AND INCENTIVES

Envergex LLC has not participated in any state programs or incentives in the last five years.

APPENDIX 1 – BUDGET NOTES

Budget Justification – Envergex LLC

Budget Period – 18 months

A. Project Leader, Dr. Srivats Srinivasachar will devote 210 hours of effort to the project for the Budget Period.

B. The salary labor rate for Dr. Srinivasachar is $ 110.10 per hour. Fringe benefits are 54.26% of salary labor rate.

C. Engineers, working for Envergex, will staff the project in North Dakota. A total of 590 hours will be devoted by the engineers.

D. The average salary rate for the Engineer/Scientist is at $31.72 per hour. Fringe benefits for are at 54.26% of salary labor rate.

E. Travel is estimated for 2 trips to University of North Dakota (Grand Forks, ND) from Sturbridge, MA at a rate $1600/trip for project execution related activities

F. Average Labor overhead is at 11.09% of direct costs (salary labor + fringe benefits only)

G. Average General & Administrative costs are 17.48% of direct costs (A+B) + labor overhead + direct travel

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BUDGET JUSTIFICATION

Salaries and Fringe

Salary estimates are based on the scope of work. The labor rate used for specific personnel is based on their current salary rate. The annual personnel cost breakdown is listed in the table below.

Personnel	Role	Rate ($/hr)	Hours	Salary ($)	Fringe ($)	Total ($)
Junior Nasah	Project Manager	44.65	180	8,037	3,054	11,091
Daniel Laudal	Senior Management	91.59	55	5,037	1,162	6,700
Brian Darby	Senior Researcher/Faculty	53.07	40	2,123	870	2,993
Research Engineer	Research Assistant	36.71	800	29,368	11,747	41,115
Graduate Student	PhD Assistant	28.85	1040	30,000	150	30,150
Resource Manager	Administrative	22.63	80	1,810	362	2,172
TOTALS				**76,376**	**17,846**	**94,222**

Fringe has been estimated as 38% for the PM, 33% for senior management, 41% for faculty, 40% for research engineer, 0.5% for grad student, and 20% for resource manager. Fringe benefits are estimated for proposal purposes only, on award implementation, only the true cost of each individual's fringe benefit plan will be charged to the project.

Materials & Supplies

These include items required for installation and operation of test equipment such as gas bottles for completing tests and tubing and fittings for connecting test equipment to analytical equipment. An itemized breakdown is presented in the Table below:

IES Supplies	Quantity	Unit Cost	Total	Justification
O2 gas bottle	6	$34	$204	Online estimate
N2 Gas bottle	6	$33	$198	"
CO2 gas bottle	6	$33	$198	"
Gas bottle rental, months	6	$15	$90	"
Swagelok stainless tubing	10	$10	$100	"
Swagelok stainless fittings	20	$22	$440	"
Flanges	4	$40	$160	"
NPT fittings	10	$48	$480	"
Plastic Tubing	500	$0.25	$125	"
Plastic fittings	20	$4	$70	"
NPK test kit	60	$33	$1,965.00	"
Thermocouples	16	$30	$480	"
Total			**$4,510.00**	

Professional Fees and Services

These include analytical usage costs for available equipment at the College of Engineering's Advanced Material Characterization Laboratory. The table below summarizes the various equipment, rates and estimated number of samples.

	Quantity	**Cost**	**Total**	**Justification**
Inductively-Coupled Plasma	30	$48	$1,440	Chemical composition of samples
X-Ray Fluorescence	30	$32	$960	Chemical composition of samples
Total Organic Carbon	120	$5	$600	Morphology of solid samples
Sample preparation	120	$11	$1,320	
Total			**$4,320**	

Indirect Cost

The indirect cost rate included in this proposal is the federally approved rate for the University of North Dakota (41%). Indirect costs are calculated based on the Modified Total Direct Cost (MTDC), defined as the Total Direct costs of the project less individual items of equipment $5000 or greater, subcontracts in excess of the first $25,000 for each award, and graduate tuition waivers.

Summary

The overall budget summary is provided below.

Salary	76,376
Fringe	17,846
Total Labor	94,222
Supplies	4,510
Professional Fees and Services	4,320
Total Direct Cost	103,052
Indirect Cost	42,251
Total Project Cost	**145,303**

APPENDIX 4 – RESUMES OF KEY PERSONNEL

SRIVATS SRINIVASACHAR, Ph.D.
Envergex LLC

Education and Training

2003-2004	Boston University, School of Management Master of Business Administration	Boston, MA
1981-1986	Massachusetts Institute of Technology Sc.D. degree in Chemical Engineering	Cambridge, MA
1976-1981	Indian Institute of Technology Bachelor of Technology, Chemical Engineering	Chennai, India

Research and Professional experience

2006 – Present: President, Envergex LLC, Sturbridge, MA:

- Mitigation of aerosol emissions from solvent-based CO_2 capture systems (Phase I STTR) - 06/16
- Developing novel materials for capturing CO_2-US DOE (Phase I/II STTR) grant (Aug. 2014)
- Developed a novel method for capturing CO_2 from flue gas (CACHYS^{TM}) - awarded a US Department of Energy grant (June 2010) DOE Phase I STTR; Commercializing CACHYS^{TM} technology - teaming with University of North Dakota on a $ 3.6 million USDOE program
- Manufactured and supplied commercial quantities and successfully demonstrated ESORB-HG® sorbent to several power utility and industrial customers at full-scale
- Developed a business plan for coal and biomass to liquids venture
- Teamed with UND and utility partner to perform engineering and costing to implement an innovative technology: activated carbon manufacturing integrated to a power plant

1999 – 2006: ALSTOM Power, Inc. (1993 – 1999: ABB Combustion Engineering, Inc. Windsor, CT):

- Technical Manager, Environmental Control Technology (March 2003-2006). Developed a new product for controlling mercury emissions from coal-fired power plants.
- Principal Consulting Engineer, New Product Business Development (Oct. 1999 to March 2003)
- Multi-business product development for control of SO2 emissions from power plants
- Environmental Group Leader, (Oct. 1997 – Sept. 1999)
- Senior Consulting Engineer, (1994 – 1997) - Project Leader on environmental and heat recovery projects and developed high-performance fuel nozzles for boilers to reduce nitric oxide emissions

1986-1993: Physical Sciences Inc. Andover, MA:

- Manager, Environmental Remediation and Resource Utilization (1992-93)
  - Principal Research Scientist (1986-92) - Principal Investigator on a multi-million-dollar university-industry project

Patents (Selected) – 16 Patents

- U.S. Patent 9,121,606, "Method of manufacturing carbon-rich product and co-products"
- U.S. Patent 8,840,706, "Capture of carbon dioxide by hybrid sorption"
- U.S. Patent 7,981,835, "System and method for coproduction of activated carbon and steam/electricity"
- U.S. Patent 6,749,681, "Method of Producing Cement Clinker and Electricity"

Other Significant Products

- U.S. Patent 8,277,542, "Method of capturing mercury from flue gas"
- U.S. Patent 8,069,797, "Control of Mercury Emissions from Solid Fuel Combustion"
- U.S. Patent 6,089,171, "Minimum Recirculation Flame Control Pulverized Solid Fuel Nozzle Tip"
- U.S. Patent 6,089,023, "Steam Generator System Operation"
- Srinivasachar, Srivats, Nelson, Teagan, Mann, Michael, Dyrstad-Cincotta, Nicholas, and Laudal, Daniel. Supercritical Treatment Technology for Water Purification - Phase I STTR Final Technical Report. United States: N. p., 2019. Web

Publications

- Van der Waat, J., Laudal, D., Feilen, H., Krishnamoorthy, G., Mann, M., Shallbetter, R., Nelson, T. and **Srinivasachar, S.**(2018). Development of a spouted bed reactor for chemical looping combustion. *Journal of Energy Resources Technology*, *140* (11), 112002
- Nelson, T., van der Watt, J.G., Laudal, D., Feilen, H., Mann, H., **Srinivasachar, S.** "Reactive jet and cyclonic attrition analysis of ilmenite in chemical looping combustion systems." International Journal of Greenhouse Gas Control. Volume 91, December 2019, 102837.
- Benson, S.A. and **Srinivasachar, S**. "Evaluation of CO_2 Capture from Existing Coal-fired Power Plants by Hybrid Sorption Using Solid Sorbents," 2014 NETL CO_2 Capture Technology Meeting July 29 – August 1, 2014, Pittsburgh, PA http://www.netl.doe.gov/events/conference-proceedings/2014/2014-netl-co2-capture-technology-meeting
- Benson, S.A., Crocker, C.R., Hanson, S.K., McIntyre, K.A., Just, B.J., Raymond, L.J., Pflughoeft-Hassett, D.F, **Srinivasachar, S.**, Barry, L.T. and Doeling, C.M., "JV Task 115-Activated Carbon Production from North Dakota Lignite – Phase IIA," Final Report, U.S. Department of Energy Cooperative Agreement No. DE-FC26-98FT40321, June 2008
- Tomomewo, O. S., Dyrstad-Cincotta, N., Mann, D., Ellafi, A., Alamooti, M., **Srinivasachar, S.**, & Nelson, T. (2020, September). Proposed Potential Mitigation of Wastewater Disposal through Treated Produced Water in Bakken Formation. In 54th US Rock Mechanics/Geomechanics Symposium. American Rock Mechanics Association.

Synergistic Activities

Expertise in energy and environmental engineering, power plant systems, and cross-industry product development. Led product/process development groups - ALSTOM Power Inc. (a global power generation company). Secured multiple patents and published over 60 technical papers.

JUNIOR N.D. NASAH
Institute for Energy Studies, University of North Dakota
Phone: (701) 777-4307; nasah.domkam@und.edu

Qualifications

2022	Ph.D. (Planned)	Chemical Engineering	University of North Dakota, USA.
2012	M.Sc.	Chemical Engineering	University of North Dakota, USA.
2007	B.Sc.	Chemistry	University of Buea, Cameroon.

Professional Experience

2019-Present: Major Projects Manager, IES, UND
Mr. Nasah's responsibilities include managing research projects specifically in the field of carbon dioxide mitigation including capture, storage and more efficient energy generation methods. His other key duties consist of identifying, developing and writing major funding proposals. Currently Mr. Nasah is a lead researcher investigating multiple sorbent technologies for capturing CO_2 from multiple sources and capturing fouling precursors that can be produced from high-alkali coals or biomass combustion.

2012-2018: Research Engineer, IES, UND.
Mr. Nasah's research focus included sampling methods to quantify ash size distribution during combustion processes, methods to separate char from oxygen carriers, coal gasification and advanced combustion methods. Mr. Nasah developed expertise in operating continuous emission monitoring systems, analytical methods such as total carbon and organic carbon measurements.

2013 – 2017: Laboratory Instructor, Department of Petroleum Engineering, UND

2010-2012: Graduate Research Assistant, Department of Chemical Engineering, UND.

Current Relevant Projects

Mitigation of Aerosol Impacts on Ash Deposition and Emissions from Coal Combustion, DE-FE0031756 (sub-awardee)	$5 million	2019
Cross-linked Micro-spherical Adsorbents from Lignite-derived Humic Acid for CO2 Capture, DE-FE0026825/S001343-USDOE (prime awardee)	$443,000	2020
Flexible Low Temperature CO2 Capture System, E-CACHYS™, DE-AR0001314 (sub-awardee)	$2 million	2020

Publications

Nasah, J., Jensen, B., Dyrstad-Cincotta, N., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. "Method for separation of coal conversion products from oxygen carriers." International Journal of Greenhouse Gas Control. Volume 88, July 2019, Pages 361-370.

Pei, P., **Nasah, J**., Solc, J., Korom, S. Laudal, D., Barse, K. "Investigation of the feasibility of underground coal gasification in North Dakota, United States." Energy Conversion and Management. Volume 113, 2016, Pages 95-103.

Pei, P., Laudal, D., **Nasah, J**., Johnson, S., Ling, K. "Utilization of Aquifer Storage in Flare Gas Reduction." Journal of Natural Gas Science and Engineering. Volume 27, Part 2, 2015, 1100-1108.

Pei, P., Barse, K., Gil, A. J., **Nasah, J**. "Waste Heat Recovery in CO_2 Compression" International Journal of Greenhouse Gas Control. Volume 30, 2014, Pages 86-96.

Pei, P., Korom, S. F., Ling, K., **Nasah, J**. "Cost Comparison of Syngas Production from Natural Gas Conversion and Underground Coal Gasification" Mitigation and Adaptation Strategies for Global Change. 2014, 1-15.

Technical Reports

Nasah, J., Jensen, B., Dyrstad-Cincotta, N., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. "Method for separation of coal conversion products from oxygen carriers." International Journal of Greenhouse Gas Control. Volume 88, July 2019, Pages 361-370.

Srinivasachar, S., **Nasah, J.**, Laudal, D. "Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO_2 Capture Systems." Final Technical Report, US Department of Energy Agreement No. DE-SC0015737, N. p. 2017.

Srinivasachar, S., Laudal, D., **Nasah, J.** "Method for Separation of Coal Conversion Products from Sorbents/Oxygen Carriers." Final Report, US Department of Energy Agreement No. DE-SC0013832. April 2016.

Synergistic Activities

Mr. Nasah's principal areas of expertise are carbon dioxide emission mitigation from fossil fuel generation sources. He has expertise on emissions characterization including fly ash from coal-fired power plants. Other areas of expertise include capture sorbent manufacturing such as activated-carbon based CO_2 sorbents and iron-based oxygen carriers.

Dr. Daniel A. Laudal, Director, Institute for Energy Studies, University of North Dakota (UND)

Education and Training

University of North Dakota	Chemical Engineering	B.S. 2006
University of North Dakota	Chemical Engineering	Ph.D. 2017
University of North Dakota	Master of Public Admin.	Expected 2022

Research and Professional Experience

2021-Present Director, UND Institute for Energy Studies (IES)
Leading the research and academic programs in Energy at the College of Engineering & Mines. Help realize the IES goal of developing UND into a premier "Energy University" that "inspires the creation of new knowledge to enable the development of revolutionary energy technologies, train the next generation of energy experts, and establish advanced industries required to make affordable emissions free energy technologies a reality". Responsibilities include identifying key technical and economic barriers to the development of secure, affordable, and reliable energy production technologies; identifying proposal opportunities and develop new relationships with potential partners; and drawing from resources across campus building teams to deliver the research, education, and outreach required to meet the needs of public and private partners.

2019-2021 Environmental Manager / Project Tundra Project Manager, Minnkota Power Coop
Led the environmental regulatory compliance and environmental planning efforts for a generation & transmission cooperative serving eastern ND and northwestern MN. As Project Tundra Project Manager, led Minnkota's development of a world-scale carbon capture and storage project for the Milton R. Young Station, a lignite coal fired power plant in ND. Responsibilities included leading development of the design, permitting and financing of the carbon capture plant and geologic storage facility.

2016-2018 Manager: Major Projects, UND Institute for Energy Studies.
Primary roles included developing and writing funding proposals, managing research projects, coordinating IES research staff and students, and process design/development of innovative solutions to challenges in the energy industry. Principal Investigator or Project Manager or several DOE, State and industry funded projects. Research focused on the following major areas: carbon management for the power industry, production of co-products from coal and associated materials, value-added opportunities/technology development for North Dakota's energy industries.

2012-2015 Research Engineer, UND Institute for Energy Studies.
Lead researcher or principal investigator on several federal, state and industry funded projects. Work involved early-stage R&D of novel processes and technologies, primarily focusing on laboratory- and bench-scale demonstrations. Areas of focus included chemical looping combustion and post combustion carbon dioxide capture.

2008-2012 Research Engineer, UND Energy & Environmental Research Center.
Research involved design and operation of various lab and pilot-scale gasification, combustion and advanced power systems. Gained invaluable experience with high pressure and high temperature systems and fluidized beds.

2006-2008 Field Engineer, Schlumberger Oilfield Services.
Design, execution and evaluation of well cementing operations in the Williston Basin. Led a team of 3-5 operators in performing various types of cement and work-over operations. Lead cement lab operator – designed, tested and validated cement compositions for each job.

Selected Publications

Benson, S., Srinivasachar, S, **Laudal, D**., Browers, B. "Evaluation of Carbon Dioxide Capture from Existing Coal Fired Plants by Hybrid Sorption using Solid Sorbents." Final Technical Report. US Department of Energy Award Number: DE-FE0007603. May 2015

Laudal, D., Benson, S., Addleman, S., Palo, D. "Leaching behavior of rare earth elements in Fort Union lignite coals of North America." International Journal of Coal Geology 191 (2018) 112-124.

Laudal, D., Benson, S., Addleman, S., Palo, D. "Rare earth elements in North Dakota lignite coal and lignite-related materials." ASME Journal of Energy Resources and Technology 140 (2018).

Mann, M; **Laudal, D.**; Benson, S. "Maintaining Coal's Prominence in a Carbon Constrained World." Conference Proceedings: 2017 International Conference on Coal Science and Technology and 2017 Australia-China Symposium on Energy. September 25-29, 2017. Beijing, China.

Nasah, J., Jensen, B., Dyrstad-Cincotta, N., Gerber, J., **Laudal, D**., Mann, M., Srinivasachar, S. "Method for separation of coal conversion products from oxygen carriers." International Journal of Greenhouse Gas Control. Volume 88, September 2019, pages 361-370.

Van der Watt, J.G., **Laudal, D**., Krishnamoorthy, G., Feilen, H., Mann, M., Shallbetter, R., Nelson, T., Srinivasachar, S. "Development of a spouted bed reactor for chemical looping combustion." Journal of Energy Resources and Technology. 140(11), 112002 (8 pages), November 2018.

Nelson, T., van der Watt, J.G., **Laudal, D**., Feilen, H., Mann, H., Srinivasachar, S. "Reactive jet and cyclonic attrition analysis of ilmenite in chemical looping combustion systems." International Journal of Greenhouse Gas Control. Volume 91, December 2019, 102837.

Pei, P., Nasah, J., Solc, J., Korom, S. **Laudal, D**., Barse, K. "Investigation of the feasibility of underground coal gasification in North Dakota, United States." Energy Conversion and Management. Volume 113, 1 April 2016, pages 95-103.

Pei, P., **Laudal, D**., Nasah, J., Johnson, S., Ling, K. "Utilization of Aquifer Storage in Flare Gas Reduction." Journal of Natural Gas Science and Engineering. Volume 27, Part 2, November 2015, 1100-1108.

Emerson, S., Zhu, T., Davis, T. Peles, A., She, Y., Willigan, R., Vanderspurt, T., Swanson, M., **Laudal**, **D**. "Liquid Phase Reforming of Woody Biomass to Hydrogen". International Journal of Hydrogen Energy, August 2013.

Synergistic Activities

Dr. Laudal's principal areas of technical expertise are carbon capture, utilization and storage (CCUS), gas/solid contacting and reaction systems, solid sorbent technology development, and mineral processing. Of specific relevance to the proposed project is his experience in developing the Envergex/UND CACHYS™ technology platform for solid sorbent-based CO_2 capture. Dr. Laudal has a long history of managing and executing large multi-disciplinary and multi-organization R&D projects. He has been involved in a wide range of technology development, from early stages all the way through commercial projects.

BRIAN J. DARBY
University of North Dakota, Department of Biology
Phone: (701) 777-4678; Fax: (701) 777-2623; brian.darby@und.edu

Education and Training

Ph.D. 2008	**University of Vermont, Burlington, VT**, Plant and Soil Science
M.S. 2004	**University of Toledo, Toledo, OH**, Ecology
B.S. 2002	**Northwestern College, Orange City, IA**, Biology

Employment History

8/17-present **Associate Professor,** Biology Department, University of North Dakota (Grand Forks, ND)
8/11-8/17 **Assistant Professor,** Biology Department, University of North Dakota (Grand Forks, ND)
6/08-6/11 **Post-doctoral Researcher,** Kansas State University (Manhattan, KS)

Position Description

Associate Professor of Biology : Supervise and maintain research laboratory in the field of Soil Ecology and Ecological Genomics, advise graduate and undergraduate researchers, teach graduate and undergraduate biology courses (General Ecology, Soil Ecology, Genomics, Ecological Genomics, Biometry, Scientific Writing), serve on Departmental, College, and University committees as needed, and contribute to professional science through peer-review and ad-hoc panel review of manuscripts and proposals.

Related Peer-Reviewed Publications

1. **Darby, B.,** R. Bryant, A. Keller, M. Jochim, J. Moe, Z. Schreiner, C. Pratt, N. H. Euliss, Jr., M. Park, R. Simmons, and C. Otto. 2020. Molecular sequencing and morphological identification reveal similar patterns in native bee communities across public and private grasslands of eastern North Dakota. **PLoS ONE** 15:e0227918.
2. **Darby B.J.,** Erickson S.F. Hervey S.D. Ellis-Felege S.E. 2016. Digital fragment analysis of short tandem repeats. ***Ecology and Evolution*****.** 6:4502-4512**.**
3. **Darby, B.J.,** Herman, M.A., 2014. Effect of prey richness on a consumer's intrinsic growth rate. ***Oecologia***. 175:243-250.
4. **Darby, B.J.,** Todd, T., Herman, M.A., 2013. High-throughput amplicon sequencing of rRNA genes requires a copy number correction to accurately reflect the effect of management practices on soil nematode community structure. ***Molecular Ecology***. 22: 5456-71.
5. **Darby, B.J.,** Neher, D.A. 2012. Stable isotope composition of microfauna supports the occurrence of biologically fixed nitrogen from cyanobacteria in desert food webs. ***Journal of Arid Environments***. 85:76-78.

6. **Darby, B.J.,** Neher, D.A., Housman, D.C, and Belnap, J. 2011. Few apparent short-term effects of elevated soil temperature and increased frequency of summer precipitation on the abundance and taxonomic diversity of desert soil micro- and meso-fauna. ***Soil Biology and Biochemistry***. 43:1474-1481.
7. **Darby, B.J.,** Jones, K.L., Wheeler, D., Herman, M.A., 2011. Normalization and centering of array-based heterologous genome hybridization between species of unknown or unequal divergence. ***BMC Bioinformatics***. 12:183.
8. **Darby, B.J.**, Neher, D.A., and Belnap, J. 2010. Impact of biological soil crusts and desert plants on soil microfaunal community composition. ***Plant and Soil*** 328:421-431.
9. **Darby, B.J.**, Neher, D.A., and Belnap, J. 2007. Soil nematode communities are ecologically more mature beneath late-than early-successional stage biological soil crusts. ***Applied Soil Ecology*** 35:203-212.
10. **Darby, B.J.**, Housman, D.C., Zaki, A.M., Shamout, Y., Adl, S., Belnap, J., and Neher, D.A. 2006. Effects of altered temperature and precipitation on desert protozoa associated with biological soil crusts. ***Journal of Eukaryotic Microbiology*** 53(6): 507-514.

Broadly Related Peer-Reviewed Publications

11. Hervey, S., Barnas, A., Stechmann, T., Rockwell, R., Ellis-Felege, S., **Darby, B.** Kin grouping is insufficient to explain the inclusive fitness gains of conspecific brood parasitism in the common eider. **Molecular Ecology.** 285(21): 4825-4838.
12. Morrison, S., **Darby, B.** (2019). Testing—and Mostly Rejecting—the Folk Wisdom of the Effective Appellate Brief. **St. Louis University Law Journal**. 63(2):
13. Barnas, A., **Darby, B.,** Vandeberg, G., Rockwell, R. F., Ellis-Felege, S. (2019). Assessment of lesser snow goose (*Anser caerulescens caerulescens*) habitat degradation in La Perouse Bay using unmanned aircraft. PLOS ONE. 14(8):e0217049
14. McKenna, T., **Darby, B.,** Yurkonis, K. (2019). Effects of monoculture conditioned soils on common tallgrass prairie species productivity. ***Journal of Plant Ecology***, 12, 474-484.
15. White, C.V, **Darby, B.J.,** Breeden, R.J., Herman, M.A., 2015. A *Stenotrophomonas maltophilia* strain evades a major *Caenorhabditis elegans* defense pathway. ***Infection and Immunity***. 84:524-536.
16. Kawakami T., **Darby B.J.,** Ungerer M.C. 2014. Transcriptome resources for the perennial sunflower *Helianthus maximiliani* obtained from ecologically divergent populations. ***Molecular Ecology Resources*** 14:812-819
17. Wheeler, D., **Darby, B.J.,** Herman, M.A., 2012. Several grassland soil nematode species are insensitive to RNA-mediated interference. ***Journal of Nematology***. 44(1):91-100.
18. Neher, D.A., Lewins, S.A., Weicht, T.R., and **Darby, B.J.** 2009. Microarthropod communitites associated with biological soil crusts in the Colorado Plateau and Chihuahuan deserts. ***Journal of Arid Environments*** 73:672-677.
19. Housman, D.C, Yeager, C.M., **Darby, B.J.,** Sanford, B., Kuske, C.R., Neher, D.A., Belnap, J. 2007. Heterogeneity of soil nutrients and subsurface biota in dryland ecosystems. ***Soil Biology and Biochemistry*** 39:2138-2149.
20. Li, F., Neher, D.A., **Darby, B.J.**, and Weicht, T.R. 2005. Contrasting effects of copper and benzo(a)pyrene concentration on life history characteristics of *Aphelenchus* and *Acrobeloides*. ***Ecotoxicology*** 14:419-429.

APPENDIX 5 – LETTERS OF SUPPORT

- University of North Dakota
- American Crystal Sugar Company – Provided for original NDIC-REP Application
- American Crystal Sugar Company – Provided for USDA Application
- ADM – Provided for USDA Application
- Red River Biorefinery – Provided for USDA Application

UNIVERSITY OF UND NORTH DAKOTA

INSTITUTE FOR ENERGY STUDIES
COLLEGE OF ENGINEERING AND MINES
COLLABORATIVE ENERGY COMPLEX ROOM 236
2844 CAMPUS ROAD – STOP 8153
GRAND FORKS, NORTH DAKOTA 58202-8153
PHONE (701) 777-3852 FAX (701) 777-4838

July 29, 2022

Dr. Srivats Srinivasachar
President, Envergex LLC
10 Podunk Road
Sturbridge, MA 01566

RE: Letter of Support for Envergex LLC Proposal to the North Dakota Renewable Energy Council entitled "Novel Process for Biocoal Production with CO_2 Mineralization to Achieve Negative Carbon Emissions."

Dear Dr. Srinivasachar,

The Institute for Energy Studies (IES) at the University of North Dakota (UND) is excited to continue our collaborations with the Envergex team to develop low-carbon technologies. In the proposed project, UND will team with Envergex to demonstrate a breakthrough technology that will enable cost-effective production of renewable biocoal sourced from North Dakota's abundant biomass resources, all with negative carbon dioxide (CO_2) emissions. Biomass energy combined with carbon capture and storage (BECCS) is one of the few methods available that can achieve negative CO_2 emissions.

In collaboration with Envergex, the UND-IES team will perform laboratory experimental testing, analytical characterization, and process modeling/economic analysis outlined in the following scope of work.

Task 1 – Laboratory Testing Equipment Construction and Sample Procurement: UND will install the Envergex testing equipment at our laboratory facility. UND will assist Envergex in the selection, procurement and characterization of feedstocks for testing. This will include both biomass materials (i.e., sugar beet pulp, water treatment sludge) and waste alkaline residues (biomass/coal ash, alkaline silicate minerals).

Task 2 – Experimental Evaluation of Hydrothermal Carbonation: UND will assist Envergex in the experimental testing of the novel approach to hydrothermally carbonize high-moisture biomass into a high quality, renewable biocoal. UND will perform analytical characterization, with existing equipment at UND, to determine the physical and chemical properties of the products and effluents produced in the process.

Task 3 – Experimental Evaluation of CO_2 Mineralization using Solid Residues: UND will assist Envergex in the experimental testing of the novel approach to directly mineralize (sequester) the CO_2 produced during biomass conversion processes. This testing will include a focus on integrating the mineralization process with the CO_2-rich gas phase effluent from the hydrothermal carbonation process examined in Task 2.

Task 4 – Product Characterization and Market Analysis: The hydrothermal carbonation and the mineralization processes each create products that have significant commercial markets. In this task, UND will assist Envergex with characterizing the physical/chemical properties of these products and performing an analysis to determine the performance/quality of the products for commercial applications. For the biocoal, we will determine combustion properties, including slagging/fouling tendency. For the CO_2 mineralization product (carbonated alkaline minerals), we will evaluate applications and performance for substitute cementitious materials and for soil amendments.

Task 5 – Process Modeling and Initial Techno-Economic Analysis (TEA): UND will assist Envergex in developing an overall process model, using Aspen Plus, for both the hydrothermal carbonation and CO_2 mineralization processes. Overall mass and energy balances will be determined. Based on the process model, we will perform a high-level TEA to estimate capital and operating costs and the potential production costs for the marketable products. This task will serve as the foundation for future work that would involve process scale up and integration.

The total cost for UND-IES' work on this project is $145,303, as outlined in the attached Budget Justification. The UND-IES project manager will be Mr. Junior Nasah, who can be reached at nasah.domkam@und.edu or 701-777-4307, should you have any questions.

We are very excited to continue our long history of collaboration with Envergex. We look forward to hearing from you soon about a positive proposal outcome.

Sincerely,

Daniel A. Laudal, PhD
Director | Institute for Energy Studies
College of Engineering & Mines
University of North Dakota
daniel.laudal@und.edu
701-777-5745

Karen Katrinak
Proposal Development Officer
Research & Sponsored Program Development
University of North Dakota
karen.katrinak@und.edu
701-777-2505

January 28, 2022

American Crystal Sugar Company

Dr. Srivats Srinivasachar
President, Envergex LLC
4200 James Ray Drive, Suite 301
Grand Forks, ND 58202

RE: Letter of Support for Envergex LLC Phase I Proposal titled "Novel Process for Biocoal Production with CO_2 Mineralization to Achieve Negative Carbon Emissions" North Dakota Renewable Energy Council

Dear Dr. Srinivasachar:

American Crystal Sugar Company (Crystal Sugar) is pleased to provide this letter of support for Envergex LLC, and the University of North Dakota (UND)'s proposed project entitled "Novel Process for Bio-coal Production with CO_2 Mineralization to Achieve Negative Carbon Emissions."

We understand that the project aims to develop a novel and cost-effective process to convert sugar beet manufacturing residues to bio-coal that can be a high-BTU value drop-in replacement for fossil fuels. We also understand that the bio-coal production process will be combined with a CO_2 capture step to sequester CO_2 using alkaline residues. The combination of bio-coal and "carbonated" ash would be a soil enhancement additive that can increase soil carbon and promote crop growth.

American Crystal Sugar Company is a world class agricultural cooperative that produces sugar from sugar beets. We are a vital part of the United States food supply and an integral part of the agricultural industry in MN and ND. Our interest in the proposed project stems from seeking improved beneficial use of our byproducts including pressed pulp (70-75% moisture), spent lime (30-35% moisture), and coal ash. We understand that your process includes upgrading all the above streams with a focus on reducing carbon in an economic manner.

We understand that in this project you will be performing proof-of-concept testing in the laboratory to verify the details and performance of your overall process: biomass to -bio-coal conversion and carbon dioxide capture with ash residue. We would be glad to provide you samples and analyses of the biomass residues and coal ash for your test program. We are willing to engage with you as you translate your experimental results to a conceptual design of the overall process providing background that would be helpful for scale-up and for commercial implementation. If the results are promising from your study, we would consider continued engagement in future development of the technology.

We look forward to working with you and UND in this project and wish you success in your pursuit of funding from the North Dakota Renewable Energy Council.

Sincerely,

Aaron Bjerke
Business Development Manager
American Crystal Sugar Company

October 26th, 2021

Dr. Srivats Srinivasachar
President, Envergex LLC
10 Podunk Road
Sturbridge, MA 01566

American Crystal Sugar Company

RE: Letter of Support for Envergex LLC Phase I Proposal titled "Novel Materials and Methods to Increase Soil Carbon" in response to USDA's Small Business Innovation Research Program Solicitation USDA-NIFA-SBIR-008541

Dear Dr. Srinivasachar:

American Crystal Sugar Company (Crystal Sugar) is pleased to provide this letter of support for Envergex LLC, and the University of North Dakota (UND)'s proposed project entitled "Novel Materials and Methods to Increase Soil Carbon."

We understand that the project aims to develop a novel and cost-effective process to capture CO_2 with inorganic residues (e.g., ash) and transform it into a mineralized product. We understand that the "carbonated" ash in combination with biochar, which could be derived from biomass waste streams, would be an excellent soil enhancement additive that can increase soil carbon and promote additional CO_2 capture and sequestration in-situ during crop growth.

Crystal Sugar is a world class agricultural cooperative that produces sugar from sugar beets. We are a vital part of the United States food supply and an integral part of the agricultural industry in MN and ND. Our interest in the proposed project stems from seeking improved beneficial use of some of our byproducts including pressed pulp (70-75% moisture), spent lime (30-35% moisture), and ash. We understand that your process addresses upgrading all the above streams with a focus on reducing carbon footprint in an economic manner.

You have indicated that, in Phase I of the project, you will be performing proof-of-concept testing in the laboratory to verify the details and performance of the different components of your overall process. We would be glad to provide you samples and analyses of the biomass residues and ash for your test program. We are willing to engage with you as you translate your experimental results to a conceptual design of the overall process providing background that would be helpful for scale-up and for commercial implementation

We look forward to working with you and UND in this project, and wish you success in your pursuit of funding from the USDA.

Sincerely,

Aaron Bjerke
Business Development Manager
American Crystal Sugar Company

November 1, 2021

Dr. Srivats Srinivasachar
President, Envergex LLC
Sturbridge, MA 01566

RE: Letter of Support for Envergex LLC/University of North Dakota Phase I Proposal titled "Novel Materials and Methods to Increase Soil Carbon" in response to USDA's Small Business Innovation Research Program Solicitation USDA-NIFA-SBIR-008541

Dear Dr. Srinivasachar:

Archer Daniels Midland Northern Sun Division (ADM) is pleased to provide this letter of support for Envergex LLC and the University of North Dakota (UND)'s proposed project entitled "Novel Materials and Methods to Increase Soil Carbon."

We understand that the project aims to develop a novel process to capture CO_2 with inorganic residues (e.g., ash) and transform it into a mineralized product. We understand that the "carbonated" ash would be an excellent soil enhancement additive that can increase soil carbon and promote additional CO_2 capture and sequestration in-situ during crop growth.

ADM is a global agriculture business that have 800+ facilities from origination of crops to processing; a global leader in human and animal nutrition. We are an integral part of the United States food supply and an integral part of the agricultural industry in MN and ND. Our interest in the proposed project stems from seeking improved beneficial use of some of our byproducts, which include biomass combustion ash and various waste biomass materials. We understand that your process addresses upgrading all of the above streams with a focus on generating value added products including soil amendments that can increase soil carbon in an economic manner.

You have indicated that, in Phase I of the project, you will be performing proof-of-concept testing in the laboratory to verify the details and performance of the different components of your overall process. We would be glad to provide you samples and analyses of the ash and, if appropriate, biomass residues for your test program. We are willing to engage with you as you translate your experimental results to a conceptual design of the material upgrading steps and providing background that would be helpful for commercial implementation

We look forward to working with you and UND in this project and wish you success.

Regards,

Guy Christensen
Oilseeds Marketing Representative
5525 136th Ave SE
Enderlin ND 58027
701-551-2871 O / 701-680-1045 C

RED RIVER BIOREFINERY

October 19, 2021

Dr. Srivats Srinivasachar
President, Envergex LLC
Sturbridge, MA 01566

RE: Letter of Support for Envergex LLC Phase I Proposal titled "Novel Materials and Methods to Increase Soil Carbon" in response to USDA's Small Business Innovation Research Program Solicitation USDA-NIFA-SBIR-008541

Dear Dr. Srinivasachar:

Red River Biorefinery is pleased to provide this letter of support for Envergex LLC and the University of North Dakota (UND)'s proposed project entitled " Novel Materials and Methods to Increase Soil Carbon."

We understand that the project aims to develop a novel and cost-effective process to capture CO_2 with inorganic residues (e.g., ash) and transform it into a mineralized product. We understand that the "carbonated" ash in combination with biochar, which could be derived from biomass waste streams, would be an excellent soil enhancement additive that can increase soil carbon and promote additional CO_2 capture and sequestration in-situ during crop growth.

Red River Biorefinery (RRB) is an ethanol production facility that produces high-grade ethanol for sanitation purposes, fuel-grade ethanol, animal feed, and renewable natural gas. The RRB facility began operations in 2020 and has one of the lowest carbon footprints of any ethanol production facility in the US. Currently our biogenic CO_2 (e.g., from ethanol fermentation) and combustion CO_2 are not captured. Capture and permanent sequestration of these streams would further reduce our carbon footprint and potentially result in a carbon-negative profile for our products.

We would be glad to have discussions with you regarding the composition and size of our CO_2 streams and to provide you materials that we may want you to evaluate in your test program. We are willing to engage with you as you translate your experimental results to a conceptual design of the overall process. With an eye on California and other markets with Low Carbon Fuel Standards that put a higher price tag on biofuels, we believe that with CO_2 capture in our plant, our products will be better positioned to achieve those standards.

We look forward to working with you and UND in this project, and wish you success in your pursuit of funding from the USDA.

Best Regards,

Keshav Rajpal
President – Red River Biorefinery LLC

APPENDIX 6 – TAX LIABILITY STATEMENT

Envergex
Sparking Innovations

July 29, 2022

Karlene Fine,
Executive Director, North Dakota Industrial Commission
State Capitol - 14th Floor
600 East Boulevard Avenue
Bismarck, ND 58505-0840

Subject: Tax liability pertaining to Envergex LLC's proposal, "Novel process for biocoal production with CO_2 mineralization to achieve negative carbon emissions"

Dear Ms. Fine,

I am writing to you regarding the Tax Liability Statement which is a requirement for the Envergex LLC's proposal to the NDIC Renewable Energy Council. As the President of Envergex LLC, I affirm that Envergex LLC has no outstanding tax liability in the State of North Dakota.

Please feel free to contact me at (508) 347-2933 or srivats.srinivasachar@envergex.com with any questions.

Thank you for the opportunity to propose this project to the Renewable Energy Council.

Sincerely yours,

Srivats Srinivasachar, Sc.D.
President, Envergex LLC