Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-241

Proposal Title: Foundational Data for Sequestering CO2 using Minnesota Minerals

Project Manager Information

Name: Brett Spigarelli

Organization: U of MN - Duluth - NRRI

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Project Basic Information

Project Summary: Can Minnesota minerals/mineral waste streams sequester CO2 safely? A fundamental study to identify candidate resources and test their CO2 storage capacity to better understand potential environmental risks and rewards.

Funds Requested: $353,000

Proposed Project Completion: 2023-06-30

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Region(s): NE

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

The problem is global climate change resulting from increasing levels of atmospheric carbon dioxide (CO2). Sequestering/storing CO2 at or near its source of generation using Minnesota minerals is the proposed opportunity. As the National Academies of Science, Engineering, and Medicine (NASEM) summarizes in Gaseous Carbon Waste Streams Utilization: Status and Research Needs (NASEM, 2019), "Only a small fraction of the carbon dioxide and methane emitted each year is currently being captured and used. Most carbon utilization technologies are in their infancy."

One carbon storage method is called "mineral carbonation". As NASEM (2019) describes, "This process converts stable CO2 into an even more stable form of carbon, typically a carbonate. Mineralization involves reaction of minerals (mostly calcium or magnesium silicates) with CO2 to give inert carbonates. The current bottleneck, however, for viable mineral carbonation processes on an industrial scale is the reaction rate of carbonation."

This bottleneck, and other research needs and considerations identified by NASEM, will be addressed by the proposed study, including:

- controlling carbonation reactions
- accelerating carbonation and crystal growth
- anticipating potential unintended outcomes and consequences

Environmental risks, rewards, and benefits must be better understood before this process is adopted within Minnesota's water-rich environment.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

Fundamental data about potential Minnesota mineral carbonation feedstocks and the mineral carbonation process itself are needed. Therefore, the project will investigate the potential of identified Minnesota minerals and byproducts to store CO2, and key chemical, physical, mineralogical, and thermodynamic reaction mechanisms. The environmental implications of this process (e.g., on water quality) must be addressed holistically prior to commercialization of this process.

"Mineral carbonation can be readily accomplished by contacting alkaline (mineral) solids, such as Ca- or Mg-rich materials, with CO2 in a fluid state or in solution. Depending on the types of alkaline solids used, these reactions can occur readily, even at ambient temperature and pressure." (NASEM, 2019).

The focus of the project will be on identifying and characterizing feedstock materials for mineral carbonation of CO2. Focus will be on identifying calcium and magnesium bearing minerals and byproducts. Materials may include byproducts generated from current quarrying operations and potential non-ferrous mineral production in Minnesota. As Snæbjörnsdóttir et al (2020) state, "The carbonation of mine waste has the advantage that it is commonly already finely ground, increasing its reactivity."

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

This forward-looking project will provide Minnesota with critical information to better understand risks, opportunities, and benefits of a potentially significant CO2-mitigating technology before it is commercialized; maximizing process-associated knowledge to prevent future "surprises". For example, the project will address water quality issues, including potential impacts that may occur due to presence of trace amounts of sulfides in potential feed-stock materials. Using byproduct materials to reduce CO2 produced by mining activity is an example of transforming inefficient linear

economy practices to a more efficient and environmentally sustainable circular economy. Specific project deliverables will include reports, peer review papers, and conference presentations.

Activities and Milestones

Activity 1: Synthesis of science/research; identification of prospective CO2-sequestering geological materials; selection and set-up of laboratory testing methods and equipment

Activity Budget: $100,000

Activity Description:
Activity 1 is the foundation for Activities 2 and 3. Activity 1 will begin with a literature review and synthesis of the state of the science and prior and current research activities. Syntheses are an effective means of assembling and disseminating information on current practice. Concurrently, geologically appropriate CO2-sequestering materials will be identified and secured for acquisition. Based on the two preceding actions, standard operating procedures and experimental design for the project's selected testing methods will be developed. Necessary laboratory equipment will be identified at NRRI or collaborating facilities, and (if lacking) acquired. Laboratory space will be set up at the NRRI's Coleraine Labs and in Duluth. Coleraine Labs, with input from UMD's Department of Chemistry and Biochemistry, focusing on preparing for the project's mineral carbonation testing. NRRI Duluth will focus on preparing for the project's environmental testing and characterization program to assess the potential impact of mineral feed-stocks and carbonation reaction products on water quality. Conceptually, dissolved CO2 would be introduced into byproduct mineral fines, like tailings, where it would react to form geologically stable carbonate minerals, thereby tying up the carbon. This reaction will have both chemical and physical (volume change) impacts, and both impacts will be assessed.

Activity Milestones:

Description	Completion Date
Synthesis of state of the science/literature review	2021-09-30
Identify and acquire prospective CO2-sequestering material sources	2021-10-31
Select testing methods, develop experimental design, acquire needed laboratory equipment, and set up laboratory space.	2021-12-31

Activity 2: Collect and characterize prospective CO2-sequestering geological materials, and perform initial testing to confirm experimental design, equipment operation, and data acquisition

Activity Budget: $113,000

Activity Description:
Activity 2 will define the technical parameters of the project, focusing on: 1) material characterization via collaboration with the University of Minnesota's Electron Microprobe Laboratory; 2) experimental design, laboratory and equipment set-up, and initial mineral carbonation testing and confirmation at the NRRI's Coleraine Labs; and 3) environmental characterization at NRRI to assess potential feed-stock impacts on water quality . Further evaluation will be done at the microscopic reaction level by the Department of Chemistry and Biochemistry at the University of Minnesota Duluth. For example, hydration of magnesium ions and their removal from olivine (a common Duluth Complex magnesium silicate mineral) crystals may limit the carbonation rate. Energy changes and local stress during magnesium ion exchange will be modeled with quantum-chemical molecular dynamics simulations to identify probable dissolution step pathways in olivine’s carbonation. Atomic-scale simulations will also address carbonation of calcium-bearing mineral wastes. For example, interactions of bicarbonate ions with the common calcium silicate mineral plagioclase will be calculated to find initial steps that lead to the mineral calcite. Variables such as temperature, gas flow rate, and gas composition on each byproduct’s ability to absorb CO2 will be measured and evaluated. The findings of Activity 2 will guide Activity 3.

Activity Milestones:

Description	Completion Date
Physically, mineralogcally, microscopically, and chemically characterize Activity 1 selected materials; work with UMTC microprobe laboratory	2022-03-31
Preliminary mineral carbonation testing at NRRI/CMRL, with follow-up characterization to assess extent of reaction	2022-06-30

Activity 3: Perform full mineral carbonation tests; characterize materials; quantify mineral carbonation potential of tested materials; and assemble, interpret, and report findings

Activity Budget: $140,000

Activity Description:
Guided by the findings of Activity 1 and results of Activity 2, Activity 3 will carry out full mineral carbonation testing on selected mineral byproduct candidates. For the proposed concept to be technically and economically practical, mineral carbonation reactions should be measurable and quantifiable within relatively short time periods. This will allow the bulk of the experimental program to be performed within a one-year period. For statistical robustness and to confirm reproducibility, a minimum of three (3) carbonation tests will be performed on each material under each treatment condition combination (e.g., atmosphere, temperature, and moisture). Follow-up characterization, again in cooperation with UMTC's Electron Microprobe Laboratory and UMD's Department of Chemistry and Biochemistry, will be conducted to assess and explain post-carbonation reaction effects. These results - combined with chemical analyses - will be compared to the project's pre-carbonation characterization findings to quantify (stoichiometrically and by mass balance) the extent and efficiency of the reactions, based on CO2 inputs and the energy required to drive the reactions. Likewise, follow-up environmental characterization and testing will be performed to assess potential post-carbonation impacts on water quality and on mineral feed-stocks that may contain trace amounts of sulfides.

Activity Milestones:

Description	Completion Date
Carbonation testing of selected byproduct materials	2022-12-31
Characterization of carbonated mineral byproducts	2023-03-31
Compilation and interpretation of results; quantification of reaction extent and efficiency; and full cost accounting	2023-04-30
Final report that is constructed for easy conversion to journal/manuscript-ready format	2023-06-30
Presentation of project findings to LCCMR	2023-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Professor Paul Siders	University of Minnesota Duluth Department of Chemistry and Biochemistry	Dr. Siders provides expertise about carbonate bonding and reaction thermodynamics, including identifying probable pathways of the dissolution step in the carbonation of minerals like olivine, and modeling energy changes and local stress during magnesium ion exchange with quantum-chemical molecular dynamics simulations.	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

Upon successful completion of the proposed project, the logical next step would be to conduct a pilot-scale study. Longer-term investments and funding strategies to support a pilot-scale study would be proportional to the current request. The approach would be to use the findings of the current proposal as proof-on-concept to leverage additional funding and collaboration via sources such as the United States Department of Energy (DOE), the National Science Foundation (NSF), the Environmental Protection Agency (EPA), other university research institutions, state agencies, and/or industry. Developing methods for extracting mineral-carbonated CO2 will be an opportunity for future research.

Project Manager and Organization Qualifications

Project Manager Name: Brett Spigarelli

Job Title: Research Metallurgist

Provide description of the project manager's qualifications to manage the proposed project.

Brett Spigarelli, Ph.D. (NRRI Coleraine Labs) will manage the project, with assistance from Lawrence Zanko (NRRI Duluth)

Dr. Spigarelli is a Research Metallurgist for NRRI Coleraine Labs. During his time with NRRI he has managed many projects to completion. These projects involved working/communicating with diverse groups of individuals, developing a project charter/scope, developing a project timeline/schedule, assigning project resources, developing a budget, and delivering high quality research results on time and in a safe manner.

Dr. Spigarelli received his B.S., M.S., and Ph.D. in Chemical Engineering from Michigan Technological University. His M.S. research was focused on carbon dioxide capture and storage at ambient conditions. His Ph.D. research expanded on his M.S. work, and was focused on capture of carbon dioxide using chemical absorption and storage via mineral carbonation using waste materials. Dr. Spigarelli's background makes him especially well-suited for leading and managing the proposed project.

Mr. Zanko is Senior Research Program Manager/Researcher 7 for Byproduct Reuse and Remediation. Since his start with NRRI in 1988, Mr. Zanko has led or participated in a broad spectrum of research projects dealing with non-ferrous minerals, ferrous minerals, and industrial minerals (with a focus on construction aggregates), and the byproducts generated therefrom. His applied research background, particularly in the area of byproduct materials generated by mineral resource production, will be used for identifying and choosing byproduct materials that not only have the best mineral carbonation potential, but are also the most practical candidates with respect to volume and economics.

Mr. Zanko received a Master of Geological Engineering, University of Minnesota, Twin Cities (UMTC); Bachelor of Geological Engineering (UMTC); and B.S. Microbiology (UMTC).

Organization: U of MN - Duluth - NRRI

Organization Description:
The Natural Resources Research Institute (NRRI) is an applied research and economic development engine for the University of Minnesota research enterprise. NRRI employs over 130 scientists, engineers and technicians to deliver on its mission to deliver research solutions to balance our economy, resources and environment for resilient communities. NRRI collaborates broadly across the University system, the state and the region to address the challenges of a natural resource-based economy.

NRRI researchers have extensive experience in managing large, interdisciplinary projects. NRRI's role is as an impartial, science-based resource that develops and translates knowledge. Projects include characterizing and defining resource opportunities, minimizing waste and environmental impact, maximizing value from natural resources and maintaining/restoring ecosystem function.

Major outcomes from NRRI projects include informing environmental management and policy and assisting industry and communities in defining and maintaining the social license to operate in natural systems. NRRI has an established mechanism for sharing outcomes through press releases, publication in peer-reviewed journals, annual reports (https://www.nrri.umn.edu/resources-publications/annual-reports), periodicals, and through social media channels.

The project will be led by NRRI's Minerals & Metallurgy Group, and will be comprised of a multidisciplinary team of researchers representing NRRI, UMD, and UMTC.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Julie Mutchler, Research Professional 3		Laboratory chemist; chemical analysis of materials and products			24.1%	0.26		$22,562
Stephen Monson Geerts - Senior Research Geologist and Mineralogy Lead, Researcher 6		Co-Investigator: mineralogical characterization of geological materials and products			26.7%	0.3		$31,745
TBD, Researcher 4		Field and laboratory assistance, data compilation			24.1%	0.2		$14,758
Sara Post, Researcher 4		Synthesis/compilation of prior research and byproducts; GIS work; and data assembly and analysis			24.1%	0.3		$17,559
Brett Spigarelli - Research Metallurgist, Researcher 5		Project Manager/Principal Investigator			26.7%	0.5		$69,746
Lawrence Zanko - Senior Research Program Manager, Researcher 7		Co-Project Manager/co-investigator			26.7%	0.3		$45,147
George Hudak, Geologist,		Mineralogical expertise and project oversight			26.7%	0.1		$19,305

Research Director 1								
Joe Canella, Principal Laboratory Technician		Conduct mineral carbonation testing			24.1%	0.4		$31,560
Meijun Cai, Researcher 6		Statistician and environmental water quality assessment			26.7%	0.4		$40,303
Paul Siders, Associate Professor		Carbonation reaction kinetics, thermodynamics, and modeling			26.7%	0.1		$17,153
							Sub Total	**$309,838**
Contracts and Services								
TBD	Professional or Technical Service Contract	Geochemical analysis of 42 samples at ~$150 per sample by certified analytical laboratory. Analyses will be conducted on mineral byproducts, pre- and post-carbonation.				0		$6,300
University of Minnesota	Internal services or fees (uncommon)	UM Twin Cities electron microprobe characterization of materials (7 days at $1155/day). Electron microprobe characterization and imaging of pre- and post-mineral carbonation materials. The level of microscopic and mineralogical detail electron microprobe analysis achieves will help us understand which mineral types and physical forms are most effective, and why.				0		$8,085
							Sub Total	**$14,385**
Equipment, Tools, and Supplies								
	Tools and Supplies	Laboratory supplies for carbonation tests	Reagents, vessels, compressed gas (e.g., CO2), glassware, thermocouples, data loggers, personal protection equipment					$5,777
	Tools and Supplies	Certified Reference Standards, 2 to 3	Certified reference standards are needed for confirming analytical precision and accuracy					$1,500
							Sub Total	**$7,277**

Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Overnight lodging and meal per diem expenses for in-state travel: 50 overnight stays @$151/day Standard GSA rate Minnesota: Lodging $96 per night M&IE: $55 per day	Lodging and daily per diem meal expenses for in-state travel					$7,550
	Other	Vehicle mileage and usage (20,300 miles at $0.575/mile and 122 days of vehicle usage at $10 per day)	Travel to source material locations within Minnesota and between Duluth and Coleraine.					$12,890
							Sub Total	**$20,440**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
		Shipping	To cover shipping cost of lab supplies, test materials, and samples					$1,060
							Sub Total	**$1,060**
							Grand Total	**$353,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	UMN unrecovered indirect costs are calculated at the UMN negotiated rate for research of 55% modified total direct costs.	Indirect costs are those costs incurred for common or joint objectives that cannot be readily identified with a specific sponsored program or institutional activity. Examples include utilities, building maintenance, clerical salaries, and general supplies. (https://research.umn.edu/units/oca/fa-costs/direct-indirect-costs)	Secured	$194,150
			Non State Sub Total	**$194,150**
			Funds Total	**$194,150**

Attachments

Required Attachments

Visual Component

File: 5435940b-08b.pdf

Alternate Text for Visual Component

The visual depicts the proposed process for using Minnesota minerals and mineral byproducts to permanently sequester CO2 in a stable carbonate mineral form and its life-cycle nature, and lists the following benefits: Permanent, benign, and stable storage of CO2; Reduction in mining mineral byproducts and waste streams; and Creation of a value-added product by using sequestered carbonates as a filler in masonry materials for construction.

Optional Attachments

Support Letter or Other

Title	File
Sponsored Projects Authorization	2f503a60-30c.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

- Patent, Copyright, or Royalty Potential
- Potential revenue generated or net income from the sale of products or assets developed or acquired with ENRTF funding

Does your project include research?

Yes

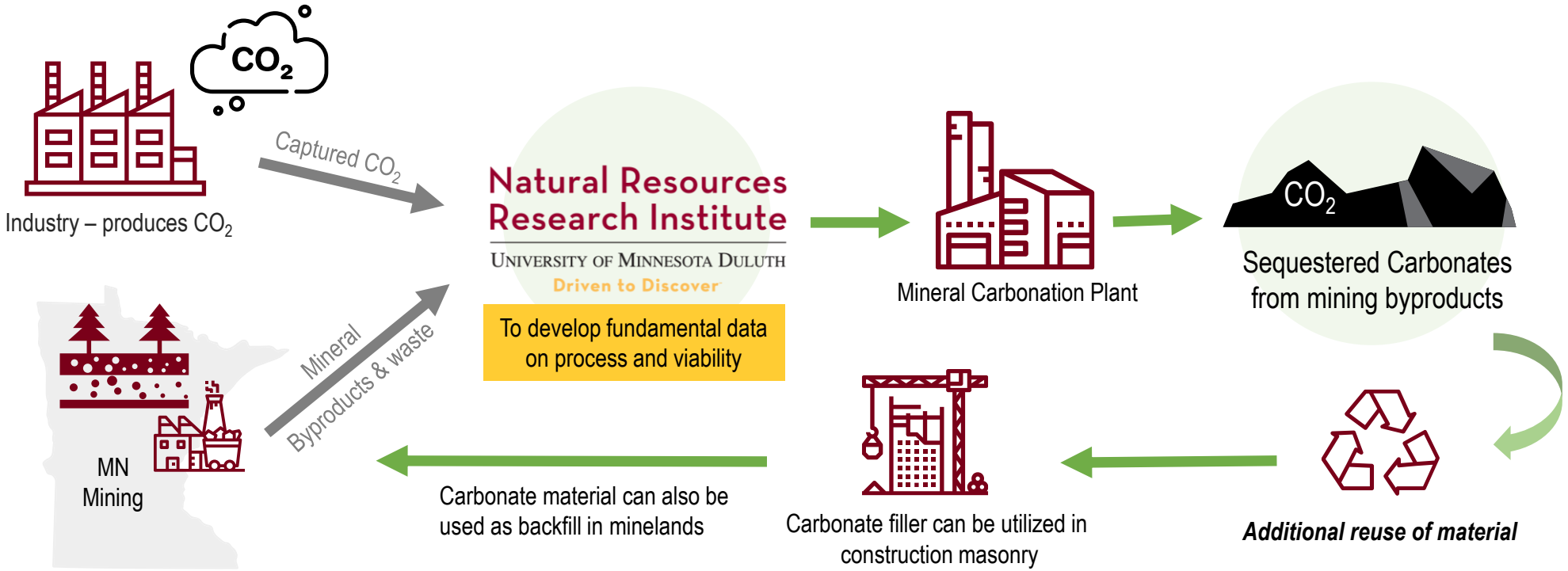
Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

PROJECT TITLE:

Foundational Data for Sequestering CO2 Using Minnesota Minerals



ABOUT: Using Minnesota's mineral byproducts, there is potential to permanently sequester industrial CO_2 in a stable form. This project will provide foundational data for the viability of permanently sequestering CO_2 in a stable, and environmentally benign, carbonate mineral form.

CHALLENGE: To mitigate the impacts of climate change by sequestering CO_2 at or near the industrial point source using a byproduct from Minnesota's mining industry.

OUTCOMES: This research will result in the identification, characterization, and quantification of the CO_2 storage potential of Minnesota minerals and mineral byproducts.

BENEFITS:

- ✓ Permanent, benign, and stable storage of CO_2
- ✓ Reduction in mining mineral byproducts and waste streams
- ✓ Creation of a value-added product - sequestered carbonates could be used as a filler in masonry materials for construction

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