Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-441

Proposal Title: Soudan Mine as a Minnesota Subsurface Hydrogen Observatory

Project Manager Information

Name: Jeff Havig

Organization: U of MN - College of Biological Sciences

Office Telephone: (509) 637-6375

Email: jeffhavig@gmail.com

Project Basic Information

Project Summary: The proposed work will characterize and integrate water chemistry, microbiology, dissolved H2, and mineralogy of Soudan Mine system and Lake Vermillion to assess H2 production and consumption in the subsurface.

ENRTF Funds Requested: $576,000

Proposed Project Completion: June 30, 2030

LCCMR Funding Category: 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 and In the Future

Narrative

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

Interest has increased in the potential for hydrogen (H2) gas production from iron rich rocks in northern Minnesota, as this might provide a new energy resource. A critical problem is a lack of data to quantify how water-mineral-microbial interactions impact H2 production and consumption in the subsurface. Accessing the rocks, water, microbiology, and gas below the surface is also challenging without expensive drilling of boreholes. Boreholes are also limited – they do not allow for discrete sampling of different levels in the subsurface and thus do not facilitate detailed evaluation of different areas or rock units. It is currently unknown if there are any impacts on subsurface water chemistry and microbiology from seasonal changes at the surface, and how far down those changes may propagate. Soudan Mine and adjacent Lake Vermillion provide an easily accessed natural laboratory for quantifying H2 production and consumption and will build on previous LCCMR funded work. This historic mine site offers direct human access to measure, monitor, and characterize the subsurface water-mineral-microbial system for natural hydrogen production and/or consumption that would otherwise be prohibitively expensive.

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

This work will provide a comprehensive characterization of the surface and groundwater chemistry, microbiology, dissolved H2 at Soudan Mine. Samples will be collected across four seasons and coupled to corresponding bedrock mineralogy to understand H2 production and/or consumption in iron formation. Of critical interest to the energy community, data could be leveraged to explore subsurface hydrogen production and consumption mechanisms in northern Minnesota. The lack of understanding of how microbiology impacts H2 in the subsurface was identified as a challenge for developing H2 as a potential energy source at the 2025 Geologic Hydrogen Summit (Duluth, MN). Recent work in level 27 at Soudan Mine revealed microbial communities consume hydrogen as part of their metabolic activities (Sheik et al., 2021), highlighting the need to characterize the entire subsurface. The proposed team combines a complimentary breadth of knowledge spanning aqueous geochemistry, microbiology, and regional geology/mineralogy. The collection of a comprehensive suite of water chemistry, dissolved H2, and microbial community composition combined with the study of minerals found in Soudan-associated drill cores held at the MN DNR Drill Core Library (Hibbing, MN) would provide the necessary dataset to carry out modeling of reactions driving H2 production and consumption in the subsurface.

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 project will provide a first of its kind comprehensive seasonal chemical, microbiological, mineralogical, and dissolved gas assessment from the surface to 2,341 feet depth of the Soudan Mine, allowing thermodynamic modeling of the water, mineral, and microbiological factors driving H2 production and consumption.

The results of this work will provide a workflow to quantify hydrogen production and consumption in complex geologic systems in northern Minnesota. Current workflows to quantify hydrogen production in Precambrian terranes with high potential for natural generation or stimulation of hydrogen have limited accounting for microbial consumption mechanisms.

Activities and Milestones

Activity 1: Collect and analyze water, dissolved gas, and microbial samples from six locations in Soudan Mine.

Activity Budget: $223,000

Activity Description:
Objective: Collect water, dissolved gas, and microbial samples across four seasons for two years from 6 sites across 5 levels at Soudan Mine. Evaluate analytical results, conduct metagenomic analyses of key microbial communities identified, and interpret analytical results to fully characterize, assess, and evaluate the impact of microbiology on dissolved H2 in the subsurface.

Tasks: Analyze and compile water, microbial, and dissolved H2 data from samples collected across sampling events for each season. Evaluate water chemistry and microbial community compositions to select targets for metagenomic analysis to determine key microbial functions associated with H2 production and/or consumption. Write a manuscript on the results of the Soudan Mine sampling to be submitted to a peer-reviewed journal.

Task execution: The postdoctoral researcher, with guidance from PI Havig and Co-Is Hamilton and Brengman, will lead the effort to collect and analyze samples, and select a subset of samples for metagenomic analysis. The postdoctoral researcher will compile and integrate analytical results, and prepare the scientific journal article manuscript.

Outcomes: A comprehensive understanding of the water chemistry and microbiology of Soudan Mine, and how it is affected by seasonal changes across two years of study, reported in a scientific journal article.

Activity Milestones:

Description	Approximate Completion Date
1. Collect and analyze Soudan samples in Y1.	June 30, 2028
4. Select, analyze, and interpret metagenomic samples.	January 31, 2029
2. Collect and analyze Soudan samples in Y2.	June 30, 2029
3. Compile/integrate water, microbial, and dissolved gas analytical, microbial sequencing results.	June 30, 2029
5. Prepare manuscript from Soudan Mine results to be submitted to a peer-reviewed scientific journal.	October 31, 2029

Activity 2: Collection and analysis of water, dissolved gas, and microbiology samples from surface water source (Lake Vermillion) feeding Soudan mine groundwater.

Activity Budget: $188,000

Activity Description:
Objective: Collect water, dissolved gas, sediment, and microbial samples across four seasons for two years from three water depths and two sediment cores at Lake Vermillion. Evaluate analytical results, conduct metagenomic analyses of key microbial communities identified, and interpret analytical results to fully characterize, assess, and evaluate the impact of microbiology on dissolved H2 in the surface water.

Tasks: Analyze and compile water, microbial, and dissolved H2 data from water samples collected across sampling events for each season, and sediment core collected in the winter. Evaluate water chemistry and microbial community compositions to select targets for metagenomic analysis to determine key microbial functions associated with H2 production and/or consumption.

Task Execution: The postdoctoral researcher, with guidance from PI Havig and Co-Is Hamilton and Brengman, will lead the effort to collect and analyze samples, and select a subset of samples for metagenomic analysis. The postdoctoral researcher will compile and integrate analytical results, and prepare the scientific journal article manuscript.

Outcomes: A comprehensive understanding of the water chemistry and microbiology of Lake Vermillion and how it is affected by seasonal changes across two years of study, to be integrated with the results from Activities 1 and 3.

Activity Milestones:

Description	Approximate Completion Date
1. Collect and analyze Lake Vermillion samples in Y1.	June 30, 2028
4. Select, analyze, and interpret metagenomic samples.	January 31, 2029
2. Collect and analyze Lake Vermillion samples in Y2.	June 30, 2029
3. Compile/integrate water, microbial, and dissolved gas analytical, microbial sequencing results.	June 30, 2029
5. Integrate results with the results from Activities 1 and 3.	June 30, 2029

Activity 3: Detailed mineralogical study of geologic drill cores associated with Soudan Mine available through the MN DNR Drill Core Repository.

Activity Budget: $165,000

Activity Description:
Objective: Evaluate the mineral and elemental compositions in geologic drill cores collected from the Soudan Mine region. Integrate mineralogy with results from Activities 1 and 2 to conduct thermodynamic modeling to determine key chemical reactions associated with H2 production and/or consumption.

Tasks: Assess and evaluate geologic drill cores associated with the Soudan area, select and sample representative portions for analysis. Prepare thin section mounts. Determine core sample mineralogy via XRD and petrographic microscopy. Analyze thin section mounts for elemental compositions via Electron Microprobe. Compile and integrate results with results from Activities 1 and 2. Conduct thermodynamic modeling to evaluate key chemical reactions associated with H2 production and/or consumption.

Task Execution: The postdoctoral researcher, with guidance from Co-I Brengman, will lead the effort to collect and analyze samples. The postdoctoral researcher will compile and integrate analytical results, conduct thermodynamic calculations, and prepare a scientific journal article manuscript.

Outcomes: A comprehensive understanding of the interconnection of water chemistry, microbiology, and mineralogy as it relates to H2 production and/or consumption across Soudan. A peer reviewed scientific journal article manuscript on the results of the complete integration of data and results of thermodynamic modeling.

Activity Milestones:

Description	Approximate Completion Date
3. Conduct thermodynamic modelling using comprehensive dataset.	January 31, 2029
1. Collect and analyze drill core samples.	May 31, 2029
2. Compile/integrate mineralogy results with water, microbial, dissolved gas, and microbial sequencing results.	June 30, 2029
4. Prepare manuscript from complete project results to be submitted to a peer-reviewed scientific journal.	June 30, 2030

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Dr. Trinity Hamilton	Dept. of Plant and Microbial Biology, College of Biological Sciences, UMN	Professor Hamilton is an expert in microbiology and genomic sample collection, analysis, and interpretation. Hamilton will provide lab space and equipment necessary for completion of the microbial component of the proposed work, mentor the postdoctoral researcher and undergraduate workers in microbial techniques, and assist in sample collection.	Yes
Dr. Latisha Brengman	Swenson College of Science and Engineering, UMN-Duluth	Professor Brengman is an expert in geology and mineralogy, has extensive experience studying geologic cores, and has held previous Soudan Mine permits. Brengman will provide lab space and equipment necessary for completion of the mineralogy component, mentor the postdoctoral researcher, and assist in sample collection.	Yes

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
All data collected will be deposited into the University of Minnesota DRUM data repository to ensure permanent and public access to all data generated by this project. All DNA sequencing and metagenomic data will be uploaded to a public DNA library with associated metadata to ensure accessibility of data generated.

A minimum of two peer-reviewed scientific journal manuscripts will be submitted for publication based on the results of the work done on this project, with potential for additional publications based on results from the work.

Dr. Brengman will communicate results to her collaborators with the National Renewable Energy Laboratory (NREL) as well as to local (Minnesota) hydrogen energy partners that she is currently working with.

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 work be funded?
Results of the proposed research will be published in peer-reviewed journal articles to make the data and results readily available to government agencies, energy resource developers, as well as the greater research community and public. As this project will generate foundational science, we predict that the results of the proposed work will be invaluable for future research projects to build upon to further our understanding of H2 consumption associated with complex, old geologic terranes, and will provide critical data to be used for developing new research/grant proposals for continued study.

Project Manager and Organization Qualifications

Project Manager Name: Jeff Havig

Job Title: Research Associate

Provide description of the project manager's qualifications to manage the proposed project.
Havig has successfully led multi-collaborator, multi-institution, and international research projects over a 25 year career as an aqueous geochemist and geobiologist, working with experts across multiple fields including microbiology, geology, limnology, ecology, environmental science, and chemistry. The results of Havig's work include 10 first author and 46

coauthored peer-reviewed scientific journal publications enhancing our understanding of fundamental water-rock-microbial interactions at locations that include lakes, hot springs, glaciers, and acid mine drainage sites. Havig's training includes a B.S. in Environmental Chemistry, a M.S. in Geology specializing in Groundwater Studies, and a Ph.D. in Geological Sciences specializing in Aqueous Geochemistry. Havig has successfully led or participated in fieldwork involved with the research projects he has participated in, building a reputation for generating a safe and professional work environment where high quality samples are properly collected according to field leading best practices for analysis to generate high quality data. Havig's work highlights his ability to work with professionals across disciplines to integrate large and complex datasets in order to answer challenging questions. Havig has assisted in mentoring PhD and postdoctoral researchers at UMN and previous institutions he has worked at. Havig has experience with using a wide range of analytical techniques, including all of the geochemical and imaging techniques requested for this project submission. Havig's work experience includes the tools and techniques critical for completion of this proposed work, including a study characterizing the water chemistry of naturally meromictic Fayetteville Green Lake (NY) resulting in 4 peer-reviewed scientific journal papers (2 first author, 2 co-author), and a collaborative project with proposal Co-Is Hamilton and Brengman studying the geochemistry, geology, mineralogy, and microbiology of the early Earth, including integrating a large and complex dataset compiled and interpreted by Havig, resulting in a manuscript that will be submitted this spring.

Organization: U of MN - College of Biological Sciences

Organization Description:
The College of Biological Sciences is part of the University of Minnesota - Twin Cities, and the home of the Department of Plant and Microbial Biology which the academic home of the Primary Investigator.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project Manager		Lead overall project, Lead on geochemistry portion of project			26.8%	0.51		$70,064
Co-investigator		Lead on microbiology portion of project			26.8%	0.24		$60,064
Co-investigator		Lead on geology and mineralogy portion of project			26.8%	0.24		$20,014
Postdoctoral Researcher		Lead in sampling, analysis of samples, and manuscript writing			20.69%	3		$255,862
2 undergraduate assistants		Assist with preparation for fieldwork, sample preparation, and sample analysis			0%	1.24		$40,960
							Sub Total	**$446,964**
Contracts and Services								
Characterization Facility, UMN	Internal services or fees (uncommon)	Electron Microprobe imaging and analyses, Scanning Electron Microscopy imaging and analyses				0.12		$4,800
University of Minnesota - Duluth	Internal services or fees (uncommon)	XRD training and analysis				0.08		$1,456
Stable Isotope Facility	Service Contract	Analysis of dissolved inorganic carbon samples, analysis of biomass samples for isotopic determination, water isotope analyses, carbonate carbon and oxygen isotope analyses				0.12		$5,678
Quantitative Bulk-Elemental Information Core	Service Contract	Analysis for water anion, cation, and trace element content, digestion of solid samples and analysis for cations and trace elements				0.08		$4,171
Jan Veizer Lab	Service Contract	Analysis of dissolved organic carbon samples				0.04		$3,280
Texas Petrographics	Service Contract	Generation of thin section mounts for drill core samples				0.04		$2,400
University of Minnesota	Internal services or	DNA sequencing for microbial community composition and for metagenomic analyses				0.08		$23,230

Genomics Center	fees (uncommon)							
TBD	Service Contract	Analysis for dissolved gasses, including CO2, CH4, and CO.				0.04		$6,794
							Sub Total	**$51,809**
Equipment, Tools, and Supplies								
	Equipment	4 Sonde probes (pH, ORP, D.O., Turbidity)	Necessary for measuring chemical and physical parameters of Lake Vermillion as context for the water, microbial, and sediments samples.					$3,400
	Tools and Supplies	Expendable material, including filters, powder pillow reagents for the Hach spectrophotometer, sample bottles/containers, chemicals needed for bottle cleaning, etc.	Necessary for the collection of water, microbial, and sediment samples					$4,471
	Equipment	2 pH probes	Necessary for measuring pH (meters already owned)					$900
	Tools and Supplies	3 DNA extraction kits	Necessary for the extraction of DNA from microbial samples for community composition and metagenomic analyses.					$2,100
	Tools and Supplies	Field supplies, including syringe filters, glass fiber filters, field notebooks, ziplock baggies, vinyl tape, writing utensils, sample collection spatulas, bulb pipettors, etc.	Necessary for the implementation of fieldwork (collecting samples) at Lake Vermillion and Soudan Mine.					$3,080
	Tools and Supplies	1 saw blade and 5 polishing mounts	Necessary for cutting drill core sections and mounting them for thin section creation as part of required sample prep for analyses proposed.					$1,000
	Equipment	Hach DR1900 Field Spectrophotometer	For the determination of Fe2+, sulfide, nitrate, ammonium, and silica in the field and in the lab.					$5,000
							Sub Total	**$19,951**
Capital Equipment								
		1 Variotech H2 tracer gas analyzer	For detection and measuring dissolved H2 gas in the field	X				$10,276
							Sub Total	**$10,276**

Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	8 sampling trips to Lake Vermillion and Soudan Mine, 4 in Y1, 4 in Y2	To collect water, microbial, dissolved gas, and sediment samples required for the completion of the project.					$37,600
	Miles/ Meals/ Lodging	2 trips to the MN DNR Drill Core Repository	To collect drill core samples for analyses as required for the completion of the proposed project.					$3,400
							Sub Total	**$41,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	2 peer-reviewed scientific journal papers	Dissemination of scientific findings as a result of the proposed work. Publishing fees include securing open access, guaranteeing access to the work for all without fee/subscription.					$6,000
							Sub Total	**$6,000**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$576,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Equipment		1 Variotech H2 tracer gas analyzer	Neither the Project Lead, nor the Co-investigators, have a field trace gas analyzer in possession or available to them. The acquisition of this equipment would save the project money overall by eliminating the need for expensive and time consuming H2 gas analysis by an external (contract) lab. **Additional Explanation :** The detection and measuring of dissolved H2 gas is difficult, but with appropriate equipment like a field trace gas analyzer, it is possible to determine the presence of dissolved H2 real time at sample locations. Using the field trace gas analyzer in lieu of expensive gas analysis via an external (contract) lab would be an overall cost savings.

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
In-Kind	Indirect costs for this proposal though not allowed, are listed as in-kind contribution of 54% MTDC which is the Federally Negotiated rate with the U of M. The indirect is proportionate to the awarded funds at a rate of 54% so if the award is reduced the F&A would be reduced.	Used for space, facilities and administrative costs	Secured	$565,038
			State Sub Total	**$565,038**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$565,038**

Total Project Cost: $1,141,038

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: fd7cb4a0-3db.pdf

Alternate Text for Visual Component

The figure has a simplified cartoon schematic representation of Lake Vermillion, Soudan Mine, and the areas where sampling would occur. It has text that reiterates the fundamental questions of the project (relating to unknowns regarding H2 production/consumption, especially for microbial community impact) and what the project will deliver....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
UMN Sponsored Projects Administration Approval for Submission	e4679677-df6.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care,

treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

Lori Nicol (Departmental Grants Management Administrator, College of Biological Sciences, University of Minnesota)

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

Yes, I understand