2019 Project Abstract
For the Period Ending June 30, 2022

PROJECT TITLE: Minerals and Water Research - Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction
PROJECT MANAGER: Rolf Weberg
AFFILIATION: University of Minnesota Duluth Natural Resources Research Institute
MAILING ADDRESS: 5013 Miller Trunk Hwy
CITY/STATE/ZIP: Duluth, MN 55811
PHONE: 218-788-2697
E-MAIL: rtweberg@d.umn.edu
WEBSITE: https://nrri.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)

APPROPRIATION AMOUNT: $300,000
AMOUNT SPENT: $280,972
AMOUNT REMAINING: $19,028

Sound bite of Project Outcomes and Results
The project provides a cost-effective process for treating wastewater to meet the wild rice sulfate standard of 10 mg/L. The data gathered from the field pilot trial at two wastewater treatment plants will help in implementing a full-scale treatment system to reduce sulfate level for protecting water resources in Minnesota.

Overall Project Outcome and Results

The State of Minnesota adopted a sulfate standard of 10 milligrams per liter (mg/L) for wild rice waters in 1973. Compliance with this standard is a challenge for small industries and municipalities as membrane-based technologies typically require high capital and operation costs. The Natural Resources Research Institute (NRRI) has developed a mobile treatment system based on barite precipitation reactions to reduce sulfate levels. In this project, NRRI deployed the trailer-based modular demonstration treatment system at two municipal wastewater treatment plants (WWTPs) in northeastern Minnesota to perform field pilot trials. The objectives of the field pilot trials were to:

(1) Evaluate the efficacy of the chemical precipitation process at a flow rate of 1-2 gallons per minute with different wastewater sources (domestic and industrial wastewater);
(2) Optimize the chemical reagent dosage levels; and
(3) Estimate the chemical reagent costs.

The pilot tests were conducted using effluent from the Virginia WWTP and the Grand Rapids WWTP from June 2021 until October 2021. The Virginia WWTP treats domestic wastewater exclusively, and the resulting effluent has relatively steady sulfate concentrations of 60 mg/L. The Grand Rapids WWTP treats a mixture of domestic wastewater and industrial wastewater supplied from a regional paper mill with a sulfate level ranging from 85 to 115 mg/L. The pilot test results indicated that the chemical precipitation system consistently reduced the sulfate levels of both wastewaters to below 10 mg/L with optimal chemical dosage rates. The chemical costs were estimated to be $2.27 and $5.50 per thousand gallons of effluent from Virginia and Grand Rapids wastewater treatment plants, respectively. Information gained from the field trials was used to develop guidelines for the future design and operation of a plant-scale system.

Project Results Use and Dissemination
This project has produced materials of interest to a wide variety of stakeholders, including the researchers, city councils, wastewater treatment plant operators, and the community. Among these products are presentations, posters, and videos. Sulfate treatment research results were presented in three conferences (Minnesota Water

Resources conference, The Society for Mining, Metallurgy & Exploration Inc. conference, and the International Mine Water Association conference), the Virginia City Council, and the University of Minnesota Duluth University for Seniors class. A YouTube video was created to describe the sulfate problem in Minnesota and our solution.

The full report is publicly available on the University of Minnesota Duluth Natural Resources Research Institute (NRRI) Website.

2019 Project Abstract
For the Period Ending June 30, 2022

PROJECT TITLE: Minerals and Water Research - Subproject 2: Western Mesabi Iron Resource Futures
PROJECT MANAGER: Rolf Weberg
AFFILIATION: University of Minnesota Duluth Natural Resources Research Institute
MAILING ADDRESS: 5013 Miller Trunk Hwy
CITY/STATE/ZIP: Duluth, MN 55811
PHONE: 218-788-2697
E-MAIL: rtweberg@d.umn.edu
WEBSITE: https://nrri.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)

APPROPRIATION AMOUNT: $275,000
AMOUNT SPENT: $275,000
AMOUNT REMAINING: $0

Sound bite of Project Outcomes and Results
This study initiated a long-term characterization program of the iron resources in Minnesota. Analysis of two sections of the iron formation produced a better understanding of the variability and potential for developing new iron-based products. With continued support, this program will provide a foundation for the future iron industry in Minnesota.

Overall Project Outcome and Results
Iron mining has been an important part of the economy of northern Minnesota for over a century. Today, mining companies process magnetite-rich taconite ore. Magnetite is important due to its chemical, magnetic, and thermal properties. All iron mining companies encounter magnetite that has been oxidized to various degrees. Minor amounts of oxidation can negatively impact the economic processing of iron ore, so oxidized material is either not mined or mined and stockpiled. Significant unoxidized parts of the iron formation are also stockpiled because they cannot be economically processed with current technology.

The purpose of this study was to initiate a long-term comprehensive characterization program of the remaining iron resources of the Mesabi Iron Range to provide a foundation for future iron industry in Minnesota. This data is being used to direct research in the areas of reducing reliance on fossil fuels, reducing emissions, and to identify and develop value-added iron products that could be produced from under-utilized portions of Minnesota iron resources. This approach can also be applied to understanding and processing waste iron stockpiles. This study has been leveraged to obtain additional State and Federal support for other mineral related studies in Minnesota.

Two complete sections of the iron formation were analyzed in this study. The results have contributed to a better understanding of the mineralogical variability within the iron formation; the impacts of oxidation on iron product quality; the potential for new iron-based products; and the presence of trace elements. Furthermore, this study also indicated that there may be a significant resource of siderite, an iron carbonate mineral, on the Mesabi Range. While siderite is unlikely to be a primary source of metallic iron, there may be other applications for siderite. Future research will focus on opportunities to reduce environmental impact while creating value-added iron products in Minnesota.

Project Results Use and Dissemination
- Presentations
    - Minnesota Minerals Coordinating Committee 2021 Virtual Cloquet Workshop Agenda Lightning Talks (4/23/2021)

- SME Minnesota Conference 2022 Presentations (4/13/2022)
- Minnesota Iron Ore and the Green Economy webinar (3/16/2022)

- Articles
  - Business North: *'Iron of the Future' program looks to new iron making technologies,* Lee Bloomquist Sep 16, 2021 Article.
  - Business North: *A bright future for mining,* Lee Bloomquist Dec 27, 2021 Article.
- Technical Report
  - Johnson, R.C., Mlinar, M.A., Spigarelli, B.P., Post, S. *Western Mesabi Iron Resource of the Future*. Natural Resources Research Institute. September, 2022. Report NRRI/TR-2022/11.

2019 Project Abstract
For the Period Ending June 30, 2022

PROJECT TITLE: Minerals and Water Research - Subproject 3: Develop emerging hydrometallurgy technologies
PROJECT MANAGER: Rolf Weberg
AFFILIATION: University of Minnesota Duluth Natural Resources Research Institute
MAILING ADDRESS: 5013 Miller Trunk Hwy
CITY/STATE/ZIP: Duluth, MN 55811
PHONE: 218-788-2697
E-MAIL: rtweberg@d.umn.edu
WEBSITE: https://nrri.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)

APPROPRIATION AMOUNT: $158,000
AMOUNT SPENT: $111,759
AMOUNT REMAINING: $46,241

Sound bite of Project Outcomes and Results

Based on outcomes of "voice of customer survey" and funding opportunities available through federal agencies, the project has identified emerging hydrometallurgical innovations with potential for processing Minnesota's in-situ and waste mineral resources with a reduced water, energy, and environmental footprint. The project has also identified bench-top hydrometallurgical research equipment required to initiate development of next generation value-added products from under-utilized and under-valued in-situ mineral and waste resources in Minnesota, specifically low-grade ores, waste tailings, metallurgical residues, incinerator ash, power plant combustion residues, and waste electrical and electronic equipment.

Overall Project Outcome and Results

Minnesota has abundant in-situ mineral resources, including deposits of iron, iron manganese, copper-nickel-cobalt-platinum group elements, titanium-vanadium, copper-zinc, gold with and without silver, sand, and aggregate. Commercial and industrial byproducts such as mine tailings, industrial residues, and waste electrical and electronic equipment also contain valuable mineral resources. To address significant environmental impact concerns associated with mining, collection, and processing of these materials, new processing technology approaches with reduced water and energy consumption and minimal environmental footprints are needed to support production of value-added products. Emerging hydrometallurgical processing technologies offer promising opportunities. To evaluate the technical, economic, and environmental benefits of emerging hydrometallurgical innovations, the Minnesota Legislative-Citizen's Commission on Minnesota Resources provided funding to the Natural Resources Research Institute (NRRI) to evaluate how to best support the development of emerging hydrometallurgical technologies in the state. The study highlights Minnesota's mineral and waste resources that have the highest potential for hydrometallurgical processing. The report also highlights key challenges anticipated by stakeholders during the commercial development of mineral and waste resources using hydrometallurgical technologies. The emerging hydrometallurgical innovations that may resolve various challenges are also identified by means of the stakeholder engagement survey and funding opportunities available through the federal agencies. The report summarizes research priorities that support development of emerging hydrometallurgical technologies in applications ranging from high-value materials to water remediation to carbon sequestration. The report shortlists key bench-scale and semi-pilot laboratory tools that will help NRRI to advance the readiness level of emerging hydrometallurgical technologies in Minnesota. The capital estimates for bench-top and semi-pilot laboratory prototypes range from $600,000 to $1.2 million. The personnel, installation, and collaboration costs range from $300,000 to $400,000.

Project Results Use and Dissemination

NRRI conducted a “Voice of Customer” survey through interviews with a broad range of stakeholders around the country. These included current or prospective mineral/metal producers, metal recyclers, hydrometallurgical R&D labs, engineering and technology providers, consultants, academia and educators, regulators, and federal agencies. The study produced a report of investigations of interest to wide variety of stakeholders, including regulators, mineral rights holder, federal agencies, prospective manufacturing and resource extraction companies, and the community.

Technical Report: Rao, S., Mlinar, M., Hudak, G., Kangas, K., and Peterson, D., 2022. Developing Emerging Hydrometallurgical Technologies: Report to the Legislative-Citizen Commission on Minnesota Resources. Natural Resources Research Institute, University of Minnesota Duluth, Report of Investigations NRRI/RI-2022/10. 179 p.

2019 Project Abstract
For the Period Ending June 30, 2021

PROJECT TITLE: Minerals and Water Research - Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota
PROJECT MANAGER: Rolf Weberg
AFFILIATION: University of Minnesota Duluth Natural Resources Research Institute
MAILING ADDRESS: 5013 Miller Trunk Hwy
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WEBSITE: https://nrri.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)

APPROPRIATION AMOUNT: $150,000
AMOUNT SPENT: $150,000
AMOUNT REMAINING: $0

Sound bite of Project Outcomes and Results
The purpose of this project was to provide a technology survey and a geographical recommendation of potentially feasible, non-battery, long-duration energy storage technology concepts that can utilize Minnesota's various topographies, geologies, and infrastructure to facilitate the state's renewable energy and greenhouse gas reduction goals. Numerous technology concepts with related siting recommendations are reported for consideration by state leaders.

Overall Project Outcome and Results
Achievement of Minnesota's renewable energy transition and associated greenhouse gas reduction goals requires development and installation of both short- and long-term energy storage capability. Battery storage options (lithium batteries) readily provide 2-4 hour duration storage. Longer-term (>8hr), high-capacity (35-200 milliwatt) storage can better facilitate capture of available renewable energy and potentially eliminate the need for natural gas-based peaking plants to provide a more stable electrical supply when intermittent resources (e.g., solar or wind) cannot supply the necessary electricity. Non-battery options harnessing physical principles involving gravity, compressed gas, waste heat and chemical processes can offer storage options with long lifetimes that do not require access to critical minerals and may offer safety improvements. Many of these options are in the development or demonstration phase and can take advantage of Minnesota's natural and man-made (former mine workings) topographical and geological features.

The project consisted of two parts. The first was a thorough survey of existing and emerging long-term, high-capacity, non-battery storage technologies with potential for applications in Minnesota. This entailed engagement with technology leaders, onsite concept evaluations and discussions with energy industry collaborators to characterize each technology. Identified technologies ranged from concepts that take advantage of mineland topographic features in northern Minnesota to others that could be deployed in municipalities or metropolitan areas. This information was collated into a summary format including industry contacts for each concept to facilitate follow-up by the state and/or industry.

The second part of the project entailed development of an interactive mapping tool to identify areas in the state where each identified technology might best be suited, considering the local topography, geology, and proximity to distribution infrastructure, industry, and applicable brownfield areas. This tool shows that there are multiple non-battery storage options in regions across Minnesota, primarily located in the vicinity of distribution infrastructure.

Project Results Use and Dissemination

The full report and three appendices are publicly available on the University of Minnesota Duluth Natural Resources Research Institute (NRRI) Website. NRRI:

- collaborated with Clean Energy Resource Teams (CERTs) personnel to organize two presentations to state stakeholders (agency, industry, academia, government) to communicate report findings and solicit feedback;
- presented to DER Energy Storage Workgroup meeting with Great River Energy and support from CERTs;
- was presented at a Minnesota House Climate and Energy Finance and Policy Committee hearing on renewable energy generation and storage; and
- Continues conversations with Minnesota Department of Commerce in conjunction with CERTs and University of Minnesota colleagues to model energy storage opportunities.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2019 ENRTF Final Work Plan (Main Document)

Today's Date: September 15, 2022

Final report

Date of Work Plan Approval: September 1, 2020

Project Completion Date: June 30, 2022

Does this submission include an amendment request? Yes

PROJECT TITLE: Minerals and Water Research

Project Manager: Rolf Weberg

Organization: Regents of the University of Minnesota

College/Department/Division: University of Minnesota-Duluth, Natural Resources Research Institute

Mailing Address: 1049 University Dr.

City/State/Zip Code: Duluth, MN 55812

Telephone Number: (218) 788-2697

Email Address: rtweberg@d.umn.edu

Web Address: https://www.d.umn.edu/

Location: Duluth, MN

Total Project Budget: $883,000.00
Amount Spent: $817,731.00
Balance: $65,269.00

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)

Appropriation Language: $883,000 the first year is to the Board of Regents of the University of Minnesota for academic and applied research through MnDRIVE at the Natural Resources Research Institute to develop and demonstrate technologies that enhance long-term Minnesota mineral opportunities. Of this amount:

(1) $300,000 is to support continued applied research to advance new technologies to improve water quality;

(2) $275,000 is to initiate the characterization of western Mesabi iron resources and development of next-generation Minnesota iron products;

(3) $158,000 is to develop emerging hydrometallurgy technology to support high-value mineral product development in Minnesota; and

(4) $150,000 is to support efforts of the Natural Resources Research Institute to accelerate demonstration of high-capacity, cost-effective energy storage using Minnesota's historical auxiliary mine lands.

This research must be conducted in consultation with the Minerals Coordinating Committee established under Minnesota Statutes, section 93.0015.

I. PROJECT STATEMENT:

The Mineral and Water Research project expands on the 2016 Legislative appropriation to accelerate applied research led by NRRI to advance economic and environmental opportunities & solutions associated with Minnesota's water and mineral resources in consultation with the Minerals Coordination Committee. Project outcomes are critical to the continued delivery of knowledge and solutions focused on Minnesota/regional challenges while also engaging key partners and collaborators and leveraging federal and industry funding.

The associated sub-projects were identified via continual broad consultation with Minnesota stakeholders, refined in legislative discussions and submitted as bills which were passed into this appropriation. Each sub-project has been designed, consistent with the final level of funding, to either deliver a final result or provide a significant step forward within the biennium timing.

There are 4 sub-projects, each focused on a specific aspect of Minnesota's mineral and water resources:

- Field demonstration of sulfate reduction technology targeting municipal water treatment facilities to provide affordable alternatives to water treatment
- Initiation of a new, long term effort to define technologies to utilize Minnesota's vast oxidized iron ore deposits to support Minnesota's future iron industry
- Define potential hydrometallurgy technologies that can afford differentiating opportunities for Minnesota mineral deposits
- Define renewable energy storage opportunities utilizing Minnesota's unique geology and water resources, including Minnesota's auxiliary mine lands.

This appropriation is to NRRI – Rolf Weberg is responsible for project outcomes, expenditures, and reporting responsibilities. Rolf Weberg serves as the sole point of contact for the project.

II. OVERALL PROJECT STATUS UPDATES:

First Update March 1, 2020

Each of the four sub-projects are managed by stage-gate project management practices during biweekly meetings to manage project execution and budgets, identify issues and resolutions, record progress via project tracking and maintain stakeholder engagement. The mobile sulfate reduction pilot trailer has been designed, the order is in process and testing is expected to initiate in late summer 2020. The Western Mesabi Iron Futures project has procured relevant core samples for evaluation and initial flowsheets have been proposed. A report of a long-term research project that provides the technical

foundation for the Emerging Hydrometallurgy Technologies project is being finalized and industry peers are ready to engage in providing input associated with the project goals. Technology scouting is nearly complete to identify high capacity/low cost renewable energy storage options for Minnesota.

AMENDMENT REQUEST May 8, 2020

Amendment request for Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction

We are requesting funds to be shifted from the travel, personnel, and lab supplies budget lines to capital equipment.

- The Travel budget would be reduced by $2,350 to a revised budget of $9,650
- The Personnel budget would be reduced by $2,625 to a revised budget of $231,425
- The Lab Supplies budget would be reduced by $2,035 to a revised budget of $39,965
- The Capital Equipment budget would be increased by $7,010 to a revised budget of $7,010

These changes are being requested because a refrigerated autosampler for the Subproject 1 would save travel to two wastewater treatment plants in Virginia and Grand Rapids, MN by saving travelling costs and personnel effort cost, and save material supplies.

To pay for these costs, we will be reducing field work travel from three times a week to two times a week. Fieldwork travel is able to be reduced because the autosampler can continuously collect samples. We are also able to reduce personnel costs because the refrigerated autosampler would save 25 trips to two wastewater treatment plants. Each round trip would average 3 hours. The overall lab supply costs would decrease because the sampling collection supplies and a refrigerator are included in the autosampler.

The Outcomes in Subproject 1 will remain the same.

Amendment Approved by LCCMR 6/4/2020.

Second Update September 1, 2020

Each project is making progress vs. objectives, but with timing adjustments due to interruptions from COVID-19 restrictions and supply chain delays. It is anticipated that no-cost extensions will be required to fulfill all project objectives. Despite fabrication delays, the sulfate reduction project is scheduled to deploy the mobile system in September, 2020. The Mesabi Iron project has completed initial ore characterization, but has endured delays in further analysis due to pandemic-impacted instrumentation availability. The Hydromet team has proceeded with stakeholder interviews, voice of customer collection and a global hydrometallurgy technology review. The renewable energy storage project has completed the technology survey and is developing criteria for recommendation for application in Minnesota.

Third Update March 1, 2021

Due to Covid-19 related delays, personnel availability and supply chain issues, a one-year, no-cost administrative extension ending June 30, 2022 per the legislative appropriation is requested to complete all project objectives.

An administrative amendment bringing the work plan completion date of these projects into agreement with the original legislative appropriation language was granted by LCCMR on 5/24/2021. The completion date of these projects is now June 30, 2022.

The mobile Sulfate Reduction equipment has been assembled and installed into a dedicated trailer; process commissioning and training is complete. An indoor demonstration is being carried out in preparation for deployment in Spring 2021. The Mesabi Iron project has completed characterization of 30 representative composite samples for chemical, mineralogical and metallurgical testing; processing evaluations have begun. The Hydrometallurgy team has completed a survey of emerging technologies with potential applications and has gathered relevant voice of customer feedback for entry into an interim report; work continues to identify resources needed to deploy such technologies in Minnesota. An interim report summarizing Minnesota-relevant energy storage technologies and developers has been prepared for review and the team is now considering siting options around the state.

AMENDMENT REQUEST March 1, 2021

Amendment request for Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction

We are requesting $4,000 to be moved from our academic professional and administrative (P&A) salary and fringe and move those costs to the temporary/casual salary and fringe. The overall amount within the Personnel section of the budget will remain the same.

- Personnel Academic P&A salary and fringe (in aggregate) would be reduced by $4,000 to a revised budget of $98,282
- Personnel Temporary/casual would be increased by $4,000 to a revised budget of $4,000

Due to a change in job status for a technician, we are requesting the temporary/casual line be opened. This employee has been working on this project, but their job class will be changing later this winter/spring.

The Outcomes in Subproject 1 will remain the same.

Amendment approved by LCCMR 5/24/2021

Amendment request for Subproject 2: Western Mesabi Iron Resource Futures

We are requesting funds be shifted from the Travel expenses in Minnesota to Personnel.

- Travel expenses in Minnesota would be reduced by $3,500 to a revised budget of $500
- Personnel would be increased by $3,500 to a revised budget of $238,931

These changes are being requested because more staff time is needed to accomplish Outcome #1 due to the number samples increasing from 26 to 30 total composite samples for analysis and testing. To pay for these costs, the project team will use virtual meetings instead of travel.

The Outcomes in Subproject 2 will remain the same.

Amendment approved by LCCMR 5/24/2021

Amendment request for Subproject 3: Develop emerging hydrometallurgy technologies

We are requesting funds be shifted from the Travel expenses in Minnesota budget line to Personnel.

- Travel expenses in Minnesota would be reduced by $9,500 to a revised budget of $500
- Personnel would increase by $9,500 to a revised budget of $138,478

These changes are being requested because more personnel time is needed to accomplish Outcome #1 due to hosting larger partner outreach meetings via videoconferencing instead of hosting face-to-face meetings with smaller groups. To pay for these costs, the project team will use less funding for travel.

The outcomes in Subproject 3 will remain the same.

Amendment approved by LCCMR 5/24/2021

Amendment request for Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota

We are requesting funds to be shifted from our Consultant and Travel costs and to move those funds to our Personnel costs for our personnel salary and fringe. The overall budget of $150,000 will remain unchanged.

- Consultant costs would be reduced by $25,000 to a revised budget of $0
- Travel costs would be reduced by $3,000 to a revised budget of $1,000
- Personnel costs for salary and fringe would be increased by $28,000 to a revised budget of $149,000

We are requesting a rebudget within our Personnel, Travel, and Consultant sections because the original concept as outlined by the consultant was found to be impractical for the chosen location. The monies from this aspect of the program were shifted to personnel to include other technology review for redox flow batteries and the use of hydrogen which were found to be technologies that could fulfill the role of longer duration storage. Due to the COVID-19 restrictions that have been implemented, the ability to travel across the state has been limited and the monies can be better used by doing more detailed computer modeling of potential locations for the various identified storage technologies.

The Outcomes in Subproject 4 will remain the same.

Amendment approved by LCCMR 5/24/2021

Fourth Update September 1, 2021

The Sulfate Reduction team successfully deployed and continuously operated the mobile pilot system at a Northern Minnesota municipal water treatment plant in June/July. Results consistently showed sulfate reduction from approximately 60 mg/L to below 10 mg/L. The system is now being deployed in a second Northern Minnesota treatment plant until the end of September to collect further data.

The Iron project team is completing detailed analyses of multiple samples to inform the development of an advanced metallurgical test program. The goal of this next phase is to recover both a magnetic iron concentrate and a non-magnetic iron concentrate from current mine waste-rock by employing a unique combination of separation technologies and characterization methods.

The Hydrometallurgy team created an interim summary of the work to date addressing Minnesota mineral and waste resource potential; hydrometallurgical technology landscaping; and stakeholder discussions. Based upon these three considerations, a list of seven research themes related to hydrometallurgical research was developed, discussed, and prioritized based upon internal discussions. These scenarios included potential research focus areas related to Minnesota ferrous, non-ferrous, and by-product/waste resources.

The Energy Storage team completed the project and produced the final report that summarizes significant non-battery, low-cost, high-capacity energy storage technologies relevant to Minnesota. Concurrent with this work, there was an interactive mapping tool developed to identify regions in Minnesota where each technology is most suitable. This report has been publicly released and will be shared with state agencies, legislators, industry, and other stakeholders in mid-September to identify potential next steps for Minnesota.

AMENDMENT REQUEST September 1, 2021:

Amendment request for Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota

We are requesting funds to be shifted from Travel to Personnel.

- Travel expenses would be reduced by $800 to a revised budget of $200
- Personnel expenses would be increased by $800 to a revised budget of $149,800

We are requesting a rebudget within the travel and personnel expenses because less travel was required due to COVID-19 and travel restrictions. Additional personnel time was required to examine how technologies could be sited within Minnesota based on geological features.

The Outcomes in Subproject 4 will remain the same.

Amendment approved by LCCMR 9/7/2021

AMENDMENT REQUEST January 26, 2022:

Amendment request for Subproject 2: Western Mesabi Iron Resource Futures

We are requesting funds to be shifted from Personnel to Professional/Technical/Service Contracts.

- Personnel expenses would be reduced by $7,431 to a revised budget of $231,500
- Professional/Technical/Service Contracts, for lab services, would be increased by $7,431 to a revised budget of $42,000

We are requesting a rebudget within the Contracts expense line because the project team requires thermal heat capacity (Cp) testing at XPS Labs to supplement the TGA-DSC testing that was conducted for the LCCMR-2019-Iron project. This new data will allow the team to quantify differences in energy requirements (e.g., endothermic vs. exothermic reactions) between different types of iron concentrates.

The Outcomes in Subproject 2 will remain the same.
Amendment approved by LCCMR 2/18/2022

Fifth Update March 1, 2022

The Sulfate Reduction team reports that the field pilot trials were performed in two municipal wastewater treatment plants in Northern MN from June 2nd to August 2nd, and from August 26th to October 8th. The combined results show that the barite precipitation technology consistently reduces sulfate concentrations to below 10 mg/L.

The Iron project team reports the full dataset for both drill core holes is nearly complete, with only a small number of chemical and thermal analyses to be completed before final reporting. The final technical report will summarize the characterization data and identify alternative production methods and product types needed for the future of the Western Mesabi Iron Range.

The Hydrometallurgy team reports that the technology survey has been leveraged to create an interim report that summarizes emerging hydrometallurgical technologies. The team is now creating an investment recommendation for instrumentation and equipment at NRRI to support introduction of hydrometallurgy into Minnesota's mineral industries.

The Energy Storage team reports the project was completed in the last reporting period.

Final Project Update: September 15, 2022

The deliverables for all four sub-projects associated with this project were fully completed:

The Sulfate Reduction project executed two successful, long-term pilot trials at regional municipal water treatment plants, demonstrating consistent reduction of sulfate contamination from a 60-115 mg/L range to <10 mg/L. Further work identified an approach to address precipitate scale on process equipment to extend operational capability. Research results are summarized in a technical report.
The Iron project has completed the data set for both drill holes which has provided a better understanding of the mineralogic controls on oxidation of the iron formation, the distribution of potentially valuable metals other than iron, the distribution of elements of environmental interest such as sulfur, mercury, and phosphorus, and potential impacts on final iron product quality. This knowledge

will be used to investigate more efficient processing methods and development of alternative iron-based products.
A technical report, available in September 2022, summarizes potential iron concentrates that could be produced from all units of the Mesabi Iron formation, recommends continued research opportunities including continued ore body characterization, development of alternate process technologies, minimization of environmental impacts and new iron-based products to diversify Minnesota's iron mining industry.

The Hydrometallurgy project has completed a detailed study highlighting challenges and opportunities associated with Minnesota's mineral and waste resources that have the highest potential for hydrometallurgical processing. Emerging hydrometallurgical innovations may offer options to resolve challenges identified in stakeholder surveys and could attract federal funding opportunities. A report summarizes research priorities for development of emerging hydrometallurgical technologies in applications ranging from high-value materials to water remediation to carbon sequestration, and recommends NRRI base investment to advance the technology readiness level of emerging technologies for potential application in Minnesota. The capital estimates for bench-top and semi-pilot laboratory prototypes range from $600,000 to $1.2 million.

The Energy Storage project was completed in a prior reporting period.

AMENDMENT REQUEST SEPTEMBER 15, 2022

Subproject 2: Western Mesabi Iron Resource Futures

We are requesting funds to be shifted to zero out funding categories

- Personnel would increase by $2,785 to a revised budget of $234,285
- Professional/Technical/Service Contracts would decrease by $2,191 to a revised budget of $39,809
- Supplies would decrease by $315 to a revised budget of $685
- Travel would decrease by $279 to a revised budget of $221

We are requesting a rebudget to reflect the small shifts in costs needed to close-out this subproject.

The Outcomes of this subproject remained the same.

Amendment approved by LCCMR 11/22/22

III. SUBPROJECTS AND OUTCOMES:

SUBPROJECT 1: Mobile Water Treatment Demonstration System for Sulfate Reduction

Description: Minnesota is globally unique in its need for a portfolio of viable approaches to reduce wastewater sulfate concentrations significantly below drinking water standards (250ppm) in wild rice regions. One technology - reverse osmosis - can reduce concentrations to 10ppm or lower, but at

operating costs that provide significant financial challenges to municipalities and industry while producing significant waste-sludge disposal issues. We propose to build a flexible, mobile demonstration system to scale up and demonstrate a treatment process based on chemical precipitation for deployment at municipal wastewater treatment facilities.

The design will be flexible to accommodate/add other developing water treatment technologies that address other water challenges in Minnesota such as excess phosphorus and nitrogen. This mobile system will support a chemical precipitation process capable of reducing sulfate concentrations from ~100 ppm to < 10 ppm and will contain a real-time monitoring laboratory to evaluate its performance and operation. Test operation will be conducted at the NRRI with synthetic or wastewater collected from facilities prior to the deployment. The mobile treatment system will be deployed at two municipal wastewater treatment plants to test and refine the chemical treatment system on site. Each will run for a duration of 1-3 months at least two seasons (summer and cold season). Treatment system performance will be evaluated through water chemistry, operational parameters, and waste management.

SUBPROJECT 1 ENRTF BUDGET: $300,000

Outcome	**Completion Date**
1. Design, assemble and commission a trailer-based mobile treatment system for in-the-field demonstration	9/30/2020
2. Deploy trailer-based system to two (2) wastewater treatment facilities for on-site testing including assessment of process efficacy, performance and economics.	6/30/2022
3. Project partner outreach will be ongoing throughout the 3-year term.	6/30/2022

First Update March 1, 2020

The project team finalized the mobile system design. The procurement of the mobile system (to be purchased with NRRI funds) was conducted by an open and competitive bid process through the University of Minnesota. Two manufacturers submitted their bids and an internal review of bids is expected to be complete shortly. Due to delays in equipment procurement, we expect field testing to be delayed until late summer, and will thus run for three months into the fall.

The team has identified potential suppliers for chemicals to be used in the pilot run. The project team engaged a regional city council to propose collaboration for pilot testing at their wastewater treatment plant, and the resulting application was approved. The team is currently working with the plant staff to develop test, safety and environmental procedures. A second test site is under discussion.

Second Update September 1, 2020

The manufacturers of the mobile water treatment system were selected and fabrication was initiated in April. Due to the COVID-19 pandemic, the delivery date is delayed until August. The project team has developed operation/safety/environment procedures. Chemical suppliers have been identified and the orders have been placed. Agreements have been established with two municipal wastewater treatment plants for pilot tests this year and next year.

Third Update March 1, 2021

The mobile pilot system was manufactured and delivered in two skid modules in late August. The skid modules were mounted and connected in an enclosed trailer. The project team developed operation, safety and environmental procedures. Engineers, technicians and operators were trained by the manufacturer and through a series of internal training modules. Due to Covid delays and supply chain interruptions, deployment to municipal water treatment facilities had to be delayed until spring 2021. The system operation parameters and mechanical performance are under evaluation via an indoor pilot trial, which is funded by an NRRI internal grant.

Fourth Update September 1, 2021

The mobile pilot system was deployed in one municipal wastewater treatment plant in Northern MN on June 2nd. The field pilot trial starting from June 4th was performed continuously to test the efficiency of low-concentration sulfate removal by chemical precipitation technology on a large scale, to estimate the cost of this process, and to evaluate the sludge recycling and production. The preliminary test results show that the chemical precipitation technology can continuously remove sulfate from 60 mg/L to below 10 mg/L. Sludge could be recycled to be used as a seed to assist the precipitation reaction. Regular system cleanup is required to remove sludge produced from the reaction and accumulated in the tanks. After the field pilot trial is completed in early August, the system will be moved to another wastewater treatment plant to perform the trial in late summer and early fall.

Fifth Update March 1, 2022

The field pilot trials were performed in two municipal wastewater treatment plants in Northern MN from June 2nd to August 2nd, and from August 26th to October 8th. The tests were run continuously on wastewater plant effluents. One of the plants, fed only by domestic wastewater, had an effluent sulfate concentration of approximately 60 mg/L. The other plant, fed by a mixture of industrial and domestic wastewater, had sulfate concentrations ranging from 80 mg/L to 120 mg/L. The later also contained chelating organics, which inhibited the barite precipitation reaction. Within each pilot trial, experiments were performed to optimize the chemical dosage amount, introduce coagulants as needed, demonstrate sludge recycling, and define design criteria of a future treatment plant. The combined results show that the barite precipitation technology consistently reduces sulfate concentrations to below 10 mg/L. The initial estimates for chemical costs of this sulfate reduction technology are approximately $2.27 and $5.88 per thousand gallons of water treated for each plant, respectively.

Final Report submitted within 45 days of project end

The State of Minnesota adopted a sulfate standard of 10 mg/L for wild rice waters in 1973. Compliance with this standard is a challenge for small industries and municipalities as membrane-based technologies typically require high capital and operation costs. The Natural Resources Research Institute (NRRI) has developed a mobile treatment system based on barite precipitation reactions to reduce sulfate levels. In this project, NRRI deployed the trailer-based modular demonstration treatment system at two municipal wastewater treatment plants (WWTPs) in northeastern Minnesota to perform field pilot trials. The objectives of the field pilot trials were to:

(1) Evaluate the efficacy of the chemical precipitation process at a flow rate of 1-2 GPM with different wastewater sources (domestic and industrial wastewater);

(2) Optimize the chemical reagent dosage levels; and

(3) Estimate the chemical reagent costs.

The pilot tests were conducted using effluent from the Virginia WWTP and the Grand Rapids WWTP from June 2021 until October 2021. The Virginia WWTP treats domestic wastewater exclusively, and the resulting effluent has relatively steady sulfate concentrations of 60 mg/L. The Grand Rapids WWTP treats a mixture of domestic wastewater and industrial wastewater supplied from a regional paper mill with a sulfate level ranging from 85 to 115 mg/L. The pilot test results indicated that the chemical precipitation system consistently reduced the sulfate levels of both wastewaters to below 10 mg/L with optimal chemical dosage rates. The chemical costs were estimated to be $2.27 and $5.50 per thousand gallons of effluent from Virginia and Grand Rapids wastewater treatment plants, respectively. Information gained from the field trials were used to develop guidelines for the future design and operation of a plant-scale system.

Field pilot trials in two wastewater treatment plants have confirmed the feasibility of using chemical precipitation technology to reduce sulfate levels below 10 mg/L from a starting concentration of between 60-115 mg/L. However, the particles produced from the precipitation reaction are prone to adsorb on the tank wall, generating a thick and hard layer of scale. The scale generation required periodic maintenance to remove it, which could potentially result in loss of treatment capacity, equipment malfunctioning, equipment replacement, and increased maintenance costs in a plant-scale system. The project team performed bench-scale tests and a 3-week indoor pilot trial to explore whether a ferric chloride pre-treatment could slow down scale generation and change the scale morphology. Both visual observation and sludge morphology examined by a scanning electron microscope (SEM) showed that ferric chloride changes the sludge morphology from small twinned flattened tabular crystals to large flattened tabular crystals, which probably helped reduce scale production and adhesion. All research results from the entire period were summarized to generate a technical report.

SUBPROJECT 2: Western Mesabi Iron Resource Futures

Description: This research will determine characteristics of iron formations to enable production of iron products from under-utilized/ under-valued ores, specifically oxidized and mixed oxidized/taconite ores. The process to recover magnetite from taconite ores was developed in response to the depletion of Minnesota's "natural" iron ore (produced from natural oxidation processes). Magnetite existing in taconite ores can be converted to hematite and/or goethite by a process called oxidation. However, today's operations avoid mining and processing oxidized iron ores. Furthermore, the taconite resources of the Mesabi Range are finite and the demand for blast furnace pellets is declining. The western Mesabi contains significant resources of oxidized and mixed oxidized / taconite ore. The purpose of this study is to initiate a long-term characterization program of the oxidized ores of the Western Mesabi Range to provide basis for future iron industry development in Minnesota.

Summing up in a "bigger picture" view vs. LCCMR goals, as indicated above, the state of Minnesota invested in development of the taconite process at the University of Minnesota. This project seeks to initiate a similar long-term effort to prepare for the state's future iron industry. To begin, systematic characterization of these more complex, future iron resources is expected to offer insights to how to best responsibly utilize iron mineral resources that are currently considered overburden, waste or spent resources. Extension and/or development of process technologies to allow use of these resources will be pursued to take advantage of this new knowledge and deliver improvements in efficiency and yield with an intended overall reduction in energy and water impacts. Continued production of feedstock for the blast furnace market coupled with participation in the electric arc furnace market provides a more resilient position for Minnesota's iron industry and brings more economic benefit to the state

Implementation of the characterization effort will require prioritization of geological sites and sampling approaches will be determined on the basis of material accessibility and collaboration with industry partners. Collaborative efforts will involve on-site visitation, laboratory work and group evaluation. Important characteristics to be assessed include mineralogy, liberation size, and chemical & thermal properties of the ores.

SUBPROJECT 2 ENRTF BUDGET: $275,000

Outcome	Completion Date
1. Determine the characteristics and variability of concentrate produced from the Western Mesabi Iron Range.	6/30/2022
2.Identify alternative production methods and product types that will need to be developed for the future of the Western Mesabi Iron Range.	6/30/2022
3. Project partner outreach will be ongoing throughout the 3-year term.	6/30/2022

First Update March 1, 2020

Four diamond drill core holes representing partially oxidized iron formations were selected and provided by an industry partner. All materials were logged and two of the samples were chosen for further evaluation to define experimental approaches, needed equipment and alternate material sources. The project team was assembled to initiate preparation of new separation flowsheet processes for development.

A new microscope and pellet press were purchased with NRRI internal funds to support the analysis of ore samples.

Next steps include sample processing for chemical and mineralogical characterization. Based upon these characterization results, the individual drill core samples will be composited together and subjected to further detailed characterization and metallurgical testing.

Second Update September 1, 2020

Drill core from two diamond drill holes containing partially oxidized iron formation have been crushed and prepared for characterization. Basic magnetic and mineralogy characterization has been completed. Further characterization awaits calibration of X-ray fluorescence instrumentation which has been severely delayed by Covid-10 pandemic limitations. Based upon the results of the characterization program on the individual drill core intervals, composite samples will be formed and prepared for more detailed characterization and for conventional iron ore metallurgical testing.

Third Update March 1, 2021

Basic mineralogic characterization was used to identify, form, and prepare thirty (30) composite samples for chemical, mineralogy, and metallurgical testing. The chemical analysis of the composites has been completed and included whole rock, trace, Rare Earth Element (REE), and low-level mercury (Hg) analyses. The mineralogy analysis of the composites has been completed. The results from the mineralogic analysis were used to identify composites for conventional magnetic and/or flotation metallurgical testing. Davis Magnetic Tube Tests (DMTT) simulate the Low Intensity Magnetic Separation (LIMS) concentrating technology used in the taconite iron ore operations on the Mesabi Range. Flotation is a concentrating technology used to recover non-magnetic iron minerals (hematite and goethite). To date, DMTT have been completed on the composites. The chemical analysis of DMTT concentrates and tails are in progress. Preliminary silica flotation tests to determine the optimal conditions for the flotation testing are in progress. Optical microscopy to determine the relationship of gangue (waste) and ore minerals has begun.

Fourth Update September 1, 2021

The basic characterization on the composite samples is complete, with the more detailed SEM/Microprobe analysis also nearly complete. The baseline metallurgical testing program on the composite samples is complete. Physical, chemical, and mineralogical analyses of the iron concentrate and tailings (waste) products are in progress; the analyses conducted on these products will be similar to the analyses that were conducted on the composite samples.

Two new samples are being formed to be used as feed samples for more advanced metallurgical testing and product characterization. For this testing program, both the iron concentrate and the tailings products will be subjected to flotation in an attempt to recover a magnetic iron (e.g., magnetite) concentrate and a non-magnetic iron (e.g., hematite and goethite) concentrate using a combination of technologies. Thermal characterization will be conducted on these products to quantify the impact each may have on a current induration circuit in a taconite processing facility.

Fifth Update March 1, 2022

The full dataset for both drill core holes is nearly complete, with only a small number of chemical and thermal analyses to be completed before final reporting. The final technical report will summarize the characterization data and identify alternative production methods and product types needed for the future of the Western Mesabi Iron Range. The report will be peer reviewed in Q2 2022 with final delivery to LCCMR by June 2022. Following the release of the final report, NRRI researchers will continue engaging the iron mining stakeholders in the state to identify future research opportunities.

The 2020 LCCMR appropriation (M.L.2021,Chp.6, Art.5, Sec.2, Subd.20a3, "Minerals and Water: Next-Generation Technologies and New Iron Products") will continue and expand upon the research that was initiated during this current appropriation by including one additional drill core sample, followed by flowsheet development for the oxidized iron resources.

Final Report submitted within 45 days of project end

Iron mining has been an important part of the economy of northern Minnesota for over a century. Today, mining companies process magnetite-rich taconite ore. Magnetite is important due to its chemical, magnetic, and thermal properties. All iron mining companies encounter magnetite that has been oxidized to various degrees. Minor amounts of oxidation can negatively impact the economic processing of iron ore, so oxidized material is either not mined or mined and stockpiled. Significant unoxidized parts of the iron formation are also stockpiled because they cannot be economically processed with current technology.

The purpose of this study was to initiate a long-term comprehensive characterization program of the remaining iron resources of the Mesabi Iron Range to provide a foundation for future iron industry in Minnesota. This data is being used to direct research in the areas of reducing reliance on fossil fuels, reducing emissions, and to identify and develop value-added iron products that could be produced from under-utilized portions of Minnesota iron resources. This approach can also be applied to understanding and processing waste iron stockpiles. This study has been leveraged to obtain additional State and Federal support for other mineral related studies in Minnesota.

Two complete sections of the iron formation were analyzed in this study. The results have contributed to a better understanding of the mineralogical variability within the iron formation; the impacts of oxidation on iron product quality; the potential for new iron-based products; and the presence of trace elements. Furthermore, this study also indicated that there may be a significant resource of siderite, an iron carbonate mineral, on the Mesabi Range. While siderite is unlikely to be a primary source of

metallic iron, there may be other applications for siderite. Future research will focus on opportunities to reduce environmental impact while creating value-added iron products in Minnesota.
The data set for both drill holes is complete and includes drill core logs, chemical, mineralogic, and metallurgical analyses of all units in the Biwabik Iron Formation. The data collected has provided a better understanding of the mineralogic controls on oxidation of the iron formation. The data has also provided an understanding of the processing characteristics of oxidized portions of the iron formation and some of the impacts that oxidation has on product quality. This knowledge will be used to investigate more efficient processing methods and development of alternative iron-based products. The data collected includes major and trace element chemical analysis that provides valuable information for the distribution of potentially valuable metals other than iron, and the distribution of elements of environmental interest such as sulfur, mercury, and phosphorus.

The technical report includes a discussion of the quality of iron concentrates that could be produced from all units of the iron formation, but especially the underutilized portions of the iron formation that are currently not mined or discarded as waste. The technical report also discusses the distribution and mode of occurrence of elements of environmental concern such as sulfur, mercury, and phosphorous. The report also includes recommendations for continued research to develop processes to reduce emissions associated with iron ore mining and processing, develop alternate mineral processing methods, and investigate alternative iron-based products to diversify Minnesota's iron mining industry. The final technical report will be available for distribution to stakeholders in September, 2022.

SUBPROJECT 3: Develop emerging hydrometallurgy technologies

Description: This research project will identify and evaluate emerging hydrometallurgical technologies with applications for processing Minnesota mineral and waste resources leading to the design of a bench- and pilot-scale hydrometallurgical research facility at UMN. Recent advances in hydrometallurgical processing offers unique capability to individually extract high value metal products from Minnesota mineral resources and mineral-based waste materials at high purity, reduced energy consumption and closed loop water cycling systems. Such capability should also allow collection of metallic by-products currently left unmanaged for enhanced economic and environmental benefit to Minnesota. Implementation of hydrometallurgical processing may ultimately enable enhancement of a circular economy approach for metallic resources and waste streams.

The project will directly engage industry and engineering collaborators across the state in the identification and evaluation of the relevance of current and emerging hydrometallurgical technologies to Minnesota mineral resources and waste materials. This includes benchmarking of current North American hydrometallurgical processing research capabilities and applicability to Minnesota resources. Travel to state collaborator locations will be included in both activities. Research results will be employed to develop a capital, equipment and process plan, as well as a government and industry funding strategy. The results of this study will provide the foundation for the concept and design development for a unique, industry-valued hydrometallurgical research facility at the NRRI Coleraine Laboratory.

SUBPROJECT 3 ENRTF BUDGET: $158,000

Outcome	Completion Date
1. Review and identify current hydrometallurgical technologies that can be utilized to process known Minnesota mineral resources and waste resources.	6/30/2021
2. Define an industry-valued hydrometallurgical facility; deliver a capital, equipment, and process plan including conceptual design, propose a funding strategy for obtaining federal assistance, and propose a plan to build such a facility at the NRRI Coleraine Laboratory.	6/30/2022
3. Project partner outreach will be ongoing throughout the ~~2~~3-year term.	6/30/2022

First Update March 1, 2020

A long-term development project to evaluate unique hydrometallurgical technology was completed in collaboration with a Canadian partner. An extensive technical report summarizing learnings and technology gaps is nearly complete. This report will form the foundation for an engagement with industry experts well-versed in the technology.

Next steps: the report will be shared with industry peers for critique, voice of the customer and identification of appropriate additions to the research team. This team will finalize the research program based upon feedback and analysis.

Second Update September 1, 2020

A long-term development project to evaluate unique hydrometallurgical technology was completed in collaboration with a Canadian partner and the final report is nearly complete. The current project team has been researching 1) Minnesota mineral and waste resources, and 2) hydrometallurgical technology landscaping for those resources that are most understood in Minnesota. Concurrently, the team has also been engaging stakeholders in the Minnesota and North American minerals and metals industry. Fifteen stakeholders were interviewed to date to provide their input and perspective on the potential role of hydrometallurgy in the Minnesota minerals and metals industry, with additional stakeholders being contacted in the near future.

Following the completion of the Minnesota mineral and waste resource potential, hydrometallurgical technology landscaping, and stakeholder interviews efforts, a conceptual design for a hydrometallurgy laboratory at NRRI will be produced and shared with stakeholders for feedback.

Third Update March 1, 2021

During this reporting period, a technology review to understand the current state of hydrometallurgical technologies for processing Minnesota-specific mineral and waste resources was finalized. The focus was on emerging hydrometallurgical techniques rather than high temperature pyrometallurgical

(smelting) methods to process Minnesota's mineral and waste resources containing titanium, manganese, iron, copper, nickel, cobalt, and platinum group elements. The research team is examining the potential application of hydrometallurgical processes on treatment of mine waste solids & effluent, and environmental remediation. A total of twenty (20) key stakeholders were interviewed by the team to understand research needs. The mineral resources and the landscape of technologies is summarized in an interim report.

Next steps are to identify and evaluate research tools and technologies to enable the production of high-value-added products while offering opportunities for waste minimization, waste residue processing, and effluent treatment. Applied research tools will include:

- Benchtop reactors to support aqueous chemistry and electrochemical research.
- Analytical tools to characterize process inputs and outputs.
- Mathematical simulation and modelling tools to quantify the energy, water, emission and overall lifecycle impact of the emerging hydrometallurgical techniques.

Fourth Update September 1, 2021

An interim summary of the work to date was assembled addressing Minnesota mineral and waste resource potential; hydrometallurgical technology landscaping; and stakeholder discussions (e.g., "Voice of Customer" problem interviews). Based upon these three considerations, a list of research themes related to hydrometallurgical research was developed, discussed, and prioritized based upon internal discussions. These scenarios included potential research focus areas related to Minnesota ferrous, non-ferrous, and by-product/waste resources.

The next step is to assemble potential hydrometallurgical concepts and share with external partners. Following the completion of this task, a conceptual engineering and capital plan will be developed to obtain the required R&D equipment, software, analytical tools, facilities, and personnel to start developing hydrometallurgical solutions to mineral challenges.

Fifth Update March 1, 2022

The technology survey has been leveraged to create an interim report that summarizes emerging hydrometallurgical technologies that may: 1) provide clean water from future mine discharges and impaired waters surrounding the geologic formations, 2) enable CO2 storage sites in non-ferrous geological formations of Minnesota, 3) supply critical raw materials for renewables-based electrification from Minnesota's non-ferrous mineral resources, and 4) create value-added materials from non-ferrous waste, tailings, and low-grade ores. Information on each technology is presented in summary format, noting the developers responsible for each technology. The team is now creating an investment recommendation for instrumentation and equipment at NRRI to support introduction of hydrometallurgy into Minnesota's mineral industries.

Final Report submitted within 45 days of project end

Minnesota has abundant in-situ mineral resources, including deposits of iron, iron manganese, copper-nickel- cobalt-platinum group elements, titanium-vanadium, copper-zinc, gold with and without silver, sand, and aggregate. Commercial and industrial byproducts such as mine tailings, industrial residues, and waste electrical and electronic equipment also contain valuable mineral resources. To address

significant environmental impact concerns associated with mining, collection and processing of these materials, new processing technology approaches with reduced water and energy consumption and minimal environmental footprints are needed to support production of value-added products. Emerging hydrometallurgical processing technologies offer promising opportunities. To evaluate the technical, economic, and environmental benefits of emerging hydrometallurgical innovations, the Minnesota Legislative-Citizen's Commission on Minnesota Resources (LCCMR) provided funding to the Natural Resources Research Institute (NRRI) to evaluate how to best support the development of emerging hydrometallurgical technologies in the state. The study highlights Minnesota's mineral and waste resources that have the highest potential for hydrometallurgical processing. The report also highlights key challenges anticipated by stakeholders during the commercial development of mineral and waste resources using hydrometallurgical technologies. The emerging hydrometallurgical innovations that may resolve various challenges are also identified by means of the stakeholder engagement survey and funding opportunities available through the federal agencies. The report summarizes research priorities that support development of emerging hydrometallurgical technologies in applications ranging from high-value materials to water remediation to carbon sequestration. The report shortlists key bench-scale and semi-pilot laboratory tools that will help NRRI to advance technological readiness level of emerging hydrometallurgical technologies in Minnesota. The capital estimates for bench-top and semi-pilot laboratory prototypes range from $600,000 to $1.2 million. The personnel, installation, and collaboration costs range from $300,000 to $400,000.

The final report highlights Minnesota's mineral and waste resources that have the highest potential for hydrometallurgical processing. The report also lists key challenges identified in stakeholder engagement surveys and potential federal funding opportunities. The report summarizes research priorities that support development of emerging hydrometallurgical technologies in applications ranging from high-value materials to water remediation to carbon sequestration. The report recommends key bench-top and semi-pilot laboratory equipment, personal, and analytical investments that will allow NRRI to advance technology readiness level of emerging technologies for application in Minnesota. The capital estimates for bench-top and semi-pilot laboratory equipment range from $600,000 to $1.2 million.

SUBPROJECT 4: Accelerate high capacity/low cost energy storage options for Minnesota

Description: This research aims to develop an understanding of Minnesota-relevant technologies that allow high-capacity, low-cost energy storage (>40 MW) with a significant duration of electrical release (durations exceeding 4 to 6 h) that will support efficient integration of renewable energy sources into the grid. This will involve an examination of both conventional and emerging technologies applied to unique circumstances in Minnesota, including utilization of auxiliary mine lands that are currently unproductive. This effort will engage industry partners, the Minnesota power industry and other collaborators in evaluation of technologies and potential match with industry needs. Some of these activities will involve site visits and technology presentations. The documented results of the study will allow decision makers to better define Minnesota's energy storage strategy, understand what is logistically and economically feasible for Minnesota and identify specific locations where technology installations could be implemented

SUBPROJECT 4 ENRTF BUDGET: $150,000

Outcome	Completion Date
1. Conduct a review of various technologies that allow high duration energy storage at greater than 40 MW capacity to be attained at low system capital and operating costs	3/31/2021
2. Identify logistically and economically feasible locations within the state where the technologies can be located that minimizes new distribution costs for the electricity	6/30/2022
3. Project partner outreach will be ongoing throughout the 3-year term.	6/30/2022

First Update March 1, 2020

A technology survey was initiated to identify specific technologies that have potential for Minnesota. The scope is to consider non-battery energy storage technologies that will take advantage of our local geology, past industrial applications, and meet the future needs of longer duration storage to facilitate renewable energy implementation.

The survey identified several technologies that are under consideration. All systems being considered will allow longer duration (>8h) storage to be achieved and at significant capacity (>35 MW to 200 MW).

Next steps involve deep dives into attributes of each technology and regional fit around Minnesota. These activities will involve on-site evaluations and engagement with technology leaders, regional leaders and energy industry representatives.

Second Update September 1, 2020

A technology review was undertaken to learn what significant non-battery technologies are under active development that could meet longer duration renewable energy storage requirements. The technologies reviewed included techniques using gravity, compressed air, and molten salt. The details of the various technologies are being summarized in report form. The team is also developing an approach for examining how the various technologies could be applied across the state that takes into account power generation & distribution, landscape & geology and individual technology requirements.

Third Update March 1, 2021

An interim report has been prepared which summarizes various energy storage technologies beyond the typical lithium ion battery systems generally employed today. Information on each technology is presented in summary format, noting the developers responsible for each technology. The team is now examining how these technologies can be sited within Minnesota based on geological features, availability of waste heat sources, and the interaction with other industrial opportunities such as mining materials to create caverns for energy storage or use of brown field sites for technology adoption.

Fourth Update September 1, 2021

The Energy Storage team completed the project and produced the final report that summarizes significant non-battery, low-cost, high-capacity energy storage technologies relevant to Minnesota. Concurrent with this work, there was an interactive mapping tool developed to identify regions in Minnesota where each technology is most suitable. This report has been publicly released and will be shared with state agencies, legislators, industry, and other stakeholders in mid-September to identify potential next steps for Minnesota.

Fifth Update March 1, 2022

The project was completed in the last reporting period.

Final Report submitted within 45 days of project end

Achievement of Minnesota's renewable energy transition and associated greenhouse gas (GHG) reduction goals requires development and installation of both short and long-term energy storage capability. Battery storage options (lithium batteries) readily provide 2-4 hour duration storage. Longer-term (>8hr), high-capacity (35-200MW) storage can better facilitate capture of available renewable energy and potentially eliminate the need for natural gas-based peaking plants to provide a more stable electrical supply when intermittent (e.g., solar or wind) resources cannot supply the necessary electricity. Non-battery options harnessing physical principles involving gravity, compressed gas, waste heat and chemical processes can offer storage options with long lifetime that do not require access to critical minerals and may offer safety improvements. Many of these options are in the development or demonstration phase and can take advantage of Minnesota's natural and man-made (former mine workings) topographical and geological features.

The project consisted of two parts. The first was a thorough survey of existing and emerging long-term, high-capacity, non-battery storage technologies with potential for applications in Minnesota. This entailed engagement with technology leaders, onsite concept evaluations and discussions with energy industry collaborators to characterize each technology. Identified technologies ranged from concepts that take advantage of mineland topographic features in northern Minnesota to others that could be deployed in municipalities or metropolitan areas. This information was collated into a summary format including industry contacts for each concept to facilitate follow-up by the state and/or industry.

The second part of the project entailed development of an interactive mapping tool to identify areas in the state where each identified technology might best be suited, considering the local topography, geology, and proximity to distribution infrastructure, industry and applicable brownfield areas. This tool

shows that there are multiple non-battery storage options in regions across Minnesota, primarily located in the vicinity of distribution infrastructure.
The project was completed in 2021. Copies of/links to the final report are furnished periodically to interested parties.

IV. DISSEMINATION:

In addition to LCCMR reporting requirements, overall project deliverables and research results will be disseminated via multiple outlets including:

- Web-based presentations to engage stakeholders including cognizant local, state, and federal government agency representatives and key industry partners.
- Workshop for wastewater treatment plant operators and regulators (eg MPCA) to disseminate the results of pilot testing.

The Minnesota Environment and Natural Resources Trust Fund (ENRTF) will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENRTF Acknowledgement Guidelines.

First update—waived by LCCMR 3/15/2021
Second update—waived by LCCMR 3/15/2021
Third update March 1, 2021

- Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction: The team has engaged targeted communities (Virginia & Grand Rapids) to execute operational agreements in support of Spring 2021 deployment & provided general outline of operations to water treatment facility operators.
- Subproject 2: Western Mesabi Iron Resource Futures: No formal dissemination activities planned or executed during this period.
- Subproject 3: Develop emerging hydrometallurgy technologies: No formal dissemination activities planned or executed during this period.
- Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota: No formal dissemination activities planned or executed during this period.

Fourth Update September 1, 2021

- Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction:
    - The sulfate reduction technology video was created on the field pilot trial site and uploaded to youtube (https://youtu.be/foFrU0sEFNs)
    - Virginia City Council visit and discussion (7/13/2021)
- Subproject 2: Western Mesabi Iron Resource Futures:
    - SME Minnesota Conference 2021 Presentation (4/13/2021)
    - Minnesota Minerals Coordinating Committee 2021 Virtual Cloquet Workshop Agenda Lightning Talks (4/23/2021)
- Subproject 3: Develop emerging hydrometallurgy technologies:

- No formal dissemination activities planned or executed during this period.
- Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota:
  - Final report shared with the NRRI Advisory Board for their review and dissemination within their stakeholder groups.
  - Collaboration between CERTs and NRRI to have two public presentations/discussions regarding the final report with state stakeholders on September 21 and 23, 2021.

Fifth Update March 1, 2022

- Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction:
  1. International Mine Water Association annual meeting in July 2021, a poster was presented
  2. Minnesota Water Resources Conference in October 2021, one oral presentation was made to present the field pilot trial results
  3. Virginia City Council meeting in November 2021, the sulfate project results were presented to the city council
- Subproject 2: Western Mesabi Iron Resource Futures:
  - The following two articles were written for Business North and reference the "Iron of the Future" initiative, of which this current LCCMR appropriation project is associated with:
    - Article in Business North: 'Iron of the Future' program looks to new iron making technologies by Lee Bloomquist Sep 16, 2021: http://www.businessnorth.com/businessnorth_exclusives/iron-of-the-future-program-looks-to-new-iron-making-technologies/article_3f407442-171a-11ec-8067-b35068c6bfd9.html
    - Article in Business North: A bright future for mining by Lee Bloomquist Dec 27, 2021: http://www.businessnorth.com/around_the_region/a-bright-future-for-mining/article_f321c65c-674a-11ec-8a7f-5399e1193fbd.html

- Subproject 3: Develop emerging hydrometallurgy technologies:
  - No formal dissemination activities planned or executed during this period
- Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota:
  - The final technical report has been shared around the state in collaboration with University of Minnesota CERTs; various state agencies, industry representatives, and NGOs participated in two webinars hosted by CERTs.
  - Further conversations are occurring with MN Department of Commerce

Final Report submitted within 45 days of project end

- Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction:
  - Oral presentation:
    - The University for Seniors class in UMD (Febuary 8, 2022)
    - Minnesota Society for Mining, Metallurgy & Exploration Conference (4/13/2022)
- Subproject 2: Western Mesabi Iron Resource Futures:
  - Presentations:

        - Minnesota Minerals Coordinating Committee 2021 Virtual Cloquet Workshop Agenda Lightning Talks (4/23/2021)
        - SME Minnesota Conference 2022 Presentations (4/13/2022)
        - Minnesota Iron Ore and the Green Economy webinar (3/16/22)
    - Articles:
        - Business North: 'Iron of the Future' program looks to new iron making technologies, Lee Bloomquist Sep 16, 2021 Article.
        - Business North: A bright future for mining, Lee Bloomquist Dec 27, 2021 Article.
    - Technical Report:
        - Johnson, R.C., Mlinar, M.A., Spigarelli, B.P., Post, S. Western Mesabi Iron Resource of the Future. Natural Resources Research Institute. August XX, 2022. Report NRRI/TR-2022/11.
- Subproject 3: Develop emerging hydrometallurgy technologies:
    - Public Outreach: NRRI conducted a "Voice of Customer" (VOC) survey involving 20 external participants. The purpose of this stakeholder engagement was to:
        - better understand the current and future needs of Minnesota's minerals industries;
        - understand current hydrometallurgical technologies and plant practices;
        - inform research strategies and prioritize technology development; and
        - As part of the survey, the team interviewed various stakeholders in a cross section within different stakeholder segments. The survey was accomplished through interviews with a broad range of stakeholders around the country. These included current or prospective mineral/metal producers, metal recyclers, hydrometallurgical R&D labs, engineering and technology providers, consultants, academia and educators, regulators, and federal agencies.
    - Technical Report: Rao, S., Mlinar, M., Hudak, G., Kangas, K., and Peterson, D., 2022. Opportunities offered by emerging hydrometallurgical technologies: Report to the Legislative-Citizen Commission on Minnesota Resources. Natural Resources Research Institute, University of Minnesota Duluth, Report of Investigations NRRI/RI-2022/10. 170 p.
- Subproject 4: Accelerate high capacity/low cost energy storage options for Minnesota:
    - Report continues to be accessed via NRRI website and/or furnished via links upon request from interested parties.

V. ADDITIONAL BUDGET INFORMATION:

A. Personnel and Capital Expenditures

Explanation of Capital Expenditures Greater Than $5,000: We plan on using funding to purchase a ISCO sequential and refrigerated Autosampler from Tech Sales Co ($7,010). The NRRI has an active sulfate reduction program investigating cost-effective chemical precipitation technology in removing sulfate

from wastewater to below 10 ppm. Based on successful lab test results, this program is going to demonstrate pilot tests in two wastewater treatment plants in near cities.

This sequential and refrigerated autosampler together with 24 sampling bottles are essential for this program. Samples can be collected in a designed frequency and will be preserved in a refrigerator for measurement. The continuous sample collection can provide more data to closely monitoring system performance even during night or weekend. It also saves an average of 3 hours for each trip, therefore saves personal time and travelling costs. Amendment Approved by LCCMR 6/4/2020

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours for entire duration of project: 16,500	Divide total personnel hours by 2,080 hours in 1 yr = TOTAL FTE: 4.0

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

Enter Total Estimated Contract Personnel Hours for entire duration of project: 1,000	Divide total contract hours by 2,080 hours in 1 yr = TOTAL FTE: 0.25

VI. PROJECT PARTNERS:

A. Partners outside of project manager's organization receiving ENRTF funding

Subproject 1: *Mobile Water Treatment Demonstration System for Sulfate Reduction*

- External partners have not been confirmed to date, but will include two wastewater treatment plant operators.

Subproject 3: *Develop emerging hydrometallurgy technologies*

- External consulting expertise (to be determined) in hydrometallurgical processing will be contracted.

Subproject 4: *Accelerate high capacity/low cost energy storage options for Minnesota*

- The project will utilize external expertise/consultants (to be determined) for the evaluation of unique geological formations specific to Minnesota's Southeast region.

B. Partners outside of project manager's organization NOT receiving ENRTF funding

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

Innovative, integrated solutions are required to help Minnesota's natural resource-based industries evolve and thrive while also maintaining commitments to the environment and our communities. This project will have long-term impacts on the creation of new understanding and the delivery of working

systems concerning stewardship of Minnesota water resources, definition of future, diversified mineral opportunities and potential use of Minnesota auxiliary mine lands for renewable energy storage. These delivery points are consistent with the state's goals concerning energy & carbon reduction, environmental stewardship, industry growth opportunities and community support & development. This work will leverage long-term relationships and public & private funding opportunities.

VIII. REPORTING REQUIREMENTS:

- Project status update reports will be submitted March 1 and September 1 each year of the project
- A final report and associated products will be submitted within 45 days of project end

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Final Budget Spreadsheet

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)
Project Manager: Rolf Weberg
Project Title: Minerals and Water Research
Organization: Natural Resources Research Institute, University of Minnesota Duluth
Project Budget: $883,000
Project Length and Completion Date: 3 years, June 30, 2022
Today's Date: 9/15/2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Budget 06/30/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 753,988	$ 720,511	$ 33,477
Professional/Technical/Service Contracts	$ 64,781	$ 43,226	$ 21,555
Equipment / Tools / Supplies	$ 47,660	$ 41,204	$ 6,456
Travel expenses in Minnesota	$ 10,571	$ 7,111	$ 3,460
Other	$ 6,000	$ 5,679	$ 321
COLUMN TOTAL	$ 883,000	$ 817,731	$ 65,269

OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Revised Budget 06/30/2022	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Amount legally obligated but not yet spent	Revised Budget 06/30/2022	Spent	Balance
Current appropriation:		$ -	$ -	$ -
Past appropriations:		$ -	$ -	$ -

The amounts on this page will automatically update, based on entries made for sub-projects 1-4.

Cells C13:E23 are locked to protect the formulas. If changes are necessary, select **Review | Unprotect Sheet.** This note will not print.

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Final Budget Spreadsheet

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)
Sub-project Manager: Lucinda Johnson
Sub-project Title: Mobile Water Treatment Demonstration System for Sulfate Redu
Organization: Natural Resources Research Institute, University of Minnesota Duluth
Sub-project Budget: $300,000
Project Length and Completion Date: 3 years, June 30, 2022
Today's Date: 9/15/2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 03/01/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 231,425	$ 224,667	$ 6,758
Lucinda Johnson, NRRI Research Director: $4,410 (74% salary, 26% fringe); 1% FTE for 2 years			
Academic P&A (in aggregate): 6 staff members est. total: $98,282 (74% salary, 26% fringe), 43.4% FTE Year 1, 34.3% FTE Year 2			
Civil Service (in aggregate): 6 staff members est. total: $106,038 (77% salary, 23% fringe), 55% FTE Year 1, 80% FTE Year 2			
Undergraduate student: $18,695 (100% salary, 0% fringe); 20% FTE Academic Year 1 & 2, 56.8% FTE Summer Year 1 & 2			
Temporary/casual: $4,000 (92.6% salary, 7.4% fringe); 14.8% FTE Year2			
Professional/Technical/Service Contracts	$ 5,950	$ 3,417	$ 2,533
PRO-Senthil-Consulting for pilot system construction. Purchasing and/or bidding of project services will comply with Minnesota Statutes pertaining to purchasing, procurement and contracting as well as the UMN Purchasing Goods and Services Admin. Policy.			
Equipment/Tools/Supplies	$ 46,975	$ 40,519	$ 6,456
Plasticware, reactor material, electrode, and DNA preparation materials for field sampling, water quality analyses. Sonde components to measure pH, conductivity, turbidity, temperature, flow.	$ 39,965	$ 33,509	$ 6,456
ISCO sequential and refrigerated Autosampler. Samples can be collected in a designed frequency and will be preserved in a refrigerator for measurement. The continuous sample collection can provide more data to closely monitoring system performance even during night or weekend.	$ 7,010	$ 7,010	$ -

Travel	$ 9,650	$ 6,690	$ 2,960
Sample collection and field testing for costs including mileage, lodging and allowable meals			
Other			
External lab analysis	$ 6,000	$ 5,679	$ 321
COLUMN TOTAL	$ 300,000	$ 280,972	$ 19,028

OTHER FUNDS CONTRIBUTED TO THE PROJECT	**Status (secured or pending)**	**Budget 03/01/2022**	**Spent**	**Balance**
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	**Amount legally obligated but not yet spent**	**Budget 03/01/2022**	**Spent**	**Balance**
Current appropriation:		$ -	$ -	$ -
Past appropriations:		$ -	$ -	$ -

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Final Budget Spreadsheet

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)
Sub-project Manager: Rod Johnson
Sub-project Title: Western Mesabi Iron Resource Futures (sub project #2)
Organization: Natural Resources Research Institute, University of Minnesota Duluth
Sub-project Budget: $275,000
Project Length and Completion Date: 3 years, June 30, 2022
Today's Date: 9/15/2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Budget 6/30/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 234,285	$ 234,285	$ -
Rod Johnson, NRRI Endowed Taconite Chair: $46,787 (74% salary, 26% fringe), 15% FTE for 2 years			
7 Academic P&A: NRRI researchers & project manager est. total: $74,363 (74% salary, 26% fringe), 36% Total FTE over 2 years			
2 Civil Service technicians: Lab techs est. total: $110,350 (74% salary, 26% fringe), 85% Total FTE over 2 years			
Professional/Technical/Service Contracts			
Lab services for chemical and thermal analses of production samples.	$ 39,809	$ 39,809	$ -
Equipment/Tools/Supplies			
Lab supplies to include sampling tools and lab analyses	$ 685	$ 685	$ -
Travel expenses in Minnesota			
Estimated monthly MN travel in coordination wtih industry partners to geological sites to determine sampling approaches and materials accessibility. with industry and University partners. Costs to include	$ 221	$ 221	$ -
Other	$ -	$ -	$ -
COLUMN TOTAL	$ 275,000	$ 275,000	$ -

OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Revised Budget 6/30/2022	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Amount legally obligated but not yet spent	Revised Budget 6/30/2022	Spent	Balance
Current appropriation:		$ -	$ -	$ -
Past appropriations:		$ -	$ -	$ -

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Final Budget Spreadsheet

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)
Sub-project Manager: George Hudak
Sub-project Title: Develop emerging hydrometallurgy technologies (sub-project #3)
Organization: Natural Resources Research Institute, University of Minnesota Duluth
Sub-project Budget: $158,000
Project Length and Completion Date: 3 years, June 30, 2022
Today's Date: 9/15/2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 03/01/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 138,478	$ 111,759	$ 26,719
George Hudak, NRRI Research Director: $17,499 (74% salary, 26% fringe), 5% FTE for 2 years			
Academic P&A (in aggregate): 7 NRRI staff members est. total: $120,979 (74% salary, 26% fringe), 37% Total FTE over 2 years			
Professional/Technical/Service Contracts			
TBD Mineral processing expertise to assist in the evaluation of hydrometallurgical technologies and applications to MN mineral resources and waste materials. Purchasing and/or bidding of project services will comply with Minnesota Statutes pertaining to purchasing, procurement and contracting as well as the UMN Purchasing Goods and Services Admin. Policy.	$ 19,022	$ -	$ 19,022
Equipment/Tools/Supplies	$ -	$ -	$ -
Travel expenses in Minnesota			
Estimated travel within MN to engage industry and engineering collaboratoers. Five trips planned per year, estimated at $1,000/trip based on three NRRI project participants per meeting.	$ 500	$ -	$ 500
Other	$ -	$ -	$ -
COLUMN TOTAL	$ 158,000	$ 111,759	$ 46,241

OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget 03/01/2022	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Amount legally obligated but not yet spent	Budget 03/01/2022	Spent	Balance
Current appropriation:		$ -	$ -	$ -
Past appropriations:		$ -	$ -	$ -

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Final Budget Spreadsheet
Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)
Sub-project Manager: Donald Fosnacht
Sub-project Title: Accelerate High Capacity/Low Cost Energy Storage Options (sub-project #4)
Organization: Natural Resources Research Institute, University of Minnesota Duluth
Sub-project Budget: $150,000
Project Length and Completion Date: 3 years, June 30, 2022
Today's Date: 9/15/2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 03/01/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 149,800	$ 149,800	$ -
Donald Fosnacht, NRRI Research Director: $60,566 (74% salary, 26% fringe), 13% FTE for 2 years			
Academic P&A (in aggregate): 2 NRRI staff members est. total: $28,754 (74% salary, 26% fringe), 10.7% FTE for 2 years			
Civil Service (in aggregate): 2 NRRI staff members est. total $59,680 (77% salary, 23% fringe), 26.7% FTE for 2 years			
Professional/Technical/Service Contracts			
	$ -	$ -	$ -
Equipment/Tools/Supplies	$ -	$ -	$ -
Travel expenses in Minnesota			
Estimate travel to MN energy-sector partners and project collaborators to conduct the technical review of technologies. Costs will include mileage, lodging and allowable meals.	$ 200	$ 200	$ -
Other			
		$ -	$ -
COLUMN TOTAL	$ 150,000	$ 150,000	$ -

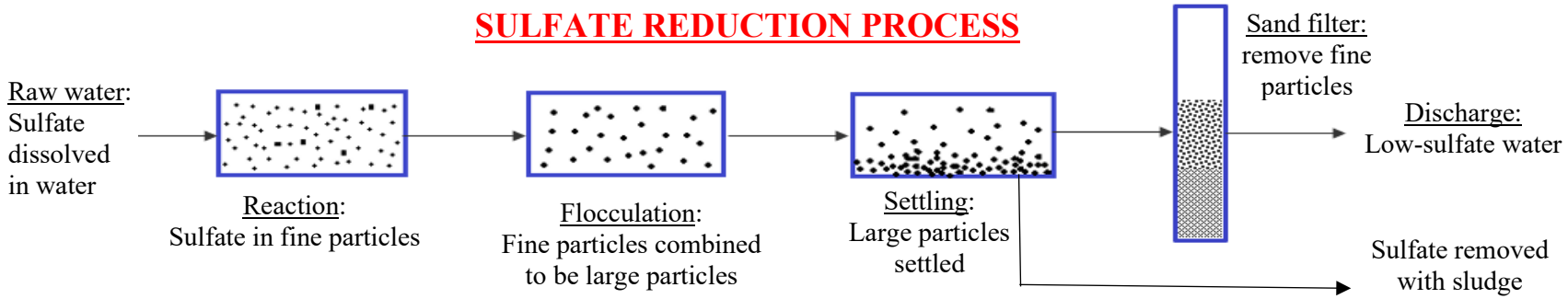
OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget 03/01/2022	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Amount legally obligated but not yet spent	Budget 03/01/2022	Spent	Balance
Current appropriation:		$ -	$ -	$ -
Past appropriations:		$ -	$ -	$ -

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

Subproject 1: Mobile Water Treatment Demonstration System for Sulfate Reduction

SULFATE REDUCTION PROCESS



DEMONSTRATION

Virginia Wastewater Treatment Plant

Domestic wastewater only
Test flow rate: 2 gal/minute (total 86,500 gallons treated)
Test duration: June 4th – August 2nd, 2021
Inflow sulfate: ~60 mg/L
Effluent sulfate: <10 ppm for 95% of the test time
Chemical cost per 1000 gal: $2.27

Grand Rapids Wastewater Treatment Plant

Domestic + Industrial wastewater (pulp mill wastewater)
Test flow rate: 1 gal/minute (total 60,000 gallons treated)
Test duration: August 26th – October 8th, 2021
Inflow sulfate: 85-115 mg/L
Effluent sulfate: <10 ppm for 82% of the test time
Chemical cost per 1000 gal: $5.50

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Natural Resources Research Institute
University of Minnesota Duluth
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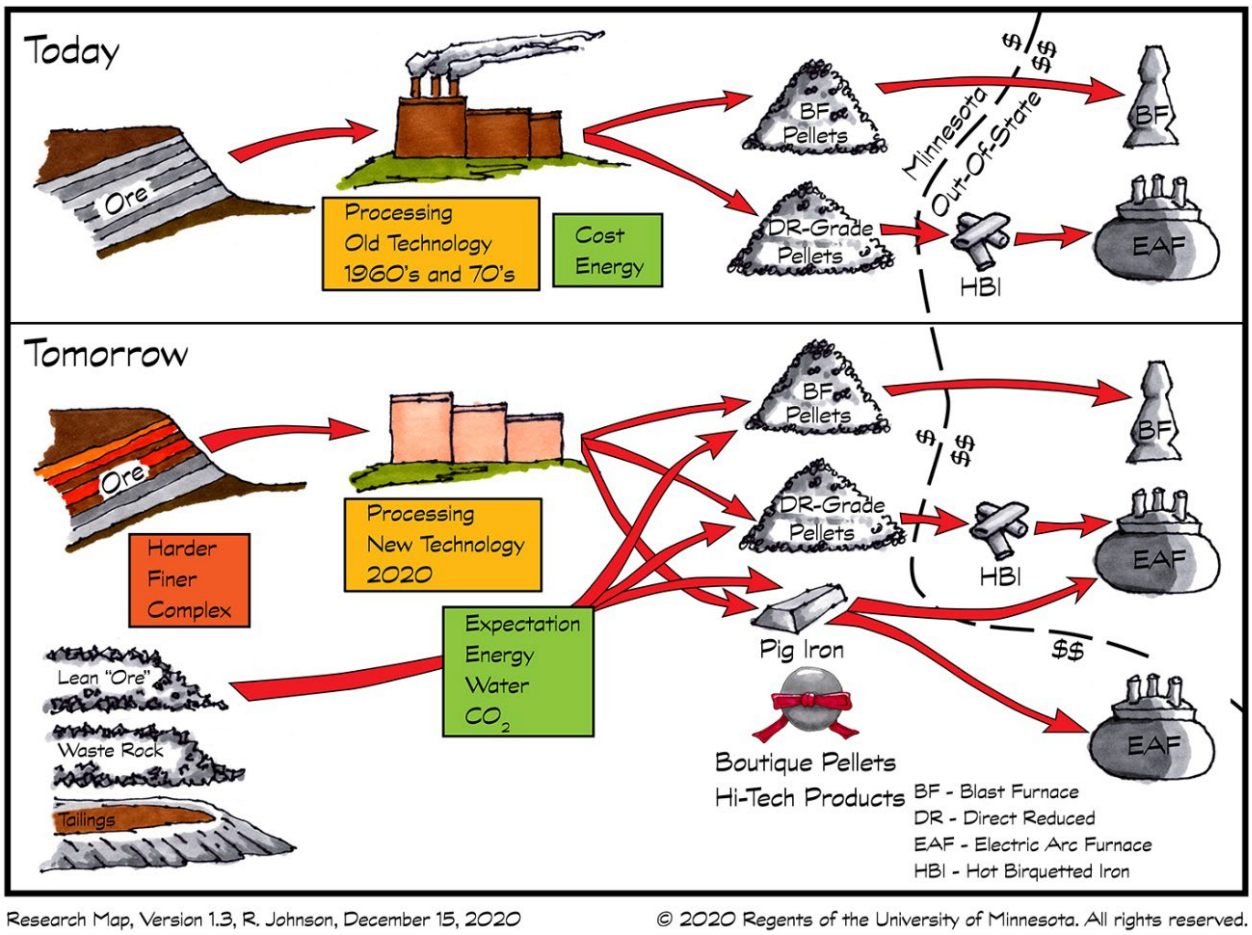
Project Title: Western Mesabi Iron Resources of the Future



Research Map, Version 1.3, R. Johnson, December 15, 2020

Above: Diagram illustrating the iron mining industry of today and a vision for the iron mining industry of tomorrow.

Today's iron mining industry is based on technology that was developed, for the most part, prior to the 1960's. This technology did not consider environmental impacts, or that it generated most of the value outside of the state of Minnesota.

Tomorrow's iron mining industry will be based on a more sustainable approach using lower quality iron formation, introducing modern technology, reducing reliance on fossil fuels, using water more efficiently, reducing emissions, developing new iron products, and generating more value for the state of Minnesota.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover℠

Opportunities Offered by Emerging Hydrometallurgical Technologies

Goal: Create a regional, comprehensive, hydrometallurgical innovation capability at NRRI to address life-cycle resource utilization in Minnesota. These facilities will have the equipment, instrumentation and expertise to perform bench and pilot-scale applied research related to the production of higher value mineral resources, removal of metallic contaminants from hydrometallurgical residues, and reduce energy consumption, water utilization and landfill waste by recovering metals and other materials from waste resources.

Problem Statement: Society's demand for metals requires that mineral resources be extracted from the earth OR recovered from commercial products or their co-products/wastes. Hydrometallurgy is one of the processing methods used to separate and purify minerals into their mostly pure metallic form. Society demands that mineral processing and hydrometallurgical processing methods be performed while maintaining clean water, clear air, and avoiding the generation of waste.

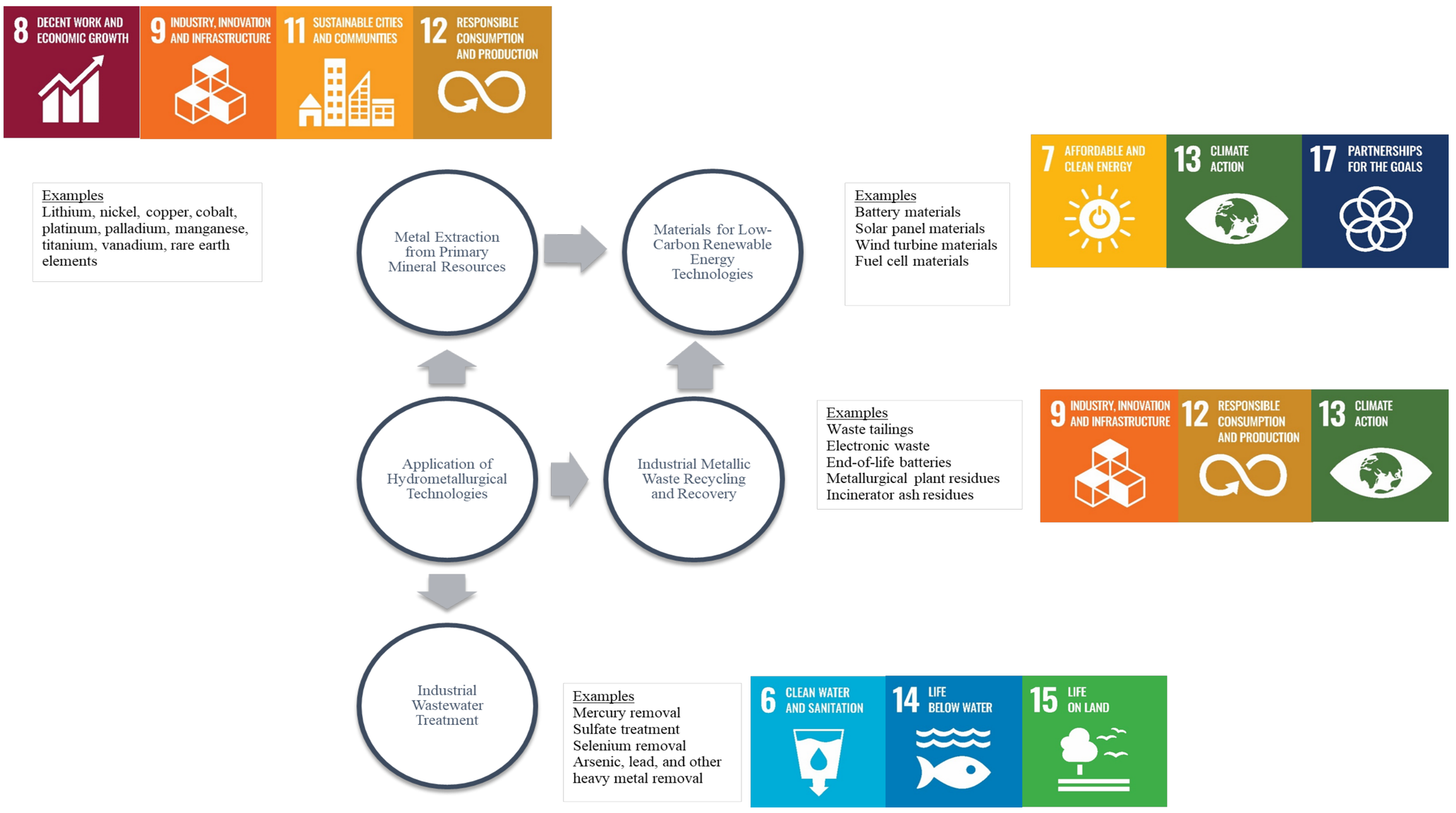
At NRRI, we are in the early stages of developing the hydrometallurgical research capabilities that will assist industry needs today and in the future. To achieve this goal, we are:

- developing and optimizing a sustainable source of minerals needed for the clean energy transition
- assessing carbon sequestration potential of regional resources
- promoting recycling rates of critical metals while protecting and conserving increasingly scarce natural resources, carbon-sequestering forests, wetlands and water resources

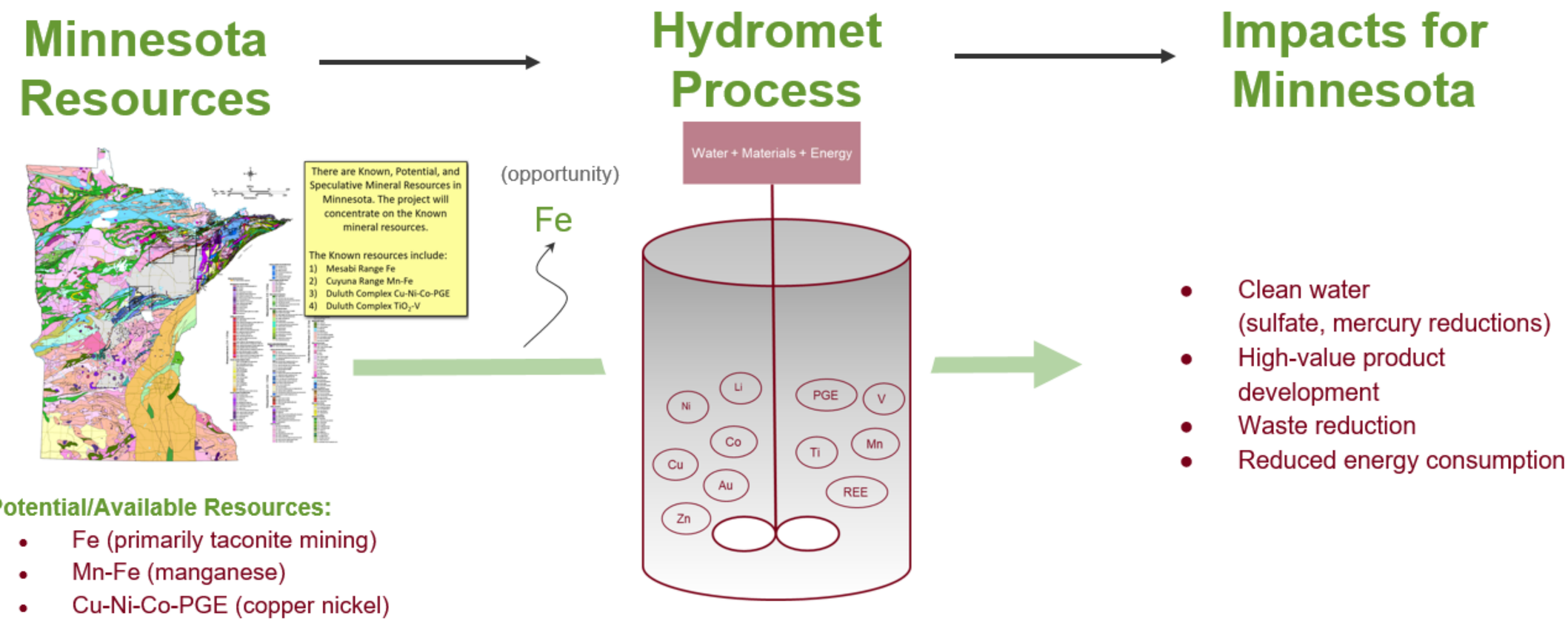
Impact:

- Improve mineral processing efficiency and waste stream recycling rates in production of mineral products needed for the transition to clean energy.
- Minimize air and water emissions of metallurgical processes to meet or exceed all regulatory requirements
- Facilitate technology adoption.
- Accelerate development of hydrometallurgy to create secondary materials that maybe useful in applications ranging from water remediation to carbon sequestration.

Role of Hydrometallurgy in Achieving Sustainable Development



Developing Next Generation Materials using Hydrometallurgical Technologies



Hydrometallurgy uses aqueous solutions for the recovery of metals from ores, concentrates, and recycled or residual materials.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Survey of Technology Options for Long-Term, High-Capacity Renewable Energy Storage in Minnesota

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

Achievement of Minnesota's renewable energy transition goals requires development and installation of both short and long-term energy storage capability. Non-battery options harnessing physical principles involving gravity, compressed gas, waste heat and chemical processes can offer storage options with long lifetime that do not require access to critical minerals and may offer safety improvements. Many of these options can take advantage of Minnesota's natural and man-made (former mine workings) topographical and geological features. **Access the full report at nrri.umn.edu**

Taraenergy.com

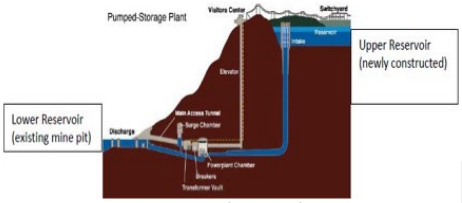
postermywall.com

Photos.com

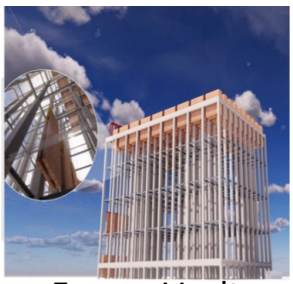
Example Technologies

MN Siting Models

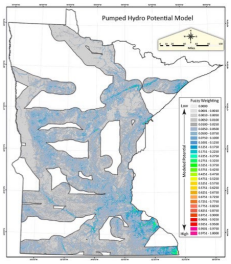
Gravity

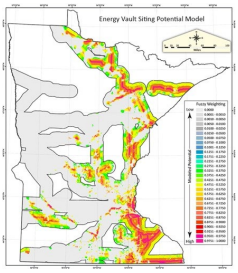


Pumped-Hydro

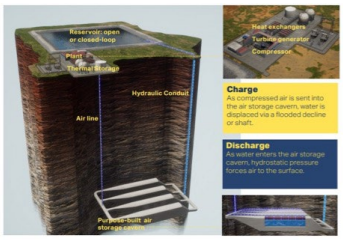


Energy Vault

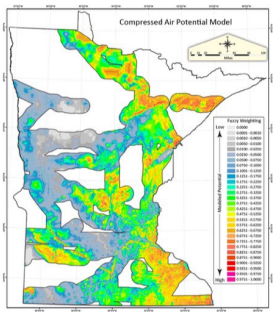




Pressure



Advanced Compressed Air (Hydrostor)



Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Environment and Natural Resources Trust Fund