Final Abstract

Final Report Approved on October 30, 2025

M.L. 2020 Project Abstract

For the Period Ending June 30, 2024

Project Title: Minerals and Water: Next-Generation Technologies and New Iron Products

Project Manager: Patrick Schoff

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Funding Source:

Fiscal Year:

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 20a3

Appropriation Amount: $450,000

Amount Spent: $450,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

This project advanced responsible use of Minnesota's iron resources by developing methods to reduce fossil fuel use, emissions, and water impacts and identifying new uses for iron materials. Application of these methods would lead to cleaner air, water, and land, while preserving natural resources and expanding opportunities for Minnesota iron.

Overall Project Outcome and Results

The purpose of this research project was to build on the long-term “Western Mesabi Iron Resources of the Future” study, which investigates how Minnesota’s remaining, lower grade iron resources can be better understood and used in new ways. The focus was to develop approaches that could utilize these iron resources while also reducing emissions, cutting fossil fuel use, and creating higher-value iron products for the future.

To accomplish these goals, researchers characterized various drill core samples and bulk samples from Minnesota’s Biwabik Iron Formation located in northeastern Minnesota. Samples were selected representing oxidized iron materials that are not currently mined or processed. NRRI’s research resulted in methods to recover iron from both magnetic and non-magnetic portions of these abundant, but unused iron formations. The results indicated that these underutilized

materials can produce iron concentrates that could be used to make steel with non-conventional technology, or be used as a material for applications other than steelmaking.

This study also explored methods to reduce environmental impacts of iron processing, including characterizing water quality during pilot-scale iron ore processing, exploring alternative chemical reagents with lower environmental impacts than those currently in use, and testing methods to lower energy use. For example, we developed a method to use a biomass-derived material called biochar as an effective substitute for coal to chemically reduce iron oxide into iron metal.

Finally, the research expanded the potential for Minnesota's iron product portfolio to develop beyond iron oxide pellets for steelmaking, including possible uses for "waste" minerals like siderite and goethite. Innovative uses for these unconventional iron resources include water treatment and high-purity iron concentrates that could potentially be used in electronic applications like batteries.

Project Results Use and Dissemination

The technical team authored a presentation titled "The Mineralogical Characterization of Low-Value Iron Formation and Their Effects on Metallurgical Response," which Dr. Lysa Chizmadia delivered at the 2024 SME Minnesota Conference in April 2024. A final technical report was submitted to LCCMR in May 2025.

Beyond formal venues such as conferences and publications, the study's data has proven valuable in discussions with current and prospective iron miners, Business & Industry clients, and federal agencies (including the U.S. Department of Energy), helping advance understanding of underutilized iron resources in the region.

Environment and Natural Resources Trust Fund

M.L. 2020 Approved Final Report

General Information

Date: November 12, 2025

ID Number: 2020-085

Staff Lead: Mike Campana

Project Title: Minerals and Water: Next-Generation Technologies and New Iron Products

Project Budget: $450,000

Project Manager Information

Name: Patrick Schoff

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Project Reporting

Final Report Approved: October 30, 2025

Reporting Status: Project Completed & Additional Update Approved

Date of Last Action: October 30, 2025

Project Completion: June 30, 2024

Legal Information

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 20a3

Appropriation Language: The appropriation in Laws 2019, First Special Session chapter 4, article 2, section 2, subdivision 8, paragraph (c), Sauk River Dam Removal and Rock Rapids Replacement, in the amount of $2,768,000, no longer needed for its original purpose is transferred as follows:

(3) $750,000 is transferred to the Board of Regents of the University of Minnesota for academic and applied research through the MnDRIVE program at the Natural Resources Research Institute to develop and demonstrate technologies that enhance the long-term health and management of Minnesota's mineral and water resources. Of this amount,

$300,000 is to support demonstration of three sulfate reduction technologies for improved water quality, and $450,000 is for continued characterization of Minnesota iron resources and for developing next-generation technologies and iron products. This research must be conducted in consultation with the Mineral Coordinating Committee established under Minnesota Statutes, section 93.0015;

(d) Transfers and Availability
The transfers under this subdivision are effective June 30, 2021, and the transferred amounts are available until June 30, 2023.

M.L. 2022, Chp. 94, Sec. 2, Subd. 19 Carryforward; Extenstions, (b) The availability of the transfers for the following projects is extended to June 30, 2024: (3) Laws of 2021 First Special Session, chapter 6, article 5, section 2, subdivision 20, paragraph (a), clause (3), Applied Research in State Mineral and Water Resources

Appropriation End Date: June 30, 2024

Narrative

Project Summary: Applied research and demonstration: enhanced value, sustainable opportunities for Minnesota iron resources and sulfate reduction in Minnesota waters

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

The iron mining industry has a long history in Minnesota, from the direct shipping ores of the past to today's taconite industry. As the higher quality ores have become depleted, process technologies have evolved to become more water intensive. The resulting impacts inevitably tie mining activities to regional water quality concerns.

While high quality ores are gone, abundant, low-quality resources remain that are bypassed as waste rock, lean ore or tailings. Profitable use of these low-quality resources requires enhanced characterization and development of novel process technologies. To be globally competitive, new processing approaches must reduce energy and water consumption, reduce carbon and other emissions and diversify the iron product portfolio. Past state investment resulted in the present taconite industry; new investment will help Minnesota lead the future.

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

A 2019 legislative appropriation and LCCMR funding initiated applied research on these two interrelated challenges. Detailed characterization of several Biwabik formation iron resource samples led to new understanding of their composition and structure. This work will continue with additional representative samples to define three types of secondary iron resources. These data will, in turn, suggest novel strategies to process these materials into iron concentrates in addition to alternate iron products for use in other applications. NRRI's unique metallurgical expertise will be leveraged to demonstrate new metallic iron products and characterize their feasibility and market acceptance.

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

Detailed characterization of Minnesota's iron mineral resources will not only identify opportunities to take advantage of reduced quality iron resources, but will also identify opportunities to reduce water use and impacts, reduce energy consumption and reduce industry footprint while expanding the state's iron product portfolio.

Project Location

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

Region(s): NE

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

Region(s): NE

When will the work impact occur?

In the Future

Activities and Milestones

Activity 1: Iron formation characterization

Activity Budget: $148,000

Activity Description:
Continue the comprehensive characterization of the iron resources of the Mesabi Iron Range. The characterization includes determining mineralogy, liberation characteristics, and metallurgical response of all portions of the iron formation. The concentrates produced from the metallurgical characterization will be analyzed for chemical properties, and impurities. Thermal analysis will be conducted on a subset of the concentrates. These data will be used to focus research to develop new processing technologies and alternative iron-based products.

Activity Milestones:

Description	Approximate Completion Date
Milestone 1: Complete logging, sectioning, and sampling of diamond drill holes	December 31, 2021
Milestone 2: Complete chemical, mineralogic and metallurgical characterization of diamond drill hole	June 30, 2022
Milestone 3: Complete characterization of partially oxidized iron formation	June 30, 2022
Milestone 4: Complete characterization of oxidized iron formation	June 30, 2022
Milestone 5: Complete characterization of siderite-rich iron formation	June 30, 2022

Activity 2: Process development

Activity Budget: $231,000

Activity Description:
Several distinct iron material types have been identified. Bench-scale metallurgical tests will be conducted to determine baseline conditions for grinding and recovery. The bench scale studies will provide data to understand the quality of concentrate that can be produced from traditionally non-ore iron formation. The impact on water quality will be assessed during the bench scale studies. Flotation is likely to be a component of mineral recovery in the future and alternatives to amines need to be assessed. A study of surfactants will be conducted to guide flotation research in the future.

Activity Milestones:

Description	Approximate Completion Date
Milestone 1: Complete bench-scale process development of Hematite recovery from tailings and Oxidized iron formation	March 31, 2023
Milestone 2: Complete bench-scale process development of partially oxidized iron formation	March 31, 2023
Milestone 3: Complete bench-scale process development Siderite rich iron	March 31, 2023
Milestone4. Compile and analyze process water chemistry	March 31, 2023
Milestone 5. Complete surfactant study.	March 31, 2023

Activity 3: Production of iron with reduced reliance on fossil fuels

Activity Budget: $71,000

Activity Description:
We will investigate use of green hydrogen and biomass to reduce blast furnace pellets.

Activity Milestones:

Description	Approximate Completion Date
Milestone 1: Iron reduction using H2; Reduction of blast furnace pellets	June 30, 2023
Milestone 2: Iron reduction using H2; Reduction of green balls with biocarbon	June 30, 2023

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Rolf Weberg	Natural Resources Research Institute, UMD	NRRI Executive Director, Dr. Rolf Weberg, who is on the Minerals Coordinating Committee, will review project progress for comment and potential collaboration at regularly scheduled Minerals Coordinating Committee meetings	No

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
We will communicate with industry, agencies and academic partners through technical presentations, reports, and technical papers to share results of this collaborative research. All public-facing research dissemination for this project will acknowledge the ENRTF funding for the project.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
This project is part of a long-term effort to define, develop, demonstrate and commercialize technologies to support future Minnesota mineral opportunities with reduced carbon footprint, water utilization, effluents and energy consumption while also driving a higher value product portfolio. The results of this project will be used to define ongoing development efforts and attract funding from external sources including the federal government, industry partners and the state of Minnesota. Permanent University Trust Funds may also be applied towards this support.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
George Hudak		Research Group Leader			25.09%	0.1		$18,063	-	-
Rodney Johnson		Project Manager			25.09%	0.46		$74,008	-	-
Matthew Mlinar		Mlinar will provide project management support and serve as a part of the project management team for this grant			25.09%	0.1		$13,091	-	-
Sara Post		Data Management			22.3%	0.2		$15,467	-	-
TBD Geologist		Geologist			25.09%	0.04		$4,118	-	-
Brett Spigarelli		Process Metallurgist and Pyrometallurgist			25.09%	0.4		$52,992	-	-
Shashi Rao		Process Metallurgist			25.09%	0.26		$30,735	-	-
Basak Anameric		Pyrometallurgist			25.09%	0.16		$23,326	-	-
Patrick Casey		Laboratory Technician Supervisor			22.3%	0.2		$14,535	-	-
Donald Reiser		Laboratory Technician			22.3%	0.44		$33,915	-	-
Joseph Cannella		Laboratory Technician			22.3%	0.16		$12,113	-	-
Richard Bellefy		Laboratory Technician			22.3%	0.1		$7,570	-	-
Michael Swanson		Laboratory Technician			22.3%	0.18		$13,906	-	-
Steven Zaitz		Laboratory Technician			22.3%	0.1		$7,725	-	-
David Haugen		Laboratory Technician			22.3%	0.4		$13,455	-	-
Stephen Monson Geerts		Geologist			25.09%	0.16		$15,607	-	-
Julie Mutchler		Laboratory Supervisor			22.3%	0.3		$24,593	-	-
Gregory Gargano		Laboratory Technician			22.3%	0.2		$15,795	-	-
James Gould		Laboratory Technician			22.3%	0.04		$2,417	-	-
Igor Kolomitsyn		Chemist			25.09%	0.16		$20,172	-	-
TBD Laboratory Technician, temp/casual		Laboratory Technician			6.91%	0.02		$680	-	-
TBD Undergraduate Student Technician		Student Technician			0%	0.01		$546	-	-
TBD Scientist, faculty		Research Scientist			25.09%	0.02		$2,889	-	-

TBD Post Doc		Laboratory Technician			17.28%	0.02		$1,226	-	-
TBD Summer Graduate Student		Laboratory Technician			18.96%	0.02		$130	-	-
Patrick Schoff		Principal Investigator			25.09%	0.01		$300	-	-
							Sub Total	**$419,374**	**$419,374**	**-**
Contracts and Services										
SEM/Microprobe, UMN Campus	Internal services or fees (uncommon)	Microprobe lab at the UM-TC campus. This lab offers non-destructive chemical analyses of solids. The electron microprobe is capable of quantitatively measuring the abundance of all elements from B to U and combines micron-scale chemical analyses with scanning electron microscopy, capable of large- and small-scale element mapping of specimens				0.02		$7,844	$7,844	-
Pace Analytical	Professional or Technical Service Contract	Pace Analytical will perform Water analyses - process water conducting thermal analyses on products that are produced at NRRI (concentrate)		X		0.02		$4,864	$4,864	-
ALS Global	Professional or Technical Service Contract	Chemical analysis - iron ore and products. Continuation of previously bid contract. ALS Global was selected for continuity of certified chemical analyses. ALS Global was the lab used for the LCCMR – Western Mesabi Iron resources of the Future				0.02		$15,417	$15,417	-
							Sub Total	**$28,125**	**$28,125**	**-**
Equipment, Tools, and Supplies										
	Tools and Supplies	Laboratory supplies	Laboratory consumables - sample bags, labels, etc.					$1,223	$1,223	-
							Sub Total	**$1,223**	**$1,223**	**-**
Capital Expenditures										

							Sub Total	**-**	**-**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Miles/ Meals/ Lodging	Local travel, GSA rates	Consultation with iron mining professionals					$1,155	$1,155	-
							Sub Total	**$1,155**	**$1,155**	**-**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										
							Sub Total	**-**	**-**	**-**
Other Expenses										
		Shipping	Cost of shipping samples to be analyzed	X				$123	$123	-
							Sub Total	**$123**	**$123**	**-**
							Grand Total	**$450,000**	**$450,000**	**-**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Contracts and Services - Pace Analytical	Professional or Technical Service Contract	Pace Analytical will perform Water analyses - process water conducting thermal analyses on products that are produced at NRRI (concentrate)	Pace is a local lab for water analysis. Water analysis requires a local lab and we have used Pace in other non-LCCMR projects. Prices were compared to other companies for previous (non-LCCMR) projects. The standard University of Minnesota contract bidding process will be used when required.
Other Expenses		Shipping	XPS, Pace Analytical, and ALS Global are external laboratories and shipping will be required to get the samples to these laboratories and assure analyses in a timely manner.

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
			State Sub Total	**-**	**-**	**-**
Non-State						
In-Kind	Internal University of MN Duluth, Natural Resources Research Institute (NRRI) Funding Review Board (FRB) Funding.	The justification for the additional effort are the following: 1) the project was extended by one year, 2) there were changes in the researchers assigned to the project (professional staff leaving and new hires), 3) some of the researchers were new to NRRI and, hence were not as efficient as seasoned researchers, and 4) replacement equipment was acquired for the project. While the cost of the replacement equipment was not charged to the project, this resulted in delays.	Secured	$55,984	-	$55,984
In-Kind	Internal University of Minnesota Duluth, Natural Resources Research Institute (NRRI) Taconite Chair funding.	QA/QC assessments revealed gaps in experimental data collection versus the objectives and deliverables promised in this study. Internal NRRI funds were dedicated to commission additional work and analysis to satisfy our obligations.	Secured	$59,615	-	$59,615
			Non State Sub Total	**$115,599**	**-**	**$115,599**
			Funds Total	**$115,599**	**-**	**$115,599**

Attachments

Required Attachments

Visual Component

File: 4631c6f5-00a.pdf

Alternate Text for Visual Component

The graphic describes the challenges facing Minnesota iron industry today and the goals and impacts for Minnesota's Next Gen Iron Industry...

Supplemental Attachments

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

Title	File
Background Check	fbcc5ff8-4f5.pdf
Institutional Letter	37928ebd-1f6.pdf
Minerals and Water: Next-Generation Technologies and New Iron Products	f86ba1f4-d89.pdf
Cover letter: Minerals and Water: Next-Generation Technologies and New Iron Products	5fbe8b2d-318.pdf
Cover letter: Minerals and Water: Next-Generation Technologies and New Iron Products	49acd2ff-98a.pdf
Minerals and Water: Next Generation Technologies and New Iron Products	c698473e-b83.pdf
Minerals and Water: Next Generation Technologies and New Iron Products - Appendices	36348159-0c8.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

Minor edits were made.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

N/A

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

Yes, I understand the UMN Policy on travel applies.

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

Yes

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

Yes

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

No

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Completion Date	Previous Completion Date: 06/30/2023 New Completion Date: 06/30/2024	An extension is requested for the following reasons. Access to the TC EPMA lab has been interrupted and mineral analysis has been delayed. Bench scale optimization has been delayed due to the failure of the Coleraine Laboratory Wilfley table. NRRI has approved funding for the purchase of a replacement Wilfley table. There has been an unexpected delay in turnaround of analyses from external laboratories.	May 26, 2023	Yes	May 26, 2023
2	Amendment Request	• Budget • Other • Budget - Professional / Technical Contracts • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Other • Budget - Non-ENRTF Funds Contributed	We are requesting rebudgets to adjust for categories that were over/underspent. Additional personnel time required for loss of seasoned staff and hiring of less seasoned staff. Reduction in services due to lower than anticipated costs. Travel adjusted due to original estimation being slightly off. Supplies increased slightly due to underestimation. We are additionally adding NRRI funds as cost-share to cover the remaining costs of the project. Justification added to Non-ENRTF Funding section.	July 10, 2024	Yes	July 11, 2024
3	Completion Date	Previous Completion Date: 06/30/2024 New Completion Date: 12/31/2024	LCCMR Administrative Workaround	July 11, 2024	Yes	July 11, 2024
4	Completion Date	Previous Completion Date: 12/31/2024 New Completion Date: 06/30/2024	LCCMR Administrative Workaround	July 11, 2024	Yes	July 11, 2024
5	Project Manager	Previous Manager: Rodney Johnson (rcjohnso@d.umn.edu) New Manager: Patrick Schoff (pschoff@d.umn.edu)	Rodney Johnson has retired.	February 18, 2025	Yes	February 18, 2025
6	Amendment Request	• Project Collaborators - Project Manager Info	NRRI has funded and performed additional work to clarify some outstanding	June 9, 2025	Yes	August 22, 2025

		• Budget - Travel and Conferences • Budget - Non-ENRTF Funds Contributed • Attachments	questions that remained after the original LCCMR funded project term was completed. The final update summarizes the work prior to submission of the final report.			

Additional Status Update Reporting

Additional Status Update August 15, 2025

Date Submitted: August 15, 2025

Date Approved: August 22, 2025

Overall Update
This research has advanced the understanding of iron resources by characterizing underutilized portions of Minnesota's Biwabik Iron Formation, evaluating magnetic separation and flotation to recover both magnetite and oxidized iron minerals (e.g., hematite, goethite), and demonstrating pathways for producing iron concentrate from materials not currently mined. It has also identified strategies to reduce water and environmental impacts through characterizing water streams in a pilot-scale beneficiation circuit, reviewing surfactant chemistry for efficiency and toxicity, and exploring alternative reagents with lower aquatic toxicity. Energy consumption and industry footprint can be reduced through approaches such as replacing fossil carbons with biochar for reduction of iron ore, which was found to be able to produce a highly metallized product. Finally, this research highlighted potential opportunities to expand Minnesota's iron product portfolio by future research in alternative uses for siderite and goethite in water treatment, and refining high-grade concentrates into high-purity iron oxides for battery applications.

Activity 1
Three separate drill core samples of oxidized iron from Minnesota's Mesabi Iron Range were analyzed. Although slight differences were detected, the mineralogical character were similar between the three samples. Beneficiation testing via magnetic separation and flotation was utilized to further characterize the test samples. In summary, magnetic separation found that most composites samples could achieve magnetite concentrates with less than 7.5% SiO_2 at a moderate grind size (at least 80% passing 125 microns), with lower cherty units, particularly LC5 and LC4, producing the highest purity concentrates at the lowest oxidation. Finer grinding lowered silica as well as increased the oxidation ratio due to removal of iron minerals such as hematite. The baseline flotation results via fine grinding (at least 90% passing 25 microns) and selective flocculation-deslime-flotation (SFDF) were varied. The Upper Slaty, the uppermost fractions of Upper Cherty, Lower Slaty, and the lowest portion of the Lower Cherty subunits contained significant impurities, while mid-hole subunits generally achieved concentrates containing reduced gangue impurity levels of less than 10% SiO2.
(This activity marked as complete as of this status update)

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Dissemination
The utility of the data from this study has been extensively used to effective describe underutilized iron resources when discussing with current and prospective iron miners in the region, including with Business & Industry clients and federal agencies.

Additional Status Update Reporting

Additional Status Update May 30, 2025

Date Submitted: August 15, 2025

Date Approved: August 22, 2025

Overall Update
All experiments and analysis have been completed and a final report has been submitted on May 30, 2025. See Activity 1, 2, and 3 for updates by activity.

Activity 1
The flotation testing on the drill core samples were repeated, analyzed, and reported. Therefore, the characterization of mineralogy, liberation, and metallurgical response of all portions of the iron formation has been completed and included in the final report submitted on May 30, 2025.
(This activity marked as complete as of this status update)

Activity 2
The data and analysis of the objectives of Activity 2, namely the bench-scale testing with bulk samples, water characterization, and Review of Surfactants in the Iron Ore Industry, were completed and included in the final report submitted on May 30, 2025.
(This activity marked as complete as of this status update)

Activity 3
The data and analysis of the objectives of Activity 3, namely the production of iron with reduced reliance on fossil fuels, were completed and included in the final report submitted on May 30, 2025. The reduction experiment results show that a highly metallized product was produced from all self-reducing agglomerate blends using biocarbon as the reductant in place of fossil coal, as was evidenced by the degree of metallization of 93–98% in the final product for three blends.
(This activity marked as complete as of this status update)

Dissemination
The utility of the data from this study has been extensively used to effective describe underutilized iron resources when discussing with current and prospective iron miners in the region, including with Business & Industry clients and federal agencies.

Status Update Reporting

Final Status Update August 14, 2024

Date Submitted: August 15, 2025

Date Approved: August 22, 2025

Overall Update
All experiments and analysis have been completed and a preliminary report has been prepared. See Activity 1 Update

Activity 1
The characterization of mineralogy, liberation, and metallurgical response of all portions of the iron formation has been completed. The concentrates produced from the metallurgical characterization have been analyzed for chemical properties, and impurities. However, an inconsistency within the flotation experiment data was discovered during final QA/QC review. NRRI will repeat the work at our expense and will submit the final corrected report by March 1, 2025.
(This activity marked as complete as of this status update)

Activity 2
Bench-scale metallurgical testing was conducted on partially oxidized, oxidized, and siderite-rich iron formations to establish baseline conditions for grinding and recovery. Magnetic separation produced satisfactory results for the partially oxidized and oxidized samples. Gravity concentration could not achieve final concentrate specification with the oxidized sample, but could be used as a pre-concentration step. In contrast, the siderite-rich sample responded poorly to all beneficiation techniques. Flotation performance across all three bulk samples was notably poor, achieving upgrade ratios of no more than 15%. These findings summarize the metallurgical behavior of bulk samples from the Mesabi Range's partially oxidized, oxidized, and siderite-rich iron formations. A pilot study on the partially oxidized iron formation also evaluated impacts on water quality. Additionally, a review of surfactant use within the iron ore industry has been completed.
(This activity marked as complete as of this status update)

Activity 3
A baseline pyrometallurgical study was conducted to explore the use of biochar in reducing iron ore agglomerates. This preliminary investigation confirmed the potential of biochar as a reductant for direct reduction of iron ore concentrates sourced from Minnesota. The results highlight the need to optimize both the amount of biochar used and the reduction conditions to enhance efficiency and assess effects on the quality of the final product.
(This activity marked as complete as of this status update)

Dissemination
A presentation was given to the Spring meeting of the SME in Duluth by Dr. Lysa Chizmadia.

Additional Status Update Reporting

Additional Status Update August 14, 2024

Date Submitted: July 10, 2024

Date Approved: July 11, 2024

Overall Update
Per LCCMR staff guidance, due to system logic, this is place holder text for update to be submitted by 8/14/2024

Activity 1
Per LCCMR staff guidance, due to system logic, this is place holder text for update to be submitted by 8/14/2024

Activity 2
Per LCCMR staff guidance, due to system logic, this is place holder text for update to be submitted by 8/14/2024

Activity 3
Per LCCMR staff guidance, due to system logic, this is place holder text for update to be submitted by 8/14/2024

Dissemination
Per LCCMR staff guidance, due to system logic, this is place holder text for update to be submitted by 8/14/2024

Status Update Reporting

Status Update April 1, 2024

Date Submitted: July 10, 2024

Date Approved: July 11, 2024

Overall Update
Experiments for Activity 1 (iron formation characterization) and Activity 2 (process development) have been completed. The experiments for Activity 3 (production of iron with reduced reliance on fossil fuels) are 90% complete. The Management of Change (MOC) procedure to assure the safe performance of the reduction of experiments using biocarbon has been completed and the reduction experiments have started with expected completion by mid-April. Reporting for Activities 1, 2 and 3 are in progress.

Activity 1
Detailed mineralogic, geometallurgical, and metallurgical analyses of the 19 composites and 3 bulk samples are complete. Chemical analyses by an external laboratory are complete. Mineralogic analysis by x-ray diffraction (XRD) are complete, analysis by optical microscopy is complete, and scanning electron microscopy data collection is complete and data analysis is 90% complete.

Microscopy and chemical and x-ray diffraction analysis of bulk samples of partially oxidized, oxidized, and siderite-rich iron formation are complete. The bench scale metallurgical analysis of bulk samples are complete and analytical results from an external laboratory are complete.

We did not submit samples to XPS for thermal analysis. Our thermal reduction was performed using pellets and we chose to use other analytical techniques to assess the performance of the reduction.

Activity 2
Baseline studies for the bench scale process development of partially oxidized, oxidized, and siderite-rich iron formation including mineralogic, chemical, geometallurgical and metallurgical analysis are complete. The bench scale optimization of partially oxidized, oxidized and siderite-rich ore types have also been completed. Samples from the bench scale optimization experiments have been submitted to an external laboratory for chemical analyses.

The surfactant study is complete.

Activity 3
The revised experimental design for iron ore reduction using biocarbon have been approved by the Management of Change committee (MOC) to assure the safe performance of the reduction experiments. Baseline studies using biocarbon to reduce the iron in blast furnace pellets have begun and are scheduled to be completed by mid-April.

Dissemination
February 1, 2024: Presentation by NRRI to DOE - representatives from ARPA-E, NREL, and IEDO.

Status Update Reporting

Status Update October 1, 2023

Date Submitted: December 21, 2023

Date Approved: December 27, 2023

Overall Update
Several circumstances required a request for and granting of an extension. The issue of accessibility to the Twin Cities EPMA lab has been resolved by establishing a working relationship with the Electron Microscopy Core, North Dakota State University. Siderite-rich iron ore bench scale optimization had been delayed due to the failure of the Wilfley table at the Coleraine Laboratory. A replacement Wilfley table has been purchased and commissioned at the Coleraine Laboratory. The bench scale siderite concentration is scheduled to be completed by the end of the year. Delays in turnaround by external labs has been addressed by submitting samples during periods of faster turnaround and maintaining regular communications with the external laboratories. An unexpected departure of a senior researcher required reassignment of tasks and responsibilities. The associated experiments have been rescheduled for completion by the end of the year. The continued geologic, mineralogic, geometallurgical, and metallurgical analysis of the Biwabik Iron Formation has expanded our understanding of the variability within the Biwabik Iron Formation. This will provide the baseline information for developing research programs to make iron ore mining more sustainable through more efficient processing and the identification of alternative higher value iron products.

Activity 1
Detailed mineralogic, geometallurgical, and metallurgical analyses of the 19 composites and 3 bulk samples are 90% complete. Samples have been submitted to external laboratories and results are pending and expected before the end of the year. Mineralogic analysis by x-ray diffraction (XRD) are complete, analysis by optical microscopy is complete, and scanning electron microscopy data collection is complete and data analysis is 25% complete.

Microscopy and chemical and x-ray diffraction analysis of bulk samples of partially oxidized, oxidized, and siderite-rich iron formation are complete. The experimental design for the bench scale metallurgical analysis of bulk samples are complete.

Activity 2
Baseline studies for the bench scale process development of partially oxidized, oxidized, and siderite-rich iron formation including mineralogic, chemical, geometallurgical and metallurgical analysis are complete. Initial bench scale low intensity magnetic separation indicate that iron-rich concentrates could be produced from the underutilized partially oxidized and oxidized bulk samples using conventional processing methods. The next stage in bench scale optimization will be to increase the total iron recovery by recovering hematite (Fe_2O_3) using flotation. This will result in the production of two concentrates with different characteristics, a magnetite (Fe_3O_4) and a hematite-rich concentrate. The new Wilfley table has been commissioned and the design of experiment for producing a siderite concentrate from siderite-rich iron ore is complete. The bench scale optimization is expected to be completed by the end of the year.

The surfactant study is underway and Is expected to be completed by the end of the year.

Activity 3
The departure of an experienced researcher required reassignment of responsibilities and a reassessment of the status of work that that had been completed. A revised experimental design has been approved by the project team. Baseline studies using H_2 to reduce the iron in blast furnace pellets are 30% complete. The initial baseline studies have shown reduction of iron using H_2. These optimization and characterization stages of this study are scheduled to be completed by the end of the year.

Dissemination

NRRI is a co-PI on LCCMR funded H2 plasma reduction research being lead by Dr. Uwe Kortshagen, UMN, Twin Cities
The results of this LCCMR managed research have been presented to several research organization to promote minerals research in Minnesota. These research organizations include: Cornell, Tufts, Oak Ridge, and Form Energy.

Status Update Reporting

Status Update April 1, 2023

Date Submitted: March 31, 2023

Date Approved: April 26, 2023

Overall Update
Detailed mineralogic, geometallurgical, and metallurgical analyses of the 19 composites samples are nearly complete. Bulk samples of partially oxidized, oxidized, and siderite-rich iron formation have been characterized.
Baseline studies for the bench-scale process development of the partially oxidized and oxidized and siderite-rich iron formation have been completed. Bench scale beneficiation plans have been prepared for bench-scale process development.
Iron reduction of blast furnace pellets using H2 has been performed. An experimental design for the reduction of green balls with biocarbon using H2 is under review.

Activity 1
Detailed mineralogic and geometallurgical analyses of the 19 composite samples and the partially oxidized, oxidized, and siderite-rich bulk samples are nearly complete. Metallurgical analysis of the 19 composite and bulk samples are underway.

Activity 2
Baseline studies for the bench scale process development have been completed. Planning for the recovery of hematite from tailings and oxidized iron formation using re-grinding, flotation, and high intensity magnetic separation at the bench scale is underway. Planning for the bench-scale process development of partially oxidized iron formation using low intensity magnetic separation and flotation is also underway. Planning for the bench-scale process development using gravity separation (Wilfley table to simulate spirals) is also underway. A team for the surfactant study has been identified and a project plan has been prepared.

Activity 3
Iron reduction of blast furnace pellets using H2 has been performed. An experimental design for the reduction of green balls with biocarbon using H2 is under review.

Dissemination
Dr. Rodney Johnson, Iron of the future: Next Generation Iron Products, University of Minnesota Duluth, University for Seniors, February 28, 2023

Status Update Reporting

Status Update October 1, 2022

Date Submitted: October 24, 2022

Date Approved: October 25, 2022

Overall Update
Detailed mineralogic, geometallurgical, and metallurgical analyses of the 19 composites samples are in progress. Bulk samples of partially oxidized, oxidized, and siderite-rich iron formation are in various stages of mineralogic, chemical, geometallurgical and metallurgical analysis. Baseline studies for the bench-scale process development of the partially oxidized and oxidized and siderite-rich iron formation have begun. This baseline data will be leveraged to design a pilot-scale processing circuit to produce iron concentrate and tailings (waste) in a complementary study funded by the Department of Energy (DOE). Experimental design for the hydrogen reduction study has been proposed, and work has begun on baseline studies.

Activity 1
Detailed mineralogic, geometallurgical, and metallurgical analyses of the 19 composites samples are close to complete. Mineralogic analysis by x-ray diffraction (XRD) are complete, and analysis by optical microscopy are in progress. Metallurgical analysis using bench scale low intensity magnetic separation (LIMS) are complete. Bulk samples of partially oxidized, oxidized, and siderite-rich iron formation are in the midst of chemical, mineralogic, geometallurgical and metallurgical analysis. Preliminary analysis suggests that iron-rich concentrates may be produced from these underutilized iron resources for the iron and steel industry, water treatment, and production of alternative iron products.

Activity 2
Baseline studies for the bench scale process development of partially oxidized, oxidized, and siderite-rich iron formation have begun including mineralogic, chemical, geometallurgical and metallurgical analysis. Initial bench scale low intensity magnetic separation indicate that iron-rich concentrates could be produced from the underutilized partially oxidized and oxidized bulk samples using conventional processing methods. The next stage in bench scale optimization will be to increase the total iron recovery by recovering hematite (Fe2O3) using flotation. This will result in the production of two concentrates with different characteristics, a magnetite (Fe3O4) and a hematite-rich concentrate.

Activity 3
Experimental design has been approved by the project team. Baseline studies using H2 to reduce the iron in blast furnace pellets have begun. The initial baseline studies have shown reduction of iron using H2. The reduction tests are currently on hold while waiting for delivery of a gas mixing gauge. Fortunately, this activity is ahead of schedule and the delivery should not put the activity behind schedule. These studies will be optimized and the reduced iron products from the studies will be characterized.

Dissemination
No update.

Status Update Reporting

Status Update April 1, 2022

Date Submitted: April 29, 2022

Date Approved: May 6, 2022

Overall Update

The characterization that began under the LCCMR-funded project titled "Western Mesabi Iron Resource Futures" (sub project #2, M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (r)) is continuing under LCCMR - Minerals and Water: Next-Generation Technologies and New Iron Products. Drill core has been logged, sampled, and preliminary chemical and mineralogic analyses completed. Composite intervals have been selected for detailed mineralogic, geometallurgical, and metallurgical testing. Three bulk samples of partially oxidized and oxidized iron formation and siderite-rich iron formation have been acquired, stored at NRRI's Coleraine Laboratory, and sampled for characterization.

Based on learnings from the "Western Mesabi Iron Resources of the Future" project, different iron ore formation types with different liberation, mineralogic, and chemical characteristics have been identified. Research teams have been selected and process development opportunities for the different iron formation types are being developed.

The research team for iron reduction of blast furnace pellets and green balls with biocarbon using hydrogen (H2) has been identified.

Activity 1

Five hundred seven feet of drill core from one hole containing variably oxidized iron formation has been logged, sawed into quarters, and sampled by NRRI geologists. Fifty-five samples were collected for determination of magnetite and mineral content. Magnetite content was determined by Satmagan analysis and mineralogy was determined using x-ray diffraction (XRD). The Satamagan and mineralogic analyses were used to identify 19 composites for detailed mineralogic, geometallurgical, and metallurgical analyses. Bulk samples of partially oxidized iron formation, oxidized iron formation and siderite-rich iron formation are at the Coleraine laboratory and have been sampled for characterization.

Activity 2

The research team for process development has been identified and meetings have been held to discuss strategies for designing the experiments necessary to improve recovery of iron oxides and siderite and to evaluate concentrate quality and alternative uses for these concentrates.

Activity 3

Teams for iron reduction have been identified and meetings to discuss experimental design have been scheduled.

Dissemination

- Dr. Rodney Johnson, Iron of the future, University of Minnesota Duluth, University for Seniors, February 22, 2022
- Dr. Brett Spigarelli, Iron Ore and Minerals of the Future, Minnesota Iron Ore and the Green Economy, March 16, 2022
- Dr. Rodney Johnson, Iron of the Future Initiative, SME Annual Meeting, Virginia, Minnesota, April 13, 2022
- Dr. Rodney Johnson, Western Mesabi Iron Resources of the Future – Geometallurgical and Metallurgical Progress Update, SME Annual Meeting, Virginia, Minnesota, April 13, 2022