



Environment and Natural Resources Trust Fund (ENRTF) M.L. 2019 ENRTF FINAL Report

Today's Date: September 15, 2022

Project Completion Date: June 30, 2022

PROJECT TITLE: Forest and Bioeconomy Research

Project Manager: Rolf Weberg

Organization: Regents of the University of Minnesota

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

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Location: Duluth, MN

Total Project Budget: \$2,200,000.00

Amount Spent: \$2,200,000.00

Balance: \$0.00

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

Appropriation Language: \$2,200,000 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 the long-term health of Minnesota's forests, extend the viability of current forest-based industries, and accelerate emerging industry opportunities. Of this amount, \$500,000 is to support development of a forest optimization tool for Minnesota forest resources, \$800,000 is for maintenance and expansion of the Natural Resource Atlas to statewide coverage, \$400,000 is to the Minnesota Forest Resource Council for continued advancement of biochar development and application to forest health, and \$500,000 is to advance emerging Minnesota technologies to produce clean syngas to drive high-value markets for forest biomass feedstocks.

I. PROJECT STATEMENT:

The Forest and Bioeconomy Research project expands on the 2016 Legislative Mineral and Water Innovation Initiative appropriation with an NRRI-led, applied research effort focused on Minnesota's

forest resources and emerging bioeconomy. Project outcomes are critical to the 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 partners and stakeholders, refined in legislative discussions and submitted as bills which were passed into this appropriation. Each sub-project is 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 forest and bioeconomy resources:

- Complete and deliver the statewide Minnesota Natural Resource Atlas to support informed planning and decision-making
- Design and deliver a data-driven, predictive forest harvest optimization tool to support forest harvest decisions
- Support MFRC experiments to define use of biochar application for forest health
- Advance emerging Minnesota technologies for production of clean syngas from Minnesota biomass sources

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:

AMENDMENT REQUEST January 28, 2020

Amendment request for Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass

We are requesting funds to be shifted from supplies and lab services to the personnel and capital equipment. The overall budget of \$500,000 will remain unchanged.

- Supplies budget would be reduced by \$3,821 to a revised budget of \$11,233
- Analytical lab services and biomass conversion would be reduced by \$70,000 to a revised budget of \$5,000
- Personnel would be increased by \$7,048 to a revised budget of \$152,994
- Capital equipment would be increased by \$66,773 to a revised budget of \$66,773

There is an increase in personnel costs due to the time needed to run the equipment that is being requested. The Analytical lab services and biomass conversion costs are being reduced because the biomass conversion will be done by the capital equipment. We have chosen to move analytical operations in house to ensure greater consistency in sample preparation and testing and for greater efficiency in use of staff time and resources.

The NRRI is requesting the purchase of capital equipment because we plan on using funding to purchase a Pyroprobe® 6200 Pyrolyzer from CDS Analytical, LLC (\$34,641) and a Micro GC fixed gas analyzer from Inficon Inc. (\$32,132).

The NRRI has an active biomass conversion program exploring development of biomass processing technologies and applications to Minnesota resources. The Pyroprobe® and Micro GC will be invaluable tools for this research program. For this project, we will be pyrolyzing (heating in a low oxygen environment) various biomass (wood, bark, grass etc.) samples and quantifying/identifying the volatile species that are formed as a result of the heating.

Specifically, it will provide basic data to confirm biomass pretreatment steps and support the design of syngas generation equipment based on application of a novel, Minnesota-based technology. This project leverages earlier NRRI investment of several million dollars in biomass pre-processing technologies.

This analytical equipment is notoriously robust with a long lifetime and holds its value well; we expect to use it routinely throughout its projected lifetime. In the event that the NRRI decides to discontinue biomass conversion research, the Institute commits to selling this equipment on the secondary market and returning those proceeds to the LCCMR.

The Outcomes in Subproject 4 will remain the same.

Amendment Approved by LCCMR 2/24/2020.

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 forest optimization tool team has formed and engaged an advisory committee and has identified a developmental test area in central Minnesota to model the tool. The Natural Resources Atlas team has expanded their scope to state-wide coverage with additions to their advisory board and access to additional databases. Biochar materials have been developed & characterized; materials are now in soil incubation experiments for evaluation for efficacy. The Syngas team completed a survey of gasification production technology & design options and settled on purchase of a new piece of equipment (Pyroprobe) to more efficiently evaluate gasification feedstocks; next steps involve definition of appropriate feedstocks and experimental design.

AMENDMENT REQUEST July 16, 2020

Amendment request for Subproject 1: Optimizing management of Minnesota's forest landscapes

We are requesting funds to be shifted from our Personnel costs for P&A salary and fringe and move those funds to our Personnel Costs for temporary/casual salary and fringe. The overall budget of \$500,000 will remain unchanged.

- Personnel costs for P&A salary and fringe would be reduced by \$3,113 to a revised budget of \$243,382
- Personnel costs for temporary/casual salary and fringe would be increased by \$3,113 to a revised budget of \$3,113

We are requesting a rebudget within our Personnel sections because the original budget did not account for temporary/casual appointments. Due to appointment updates, our employee, Kristofer Johnson, has a temporary/casual appointment. Mr. Johnson manages server operations and programming for the development of the online Forest Optimization tool and his role is critical for the timely completion of this project. We have not charged anything to the new salary and fringe categories yet but would like to charge costs back to 6/22/2020.

The Outcomes in Subproject 1 will remain the same.

Amendment Approved by LCCMR 8/19/2020.

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. The Forest Optimization Tool effort has selected modeling tool software and is actively building concept models with input from advisory teams. The Minnesota Natural Resource Atlas team has continued to expand database access to include agricultural and water data, add customer-friendly functionalities and provide training for stakeholders. Despite production delays, biochar evaluation for enhanced forest health has proceeded with incubation, analysis and seedling field planting. The syngas team has selected metallic iron production as a Minnesota-relevant market target, onboarded instrumentation to define optimal biomass pretreatment and identified a syngas scaleup partner for the next phase of the project.

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.

Models for landscape, carbon sequestration, bird & mammal habitat and water quality/quantity have been completed for nearly half of the study area towards development of the Forest Optimization Tool.

Additional efforts to quantify valuation of forest ecosystem services and design of the user interface infrastructure are now progressing.

The Minnesota Natural Resource Atlas has been expanded to statewide coverage with additional data layers, enhanced functionality for simplified user access, a user monitoring system and continuing training and outreach.

Approximately two tons of biochar materials were produced and characterized for application in MFRC's forest regeneration field experiment to determine effects of biochar on forest health. The research team has also engaged the forest industry to identify challenges to encouraging development of a biochar industry for Minnesota.

Laboratory biomass pretreatment experiments are now providing data for selection of optimal pilot-scale conditions to produce feedstock for clean syngas production in collaboration with research partners for application in the energy, transportation and mineral processing industries.

AMENDMENT REQUEST March 1, 2021

Amendment request for Subproject 1: Optimizing management of Minnesota's forest landscapes

We are requesting funds be shifted from the Personnel budget line to Other Costs

- Personnel would be reduced by \$10,600 to a revised budget of \$475,411
- The overall Other Costs category would be increasing by \$10,600 to an overall revised budget of \$13,912.
 - Other Costs (data storage) budget would increase by \$2,800 to a revised budget of \$2,800
 - Other Costs (printing) would be increased by \$2,400 to a revised budget of \$2,400
 - Other Costs (mailing) would be increased by \$5,400 to a revised budget of \$5,400

These changes to Other Costs (data storage) are being requested to allow for the purchase of a Network Attached Storage (NAS) unit to safely store the large amount of data that will be generated by the project. The built-in redundancy in the NAS, along with its new hard drives, will minimize the chance of any data loss due to drive failures.

These changes to Other Costs (printing and mailing) will be in an effort to better understand how Minnesotans value ecosystem services, we are conducting a discrete choice experiment survey. To increase participation and ensure only Minnesotans' preferences are included, we are using a hybrid approach in which potential survey participants will receive multiple mailings that prompt them to take an online survey. This approach has been shown to yield higher participation rates than contact and promoting via email.

The Outcomes of this subproject will remain the same.

Amendment approved by LCCMR 5/24/2021

Amendment request for Subproject 3: MFRC to support advancement of biochar for forest health

We are requesting funds to be shifted from laboratory services to supplies and professional services. The overall budget of \$400,000 will remain unchanged.

- Sample analysis services will be decreased by \$11,423 to a revised budget of \$5,112
- Lab Services will be increased by \$1,051 to a revised budget of \$11,051
- Lab services/biomass conversion will be increased by \$520 to a revised budget of \$20,520
- Supplies will be increased by \$9,852 to a revised budget of \$30,852

We are requesting a change in these categories to account for additional costs that were not anticipated in the original budgeting. The original laboratory services was redeployed to cover analysis of biochar samples. This required different and more extensive analyses. Some of this work was performed internally at NRRI. This necessitated future supplies expenses for calibration standards, reagents, and supplies. The biomass conversion addition of \$520 is to cover routine analyses performed by a commercial laboratory.

The outcomes of this subproject will remain the same.

Amendment approved by LCCMR 5/24/2021

Amendment request for Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass

We are requesting funds to be shifted from our external contractor and travel costs and move those funds to our Personnel Costs for salary and fringe. The overall budget of \$500,000 will remain unchanged.

- Contracted services costs for project partners will be reduced by \$53,488 to a revised budget of \$196,512 and the contractor will change from Gradient Technologies to EERC.
- Travel costs would be decreased by \$8,000 to a revised budget of \$2,000
- Analytical lab services and biomass conversion would be reduced by \$4,000 to \$1,000
- Supplies costs will be increased by \$8,052 to a revised budget of \$19,285
- Shipping costs will be increased by \$1,000 to a revised budget of \$5,000
- Personnel costs for salary and fringe would be increased by \$56,436 to a revised budget of \$209,430

We are requesting a change in the collaborator responsible for demonstration of clean syngas production from Gradient Technologies to the University of North Dakota Energy and Environmental Research Center (EERC). Due to changes in personnel and business focus for Gradient Technologies, this project no longer fits their business mission, and they will no longer invest in further development of their gasifier system. EERC has a long-term investment in development and commercialization of gasification systems, advanced laboratory and pilot-scale capabilities for gasification research, and an ongoing research portfolio in renewable energy systems that compliments this project. A chance to collaborate with EERC will allow us to deliver data from pilot-scale gasification of forest biomass with

comprehensive analytical and performance data that will be useful to companies looking to develop markets for renewable syngas from Minnesota's forest biomass.

The reduction in travel is because travel to Gradient Technologies will no longer be necessary. There will be a trip to East Grand Forks, Minnesota to meet with EERC. An increase in personnel time is because we are no longer outsourcing our work to Gradient Technologies; some of that work will be done in house.

Reason for selecting new partner

- The EERC has unique facilities, and deep experience in syngas production.
- EERC's engineers will process up to 500kg of pretreated biomass from NRRI and demonstrate clean syngas production.
- EERC's engineers will provide comprehensive analytical data of the gasification process running at steady state

Suggested outcome scope change

The new deliverables will include actual production and analysis of syngas rather than an engineering study. See subproject 4 below for suggested change.

Additional Justification:

1. There is no equivalent option available in Minnesota,

After Gradient Technologies informed us that they would not complete the design, build, and testing of a HP gasifier feed system, we sought the advice of experienced engineers who were not able to find equivalent services in Minnesota. Rather than purchase substandard equipment, we sought a way to gather relevant data for evaluation of biomass pretreatment and feed systems through contracting with engineers and researchers who already own and regularly operate gasification equipment and have the necessary expertise to complete the project. There were no companies available within Minnesota with both the expertise and existing equipment to complete the testing, but we were referred by experienced engineers to EERC.

2. The offered contract is fair and reasonable based on the rates of other organizations (citing the costs of working with Gradient Technologies would be helpful), and

The UND-EERC has a well-established program in gasification technology, as well as fully instrumented pilot-scale systems and experienced staff. It would cost more than \$80 Million to duplicate the pilot-scale equipment at NRRI. Therefore the EERC offered us a service contract for one week of running to gather the equivalent data. Their service contract rates are cost competitive and transparent. The rates are offered to all partners, including university researchers, industry, and the federal government.

3. How this contract will benefit the State of Minnesota.

The overall objective of this project is to demonstrate biomass gasification technologies to use Minnesota biomass to displace fossil fuels. Working with UND-EERC and their experienced staff gives us the opportunity to rapidly advance this goal through collaboration with experienced researchers and professional-grade equipment to collect data from industry-relevant pilot equipment. With encouragement from Minnesota Power's management, we have developed a partnership with UND-EERC to develop a long-term partnership that combines NRRI's expertise with biomass processing with EERC's expertise in energy. EERC is well regarded by the US Department of Energy, with a \$49M portfolio of federally-funded projects related to energy and

environmental work. Working together we can pursue bigger federal and industry contracts to develop commercial uses of Minnesota biomass energy projects more successfully together than we can individually.

4. Please clarify for us how transitioning this subproject outcomes from “Complete engineering design, assembly and evaluation of biomass feed system to high-pressure gasifier” to “Demonstrate syngas production from pretreated biomass at pilot scale” are equivalent. The first outcome indicates to us that a feed system and gasifier will be built in Minnesota, while the second indicates that syngas production will be demonstrated, but it does not include an explanation of continued benefits for Minnesota syngas production.

We made a decision to invest funding in a way that addresses the project’s overall goal of demonstrating biomass gasification at an industry-relevant scale. The project is better served by renting professional grade pilot equipment rather than owning small laboratory-scale equipment. Furthermore, a small laboratory unit will be useful for only this experiment and then will require further investment, up to several million dollars, to generate any industry-relevant data. By renting rather than buying we can make the best use of state funds to accelerate the development of Minnesota biomass technologies.

Fourth Update September 1, 2021

The Forest Optimization modeling efforts are nearing two thirds completion for landscape, water, and habitat. Ecosystem evaluation survey attracted more than 600 respondents to provide insight for societal value of forest lands. The website structure and programming has been initiated.

The natural resource Atlas team has incorporated additional data sets (nearly 400 total) to include agricultural, water flow, and climate data layers to the Atlas tool. Additional functionalities have been added to make the user interface more effective and outreach tools continue to be developed for deployment around the state.

The Biochar for forest health team is completing the detailed surface analysis of biochar materials prepared earlier in this project. This data will be used to interpret the impacts of these biochars on forest health in both greenhouse and field studies. A carbon lifecycle study comparing conversion of Emerald Ash Borer infested trees to biochar versus natural decay has been completed.

The Syngas team employed statistically designed benchtop torrefaction experiments introducing steam treatment. Results have confirmed significantly decreased tars and increased hydrogen yield when these pretreated materials are used in syngas production. These learnings are now being applied on the demonstration scale at NRRI Coleraine Laboratory. The materials produced will be used to support gasification studies in collaboration with University of North Dakota EERC in the coming months.

AMENDMENT REQUEST September 1, 2021:

Amendment request for Subproject 1: Optimizing Management of Minnesota’s Forest Landscapes

We are requesting funds be shifted from Equipment/Tools/Supplies to Other Costs (NAS data storage)

- Equipment/Tools/Supplies would be reduced by \$267 to a revised budget of \$933
- The Other Costs category for “Data Storage: Purchase of a Network Attached Storage (NAS)” would be increasing by \$267 to an overall revised budget of \$3,067.

These changes to Equipment/Tools/Supplies and Other Costs are being requested to allow for the purchase of a Network Attached Storage (NAS) unit to safely store the large amount of data that will be generated by the project. A Network Attached Storage (NAS) unit will be purchased to store the large number of spatial data files generated by the project. The unit will cost \$267 more than we had budgeted.

The Outcomes of this subproject will remain the same.

Amendment request for Subproject 3: MFRC to support advancement of biochar for forest health

We are requesting funds be shifted from Personnel to Equipment/Tools/Supplies and Professional/Technical/Service Contracts (UMTC Lab services).

- Personnel would be reduced by \$1,845 to a revised budget of \$323,620
- Supplies would be increased by \$450 to a revised budget of \$31,302
- Professional Services (UMTC Lab Services) would be increased by \$1,395 to a revised budget of \$12,446

These changes to Supplies and UMTC Lab Services are being requested to allow for an additional three months of greenhouse costs. Additional supplies are anticipated for the use of the greenhouse. Additional time is needed in the greenhouse to complete the greenhouse performance testing.

The Outcomes of this subproject will remain the same.

Amendment request for Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass

We are requesting funds be shifted from Shipping to INFICON Online training, under Professional/Technical/Service Contracts. We are also requesting our UND-EERC contract to be increased by \$2,563 by reducing the travel and shipping costs.

- Shipping would be reduced by \$1,963 to a revised budget of \$3,037
- INFICON online training (under Services) would be increased by \$1,400 to a revised budget of \$1,400
- Travel would be reduced by \$2,000 to a revised budget of \$0
- UND-EERC (under Services) would be increased by \$2,563 to a revised budget of \$199,075

These changes to Shipping, and Services (INFICON Online training and UND-EERE contract) are being requested because the newly acquired Inficon fixed gas analyzer required an online training by users at NRRI. The online training prepares users how to properly use and maintain the piece of equipment to ensure the proper running and quality work from the equipment. We are requesting additional funds to

be added to the UND-EERC contract because the estimated quote did not anticipate the increased costs for Fiscal Year 2022. The initial quote estimated using FY20 and FY21 costs.

The Outcomes of this subproject will remain the same.

Amendments approved by LCCMR 9/3/21

Fifth Update March 1, 2022

The Forest Optimization tool; the modeling is complete for the pilot study area consisting of 3,800,000 acres in Northeastern Minnesota. The website and decision support tools are nearly complete and beta testing will initiate shortly.

The natural resource Atlas now has more than 450 vetted data layers. Continued work has improved the efficiency of updates, engaged agencies, K-12, municipal, and tribal stakeholders. We currently developing a funding model for long-term support.

The Biochar for forest health team has completed all tasks related to the field and laboratory research. The team is proceeding to develop the research and commercialization ecosystem scenarios and dissemination activities, which will be included as part of the final technical report.

The Syngas team transitioned from bench-top to demonstration-scale production of biochar compositions for syngas generation in cooperation with our partners at the Energy and Environment Research Center (EERC) in Grand Forks, ND. We continue to develop industry relationships pursuing opportunities for syngas in the industrial sector focused on waste reduction and decarbonization.

AMENDMENT REQUEST March 1, 2022

Subproject 1: Optimizing Management of Minnesota's Forest Landscapes

We are requesting funds to be shifted into personnel costs from travel, mailing, data storage "other", and data storage "supplies". We are also requesting funds to be shifted into the GIS Lab Fees and printing and remove the money from data storage "supplies" and mailing costs.

- Personnel would be increased by \$10,454 to a revised budget of \$485,865
- GIS Lab fees would be increased by \$828 to a revised budget of \$4,140
- Printing would be increased by \$701 to a revised budget of \$3,101
- Travel would be decreased by \$9,271 to a revised budget of \$206
- Mailing would be decreased by \$1,542 to a revised budget of \$3,858
- Data storage "other" would be decreased by \$237 to a revised budget of \$2,830
- Data storage "supplies" would be decreased by \$933 to a revised budget of \$0

Due to Covid-19, almost all project travel was cancelled. These funds were rebudgeted to personnel to ensure our ability to offer remote options for meeting, testing, and training. Mailing and data storage were less expensive than estimated and no field supplies were needed, so those funds were rebudgeted to personnel. Data storage needs were met through supporting existing GIS Lab infrastructure and

services through lab fees and the purchasing of additional network attached storage. No field supplies were needed. Printing was more expensive than estimated and mailing was less expensive than estimated. Some of the surplus mailing budget was used to cover the printing deficit

The Outcomes of this subproject will remain the same.

Amendment approved by LCCMR 3/4/2022

Subproject 3: MFRC to support advancement of biochar for forest health

We are requesting funds to be shifted into personnel and supplies from professional services and travel

- Personnel would be increased by \$2,343 to a revised budget of \$325,963
- Supplies would be increased by \$69 to a revised budget of \$31,371
- Sample analysis would be decreased by \$972 to a revised budget of \$4,140
- Lab services would be decreased by \$3 to a revised budget of \$12,443
- Travel would be decreased by \$1,437 to a revised budget of \$5,563

Increased Personnel to reflect more effort in UMN laboratories in place of travel and external services. Decrease Professional/Technical/Service contracts because fewer samples were analyzed by outside laboratories. Increase Equipment/Tools/Supplies Supplies for lab bioassay to purchase marking tape and stakes to overwintering of biochar-treated seedlings so that they can be identified in future seasons. Decrease Travel Expenses in Minnesota because further winter travel to Cloquet Forestry Center will not be required.

The Outcomes of this subproject will remain the same.

Amendment approved by LCCMR 3/4/2022

Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass

We are requesting funds to be shifted into lab supplies from personnel, lab services, capital equipment, and shipping.

- Personnel would be decreased by \$407 to a revised budget of \$209,023
- Analytical lab services would be decreased by \$320 to a revised budget of \$680
- Lab supplies would be increased by \$3,038 to a revised budget of \$22,323
- Pyroprobe capital equipment would be decreased by \$45 to a revised budget of \$34,596
- Micro GC capital equipment would be decreased by \$257 to a revised budget of \$31,875
- Shipping would be decreased by \$2,009 to a revised budget of \$1,028

Decreased Personnel to reflect less effort in UMN facilities and more external services. Decreased Analytical lab services contracts because fewer samples were analyzed by outside laboratories. Increased Equipment/Tools/Supplies Lab supplies to purchase reagents and supplies necessary for surface analysis of biochars. Decreased Capital Expenditures to reflect savings realized by using online

instrument training during COVID travel restrictions. Decreased estimated shipping costs to reflect costs saved by shipping samples in two bulk shipments rather than individually.

The Outcomes of this subproject will remain the same.

Amendment approved by LCCMR 3/4/2022

AMENDMENT REQUEST April 11, 2022

Subproject 2: Expanding the Interactive Natural Resource Atlas for Minnesota

We are requesting funds to be shifted from personnel costs to GIS lab fees and data storage.

- Personnel would be decreased by \$5,500 to a revised budget of \$776,531
- GIS Lab fees would be increased by \$2,400 to a revised budget of \$8,836
- Data Storage would be increased by \$3,100 to a revised budget of \$3,100

The Atlas project requires that we store and serve large amounts of spatial data. The purchase of a Network Attached Storage (NAS) unit to serve as an offsite backup for the Atlas project will make our project infrastructure more reliable. This project relies on the computing resources and data storage infrastructure of NRRI's GIS Lab. This lab is supported through the application of fees to projects that use the labs resources. As this project grows, more resources are needed. A primary use of these additional funds will be to acquire an additional virtual server for testing and development of the Atlas web mapping application.

The Outcomes of this subproject will remain the same.

Amendment by LCCMR 4/22/22

Final Project Update: September 15, 2022

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

Creation of the Forest Optimization tool and its associated website are now complete for the 3,800,000 acre study area. The final result has been rebranded as the Forest Change Assessment and Simulation Tool (ForCAST) which is now publicly available and free to use at mnforecast.org. The tool and website allow land managers to better understand how climate and management decisions can impact harvests, economic valuation and critical forest ecosystem services.

Extension of the Natural Resources Atlas tool to statewide coverage is now complete. The tool now accesses >500 separate vetted datasets with recent additions focused on agriculture, forestry and water resources. Functionality improvements were also made to make the Atlas more robust, responsive and reliable per stakeholder input. Multiple outreach and training efforts have introduced the tool to a growing statewide user base (60-100/day) and website analytics are being employed to monitor tool performance and relevance.

Biochar for forest health: the NRRI materials analysis laboratory finalized biochar porosity measurement techniques and characterized biochar samples used in this study. The MFRC team completed greenhouse performance studies of biochar-enhanced soils and collected one year data on biochar impact on oak and red pine seedlings, showing limited, but positive effects. NRRI activities to engage potential industrial partners has helped to attract multiple companies to explore biochar production from wood residuals in Minnesota.

Benchtop gasification trials identified black ash biomass pretreatment conditions (temperature, steam injection, throughput) needed to optimize Syngas output and quality. Project partners at EERC completed pilot-scale gasification trials of the same pretreated materials, confirming the laboratory observations via biomass injection into a fluidized bed gasifier. Commercial outreach activities continue to identify multiple industrial applications and interests regarding syngas, particularly with the increasing focus on fossil carbon reduction across industries.

AMENDMENT REQUEST SEPTEMBER 15, 2022

Subproject 2: Expanding the Interactive Natural Resource Atlas for Minnesota

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

- Personnel would increase by \$12,746 to a revised budget of \$786,277
- Supplies would decrease by \$2,378 to a revised budget of \$22
- Travel would decrease by \$8,575 to a revised budget of \$558
- Other costs would increase by \$1,207 to a revised budget of \$13,143

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

Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass

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

- Personnel would increase by \$1,796 to a revised budget of \$210,819
- Professional/Technical/Service Contracts would decrease by \$1,296 to a revised budget of \$199,859
- Other costs would decrease by \$500 to a revised budget of \$528

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: Optimizing management of Minnesota's forest landscapes

Description: Minnesota forests provide many diverse products and services, from the production of sawtimber, pulp and new biochemicals and biofuels to provision of societally important values such as water quality, wildlife habitat and recreational opportunities. The social, economic, and ecological benefits of forest lands provide the foundation for sustaining prosperous and resilient communities. Making sound, landscape-scale decisions on forest management that balance these products and services is becoming more and more challenging as forests change and industry needs evolve. Forests show a wide range of variation across Minnesota's geographically complex landscape, and understanding regional variation in composition, productivity, and potential to provide ecological and social benefits is critical for making sound management decisions. The goal of this project is to develop a spatially explicit decision tool that integrates forest productivity, ecosystem service, and economic information to identify the benefits and tradeoffs of land management decisions.

We will accomplish this goal by:

- mapping the variability of key forest attributes (productivity, composition, structure, biomass availability, forest health, habitat, water quality) across the Minnesota forest landscape;
- predicting how future management decisions and climate change will affect forest attributes;
- quantifying the value of forest ecosystem services such as maintaining or enhancing water quality, providing wildlife habitat, and producing timber for woods products industries;
- assessing new demands for forest resources given emerging biochemical and advanced biofuel industries;
- collaborating with end users to integrate this information into a publicly accessible decision support tool for optimizing decisions that balance economic, ecological and social concerns.

When completed, this tool will be deployed to end-users (industry, agencies, other stakeholders) with training and collection of recommendations. It will be initially housed at the NRRRI with transfer to an appropriate state agency once fully deployed; potential options include MNDNR and DIRRR.

SUBPROJECT 1 ENRTF BUDGET: \$500,000

Outcome	Completion Date
1. Map resources and ecosystem services; predict management outcomes; assign economic values to current and future forest services and products for the Minnesota forest landscape.	12/30/2021
2. Develop a decision support tool that assesses social, ecological and economic outcomes of forest management decisions.	6/30/2022

3. Project partner outreach will be ongoing throughout the 3-year term.	6/30/2022
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First Update March 1, 2020

The conceptual model for the forest optimization tool was completed; it identifies the flow of information from assessing current forest condition, modeling forest growth into the future, identifying appropriate models for wildlife and water quality, and developing a framework for evaluating ecosystem services. We created an advisory board consisting of representatives from forest industry, county, state and federal land management agencies, and non-governmental organizations and held an initial meeting to obtain their input. We identified a 10,000 acre test landscape in central Minnesota to test modeling approaches, conducted a 50-year growth projection and assessed changes in avian and wildlife habitat at decadal intervals. NRRI staff attended trainings for the LANDIS-II and Forest Vegetation Simulator (FVS) models. A user needs assessment is underway.

Second Update September 1, 2020

We have selected four watersheds in Northeast Minnesota encompassing 4 million acres as a test area for the forest optimization tool. The modeling team has completed an updated forest inventory of all forest lands within the test area. We have selected LANDIS-II software as the modeling tool. As a part of this, we have developed harvest scenarios and are testing each to evaluate the output. The wildlife team is working toward aligning their model with the LANDIS-II output and the water team is evaluating water quality and water quantity models that will work with the LANDIS-II output. Efforts to understand how Minnesotans value non-timber forest products and services are underway. Regional foresters and forest ecology experts have been engaged to learn more about currently available tools, forest management practices, and their ability to consider non-timber forest products and services in the planning process.

Third Update March 1, 2021

Landscape and carbon sequestration modeling has been completed for approximately half of the study area. Bird and mammal habitat models and water quantity and quality models have been refined with results being generated for a subset of the study area. A survey has been developed to assess how Minnesota residents value the ecosystem services that the state's forests provide. Once through the University's Internal Review Board, the survey will be sent to 9,000 residents across the northern region of the state. The information gained from the survey will be used to assign both monetary and non-monetary values to the ecosystem services that are being assessed by the different modeling groups. Design of the Tool's User Interface and Information Technology infrastructure has begun, with an emphasis on delivering the large amount of information generated by the project in an efficient and intuitive manner.

Fourth Update September 1, 2021

Landscape and carbon sequestration modeling is two thirds complete. Water quantity and quality modeling is approximately half complete. The bird and mammal habitat models have been further refined and made more computationally efficient. More than 600 people have responded to the survey assessing how Minnesota residents value the ecosystem services that the state's forests provide. Statistical analysis of the results has begun, providing critical insight on how society values forests. After meeting with our Advisory Committee and completing several focus groups with potential end users to better understand user needs and limitations, wireframes have been developed for both the project website and decision support tool. Initial programming of the decision support tool has begun, with progress being made on data display and site selection functionality.

Fifth Update March 1, 2022

All project modeling is complete. This includes landscape (forest composition), carbon, bird and wildlife habitat, water quality and quantity, and associated economic valuation from 2020 to 2100 across the entire pilot study area of 3,800,000 acres in Northeastern Minnesota. Substantial progress has been made on both the website and the decision support tool. The website has been designed and drafted. Website content, including information about the project and modeling methodology documentation, is nearly complete. The decision support tool now has full site selection capability, the ability to add and visualize different formats of modeled data, and expanded functionality related to within-tool navigation. Planning for beta testing the application has begun.

Final Report submitted within 45 days of project end

The decision support tool and website, the final deliverables of the project, are complete. Both are publicly available and free to use at mnforecast.org. The decision support tool, branded as the Forest Change Assessment and Simulation Tool (ForCAST), allows users to select an area of interest, one of three climate scenarios, one of four forest management scenarios, and a year of interest in ten year time steps between 2020 and 2100. Once those are selected, data is available for four forest metrics; four water quantity and three water quality metrics; carbon sequestration; and habitat quality for six mammal groups, 26 individual mammal species, and 13 bird groups. These data are mapped and can be summarized through trend and bar charts. Additionally, economic valuation, in the form of willingness to pay, is provided for water quality, timber production, carbon sequestration, and game and non-game species wildlife habitat. The website provides project information and documentation of the methods. Together, they allow land managers to better understand how climate and management decisions can impact harvests and forest ecosystem services.

SUBPROJECT 2: Expanding the interactive natural resource Atlas for Minnesota

Description: Minnesota is fortunate to have a wealth of spatial data about the built and natural environments. Unfortunately, it is not accessible to most people. The Minnesota Natural Resource Atlas - Northeast Region (mnnaturalresourceatlas.org) has removed access barriers in 26 counties in Northeast and North Central Minnesota by providing access to over 275 multi-disciplinary spatial data layers through an intuitive, easy to use online mapping tool. The tool was developed hand-in-hand with

end users (identified as the general public or small organizations with limited in-house technical capacity), who helped to identify relevant data and prioritize development of the most relevant analytical tools. The first phase of the Atlas focused on delivery of data relevant to mining regions of NE Minnesota, with an emphasis on geology and water-based resources. We propose to leverage the existing infrastructure to expand the Atlas to the entire state and broaden the data offerings to include more detailed forestry, agriculture, water, and social science data. Specifically, we propose to:

1. assess data and functionality needs across economic sectors not currently covered by the Atlas
2. expand the data sources and analysis functions to enhance forestry, agriculture and cultural resource data and information.
3. expand the extent of the Atlas to the entire State of Minnesota,
4. develop outreach and training materials to build and support the user base.

The enhanced tool will be developed with direct engagement of expanded end user and data manager advisory groups including statewide minerals, forestry, agriculture, water, infrastructure and demographics resources (e.g.: MNDNR, MPCA, MFRC, etc.). ENTRF funds will be used to complete development of the software tools to incorporate the statewide data set and make available for above-listed stakeholder review and recommendation. Once complete it will be housed at the NRRRI with transfer to an appropriate state agency (e.g.: MNDNR, DIRRR) once fully deployed.

SUBPROJECT 2 ENRTF BUDGET: \$800,000

Outcome	Completion Date
1. Expand extent of Atlas to the entire state and expand content and functionality to meet the needs of additional end users.	6/30/2022
2. Develop outreach and training materials, and develop a funding model to enable long-term viability of data content and functionality.	6/30/2022
3. Project partner outreach will be ongoing throughout the 3-year term.	6/30/2022

First Update March 1, 2020

The Atlas team has updated the existing data catalogue, expanded the footprint to the entire State of Minnesota, issued invitations for the Atlas Advisory Committee, and sent out an initial survey to end users to request information about potential data sets to add to the catalogue. Groups of researchers covering forestry, agriculture, water, and cultural resources identified end users and developed a preliminary list of new data sources. Training materials are under development.

Second Update September 1, 2020

The Atlas team has engaged the Advisory Committee in group and individual meetings to solicit guidance on how to meet the needs of different sectors and organizations. Data layers indicating nitrogen and phosphorus use for agricultural fertilizer applications have been developed. Initial work to expand our water quality data has been completed. Results from end-user surveys have identified data

that are most important to Atlas users and will soon give insight into which functionally is most important. Work has begun to move the Atlas to a virtual server, ensuring a more robust web site and the ability to easily allocate more computing resources as the user base grows. Keyword search has been added to the interactive map and initial work has been completed to make database queries more efficient. Training has been adapted to remote delivery and two Northeastern Minnesota government organizations received training on how to use the Atlas for their work involving soil and water conservation.

Third Update March 1, 2021

The Atlas team has continued to expand the data catalog and enhance functionality. Stream and Lake water quality data layers have been developed, Audubon Society Important Bird Areas and Minnesota Forest Resources Council planning boundaries were acquired. An initial assessment of cultural resource data needs has been completed, and multiple meetings were held with the Department of Natural Resources to identify additional forestry and wildlife habitat data. Legend and data attribute display, map labeling, and data filtering functionality have all been improved. Analysis can now be conducted on filtered data. An assessment of functionality needs was conducted with trained Atlas users, this will guide further development efforts. The mapping application has been moved to a virtual server, allowing us to easily allocate more computational resources as the user base expands. A comprehensive data use monitoring system has been developed and allows us to better understand how and where users are engaging with the Atlas. The training and outreach program has trained more than 300 individuals employed in education, local government, state agencies, non-government organizations, and the private sector. More training events are scheduled throughout late winter and early spring.

Fourth Update September 1, 2021

The number of data layers available through the Atlas is nearly 400. We have developed additional data, including updated agricultural nutrient applications for both manure and synthetic fertilizers. Work is ongoing to develop a Stream Power Index at a 3 m resolution for the entire state. We have acquired 30 additional orthophotography layers and 8 additional data layers that were identified by external collaborators. Sixty additional climate layers were identified for future addition through a meeting with the State Climatology Office. Functionality has been expanded to include the ability to return data attributes for features within a boundary. Work has continued to expand the user base through remote training, with multiple sessions held throughout late winter and spring. The Atlas has also been integrated into the Board of Water and Soil Resources Technical training program, providing us a platform to reach local government employees that work on environmental issues throughout the state.

Fifth Update March 1, 2022

The Atlas now has more than 450 vetted data layers. We have worked to improve the efficiency of our quarterly data updates and continue to work closely with our target users to ensure that we have or can acquire the data they need. We are currently working with DNR Resource Assessment to make the Atlas more useful for forestry applications. This will include the addition of forestry-centric data and the development of a collaborative training workshop targeted at practicing foresters. We are also

collaborating with U-Spatial and the Minnesota Association of Geography Educators to develop lesson plans for K-12 students that center on the Atlas, providing teachers easy access to spatial data in the classroom. We have begun a Tribal government-focused training and outreach campaign with a training session with Fond du Lac Resource Management. We recently met with the director of the MN Association of Townships to identify opportunities to broaden use of the Atlas by township employees throughout the state. Refinements have been made to data symbology based on user feedback. We are currently developing a funding model for long-term support.

Final Report submitted within 45 days of project end

The Atlas project is complete. Throughout the project, we worked closely with our original Atlas users, target users in the expanded geographic area, and our advisory committee to identify and prioritize data and functionality needs. Data, with an emphasis on agriculture, forestry, and water resources, were developed or acquired and now total more than 500. Functionality that allowed users to more easily visualize, analyze, and share data was developed, tested, and deployed. This included enhanced ability to query and filter data, improvements to attribute data and legend formatting, improvements to data symbology, and the development of custom software to monitor data use within the mapping tool. Improvements were also made to make the Atlas more robust, responsive and reliable. These included the movement of the Atlas to a virtual server with more computational and storage resources, improvements to the data maintenance and updating processes, and the improvement of our backup system.

Training, outreach, and education were used to raise awareness of the project and expand Atlas users. Google analytics on the site indicate a growing user base with typical daily weekday unique visitors ranging from 60 to 100 and their locations distributed throughout the state, with the highest concentration in the Twin Cities metro area and Duluth. Internal software was developed that allows us to monitor which data is being requested and for which geographical area. This software indicates that water, natural and administrative boundaries, and biological data are the most frequently accessed and that users are viewing data for locations throughout the state.

SUBPROJECT 3: MFRC to support advancement of biochar for forest health

Description: Utilization of wood for biochar has potential to enhance forest-based economies, increase forest health, and increase soil C sequestration, but several barriers exist to operational utilization. This project will address key barriers to biochar utilization by identifying optimal biochar characteristics that improve soil functions, demonstrating the benefits of biochar to tree survival and growth, evaluating techniques and approaches for biochar production and application in operational forested settings, and estimating the potential for net C sequestration under a range of biochar utilization scenarios. We will use controlled laboratory experiments to assess different biochar types to identify the biochar characteristics (e.g., optimal fixed carbon content, degree of torrefaction, particle size, feedstock) that are most useful to increasing soil functions (water holding capacity, nutrient availability, C storage) important to forest health. We will also evaluate production, transport, and application logistics to identify conditions that will be necessary for utilization of biochar in operational forestry settings. To

achieve this, we will review existing techniques for forest application, survey loggers and operators on novel application techniques, and conduct an economic analysis to estimate cost-benefits of biochar under a range of production and market conditions. Results will provide a foundation for longer-term assessments of biochar utility in operational forestry settings.

SUBPROJECT 3 ENRTF BUDGET: \$400,000

Outcome	Completion Date
1. Identification of biochar compositions that enhance soil functions	6/30/2022
2. Evaluation of factors influencing cost-effective production, application 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

We have made excellent progress with work on Subproject 3 and are on track with the overall timeline. NRRIs Biomass Conversion Laboratory has produced six custom biochars from black ash and balsam fir. The six biochars are currently being analyzed for a suite of chemical and physical properties (e.g., nutrient content, surface area, water holding capacity) for characterization. Characterization is approximately 65% complete, and includes analysis of four commercial biochars for comparison. We have also initiated a soil incubation experiment to evaluate the effect of the custom biochars on soil functions important to forest health. The incubation will run for 60 days, with measurements of nutrient cycling and microbial activity occurring on a weekly basis. Work related to estimating the net C sequestration potential of biochar and the logistics assessments will commence in the next month. We were also able to leverage project resources to conduct additional measurements on some existing biochar/tree growth studies, which will be used to demonstrate the longer-term utility of biochar application at projects end. Outreach: Subproject lead R. Slesak gave a field tour on biochar utilization in forestry at the fall annual meeting of the Lake States Forest Resources Association (forest industry groups).

Second Update September 1, 2020

Progress continues, but with several delays and adjustments resulting from the coronavirus pandemic and the associated UMN shutdown. NRRIs Biomass Conversion Laboratory produced two additional biochar compositions for evaluation and analysis of chemical and physical properties has been completed. The soil lab incubation was concluded earlier than planned to coincide with UMN closure, but final analysis of soil, water, and gas samples has not been completed because of analytical lab closures and associated backlogs. We installed two new experiments designed to assess the effects of biochar on seedling growth, physiology, and drought resistance. One experiment is being conducted at UMN's St. Paul campus in a controlled greenhouse, and the other is a field study located at the Cloquet

Forestry Center. For the field study, biochar application is delayed until early September because of production delays. Therefore, we will have limited ability to assess biochar effects on seedling growth prior to the end of the project period. Assessment of carbon sequestration potential is progressing on time, with scenario development and initial assessment of biochar production carbon “costs” completed. The logistics assessment has been initiated, but focus groups will be delayed until coronavirus risks are reduced.

Third Update March 1, 2021

This project continued to progress towards completion of all of its major goals, making up for time lost to the COVID-19 pandemic earlier in 2020. We completed pilot production of approximately two tons of biochar for the reforestation field experiment. This biochar was installed as part of the forest regeneration field experiment at the University of Minnesota’s Cloquet Forestry Center. All biochar samples were characterized for their elemental and chemical makeup, water holding capacity, ion exchange capacity, liming capacity and pH. The only characterizations that have not yet been completed are the surface characterizations, which are awaiting some facilities upgrades before we can install the appropriate instrumentation. In the last period, the team also continued to develop relationships throughout Minnesota with forest products professionals, entrepreneurs, and researchers, to identify knowledge, market, and technological gaps that must be addressed to encourage the development of a biochar industry for Minnesota.

Fourth Update September 1, 2021

All of the biochar production and most of the testing is now complete, and work remains to finish the field and greenhouse performance testing as well as complete the carbon life cycle estimate. The remaining physical property testing is the surface/porosity testing. The two surface analysis instruments were installed and are now operational with staff learning to operate them. We will complete training on these instruments by September and then collect the surface area data for all the biochar produced for this program. We have also finished the carbon life cycle analysis harvesting Emerald Ash Borer infested trees and making biochar compared to a counterfactual where infested trees are left to decay naturally. The greenhouse study of biochar impacts on drought tolerance of saplings is ongoing as is the field studies of biochar on tree planting success at the Cloquet Forestry Center. We are on schedule to finish the field and greenhouse studies to allow correlation with the measured biochar physical properties.

Fifth Update March 1, 2022

A greenhouse-based study on the impact of biochar on drought response of saplings concluded in December of 2021, and final field measurements were completed by late October. MFRC scientists are compiling all data from both experiments for final reporting. We also completed a draft summary on the carbon life cycle impact of converting emerald ash borer killed trees into biochar for inclusion in the final technical report. The materials laboratory completed the surface analysis of the biochars made for these experiments. The team also identified the need for a new gas absorption measurement method to support the development of the future biochar industry. With these tasks complete, we have

completed all laboratory and field research. We are continuing to develop the research and commercialization ecosystem scenarios and dissemination activities, which will be included as part of the final technical report.

Final submitted within 45 days of project end

The NRRI materials analysis laboratory completed development of the new biochar surface porosity characterization technique. Surface pores from 0.2nm to 50 µm were fully characterized. These new measurements are important because different pore size ranges perform different functions when the biochar is used in a forest soil or other application. The MFRC research team completed their laboratory and greenhouse studies of biochar impacts on nutrient cycling and drought tolerance. They found that biochar helped retain nitrogen in the soil, while the highest temperature biochars also reduced organic carbon washout from the soils. The MFRC team also completed the first growing season measurements after applying biochar to red pine and red oak seedlings in the field study; there were limited, but positive effects of biochar on seedling photosynthesis and respiration. Continued measurements will continue beyond the end of the project to determine if there are differences in tree growth and productivity. NRRI has completed outreach to industrial partners. The experience gained through this project has helped to attract multiple companies to explore biochar production from wood residuals in Minnesota.

SUBPROJECT 4: Advance emerging Minnesota technologies to produce clean syngas from biomass

Description: Synthesis gas, abbreviated as syngas, is a gaseous mixture of hydrogen and carbon monoxide that can be converted into a variety of fuels and chemicals. When produced from biomass, the resultant products are carbon neutral products that will be necessary for industries such as aviation, mining, and chemicals to achieve their sustainability goals. NRRI will contract with the University of North Dakota's Energy and Environment Research Center (UND-EERC) to demonstrate advance the state of the art syngas production from pretreated Minnesota biomass and address the shortcomings in cost and purity of syngas production that have inhibited its commercial viability. The project will advance two goals to this end:

1. demonstrate that NRRI's existing biomass conversion technology as a "front end" pretreatment to syngas production improves the purity of the syngas, and
2. feed pretreated biomass into a pilot-scale high-pressure gasifier and assess its performance.

Since the gasifier operates at high pressure (in excess of 350 psia), feeding torrefied biomass into the gasifier would benefit from small-scale testing. The long-term aim is to work with private and university partners to secure funding to integrate a demonstration-scale gasification unit into the NRRI's Biomass Conversion Laboratory in Coleraine, MN.

SUBPROJECT 4 ENRTF BUDGET: \$500,000

Outcome	Completion Date
1. Characterize clean syngas production from pretreated biomass	6/30/2022
2. Demonstrate syngas production from pretreated biomass at pilot scale	6/30/2022
3. Project partner outreach will be ongoing throughout the 3-year term.	6/30/2022

First Update March 1, 2020

We have progressed in all three project deliverables this quarter. We have developed testing methods and a plan to evaluate syngas quality from Minnesota forest resources. After careful consideration for how to effectively gather meaningful data to support the long-term goals of this project, we concluded that purchasing a commercial unit (Pyroprobe) for gasification analyses was undoubtedly the best approach. We have identified, vetted and ordered the necessary equipment and made the necessary budget adjustments. We are negotiating a contract with a Minnesota-based company for engineering design of a biomass feed system for high-pressure gasification. The contractor has shared the project scope and deliverables with us and we are finalizing a timeline and budget. We have begun our outreach with federal and international partners to build a coalition that will attract the funding necessary for ongoing R&D in syngas production.

Second Update September 1, 2020

Based on characterization data and market review, we have identified opportunities for metallic iron products from Minnesota iron ores that can be produced by incorporating syngas as the reductant. This will allow Minnesota to export more valuable reduced iron products made with renewable carbon sources to fulfill future needs of the steel industry. We have acquired the instrumentation and have developed the experimental designs to determine the optimal biomass pretreatment conditions for scale-up at NRRI's Biomass Conversion Lab. We have also initiated a relationship with collaborators who have the equipment necessary to scale up syngas production.

Third Update March 1, 2021

We continue our progress towards completion of our program goals. Over the past quarter we successfully built and installed the bench top scale equipment to rapidly evaluate the performance of different biomass under different pretreatment conditions and instrumentation to measure the syngas quantity and quality. We developed a definitive screening experimental design so that results from these experiments will be used to select optimal pretreatment conditions for pilot-scale work. The NRRI Biomass Conversion Laboratory (BCL) in Coleraine, MN has been preparing equipment for the plot-scale phase of the project, pending the results from the laboratory-scale work. We have met with research partners and companies interested in working with us to develop a clean syngas industry in Minnesota,

as well as end users in the transportation, energy, and mineral processing industries who would be customers for syngas. This customer discovery will guide our program development efforts.

Fourth Update September 1, 2021

During this period we completed the analyses and data gathering required to plan the final phase of this project. We completed the pretreatment at the bench-top scale at three levels of temperature and two atmosphere treatments, steam and nitrogen. We completed the analytical work with bench-top pyrolysis to analyze the yield of syngas (hydrogen and carbon monoxide) and contaminants (tars). Our results indicate that steam torrefaction significantly reduced tars while increasing hydrogen yield. Based on these observations we designed a steam addition system to the pilot torrefaction kiln to test this at an industrially relevant scale. These results informed our selection of pretreatment conditions at the pilot scale for performance evaluation in a pilot gasification system. This work has prepared us to finalize the contract with the University of North Dakota EERC for the pilot-scale gasification tests.

Fifth Update March 1, 2022

We completed the analysis of the benchtop torrefaction pretreatment using the pyrolysis probe. The bench top data provided guidance for the pretreatment scale-up. The NRRI Biomass Conversion Laboratory demonstration unit produced ten 250 pound samples at a range of temperatures with and without steam injection. These were forwarded to our partners at the Energy and Environment Research Center (EERC) in Grand Forks, ND, for gasification experiments. EERC will perform the gasification work in February, 2022, and provide the results to NRRI by March, 2022. We continue to develop industry relationships pursuing opportunities for syngas in the industrial sector focused on waste reduction and decarbonization.

Final Report submitted within 45 days of project end

We completed analysis of benchtop gasification trials on pretreated black ash biomass. The results confirmed our prediction that pretreatment reduced tars during gasification. Higher temperature treatments, up to 300°C, and steam injection decreased the tar production the most, but at the expense of syngas yield. Optimum pretreatment conditions to reduce tar with minimal syngas yield penalty ranges between 240-280°C with steam. The EERC team completed pilot-scale gasification trials on ten samples of black ash, confirming the benefits of biomass pretreatment on tar reduction and also in biomass injection into a fluidized bed gasifier. NRRI's commercial outreach has determined that there are key market opportunities for syngas utilization in heavy industry; iron and steel production, renewable methane, and renewable hydrogen production. We will continue our industrial outreach beyond the end of this project to socialize renewable syngas with Minnesota-based industry.

IV. DISSEMINATION:

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

- Presentations, some in cooperation with MFRC, to public forest, water, and agriculture management agencies, forest and energy industry partners and relevant trade organizations.
- Workshops/presentations to train end users of the forest optimization tool and the Minnesota Natural Resource Atlas enhancements.

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: Optimizing management of Minnesota’s forest landscapes: The team has held multiple meetings with an advisory board comprised of tool stakeholders to ensure alignment with project objectives & expectations; a public stakeholder survey is under preparation for distribution in Spring 2021.
- Subproject 2: Expanding the interactive natural resource Atlas for Minnesota: The team continues to engage an advisory board to ensure alignment with project objectives and end-user needs; the training and outreach program has trained more than 300 individuals employed in education, local government, state agencies, non-government organizations, and the private sector. More training events are scheduled throughout late winter and spring.
- Subproject 3: MFRC to support advancement of biochar for forest health: The team has presented progress overviews to Minnesota Forest Industries, the Minnesota Forest Resources Council; presented biochar discussion in a Bioeconomy Coalition of Minnesota webinar. Dovetail Partners held workshops with forest product producers.
- Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass: No formal dissemination activities planned or executed during this period.

Fourth Update September 1, 2021

- Subproject 1: Optimizing management of Minnesota’s forest landscapes:
 - The team has held focus groups with stakeholders within the forest industry to better understand information needs and technical capabilities. The general public was surveyed to assess how they value Minnesota’s forests and the ecosystem services they provide. The team continues to work with an advisory panel.
- Subproject 2: Expanding the interactive natural resource Atlas for Minnesota:
 - Additional training has been conducted with local governments, conservation organizations, and non-governmental organizations in Northeastern and South-Central Minnesota. The Atlas was featured in newsletters by both the Natural Resources Research Institute and the Department of Iron Range Resources And Rehabilitation. The team is also working with the soil experts at the University of Minnesota to create on-going training programs.
- Subproject 3: MFRC to support advancement of biochar for forest health

- We contracted with Dovetail Partners to meet with landholders and forest industry members to discuss opportunities for biochar production and application in forests. The report, entitled “Biochar Potential in Minnesota’s Forests” was finalized and published in July 2021 by Dovetail Partners. The report is available here <https://www.dovetailinc.org/portfoliodetail.php?id=60f055b06fe8f>
- Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass
 - The team collaborated with NRRI metallurgical engineers to identify near-term market opportunities to utilize syngas in place of fossil fuels for the iron and steel industry. Team members met privately with three international firms with connections to Minnesota’s iron industry to gauge industry interest in this technology. We learned that there is substantial demand for low-carbon-impact steel production and syngas from biomass is one technology that could help achieve this goal. We are seeking further funding to pursue this research with the industry.

Fifth Update March 1, 2022

- Subproject 1: Optimizing management of Minnesota’s forest landscapes (“ForOpt”):
 - Presentations on the project were given at the Minnesota Geographic Information System/Land Information System conference and at the Forestry and Wildlife Research Review Conference.
- Subproject 2: Expanding the interactive natural resource Atlas for Minnesota:
 - A current focus of the project is to raise awareness of the Atlas and to engage multiple organizations through outreach and training. Demonstrations of the Atlas were given at the UMD GIS Day, U of MN Day of Data, and the International Coastal Atlas Network Conference. Recent training events have focused on Secondary and Post-Secondary education, Tribal governments, and MN Association of Townships. Multiple training events are scheduled for late winter and early spring.
- Subproject 3: MFRC to support advancement of biochar for forest health:
 - E Singsaas Presented NRRI’s Biochar Initiative to Mineland Vision Meeting (Virtual presentation, 10-26-2021).
- Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass:
 - E Singsaas Presented to the Grand Rapids Wood-to-Biofuel meeting led by the Great Plains Institute. Timber Lake Lodge, Grand Rapids, MN (12-13-2021)

Final Report submitted within 45 days of project end

- Subproject 1: Optimizing management of Minnesota’s forest landscapes (“ForOpt”):
 - The Forest Change Assessment and Simulation Tool (ForCAST) was publicly launched on July 19 through a Sustainable Forests Education Cooperative (SFEC) webinar. Approximately forty industry professionals attended. A subsequent three hour workshop is scheduled through the SFEC for September 29. ForCAST is freely available at mnforcast.org.
- Subproject 2: Expanding the interactive natural resource Atlas for Minnesota:
 - The Minnesota Natural Resource Atlas is freely and publicly available online at mnatlas.org. Dissemination through training, outreach, and education were key components of the project. Articles were contributed to relevant newsletters and

publications to raise awareness, and free training sessions were offered to organizations throughout the state. Eight 15 to 30 minute project overview presentations that included Atlas demonstrations were also conducted. In total, 38 training or demonstration events were conducted with over 1000 individuals participating from conservation organizations, K-12 or post-secondary education, academia, and tribal, local, state, and federal governments.

- Subproject 3: MFRC to support advancement of biochar for forest health:
 - Toczydlowski, Alan JZ; Robert A Slesak; Rodney T Venterea; Kurt A Spokas. *Effect of Biochar Feedstock and Pyrolysis Temperature on Nutrient Cycling in Forest Soil*. 2021 ASA, CSSA and SSSA International Annual Meetings, Salt Lake City, Utah. Oral presentation November 7-10, 2021.
 - Reuling, Laura F; Alan JZ Toczydlowski; Robert A Slesak; Marcella A Windmuller-Campione. *Effects of biochar on drought tolerance of Pinus banksiana seedlings*. USFS National Silviculture Workshop, Kellogg, ID. Oral presentation July 12-14, 2022.
 - McFarland, Ashley; Fernholz, Kathryn; Groot, Harry. *Biochar Potential in Minnesota's Forests*. Commissioned Report 2021.
 - Singaas, Eric. *Engineering functional biochar for specific applications*. North American Biochar & Bioenergy Conference, Morgantown, West Virginia. Oral Presentation August 8-11, 2022.
 - Barry, Brian. *A new approach for complete pore size distributions and regime-specific total pore volume determinations of biochars*. North American Biochar & Bioenergy Conference, Morgantown, West Virginia. Oral Presentation August 8-11, 2022.
 - Singaas E, Barry B, Kolomitsyna O, Kacharov O, Yemets S, Young M, Toczydlowski A, and Slezak R. 2022. Biochar from insect-damaged trees used as a forest soil amendment: production, characterization, and application. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/16.
- Subproject 4: Advance emerging Minnesota technologies to produce clean syngas from biomass:
 - Singaas E, Kolomitsyna O, Kacharov O, Yemets S, Young M, Barry B. 2022. Biomass pretreatment to make clean syngas from Minnesota wood residuals. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/17.

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 Pyroprobe® 6200 Pyrolyzer from CDS Analytical, LLC (\$34,641) and a Micro GC fixed gas analyzer from Inficon Inc. (\$32,132).

The NRRI has an active biomass conversion program exploring development of biomass processing technologies and applications to Minnesota resources. The Pyroprobe® and Micro GC will be invaluable tools for this research program. For this project, we will be pyrolyzing (heating in a low oxygen environment) various biomass (wood, bark, grass etc.) samples and quantifying/identifying the volatile species that are formed as a result of the heating. Specifically, it will provide basic data to confirm biomass pretreatment steps and support the design of syngas generation equipment based on application of a novel, Minnesota-based technology. This project leverages earlier NRRI investment of several million dollars in biomass pre-processing technologies.

This analytical equipment is notoriously robust with a long lifetime and holds its value well; we expect to use it routinely throughout its projected lifetime. In the event that the NRRI decides to discontinue biomass conversion research, the Institute commits to selling this equipment on the secondary market and returning those proceeds to the LCCMR.

Amendment Approved by LCCMR **2/24/2020**.

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

Enter Total Estimated Personnel Hours for entire duration of project: 40,000	Divide total personnel hours by 2,080 hours in 1 yr = TOTAL FTE: 9.5
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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: 4200	Divide total contract hours by 2,080 hours in 1 yr = TOTAL FTE: 3.0
---	---

VI. PROJECT PARTNERS:

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

Subproject 4: *Advance emerging Minnesota technologies to produce clean syngas from biomass*

- Josh Stanislawski
Director of Energy Systems Development
Energy & Environmental Research Center
University of North Dakota
Phone: (701) 777-5087
Fax: (701) 777-5181
jstanislawski@undeerc.org

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

Subproject 1: Optimizing Management of Minnesota's Forest Landscapes

- Brian Sturtevant
Research Ecologist
Northern Research Station
US Forest Service
- Mark White
Ecologist
Nature Conservancy

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 and delivery of new tools to support Minnesota resource decision-making and the demonstration of biomass processing technologies to better foster forest health and derive value-added materials from waste and secondary species forest biomass. These delivery points are consistent with the state's goals concerning energy & carbon reduction, forest stewardship, industry growth opportunities and community support & development. This work will leverage long-term relationships and funding opportunities across academia, industry, agencies and other Minnesota stakeholders.

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 Budget Spreadsheet - FINAL

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

Project Manager: Rolf Weberg

Sub-project Title: Forest and Bioeconomy Research

Organization: Natural Resources Research Institute, University of Minnesota Duluth

Project Budget: \$2,200,000

Project Length and Completion Date: 3 years, June 30, 2022

Today's Date: 09/15/2022



ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Budget 06/30/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	\$ 1,808,924	\$ 1,808,924	\$ -
Professional/Technical/Service Contracts	\$ 236,962	\$ 236,962	\$ -
Equipment/Tools/Supplies	\$ 53,716	\$ 53,716	\$ -
Capital Expenditures Over \$5,000	\$ 66,471	\$ 66,471	\$ -
Travel expenses in Minnesota	\$ 6,327	\$ 6,327	\$ -
Other	\$ 27,600	\$ 27,600	\$ -
COLUMN TOTAL	\$ 2,200,000	\$ 2,200,000	\$ -

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:E25 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 Budget Spreadsheet - FINAL

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

Sub-project Manager: George Host

Sub-project Title: Optimizing Management of Minnesota's Forest Landscapes (sub-project #1)

Organization: NRRI

Sub-project Budget: \$500,000

Project Length and Completion Date: 3 years, June 30, 2022

Today's Date: 09/15/2022



ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 03/01/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	\$ 485,865	\$ 485,865	\$ -
G. Host, NRRI Research Director: \$27,598 (74% salary, 26% fringe), 8% FTE for 2 years			
Academic P&A (in aggregate): 9 staff members est. total: \$232,782 (74% salary, 26% fringe), 114% FTE for 2 years			
Civil Service (in aggregate): 4 staff members est. total: \$124,688 (77% salary, 23% fringe), 83% FTE Year 1 and 83% FTE Year 2			
Post Doc: \$87,230 (81% salary, 19% fringe): 50% FTE for 2 years			
Temp/Casual: \$3,113 (93% salary, 7% fringe): 3.6% FTE for 1 year			
Professional/Technical/Services	\$ -	\$ -	\$ -
Equipment/Tools/Supplies			
Data storage (est. cost for 2 TB of storage of research data) and field supplies	\$ -	\$ -	\$ -
Capital Expenditures	\$ -	\$ -	\$ -
Travel expenses in Minnesota			
Project meetings in the Twin Cities; Consultation with MN end users; Outreach training in MN (year 2 only), MN conference travel to include mileage, lodging and allowable meals.	\$ 206	\$ 206	\$ -
Other	\$ 13,929	\$ 13,929	\$ -
GIS Lab fees	\$ 4,140	\$ 4,140	\$ -
Data storage: purchase of a Network Attached Storage (NAS) unit to safely store the large amount of data	\$ 2,830	\$ 2,830	\$ -
Printing: Cost of printing surveys for survey participants	\$ 3,101	\$ 3,101	\$ -
Mailing: Cost of mailing printed surveys	\$ 3,858	\$ 3,858	\$ -
COLUMN TOTAL	\$ 500,000	\$ 500,000	\$ -

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:		\$ -	\$ -	\$ -

Attachment A:

Environment and Natural Resources Trust Fund

M.L. 2019 Budget Spreadsheet - FINAL

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

Sub-project Manager: Lucinda Johnson

Sub-project Title: Expanding the Interactive Natural Resource Atlas for Minnesota (sub-project #2)

Organization: Natural Resources Research Institute

Sub-project Budget: \$800,000

Project Length and Completion Date: 3 years, June 30, 2022

Today's Date: 09/15/2022



ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 06/30/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	\$ 786,277	\$ 786,277	\$ -
Lucinda Johnson, NRRI Research Director: \$43,458 (74% salary, 26% fringe), 10% FTE for 2 years			
Academic P&A (in aggregate): 12 staff members est. total \$423,207 (74% salary, 26% benefits), FTE Year 1 = 192.5%, Year 2 = 187.5%			
Civil Service (in aggregate): 6 staff members est. \$291,983 (77% salary, 23% benefits), FTE: Year 1 = 205%, Year 2 = 175%			
Temp or Casual Appointment: \$13,536 (92% salary, 8% benefits), 15% FTE for 2 years			
Undergraduate Student: \$9,847 (100% salary, 0% benefits), 21% FTE for 2 years			
Equipment/Tools/Supplies			
Assessment, Outreach, and Training Materials	\$ 22	\$ 22	\$ -
Capital Expenditures	\$ -	\$ -	\$ -
Travel expenses in Minnesota			
In-state agency meetings; workshops; UMTC team meetings. Travel costs to include mileage, lodging and allowable meals.	\$ 558	\$ 558	\$ -
Other	\$ 13,143	\$ 13,143	\$ -
GIS Lab Fees; Domain web-hosting (fee for web-hosting Atlas); and server fees (for external server to run Atlas interactive mapping application)	\$ 10,313	\$ 10,313	\$ -
Purchase of a Network Attached Storage (NAS) unit to serve as an offsite backup for the Atlas project will make our project infrastructure more reliable.	\$ 2,830	\$ 2,830	\$ -
COLUMN TOTAL	\$ 800,000	\$ 800,000	\$ -

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:		\$ -	\$ -	\$ -

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

Legal Citation: M.L. 2019. First Special Session. Chp. 4. Art. 2. Sec. 2. Subd. 3 (a)
Sub-project Manager: Rob Slesak
Sub-project Title: MFRC to support advancement of biochar for forest health (sub-project #3)
Organization: Natural Resources Research Institute, University of Minnesota Duluth
Sub-project Budget: \$400,000
Project Length and Completion Date: 3 years, June 30, 2022
Today's Date: 09/15/2022



ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 03/01/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	\$ 325,963	\$ 325,963	\$ -
Rob Slesak, MFRC Director of Applied Research and Monitoring : 0% FTE for 2 years and Rolf Weberg, NRRI Executive Director: 0% FTE for 2 years			
6 Academic P&A: 3 UMTC faculty and reserchers est. total: \$289,820 (74% salary, 26% fringe), 175% Total FTE over 2 years; 3 NRRI researchers est. total: \$29,719 (74% salary, 26% fringe), 11% Total FTE over 2 years			
1 Civil Service technician (NRRI) est. total: \$5,926 (77% salary, 23% fringe), 5% Total FTE over 2 years			
Professional/Technical/Service Contracts	\$ 37,103	\$ 37,103	\$ -
Estimated external sample analysis services	\$ 4,140	\$ 4,140	\$ -
UMTC lab services for use of growth chambers and analysis of soil, leachate and plant tissue est. at \$10,000	\$ 12,443	\$ 12,443	\$ -
NRRI Analytical lab services and biomass conversion est. at \$20,000	\$ 20,520	\$ 20,520	\$ -
Equipment/Tools/Supplies			
Supplies for lab bioassay including custom incubation cores, soil moisture sensors and	\$ 31,371	\$ 31,371	\$ -
Capital Expenditures	\$ -	\$ -	\$ -
Travel expenses in Minnesota			
Estimated travel costs (including mileage, lodging and allowable meals) to field trial sites in Minnesota. Locations to be determined.	\$ 5,563	\$ 5,563	\$ -
COLUMN TOTAL	\$ 400,000	\$ 400,000	\$ -

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:		\$ -	\$ -	\$ -

Attachment A:**Environment and Natural Resources Trust Fund****M.L. 2019 Budget Spreadsheet - FINAL****Legal Citation:** M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (q)**Sub-project Manager:** Eric Singaas**Sub-project Title:** Advance emerging Minnesota technologies to produce clean syngas from biomass (Sub-project #7)**Organization:** Natural Resources Research Institute, University of Minnesota Duluth**Sub-project Budget:** \$500,000**Project Length and Completion Date:** 3 years, June 30, 2022**Today's Date:** 09/15/2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget 06/30/2022	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	\$ 210,819	\$ 210,819	\$ -
Eric Singaas, NRRI Research Director: \$34,342 (74% salary, 26% fringe), 10% FTE for 2 years			
4 Academic P&A: NRRI researchers & project manager est. total: \$135,883 (74% salary, 26% fringe), 40% Total FTE over 2 years			
1 Civil Service technician, \$27,449 (77% salary, 23% fringe), 15% Total FTE over 2 years			
1 BU technician, \$11,756 (77% salary, 23% fringe), 21.4% Total FTE over 1 year			
Professional/Technical/Service Contracts	\$ 199,859	\$ 199,859	\$ -
Analytical lab services and biomass conversion	\$ -	\$ -	\$ -
Contracted services with project partner (UND-EERC) for engineering design and prototype development of gasifier feed mechanism. 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.	\$ 198,459	\$ 198,459	\$ -
INFICON Online Training: Final training for Pryoprobe ordered in June	\$ 1,400	\$ 1,400	\$ -
Equipment/Tools/Supplies			
Lab supplies to include analytical reagents, sample vessels and biomass samples	\$ 22,323	\$ 22,323	\$ -
Capital Expenditures Over \$5,000	\$ 66,471	\$ 66,471	\$ -
Pyroprobe 6200 Pyrolyzer from CDS Analytical, LLC to pyrolyze samples	\$ 34,596	\$ 34,596	\$ -
Micro GC fixed gas analyzer from Inficon Inc. pyrolyze samples	\$ 31,875	\$ 31,875	\$ -
Travel expenses in Minnesota			
Travel to Twin Cities and East Grand Forks to meet with project collaborators. Est. 4 trips @ \$500/trip inclusive of mileage, parking and allowable meals	\$ -	\$ -	\$ -
Other			
Est. cost for shipping biomass samples to lab and testing sites	\$ 528	\$ 528	\$ -
COLUMN TOTAL	\$ 500,000	\$ 500,000	\$ -

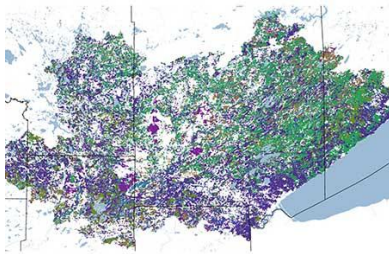
OTHER FUNDS CONTRIBUTED TO THE PROJECT	Spent	Balance
Non-State:	\$ -	\$ -
State:	\$ -	\$ -
In kind:	\$ -	\$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Spent	Balance
Current appropriation:	\$ -	\$ -
Past appropriations:	\$ -	\$ -

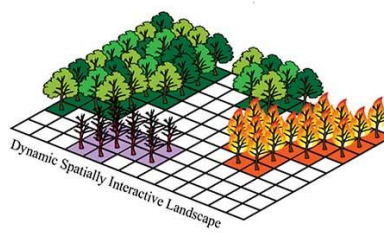
ForCAST: Forest Change Assessment and Simulation Tool

The ForCAST tool attempts to provide forestry professionals and land managers with an opportunity to evaluate how a changing climate and changing markets might affect Minnesota's forests and the ecosystem services that they provide.

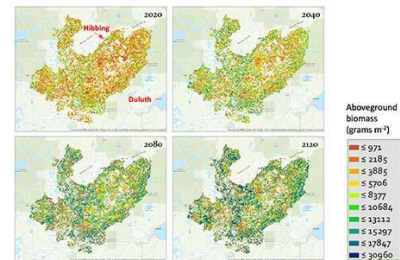
ForCAST Process



Develop landscape-scale forestry management and climate scenarios.

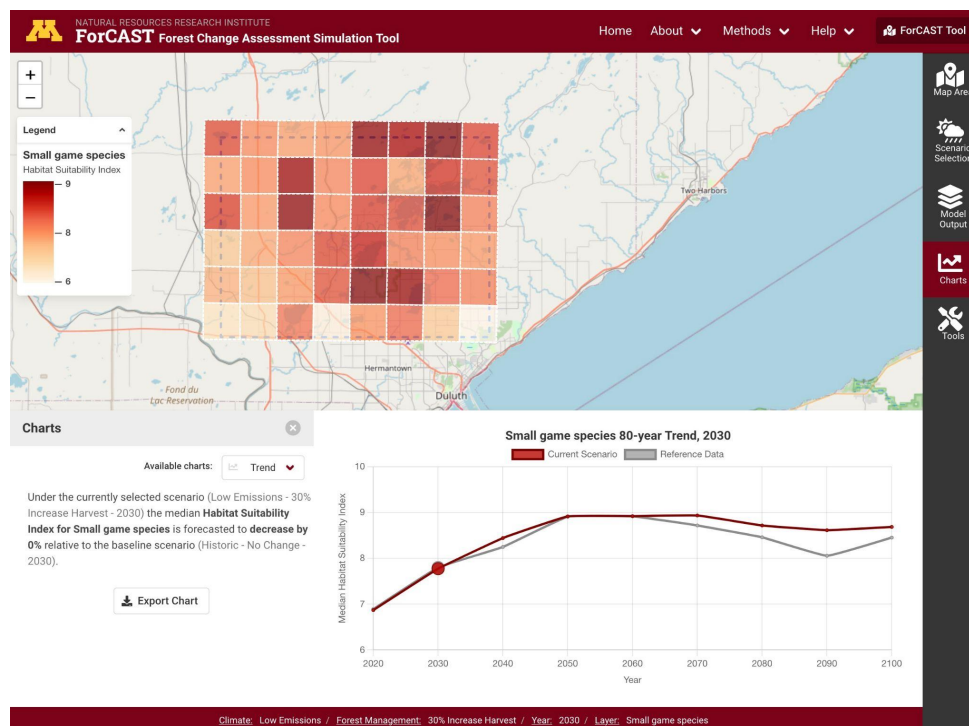


Simulate future forest composition and structure from 2020 to 2100.



Model and evaluate forest ecosystem services from 2020 to 2100.

Interactive Tool



All model results are delivered to users through a custom, interactive mapping tool. The tool allows users to visualize and summarize how forest composition and goods and services change through time under different management and climate scenarios. Data is available to download for use within a desktop Geographic Information System.



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).

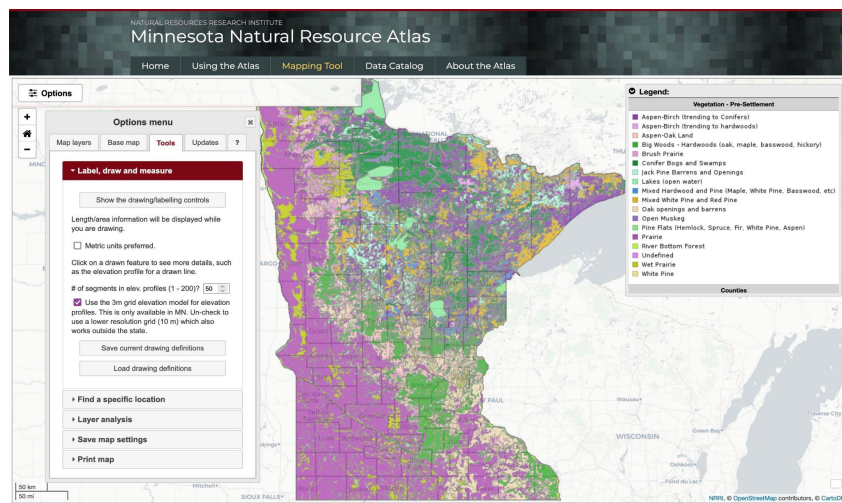
Minnesota Natural Resource Atlas

**Natural Resources
Research Institute**

UNIVERSITY OF MINNESOTA DULUTH
Driven to Discover

Small organizations throughout the state often lack the resources and capacity to incorporate mappable, also known as spatial, data into their decision making processes. As a result, decisions that impact our state's natural resources are being made with incomplete information. The Minnesota Natural Resource Atlas provides all Minnesotans with free and easy access to spatial data through a simple, online Geographic Information System (GIS).

Interactive Mapping Application



The Interactive Map provides a basic set of GIS tools for viewing, exploring, analyzing, and sharing spatial data. These tools allow users to better understand spatial data and incorporate it into their decision making processes.

Robust Data Catalog

The Data Catalog provides access to more than 500 spatial data layers from trusted sources. All data are available for use within the Interactive Map and most can be downloaded for external use. Data categories include:

Agriculture	Biota	Boundaries	Climate	Environment
Animal rearing, crop raising, and associated activities.	Flora and/or fauna in the natural environment. Management Units	Natural and political boundaries.	Current and historical weather records.	Resources, conservation, and degradation. Ecological classification and indexes.
Geology & Topography	Imagery & Land Cover	Infrastructure	Society & Economy	Water
Geology, mineral resources, and elevation.	Orthophotography of the landscape and land cover.	Transportation and communication networks, industrial resources, and water systems.	Demographics and social and economic resources and challenges.	Surface and groundwater characteristics.

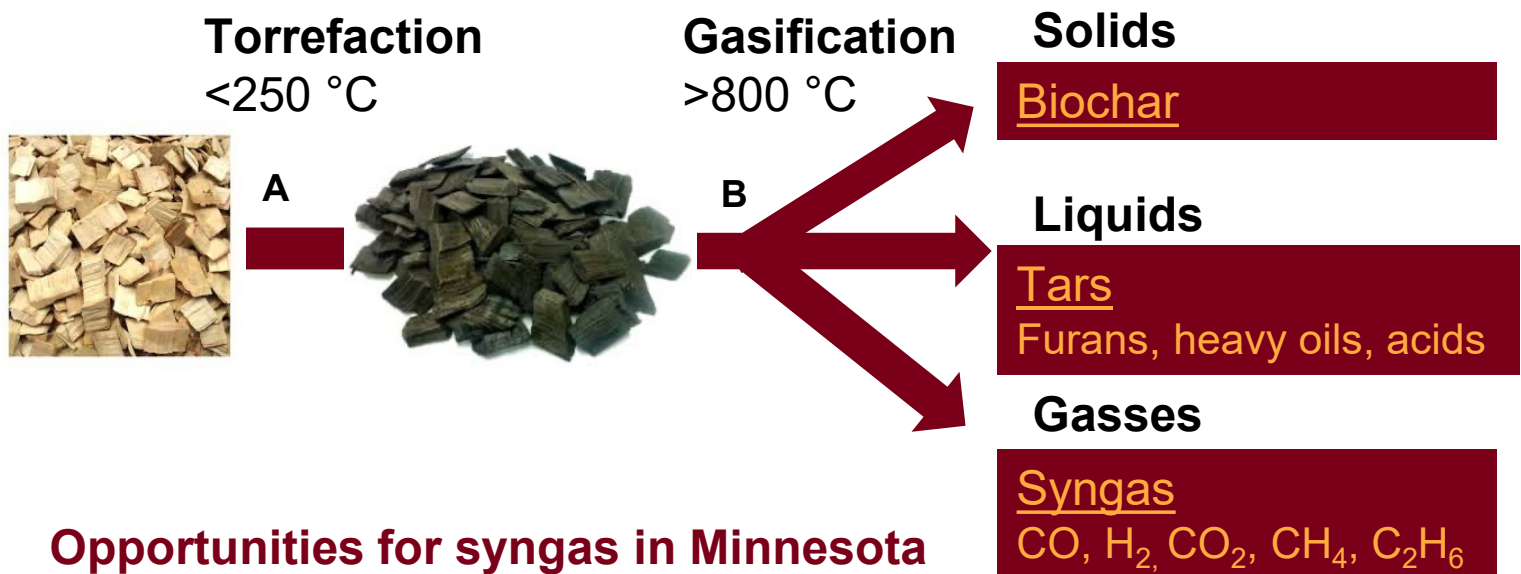


Funding for the statewide expansion and enhancement of the Minnesota Natural Resource Atlas was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Advance Emerging Technologies to Produce Clean Syngas from Biomass

Syngas produced from biomass can be used to make carbon neutral Hydrogen, Methane, Fuels, and Steel. *This project focuses on:*

1. Develop torrefaction pretreatment conditions to improve syngas production from residual biomass
2. Demonstrate clean syngas from biomass at pilot scale
3. Understand the future of renewable fuels in Minnesota's industrial economy



Opportunities for syngas in Minnesota

- Hydrogen economy
- Renewable natural gas
- Low carbon iron and steel products
- Renewable Jet and Diesel fuels
- Forest fuel reduction
- New markets for forest biomass



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).

2019 Project Abstract

For the Period Ending June 30, 2022

PROJECT TITLE: Forest and Bioeconomy Research - Subproject 1: Optimizing management of Minnesota's forest landscapes

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 (q)

APPROPRIATION AMOUNT: \$500,000

AMOUNT SPENT: \$500,000

AMOUNT REMAINING: \$0

Sound bite of Project Outcomes and Results

Projections of Minnesota forest composition and associated ecosystem services were developed under different climate and management scenarios from 2020 to 2100. This information was made freely available through a custom website and interactive mapping tool, providing resource managers with critical information for planning.

Overall Project Outcome and Results

Forest management is an increasingly complex discipline that requires the balancing of economics and ecology in the face of changing markets and climate. Beyond providing lumber, pulp, and other forest products, forests provide many additional goods and services that benefit society. Known as "ecosystem goods and services," these include sequestering carbon, providing habitat for wildlife, maintaining water quality and quantity, and others. Understanding both how forests will change over time and how society values the goods and services they provide is critical to the successful management of Minnesota's forests.

This project was designed to provide projections of how forest composition and the goods and services that forests provide will change from 2020 to 2100 under different management and climate scenarios on 3,800,000 acres in northern Minnesota. It also helps users understand how Minnesotans value those forest goods and services. Foundational landscape change modeling was done using the LANDIS-II model, allowing for a better understanding of forest composition and carbon. Subsequent wildlife habitat and water quality and quantity modeling were done using the WHINGS and HSPF models, respectively. All models were run for each of the 12 unique combinations of our management and climate scenarios. Focus groups and surveys were used to quantify value.

Minnesota's forest managers indicated that they would like to consider ecosystem services when making harvest and management decisions but lack the information to do so. The primary deliverable of this project is the Forest Change Assessment Simulation Tool, or ForCAST. This interactive mapping and decision support tool contains all of our projections of forest composition and associated ecosystem services and estimates of value, allowing for the development of informed, long-term management strategies that aren't exclusively driven by the economics of timber markets.

Project Results Use and Dissemination

ForCAST, an interactive mapping and decision support tool developed as the main deliverable of this project, is freely and publicly available through the project [website](#). The website also provides access to comprehensive project and methodology documentation. During development, awareness was raised about the project through presentations at the Minnesota GIS/LIS conference and a combined meeting of the Minnesota Society of American Foresters and the Sustainable Forests Education Cooperative's (SFEC) Forestry and Wildlife Research Review. ForCAST was launched through a SFEC webinar in July 2022 with a subsequent training event scheduled through SFEC in September.

2019 Project Abstract

For the Period Ending June 30, 2022

PROJECT TITLE: Forest and Bioeconomy Research - Subproject 2: Expanding the Interactive Natural Resource Atlas for Minnesota

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 (q)

APPROPRIATION AMOUNT: \$500,000

AMOUNT SPENT: \$500,000

AMOUNT REMAINING: \$0

Sound bite of Project Outcomes and Results

The Minnesota Natural Resource Atlas is an easy to use interactive mapping tool and spatial database that is freely available to all Minnesotans. It lowers or removes the barriers that prevent spatial data from informing the decisions that impact our state's natural resources.

Overall Project Outcome and Results

Organizations and natural resources managers in Minnesota are often required to make decisions that impact our natural resources while using incomplete information. Spatial data contains valuable information that can improve decision making and outcomes. However, accessing it typically requires specialized software and advanced technical skills. The Minnesota Natural Resource Atlas was designed to be a statewide resource that improves access to spatial data and the information and insights that it contains.

The Atlas project was a statewide expansion and enhancement of an earlier version that served 27 counties in northeast and north central Minnesota. We worked closely with our original Atlas users, target users in the expanded geographic area, and our advisory committee to identify data and functionality needs. More than 500 additional data sets, with an emphasis on agriculture, forestry, and water resources, were developed or acquired. Functionality that allowed users to more easily visualize, analyze, and share data was developed, tested, and deployed. Improvements were also made to make the Atlas more robust, responsive, and reliable.

Training, outreach, and education were used to raise awareness of the project and expand Atlas users. Google analytics on the site indicate a growing user base with typical daily weekday unique visitors ranging from 60 to 100 and their locations distributed throughout the state, with the highest concentration in the Twin Cities metro area and Duluth. Internal software was developed that allows us to monitor which data is being requested and for which geographical area. This software indicates that water, natural and administrative boundaries, and biological data are the most frequently accessed and that users are viewing data for locations throughout the state.

The Minnesota Natural Resource Atlas is a valuable resource for the state. Ultimately, it is making spatial data more accessible for all Minnesotans.

Project Results Use and Dissemination

The Minnesota Natural Resource Atlas is freely and publicly available online. Dissemination through training, outreach, and education were key components of the project. Articles were contributed to relevant newsletters

and publications to raise awareness, and free training sessions were offered to organizations throughout the state. Eight 15 to 30 minute project overview presentations that included Atlas demonstrations were also conducted. In total, 38 training or demonstration events were conducted with over 1000 individuals participating from conservation organizations, K-12 or post-secondary education, academia, and tribal, local, state, and federal governments.

2019 Project Abstract

For the Period Ending June 30, 2022

PROJECT TITLE: Forest and Bioeconomy Research - Subproject 3 MFRC to support advancement of biochar for forest health

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 (q)

APPROPRIATION AMOUNT: \$400,000

AMOUNT SPENT: \$400,000

AMOUNT REMAINING: \$0

Sound bite of Project Outcomes and Results

Biochar is a material that can be produced from residual biomass that can improve soil health and reforestation while storing carbon for the long term in soils. This project demonstrated production and deployment of insect-damaged balsam fir and black ash as biochar to improve seedling regrowth and retain nutrients in sandy forest soils.

Overall Project Outcome and Results

We demonstrated the concept of using Minnesota black ash and balsam fir as feedstocks for the generation of biochar for forest soil amendments to improve reforestation efforts. We produced biochars from both black ash and balsam fir wood chips at a variety of temperatures and characterized these by measuring different physical and chemical properties.

The fully-characterized biochar samples were evaluated in greenhouse plant growth studies. Biochars from black ash and balsam fir processed at 550°C were the most promising candidates for positive soil health improvements, as these products revealed a) the highest water holding capacities, b) minimization of potentially harmful mobile organics (extractives content), and c) greatest nitrogen and dissolved organic carbon retention. Field trials were then performed at the Cloquet Forestry Center to evaluate biochar impact on red pine and red oak seedling survival. Biochars were added to the soil surrounding newly-planted red pine and red oak seedlings using a randomized nested design with appropriate controls. Early results on photosynthesis and respiration rates from the field study are positive but conclusions on biochar's role on improving seedling survival will require long-term monitoring at the field site, extending beyond the end of this project.

We also produced two literature reviews. The first study examined net carbon sequestration potential of using biochar in forest regeneration projects and concluded that there is ample supply of black ash in Minnesota to support industrial-scale biochar production and that 20 years of biochar production in Minnesota, just from black ash, would sequester approximately 6.7 million tons of CO₂. The second study was a techno-economic analysis performed by Dovetail Partners. This report concluded that the ecological and economical benefits of biochar implementation are best suited for revegetation efforts for jack and red pine in areas with sandy soils. This report can be found online: [Dovetail Partners report](#).

Project Results Use and Dissemination

- 1) Toczydlowski, Alan JZ; Robert A Slesak; Rodney T Venterea; Kurt A Spokas. Effect of Biochar Feedstock and Pyrolysis Temperature on Nutrient Cycling in Forest Soil. 2021 ASA, CSSA and SSSA International Annual Meetings, Salt Lake City, Utah. Oral presentation November 7-10, 2021.
- 2) Reuling, Laura F; Alan JZ Toczydlowski; Robert A Slesak; Marcella A Windmuller-Campione. Effects of biochar on drought tolerance of Pinus banksiana seedlings. USFS National Silviculture Workshop, Kellogg, ID. Oral presentation July 12-14, 2022.
- 3) McFarland, Ashley; Fernholz, Kathryn; Groot, Harry. Biochar Potential in Minnesota's Forests. [Commissioned Report 2021.](#)
- 4) Singaas, Eric. Engineering functional biochar for specific applications. North American Biochar & Bioenergy Conference, Morgantown, West Virginia. Oral Presentation August 8-11, 2022.
- 5) Barry, Brian. A new approach for complete pore size distributions and regime-specific total pore volume determinations of biochars. North American Biochar & Bioenergy Conference, Morgantown, West Virginia. Oral Presentation August 8-11, 2022.
- 6) Singaas E, Barry B, Kolomitsyna O, Kacharov O, Yemets S, Young M, Toczydlowski A, and Slezak R. 2022. Biochar from insect-damaged trees used as a forest soil amendment: production, characterization, and application. Natural Resources Research Institute, University of Minnesota Duluth, [Technical Report](#) NRRI/TR-2022/16.
- 7) Singaas, E., Kolomitsyna, O., Kacharov, O., Young, M., and Barry, B. 2022. Biomass pretreatment to make clean syngas from Minnesota wood residuals. Natural Resources Research Institute, University of Minnesota Duluth, [Technical Report](#) NRRI/TR-2022/17
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2019 Project Abstract

For the Period Ending June 30, 2022

PROJECT TITLE: Forest and Bioeconomy Research - Subproject 4 Advance emerging Minnesota technologies to produce clean syngas from biomass

PROJECT MANAGER: Rolf Weberg

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FUNDING SOURCE: Environment and Natural Resources Trust Fund

LEGAL CITATION: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 3 (q)

APPROPRIATION AMOUNT: \$500,000

AMOUNT SPENT: \$500,000

AMOUNT REMAINING: \$0

Sound bite of Project Outcomes and Results

Synthesis gas (syngas) is a mixture of combustible chemicals that can be used to replace fossil fuels for industrial processes, hydrogen, and fuel production. This project demonstrated that forest residuals from insect-damaged trees can be pretreated to improve their conversion efficiency to make cleaner syngas.

Overall Project Outcome and Results

Achievement of Minnesota's renewable energy transition and associated greenhouse gas (GHG) reduction goals requires development of non-fossil fuel alternatives for fuels and processes that are impractical to convert to electrical power. Key syngas applications include production of renewable diesel, jet fuel, and hydrogen, as well as direct use of syngas for production of iron and steel products. Our objective was to demonstrate that low-value forest biomass could be used to generate clean syngas for these markets in Minnesota by pretreating the biomass to improve its physical and chemical properties.

Our objective was to determine the best pretreatment conditions for one Minnesota biomass that would improve the yield of syngas components (H_2 , CO, CH_4) relative to contaminants (tars) with the minimal processing temperature, time, and handling. Our results showed that addition of temperature and steam during pretreatment significantly reduced the tars produced during gasification, but with some loss in syngas yield. Therefore, we concluded that a mild steam treatment between 240-260°C with low residence time was optimal for pretreating black ash to make syngas.

Pilot-scale gasification trials on pretreated biomass was performed at the University of North Dakota Energy & Environmental Research Center, which ran pilot tests in their fluidized bed gasifier on eight different samples of black ash pretreated between 180 and 300°C and untreated biomass controls. The pilot results confirmed that pretreatment reduced tar production at the expense of reduced syngas yield. More importantly, however, the pilot tests showed that pretreatment improves the grindability of the biomass, making it easier to handle and feed to a gasifier.

These results demonstrate that renewable hydrogen, methane, or fuels can be made from Minnesota's biomass residuals by gasification, and low-temperature pretreatment will help.

Project Results Use and Dissemination

Singsaas E, Kolomitsyna O, Kacharov O, Yemets S, Young M, Barry B. 2022. Biomass pretreatment to make clean syngas from Minnesota wood residuals. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/17.