Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-116

Proposal Title: Complete Municipal Solid Waste Valorization Towards Carbon Neutrality

Project Manager Information

Name: Roger Ruan

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

Office Telephone: (612) 804-2270

Email: RUANX001@UMN.EDU

Project Basic Information

Project Summary: The proposed technology converts municipal solid waste into aromatics, green hydrogen, and biochar via a catalytic microwave-assisted pyrolysis process coupled with a porous calcium oxide based chemical looping process.

Funds Requested: $499,000

Proposed Project Completion: June 30, 2026

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

Project Location

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

Statewide

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

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

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

Plastic and organic waste streams generated by human activities produce greenhouse gas emissions during every stage of its lifecycle, posing a significant threat to our climate, ecosystem, health, and food safety. In 2018, the US generated 292.4 million tons of municipal solid waste (MSW), of which 50% was sent to landfills. The majority of the constituents of these 147 Mt are organic – plastics (27 Mt), wood (12 Mt), paper (17 Mt), and food waste (35 Mt). According to the Minnesota Pollution Control Agency, The State of Minnesota produces nearly 3.5 Mt of solid waste that need to be disposed of in Minnesota in 2020, of which only 18% was recycled and the rest went to landfills. Therefore, recycling waste materials that are being thrown away in large quantities, brings several economic and environmental benefits. Currently, the most common method to recycle MSW is direct incineration that would definitely emit lots of greenhouse gas and other pollutants and is a loss of the resources. In contrast, researchers are looking for various ways to efficiently upcycle these valuable plastics and organic wastes. Pyrolysis is one such promising and economically viable treatment through maximum utilization approach to produce desirable products.

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

This project is designed to develop a CO2-negative municipal solid waste valorization technology for production of marketable products, including aromatics, green hydrogen, and biochar, from MSW and hence reduce wastes and protect the environment. The project addresses Priority E: Air Quality, Climate Change, and Renewable Energy.
The overall goal of our research program is to develop a municipal solid waste valorization technology that will integrate a catalytic microwave-assisted pyrolysis and a chemical looping process. The proposed technology converts MSW into aromatics and biochar via a catalytic microwave-assisted pyrolysis process first, and uses a porous calcium oxide based material to absorb CO2 and produce high purity hydrogen in a chemical looping process. The specific objectives of the project include:
Process development: verification of the proposed technology; study of effects of microwave-assisted pyrolysis/catalysis temperature, catalysts on aromatic selectivity; evaluation of CO2 removal and hydrogen enhancement; optimization of the process.
Impact assessment: preliminary input-output analysis to provide assessment of economic potential and environmental and ecological benefits.

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

The specific project outcomes will include the demonstration of catalytic microwave-assisted pyrolysis of MSW coupled with a chemical looping process for aromatics, biochar, and green hydrogen, the potential of catalytic microwave-assisted pyrolysis technology to become technically and financially viable for MSW treatment and valorization, reducing MSW in Minnesota and mitigating CO2 emission.

Activities and Milestones

Activity 1: Catalytic microwave-assisted pyrolysis of MSW

Activity Budget: $250,000

Activity Description:
We will first test different catalysts using a standard process with our bench scale catalytic microwave-assisted pyrolysis system. The results from the initial tests will guide our catalyst development for aromatic production. In order to selectively produce aromatics in the liquid product and maximize the catalyst lifetime, hierarchically micro-meso-macropore zeolites will be also developed. By designing hierarchically porous micro/nano-sized zeolite crystals with better interconnection between different porosity, an unimpeded transport path and enhancing accessibility to active sites within micropores will be provided. Multi-level porosity ensures the high catalytic selectivity and stability. The key processing parameters and conditions to be investigated and adjusted are pyrolysis/catalysis temperature, residence time, and catalysts.

Activity Milestones:

Description	Completion Date
Collection and characterization of MSW	September 30, 2024
Initial test of catalytic microwave assisted pyrolysis of MSW	December 31, 2024
Process development and investigation	June 30, 2025
Evaluation of the process and product yield and quality	June 30, 2025

Activity 2: CO2 removal and H2 enhancement in a chemical looping process

Activity Budget: $160,000

Activity Description:
The non-condensable pyrolytic gas mixture (composed of CO, CO2, H2, CH4 and C1-C4 hydrocarbons) will be further transported into a chemical looping unit, where CO2 can be absorbed by calcium oxide and CO and CH4 can react with steam to produce hydrogen. The produced calcium carbonate will be delivered to another high temperature process for CO2 release, where the pure CO2 can be collected for other purposes, e.g. plastic manufacturing, carbon material activation. This chemical looping process can not only separate CO2 but also enhance hydrogen production, thereby improving the economic and environmental competitiveness of catalytic microwave-assisted pyrolysis technology. Some metal promoters will be also loaded on the porous calcium oxide to enhance hydrogen production via CH4/CO steam reforming reactions. Process parameters including temperature, porous calcium oxide structure, and reactor design will be optimized.

Activity Milestones:

Description	Completion Date
Different porous calcium oxides will be designed and evaluated	June 30, 2025
Optimization of the process	June 30, 2025
Energy efficiency will be evaluated	June 30, 2025
Verification of the process	December 31, 2025

Activity 3: Evaluate the potential economic, environmental and ecological impacts of the proposed technology

Activity Budget: $89,000

Activity Description:

For this small project, we plan to conduct preliminary studies to provide big pictures of the potential economic, environmental and ecological impacts of the proposed technology. Additional data on mass and energy balance will be collected. Greenhouse gas emission during the process will be monitored. An input-output model will be used for economic analysis. The energy consumption, greenhouse gas emission, and waste reduction will be considered in the assessment of environmental and ecological impacts of the technology.

Activity Milestones:

Description	Completion Date
Collection of mass and energy balance data	December 31, 2025
Monitoring of greenhouse gas emission	December 31, 2025
Estimate of potential reduction in MSW and production of valuable products	December 31, 2025
Preliminary assessment of economic, environmental, and ecological impacts	June 30, 2026

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Paul Chen	University of Minnesota	Co-PI	No

Long-Term Implementation and Funding

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

The results of this effort will be used for seeking external agencies such as the National Science Foundation and the US Department of Energy. The potential economic, environmental and ecological impacts will be also presented to the stakeholders to raise their awareness and attract their support. We will seek industry partners and private, state, and federal funding to further develop and eventually commercialize the technology.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Demonstrating Innovative Technologies to Fully Utilize Wastewater Resources	M.L. 2014, Chp. 226, Sec. 2, Subd. 08c	$1,000,000
Development of Innovative Sensor Technologies for Water Monitoring	M.L. 2016, Chp. 186, Sec. 2, Subd. 04j	$509,000

Project Manager and Organization Qualifications

Project Manager Name: Roger Ruan

Job Title: Professor and Director

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

Dr. Ruan, Professor and Director of Graduate Studies of Bioproducts and Biosystems Engineering Department, and Director of Center for Biorefining at University of Minnesota, is a Fellow of ASABE, IFT, Vebleo, and IAAM, and has received many other awards, including CAFS Professional Achievement and Scientist of IAAM, etc. He is a top cited author in engineering and technology with an h-index of 80, i10-index of 392, and has over 25,000 citations. Dr. Ruan's research include renewable energy and environment technologies for sustainable development. He has published over 500 referred journal articles, two books, 24 book chapters, and holds 20 US patents in the areas of municipal, agricultural, and industrial liquid and solid waste including biomass and waste plastics treatment and utilization through novel anaerobic digestion, microalgae and hydroponic cultivation, pyrolysis and gasification, airborne and other pathogen disinfection and pollutant control, catalysis, non-thermal plasma, and nitrogen fixation, etc. He has received over 200 grants totaling over $45 million in various funding for research, including major grants from USDA, DOE, DOT, DOD, LCCMR, and industries. He has served as guest editor or editorial board member of Bioresource Technology, Renewable Energy, Engineering, Applied Catalysis and Chemical Engineering, Journal of Food Process Engineering, The Open Plasma Physics Journal, and Associate Editor of Transactions of ASABE, Engineering Applications in Agriculture, and Transactions of CSAE, and Chairman of Editorial Board and Editor-in-Chief of International Journal of Agricultural and Biological Engineering, etc. He has supervised over 75 graduate students, 140 post-doctors, research fellows, and other engineers and scientists. He has given over 300 keynote lectures, invited symposium presentations, and short courses. His earlier LCCMR funded projects have resulted in several patented technologies which have been successfully licensed to the industry. He has the technical expertise and project management experience to ensure the execution of proposed project.

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

Organization Description:
The Center for Biorefining is a University of Minnesota research center affiliated with the College of Food, Agricultural and Natural Sciences and help coordinate the University efforts and resources to conduct exploratory fundamental and applied research and provide education on science and technology for environment protection and circular economy; stimulate collaboration among the University researchers, other public sector investigators, and private investigators involved in biobased production technology development; promote technology transfer to industries; and foster economic development in rural areas. The Center's research programs are founded by DOE, USDA, DOT, DOD, LCCMR, IREE, Xcel Energy, and other federal and state agencies, NGOs, and private companies. The Center is equipped with state of the arts analytical instruments, and processing facilities ranging from bench to pilot scale.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Professor/faculty		Primary Investigator - project lead, advises researchers, plans and directs research, oversees budget, monitors and reports progress			33.5%	0.06		$15,940
Professor/faculty		Co-Primary Investigator - advises researchers, designs and directs experiments, conducts data analysis, writes reports and publications			33.5%	0.15		$69,062
1 Graduate Research Assistant		carries out experiments, collects and analyzes data, prepares reports and manuscripts			45%	1.5		$160,139
Post Doctoral Reseracher		designs and carries out experiments, collects and analyzes data, prepares reports and manuscripts			20.9%	3		$185,001
							Sub Total	**$430,142**
Contracts and Services								
equipment manufacturer	Professional or Technical Service Contract	Maintenance and repair, including callibration				0		$9,000
							Sub Total	**$9,000**
Equipment, Tools, and Supplies								
	Equipment	Components for fabrication of a small pilot system including reactor vessel, high voltage power supply, catalysts, pumps, membrane separator	To fabricate a small pilot system for extensive testing, cost analysis, and demonstration					$25,000
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including feedstock, catalysts, chemicals, consumable supplies for analytical instruments	For running experiments and operating conversion systems					$31,858
							Sub Total	**$56,858**
Capital Expenditures								
							Sub Total	-

Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	12 one-day 3-person trips, ~100 miles each round trip ($0.585/mile), meals @$49/person	Visits to MSW sites and collect samples					$3,000
							Sub Total	**$3,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$499,000**

Classified Staff or Generally Ineligible Expenses

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

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Attachments

Required Attachments

Visual Component

File: 2eeb0aaf-abd.pdf

Alternate Text for Visual Component

The visual shows the majority of MSW enters into landfills, lakes, rivers, or oceans and poses a great threat to our ecological system. Catalytic microwave-assisted pyrolysis (CMAP) coupled with a chemical looping technology provides a feasible and promising solution to the problems and produce valuable products and positive environmental impacts....

Optional Attachments

Support Letter or Other

Title	File
Financial audit	c0bec3bb-235.pdf
Institutional Authorization to Submit	ff942698-52d.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

Yes

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

Yes

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

No

Does your project include original, hypothesis-driven research?

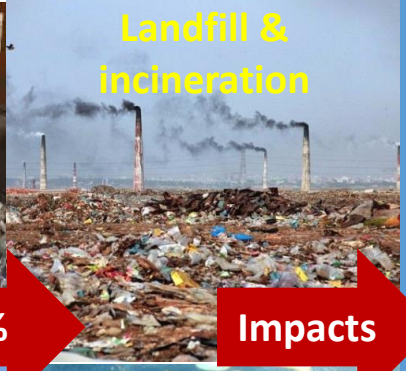
Yes

Does the organization have a fiscal agent for this project?

No

MSW

82%



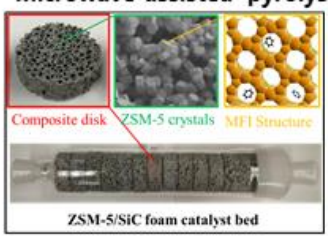
Impacts

- Pollute land, rivers, and lakes
- Pollute drinking water
- Linked to cancer, birth defects, immune-system problems, and childhood developmental issues
- Endanger wild lives and biodiversity
- Disturb forest and clog waterways
- A significant economic burden to waste treatment infrastructure

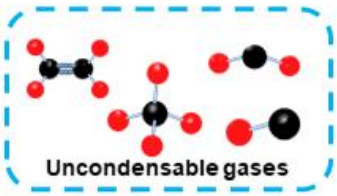
solution

MSW

Microwave-assisted pyrolysis



Advanced catalysis



Uncondensable gases

Chemical looping process

Carbon dioxide adsorbent

Used for biochar activation or other purposes

Biochar

Aromatics

Outcome of the Project

- An advanced CMAP technology coupled with chemical looping process will be developed for cost effectively converting MSW to aromatics, biochar, and green hydrogen.
- Potential economic and environmental impacts of the proposed strategy will be evaluated.
- The research findings will be used for seeking industrial partnerships and external funds for further R & D efforts