Environment and Natural Resources Trust Fund

2022 Request for Proposal

General Information

Proposal ID: 2022-055

Proposal Title: Chemical and molecular recycling of environmental plastics

Project Manager Information

Name: Roger Ruan

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

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Project Basic Information

Project Summary: Develop a novel pyrolysis-reforming technology to convert waste plastics to high quality naphtha for new plastic production and recover the non-condensable pyrolytic gas for carbon nanotubes (CNTs) and hydrogen production.

Funds Requested: $910,000

Proposed Project Completion: June 30 2025

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 materials are extremely popular all over the world and used in all areas of our lives thanks to their unique properties of being strong, lightweight, and easily shaped. However, the vast majority of waste plastics ever produced enters into landfills or our ecosystems, creating a plastic waste crisis. Currently, the most common solution to recycle the plastic waste is thermomechanical processing that is constrained by many challenges. The recycled plastics after melting and remolding have poorer properties than those of the virgin plastics, limiting the recycled plastics to lower quality products. This downcycling process makes the waste plastic recovery financially unattractive in the industry. On the other hand, the plastic-to-fuels technology can alleviate the plastic solid waste pollution, but it is unable to offset the demand for virgin plastics, making no contribution to a circular economy and greenhouse gas reduction. The main aspect missing from the current techniques is the lack of a feasible and promising approach to recycle/upcycle waste plastics in a more sustainable and long-term manner from both ecological and economical standpoints.

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

The proposed pyrolysis-reforming technology is designed to convert waste plastics to high quality high value naphtha that is injected to new plastic manufacturing, creating a circular economy with minimal greenhouse emission. The byproduct, non-condensable gas, produced from the pyrolysis-reforming process will be recovered for production of CNTs as emerging nano-materials and hydrogen as fuel or chemical feedstock via chemical vapor deposition technique. In a nutshell, the proposed technology uses microwave assisted pyrolysis (MAP) process to convert waste plastics to wax, and then catalytically reform the wax to high quality naphtha over newly designed catalysts while converting the non-condensable gases to high quality CNTs and hydrogen.

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 improvement of the existing 200 kg plastics/day MAP system, designing promising catalysts for higher quality naphtha and CNTs, and the development of a structured catalytic reactor for systems analysis and demonstration. These outcomes will move the technology closer to commercial implementation, which will provide a sustainable way to utilize waste plastics, improve the financial outlook of the plastic waste recycling industry, reduce fossil energy demand and CO2 emission, and thus reduce environmental impacts of the plastic waste recycling industry.

Activities and Milestones

Activity 1: Conversion and reforming process development and improvement

Activity Budget: $268,974

Activity Description:
Our approach is to convert waste plastics to long chain hydrocarbons (LCHC), and crack and reform LCHC to naphtha. We will first use a bench scale pyrolysis-reforming system with the same technical characteristics as our existing 200 kg plastics/day MAP system to achieve fast screening of catalysts and optimize the process. The improvement of initial conversion process will be realized through pyrolysis system improvement and processing parameter optimization such as feedstock loading, temperature, agitation mixing speed, heating rate, and residence time. The cracking and reforming processes will heavily rely on the improvement of our proposed catalytic process. Different catalysts will be developed to improve cracking performance in the first catalytic reforming zone and the hydrogenation process in the second catalytic reforming zone. The focus will be on how to tailor the acidity and pore structure of metals/SiO2 catalysts in the first catalytic zone to maximize the wax cracking with the minimal aromatic formation. Then, we will use SiC foam structure as a catalyst bed on which selected catalysts are loaded, and raise and maintain catalysis reaction temperatures using microwaves. A novel structured catalytic reactor for cracking and reforming will be developed and incorporated with the main conversion reactor.

Activity Milestones:

Description	Completion Date
MAP process optimization	December 31 2022
Catalysts will be prepared, characterized, and tested	June 30 2023
Structured catalysts will be developed	January 31 2024
A novel structured catalytic reactor will be developed and tested	June 30 2024

Activity 2: Recover non-condensable pyrolytic gas for CNTs and hydrogen production

Activity Budget: $200,000

Activity Description:
The non-condensable pyrolysis gases containing abundant carbon sources (CH4 and C1-C4 hydrocarbons) will be introduced into a high temperature chemical vapor deposition process for CNTs production. After element carbon is consumed, the residual gas would be mainly composed of hydrogen. A wide variety of metal oxides, such as Ni, Co, Fe, Cu, will be tested for producing high performance CNTs and hydrogen.

Activity Milestones:

Description	Completion Date
Non-condensable gas-to-CNTs and hydrogen technology will be developed and improved	January 31 2024
A wide variety of catalysts will be evaluated	June 30 2024

Activity 3: Catalytic microwave-assisted pyrolysis (CMAP) improvement

Activity Budget: $400,000

Activity Description:
Based on our experience with the existing 200 kg/day system, we will improve the design of several key components and incorporate a novel structured catalytic reactor and non-condensable gas recovery for demonstration. Specifically, the mixing states of silicon carbide (SiC) balls (as a microwave absorbent and heat carrier) inside the microwave reactor will

be further improved by innovative mechanical mixer design so that the temperature field can be much more uniform without very high mixing rate, enabling the heat transfer between plastic particles and SiC balls more efficient and residence time to be more effectively controlled.

Activity Milestones:

Description	Completion Date
The existing 200 kg/day CMAP system will be improved and tested	June 30 2024
Structured catalytic reactors will be designed, incorporated and tested	December 31 2024

Activity 4: Evaluate environmental impacts and economic performance

Activity Budget: $41,026

Activity Description:
The mass and energy balance data together with emission data will be used to evaluate the environmental and economic performance using mathematics models. This evaluation will provide good assessment of the environmental impact of the proposed technology. Further R&D efforts and commercialization strategy will be recommended.

Activity Milestones:

Description	Completion Date
The energy efficiency, cost, and emission will be evaluated	December 31 2024
Environmental impacts will be assessed	June 30 2025
Further R&D and commercialization strategy will be recommended	June 30 2025

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 be funded?

The waste plastics-to-naphtha technology is very promising, and many major companies are extremely interested in it. We are closely collaborated with several of them and they have provided some financial and other support for our preliminary work. More new scientific knowledge on plastic-to-naphtha, CNTs, and hydrogen technology acquired through research and the demonstration will help raise significant interests from the public. More grants would be obtained from industry partners and private, state, and federal government 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. Roger Ruan, Professor and Director of Graduate Studies, Department of Bioproducts and Biosystems Engineering, and Director of Center for Biorefining at University of Minnesota, is a Fellow of ASABE and a Fellow of IFT. Dr. Ruan's research focuses on renewable energy and environment technologies for sustainable development and circular economy. Specifically, he has conducted research and published his findings in the areas of municipal, agricultural, and industrial wastewater treatment and utilization through novel anaerobic digestion, microalgae cultivation, and hydroponic cultivation, biomass and solid wastes (including plastics) pyrolysis and gasification, airborne and other pathogen disinfection and pollutant control, catalysis, non-thermal plasma, and nitrogen fixation, etc. He is a top-cited author with an h-index of 69, i10-index of 301, and over 19,000 citations. He has supervised over 75 graduate students, 140 post-doctors, research fellows, and other engineers and scientists, and 21 of his Ph.D. students and post-doctors hold university faculty positions. He has also been invited to give over 300 keynote lectures, invited symposium presentations, company seminars, and short courses. Professor Ruan has received and managed over 200 projects totaling over $45 million in various funding for research, including major funding 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. His earlier LCCMR funded projects have resulted in several patented technologies which have been successfully licensed to the industry. Therefore, he has the technical expertise and project management experience to ensure the execution of proposed projects.

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 helps 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		PI - 2 weeks summer salary			36.5%	0.12		$30,285
Professor/faculty		Co-PI - contract faculty			36.5%	0.24		$66,920
Graduate Research Assistant		Two researchers			45%	3		$301,902
Post Doc Researcher		Conduct research			25.4%	3		$191,887
							Sub Total	**$590,994**
Contracts and Services								
University of Minnesota	Internal services or fees (uncommon)	lab services				-		$15,000
University of Minnesota	Internal services or fees (uncommon)	adjustments, repairs, and maintenance on newly fabricated equipment				0		$6,000
							Sub Total	**$21,000**
Equipment, Tools, and Supplies								
	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					$45,570
	Equipment	Components for fabrication of a small pilot system including reactor vessel, insulation materials, magnetrons, control, motors, mixer, feeder, valves, etc.	To fabricate a small pilot system for extensive testing, cost and emission analysis, and demonsration					$250,000
							Sub Total	**$295,570**
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 ($0.56/mile), meals @$49/person	Visits to waste management sites, feedstock collection and transport					$2,436
							Sub Total	**$2,436**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$910,000**

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

Optional Attachments

Support Letter or Other

Title	File
Institutional Approval to Submit	c24d7036-d1b.pdf
Visual graphic	64c336a6-740.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

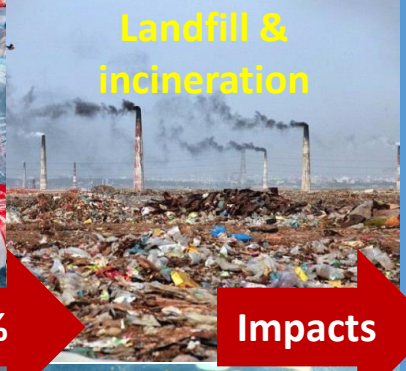
Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

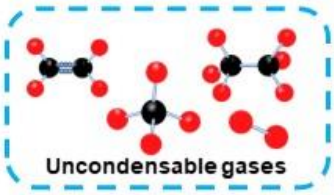
90%



Impacts

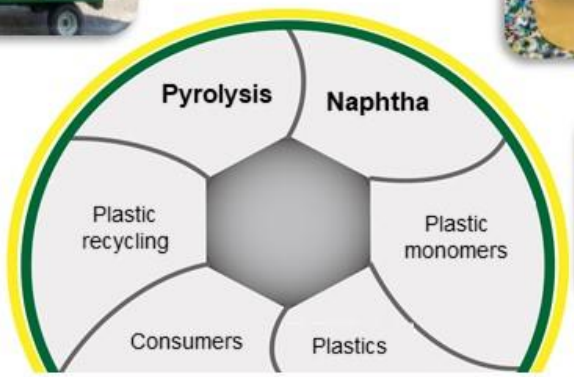
- Pollute land, rivers, and lakes
- Pollute drinking water
- Linked to cancer, birth defects, immune-system problems, and childhood developmental issues
- Endanger wild lives and biodiversity
- Disturb forest and clog waterways
- A significant economic burden to waste treatment infrastructure

solution



Chemical vapor deposition

Tandem catalysis



Outcome of the Project

- An advanced CMAP technology coupled with chemical vapor deposition will be developed for cost effectively converting plastic wastes to naphtha, CNTs, and 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