Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-305

Proposal Title: Reducing Plastic Waste by Innovating Waste-To-Energy Conversion Technology

Project Manager Information

Name: Boya Xiong

Organization: U of MN, College of Science and Engineering

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Project Basic Information

Project Summary: The goal is to leverage bacteria and a mechanical mill to efficiently degrade and convert plastic waste into energy, reducing plastic waste accumulation from incinerators and landfills in Minnesota.

Funds Requested: $530,000

Proposed Project Completion: 2024-06-30

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?

In the Future

Narrative

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

In Minnesota, plastic occupies 18% of the total municipal solid waste stream (11% nationwide). A 2019 report on the State of Recycling in Minnesota highlighted the negative impact of plastic waste management on air and water quality:

1. The low value of and lack of a market for recycled materials prohibit plastic recycling (less than 10%).
2. Even when collected as a "recyclable", most plastic wastes end up in incinerators and landfills. Incinerators are major contributors to CO2 emissions, and are operated only at 20-30% energy efficiency. By improving the efficiency of waste-to-energy production, we can generate energy with lower overall emissions.
3. Plastics in the form of micro- and nano-size particles have polluted Minnesota's water.

By 2035, the annual generation of plastic waste will double, thus we will have to double the capacity of incinerators or landfills. Alternative solutions that can reduce plastic waste and convert this waste to energy are urgently needed. Polyethylene terephthalate (PET) is one of the most abundantly produced and disposable polymers. Some specialized bacteria can degrade PET into more biodegradable molecules for energy production. This biological conversion, however, occurs at a rate that is not efficient enough to implement at a meaningful scale.

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.

We propose a two-step process that can efficiently convert PET to methane and hydrogen as energy sources:
1) Leverage specialized PET-degrading bacteria and mechanical mills to break down durable PET into small organic molecules that are more biodegradable by a wide range of bacteria;
2) Convert the degraded plastic molecules to hydrogen and methane using a second, much more common fermentative bacterial community (e.g. as present in anaerobic digesters).
We have started screening and enriching very specialized PET degrading bacteria strains that are native to Minnesota and hold promise in efficiently degrading PET. Prior to biodegradation, the densely packed long chain molecules of PET need to be altered so that these chemical bonds are accessible to these unique bacteria, which can only attach and degrade surface PET layers, working deeper into the plastic as they degrade. Inspired by the principles active in cow stomachs, we hypothesize that introducing mechanical treatment that grinds plastic into smaller pieces with more surface area will significantly increase the efficiency of plastic conversion by these PET-degrading bacteria. We then will determine the potential to generate biohydrogen and/or biomethane as energy from the degradation products of the specialized PET-degrading bacteria.

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 outcome of this work demonstrates the proof-of-concept of an innovative solution to reduce plastic waste, at higher energy efficiencies and lower environmental emissions compared to incineration and landfilling. This type of plastic waste conversion technology will incentivize waste collection and better management practices, in turn reducing plastic pollution to Minnesota's water resources. The project outcome will protect the quality of both water and air resources in Minnesota.

Activities and Milestones

Activity 1: Screen for the best PET-degrading microorganisms from sediment, soil, and wastewater

Activity Budget: $179,121

Activity Description:
A wide range of environmental samples that are impacted by PET waste will be collected and used to inoculate PET-film containing media. The visual and mass change of the PET film will be evaluated to screen and then isolate Minnesota's native bacteria with the best ability to degrade PET. Bacteria will then be enriched and growth conditions will be optimized.

Activity Milestones:

Description	Completion Date
Isolate and identify PET-degrading bacteria from environmental samples	2022-06-30
Enrich and optimize cultivation conditions for PET-degrading isolates	2022-12-31

Activity 2: Develop biomechanical cotreatment that converts plastic into a sludge of soluble molecules

Activity Budget: $168,916

Activity Description:
It has been previously shown that introducing a ball mill treatment can increase the accessibility of natural polymers (e.g., woody cellulose) to bacteria and achieve an overall energy efficiency of 67%. First, mechanical milling and microbial degradation will be performed sequentially. Parameters of milling (i.e., rotation rate and milling time) will be optimized based on the fragmented plastic particle size. Then bacteria selected from activity 1 will be inoculated after milling. Second, milling and microbial degradation will be combined. The final chemical structure and size of soluble molecules will be analyzed to evaluate the effectiveness of cotreatment. The energy input and microbial tolerance of milling will also be evaluated.

Activity Milestones:

Description	Completion Date
Optimize PET loading and nutrients of mechanical mill during microbial degradation	2023-06-30
Evaluate and optimize mechanical milling before and after microbial degradation	2023-06-30
Calculate the energy consumptions and investigate microbial tolerance of mechanical milling	2023-12-31

Activity 3: Evaluate the potential for bacteria to further convert plastic solutions into hydrogen or methane

Activity Budget: $181,963

Activity Description:
We hypothesize that after mechanical processing and initial aerobic biodegradation by specialized PET-degrading bacteria, soluble molecules will be left that will be amenable to anaerobic microbial degradation with the concomitant production of biohydrogen and/or biomethane. The products of the milling and microbial degradation steps described above in Activity 2 will be added to anaerobic reactors amended with a mixture of different anaerobic bacteria and a range of other food sources that can act as stimulants for anaerobic degradation. The production of methane and

hydrogen will be measured with time at different incubation temperatures to determine to what extent the plastic solutions can be degraded anaerobically and what conditions are needed to facilitate this process.

Activity Milestones:

Description	Completion Date
Evaluate hydrogen and methane generation potential of soluble plastic using adaptable mixed bacteria community	2024-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Paige Novak	University of Minnesota, Department of Civil, Environmental and Geo-Engineering	Dr. Novak specializes in biological transformation of hazardous substances or pollutants. Recently, Dr. Novak developed a novel anaerobic wastewater treatment system to recover energy and remove pollutants from industrial wastewaters. Dr. Novak will advise and guide graduate students on optimizing the anaerobic digestion of pre-treated PET for biogas production.	Yes
Sebastian Brehens	University of Minnesota, Department of Civil, Environmental and Geo-Engineering	Dr. Behrens is an environmental microbiologist who combines environmental engineering, microbiology, and molecular biology to understand bioremediation of contaminants (including plastics). Dr. Behrens will advise and guide graduate students on the enrichment, isolation, and characterization of PET-degrading bacteria and their application to the anaerobic digestions of pre-treated PET for biogas.	Yes

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?

We will disseminate this technological development to the Minnesota Pollution Control Agency, local recycling and incineration facilities, in order to identify possible mechanisms that integrate the new technology into current waste management infrastructure. We will seek for more state and national funding for process optimization after demonstrating the success at the small lab scale. We also hope to work with a team at the Carlson School of Management to determine realistic value propositions for the technology. We will also organize outreach events to educate the public about advances in novel plastic waste-to-energy technologies and arise the awareness of plastic issue.

Project Manager and Organization Qualifications

Project Manager Name: Boya Xiong

Job Title: Assistant professor in Civil, Environmental and Geo-engineering

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

Dr. Xiong is currently a post-doctoral research associate at the Massachusetts Institute of Technology. She will begin her appointment in August 2020 as an assistant professor at the University of Minnesota in the Department of Civil, Environmental, and Geo- Engineering. Her research primarily focuses on polymer degradation and advanced organic chemical analysis to guide sustainable materials design and processes for circular economy. Dr. Xiong will advise and guide graduate students on design and characterize the plastic breakdown using a mechanical mill and cotreatment with enzymatic digestion. Dr. Xiong will work with Dr. Brehens and Dr. Novak on data analysis and publishing the scientific finding of this work. In addition, Dr. Xiong will disseminate the result and propose technological integration mechanisms to LCCMR, Minnesota Pollution Control Agency, and other recycling and incineration facilities. Dr. Xiong will also organize outreach events to educate the general public about plastic pollution and the importance of recycling.

Organization: U of MN - Twin Cities

Organization Description:

The University of Minnesota is one of the largest, most comprehensive, and most prestigious public universities in the

United States, leading research areas including water quality and material science (http://www1.umn.edu/twincities/01_about.php). The laboratories of the PI and/or core facilities at the University of Minnesota contain the entire essential fixed and moveable instrumentation needed for the proposed studies.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Principal investigator		Supervise overall research project, lead activity 2, design experiments and supervise graduate students for cotreatment			27%	0.18		$30,230
Co-investigator		Lead project activity 1, design experiments and supervise graduate students for PET-degrading bacteria isolation and enrichment			27%	0.24		$51,885
Co-investigator		Lead project activity 3, design experiments and supervise graduate students for microbial biogas production			27%	0.01		$12,169
Graduate student		Design and perform experiments for isolation and enrichment of PET-degrading bacteria, and microbial biogas production			44%	1.5		$152,154
Graduate student		Design and perform experiments for evaluating and optimizing cotreatment (e.g., plastic material characterization) and analyzing degraded plastic products			44%	1.5		$152,154
							Sub Total	**$398,592**
Contracts and Services								
University of Minnesota Genomics Center	Internal services or fees (uncommon)	University of Minnesota Genomics Center will provide sequencing service to identify the species of PET-degrading bacteria isolated from the environment.				-		$16,000
University of Minnesota, Characterization facility	Internal services or fees (uncommon)	The characterization facility provides service and shared instruments so that we can characterize the property of plastic change during bacteria and mechanical degradation.				0		$10,000
Minnesota Nano Center	Internal services or fees (uncommon)	Minnesota Nano Center will provide particle size analysis service to evaluate the size of particles generated by mechanical milling of plastic				0		$1,750
Masonic Cancer Center	Internal services or	Masonic Cancer Center will provide liquid chromatography- mass spectrometry analysis to				-		$20,000

	fees (uncommon)	characterize the structure of degraded PET molecules.						
							Sub Total	**$47,750**
Equipment, Tools, and Supplies								
	Equipment	An anaerobic reactor (one) and associated supplies (e.g., pumps)	To convert the soluble plastic into biogas energy					$16,000
	Tools and Supplies	Microbial cultivation and molecular biology supplies	To cultivate PET-degrading bacteria and anaerobes and identify the bacteria species using molecular biology tools					$45,000
	Tools and Supplies	PET plastic samples	PET plastic will be synthesized so we know the exact composition and properties					$500
	Tools and Supplies	General lab supplies	Common lab supplies for wet chemistry and microbiology labs (pipett tips and centrifuge tubes)					$2,158
							Sub Total	**$63,658**
Capital Expenditures								
		Restsh high energy ball mill (one)	To grind plastic particle to enhance its conversion to energy					$13,000
							Sub Total	**$13,000**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Travel around the states to collect PET samples	To collect PET samples in environments for isolating PET-degrading bacteria					$1,000
							Sub Total	**$1,000**
Travel Outside Minnesota								

							Sub Total	**-**
Printing and Publication								
	Publication	Publication fee	Publication charges to make the journal article publication open access					$6,000
							Sub Total	**$6,000**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$530,000**

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				
In-Kind	University of Minnesota	facilities/administratve costs (55% of direct costs excluding permanent equipment and graduate student tuition) are provided in-kind	Potential	$230,055
			State Sub Total	**$230,055**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$230,055**

Attachments

Required Attachments

Visual Component

File: efcfc040-ae2.pdf

Alternate Text for Visual Component

Mechanical mill helps bacteria to degrade plastic waste and convert into energy at a higher rate and efficiency, reducing plastic waste and the emission of waste-to-energy infrastructure.

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

- Patent, Copyright, or Royalty Potential

Does your project include research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Mechanical mill helps bacteria to degrade plastic waste and convert into energy at a higher rate and efficiency