Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-367

Proposal Title: Resilient Sustainable Bioeconomy Utilizing Minnesota's Waste Bioresources.

Project Manager Information

Name: Shri Ramaswamy

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

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Project Basic Information

Project Summary: Develop a resilient, sustainable bioeconomy utilizing waste bioresources such as under-utilized diseased plants, invasive species, forestry waste, agricultural residues, and food waste to help improve Minnesota's land and water resources.

ENRTF Funds Requested: $712,000

Proposed Project Completion: June 30, 2030

LCCMR Funding Category: Resiliency (A)

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.

Effective utilization of diseased plants, invasive species, forestry waste, agricultural residue and food waste is of paramount importance for a resilient, healthy natural systems ecology and the environment. The accumulation of biowastes creates negative impacts on clean water and natural habitat. Natural fires historically have resolved this issue but, for many reasons, uncontrolled natural fires and controlled burns are not feasible. Unused waste from diseased plants, invasive species, forest, and agricultural residues cause significant environmental degradation by leaching organic pollutants, pathogens, and excessive nutrients into water bodies. This drives eutrophication (algal blooms, low oxygen), kills aquatic life, reduces biodiversity, degrades soil health, and introduces harmful contaminants into ecosystems [1, 2, 3, 4, 5]. Effective utilization of waste resources will help address the impacts of climate change and land use changes and help minimize contaminants from run-offs and improve water quality. Effective conversion of agri-forest waste into value-added bioproducts including biofuels such as ethanol and sustainable aviation fuels (SAF) and biochemicals that can replace petroleum-based chemicals and fuels and meet their ever-increasing demand can help build an economically viable and environmentally sustainable, circular bioeconomy and ensure resiliency in agricultural and natural resource ecosystems.

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.

We propose to develop a novel process to effectively utilize waste bioresources to create sustainable fuels and bioproducts contributing to a vibrant, rural bioeconomy. We propose utilizing waste bioresources to economically produce ABE (acetone (A), butanol (B), and ethanol (E)). Butanol and ethanol can be used as drop-in biofuel or converted to sustainable aviation fuels (SAF); acetone is a widely used industrial solvent. Current technology for ABE manufacture has serious drawbacks including severe product inhibition, low ABE yield, productivity, and low product concentration, high energy consumption and a high production cost [6, 7]. We propose to address this major challenge by integrating the bioprocessing step, such as ABE fermentation, with separation and purification using a Membrane Solvent Extraction (MSE) technology. This process will help improve the efficiency of utilization of waste bioresources, reduce the water consumption, energy consumption and GHG emissions. We propose to develop a novel technology that promises to effectively utilize waste resources and reduce energy consumption by 35%, reduce water consumption by 25%, and reduce GHG emissions by 25% making it more economically viable and environmentally sustainable over current commercial technologies.

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?

Considering climate change and land use changes, Minnesota faces a significant challenge with unused waste from diseased plants, invasive species, forest waste, agricultural residue and food waste and its concomitant effect on water quality and environmental degradation [1,2,3]. The project aims to develop a resilient, sustainable bioeconomy utilizing Minnesota's waste bioresources. The project outcome is developing comprehensive and viable engineered solutions targeting effective utilization of waste resources, and, hence, addressing impacts of climate change and land use changes. The proposed approach will also help in minimizing contaminants from run-offs and help improve water quality.

Activities and Milestones

Activity 1: Development of a novel pretreatment and optimization of ABE fermentation using diverse waste bioresources.

Activity Budget: $299,457

Activity Description:
We will begin with collecting and analyzing Minnesota's diverse waste bioresources including diseased plants, invasive plant species, forestry residues and agricultural residues, and food waste to evaluate their potential as sustainable feedstocks. The study will assess the quantity, seasonal availability, geographic distribution, and logistical factors such as transportation distance, handling requirements, preprocessing needs and storage stability to ensure a consistent and cost-effective supply chain in the state.

We will conduct appropriate pretreatment to convert lignocellulosic waste bioresources, mentioned above, into high-yield, low-toxicity sugars needed for the ABE fermentation. Then, we will develop and optimize the ABE fermentation process using selected microbial strains capable of converting sugars into acetone, butanol, and ethanol. Fermentation process conditions such as sugar feeding rate, nutrient and growth media composition, temperature, pH, agitation and dissolved oxygen levels will be determined experimentally and optimized to enhance the rate and yield of target products such as acetone, butanol and ethanol. This will be conducted at the West Central Research and Outreach Center, Morris, Minnesota. The obtained fermentation broth from above studies will be used in Activity 2.

Activity Milestones:

Description	Approximate Completion Date
Collect and characterize the different waste bioresources including their availability and geographic locations across the	December 31, 2027
Identify and optimize the required pretreatment for different waste bioresources	March 31, 2028
Develop and conduct ABE fermentation with appropriate process conditions using selected MN biomass resources.	June 30, 2029
Continue to optimize the developed process making it suitable for various waste bioresources.	June 30, 2030

Activity 2: Development and experimental evaluation of Liquid-Liquid Equilibrium for the ABE fermentation broth

Activity Budget: $143,490

Activity Description:
We will perform the experimental evaluation and theoretical simulation of the Liquid-Liquid Equilibrium (LLE) of the ABE-water-extractant ternary systems and screen out the best extractant or extractant mixture that is tailored for this application. Similar to conventional liquid-liquid extraction, screening for efficient extractants using an appropriate selection criterion is a critical step to the membrane solvent extraction. As part of this activity, a more thorough analysis of LLE characteristics of the biofuels and biochemical mixture with the extractant and extractant mixture will be conducted and appropriate extractant will be selected. Based on our preliminary results, a few extracting solvent/extractant candidates or their mixtures such as 1-octanol, 2-ethyl-1-hexanol, 1-decanol and 2,6-Dimethyl-4-heptanol will be considered. 2,6-Dimethyl-4-heptanol, 2-ethyl-1-hexanol were shown to have promising extraction characteristics [3, 4]. The commercial process simulation software, Aspen Plus, will be used to theoretically predict LLE characteristics, the distribution coefficients and selectivity (or separation factors) for the various solute-solvent systems to aid screening the extractants. The UNIF-LL model in Aspen Plus will be selected for LLE prediction. This will help us select appropriate extraction solvent(s) for effectively extracting the biofuels and biochemicals.

Activity Milestones:

Description	Approximate Completion Date
Conduct LLE experiments to determine the partition coefficients and selectivity for various biofuel components.	September 30, 2028
Conduct theoretical LLE predictions to determine the partition coefficients and selectivity for biofuels and biochemicals.	January 31, 2029
Compare the results and select the best extractant or extractant mixture tailored for ABE mixture.	July 31, 2029

Activity 3: Development and experimental evaluation of membrane solvent extraction (MSE) for the ABE fermentation broth

Activity Budget: $190,631

Activity Description:
We will develop a single stage membrane solvent extraction (MSE) process using the extractants selected from Activity 2 to evaluate the performance of the MSE process including extraction dynamics, mass transfer characteristics and efficiency of separation. The model ABE broth and the real ABE broth from Activity 1 will be used. A commercial hydrophobic hollow fiber polypropylene membrane module, that has been successfully used in our previous work, will be used for the MSE process [4]. The aqueous broth and organic solvent will be circulated through the membrane module and ABE concentrations in both phases as a function of extraction time will be determined [3, 4]. Using the dynamic concentration profiles, membrane transfer flux rates, the separation efficiency, and the overall mass transfer coefficient will also be estimated [4]. This will enable us to develop the MSE process and determine appropriate processes and design parameters including flows, pressure drops and concentrations and fluxes. This information can be used in the process modeling, simulation, TEA and LCA in Activity 4.

Activity Milestones:

Description	Approximate Completion Date
Conduct the MSE experiments under varying process conditions for the model ABE broth mixture	June 30, 2029
Conduct the MSE experiments under varying process conditions for filtered ABE broth mixture from Activity-1	December 31, 2029
Determine the optimum MSE process parameters based on the experimental data and modeling results	June 30, 2030

Activity 4: Conduct techno-economic analysis (TEA) and life-cycle assessment (LCA) for the integrated ABE bioprocess and MSE

Activity Budget: $78,422

Activity Description:
We will conduct detailed process modeling and techno-economic analysis (TEA) and Life Cycle Assessment (LCA) of the integrated bioprocess – MSE in situ product removal, and subsequent downstream separation. This will be based on our previous work [10, 11] and the NREL Aspen Plus model of corn stover to ethanol and n-butanol biorefinery[12, 13]. This will help to evaluate the economic viability, reductions in energy use, water use, improvement in productivity and yield, and capital and operating costs using the proposed technology. We will conduct additional fermentation (Activity 1) and MSE (Activity 3) experiments to provide necessary data for this activity. Conduct preliminary assessment on the removal and use of waste bioresources and their impact on water quality in the state. The goal of the proposal is to decrease energy use by a target of 35% or more and reduce cooling water use by 30% or more, reduce GHG emissions of the

overall process by 25%, and improve the productivity and yield by 25% to accelerate commercialization of biofuels including SAF and biochemicals production using Minnesota's waste bioresources.

Activity Milestones:

Description	Approximate Completion Date
Conduct TEA and LCA of the conventional and novel integrated bioprocessing and MSE	November 30, 2029
Determine the potential energy, water use savings, GHG reductions and identify approaches for further optimization	March 31, 2030
Determine the potential for commercial implementation and producing additional biofuels including SAF in the state	June 30, 2030

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Veluchamy Chitraichamy	UMN West Central Research and Outreach Center	Research Assistant Professor	Yes
Hua-jiang Huang	University of Minnesota, Department of Bioproducts and Biosystems Engineering	Research Associate Professor	Yes

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
The project team will implement a comprehensive dissemination and data-sharing strategy to ensure that project findings, data, products, and outcomes are accessible to stakeholders, researchers, policymakers, and the public while fully complying with ENRTF Acknowledgement Requirements. Findings on this project will be shared through peer-reviewed journal publications, conference presentations, technical reports, and stakeholders. Annual and final reports will be submitted to ENRTF as required. All datasets will be quality-controlled, documented with metadata, and made publicly available through a UMN supported repository. All publications, presentations, outreach materials, and digital content will prominently acknowledge support from the Environment and Natural Resources Trust Fund using the required funding statement and official logo, ensuring full adherence to ENRTF acknowledgement policies.

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?
In addition to disseminating the research results in reports, conferences and journal publications, we will seek additional funding from state and federal agencies and private industry to extend the proposed laboratory-scale work. This includes 1) development of a multi-stage process; 2) continuous, state-state operation and optimization of an integrated multi-stage fermentation and extraction process; and working with commercial partners in 3) pilot scale evaluation of the integrated bioprocessing-separation and purification technology, 4) detailed environmental impacts and sustainability assessment, 5) technology commercialization and implementation.

Project Manager and Organization Qualifications

Project Manager Name: Shri Ramaswamy

Job Title: Professor

Provide description of the project manager's qualifications to manage the proposed project.
Dr. Shri Ramaswamy is Professor, Department of Bioproducts and Biosystems Engineering, University of Minnesota. Shri has been a faculty member at the U of M for about 31 years and was the head of the department for 14 years. He has degrees in chemical engineering and paper science and engineering and over nine years of pulp and paper and chemical

industry experience in process and products engineering and research and development. Prof. Ramaswamy's research expertise includes biomass utilization, process engineering, process development, separation and purification technologies, process intensification, industrial decarbonization and techno economic analysis, life cycle assessment. He has conducted relevant research on the sustainable utilization of bioresources to produce biofuels, sustainable aviation fuels and value-added bioproducts. He has experience leading large group projects at the national level with members from academia, industry and national laboratories.

Prof. Shri Ramaswamy will serve as the PI and coordinate the execution of the project, involved in project management, reaching the relevant progress milestones and deliverables and dissemination of research results. We bring together a team of investigators and researchers (Ramaswamy, S., Huang, H., Chitraichamy, V) with extensive background and research expertise in process engineering, process development and bio-based products engineering. Our group has experience in developing relevant experimental methods, analytical characterization and modeling and simulation capabilities that can be successfully used in this proposal.

Dr. Ramaswamy is a Fellow of the American Institute of Chemical Engineers (AICHE), Fellow of the Technical Association of the Pulp and Paper Industry (TAPPI), Fellow of the International Academy of Wood Science (IAWS) and recipient of the AICHE Andrew Chase award.

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

Organization Description:
The mission of the College of Food, Agricultural and Natural Resource Sciences (CFANS) is "to advance Minnesota as a global leader in food, agriculture, and natural resources through extraordinary education, science-based solutions, and dynamic public engagement that nourishes people and enhances the environment in which we live." CFANS envisions "a better tomorrow, it includes disease-resistant crops, products that protect our health, lakes free from invasive species, and so much more. We use science to find answers to the world's grand challenges and solve tomorrow's problems."

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Chitraichamy Co-PI: Faculty w/ 9 month appointment seeking summer salary		Co-project lead, coordinate research on pretreatment and fermentation, design experiments mentor graduate research assistant and postdoc researcher and undergrads, co-prepare project reports			26.8%	0.33		$45,401
Contract research faculty Huang for PI Ramaswamy - appointment dependent on projects funded		conducting experimental work and modeling and simulation, data analysis, research dissemination			26.8%	1.5		$160,713
research professional for PI Ramaswamy- appointment dependent on projects funded		conducting experimental work, analytical characterization, data analysis, research dissemination, working with UGs			26.8%	1.98		$135,933
multiple undergrad students for PI Ramaswamy		assisting researchers in setting up the experiments, conducting the experiments and analytical characterization			0%	2.25		$79,107
Post doc student for PI Chitraichamy		working on experimental design, conducting experimental work, analytical characterization, data analysis, research dissemination, supervise graduate and undergraduate student.			20.7%	1.5		$124,917

Grad student for PI Chitraichamy		conducting experimental work, analytical characterization, data analysis, research dissemination, working with undergraduate student			45.7%	0.75		$94,163
undergrad students for PI Chitraichamy		receive research training and collect experimental data and analytical characterization.			0%	0.18		$6,475
							Sub Total	**$646,709**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	solutes and solvents, reagents, GC, HPLC columns, detector, valves, pumps, service maintanence; consumables like filter paper, enzymes, pipet tips, chemicals, glass ware, safety glasses and gloves -	for PI Ramaswamy experimental work and analytical characterization					$11,791
	Equipment	membrane cartridges, pumps, flow meters, valves, tubing, temperature control, solvent recovery distillation setup	components for Ramaswamy laboratory MSE set up					$25,000
	Equipment	For fermenter; Purchase of small, non-capital lab equipment to enable pretreatment and fermentation experimental research.	for co-PI Chitraichamy work on pretreatment and fermentation of waste bioresources					$10,000
	Tools and Supplies	Consumable lab supplies and tools. Analytical supplies for conducting pretreatment and fermentation experiments.	for PI Chitraichamy and students to conduct work on pretreatment, fermentation and analytical characterization					$18,500
							Sub Total	**$65,291**
Capital Equipment								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**

Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$712,000**

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	**-**

Total Project Cost: $712,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 2c51df2e-d0e.pdf

Alternate Text for Visual Component

This figure describes utilizing Minnesota's waste bioresources such as under-utilized diseased plants, invasive species, forestry waste, agricultural residues, and food waste to produce biofuels including Sustainable Aviation Fuels (SAF) and value-added bioproducts and help improve Minnesota's land and water resources, contribute to a resilient ecosystem and a sustainable bioeconomy....

Supplemental Attachments

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

Title	File
Letter of Approval to Submit by U of M	ddd3ef13-fd6.pdf
Support Letter Minnesota Environmental Initiative (MEI)	40e444d9-9e9.pdf
Biographical Sketch - CV Huang	94fefef7-0be.pdf
Biographical Sketch - CV Chitraichamy	f9aa44ee-0c6.pdf
Biographical Sketch - CV Ramaswamy	c6fd4c75-9d5.pdf
LCCMR Support Letter - Greg Cuomo	271bd540-b6c.pdf
References Literature Cited	49e87b6f-32c.pdf
David Kolsrud MN Farmer Support Letter	79015732-19b.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

N/A

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

Yes

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

Yes

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

No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care, treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

Dr. Velu Chitraichamy, WCROC, Morris, MN; Wendy Moylan, BBE Accountant

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A