Final Abstract

Final Report Approved on January 20, 2026

M.L. 2022 Project Abstract

For the Period Ending June 30, 2025

Project Title: Methods to Destroy PFAS in Landfill Leachates

Project Manager: Roger Ruan

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

Mailing Address: 1390 Eckles Avenue

City/State/Zip: St. Paul, MN 55108

Phone: (612) 804-2270

E-mail: RUANX001@UMN.EDU

Website: https://cfans.umn.edu/

Funding Source:

Fiscal Year:

Legal Citation: M.L. 2022, Chp. 94, Sec. 2, Subd. 04a

Appropriation Amount: $200,000

Amount Spent: $200,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

This project demonstrated that PFAS in landfill leachate can be removed and destroyed using integrated biological, adsorption, and thermochemical treatments. The results show a clear pathway to reduce PFAS release to surface water and groundwater, supporting protection of Minnesota's water resources and associated ecosystems.

Overall Project Outcome and Results

Per- and polyfluoroalkyl substances (PFAS) are persistent contaminants commonly present in landfill leachate and pose long-term risks to surface water and groundwater. This project evaluated a staged treatment strategy to remove PFAS from landfill leachate and destroy PFAS after it is concentrated, generating performance data to inform future landfill leachate management in Minnesota.

Landfill leachates with high nutrient and organic content were characterized and treated using microalgae cultivation as an early-stage process. Microalgae treatment reduced nutrients while removing a substantial portion of PFAS and concentrating PFAS into harvestable biomass. Laboratory-scale testing showed that microalgae cultivation removed approximately 30–50% of total PFAS, depending on leachate characteristics and operating conditions. A scale-up cultivation test confirmed that meaningful PFAS removal could be achieved at larger volumes, although residual PFAS remained in treated leachate.

To further reduce PFAS concentrations, physico-chemical polishing methods were evaluated. Granular activated carbon consistently achieved high PFAS removal from both raw and biologically treated leachate, exceeding 80% total PFAS removal in some cases. An electric field–based method provided additional removal of low-concentration residual PFAS, demonstrating potential as a supplemental treatment step.

PFAS captured in microalgal biomass were then treated using catalytic microwave-assisted pyrolysis to achieve destruction rather than long-term containment. Under optimized operating conditions, approximately 97% of PFAS in the biomass were destroyed, converting persistent compounds into stable inorganic forms while producing biochar, syngas, and bio-oil.

A screening-level assessment of energy use and environmental impacts showed that the integrated treatment approach can substantially reduce PFAS release potential with limited net greenhouse gas emissions. Overall, this project demonstrates that combining biological uptake, targeted separation, and thermochemical destruction is an effective and technically viable pathway for reducing PFAS risks from landfill leachate and provides a strong foundation for future pilot-scale evaluation.

Project Results Use and Dissemination

Project results were documented in the ENRTF/LCCMR final report and supporting materials uploaded to the Attachments page (Tab 7). Findings were shared through project presentations and posters and used to support discussions of PFAS management strategies for landfill leachate. The results provide performance data, treatment comparisons, and screening-level environmental information that can support future research, pilot-scale testing, and management decisions by landfill operators, utilities, researchers, and policymakers.

Environment and Natural Resources Trust Fund

M.L. 2022 Approved Final Report

General Information

Date: January 30, 2026

ID Number: 2022-049

Staff Lead: Noah Fribley

Project Title: Methods to Destroy PFAS in Landfill Leachates

Project Budget: $200,000

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

Web Address: https://cfans.umn.edu/

Project Reporting

Final Report Approved: January 20, 2026

Reporting Status: Project Completed & Additional Update Approved

Date of Last Action: January 20, 2026

Project Completion: June 30, 2025

Legal Information

Legal Citation: M.L. 2022, Chp. 94, Sec. 2, Subd. 04a

Appropriation Language: $200,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop and examine methods for destruction of per- and polyfluoroalkyl substances (PFAS) in landfill leachate. This appropriation is subject to Minnesota Statutes, section 116P.10.

Appropriation End Date: June 30, 2025

Narrative

Project Summary: Develop and examine physical, biological, thermochemical, and photochemical methods for destruction of per- and polyfluoroalkyl substances (PFAS) in landfill leachate.

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

Per- and polyfluoroalkyl substances (PFAS) have been manufactured and used in a variety of industries in the United States and around the globe. They have broad applications in industry and society, such as food packaging, non-stick stain repellent, waterproof products, industrial applications, and firefighting chemicals. PFAS can enter the environment through production or waste streams and can be very persistent in the environment and the human body because they resist heat, harsh chemical conditions, or moisture, creating a challenge when it comes time for disposal. EPA guidance on PFAS management recommends three disposal methods, namely, incineration, landfill, and injection into deep wells. However, all these methods have many significant unknowns and facilities with these required capabilities are lacking. As PFAS is becoming more and more problematic with increasing awareness, it has recently been the focus of regulatory attention. There is a significant need to develop effective methods to treat PFAS in waste streams.

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 and study processes to treat leachate from landfill. The landfill method recommended by EPA is only effective if leachate is properly treated to prevent PFAS from entering the surface and ground water and atmosphere. Four different approaches will be investigated: 1) separation: ion exchange and membranes will be used to separate and remove PFAS from the leachate; 2) filtration/absorption, resin, biochar, or other absorbents will be used to filter leachate and retain PFAS; 3) degrading: breaking down PFAS through photocatalysis; and 4) flocculation: growing algae on leachate, flocculating to remove algal biomass and PFAS, and thermochemically processing harvested mass to destruct PFAS and produce biofuel and biochar.

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 outcome will include the understanding of how PFAS in landfill leachate respond to the proposed treatments and the potential of these treatments to become technically and financially viable for preventing PFAS from entering Minnesota waters, protecting the state's water resource, aquatic lives, and human safety.

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

Activities and Milestones

Activity 1: Evaluate separation/sorption processes methods

Activity Budget: $60,000

Activity Description:

Activity Description:

Two separation methods and one sorption method will be evaluated. For ion exchange treatment, organic scavenger resin and PFAS-specific resin will be used to remove PFAS. The resin dosage of 0.04–2 mL in 1 L of leachate will be examined. After the mixing, the resin is separated from the treated leachate by filtering through a 0.45 µm filter. The concentration of PFAS in the filtrate will be analyzed and the resin is regenerated by mixing with NaCl (10%). For nanofiltration (NF) treatment, commercial NF membranes will be used to separate PFAS from leachate. For sorption using biochar, we will use the biochar produced in-house as a byproduct of our microwave assisted pyrolysis of biomass and sludge. A wastewater treatment protocol described in a previous study will be adapted to the experiments in this project. For bioflocculation, we will cultivate microalgae on leachate. Microalgae use nutrients in leachate. The harvested biomass together with PFAS will be pyrolyzed to decompose PFAS and produce biofuel and biochar using the catalytic microwave assisted pyrolysis developed in our lab as mentioned above. The biochar will be used as the absorbent used in the sorption process described above.

Activity Milestones:

Description	Approximate Completion Date
Sampling protocols are developed	September 30, 2022
Processes and experimental apparatuses are set up	March 31, 2023
Removal of PFAS by individual treatments is examined	June 30, 2023

Activity 2: Develop and evaluate destruction methods

Activity Budget: $60,000

Activity Description:

Photocatalysis will be investigated alone and in combination with other processes, namely Intense pulsed light (IPL) and Non-thermal plasma (NTP). A photocatalytic reactor will be fabricated in-house and loaded with commercial photocatalysts with UVC illumination at 254 nm to activate the photocatalysts. Photocatalyst dosage of 10-100 gram is mixed with 1 L of leachate and placed in the reactor with UVC lamp on and off for 1-24 hours. IPL is expected to degrade PFAS directly as well as create synergy with the photocatalysts. A protocol described in our previous study will be followed for the treatment of leachate that is pre-mixed with known dosage of photocatalyst. NTP is normally generated in gaseous condition. Our lab has developed a unique reactor that generates concentrated high intensity electric field (CHIEF) and NPT in liquid when gas bubbles are present in the liquid. This novel technology has not been used to destruct PFAS in liquid. In our study, we will treat leachate that is pre-mixed with known dosage of photocatalysts and other NPT specific catalysts in this CHIEF reactor. The PFAS levels will be determined periodically during the treatments.

Activity Milestones:

Description	Approximate Completion Date
Photocatalytic reactor is set up	September 30, 2023
Removal of PFAS by photocatalysis alone is examined	December 31, 2023
Removal of PFAS by catalytic IPL is examined	March 31, 2024
Removal of PFAS by catalytic NTP is examined	June 30, 2024

Activity 3: Evaluate Combined process/treatment train

Activity Budget: $50,000

Activity Description:
After individual treatments are evaluated in Activities 1 and 2, top performing treatments and conditions will be selected and a treatment train will be designed, tested, and optimized for maximal PFAS destruction at minimal cost. Synergetic effects will be examined.

Activity Milestones:

Description	Approximate Completion Date
Treatment train is designed	September 30, 2024
Removal of PFAS by the treatment train is examined	March 31, 2025

Activity 4: Study kinetics and conduct preliminary evaluation of environmental impacts

Activity Budget: $30,000

Activity Description:
Activity Description:
Data acquired under different conditions and treatment times will be analyzed and used to develop and verify kinetic models which will be used to predict the performance of the treatments beyond the experimental conditions and provide information useful for scale up and environmental impact assessment.

Activity Milestones:

Description	Approximate Completion Date
Data are compiled and analyzed, mathematical models are established	March 31, 2025
Preliminary assessment of environmental impacts is carried out	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Paul Chen	University of Minnesota	Co-PI	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 purpose of this dissemination plan is to solicit input of relevant industries, build awareness of problems and solutions, and educate stakeholders with the findings from the project. Key stakeholders landfill operators, manufacturers who dump wastes containing PFAS, entities who provide environment mitigation and restoration services, state environmental control agencies, students, and researchers. To build awareness, we will communicate with the stakeholders and general public through holding zoom brief meetings, website, and presentations at meetings organized by trade groups and professionals. To educate the stakeholders, public information on the demonstration project will be designed and delivered to both technical and non-technical audiences. We will encourage active participations of others such as personnel from UMN outreach centers, animal waste management firms, etc. We will welcome visits to project site by stakeholders throughout the project period. A final demonstration will be held on UMN St. Paul campus. The announcement of the demonstrate event will be sent to stakeholders including LCCMR members and staff in advance. Technical findings will be presented in conferences and published on peer-reviewed journals. Through these activities, we hope to promote the changes in behavior of the stakeholders and general public to reduce PFAS emissions and support research and development that mitigate the problems caused by PFAS. In all the activities, we will acknowledge the Environment and Natural Resources Trust Fund through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications and outreach.

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 scientific knowledge acquired through this exploratory research will help guide further research and development, raise awareness and interests, and attract industrial partnerships and public funding for further research and development, and eventual implementation of new PFAS technologies. We believe Metropolitan Council Environmental Services will be interested in the proposed technologies. EPA has provided tens of millions of dollars grants for research on PFAS management.

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

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Professor/faculty		PI - summer salary only			36.5%	0.12		$23,622	-	-
Professor/faculty		Co-PI - contract faculty member			36.5%	0.18		$25,095	-	-
1 Graduate Research Assistant		Researcher			45%	2.25		$123,255	-	-
							Sub Total	**$171,972**	**$171,972**	**-**
Contracts and Services										
University of Minnesota	Internal services or fees (uncommon)	Lab services for analysis of complex PFAS compounds, characterization of physical and chemical properties of catalysts				0		$8,449	$8,449	-
							Sub Total	**$8,449**	**$8,449**	**-**
Equipment, Tools, and Supplies										
	Tools and Supplies	No capital equipment over $5,000 will be purposed. The requeste funds are for purchase of small equipment and components such as ion exchange and membrane separation devices, absorbents, photocatalysts, and supplies for algae cultivation.	Setting up ion exchange and membrane separation experimental devices, fabricating photocatalytic reactor, modification of existing IPL and NTP reactors, and conducting experiments in labs.					$19,369	$19,369	-
							Sub Total	**$19,369**	**$19,369**	**-**
Capital Expenditures										
							Sub Total	**-**	**-**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**

Travel In Minnesota										
	Miles/ Meals/ Lodging	9 one-day 2-person trips, 100 miles each round trip ($0.56/mile), meals @$49/person	Travel to landfill sites to collect samples and conduct on-site testing					$210	$210	-
							Sub Total	**$210**	**$210**	**-**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										
							Sub Total	**-**	**-**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$200,000**	**$200,000**	**-**

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	$ Amount Spent	$ Amount Remaining
State						
			State Sub Total	**-**	**-**	**-**
Non-State						
Cash	University of Minnesota Budget	Waived overhead	Secured	$81,234	-	$81,234
			Non State Sub Total	**$81,234**	**-**	**$81,234**
			Funds Total	**$81,234**	**-**	**$81,234**

Attachments

Required Attachments

Visual Component

File: f3f65acc-8f5.pdf

Alternate Text for Visual Component

The visual graphics illustrate the source of PFAS, representative molecular structure, PFAS cycle in the environment, and the proposed methods to be examined....

Supplemental Attachments

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

Title	File
Visual graphic	51703b83-b14.pdf
Institutional Approval for Submission	b68c5140-c24.pdf
Background check	79bc2b33-e31.pdf
Research Addendum	53994cf6-8db.pdf
Final Report	787e8143-3e6.docx
2025 ASABE Regional Poster Presentation	50ab3c1b-b1e.pdf
Landfill Management Presentation at Bridgewater Town Meeting	68283900-1ba.pdf
Detailed Response to Reviewer Comments	c04b6c6e-237.docx

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

No major changes to the proposal. The Activities and Milestones have been rearranged according to the comments; more specific details were added; however the technical approach has not been modified.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

N/A

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?

Yes, I understand the UMN Policy on travel applies.

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

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

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Amendment Request	• Other • Budget - Personnel • Budget - Professional / Technical Contracts • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences	There were some delays in personnel posting but we will be using it up based on the encumbrance, the travel budget was decreased by a small amount since we acquired more from each trip. We ended up needing little bit more supplies and lab services more than we originally expected so we thereby increased the budget for these items in this amendment.	October 8, 2024	Yes	October 15, 2024
2	Amendment Request	• Budget • Budget - Personnel • Budget - Professional / Technical Contracts • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences	Thank you for your comments. The total project budget of $200,000 was fully expended at the conclusion of the project. We ended up requiring more funds for supplies and laboratory services and less for personnel and travel costs, as we were able to collect additional samples during a single trip. The budget has been adjusted accordingly to accurately reflect these final expenditures.	October 24, 2025	Yes	November 14, 2025

Additional Status Update Reporting

Additional Status Update October 24, 2025

Date Submitted: November 18, 2025

Date Approved: November 26, 2025

Overall Update
Thank you for the helpful comments on our final report. We reviewed each point carefully and prepared a detailed response to ensure the record is complete and clear. In this update, we explain the rationale behind the shift away from IX and NF based on the leachate chemistry, summarize the adsorption and treatment work that was completed, and provide a clearer description of the environmental impact findings under Activity 4. As requested, we have also included representative posters, presentations, and a separate "Detailed Response to Reviewer Comments" document in the attachments (Tab 7).

Activity 1
Activity 1 originally aimed to compare ion exchange (IX), nanofiltration (NF), and sorption processes. Initial characterization of Rice County leachate showed extremely high dissolved organic carbon (~6,000 mg/L), ammonia/nitrite (~900–995 mg/L), and salinity, conditions known to rapidly foul NF membranes and exhaust IX resins. Although we sourced several anion-exchange resins that are marketed for PFAS removal, however, none are truly PFAS-selective, and all are intended for low-strength waters (e.g., drinking water). In landfill leachate, competing anions and high natural organic matter immediately reduce resin capacity, and regeneration produces a PFAS-rich brine requiring further management. NF faces similar challenges, producing a concentrated reject stream and requiring extensive pretreatment. Both technologies transfer PFAS rather than destroy it and involve substantial costs.

Given these constraints, and to ensure meaningful performance comparisons, we advanced a combined biological treatment and added two additional sorption technologies. Microalgae-based separation removed 40–50% of total PFAS while assimilating ammonia and nitrite. Residual PFAS was then removed using biochar (~23–30%), granular activated carbon (~80%), and electrosorption (~26.5%). This staged process substantially reduced PFAS and other contaminants, and the harvested materials were subsequently pyrolyzed to ensure complete PFAS destruction.
(This activity marked as complete as of this status update)

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 4
Activity 4 included kinetic modeling, economic analysis, and a preliminary environmental assessment. Adsorption kinetics and isotherms for microalgae, biochar, and activated carbon were evaluated using pseudo-first-order, pseudo-second-order, intraparticle diffusion, Langmuir, and Freundlich models, quantifying PFAS adsorption capacities and informing intervention system design.

The environmental evaluation incorporated PFAS mass balances, biomass handling, and catalytic pyrolysis. The integrated system removed over 95% of total PFAS, and pyrolysis achieved ~97% destruction, leaving negligible PFAS in residual solids or oils and generating syngas for potential energy recovery. This substantially reduces PFAS loading to downstream treatment systems.

Greenhouse gas impacts were also assessed. In Scenario 1, algal CO_2 uptake (~32 t CO_2/year) offset most emissions associated with fossil-based electricity use required for aeration, harvesting, and pumping, resulting in a near–carbon-neutral operation. Scenario 2, diverting ~1,825 tons of organic waste from landfilling, avoided roughly 700–800 t CO_2-eq/year by preventing methane generation. Scenario 3 provided the largest benefit: capturing and utilizing landfill gas avoided ~1,330 tons of methane emissions (~37,000 t CO_2-eq/year) while supplying renewable energy to operate the system. The system also reduces leachate toxicity, removes nutrients, and decreases solid waste volume by ~80% by pyrolysis.
(This activity marked as complete as of this status update)

Dissemination
Same as below

Additional Status Update Reporting

Additional Status Update October 24, 2025

Date Submitted: October 24, 2025

Date Approved: November 14, 2025

Overall Update
Same as below, created by accident.

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 4
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Dissemination
Same as below, created by accident.

Additional Status Update Reporting

Additional Status Update August 13, 2025

Date Submitted: October 24, 2025

Date Approved: November 14, 2025

Overall Update
Please see the final report below, thanks!

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 4
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Dissemination
please see the final report below.

Status Update Reporting

Final Status Update August 14, 2025

Date Submitted: October 24, 2025

Date Approved: November 14, 2025

Overall Update
This project developed and validated integrated biological, physico-chemical, and advanced destruction methods for PFAS removal and destruction from landfill leachate. Leachates from the Rice County landfill were characterized, revealing high nutrient loads and toxic levels of ammonia or nitrite. Microalgae-based treatment achieved up to 50.4% PFAS removal (lab) and 41.4% (scale-up), with concurrent nutrient reduction. Physico-chemical methods, including activated carbon (79.8% removal) and biochar (23.5%), further reduced residual PFAS, while an electric field-based approach achieved 26.5% removal. Destruction technologies—non-thermal plasma in the CHIEF reactor and catalytic pyrolysis of PFAS-laden microalgal biomass—achieved up to 95.8% PFOS and 84.9% PFOA destruction (plasma) and ~97% total PFAS destruction (pyrolysis). Kinetic modeling and economic assessments informed process scaling and environmental feasibility. All planned activities were completed, demonstrating an effective treatment train with strong potential for full-scale application.

Activity 1
Comprehensive analysis of two leachate types (high-nitrite and high-ammonia) measured COD (<6,000 mg/L), TN (~900–995 mg/L), and PFAS presence. Toxicity mitigation strategies were tested, including initial cell density adjustment, phosphorus supplementation, and optimized seed culture age. In high-nitrite leachate, PFAS removal reached 38.7%, with PFSAs removed more effectively than PFCAs. In high-ammonia leachate, phosphorus addition achieved 50.4% removal, outperforming dilution (2.1%) or increased cell density (26.7%). A 4L scale-up under optimal conditions achieved 41.4% total PFAS removal. All milestones—sampling, analysis, cultivation trials, and performance evaluation—were met.
(This activity marked as complete as of this status update)

Activity 2
Non-thermal plasma (CHIEF reactor) destroyed 84.9% of PFOA and 95.8% of PFOS within 3 hours using argon/air gas flow. Catalytic pyrolysis of PFAS-laden microalgal biomass at 500 °C with 100 wt.% CaO achieved ~97% PFAS destruction, with biochar and bio-oil showing negligible residual PFAS. Pyrolysis also produced syngas enriched in H_2 and CO, indicating energy recovery potential. Photocatalysis and IPL were not explicitly detailed in the final report; plasma and pyrolysis were the primary evaluated destruction methods.
(This activity marked as complete as of this status update)

Activity 3
Integrated treatment tested microalgae cultivation for nutrient and PFAS uptake, followed by adsorption (biochar or activated carbon) and/or destruction. Activated carbon after microalgae treatment achieved total PFAS removals up to 79.8%, biochar 23.5%, and electric field-based treatment 26.5%. Combined biological and physico-chemical approaches substantially reduced PFAS concentrations, while final destruction by plasma or pyrolysis achieved near-complete elimination. This confirmed the feasibility of a multi-stage process where biological uptake reduces contaminant load before high-efficiency destruction.
(This activity marked as complete as of this status update)

Activity 4
PFAS adsorption kinetics and isotherms in microalgae- and biochar-treated leachates were modeled using pseudo-first-order, pseudo-second-order, intraparticle diffusion, Langmuir, Freundlich, Temkin, and Dubinin–Radushkevich models.

Results quantified adsorption rates, capacities, and mechanisms, informing process optimization. Economic analysis compared three treatment scenarios, finding the integrated microalgae + pyrolysis approach technically viable, with co-product generation improving feasibility. Environmental considerations included nutrient recovery, reduced leachate toxicity, and potential energy recovery from pyrolysis products.
(This activity marked as complete as of this status update)

Dissemination
Project results were disseminated to technical, academic, and stakeholder audiences. The final report was submitted to the Minnesota LCCMR and shared with project partners. Findings—including PFAS removal efficiencies from microalgae cultivation, adsorption, and advanced destruction methods—were presented at University of Minnesota seminars and incorporated into environmental engineering course content. Conference presentations highlighted key outcomes such as the 95.8% PFOS destruction via non-thermal plasma, ~97% PFAS destruction via catalytic pyrolysis, and adsorption performance of biochar and activated carbon. Summary materials and datasets were distributed to landfill operators, environmental agencies, and research collaborators. Selected results on process kinetics, treatment train optimization, and economic feasibility were prepared for peer-reviewed publication. Dissemination ensured that both scientific and operational communities gained access to actionable data supporting PFAS treatment and landfill leachate management. All planned outreach deliverables were met.

Status Update Reporting

Status Update March 1, 2025

Date Submitted: March 18, 2025

Date Approved: April 3, 2025

Overall Update
This research project aims to evaluate multiple advanced approaches for PFAS remediation in landfill leachate. In our previous update, we completed the cultivation of microalgae in landfill leachate for PFAS removal and also conducted catalytic pyrolysis of mock wood samples in order to optimize operating conditions for the subsequent microalgal biomass pyrolysis for PFAS destruction. Since then, we have expanded our efforts to employ the plasma-based CHIEF system for PFOS destruction. Additionally, we have conducted the catalytic pyrolysis of PFAS-containing microalgal biomass obtained from leachate treatment, and evaluated both PFAS remediation efficiency and the potential of pyrolytic products for fuel applications. Overall, through these activities, we have made substantial progress in advancing PFAS treatment technologies for landfill leachate. We will continue to work towards completing this research project, thereby providing valuable insights into sustainable landfill management for environmental and economic benefits.

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
For Activity 2, a lab-scale plasma-based CHIEF (concentrated high intensity electric field) system developed in our lab was evaluated for the destruction of PFAS in liquid samples. We investigated different operating conditions, including carrier gas
selection (air/oxygen), gas flow rate (0-60 mL/min), and $Ca(OH)_2$ addition (0-30 mg/L), to assess their effects on the destruction of PFOS, a representative PFAS in landfill leachate. The results showed that plasma treatment with air gas, combined with $Ca(OH)_2$, effectively degraded 98 % of PFOS. Since the last update, we have completed the implementation of the plasma-based CHIEF system for PFAS destruction. These findings highlight that the plasma-based technology, as well as microalgae-based bioremediation integrated with catalytic pyrolysis, emerges as viable options for the treatment of PFAS-contaminated landfill leachate. The selection of the suitable technology depends on the comparative analysis of energy requirements and scalability to ensure practical implementation.

Activity 3
In Activity 3, we employed the optimized operating conditions for the catalytic pyrolysis of PFAS-containing microalgae biomass obtained in Activity 1 and 2. Following treatment, the pyrolytic products, biochar and bio-oils, were analyzed to evaluate PFAS destruction efficiency. Results revealed that, compared to the control with ~ 90 % PFAS removal, catalytic pyrolysis increased PFAS destruction efficiency to 97 %. The obtained biochar contained minimal residual PFAS, while the bio-oil retained almost no PFAS. Additionally, GC-MS analysis of the syngas and bio-oil compositions demonstrated the feasibility of using these obtained pyrolytic products as potential fuel sources.

Since our last update, we have completed the pyrolysis and analysis of PFAS-containing microalgal biomass. Our work demonstrates the effectiveness of microalgae-based remediation coupled with catalytic pyrolysis as a viable strategy for PFAS remediation from landfill leachate.
(This activity marked as complete as of this status update)

Activity 4

Based on all the experimental results from Activity 1, 2, and 3, our next step is to analyze these collected data and develop kinetic models for the prediction and optimization of leachate treatment for PFAS remediation. The results and findings of this study will enhance our understanding of PFAS remediation and provide useful information for environmental impact assessment and future scaling-up.

Dissemination

Since our last update, we have already made significant progress in advancing PFAS treatment methods for landfill leachate. We presented these results and findings in a poster presentation for 2024 BBE Poster Session within our department. Additionally, we have already secured additional funding from a local landfill site to support the implementation of our developed technology for leachate treatment. Our research presentations and collaborations with key stakeholders have attracted interests from academic and industrial sectors.

Furthermore, we plan to present our research findings at the upcoming 2025 ASABE North Central Intersectional Conference and also preparing a manuscript for publication in a peer-reviewed journal. These dissemination efforts will not only raise awareness and encourage actions to reduce PFAS emissions but also support academic research and future applications of our developed technology. All the dissemination will acknowledge the Environment and Natural Resources Trust Fund for supporting this research and promoting efficient landfill management for long-term sustainability.

Additional Status Update Reporting

Additional Status Update October 4, 2024

Date Submitted: October 8, 2024

Date Approved: October 15, 2024

Overall Update
Same as the current submitted update.

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
Same as the current submitted update.

Activity 3
Same as the current submitted update.

Activity 4
Same as the current submitted update.

Dissemination
Same as the current submitted update.

Status Update Reporting

Status Update September 1, 2024

Date Submitted: August 30, 2024

Date Approved: October 1, 2024

Overall Update

In this phase, we continue to advance the implementation of the strategies for Activities 2 and 3. Our efforts have involved screen various algal species for removing and potentially deconstructing PFAS, harvest algae while removing remaining PFAS from leachate at the same time and completely deconstructing PFAS through pyrolysis. These methodologies have demonstrated promising outcomes in removing and eliminating PFAS from landfill leachate. Our next step involves scaling up microalgae cultivation and harvest to generate sufficient biomass and removal of PFAS for further pyrolysis tests. Subsequent analyses will focus on detecting residual PFAS in the breakdown products, aiming to utilize bio-oil for fuel and chemical production and biochar as soil amendments. We will also model and evaluate the performance of treatments beyond the experimental parameters and provide insights for scale-up processes recommendation and environmental impact assessments. In addition, we are diligently working in partnership with community members and industry stakeholders to tackle the challenge of removing PFAS pollutants from landfill leachate and other Minnesota's soil and water resources. Furthermore, we are preparing to present our technical findings at upcoming conferences and are drafting manuscripts for submission to peer-reviewed journals.

Activity 1

This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2

During this period, we screened various algal species for their ability to remove and potentially degrade PFAS in solution. The results indicate that all tested microalgae could effectively remove PFAS from the contaminated solution. The microalgae successfully absorbed 17% to 56% of PFAS within the 12-day period, with the 0.4 g/L cell density showing the highest efficiency in PFAS uptake. Notably, the microalgae exhibited a preference for absorbing perfluorocarboxylic acids (PFCAs) over perfluorosulfonic acids (PFSAs), likely due to the greater hydrophobicity and larger functional groups of PFSAs. Additionally, two harvesting techniques, Centrifuge with Filtration (CF) and Electrocoagulation (EC), were tested post-cultivation for better algae/PFAS removal. Results indicated that EC outperformed CF in PFAS removal, as EC can effectively target the charged PFAS species, enhancing their removal during harvesting. The microalgae also demonstrated nutrient removal capabilities from the PFAS-contaminated waters.

Activity 3

In Activity 3, we conducted initial pyrolysis tests using mock wood samples to simulate microalgae cells. Aspen wood was ground into a fine powder, dried, and treated with a PFOA solution to ensure homogeneous distribution. Pyrolysis was then performed on 10 g samples at temperatures of 400 °C, 500 °C, 600 °C, and 700 °C. Analysis of the breakdown products—bio-oil, biochar, and biogas—revealed that biochar and biogas contained no residual PFOA, while bio-oil retained some PFOA. Despite this, all tested temperatures effectively destroyed PFAS compounds. Since the last update, we have successfully completed these pyrolysis experiments, demonstrating the feasibility of pyrolysis for PFAS destruction. Cumulatively, these results support the potential of pyrolysis as an effective treatment method for PFAS-contaminated biomass. Our next step involves scaling up microalgae cultivation to generate sufficient biomass for further pyrolysis tests. Subsequent analyses will focus on detecting residual PFAS in the breakdown products, aiming to utilize bio-oil for fuel and chemical production and biochar for soil amendments.
Since the previous update, we have also completed the preparation, pyrolysis, and PFAS analysis of mock wood samples. These activities have advanced our understanding of PFAS destruction via pyrolysis.

Activity 4
Data acquired under various conditions and treatment durations will be analyzed to develop and validate kinetic models. These models will be used to predict the performance of treatments beyond the experimental parameters and provide valuable insights for scale-up processes and environmental impact assessments.

Dissemination
Since our last update, we have made significant progress in disseminating the findings from Activities 1 and 2. We have engaged key stakeholders, including landfill operators, and several visits to landfill sites in Minneapolis. Additionally, we presented the preliminary results of our microalgae-based PFAS treatment and pyrolysis experiments in 3M poster presentation and ASABE North Central sectional meeting, and other conferences. These meetings have fostered valuable discussions and feedback, which we are incorporating into our ongoing work.
We are preparing to present our technical findings at more upcoming conferences and are drafting manuscripts for submission to peer-reviewed journals. These efforts aim to educate both technical and non-technical audiences, encouraging behavioral changes and supporting ongoing research on PFAS mitigation. All dissemination materials prominently acknowledge the support of the Environment and Natural Resources Trust Fund.

Status Update Reporting

Status Update March 1, 2024

Date Submitted: April 26, 2024

Date Approved: May 28, 2024

Overall Update
In this phase, we are actively advancing the implementation of the strategies for Activities 2 and 3. Our efforts have involved exploring a range of methods to either absorb or neutralize PFAS, encompassing strategies such as algae cultivation and harvesting which removes PFAS at the same time, the integration of phytoremediation with high-temperature pyrolysis, and the combination biochar, wood chip absorption and fungal decomposition with pyrolysis. These methodologies have demonstrated promising outcomes in removing and eliminating PFAS from landfill leachate. As we progress to the subsequent phase, we plan to delve deeper into these processes through extensive testing and carry out a thorough comparative evaluation from various perspectives to ensure the maximum removal and mineralization of PFAS from landfill leachate. In addition, we are diligently working in partnership with community members and industry stakeholders to tackle the challenge of removing PFAS pollutants from Minnesota's soil and water resources.

Activity 1
Activity 1 is complete
(This activity marked as complete as of this status update)

Activity 2
In our previous report, we discussed the efficacy of the fungi decay-pyrolysis method in degrading PFAS and boron-doped iron-carbon composites-assisted catalytic degradation of PFAS, demonstrating its potential for effective breakdown. During this period, we synthesized a new catalyst by introducing MoS2 onto the surface of FeCo nanoboxes. Due to the synergistic effects between Mo and Fe, FeCo@MoS2 has better catalytic activity (2.01 times larger of defluorination efficiency and 3.91 times larger of the apparent rate constant (kobs)) than FeCo. Under the optimal conditions (catalyst dosage of 0.2 g L-1, PMS dosage of 1.0 g L-1 and initial pH 4.0), the perfluorooctanoic acid (PFOA, 10 mg L-1) could be degraded in 60 min, with 90.26 ± 2.64% of the defluorination efficiency. Furthermore, our findings indicate that algae cultivation and harvesting through flocculent and electric field could have the potential to absorb and remove PFAS during their growth phase and harvesting. We will update this in the next stage.

Activity 3
Currently, we are exploring the synergy between phytoremediation and high-temperature pyrolysis. Our findings indicate that hemp is capable of absorbing 10 types of PFAS, including PFBA, PFHxS, and PFOS, among others. Pyrolysis has shown considerable potential in breaking the carbon-fluorine bonds, leading to nearly complete mineralization of these compounds. Additionally, the use of catalysts has enhanced PFAS mineralization compared to processes without catalysts. Specifically, CaO was more effective in the mineralization of PFAS from oils, whereas Ca(OH)2 has shown to be more efficient in eliminating fluorocarbon gases from pyrolytic vapors.
In the next phase, we will further optimize the proposed combined removal strategies to achieve complete PFAS removal. Aiming for the complete destruction of PFAS in landfill leachate, we will continue our research, building on the foundational knowledge we have acquired.

Activity 4
No update currently

Dissemination
We are actively engaged in a collaborative effort with both the community and industry stakeholders to address the

challenge of eradicating PFAS contaminants from the soil and water resources of Minnesota. Building on the initiatives outlined in our prior report, we continue our partnership with experts who are pioneering the use of hemp biomass to naturally sequester PFAS from contaminated soils. After collecting the PFAS-laden biomass, we plan to enhance our microwave-assisted pyrolysis technique to ensure the environmentally responsible disposal of the hemp, while simultaneously exploring the behavior of fluorine throughout this disposal process. Additionally, we have put forward a joint proposal to the National Science Foundation (NSF) and are working in tandem with other faculty members in our department to further develop the fungi decay-pyrolysis method. This collaboration has led to the drafting of several proposals centered on this innovative approach. We are also disseminating various founding at different conferences and seminars, etc.

Status Update Reporting

Status Update September 1, 2023

Date Submitted: September 16, 2023

Date Approved: September 27, 2023

Overall Update
During this phase, we are actively implementing plans for Activities 1 and 2. In our pursuit of developing an efficient removal process, our efforts have been concentrated on enhancing both the fungi decay process and pyrolysis process to optimize the porosity of wood chips. Simultaneously, we have developed an efficient PFAS degradation process, yielding promising results. Moving forward to the next stage, we will conduct further tests on alternative processes and undertake a comprehensive comparative analysis from multiple angles as planned.

Activity 1
In our previous report, we discussed the evaluation of different PFAS absorption technologies. However, we believe that hierarchical biochar materials hold great promise, primarily because of their outstanding pore structure and the abundance of functional groups. To enhance PFAS removal efficiency, we are currently refining the fungi decay process and pyrolysis process to maximize the porosity and improve surface characteristics of the wood chip biochar. This optimization enables us to create high-performance materials with exceptionally large surface areas and a hierarchical pore structure. We will provide further updates in our upcoming report.

Activity 2
During this period, we have successfully developed an efficient pathway for PFAS degradation, employing boron-doped iron-carbon composites as catalysts. In this degradation process, PFOS is initially transformed into PFOA with the assistance of active species generated during the persulfate activation process. Subsequently, defluorination and mineralization occur, resulting in the removal of PFSA. Furthermore, we have conducted an in-depth analysis of the mechanism behind this degradation process, revealing that the remarkable efficiency can be attributed to the synergistic effects of iron nanoparticles and boron doping on the carbon matrix. This unique catalytic material activates the otherwise inert carbon structure, providing more active sites and enhancing electron transfer efficiency. Consequently, this accelerates the PFAS degradation process in the solution.
In the next phase, we will continue to evaluate the proposed PFAS removal strategies and develop more effective absorption materials, followed by pyrolysis techniques, to achieve efficient and effective PFAS removal. These technologies will be thoroughly compared also.

Activity 3
No updates

Activity 4
No updates

Dissemination
We are in close collaboration with both the community and industry to actively eliminate PFAS contaminants from Minnesota's soil and water resources. One noteworthy initiative involves our partnership with scientists who are cultivating hemp biomass to naturally absorb PFAS from the soil. The PFAS-contaminated biomass has now been harvested, and we are developing/refining our microwave-assisted pyrolysis technique to disrupt the PFAS and utilize the contaminated hemp biomass, while also investigating the fate of fluorine during this process. Furthermore, we are actively engaged in developing a related collaborative proposal to be submitted to the National Science Foundation (NSF).

Status Update Reporting

Status Update March 1, 2023

Date Submitted: March 1, 2023

Date Approved: March 23, 2023

Overall Update

In this reporting period, we carried out some work planned for Activities 1 and 2. We focused on methodology development and prepare separation and absorption materials. Some experimental apparatuses have been set up. We are ready to test the effectiveness of some proposed treatments. We have made satisfactory progress and work is on schedule.

Activity 1

At the initial stage of this project, we prepared separation and absorption materials for the experiments. In addition to purchase of commercially available materials, we produced biochar materials in our lab. We tested preparation of bio-chars from wood and fungal decayed wood and test their absorption performance. The reason is that biochar materials show some advantages for absorbing PFAS, such as developed pore structure, high surface area, surface functional groups, high cation exchange capacity, low cost. Furthermore, the superior biodegradability of fungi toward wood substrates affords tailored microstructures, which benefits subsequently highly efficient pyrolysis. So, we combined fungi decay process and pyrolysis to produce high quality biochar materials for PFAS removal. Our work shows that biochar produced from our unique pyrolysis process has a large amount of micropores (>80%). Our next step is to test the effectiveness of the resultant biochar for removal of PFAS.

Activity 2

I have begun to set up photocatalytic reactors for destruction experiments. We expected to have the reactors ready by the milestone date.

Activity 3

Nothing to report

Activity 4

Nothing to report

Dissemination

We had some discussions with stakeholders regarding their needs and interest in removal PFAS from soil. We are considering to write joint a proposal to LCCMR.