December 20, 2023

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**RE: Draft Amended Pretreatment Discharge Permit for New England Waste Services, Inc. (Permit No. 3-1406)**

Thank you for the opportunity to provide comments on the Draft Amended Pretreatment Discharge Permit ("Pretreatment Permit) and Leachate Treatment Study Plan ("Pilot Plan") for New England Waste Services of Vermont, Inc. ("Casella"). These comments are submitted on behalf of Conservation Law Foundation ("CLF") and Just Zero.[1]

CLF's mission is to conserve natural resources, protect public health, and build healthy communities in Vermont and throughout New England. Through its Zero Waste Project, CLF aims to protect communities and our environment from the toxic dangers of unsustainable waste practices and advance waste reduction, diversion, and recycling.

Just Zero is a national non-profit environmental advocacy organization that works alongside communities, policy makers, scientists, organizers, and others to implement just and equitable solutions to climate-damaging and toxic production, consumption, and waste disposal practices. Just Zero's staff believes that all people deserve Zero Waste solutions with zero climate-damaging emissions and zero toxic exposures.

We recognize and appreciate the steps the Agency of Natural Resources ("Agency") is taking to address the release of per- and polyfluoroalkyl substances ("PFAS") into the environment from landfill leachate. The piloting of a treatment system to reduce and remove the concentrations of PFAS in landfill leachate prior to discharge to a wastewater treatment plant ("WWTP") is a critical first step in creating of a comprehensive statewide system focused on reducing the release of these highly toxic and pervasive compounds into the environment. Prior to this, Vermont's system for managing leachate did not address the fact that leachate is known to contain high concentrations of PFAS. We commend the Agency for taking the issue of PFAS contamination seriously and working proactively to limit the release of these compounds.

**However, as currently drafted, the Pretreatment Permit and the Pilot Plan raise significant public health and environmental concerns that the Agency must address.** As we explain in greater detail below:

- Section I – The development of a pretreatment system to remove PFAS in landfill leachate is imperative.

[1] Hereinafter these organizations are collectively referred to as "we."

- Section II – The permitting process surrounding the development of the Pilot Plan has raised concerns regarding the Agency's ability and willingness to sufficiently scrutinize the proposed treatment system.
- Section III – The Agency has failed to establish the success criteria needed to accurately evaluate whether the adopted treatment system will warrant expansion.
- Section IV – There is inadequate evidence that the Foam Fractionation system Casella intends to utilize will effectively and consistently remove the variety of PFAS compounds – and PFAS precursors – known to be present in landfill leachate. Additionally, both the residuals management and air emissions plans pose unacceptable risk of environmental contamination.
- Section V – In this section, we outline our recommendations for the development of a more robust and evidence-based treatment system that will not only help remove the current class of regulated PFAS in landfill leachate, but also additional PFAS compounds that are of emerging concern and PFAS precursors.

In support of our comments, we have also attached an analysis of the proposed Pilot Plan conducted by two experts in the field of civil and environmental engineering, Yang Yang, PhD and Thomas Holsten, PhD Attachment A includes their report ("Expert Report") and respective credentials.

Ultimately, the Pilot Plan can be an important step forward in addressing the inadequacies of Vermont's existing leachate management system. **However, approving Casella's proposed treatment system would allow the piloting of a single treatment technology that has not been sufficiently demonstrated on landfill leachate or as a means of separating or destroying PFAS.** Therefore, the Agency must reject the proposed Pilot Plan and should instead adopt a more robust treatment chain as described below.

## I. Background on the Importance of Leachate Pretreatment as a Means of Reducing PFAS Contamination.

The current regulatory system of managing landfill leachate in Vermont is inadequate to address PFAS. This is especially concerning given that outside of manufacturing, landfill leachate is one of the most prevalent pathways for the release of PFAS into the environment.[2]

Currently, Vermont manages all leachate through WWTPs. These facilities are not equipped to remove the diverse and complex range of contaminants in leachate prior to discharge into surface waters. Instead, the treatment is primarily focused on reducing wastewater discharges of so-called conventional pollutants: oil, grease, organics like nitrogen and phosphorous, total suspended solids, and settleable matter. Importantly, these facilities do not address the presence of PFAS.

The result of this ineffective management system is that PFAS-contaminated wastewater is currently being discharged from WWTPs into surface waters. This is especially true for WWTPs

[2] Malovanyy, A., Fredrik, H., Bergh, L., Liljeros, E., Lund, T., Suokko J., & Hinrichsen, H., Comparative Study of Per-and-Polyfluoroalkyl Substance Removal From Landfill Leachate, Journal of Hazardous Materials, 450, 132505. (Oct. 15, 2023). https://doi.org/10.1016/j.jhazmat.2023.132505

that accept wastewater from sources known to contain high concentrations of PFAS, such as landfill leachate. In fact, WWTPs that accept landfill leachate have higher PFAS concentrations in effluent than all other plants in Vermont.[3] Worse, there is growing evidence that the oxidation process that occurs at WWTPs can convert unregulated compounds such as fluorotelomer carboxylates into both regulated and unregulated PFAS compounds.[4] This includes the creation of perfluoroalkyl acids – a form of PFAS that is highly toxic.[5]

The PFAS in the effluent discharged from the WWTPs then bioaccumulates and disperses into the wider environment. Once released into the environment, PFAS are difficult to contain and remediate because of their longevity. A growing body of science has documented that there are significant adverse health effects associated with exposure to PFAS, including liver damage, thyroid disease, decreased fertility, high cholesterol, obesity, endocrine system disruption, hormone suppression, and cancer.[6] In fact, on December 1, 2023, the International Agency for Research on Cancer classified PFOA as a cancer-causing substance.[7]

Developing a pilot to test and evaluate technologies that can effectively and consistently remove PFAS compounds from landfill leachate will significantly reduce the release of these toxic compounds into the environment. In fact, the results of the pilot will likely have a precedential effect throughout the region and the country.

Effectively managing PFAS in leachate is increasingly important as both federal and state regulators develop new requirements for these toxic compounds. In many ways, this regulatory shift has already begun. The U.S. Environmental Protection Agency ("EPA") has proposed regulations to designate PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA" or "Superfund").[8] Additionally, EPA has announced plans to develop new effluent limitations guidelines and pretreatment standards for landfill leachate.[9] The announcement comes after a determination that

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[3] Weston & Sampson, Summary Report for the Vermont Department of Environmental Protection: Poly-and Perfluoroalkyl Substances Inputs to Wastewater Treatment Facilities, Section 1, p. 1-1. (Mar. 26, 2022). Available, https://dec.vermont.gov/sites/dec/files/wmp/residual/2021%20VTDEC%20PFAS%20Inputs%20to%20WWTF%20Study.2022March29.pdf

[4] Helmer, R. W., Reeves, D. M., & Cassidy, D. P. (2022). Per- and polyfluorinated alkyl substances (PFAS) cycling within Michigan: Contaminated sites, landfills and wastewater treatment plants. Water Research, 210, 117983. https://doi.org/10.1016/j.watres.2021.117983

[5] *Id.*

[6] National Toxicology Program, Monograph on Immunotoxicity Associated with Exposure to Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), U.S. Department of Health and Human Services, p. 16. (Sept. 2016). Available at https://ntp.niehs.nih.gov/sites/default/files/ntp/ohat/pfoa_pfos/pfoa_pfosmonograph_508.pdf

[7] International Agency for Research on Cancer, Monogrpahs Evaluate the Carcinogenicity of PFOA and PFOS, World Health Institute. (Dec. 1, 2023). https://www.iarc.who.int/news-events/iarc-monographs-evaluate-the-carcinogenicity-of-perfluorooctanoic-acid-pfoa-and-perfluorooctanesulfonic-acid-pfos/

[8] EPA, Designation of Perfluorooctanoic Acid (PFOA) and Perfluorooctanesulfonic Acid (PFOS) as CERCLA Hazardous Substances, Proposed Rule, 87 Fed. Reg. 54415 (Sept. 6, 2022). Available at https://www.federalregister.gov/documents/2022/09/06/2022-18657/designation-of-perfluorooctanoic-acid-pfoa-and-perfluorooctanesulfonic-acid-pfos-as-cercla-hazardous

[9] Megan Quin, EPA Proposes Further Leachate Regulations After Study Find PFAS at 95% of Surveyed Landfills, Waste Dive (Jan. 24, 2023). Available at https://www.wastedive.com/news/pfas-epa-landfill-leachate-swana-nwra-wm-republic/641030/

new effluent guidelines for landfills are necessary to address the presence of PFAS in leachate.[10] States such as California, Michigan, New Jersey, Maine, and Washington, are also taking steps to limit PFAS, which has prompted increased attention on pretreatment technology for landfill leachate.[11] Most notably, in 2022, the Maine legislature enacted a resolve which directed the Bureau of General Services to conduct a study to identify readily available methods to reduce the concentrations of PFAS generated from landfills in the state.[12] The findings of the study are expected to result in proposals to develop pretreatment requirements for landfill leachate.

As states across the country continue to grapple with PFAS contamination they will undoubtably look at the steps Vermont is taking to address PFAS in leachate. The results of this Pilot Plan will likely inform pretreatment requirements for landfill leachate, technology based effluent limitations for PFAS from wastewater including landfill leachate, and the development of surface water quality standards for PFAS at both the federal and state level. Therefore, it is imperative that the Agency adopt a strong pilot project plan at the outset and then play an active role in the oversight and evaluation of the selected pretreatment technologies.

## II. The Agency Has Failed to Provide the Public with Sufficient Opportunity to Weigh in on the Development of the Pilot Project.

The administrative process leading up to the Pilot Plan has been unsatisfactory. The Agency's actions – and inaction – have raised serious concerns that the Agency is failing to uphold the public's right to weigh in on the design and location of the treatment system. This in turn has led to more public concern about the rigor which the Agency is overseeing the Pilot Plan and scrutinizing the Project.

The Pretreatment Permit, which Casella is currently operating under requires the company to pilot a leachate treatment system. Specifically, the Pretreatment Permit requires Casella to submit a Pilot Plan in the form of an application to amend the current Pretreatment Permit.[13] Critically, this means that the Pilot Plan would therefore be subject to Agency review and approval, and all public notice, hearing, and comment provisions applicable to permit amendments. Once approved, the Pilot Plan would ultimately determine the leachate treatment system that Casella is required to install and operate, "in accordance with the approved plan", per the Pretreatment Permit.

[10] See, e.g., U.S Environmental Protection Agency, Landfill Effluent Guidelines. Available at https://www.epa.gov/eg/landfills-effluent-guidelines; and U.S. Environmental Protection Agency, Effluent Guidelines Program Plan 15. Available at https://www.epa.gov/eg/current-effluent-guidelines-program-plan
[11] April Reese, Some Landfills Will Begin Treating PFAS On-Site As Regulators Move to Adopt New Limits, Waste Dive. (Jan. 17, 2023). Available at https://www.wastedive.com/news/pfas-landfill-leachate-epa-casella-waste-connections/639462/#:~:text=The%20next%20year%2C%20a%20report,other%20plants%20in%20the%20state.
[12] Maine Resolves 2021, Ch. 172. (May 2, 2022)
[13] Agency of Natural Resources, Pretreatment Discharge Permit for New England Waste Services of Vermont, Permit No. 3-1406, Section 5, Pg. 8. Available at https://anrweb.vt.gov/Pubdocs/DEC/ENB/WWINV/21339-3-1406_DraftPermit.20231107.pdf

After the Pretreatment Permit was issued – but before the Agency approved Casella's Pilot Plan for the development of a leachate treatment system – the Agency granted Casella a Solid Waste Management Facility Certification Amendment, Permit No. OL510-2022-28 (the "Facility Amendment"). The Facility Amendment authorized Casella to construct a building at the Coventry Landfill that would house the leachate treatment system. The details of this system were still entirely unknown, since the Pilot Plan had not yet been released to the Agency, let alone to the public. We expressed in our joint letter submitted on January 4, 2023, that the Agency put the cart before the horse by allowing on-site construction of the treatment system building before the Pilot Plan was even released, reviewed by the public, and approved by the Agency.[14]

More recently, as expressed in our letter to the Department on Oct. 12, 2023, we discovered that Casella had surreptitiously constructed and begun operating a leachate treatment system before the Agency had approved the Pilot Plan, and before the public had the opportunity to weigh in via their procedural right to public comment and a hearing.[15] We underscored in that letter that the Agency should halt operations of the treatment system until the Pilot Plan underwent its due process, and thereby hold Casella to comply with the terms of their Pretreatment Permit. The Agency declined to take such action, and the system remains operational.

We will not repeat our detailed explanation of Casella's violation of their permit terms. However, we remain concerned about the Agency's ability to critically review the proposed Pilot Plan given Casella has already constructed and begun operation of the leachate treatment system. We hope the Agency will allay these concerns and demonstrate that they are indeed giving the public comment period true weight by seriously considering each comment and incorporating those with merit into the final review of the Pilot Plan. Specifically, we ask that the Agency show this commitment by requiring significant changes in the Pilot's design if that is necessary to best protect public health and the environment; anything less would be an abdication of the Agency's duty.

## III. The Agency Must Take a More Active Role in the Development, Implementation, and Review of the Pilot Project.

The Pretreatment Permit and the Pilot Plan do not include conditions that are necessary to ensure the Agency is properly scrutinizing the proposed treatment system or regulating the operation of the chosen treatment system. This is extremely concerning given that the results of the Pilot Plan will have significant impacts on the development of regulations regarding PFAS and landfill leachate in Vermont. Given the extensive and well-documented evidence regarding the widespread environmental and public health impacts associated with exposure to PFAS, as well as the role landfill leachate plays in the release of these toxic compounds into the environment,

[14] *See* Conservation Law Foundation's and Just Zero's letter, "Re: Coventry Landfill Permits: Solid Waste Management Facility Certification Amendment, OL510-2022-28 and Pretreatment Discharge Permit No. 3-1406", dated Jan. 4, 2023.
[15] *See* CLF's, Just Zero's and Vermont Natural Resources Council's letter, "Re: Violations of Permit No. 3-1406 and State Law – New England Waste Services of Vermont, Inc.'s Leachate Treatment Pilot Study Plan", dated Oct. 12, 2023.

the Agency must set clear parameters for how it will evaluate the selected treatment system and determine whether it was successful or not.

**Currently, the Agency has not explained how it will evaluate the effectiveness of the piloted technology.** This is despite the Agency committing to utilizing the results of the Pilot Plan to establish a Technology Based Effluent Limit and/or treatment standard for PFAS in leachate.[16] Instead, the Agency has given Casella near absolute control over the selection and operation of a treatment system that will be used to inform the development of future regulations. This is unacceptable and inappropriate. Casella is a private, regulated entity and will be directly and financially impacted by the regulations that the Agency intends to develop using the results of the Pilot Plan. Casella should not be given carte blanche over a crucial project that will directly inform what those regulations require.

**Given the importance of the Pilot Plan, the Agency must establish clear criteria for how it will determine whether the chosen technology is successful or not.** These criteria should inform how the Agency evaluates the progress reports submitted by Casella during the duration of the pilot, and whether or not the chosen technology should be scaled to full system implementation and used to inform any further regulatory action regarding PFAS in landfill leachate. At a minimum, these criteria must include:

(1) What effluent concentrations are considered acceptable;
(2) The ability of the chosen treatment system to consistently and reliably meet the target effluent concentrations;
(3) Whether the selected treatment system can effectively remove additional conventional, nonconventional, and toxic compounds, including additional PFAS compounds that are not currently regulated in Vermont, and PFAS precursors;
(4) The quantity of residual waste, the concentration of PFAS in the residual waste, and whether the residual waste streams are capable of effective and environmentally sound management;
(5) Whether the chosen treatment system can be effectively scaled to treat all leachate generated at the landfill; and,
(6) The overall cost of the treatment system, which includes the cost of full-scale implementation, maintenance, and residual waste management.

Setting these parameters is necessary so that the public and the permittee understand how the Agency will evaluate the piloted technology and determine whether the technology is sufficient in treating leachate to remove the concentration of PFAS to a level and in a manner that is protective of the environment and public health.

**In terms of the target effluent concentrations, the Agency should utilize Vermont's Drinking Water Standard for PFAS, which is 20 ng/L or 20 parts per trillion ("ppt").[17]** In other words, successful pretreatment for the purpose of the Pilot Project – for this target effluent concentration criteria alone – would be based on the ability of the chose treatment system to

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[16] Agency of Natural Resources, Pretreatment Discharge Permit for New England Waste Services of Vermont, Permit No. 3-1406, Section 5, Pg. 7. Available at https://anrweb.vt.gov/Pubdocs/DEC/ENB/WWINV/21339-3-1406_DraftPermit.20231107.pdf

[17] Water Supply Rule, 12-030-003 VT. Code R.

reduce the combined level of PFOA (perfluorooctanoic acid), PFOS (perfluorooctane sulfonic acid), PFHxS (perfluorohexane sulfonic acid), PFHpA (perfluoroheptanoic acid), and PFNA (perfluorononanoic acid) to 20 ppt or below.

In the absence of a public health standard, or any comparable surface water standard for PFAS, the drinking water standard is an appropriate success metric for evaluating pretreatment technologies. The Maine Legislature recently commissioned a study of available leachate pretreatment technologies.[18] The Maine Legislature limited the scope of the study to an evaluation of readily available treatment technologies that can reduce the concentration of six regulated PFAS to no more than 20 ppt, which is the Maine Interim Drinking Water Standard for PFAS.[19] Moreover, the Brown and Caldwell Conceptual Leachate Treatment Scoping Study for the New England Waste Services of Vermont Landfill analyzed at least one technology – Rochem Reverse Osmosis – on its ability to remove the Vermont regulated PFAS compounds from wastewater to levels below health advisory levels for drinking water.[20]

It is also important to note that Casella has publicly stated that the goal of the Pilot Plan is to reduce the concentration of regulated PFAS in landfill leachate to levels below Vermont's Drinking Water Standard. In an interview with Waste Dive, Samuel Nicolai, Casella's Vice President of Engineering and Compliance stated that with the Pilot Plan, the company is "aiming to try to get levels in leachate below laboratory detection limits, which are typically in that one to two ppt range."[21] In the same interview, Mr. Nicolai said that Casella "believe[s] we will be successful at doing that."[22]

## IV. The Proposed Foam Fractionation Treatment System Poses Serious Environmental and Public Health Concerns Which the Agency Must Address.

Casella proposes to utilize a foam fractionation system as the sole treatment technology for the duration of the Pilot Plan**.** However, Casella has failed to provide necessary data to support the use of this technology as the sole treatment method. In fact, there is minimal evidence to warrant the use of foam fractionation as a standalone leachate pretreatment technology. Moreover, the complex nature of landfill leachate may cause issues with the foam fractionation process thereby limiting the ability of the treatment technology to effectively remove and reduce PFAS from the material.

Additionally, the standalone foam fractionation system raises significant environmental and public health concerns which Casella has not adequately addressed. This includes concerns over the technology's ability to address the wide array of PFAS in the leachate, the ability to

[18] Maine Resolves 2021, Ch. 172. (May 2, 2022)
[19] *Id.*
[20] Brown and Caldwell, Conceptual Leachate Treatment Scoping Study for New England Waste Services of Vermont Landfill, p. ES-3. (Oct. 11, 2019). [ Hereinafter "Leachate Treatment Scoping Study"] Available at https://anrweb.vt.gov/PubDocs/DEC/SolidWaste/OL510/OL510%202019.10.15%20Conceptual_Leachate_Treatmnt_Scoping_Study.pdf
[21] April Reese, Some Landfills Will Begin Treating PFAS On-Site As Regulators Move to Adopt New Limits, Waste Dive. (Jan. 17, 2023). Available at https://www.wastedive.com/news/pfas-landfill-leachate-epa-casella-waste-connections/639462/#:~:text=The%20next%20year%2C%20a%20report,other%20plants%20in%20the%20state.
[22] *Id.*

effectively manage the residual waste which will contain extremely high levels of PFAS, and ineffective monitoring of air emissions.

Given these concerns, the Agency must reject the Pilot Plan. While foam fractionation may be a component of a larger treatment process, there is insufficient evidence to warrant the technology as a stand-alone treatment process. This is crucial given the Agency's goal of using the results of the Pilot Plan in the development of future regulation.

A. The Chosen Foam Fractionation Treatment System Is Unproven and Lacks Sufficient Data to Warrant Selection as a Standalone Treatment Technology.

**Casella has failed to provide necessary data to illustrate that foam fractionation is a proven and established method for treating landfill leachate to address the presence of PFAS.** Foam fractionation was not considered in the Brown and Caldwell Scoping Study because the technology was "not demonstrated with leachate or PFAS treatment to lower ppt concentrations."[23] Similarly, in 2020, the EPA formed the PFAS Innovative Treatment Team to explore innovative tools and methods for destroying or removing PFAS in various media and waste.[24] One of the evaluated waste streams was landfill leachate.[25] The EPA did not evaluate foam fractionation as a treatment system because the technology failed to meet the success criteria which included effectiveness, readiness, applicability, and safety outputs.[26] In fact, since the completion of the Brown and Caldwell Scoping Study in 2019, only a handful of studies have been published regarding foam fractionation as a means of addressing PFAS in landfill leachate. Many of the studies note that there are significant data gaps regarding the technology's effectiveness when addressing PFAS in a complex medium such as landfill leachate.

Casella's choice to use a foam fractionation system here appears to be entirely based on the results of an identical system at a landfill in Sweden. However, Casella has failed to provide any of the underlying data necessary to understand the actual results of the Swedish system. While the Pilot Plan mentions there was a bench study, notably, no data or findings from that study are included in Casella's submissions.

Additionally, the limited information Casella has provided shows that the case study in Sweden is not analogous to the situation at the Coventry Landfill. **The leachate generated at the Coventry Landfill – which will be subject to the Pilot Plan – contains PFAS levels that are significantly higher than the levels at the Swedish landfill.**

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[23] Leachate Treatment Scoping Study, Section 2, p. 2-1. (Oct. 11, 2019).
[24] U.S. Environmental Protection Agency, PFAS Innovative Treatment Team. Available at https://www.epa.gov/chemical-research/pfas-innovative-treatment-team-pitt
[25] Brian Gullett, EPA PFAS Innovative Treatment Team Finding on PFAS Destruction Technologies, U.S. Environmental Protection Agency, p. 6. (Feb. 17, 2021). Available at https://www.epa.gov/sites/default/files/2021-02/documents/pitt_findings_toolsresources_webinar_02172021_final.pdf
[26] *Id.* at 9.

- The concentration levels of PFOA in the leachate at the Swedish landfill were 350 ppt.[27] The levels of PFOA at Coventry were 1,711 ppt.[28]
- The levels of PFHpA in the leachate at the Swedish landfill were 120 ppt.[29] The levels at Coventry are 720 ppt.[30]
- The levels of PFNA in the leachate at the Swedish landfill were 76 ppt.[31] The levels at Coventry are 863 ppt.[32]
- The level of PFHxS in the leachate at the Swedish landfill was 65 ppt.[33] The levels at Coventry are 378 ppt.[34]

Casella has not provided any evidence as to how the foam fractionation system would work when managing leachate that contains significantly higher concentrations of PFAS.

The use of the foam fractionation system at the Swedish landfill is documented in one research paper. Importantly, the paper is not peer-reviewed. Additionally, the authors of the research paper all have a clear conflict of interest in promoting the success of the foam fractionation treatment system. The lead author, David J. Burns, and one of the secondary authors, Peter J. C. Murphy, work for the company that manufactures and sells the treatment technology assessed in the study.[35] Another author, Helena M. Hinrichsen, works at the landfill where the technology was implemented.[36] The final author, Paul Stevenson, owns a private company that focuses on developing foam fractionation systems.[37] Clearly, the researchers all have a financial motive in presenting foam fractionation as a viable and effective method of treating landfill leachate to address PFAS. In fact, this pecuniary interest was disclosed in the research paper.[38]

The lack of unbiased data to support the use of a selected technology would be concerning in any instance, but it is especially problematic given the lack of peer-reviewed studies on the effectiveness of foam fractionation as a means of addressing PFAS in leachate.

B. The Complex Nature of Landfill Leachate May Cause Issues with the Foam Fractionation Treatment Process

Leachate is a highly variable liquid whose unpredictable composition can determine the success or failure of foam fractionation. This variability creates several additional concerns with the

[27] Brown and Caldwell, Leachate Treatment Study Plan for New England Waste Services of Vermont Landfill, Attachment A: SAFF Pilot Unit Information, Swedish Landfill Leachate, p. 12. (Revised Oct. 5, 2023).
[28] Brown and Caldwell, Leachate Treatment Study Plan for New England Waste Services of Vermont Landfill, Section 2.3: Treatment of Liquids and Residuals, p. 2-5. [Hereinafter "Leachate Treatment Study Plan."]
[29] Leachate Treatment Study Plan: Attachment A: SAFF Pilot Unit Information, Swedish Landfill Leachate, p. 12.
[30] Leachate Treatment Study Plan, Section 2.3: Treatment of Liquids and Residuals, p. 2-5.
[31] Leachate Treatment Study Plan: Attachment A: SAFF Pilot Unit Information, Swedish Landfill Leachate, p. 12.
[32] Leachate Treatment Study Plan, Section 2.3: Treatment of Liquids and Residuals, p. 2-5.
[33] Leachate Treatment Study Plan: Attachment A: SAFF Pilot Unit Information, Swedish Landfill Leachate, p. 12..
[34] Leachate Treatment Study Plan, Section 2.3: Treatment of Liquids and Residuals, p. 2-5.
[35] Burns, D. J., Hinrichsen, H. M., Stevenson, P., & Murphy, P. J. (2022). Commercial-scale remediation of per- and polyfluoroalkyl substances from a landfill leachate catchment using surface-active foam fractionation (SAFF®). Remediation Journal, 32(3), 139–150. https://doi.org/10.1002/rem.21720
[36] *Id.*
[37] *Id.*
[38] *Id.*

plan's limitations, including: the aforementioned lack of bench data and the lack of any contingency plan should the foam fractionation system fail to perform as proposed. Additionally, the Pilot Plan's current proposed sampling frequency needs to increase to adequately capture leachate's variability throughout the year.

Landfill leachate is a heterogenous makeup of organic and inorganic substances that can influence removal efficiencies.[39] With regard to removing PFAS in landfill leachate using foam fractionation, the separation process is based on the absorption of PFAS to the air-water interface of bubbles (that is, foam formation is a necessary part of the process).[40] Some PFAS, such as PFOA and PFOS, can cause foam formation, but it is dependent on numerous factors such as the concentration of PFAS, gas flow rate, pH, temperature, choice of surfactants, and the properties of the components being separated.[41] This long list of factors is concerning given that leachate properties inevitably vary.[42]

This unpredictability of success is exemplified in an Australian case study where leachate samples foamed poorly, and thus co-surfactants had to be added to make the system effective.[43] Certain waters can also require extended contact time with the reactor, adding to the cost and size of the system.[44]

**The Pilot Plan fails to lay out a contingency plan if the system or leachate at Coventry does not perform as they did in the Swedish study.** It is likely the results will not be comparable given that the leachate in the Swedish study and the leachate generated at Coventry are different and contain markedly different concentrations of PFAS and other organic and inorganic compounds. Therefore, a contingency plan is necessary. This contingency plan could include adding co-surfactants, for instance. That said, there is a lack of information regarding which surfactants work best and how effective they are.[45] The possibility of foam fractionation's ineffectiveness with Coventry's leachate underscores how important it is for the Agency to set performance levels and for Casella to provide evidence that foam fractionation is achieving those levels. Thus far, they have not provided any such evidence.

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[39] Zhang, M., Zhao, X., Zhao, D., Soong, T. Y., & Tian, S. (2023). Poly- and Perfluoroalkyl Substances (PFAS) in Landfills: Occurrence, Transformation and Treatment. *Waste management (New York, N.Y.)*, *155*, 162–178. https://doi.org/10.1016/j.wasman.2022.10.028
[40] *Id.*
[41] Morrison, A. B., Strezov, V., Niven, R. K., Taylor, M. P., Wilson, S. P., Wang, J., … & Murphy, P. (2023). Impact of salinity and temperature on removal of pfas species from water by aeration in the absence of additional surfactants: a novel application of green chemistry using adsorptive bubble fractionation. Industrial &Amp; Engineering Chemistry Research, 62(13), 5635-5645. https://doi.org/10.1021/acs.iecr.3c00150
[42] Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and long-term composition of msw landfill leachate: a review. Critical Reviews in Environmental Science and Technology, 32(4), 297-336. https://doi.org/10.1080/10643380290813462
[43] Buckley, T.; Karanam, K.; Han, H.; Vo, H. N. P.; Shukla, P.; Firouzi, M.; Rudolph, V. Effect of Different Co-Foaming Agents on PFAS Removal from the Environment by Foam Fractionation. Water Res. 2023, 230, 119532. https://doi.org/10.1016/j.watres.2022.119532
[44] *Id.*
[45] Vo, P. H. N., Buckley, T., Xu, X., Nguyen, T. M., Rudolph, V., & Shukla, P., Foam fractionation of Per- and Polyfluoroalkyl Substances (PFAS) in Landfill Leachate using Different Cosurfactants. Chemosphere, 310, 136869., (2023), https://doi.org/10.1016/j.chemosphere.2022.136869

C. Foam Fractionation as a Stand-Alone Treatment is Inadequate as it Fails to Remove Toxic Short-Chain PFAS and Precursors

Existing evidence around the limitations of foam fractionation also presents two glaring environmental and public health concerns. **First, foam fractionation does not capture short-chain PFAS, including those with proven toxicology. Second, foam fractionation barely captures PFAS precursors, which are likely to convert into regulated PFAS when processed through WWTPs.** These limitations warrant implementing an add-on treatment system, bio-pretreatment and reverse osmosis, as detailed below in Section V.

*i. Foam Fractionation Does Not Remove Short-Chain PFAS*

**Foam fractionation does not remove short-chain PFAS, some of which have been shown to be highly mobile, toxic, and dominant in wastewater.[46] The** dangers of certain short-chain PFAS are increasingly documented.[47] One study in the Chemical Engineering Journal found that short-chain PFAS compounds are "more widely detected, more persistent and mobile in aquatic systems, and thus may pose more risks on the human and ecosystem health" than long-chain compounds.[48]

While much research remains, two short-chain PFAS in particular have already been identified as toxic, perfluorobutanoic acid ("PFBA") and perfluorobutanesulfonic acid ("PFBS").[49] Both PFBS and PFBA are candidates for future USEPA regulation.[50] Both compounds are replacements for PFAS compounds that were phased out by manufacturers facing mounting scrutiny and regulation.[51] In the EPA's most recent Toxicological Review of PFBA they

[46] Runwei, L., MacDonald Gibson, J., Predicting the Occurrence of Short-Chain PFAS in Groundwater using Machine-learned Bayesian Networks, Frontiers. (Nov. 3, 2022). https://www.frontiersin.org/articles/10.3389/fenvs.2022.958784/full; Gobelius L, Glimstedt L, Olsson J, Wiberg K, Ahrens L. Mass Flow of Per- and Polyfluoroalkyl substances (PFAS) in a Swedish Municipal Wastewater Network and Wastewater Treatment Plant, Chemosphere. (Sep. 2023). https://pubmed.ncbi.nlm.nih.gov/37302497/

[47] Environmental Working Group, Study: Newer PFAS Chemicals 'May Pose More Risks' Than Those They Replaced. (Aug. 22, 2019). https://www.ewg.org/news-insights/news-release/study-newer-pfas-chemicals-may-pose-more-risks-those-they-replaced

[48] Li, F., Duan, J., Tian, S., Ji, H., Zhu, Y., Wei, Z., Zhao, D., Short-chain Per- and Polyfluoraklyl Substances in Aquatic Systems: Occurrence, Impacts and Treatment, Chemical Engineering Journal, Vol. 380, 122506. (Jan. 15, 2020). https://www.sciencedirect.com/science/article/abs/pii/S1385894719319096

[49] Chen, F., Wei, C., Chen, Q., Zhang, J., Wang, L., Zhou, Z.; Chen, M., Liang, Y., Internal Concentrations of Perfluorobutane Sulfonate (PFBS) Comparable to Those of Perfluorooctane Sulfonate (PFOS) Induce Reproductive Toxicity in Caenorhabditis Elegans. *Ecotoxicol. Environ. Saf.* **2018**, *158*, 223–229. https://doi.org/10.1016/j.ecoenv.2018.04.032; Gomis, M. I., Vestergren, R., Borg, D., Cousins, I. T, Comparing the Toxic Potency in Vivo of Long-Chain Perfluoroalkyl Acids and Fluorinated Alternatives. *Environ. Int.* **2018**, *113*, 1–9. https://doi.org/10.1016/j.envint.2018.01.011

[50] Desharnais, K., Fracassi, T., Ross, D., Guc, M., USEPA Advances Toward Regulation of PFAS in Drinking Water, Environmental Law and Policy Monitor. (Feb. 25, 2021). https://www.environmentallawandpolicy.com/2021/02/usepa-advances-toward-regulation-of-pfas-in-drinking-water/, "These are the PFAS compounds for which we are likely to next see regulatory action at the federal level."

[51] Environmental Working Group, The New Generation of 'Forever Chemicals' – Toxicity, Exposure, Contamination and Regulation. (May, 2021). https://www.ewg.org/news-insights/news/new-generation-forever-chemicals-toxicity-exposure-contamination-and-regulation

concluded, "the available evidence indicates that developmental, thyroid, and liver effects in humans are likely caused by PFBA exposure in utero or during adulthood."[52] PFBS health outcomes include developmental delays, effects on female reproductive organs, cellular changes to kidneys, effects on the liver and lipids, and most dramatically, effects on the thyroid.[53]

Based on evidence of human toxicity, the EPA has included PFBS in its proposed PFAS National Primary Drinking Water Regulation, which they anticipate finalizing by the end of 2023, and which they have predicted "will prevent thousands of deaths and reduce tens of thousands of serious PFAS-attributable illnesses."[54] In short, the data and regulatory tide are clear: PFBS and PFBA, two short-chain PFAS compounds, are toxic and will, in the near future, be federally regulated. Critically, neither of these compounds are captured by foam fractionation despite being abundant in Coventry's leachate.

In the Brown and Caldwell Scoping Study, both PFBA and PFBS were identified in the untreated landfill leachate at Coventry.[55] In fact, PFBA had the highest concentration of all PFAS compounds identified in that raw leachate.[56] This is typical of landfill leachate. In a study of PFAS in leachate of 22 landfills in Germany, the dominating compounds in the untreated leachate were PFBA and PFBS.[57] In the Montpelier WWTP – where both the pretreated and untreated Coventry landfill leachate will go – as is the case with all WWTPs, short chain PFAS dominate the influent and effluent.[58] Foam fractionation is ineffective at capturing short-chain PFAS, and specifically does not capture PFBA and PFBS.[59] In a study examining leachate treatment in Florida at an active municipal solid waste landfill, foam fractionation could not effectively remove PFBA or PFBS at the pilot scale.[60] This limitation was also acknowledged by

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[52] U.S. Environmental Protection Agency, IRIS Toxicological Review of Perfluorobutanoic Acid (PFBA, CASRN 375-22-4) and Related Salts. (Dec. 2022). https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0701tr.pdf

[53] U.S. Environmental Protection Agency, Technical Fact Sheet: Toxicity Assessment for PFBS. (April, 2021). https://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=542401

[54] U.S. EPA, PFAS: PFOA and PFIS National Primary Drinking Water Regulation Rulemaking, Docket ID: EPA-HQ-OW-2022-0114. (Mar. 14, 2023). https://www.regulations.gov/docket/EPA-HQ-OW-2022-0114/unified-agenda

[55] Leachate Treatment Scoping Study, Attachment A, Estimated Raw Leachate Loads, p. 3. (Oct. 11, 2019).

[56] *Id.*

[57] Busch, J., Ahrens, L., Sturm, R., Ebinghaus, R., Polyfluoroalkyl Compounds in Landfill Leachates. Environ Pollution. (May, 2010). https://pubmed.ncbi.nlm.nih.gov/20053490/#:~:text=The%20dominating%20compounds%20in%20untreated,(PFBS)%20(24%25).

[58] Weston & Sampson, Poly-and Perfluoroalkyl Substances at Wastewater Treatment Facilities and Landfill Leachate, 2019 Summary Report. https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/02.03.20_PFAS%20in%20LF%20and%20WWTF%20Final%20Report.pdf

[59] Robey, N. M., da Silva, B. F., Annable, M. D., Townsend, T. G., Bowden, J. A., Concentrating Per- and Polyfluoroalkyl Substances (PFAS) in Municipal Solid Waste Landfill Leachate Using Foam Separation. Environ. Sci. Technol. 2020, 54 (19), 12550–12559. (Aug. 31, 2020). https://doi.org/10.1021/acs.est.0c01266

[60] Smith, S. J., Wiberg, K., McCleaf, P., Ahrens, L. Pilot-Scale Continuous Foam Fractionation for the Removal of Per- and Polyfluoroalkyl Substances (PFAS) from Landfill Leachate. ACS EST Water, *2* (5), 841–851. (May 4, 2022) https://doi.org/10.1021/acsestwater.2c00032

SAFF® (the specific foam fractionation technology proposed in the Pilot Plan) when discussing the technology's use at commercial scale.[61]

Installing a system that cannot remove these short-chain compounds is shortsighted and a shirking of the Agency's duty to protect the environment and public health. Practically speaking, it may very well result in a huge investment in a system that will be unable to comply with federal regulation in the very near future. A treatment train that would address these compounds, in addition to the five PFAS compounds currently regulated in Vermont, is described in Section VI.

*ii. Foam Fractionation Does Not Address PFAS Precursors That Are in the Target Leachate*

**An equally alarming defect in the Pilot Plan is that foam fractionation is unlikely to capture PFAS precursors.[62]** This is particularly problematic given that such precursors can form regulated PFAS through processing at the Montpelier WWTP, thereby undermining this entire effort to extract even the currently regulated list of five PFAS compounds from Coventry's leachate.

Landfill leachate contributes high concentrations of precursors to WWTPs.[63] The leachate transmits these PFAS precursors to WWTPs, at which point the precursors convert to identifiable PFAS, including those currently regulated in Vermont. A study commissioned by the Vermont Department of Environmental Conservation found that "Total Oxidizable Precursors Assay ("TOPA") data" indicates that "precursors may be the predominant source of PFAS in wastewater."[64] This is alarming because precursors are likely to convert into regulated PFAS during their processing at the receiving WWTP.

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[61] Yang Y., Holsen., T, Review of Leachate Treatment Study Plan for New England Waste Services (NEWSVT) Landfill As Required by Condition I.A.5 of the State of Vermont Agency of Natural Resources Department of Environmental Conservation Watershed Management Division Pretreatment Discharge Permit 301406, 4. (Dec. 7, 2023). Available in Attachment A to this Comment. [*Hereinafter*, "Expert Report, Attachment A".]

[62] PFAS precursors are compounds that include fluorotelomers and perfluorinated sulfonamides which can interact and form identifiable PFAS compounds that include can include the five PFAS compounds regulated in Vermont.

[63] Bolan, N., Sarkar, B., Yan, Y., Li, Q., Wijesekara, H., Kannan, K., Tsang, D. C. W., Schauerte, M., Bosch, J., Noll, H., Ok, Y. S., Scheckel, K., Kumpiene, J., Gobindlal, K., Kah, M., Sperry, J., Kirkham, M. B., Wang, H., Tsang, Y. F., … Rinklebe, J. (2021). Remediation of Poly- and perfluoroalkyl substances (PFAS) Contaminated Soils – to Mobilize or to Immobilize or to Degrade? Journal of Hazardous Materials, 401, 123892. https://doi.org/10.1016/j.jhazmat.2020.123892; Liu, Y., Robey, N. M., Bowden, J. A., Tolaymat, T. M., da Silva, B. F., Solo-Gabriele, H. M., & Townsend, T. G. (2020). From waste collection vehicles to landfills: Indication of per- and polyfluoroalkyl substance (PFAS) transformation. Environmental Science & Technology Letters, 8(1), 66–72. https://doi.org/10.1021/acs.estlett.0c00819

[64] Weston & Sampson, Summary Report for the Vermont Department of Environmental Protection: Poly-and Perfluoroalkyl Substances Inputs to Wastewater Treatment Facilities, Section 1, p. 1-1. (Mar. 26, 2022). Available at, https://dec.vermont.gov/sites/dec/files/wmp/residual/2021%20VTDEC%20PFAS%20Inputs%20to%20WWTF%20Study.2022March29.pdf

**It is now well established that WWTPs convert unidentified precursors in the influent into identified PFAS in their effluent, including those currently regulated in Vermont.**[65] In a recent study of three WWTPs, PFHxA, PFOA, PFHxS, and PFOS had net mass *increases* in the effluent by on average 83%, 28%, 37%, and 58%, respectively.[66] PFOA, PFOS, and PFHxS are currently regulated in Vermont. If precursors are not accounted for and adequately removed during the leachate pretreatment process, the leachate will likely continue to burden the receiving WWTP with influent that will become effluent containing currently regulated PFAS compounds — and in so doing they would continue to pollute the Winooski River and thereby harm Vermonters and Vermont's natural resources.

**Foam Fractionation is unlikely to adequately remove precursors.**[67] At best it would remove 10-40% of precursors, based on a study conducted in Sweden in 2021.[68] Moreover, as it currently stands, Casella has not provided the results of their non-targeted TOPA results, and has stated that they will not be conducting more TOPA testing[69] throughout their pilot despite the known variability of leachate.[70] Their postponement of providing such data is very concerning, as is their lack of intent to continue to test the leachate for precursors, both before and after treatment. Just as they failed to provide any bench data, they also failed to demonstrate what precursors were found with TOPA testing and are clear that they will not be doing further testing of precursors in their pilot. This is all the more troubling when coupled with the fact that they propose to use a stand-alone foam fractionation system that will not extract the precursors.

At a minimum, Casella must conduct TOPA testing throughout the duration of the Pilot Plan. TOPA testing should focus on identifying the specific compounds produced by the TOPA oxidation process. Additionally, as discussed in Section V, the Agency should require the adoption of Reverse Osmosis as an add-on treatment given that it has been shown to target precursors as well as long-chain and short-chain PFAS. Importantly, the TOPA testing should be conducted both before and after the Reverse Osmosis treatment.

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[65] *See* Expert Report, Attachment A, at 2, citing Phong Vo, H. N., Ngo, H. H., Guo, W., Hong Nguyen, T. M., Li, J., Liang, H., Deng, L., Chen, Z., Hang Nguyen, T. A. Poly-and Perfluoroalkyl Substances in Water and Wastewater: A Comprehensive Review from Sources to Remediation. J. Water Process Eng., 36, 101393. (Aug. 2020) https://doi.org/10.1016/j.jwpe.2020.101393

[66] Eriksson, U., Haglund, P., Kärrman, A. Contribution of Precursor Compounds to the Release of Per- and Polyfluoroalkyl Substances (PFASs) from Wastewater Treatment Plants (WWTPs). J. Environ. Sci. 61, 80–90. (2017) https://doi.org/10.1016/j.jes.2017.05.004

[67] McCleaf, P.; Kjellgren, Y.; Ahrens, L. Foam Fractionation Removal of Multiple Per- and Polyfluoroalkyl Substances from Landfill Leachate. AWWA Water Sci., 3 (5), e1238. (Sept. 2021) https://doi.org/10.1002/aws2.1238

[68] *Id.*

[69] TOPA is a method used to quantitatively characterize how many unknown precursors there are in fluid or water. Running such an analysis would enable the permit applicant to determine if precursors are present in the leachate, and if so, if they are being caught by the treatment system proposed in our comment and in the Expert Report, Attachment A.

[70] *See* New England Waste Services, Inc. Letter to Ms. Amy L. Polaczyk, Pretreatment Permit #3-1406, Response to Preliminary Comments, July 20, 2023, 4., (Oct. 5, 2023), "TOP Assay Results were previously collected during the Bench Scale study and will be provided in the final report. NEWS is not planning to collect additional samples for TOP assay testing during the pilot study." Available at: 21339-NEWS response cover to ANR July 20 preliminary rfmi.pdf (vt.gov)

D. The Proposed Residual Management Plan is Unproven and Likely to Result in Leaching PFAS back into the Landfill.

Foam fractionation results in a residual waste called foamate. This foamate will contain significantly elevated concentrations of PFAS. How these materials are managed is imperative to minimize the risk of cycling and the release of PFAS into the environment. The Pilot Plan proposes to "solidify" foamate by mixing it with Portland cement or "similar" compounds.[71] The subsequent mixture will then be landfilled.[72] Casella argues that this residual management plan is sufficient to "minimize potential cycling."[73] However, Casella has not provided any evidence to support the conclusion that the proposed residual management plan will effectively sequester PFAS. In fact, there is significant data suggesting that PFAS will in fact leach out, increasing the risk of environmental contamination and the likelihood of increased PFAS levels in the leachate moving forward.

**The use of Portland cement or a similar compound to encapsulate the PFAS in foam fractionate to minimize potential recycling is an unproven technology with no supporting publications or reports that demonstrate that this method would be successful.[74]** Currently, there is no official EPA guidance for the disposal of PFAS in foamate. We could not find a single publication citing data on using PFAS-laden foam fractionation liquid in a Portland cement mix. The single publication on the use of cement to solidify PFAS showed that leaching of long-chain PFAS decreased while the leaching of short-chain PFAS actually increased.[75]

Conversely, there are numerous publications for comparable classes of compounds that cast serious doubt on the solidification proposal's efficacy. One report found that "PAHs (polycyclic aromatic hydrocarbons) leach to a relatively high extent" after solidification, and another showed that concentrations for adsorbable organic halogens ("AOX") in pulp and paper were above regulatory levels after being solidified in cement.[76] Because most PFAS are AOX (halogenated substances that are adsorbed from water onto activated carbon), it is logical to extrapolate that the proposed Portland cement (or similar) mixture will fail to contain the PFAS and these toxic chemicals will leach back into the landfill. [77] Such leaching would see PFAS reenter the leachate stream and pose higher risk of environmental contamination.[78] Alarmingly, the Pilot Plan also

[71] Leachate Treatment Pilot Plan, Section 2.4: Liquids and Residuals Management, p. 2-5.
[72] *Id.*
[73] *Id.*
[74] Expert Report, Attachment A, p. 5.
[75] *Id.*, citing Bierbaum, T., Klaas, N., Braun, J.; Nürenberg, G., Lange, F. T., Haslauer, C., Immobilization of Per- and Polyfluoroalkyl Substances (PFAS): Comparison of Leaching Behavior by Three Different Leaching Tests. *Sci. Total Environ.*, *876*, 162588. (2023). https://doi.org/10.1016/j.scitotenv.2023.162588
[76] .*Id.,* citing Mulder, E., Brouwer, J. P.;, Blaakmeer, J., Frénay, J. W. Immobilisation of PAH in Waste Materials. *Waste Manag*, *21* (3), 247–253. (2001). https://doi.org/10.1016/S0956-053X(00)00097-0. and Yilmaz, O., Ünlü, K., Cokca, E. Solidification/Stabilization of Hazardous Wastes Containing Metals and Organic Contaminants. *J. Environ. Eng.*, *129* (4), 366–376. (2003) https://doi.org/10.1061/(ASCE)0733-9372(2003)129:4(366)
[77] Expert Report, Attachment A, p. 5.
[78] *Id.*

cites there will be "spent cartridge filter that may contain elevated concentrations of PFAS" but does not explain how these filters will be managed.[79]

**A safer and more effective residual management methodology for foamate is electrochemical oxidation ("EO") and plasma discharge ("plasma").** Additionally, these residual management methodologies are also effective at addressing the residual waste from our suggested treatment chain as described in Section V. Electrochemical oxidation, an advanced oxidation process, is an efficient method for destroying PFAS in water, resulting in degradation of both long- and short-chain PFAS.[80] Plasma-based treatment uses electrical discharge plasma to convert water into a mixture of highly reactive species, which rapidly and non-selectively degrade a broad spectrum of PFAS.[81]

Estimates for how much foamate EO and plasma would be treating, if adopted as residual management technologies, are provided in the attached Expert Report. Both EO and plasma are commercially viable options for residuals management that would limit the potential of leachate recycling back into the leachate stream and exposing communities and the environment to undue risk.[82] The Agency should require a residuals management plan that will actually accomplish this goal. Additionally, the Agency should require Casella to explain how they intend to manage the spent cartridge filters they reference in the Pilot Project.

E. Casella Has Failed to Adequately Address the Concerns Over Air Emissions Associated with the Selected Treatment System.

**Air emissions containing various toxics, including PFAS, semi-volatile organic compounds ("SVOCs") and volatile organic compounds ("VOCs"), from the proposed foam fractionation system are anticipable and should be tested for.** Air supply for the foam fractionation treatment unit will be pulled in from outside air and then exhausted to ambient air after passing through a vapor phase granular activated carbon ("GAC") unit to remove potential residual VOCs and odor compounds including hydrogen sulfide.[83] While the inclusion of the GAC system is a welcome addition, more monitoring is necessary to fully understand the air emission risks associated with this treatment technology. This is especially true given that one of the underlying goals of the Pilot Plan is to determine whether the chosen treatment system should be scaled up to manage all leachate. A key parameter in understanding whether the technology warrants scaling is the associated air emissions.

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[79] Leachate Treatment Pilot Plan, Section 2.4: Liquids and Residuals Management, p. 2-5.

[80] Smith S. J., Lauria, M., Ahrens, L., McCleaf, P., Hollman, P., Seroka, S. B., Hamers, T., Arp, H. P., Wiberg, K., Electrochemical Oxidation for Treatment of PFAS in Contaminated Water and Fractionated Foam—A Pilot-Scale Study, ACS EST Water. (Mar., 2023) https://doi.org/10.1021/acsestwater.2c00660

[81] Sunka, P., Babický, V., Clupek, M., Lukes, P., Simek, M., Schmidt, J., and Cernak, M., . Generation of Chemically Active Species by Electrical Discharges in Water. Plasma Sources Science and Technology, 8(2), pp. 258-265. (1999) https://doi.org/10.1088/0963-0252/8/2/006; Singh, R.K., Multari, N., Nau-Hix, C., Anderson, R.H., Richardson, S.D., Holsen, T.M. and Mededovic Thagard, S.,. Rapid Removal of Poly- and Perfluorinated Compounds from Investigation-Derived Waste (IDW) in a Pilot-Scale Plasma Reactor. Environmental Science and Technology, 53(19), pp.11375-11382, (2019) https://doi.org/10.1021/acs.est.9b02964

[82] *Id.*

[83] Leachate Treatment Study Plan, Section 2.11.1: Air Emissions, p. 2-9.

Determining if any PFAS, SVOCs or VOCs will be discharged through the stack gas after carbon absorption during the pilot system's continued operation is critical to protecting Vermont's environment and nearby communities. Research has shown elevated airborne PFAS concentrations from foam fractionation that "have implications for worker safety and prevention of PFAS-emissions to the atmosphere."[84] While stack emissions testing methodology is still being finalized, conducting such testing would nonetheless provide valuable data on the project's PFAS air emissions. The recommended methodology here is Other Test Method 45, (OTM-45) Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources. Additionally, "there are relatively simple and proven air sampling techniques that should be employed" to test for PFAS.[85] These techniques are described in Expert Report, Attachment A, page 4, and include: collecting air samples using high-volume air samplers, and simple wipe tests.[86] These latter methods are cost-effective and still add safeguards while also helping identify the air emissions associated with the proposed treatment system.

Unfortunately, leachate contains various other potentially harmful SVOCs and VOCs that are likely to be removed by the foam fractionation process and born into the atmosphere though the off-gas. "A global survey of the VOCs and SVOCs in leachate from 103 landfill sites combined with 27 published manuscripts on leachate treatment showed that polycyclic aromatic hydrocarbons ("PAHs"), phthalate acid esters ("PAEs"), and phenols were the most frequently detected SVOCs in leachate."[87] Alarmingly, four VOCs (toluene, ethylbenzene, xylenes, and benzene) in particular were commonly detected at high concentrations.[88] All of these compounds would likely be removed from the leachate during foam fractionation and could end up in the gas phase, potentially leaving the system, and posing an environmental and public health threat necessitating monitoring. Recommended monitoring methods include EPA Methods TO-4A and TO 13A for SVOCs and TO-14, TO-15 or TO-17 for VOCs.[89] The above testing is the necessary route for the Agency to take—or have Casella take—in carrying out the Agency's mission of protecting natural resources and human health.

## V. Recommended Treatment Chain

Based on extensive research by both our in-house and contracted experts, we recommend a leachate treatment system that would drastically reduce the current list of five regulated PFAS compounds, as well as both toxic short-chain PFAS, and precursors that will likely convert into regulated PFAS compounds upon processing at a WWTP. Specifically, these additional treatment

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[84] Smith, S. J., Lewis, J., Wiberg, K., Wall, E., & Ahrens, L., Foam fractionation for removal of per and polyfluoroalkyl substances: Towards closing the mass balance. Science of The Total Environment, 871, 162050. (2023) https://doi.org/10.1016/j.scitotenv.2023.162050

[85] Expert Report, Attachment A, p. 4.

[86] *Id.*, citing, Barber, J. L., Berger, U., Chaemfa, C., Huber, S., Jahnke, A., Temme, C., Jones, K. C. Analysis of Per- and Polyfluorinated Alkyl Substances in Air Samples from Northwest Europe. *J. Environ. Monit.* **2007**, *9* (6), 530–541, (2007) https://doi.org/10.1039/B701417A and Young, A. S., Sparer-Fine, E. H., Pickard, H. M., Sunderland, E. M.; Peaslee, G. F.; Allen, J. G. Per- and Polyfluoroalkyl Substances (PFAS) and Total Fluorine in Fire Station Dust. *J. Expo. Sci. Environ. Epidemiol.*, *31* (5), 930–942, (2021) https://doi.org/10.1038/s41370-021-00288-7.

[87] Expert Report, Attachment A, p. 4.

[88] He, X-s., Pan, Q., Xi, B-D., Zheng, J., Liu, Q-Y., Sun, Y., Volatile and semi-volatile organic compounds in landfill leachate: Concurrence, removal and the influencing factors. Water Research 245 (2023) 120566

[89] *Id.*

technologies should be composed of both biological pretreatment ("bio-pretreatment") and reverse osmosis ("RO").[90] **A combination of bio-pretreatment and RO alongside the existing foam fractionation system would provide a safer and more established and reliable form of treatment than a standalone foam fractionation system.**

Given that the foam fractionation system is already in operation, adding bio-pretreatment and RO would serve as a critical upgrade to the system, without the need to tear down the operational foam fractionation system. Bio-pretreatment enhances the performance of RO as it breaks down organics to lessen the chance of the membrane in the RO system fouling and improves the overall performance of the RO membrane system.[91] A membrane bioreactor will ensure that the RO unit described next functions to the best of its ability.

RO is a well proven process to remove PFAS of all chain lengths from raw leachate, including the five compounds currently regulated in Vermont.[92] RO has also been shown to effectively remove precursors.[93] Unlike foam fractionation, whose shortcomings and lack of evidence we have outlined above, RO has been an established methodology for separating PFAS from landfill leachate for over two decades. Guiding details for the recommended treatment are laid out in the Expert Report, attached. Notably, in the Scoping Study conducted by Brown and Caldwell which initiated this entire pilot project, the authors concluded that RO was the best available technology for effectively removing targeted PFAS down or even "below health advisory levels for drinking water.[94]

RO results in a concentrated stream that would contain a high concentration of PFAS, known as "RO concentrate." The recommended treatment to destroy PFAS in such concentrate is EO and plasma.[95] As discussed in Section VI, these are the same residuals management methods recommended for the foamate produced by the foam fractionation system. The attached Expert Report provides a more detailed account for designing of both the EO and plasma treatment systems that are capable and necessary to addressing the residuals of both the proposed foam fractionation system, as well as the recommended RO system.[96]

## VI. Conclusion

We strongly support the Agency's work to develop a treatment system and subsequent regulations to address the presence of toxic PFAS compounds in landfill leachate. Moreover, we believe that a robust, and well-designed and monitored pilot project is an important step in this process. However, as currently drafted both the Pretreatment Permit and the Pilot Plan are

[90] Expert Report, Attachment A, p. 5-6.
[91] Expert Report, Attachment A, p. 5; Hu, J. Y., Song, L. F., Phua, E. T., Ng, J. W., Biofiltration Pretreatment for Reverse Osmosis (RO) Membrane in a Water Reclamation System, Chemosphere. (Mar. 2005). https://pubmed.ncbi.nlm.nih.gov/15698653/
[92] Chianese, A.; Ranauro, R., Verdone, N. Treatment of Landfill Leachate by Reverse Osmosis, *Water Res.*, *33* (3), 647–652. (1999) https://doi.org/10.1016/S0043-1354(98)00240-1
[93] Glover, C. M., Quiñones, O., Dickenson, E. R. V., Removal of Perfluoroalkyl and Polyfluoroalkyl Substances in Potable Reuse Systems. Water Res., *144*, 454–461. (2018) https://doi.org/10.1016/j.watres.2018.07.018
[94] Leachate Treatment Scoping Study, Executive Summary, p. ES-3.
[95] Expert Report, Attachment A, p. 6.
[96] Expert Report, Attachment A, p. 7-9.

insufficient. We strongly urge the Agency to adopt the recommendations contained in these comments.

Respectfully submitted,

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Just Zero

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Staff Attorney
Conservation Law Foundation

**Attachment A:**

**Yang Y., Holsen., T, Review of Leachate Treatment Study Plan for New England Waste Service Landfill as Required by Condition I.A.5 of the State of Vermont Agency of Natural Resources Department of Environmental Conservation Watershed Management Division Pretreatment Discharge Permit 3-1406 (Dec. 7, 2023)**

**Review of "Leachate Treatment Study Plan for New England Waste Services (NEWSVT) Landfill As Required by Condition I.A.5 of the State of Vermont Agency of Natural Resources Department of Environmental Conservation Watershed Management Division Pretreatment Discharge Permit 3-1406. Revised December 7, 2023 Project Number: 157518"**

Yang Yang, Ph.D.; Thomas Holsen, Ph.D.

**1. Synopsis of Treatment Process.**

This synopsis summarizes key information related to PFAS monitoring and treatment from the document (denoted as "**study plan**" in the following content). In the study plan, the proposed foam fractionation (FF) treatment system will treat leachate from the existing NEWSVT leachate storage tanks. Raw leachate will be pumped from the onsite leachate storage tanks to the treatment system, and treated leachate will be returned to the storage tanks prior to disposal. The expected system capacity for treatment is up to 75,000 gpd. The anticipated PFAS concentration in leachate is listed below.

| Parameter | Units | Average Concentrations |
|---|---|---|
| Perfluoroheptanoic acid (PFHpA) | ng/L | 710 |
| Perfluorohexane sulfonic acid (PFHxS) | ng/L | 378 |
| Perfluorononanoic acid (PFNA) | ng/L | 863 |
| Perfluorooctanesulfonic acid (PFOS) | ng/L | 214 |
| Perfluorooctanoic acid (PFOA) | ng/L | 1,711 |

*ng/L = nanograms/liter*

Exhaust gas will pass through a granular activated carbon (GAC) unit. PFAS in exhaust gas will not be monitored. Foamate will be solidified by Portland cement and then returned to landfill. Testing of leaching of PFAS from the cement was not planned.

In general, we agree that FF is a plausible component of PFAS treatment. The following content provides concerns about the feasibility, safeguards, and efficacy of the current plan and technical recommendations for the removal and destruction of PFAS beyond those listed in the VT5.

**2. Concerns about incomplete coverage of PFAS and inadequate removal of precursors**

EPA Method 1633 is a cornerstone for the environmental surveillance study of PFAS. All the listed PFAS that can be quantified by this method have the potential to be regulated in the future upon further investigation of toxicity and risk assessment. The EPA Method 1633 covers 40 PFAS; $C_{n=3\text{-}9}$ perfluorinated carboxylates (n refers to the number of fluorocarbons), $C_4$-$C_{10}$ perfluorinated sulfonates, fluorotelomers (4:2, 6:2, and 8:2), and precursors have been detected in leachate.[1,2] The concentrations of these dominant compounds range from 10-$10^4$ ng/L in the USA. Notably, short-chain PFAS ($C_{n=3\text{-}7}$) have concentrations commensurate with perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS).[3,4]

As will be discussed below, the FF method is inefficient in removing short-chain PFAS as well as precursors that can be converted into the VT5 during wastewater treatment plant (WWTP) processing. Thus, we conclude that the scope of work on monitoring VT5 in the pilot-scale study is concerningly limited as the number of regulated PFAS compounds continues to increase at federal and state levels, and the failure to ensure extraction of precursors could undermine the entire stated goal of the system—providing WWTPs with leachate free of the VT5. Increasing regulation of PFAS should be anticipated for and used to evaluate this system. In addition, the non-targeted total oxidizable precursors assay (TOPA) should be included, and the specific compounds produced by the TOPA oxidation process should be determined. TOPA is a method used to quantitatively characterize how many unknown precursors there are in fluid or water. Running such an analysis would enable the permit applicant to determine if precursors are present in the leachate, and if so, if they are being caught by the expanded treatment system proposed below.

It is well known that WWTPs convert unidentified precursors into identified PFAS, including those on the VT5 list.[5] For example, in a recent study of three WWTPs, perfluorohexanoic acid (PFHxA), PFOA, perfluorohexanesulfonic acid (PFHxS), and perfluorooctane sulfonic acid (PFOS) had a net mass increases in the effluent of on average 83%, 28%, 37%, and 58%, respectively.[6] If unidentified precursors are not removed, the release of treated water to the WWTP and the conversion of those compounds into regulated PFAS in the WWTP could cause the release of those compounds in the WWTP effluent. The proper route to avoid this potential violation and public health hazard is to employ the TOPA method to figure out if precursors are present in the leachate, and if they are being removed by the reverse osmosis system proposed below; notably, foam fractionation alone would likely not remove such precursors.[7]. However, there is evidence that reverse osmosis also removes precursors.[8] The necessity to remove precursors is further reason to expand the treatment system from foam fractionation alone, to the reverse osmosis system outlined below.

In addition to the inadequate coverage of target PFAS, the treatment end goals for removing the VT5 are unclear. There are no success criteria established for this study. What effluent concentrations, treatment capacity, treatment costs, and reliability must be met for the FF process to be considered acceptable? Specifically for effluent concentrations, the values in the water treatment plant (WWTP) permit for effluent testing of target MDL for PFHxS, PFHpA, PFNA, PFOS, and PFOA of no greater than 20 ng/L would be appropriate to align with Vermont's drinking water standards.

**3. Concerns about FF performance**

The study plan demonstrated the performance of FF by showing the efficacy of treating Swedish landfill leachate. Although there is a mention that there was a bench study, notably, no data or findings from that study are included. The lack of bench data is concerning because several of the PFAS are present at concentrations that are near an order of magnitude higher than found in the Swedish study. The Australian feed water had higher concentrations, so it's more of an analog, but it still underscores the importance of bench-scale proof of concept testing. More difficult waters may require more reactor contact time, which increases the size and cost of the system. For example, a case study in Australia showed that the leachate samples had poor foamability. The FF was only functional when co-foaming surfactants were added. [9] There is no such contingency plan laid out in the Pilot plan, despite the possibility that the leachate may not foam as expected. As of now, there is no proof that the SAFF FF system used in the Swedish study works on the leachate generated at Coventry, either at the bench scale or at a larger scale. Such evidence should be provided before the study plan is approved.

It is well known that leachate characteristics vary throughout the year. This is acknowledged in Section 1.2, where it is stated that "the treatment system will be operated under a variety of conditions to evaluate its response to temporal variations in leachate quality and key operational parameters." However, the current sampling frequency proposed is insufficient to ensure that the effect of the variability in leachate quality throughout the year on removal rates is properly evaluated. Moreover, as mentioned above, no contingency plan was provided in case the leachate has no or less-than-ideal foaming potential. Such a contingency plan could include, but not be limited to, adding co-foaming surfactants.

Notably, even if the FF functions as the applicant proposes it will, the performance of removing PFAS beyond VT5 is limited. The treatment of leachate collected from a 20-year-old cell of an active MSW landfill in central Florida shows that FF has poor performance (<50% removal) on removing $C_{n<6}$-PFSAs and $C_{n<5}$ PFCAs.[10] Importantly, this bench-scale study in Florida shows that FF could not remove PFBA, [10] which is a candidate PFAS to be regulated by USEPA. The poor or lack of removal of PFBA and

PFBS was reported at the pilot scale.[11] This limitation was also acknowledged by SAFF® (technology to be adopted in the pilot plan) at commercial scales.[12] Both PFBA and PFBS have been shown to have toxicology concerns,[13,14] and have been shown to persist after FF treatment; the public health risks of these chemicals persisting after the FF treatment is further justification to use an expanded treatment system, composed of bio-pretreatment and reverse osmosis, as discussed in Section 6.

Given the lack of any bench or larger-scale data and the variability of leachate throughout the year, we conclude that the SAFF FF process performance on the removal of VT5 in the NEWSVT leachate is yet to be determined. The FF process is incapable of removing short-chain PFAS not included in VT5. It is a missed opportunity for the study plan not to address these candidate PFAS that are facing scrutiny and possible regulation in the near future due to emerging toxicology findings, in addition to non-targeted compounds, as discussed above.

**4. Concerns about air emission**

Although stack emissions testing techniques are still under development (Other Test Method 45 (OTM-45) Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources), using this approach would add valuable data to the project. Determining if any PFAS will be discharged through the stack gas after carbon absorption is an open question that should be evaluated. In addition, there are relatively simple and proven air sampling techniques that should be employed. For example, air samples can be collected using high-volume air samplers employing sampling modules containing glass-fiber filters (GFFs) and glass columns with a polyurethane foam (PUF)–XAD-2–PUF sandwich.[15] These could be employed in the vicinity of the off gas to determine if PFAS are being emitted from the system. In addition, simple wipe tests of surfaces exposed to the off-gases would be a useful and inexpensive way to determine if PFAS are leaving the system.[16]

There are numerous other potentially harmful semi-volatile organic compounds (SVOCs) and volatile organic compounds (VOCs) found in leachate that are likely to be removed by the foam fractionation process and be in the off-gas. A global survey of the VOCs and SVOCs in leachate from 103 landfill sites combined with 27 published manuscripts on leachate treatment showed that polycyclic aromatic hydrocarbons (PAHs), phthalate acid esters (PAEs), and phenols were the most frequently detected SVOCs in leachate. In addition, four VOCs (toluene, ethylbenzene, xylenes, and benzene) were frequently detected at high concentrations.[17] All of these compounds would likely be removed from the leachate during foam fractionation and could end up in the gas phase, potentially leaving the system. All could potentially pose a threat and should be monitored. Appropriate methods include EPA Methods TO-4A and TO 13A for SVOCs and TO-14, TO-15 or TO-17 for VOCs.

**5. Concerns about foamate solidification**

Currently, there is no official guidance for the disposal of PFAS in foamate. The use of Portland cement (or similar) to encapsulate the PFAS in foam fractionate to minimize potential recycling is an unproven technology and the relevant research conducted herein casts serious doubts on the solidification's efficacy. There are no publications or reports available that indicate this treatment is effective. In a recent publication, it was found that for PFAS-contaminated soil treated with cement and bentonite, the leaching of long-chain PFAAs was reduced while the leaching of short-chain PFAAs was enhanced.[18] While there is only the single manuscript cited above on PFAS solidification using cement, there are numerous other articles for similar classes of compounds that suggest it may not be effective. For example, Mulder et al. report that "PAHs leach to a relatively high extent" after solidification,[19] and Yilmaz et al. reported that for adsorbable organic halogens (AOX) in pulp and paper sludge solidified with cement,[20] AOX concentrations were above regulatory levels (tested was done with the U.S. Environmental Protection Agency Toxicity Characteristic Leaching Procedure (TCLP)). )). Note that most PFAS are AOX (halogenated substances that are adsorbed from water onto activated carbon). Based on the published evidence it is reasonable to conclude the proposed process will not effectively isolate the PFAS and will allow PFAS in the foam to quickly re-enter the leachate stream

**6. Recommendations on separation technology for leachate treatment, and for targeting both long-chain and short-chain PFAS, as well as precursors**

Given that FF does not target short-chain PFAS and does not sufficiently capture precursors, it is recommended that a separation process capable of removing short-chain ($C_{n<6}$) PFAS and precursors is included in the design. Adsorption by granular activated carbon and resins are not good candidates because of their inefficacy in removing short-chain PFAS and possible compromised performance in the presence of competitive organics and ionic components. However, a combination of biological pretreatment and reverse osmosis (RO) would be a safer and more reliable choice. Biological treatment aims to break down organics to mitigate membrane fouling. The following RO step is a proven process to treat raw leachate.[21] Recently, RO demonstrated the capability to remove PFAS at all chain lengths ($C_{n>1}$).[22,23] Moreover, as stated above, there is evidence that reverse osmosis also removes precursors.[8] The Bio+RO process, specifically the combination of membrane bioreactor (MBR) and RO, is a mature technology for leachate treatment.[24] Commercialized membranes tailored for PFAS removal in leachate were reported by PCI membranes, Saltworks, and Aclarity (internet sources; no conflict of interests involved).[25–27] A project of treating 75,000 gpd of leachate is being conducted by SCS Engineers in North Carolina.[28]

While FF is a plausible component in treating leachate for PFAS, we herein provide a suggested treatment process that can be an add-on (to be placed after FF) or stand-alone (to replace FF) to eliminate VT5 and other PFAS covered by EPA method 1633. As shown in Figure 2, the treatment train contains a bio-pretreatment unit to reduce the organic loads and thereby mitigate RO membrane fouling. PFAS at all chain lengths will then be removed by the RO unit, as well as a larger swath of precursors. The RO concentrate (10-20% volume of the inlet flow) can be treated by destructive technology, EO or Plasma (discussed in detail below), to mineralize PFAS. We believe this treatment train will better protect the practitioner from regulator noncompliance in the face of an increasing list of PFAS of public concern as well as PFAS precursors, and that this treatment train will decrease public health risks, as compared to the FF proposal.

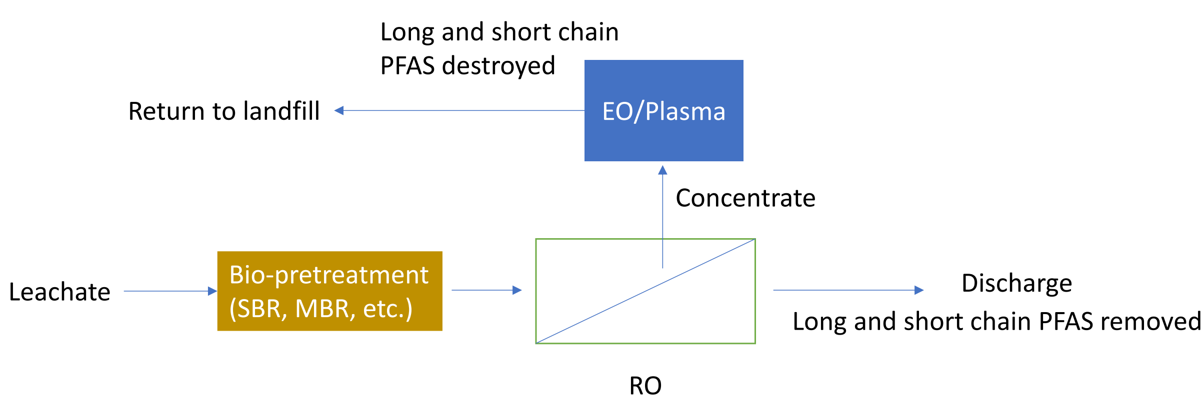


**Figure 1.** Suggested treatment train to remove and destroy long and short chain PFAS.

**7. Recommendations on destructive technology for concentrate treatment**

Current PFAS destruction technologies include (1) electrochemical oxidation (EO), (2) plasma discharge, (3) UV-sulfite reduction, (4) hydrothermal treatment (including two subset technologies: Hydrothermal alkaline treatment and supercritical water oxidation), and (4) sonolysis. The performance of UV-sulfite could be compromised by organics.[29] Hydrothermal treatment requires the addition of excessive alkaline (1-5 M NaOH) and specialized equipment to withstand high temperatures and pressurization.[30,31] These technologies have attracted significant investments and become the backbone of several start-up companies (Aquagga and 374Water). Though these hydrothermal approaches can destroy PFAS in concentrated AFFF and sorbents, no study reported the treatment of leachate or foamate derived from leachate. Our evaluation is that the hydrothermal process is still limited by the treatment capacity. The Aquagga system has a maximum capacity of 240 gpd (based on a personal conversation with a developer). Sonolysis is known for its higher energy consumption than peer approaches.[32] This leaves EO and plasma as feasible options. More importantly, their performance on PFAS destruction was validated in leachate treatment.[33,34] Direct deployment of these technologies in leachate treatment is difficult given the volumes generated, although plasma technology, in particular, is rapidly advancing and may be able to treat the needed volumes in the near future. However, EO or plasma could be used to treat concentrates of leachate with higher PFAS loads and a lower volume, which would eliminate the need for solidification and limit PFAS recycling in the leachate. These destructive technologies could be applied at the end of the treatment process, so that the PFAS in the RO concentrate as well as the foamate (discussed below) were eliminated.

If FF is to be used as the first step toward PFAS control in landfill leachate, based on the Swedish data provided, in the ideal scenario, >97% of the VT5-PFAS may be removed from the leachate. The volume of foamate is unclear in the study plan, although the volume of foamate could be 10% of the total inlet volume.[11] Assuming >99% removal of PFOA in leachate, as the Swedish study attained, the foamate could have a concentration of ~17,000 ng/L at a volume of 7,500 gpd. This is a very large volume of foamate and shows how challenging treating the foamate could be.

Recommended destructive technologies include EO and plasma, for both the RO concentrate from the recommended treatment train, and the foamate from the existing plan. EO treatment of PFAS in leachate has been extensively reported. Destruction of PFOA and PFOS was readily achieved.[35] Directly applying EO to treat leachate may convert precursors to shorter-chain PFAS, leading to the net concentration increase of PFAS in the treated effluent.[36] Extended treatment duration (from 8 to 30 h) or operation at a higher current density (from 20 to 80 $mA/cm^2$) could lead to the net decrease of PFAS.[34,37] A more appropriate niche for EO is to use it to treat foamate. A pilot-scale study in Uppsala, Sweden, demonstrated the destruction of 60% of total PFAS. Specifically, ~20% of $C_{n<6}$ PFAS and >80% of $C_n$>6 PFAS were destroyed. The study used PFOA degradation as a benchmark. The energy consumption of the FF+EO treatment train to remove and destroy >90% of PFOA is 75 $kWh/m^3$.

Plasma treatment is another promising PFAS destruction technology with high technical readiness and is being applied at pilot and commercial scales.[38,39] These studies utilized an enhanced-contact plasma reactor, in which plasma was generated in argon gas and contacted the gas-liquid interface occupied by PFAS. In this reactor, argon is pumped through a submerged gas diffuser to transport PFAAs and precursors to the liquid surface, where they form a layer of foam that is degraded by the plasma-generated species. Though there was no literature report, plasma should be effective in the treatment of leachate foamate since the process already involves gas purging and reactions in the foam phase. With the aid of additional surfactants (e.g., CTAB), the plasma treatment exhibited broad-spectrum reactivity toward the destruction of both short- and long-chain PFAS in synthetic wastewater and leachate.[33,40] The energy consumption to destroy >90% of PFOA and PFOS ranged from 20 to 36 $kWh/m^3$. This information would be the starting point for designing the plasma treatment system for the foamate.

## 8. Recommended workflow for controlling VT5 in management of residuals (foamate)

One of our major concerns with the pilot plan as it stands is that VT5 will be accumulated in foamate rather than destroyed, as the proposed solidification process is not a validated approach. As discussed above, contrasting results in the published studies suggest PFAS leaching is possible, even likely. Therefore, it is suggested that the study plan include destructive technology to destroy PFAS in the foamate (**Figure 1**). EO and plasma are two commercially viable options, as explained above.

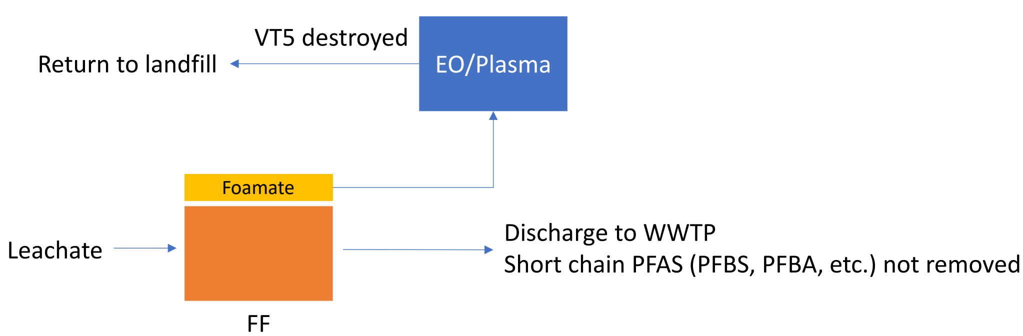


**Figure 2**. Suggested workflow to destroy VT5 PFAS in the FF-based treatment train.

**10. Major conclusions**

- The current study plan is not supported by preliminary data on treating VT5 PFAS in NEWSVT's leachate. Major technical risks reside in (i) uncertainties in the foamability of NEWST's leachate, (ii) uncertainties in the removal efficiencies of VT5 and (iii) no contingency plan to cope with the variations of PFAS concentrations and water qualities,
- The lack of air monitoring is concerning because the proposed technology is likely to result in toxics being released into the atmosphere, as described above. Determining if any PFAS discharged through the stack gas after carbon absorption is an open question that should be evaluated. There are relatively simple and proven air sampling techniques that should be employed, as described above. Moreover, various EPA methods outlined above should be employed to monitor the air for SVOCS and VOCS.
- The current residuals management plan is not recommendable. PFAS solidification in Portland Cement is unlikely to prevent PFAS leaching back into the leachate. There are destructive technologies currently available that can destroy PFAS removed by FF, limiting their recycling in the leachate. For the removal and destruction of VT5 in foamate, we recommend the use of EO or plasma. We also recommend the use of EO and plasma for the destruction of RO concentrate, if our recommended additional treatment system is incorporated.
- The current proposed system--even if it works as claimed, despite the lack of evidence--does not account for treating other PFAS of emerging or proven public health concern. For the removal and destruction of long- and short-chain PFAS covered by EPA Method 1633, we recommend the use of bio pretreatment + RO or FF+bio-pretreatment + RO to concentrate long- and short-chain PFAS, including PFBA and PFBS. The concentrate could then be treated by EO or plasma.
- Limiting the scope of the PFAS study to only VT5 may expose the practitioner to regulatory noncompliance for controlling other PFAS, including short-chain perfluorinated PFAS covered in EPA Method 1633 in the future; limiting treatment to VT5 also ignores public health concerns of other PFAS, as described above. In addition, if unknown precursors (cannot be detected by EPA Method 1633), polyfluorinated compounds (covered by EPA Method 1633), and sulphonamides (covered by EPA Method 1633) are not removed by the FF process, their conversion into regulated PFAS (those in the VT5) after leachate discharge may expose the facility and the WWTP to future liabilities, as well as posing a risk to public health.

**References**


(1) Lu, J.; Lu, H.; Liang, D.; Feng, S.; Li, Y.; Li, J. A Review of the Occurrence, Monitoring, and Removal Technologies for the Remediation of per- and Polyfluoroalkyl Substances (PFAS) from Landfill Leachate. *Chemosphere* **2023**, *332*, 138824. https://doi.org/10.1016/j.chemosphere.2023.138824.

(2) Coffin, E. S.; Reeves, D. M.; Cassidy, D. P. PFAS in Municipal Solid Waste Landfills: Sources, Leachate Composition, Chemical Transformations, and Future Challenges. *Curr. Opin. Environ. Sci. Health* **2023**, *31*, 100418. https://doi.org/10.1016/j.coesh.2022.100418.

(3) Allred, B. M.; Lang, J. R.; Barlaz, M. A.; Field, J. A. Physical and Biological Release of Poly- and Perfluoroalkyl Substances (PFASs) from Municipal Solid Waste in Anaerobic Model Landfill Reactors. *Environ. Sci. Technol.* **2015**, *49* (13), 7648–7656. https://doi.org/10.1021/acs.est.5b01040.

(4) Lang, J. R.; Allred, B. M.; Field, J. A.; Levis, J. W.; Barlaz, M. A. National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate. *Environ. Sci. Technol.* **2017**, *51* (4), 2197–2205. https://doi.org/10.1021/acs.est.6b05005.

(5) Phong Vo, H. N.; Ngo, H. H.; Guo, W.; Hong Nguyen, T. M.; Li, J.; Liang, H.; Deng, L.; Chen, Z.; Hang Nguyen, T. A. Poly-and Perfluoroalkyl Substances in Water and Wastewater: A Comprehensive Review from Sources to Remediation. *J. Water Process Eng.* **2020**, *36*, 101393. https://doi.org/10.1016/j.jwpe.2020.101393.

(6) Eriksson, U.; Haglund, P.; Kärrman, A. Contribution of Precursor Compounds to the Release of Per- and Polyfluoroalkyl Substances (PFASs) from Waste Water Treatment Plants (WWTPs). *J. Environ. Sci.* **2017**, *61*, 80–90. https://doi.org/10.1016/j.jes.2017.05.004.

(7) McCleaf, P.; Kjellgren, Y.; Ahrens, L. Foam Fractionation Removal of Multiple Per- and Polyfluoroalkyl Substances from Landfill Leachate. *AWWA Water Sci.* **2021**, *3* (5), e1238. https://doi.org/10.1002/aws2.1238.

(8) Glover, C. M.; Quiñones, O.; Dickenson, E. R. V. Removal of Perfluoroalkyl and Polyfluoroalkyl Substances in Potable Reuse Systems. *Water Res.* **2018**, *144*, 454–461. https://doi.org/10.1016/j.watres.2018.07.018.

(9) Buckley, T.; Karanam, K.; Han, H.; Vo, H. N. P.; Shukla, P.; Firouzi, M.; Rudolph, V. Effect of Different Co-Foaming Agents on PFAS Removal from the Environment by Foam Fractionation. *Water Res.* **2023**, *230*, 119532. https://doi.org/10.1016/j.watres.2022.119532.

(10) Robey, N. M.; da Silva, B. F.; Annable, M. D.; Townsend, T. G.; Bowden, J. A. Concentrating Per- and Polyfluoroalkyl Substances (PFAS) in Municipal Solid Waste Landfill Leachate Using Foam Separation. *Environ. Sci. Technol.* **2020**, *54* (19), 12550–12559. https://doi.org/10.1021/acs.est.0c01266.

(11) Smith, S. J.; Wiberg, K.; McCleaf, P.; Ahrens, L. Pilot-Scale Continuous Foam Fractionation for the Removal of Per- and Polyfluoroalkyl Substances (PFAS) from Landfill Leachate. *ACS EST Water* **2022**, *2* (5), 841–851. https://doi.org/10.1021/acsestwater.2c00032.

(12) Burns, D. J.; Hinrichsen, H. M.; Stevenson, P.; Murphy, P. J. C. Commercial-Scale Remediation of per- and Polyfluoroalkyl Substances from a Landfill Leachate Catchment Using Surface-Active Foam Fractionation (SAFF®). *Remediat. J.* **2022**, *32* (3), 139–150. https://doi.org/10.1002/rem.21720.

(13) Chen, F.; Wei, C.; Chen, Q.; Zhang, J.; Wang, L.; Zhou, Z.; Chen, M.; Liang, Y. Internal Concentrations of Perfluorobutane Sulfonate (PFBS) Comparable to Those of Perfluorooctane Sulfonate (PFOS) Induce Reproductive Toxicity in Caenorhabditis Elegans. *Ecotoxicol. Environ. Saf.* **2018**, *158*, 223–229. https://doi.org/10.1016/j.ecoenv.2018.04.032.

(14) Gomis, M. I.; Vestergren, R.; Borg, D.; Cousins, I. T. Comparing the Toxic Potency in Vivo of Long-Chain Perfluoroalkyl Acids and Fluorinated Alternatives. *Environ. Int.* **2018**, *113*, 1–9. https://doi.org/10.1016/j.envint.2018.01.011.

(15) Barber, J. L.; Berger, U.; Chaemfa, C.; Huber, S.; Jahnke, A.; Temme, C.; Jones, K. C. Analysis of Per- and Polyfluorinated Alkyl Substances in Air Samples from Northwest Europe. *J. Environ. Monit.* **2007**, *9* (6), 530–541. https://doi.org/10.1039/B701417A.
(16) Young, A. S.; Sparer-Fine, E. H.; Pickard, H. M.; Sunderland, E. M.; Peaslee, G. F.; Allen, J. G. Per- and Polyfluoroalkyl Substances (PFAS) and Total Fluorine in Fire Station Dust. *J. Expo. Sci. Environ. Epidemiol.* **2021**, *31* (5), 930–942. https://doi.org/10.1038/s41370-021-00288-7.
(17) He, X.-S.; Pan, Q.; Xi, B.-D.; Zheng, J.; Liu, Q.-Y.; Sun, Y. Volatile and Semi-Volatile Organic Compounds in Landfill Leachate: Concurrence, Removal and the Influencing Factors. *Water Res.* **2023**, *245*, 120566. https://doi.org/10.1016/j.watres.2023.120566.
(18) Bierbaum, T.; Klaas, N.; Braun, J.; Nürenberg, G.; Lange, F. T.; Haslauer, C. Immobilization of Per- and Polyfluoroalkyl Substances (PFAS): Comparison of Leaching Behavior by Three Different Leaching Tests. *Sci. Total Environ.* **2023**, *876*, 162588. https://doi.org/10.1016/j.scitotenv.2023.162588.
(19) Mulder, E.; Brouwer, J. P.; Blaakmeer, J.; Frénay, J. W. Immobilisation of PAH in Waste Materials. *Waste Manag.* **2001**, *21* (3), 247–253. https://doi.org/10.1016/S0956-053X(00)00097-0.
(20) Yilmaz, O.; Ünlü, K.; Cokca, E. Solidification/Stabilization of Hazardous Wastes Containing Metals and Organic Contaminants. *J. Environ. Eng.* **2003**, *129* (4), 366–376. https://doi.org/10.1061/(ASCE)0733-9372(2003)129:4(366).
(21) Chianese, A.; Ranauro, R.; Verdone, N. Treatment of Landfill Leachate by Reverse Osmosis. *Water Res.* **1999**, *33* (3), 647–652. https://doi.org/10.1016/S0043-1354(98)00240-1.
(22) Mastropietro, T. F.; Bruno, R.; Pardo, E.; Armentano, D. Reverse Osmosis and Nanofiltration Membranes for Highly Efficient PFASs Removal: Overview, Challenges and Future Perspectives. *Dalton Trans.* **2021**, *50* (16), 5398–5410. https://doi.org/10.1039/D1DT00360G.
(23) Liu, C.; Zhao, X.; Faria, A. F.; Deliz Quiñones, K. Y.; Zhang, C.; He, Q.; Ma, J.; Shen, Y.; Zhi, Y. Evaluating the Efficiency of Nanofiltration and Reverse Osmosis Membrane Processes for the Removal of Per- and Polyfluoroalkyl Substances from Water: A Critical Review. *Sep. Purif. Technol.* **2022**, *302*, 122161. https://doi.org/10.1016/j.seppur.2022.122161.
(24) Anna Tałałaj, I.; Bartkowska, I.; Biedka, P. Treatment of Young and Stabilized Landfill Leachate by Integrated Sequencing Batch Reactor (SBR) and Reverse Osmosis (RO) Process. *Environ. Nanotechnol. Monit. Manag.* **2021**, *16*, 100502. https://doi.org/10.1016/j.enmm.2021.100502.
(25) 2019-09-30. *Single Stage Treatment of Landfill Leachate*. PCI Membranes. https://www.pcimembranes.com/articles/single-stage-treatment-of-landfill-leachate/ (accessed 2023-11-20).
(26) Zoshi, J. *Ultra High Pressure Reverse Osmosis for Landfill Leachate*. Saltworks Technologies. https://www.saltworkstech.com/articles/ultra-high-pressure-reverse-osmosis-for-landfill-leachate/ (accessed 2023-11-20).
(27) *PFAS Treatment Technologies Whitepaper*. Aclarity, Inc. https://www.aclaritywater.com/landfill-pfas-treatment-technologies/ (accessed 2023-11-20).
(28) *Landfill Leachate Treatment Plant Using Reverse Osmosis, New Hanover County in Wilmington, NC*. SCS Engineers. https://www.scsengineers.com/scs-project-case-stu/landfill-leachate-treatment-plant-using-reverse-osmosis-new-hanover-county-wilmington-nc/ (accessed 2023-11-20).
(29) Fennell, B. D.; Fowler, D.; Mezyk, S. P.; McKay, G. Reactivity of Dissolved Organic Matter with the Hydrated Electron: Implications for Treatment of Chemical Contaminants in Water with Advanced Reduction Processes. *Environ. Sci. Technol.* **2023**. https://doi.org/10.1021/acs.est.3c00909.
(30) Hao, S.; Choi, Y.-J.; Wu, B.; Higgins, C. P.; Deeb, R.; Strathmann, T. J. Hydrothermal Alkaline Treatment for Destruction of Per- and Polyfluoroalkyl Substances in Aqueous Film-Forming Foam. *Environ. Sci. Technol.* **2021**, *55* (5), 3283–3295. https://doi.org/10.1021/acs.est.0c06906.
(31) Hao, S.; Reardon, P. N.; Choi, Y. J.; Zhang, C.; Sanchez, J. M.; Higgins, C. P.; Strathmann, T. J. Hydrothermal Alkaline Treatment (HALT) of Foam Fractionation Concentrate Derived from PFAS-

Contaminated Groundwater. *Environ. Sci. Technol.* **2023**, *57* (44), 17154–17165. https://doi.org/10.1021/acs.est.3c05140.
(32) Kalra, S. S. Sonolytic Destruction of Per- and Polyfluoroalkyl Substances in Groundwater, Aqueous Film-Forming Foams, and Investigation Derived Waste. *Chem. Eng. J.* **2021**, *425*, 131778.
(33) Singh, R. K. Treatment of PFAS-Containing Landfill Leachate Using an Enhanced Contact Plasma Reactor. *J. Hazard. Mater.* **2021**, *408*, 124452.
(34) Maldonado, V. Y.; Schwichtenberg, T.; Schmokel, C.; Witt, S. E.; Field, J. A. Electrochemical Transformations of Perfluoroalkyl Acid (PFAA) Precursors and PFAAs in Landfill Leachates. *ACS EST Water* **2022**, *2* (4), 624–634. https://doi.org/10.1021/acsestwater.1c00479.
(35) Pierpaoli, M.; Szopińska, M.; Wilk, B. K.; Sobaszek, M.; Łuczkiewicz, A.; Bogdanowicz, R.; Fudala-Książek, S. Electrochemical Oxidation of PFOA and PFOS in Landfill Leachates at Low and Highly Boron-Doped Diamond Electrodes. *J. Hazard. Mater.* **2021**, *403*, 123606. https://doi.org/10.1016/j.jhazmat.2020.123606.
(36) Maldonado, V. Y. A Flow-through Cell for the Electrochemical Oxidation of Perfluoroalkyl Substances in Landfill Leachates. *J. Water Process Eng.* **2021**, *43*, 102210.
(37) Urtiaga, A.; Gómez-Lavín, S.; Soriano, A. Electrochemical Treatment of Municipal Landfill Leachates and Implications for Poly- and Perfluoroalkyl Substances (PFAS) Removal. *J. Environ. Chem. Eng.* **2022**, *10* (3), 107900. https://doi.org/10.1016/j.jece.2022.107900.
(38) Singh, R. K.; Multari, N.; Nau-Hix, C.; Anderson, R. H.; Richardson, S. D.; Holsen, T. M.; Mededovic Thagard, S. Rapid Removal of Poly- and Perfluorinated Compounds from Investigation-Derived Waste (IDW) in a Pilot-Scale Plasma Reactor. *Environ. Sci. Technol.* **2019**, *53* (19), 11375–11382. https://doi.org/10.1021/acs.est.9b02964.
(39) *DMAX Plasma – DMax Plasma offers edge water purification solutions to remove PFASs from water.* https://dmaxplasma.com/ (accessed 2023-11-21).
(40) Li, R.; Isowamwen, O. F.; Ross, K. C.; Holsen, T. M.; Thagard, S. M. PFAS–CTAB Complexation and Its Role on the Removal of PFAS from a Lab-Prepared Water and a Reverse Osmosis Reject Water Using a Plasma Reactor. *Environ. Sci. Technol.* **2023**, *57* (34), 12901–12910. https://doi.org/10.1021/acs.est.3c03679.

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He is an associate editor of *Emerging Contaminants* and an Early Career Editorial Board member of *ACS ES&T Engineering*. His research group at Clarkson received funding from NSF, DoD, DoE, Bill and Melinda Gates Foundation, New York State Department of Environmental Conservation, and the Environmental Research and Education Foundation. He received the prestigious NSF CAREER award in 2023. He was introduced to the “40 under 40 recognition program” by the American Academy of Environmental Engineers and Scientists.