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Casella Juniper Ridge Landfill

LEEF System® Treatability Study at Juniper Ridge Landfill

August 21, 2025
Business Confidential

Version	Date	Notes
1.0	August 19, 2025	Original
2.0	August 20, 2025	Changes made to display of results
3.0	August 21, 2025	Updated – discussion, conclusion

Revision History

Executive Summary

- **High Removal of Long-Chain PFAS:** PFOA, PFOS, and other long-chain compounds were consistently reduced by >99.5%, with final concentrations near or below analytical detection limits.
- **Short-Chain PFAS Performance:** Short-chain compounds showed variable removal, though some were reduced at higher rates than typically observed in similar studies, increases in short chain PFAS concentrations were observed in some tests. Seasonal cold conditions are expected to further improve short-chain removal.
- **Residual Waste Stream:** Foam fractionation and concentration reduced residual waste to ~0.7% of influent leachate volume, providing a manageable waste stream.
- **Reliable Operation:** The LEEF System® ran smoothly with minimal manual intervention and no issues with clogging or scaling, demonstrating the LEEF Systems® robustness and scalability.

In June 2025, the Water and Carbon Group (WCG) conducted a treatability demonstration study at Juniper Ridge Landfill using the LEEF System®, a proprietary foam fractionation technology, to evaluate its effectiveness in removing per- and polyfluoroalkyl substances (PFAS) from Juniper Ridge landfill leachate. The demonstration targeted the removal of all long-chain PFAS compounds.

The trailer tested a range of operating conditions, including varying hydraulic retention times (HRT), flow rates, and air flow rates, to determine the optimal performance for PFAS removal. Long-chain PFAS (e.g., PFOS, PFOA) were consistently reduced (>99.5% removal) to near or below analytical detection limits under most conditions. Short-chain PFAS showed varying removal rates; however, performance for some compounds was better than WCG had previously observed. This outcome was consistent with expectations, given the lower surface activity of short-chain compounds.

The PFAS removed via foam fractionation is contained in the foam that leaves the LEEF System®. The system has two processes: a primary treatment stage and a concentration stage. The primary system foam generation averaged approximately 5.5% of the influent volume. The concentration step reduced the foamate volume to approximately 0.7% of the influent leachate.

This demonstration was completed in June. During winter months, the leachate is expected to be significantly colder. Colder water temperatures will affect the treatment process in two ways. First, the system will experience increased foam production and firmer foam structure. Secondly, the higher foam production is anticipated to result in improved short-chain PFAS removal efficiency.

The LEEF System operated reliably throughout the study, requiring minimal manual intervention and no clogging or scaling. Overall, the trailer demonstrated that the LEEF System® is a viable and scalable technology for PFAS removal at Juniper Ridge Landfill.

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Objectives

The Objectives of this demonstration treatability study were as follows:

1. Treat Leachate to reduce the concentration of total PFAS in the leachate.
2. Minimize the volume of PFAS-enriched foamate generated.
3. Demonstrate the operational robustness of the LEEF System® with site leachate.
4. Produce reliable data to enable the creation of a cost estimate and design for a full-scale system.

Demonstration Process Flow

Three tests were conducted using leachate from the supply tank, with incremental increases in flow rate to evaluate the hydraulic retention time (HRT) most suitable for full-scale application:

1. 0.75 GPM | 40 min HRT (per fractionator) | 2 CFM | June 2, 2025
2. 1.0 GPM | 30 min HRT (per fractionator) | 2 CFM | June 3, 2025
3. 1.25 GPM | 25 min HRT (per fractionator) | 2 CFM | June 5, 2025

A test was also conducted on Pump House 5 leachate as a point of difference for comparing results.

4. 0.75 GPM | 40 min HRT (per fractionator) | 2 CFM | June 2, 2025

After these tests were completed, a concentration step was performed to further concentrate the residual foamate and minimize the waste stream. This process ran as a semi-batch process.

The raw leachate chemistry can be characterized below.

Test	***Leachate Supply Tank***	***Pump House 5***
TDS (ppm)	9,200	18,000
TSS (ppm)	86	14
COD (ppm)	3100	3900
BOD (ppm)	890	250
Ammonia (N) (ppm)	691	1240
pH	7.25	7.39
Alkalinity (CaCO3) (ppm)	3670	3520
Aluminum (ppm)	2.31	0.5
Calcium (ppm)	406	214
Iron (ppm)	16.4	2.53
Magnesium (ppm)	172	220
Manganese (ppm)	14.5	1.09
Hardness (ppm)	1,722	1,440

Table 1: Raw Leachate Characteristic Comparison

Leef System® Process Flow

Demonstration Process Flow

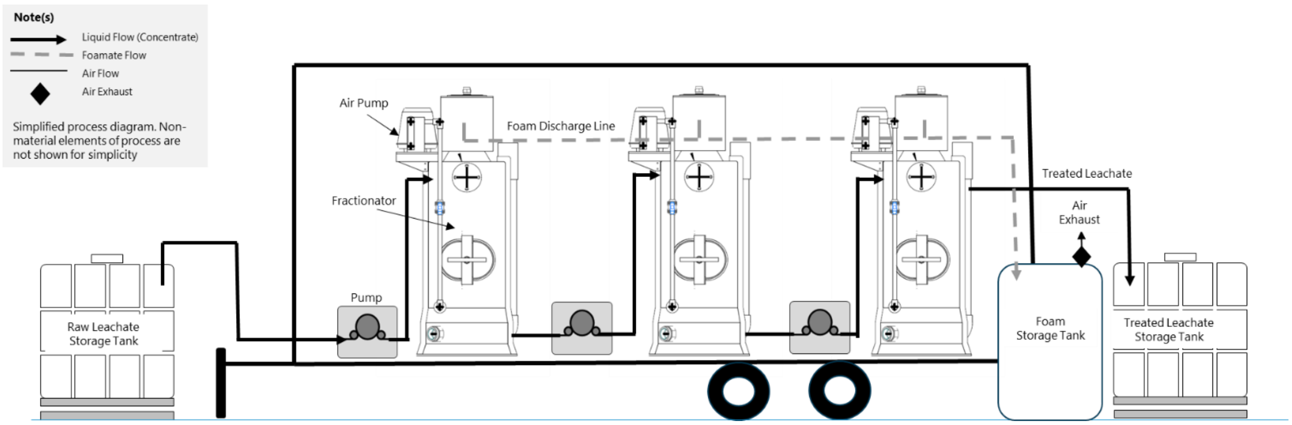

Figure 1: LEEF System® Process flow.

This diagram outlines the process flow of the Demonstration trailer LEEF System®. Raw leachate first enters fractionator one, where air is sparged into the leachate through a diffuser, promoting the formation of foam within the liquid column. This foam is forced through the cone in the hood of the fractionator and into a collection tank. The partially treated leachate then sequentially flows through Fractionators two and three, each functioning identically to the first stage. The system runs for at least two hours at a constant flow rate, ensuring it is running under steady-state conditions before sampling.

Figure 2: Interior of Trailer

The LEEF System® is a flow-through system with all three fractionators processing leachate in series. Operator involvement is minimal and primarily focused on maintaining consistent fluid levels within each fractionator and adjusting the airflow to ensure a visually optimal foam.

A vapor phase granular activated carbon (GAC) exhaust system was employed for the Juniper Ridge Demonstration.

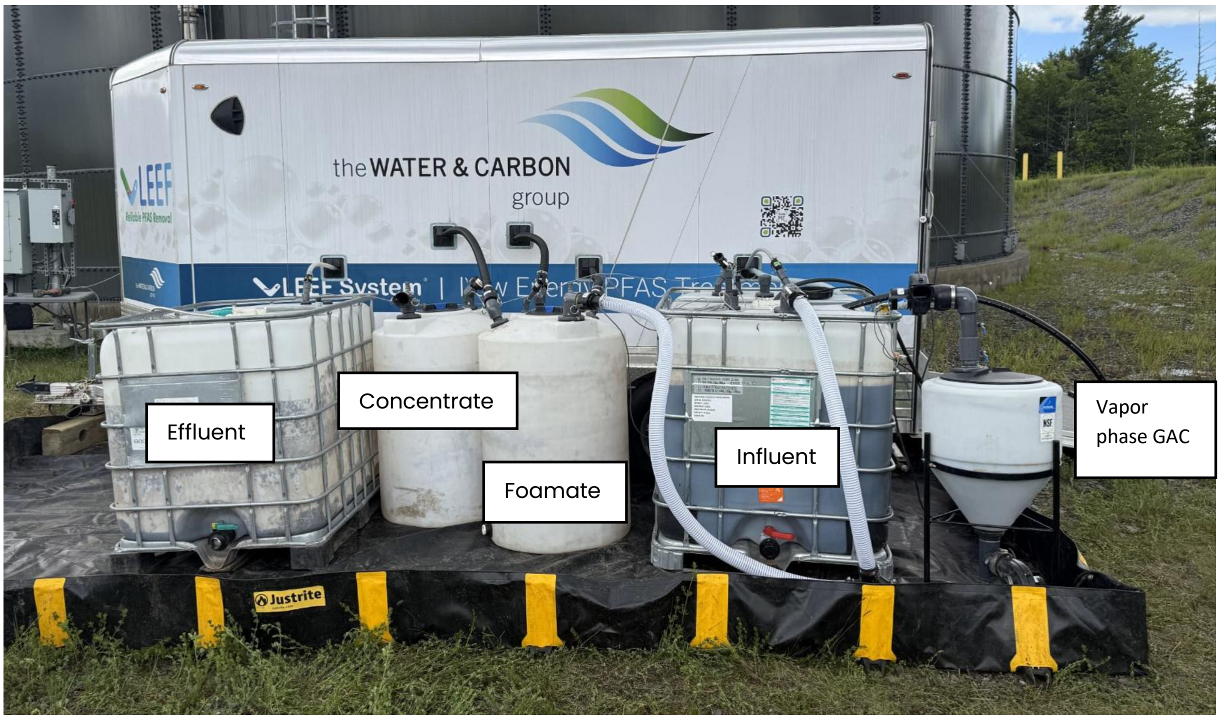

Figure 3: Exterior setup of the trailer.

Concentration Step

Once general testing was completed, the collected foamate was concentrated again to increase PFAS concentration and minimize the waste stream. During this demonstration, the foamate was treated using a semi-batch process through a single fractionator. During the concentration step, the influent foamate creates more foam than the leachate would, as it has a higher concentration of surface-active compounds. Typically, WCG aims to condense the foamate in a full-scale system to less than 0.5% of the original leachate volume introduced to the system.

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Results and Discussion

The section below covers the results and performance of the LEEF System® from the treatability study conducted at the Juniper Ridge Landfill. All samples taken were sent to Pace Analytical for testing. All tests conducted using EPA Method 1633.

Removal Rates

Across 4 tests the results can be seen in the table below.

PFCA	*Raw Leachate (ng/L)*	*Treated Leachate*	*Removal Percentage*
PFBA	6,400 – 3,300	12,000 – 1,800	(A) - 59.5%
PFPeA	4,400 – 1,900	8,700 – 3,500	(A) - 43.5%
PFHxA	9,100 - 2,400	2,200 – 930	8.5% - 89.8%
PFHpA	1,500 - 660	14 – ND	98% - 100%(B)
PFOA	3,200 – 1,700	14 – 2.3	99. 5% - 99.95%
PFNA	170 – 86	ND	100%(B)
PFDA	65 - 38	0.79-ND	98% - 100%(B)
PFSA	**Raw Leachate (ng/L)**	**Treated Leachate**	**Removal Percentage**
PFBS	6,700 - 900	17,000 – 1,200	(A) - 65%
PFPeS	43 – 9.6	1.9 – ND	80% - 100%(B)
PFHxS	470 – 200	1.3 - ND	99.35% - 100%(B)
PFHpS	6 – 2.6	1.3 - ND	99.35% - 100%(B)
PFOS	220 - 120	1.7 - ND	98.85% - 100%(B)
PFNS	ND	ND	-
PFDS	ND	ND	-

Test Notes

- (A) – Select tests showed an increase in compound
- (B) – If test results are below the limit of detection (LOD) of the sample, removals are assumed to be 100%
- (-) – Removal Rate is not relevant due to both values being below LoD
- (ND) – Below limit of detection
- Cells Highlighted light grey are short chain PFAS, as per ITRC regulatory Framework for PFAS
- The range in Raw PFAS is likely due to a rain event that occurred the weekend before the demonstration ran.

Discussion

Testing Method

All PFAS analyses in this study were conducted using EPA Draft Method 1633, which is currently the most comprehensive and widely accepted protocol for quantifying PFAS in complex matrices such as landfill leachate. Method 1633 achieves very low detection and quantification thresholds, with typical limits of detection (ND) on the order of 1–2 ng/L (ppt) and limits of quantification (LOQ) near 10 ng/L. These values, however, can be influenced by matrix interferences, including co-eluents and other co-contaminants present in leachate, which may elevate practical reporting limits or contribute to variability at the low end of the analytical range. As a result, reported concentrations close to the method's LOD or LOQ should be interpreted with consideration of both laboratory uncertainty and the complex chemistry of landfill leachate. For this reason, as discussed in the conclusions of this report, WCG recommends that long-term operational performance benchmarks be established above the method LOQ/LOD to account for statistical variability and to ensure compliance evaluations reflect true system capability rather than isolated analytical fluctuations.

General Tests

The LEEF System® demonstrated effective and consistent removal of all long-chain PFAS compounds, with concentrations reduced to near or below detection limits under most test conditions. These results were achieved using only ambient air sparging, without the addition of treatment chemicals. Most of the key regulated compounds under Maine's 2021 maximum contaminant levels (PFOA, PFOS, PFHpA, PFNA, PFDA, and PFHxS) were consistently reduced to below detection limits, with PFOA and PFOS measured consistently below the limit of quantification (<10 ng/L).

Short-chain PFAS are more difficult to remove due to their lower surface activity and limited response to foam fractionation. Even without additives, the demonstration achieved higher-than-expected removal of short-chain compounds. With the use of an additive (WCG-01), removal of over 80% of total short-chain PFAS is anticipated.

Some short-chain PFAS showed apparent increases from raw to treated samples. However, WCG does not consider these changes to be significant. The affected reported results are flagged with qualifiers S-29 and E, indicating that the values are both estimated (E) and outside of laboratory control limits (S-29). WCG believes these reported increases are more likely the result of reporting variability rather than actual concentration increases. Nonetheless, we believe minimal to no removal of these compounds occurred during the tests in which these flags were reported.

Removal performance varied based on the operational conditions, especially the hydraulic retention time (HRT). The best results were found in test 3 with a 30 min retention time per vessel, this gives a total system retention time of 90 minutes.

Foam Generation

Foam production is influenced by a variety of factors, including the concentration of inherent surfactants (such as PFAS and co-surfactants), HRT, air flow rate, and temperature. Variability in leachate chemistry and physical characteristics can significantly affect formation, often to the same degree as operational settings. Consequently, foam production cannot be established as a fixed design parameter due to the dynamic nature of these variables.

Foam generation in the primary fractionation stage averaged ~5.5% of the influent volume. In all tests, each of the three fractionators produced dry, stable foam with a persistent structure that did not collapse readily.

Figure 4 Foam generated in the first second and third fractionator during test 1

Concentration Step

During the concentration step PFAS in the foam was concentrated by more than 10x its influent level. Overall, the concentrated residual of the system was 0.7% the raw leachate introduced into the LEEF system. This value is higher than what we would expect a full-scale system to create; this is a byproduct of using smaller manually operated fractionators.

Operational Considerations

The system operated reliably throughout the week-long demonstration and required minimal manual intervention. No scaling was observed on the diffuser during this period. However, the leachate hardness (1400 - 1,750 ppm) is comparable to levels seen in leachate processed by WCG's full scale LEEF System®, where scaling has been observed.

Conclusion

The LEEF System® successfully met all technical objectives during the demonstration treatability study at Juniper Ridge Landfill. Overall, the results support the viability of the LEEF System® for selective and scalable PFAS removal, with design considerations such as optimized HRT playing a key role in achieving performance targets across a broad range of PFAS compounds. Across all long-chain PFAS, results showed consistently high removal efficiency, with concentrations consistently reduced below the limit of quantification and most approaching or passing the limit of detection. Short-chain PFAS removal was variable, with some compounds showing strong reduction while others increased.

While the demonstration achieved non-detect or near-detection-limit concentrations for long-chain PFAS, it is important to recognize that statistical variability in long-term operation—including influent variability, system dynamics, and laboratory analytical variation—may occasionally produce measured concentrations above the LoQ or LoD even when overall treatment performance remains highly effective. To account for this natural variability, WCG recommends establishing operational performance benchmarks above the analytical LoQ/LoD, ensuring that compliance evaluations reflect true system capability rather than isolated analytical fluctuations.

The results demonstrate the robustness of the LEEF System® and its ability to reliably remove PFAS from Juniper Ridge leachate.