

BIOFORCETECH SYSTEMS: BREAKING NEW GROUND IN PFAS REMOVAL

Bioforcetech has been at the cutting edge of PFAS removal testing and research since 2019, as the company behind North America's first and only operational full-scale biosolids pyrolysis system. Bioforcetech led several rounds of PFAS testing and participated in the development of methodologies on samples from various pyrolysis systems at different scales. This extensive testing consistently demonstrated the technology's superior performance in PFAS removal.

Bioforcetech began testing for PFAS via independent tests in 2019, continuing with studies in partnership with the U.S. Environmental Protection Agency (EPA) in 2020, and culminating in groundbreaking, third-party testing by Brown and Caldwell on the full-scale BFT SigmaOne Pyrolysis unit, with results published in the Fall of 2025. Since then, BFT has expanded to analyses of client biosolids in 2024 and 2025 using our bench-scale pyrolysis unit, with successful, repeatable results. BFT continues to offer PFAS testing on the bench-scale pyrolysis unit, as part of their feasibility study services to US-based clients. **The studies conducted by Bioforcetech, the EPA, and Brown & Caldwell show that, in these Bioforcetech systems and under these operating conditions, targeted PFAS present in dried biosolids do not persist in biochar at detectable levels, and do not appear to accumulate significantly in scrubber water.**

PFAS testing in biosolids and biochar has evolved alongside the testing of pyrolysis equipment by Bioforcetech, in some cases with testing on these systems setting the stage for the establishment of new methods. The most recent testing conducted by Brown and Caldwell included samples taken at various stages and locations throughout the process. It is the most extensive PFAS testing conducted to date on a system of this kind.

PFAS TESTING WITH THE UNITED STATES EPA

In June 2020, the EPA approached Bioforcetech with a request to test the removal of PFAS from sewage sludge biosolids by pyrolysis technology. The EPA selected Bioforcetech for these tests as the only pyrolysis system currently operating in this setting in the US. The EPA designed a series of tests with the objective of characterizing the removal of targeted PFAS from biosolids to biochar and scrubber water, and to gather preliminary gas-phase emission data from a full-scale pyrolysis system at Silicon Valley Clean Water (SVCW), in Redwood City, California.

At SVCW, three BFT BioDryers feed a pyrolysis reactor equipped with a thermal oxidizer, wet scrubber, and activated carbon filter (Note: this is an earlier pyrolysis system and not the units sold today). The BioDryers increase solids from 20% to 75–90% dry and produce Class A biosolids, which are then used as pyrolysis feedstock. Samples were taken from dried biosolids, biochar, scrubber water, and tap water. Two independent laboratories analyzed solids and

liquids using modified EPA Method 537 with isotope dilution, solid phase extraction (SPE), and LC–MS/MS for 36 and 41 PFAS, respectively. Removal efficiency (RE) from dried biosolids to biochar was computed on a mass-rate basis using measured concentrations and flow rates; when biochar concentrations were below reporting limits, minimum detection limits (MDLs) were substituted, yielding “greater than” RE values.

A total of 21 types of PFAS were detected in input dried biosolids, while **in biochar, all targeted PFAS were below reporting limits**, with only single low-level detections of PFOS and PFBA. Using MDLs as upper bounds for biochar concentrations, calculated PFAS REs ranged from >81.3% to >99.9% (average >97.4%). For the 16 compounds above reporting limits, RE exceeded 99%. Scrubber water contained very limited targeted PFAS, indicating no clear bulk liquid-phase sink for thermally mobilized PFAS.¹

The EPA study also analysed gas-phase emissions from the pyrolysis system. A method was devised to analyse the hot exhaust (after syngas combustion, heat exchanger, and scrubber), check for system leaks at the biosolids inlet and biochar outlet (i.e., unintended PFAS-containing gas escape paths) and characterize key combustion gases. Note that prior to this study, no established testing method for detecting PFAS in flue gas existed. Samples were taken at the syngas combustion exhaust, heat exchanger outlet, scrubber outlet, near the biosolids inlet and biochar outlet. No significant gas leakage was observed. The results indicated generally low combustion byproducts, with CO mostly below detection and methane below ambient levels.

PFAS TESTING WITH BROWN AND CALDWELL: THE MOST COMPREHENSIVE TESTING TO DATE

Bioforcetech’s latest, most extensive and exact independent testing on PFAS removal with pyrolysis was performed in collaboration with Brown and Caldwell in 2025. This testing confirmed that **Bioforcetech’s Pyrolysis system achieves 99.98% PFAS removal across all output streams**, including biochar, discharge water, and exhaust gases.

The study was conducted at Silicon Valley Clean Water, where a full-scale BFT SigmaOne pyrolysis unit is currently in operation, replacing a previous unit that was retired in 2024. This system conducts pyrolysis at 550 to 630°C, with thermal oxidation of the off-gas at 980°C. The study sampled at eight points throughout the system in various outputs (**Figure 1**). In the years following the 2020 study, the US EPA developed and published standardized methods for this type of testing built upon the testing done earlier. These standardized methods were utilized during this study.

Table 1: PFAS testing from Brown and Caldwell.

	Dried Biosolid	Biochar
	Mean $\dot{m}$ ($\mu\text{mol/run}$)	
PFPeA	0.5	ND
PFHxA	3.8	ND
PFHpA	0.7	ND
PFOA	14	ND
PFNA	0.6	ND
PFDA	2.6	ND
PFUnA	0.4	ND
PFDaA	0.8	ND
PFTeDA	0.2	ND
PFOS	5	ND
NMeFOSAA	4.1	ND
NEtFOSAA	2.9	ND
NMeFOSE	5	ND
NEtFOSE	4.2	ND
5:3 FTCA	43	ND
7:3 FTCA	21	ND

Input dried biosolids were analyzed using [EPA 1633A](#): 16 PFAS were detected, six PFAS were detected below the reporting limit, while 18 were not detected. On the other hand, **in biochar again all targeted PFAS were below reporting limits (Table 1)**. Removal efficiency (RE) from dried biosolids to biochar was computed on a mass-rate basis, as in the EPA study. Of all PFAS compounds identified in the input material, only 0.02% remained anywhere in the system. The process point of highest removal was the thermal oxidizer prior to exhaust scrubbing.

The exhaust gases were analyzed using EPA methodologies [OTM-45](#) and [OTM-50](#). OTM-45 is a performance-based method for the quantitative analysis of specific semivolatile and condensable PFAS in air emissions from stationary sources, while OTM-50 is more broadly applied for the quantitative analysis of specific volatile fluorinated compounds (VFCs) that originate from known industrial products and products of incomplete thermal destruction. Of the 50 PFAS tested by OTM-45, two were not detected, eight were detected below reporting limits, and three (PFOA, PFBS, PFHpA) were found to be present. No VFCs were detected at the accredited laboratories contracted for this study using the EPA approved OTM 50 method. A peer review article describing the study and its results in detail is currently under production.

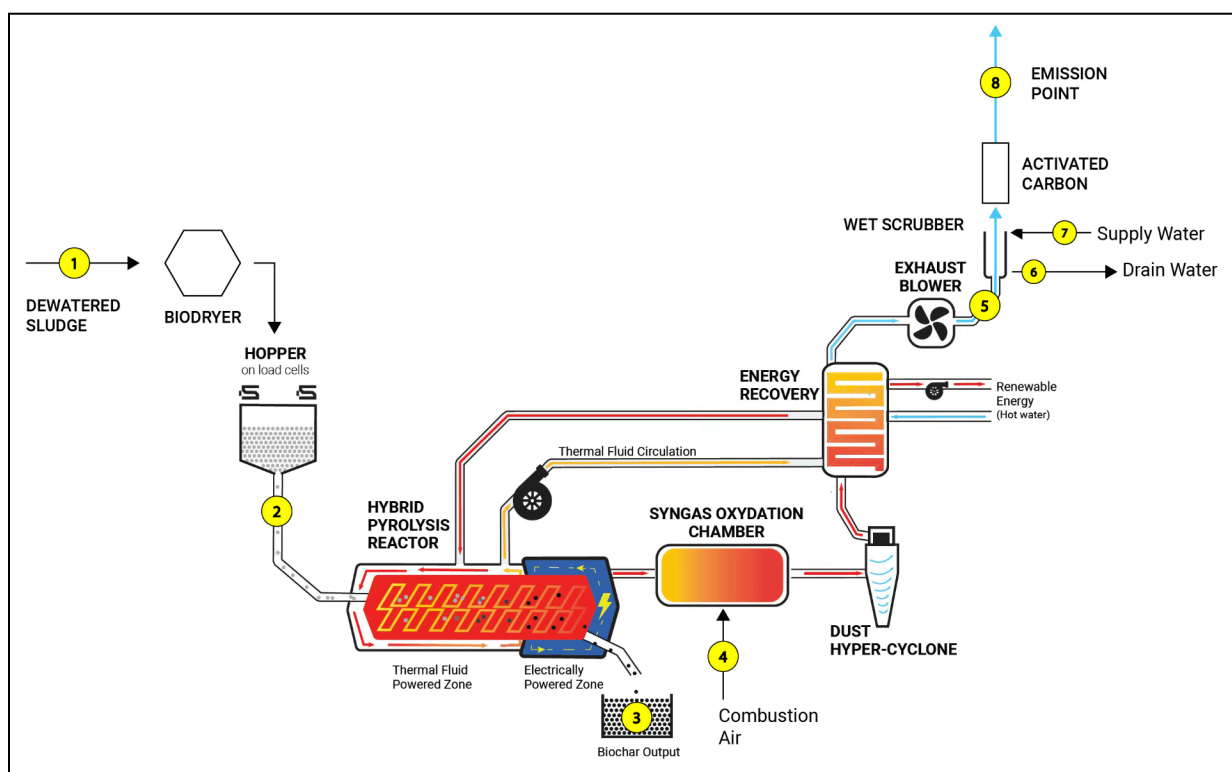


Figure 1. Testing locations sampled in the Brown and Caldwell study.

ONGOING FEASIBILITY TESTING

Bioforcetech has performed PFAS testing on samples from clients, and continues to offer PFAS testing of input feedstocks and output biochar to our US-based clients, as an add-on to our standard feasibility studies. This testing is performed using a BFT bench-scale pyrolysis unit, and samples are sent to an accredited analytical laboratory, where they are analyzed following EPA Method 1633A. To date, Bioforcetech has tested several samples from wastewater treatment plants across the country in feasibility studies. No PFAS were detected in these biochars.

While results from private clients will not be disclosed in this paper, Bioforcetech has recently conducted internal PFAS testing feasibility studies on BFT BioDryer dried samples from Silicon Valley Clean Water (Redwood City, California). A total of 15 PFAS compounds were detected in biosolids, while none were detected in biochar (**Table 2**).

Table 2. Summary of Bioforcetech bench-scale pyrolysis PFAS testing in biosolids and biochar at SVCW.

Analyte	Biosolids (ng/g)	Biochar (ng/g)
PFBA	Not Detected	Not Detected
3:3 FTCA	Not Detected	Not Detected
PFPeA	1.39	Not Detected
PFBS	9.71	Not Detected
4:2 FTS	Not Detected	Not Detected
PFHxA	8.78	Not Detected
PFPeS	Not Detected	Not Detected
HFPO-DA	Not Detected	Not Detected
5:3 FTCA ¹	70.1	Not Detected
PFHpA	1.57	Not Detected
ADONA	Not Detected	Not Detected
PFHxS	Not Detected	Not Detected
6:2 FTS	Not Detected	Not Detected
PFOA	31.5	Not Detected
PFHpS	Not Detected	Not Detected
7:3 FTCA ²	57.3	Not Detected
PFNA	1.30	Not Detected
PFOSA	Not Detected	Not Detected
PFOS	7.67	Not Detected
9CI-PF3ONS	Not Detected	Not Detected
PFDA	10.3	Not Detected
8:2 FTS	Not Detected	Not Detected
PFNS	Not Detected	Not Detected
MeFOSAA	18.8	Not Detected

¹ 5:3 FTCA (5:3 fluorotelomer carboxylic acid) is released from products like carpets that contain PFAS, making it a common indicator of PFAS contamination originating from landfills; it is a breakdown product of other fluorotelomer compounds used in manufacturing various consumer goods.

² 7:3 FTCA (fluorotelomer carboxylic acid) is a breakdown product of fluorotelomer alcohols, which are used in various industrial and consumer products, and is considered a major byproduct of their biodegradation, i.e., it is created when these chemicals are broken down by bacteria in the environment; it is often detected in water, soil, and even wildlife due to its persistence in the environment.

EtFOSAA	17.5	Not Detected
PFUnA	Not Detected	Not Detected
PFDS	Not Detected	Not Detected
11Cl-PF3OUdS	Not Detected	Not Detected
10:2 FTS	Not Detected	Not Detected
PFDaA	3.33	Not Detected
MeFOSA	Not Detected	Not Detected
PFTTrDA	Not Detected	Not Detected
PFTeDA	Not Detected	Not Detected
EtFOSA	Not Detected	Not Detected
PFHxDA	Not Detected	Not Detected
PFODA	Not Detected	Not Detected
MeFOSE	15.2	Not Detected
EtFOSE	9.39	Not Detected

CONCLUSION

Bioforcetech biosolids pyrolysis systems have been tested under the most rigorous and extensive PFAS removal studies conducted to date. From bench-scale feasibility to full-scale, operational biosolids processing, the results consistently demonstrate that Bioforcetech's pyrolysis technology effectively removes PFAS, producing a safe biochar product.

CITATIONS

1. Thoma, E. D. et al. Pyrolysis Processing of PFAS-Impacted Biosolids, a Pilot Study. *J Air Waste Manag Assoc* **72**, 309–318 (2022).
2. Winchell, L. J. et al. Fate of perfluoroalkyl and polyfluoroalkyl substances (PFAS) through two full-scale wastewater sludge incinerators. *Water Environment Research* **96**, e11009 (2024).
3. Abu-Orf, Mohammad, Khan, Kamruzzaman, & Blate, Micah. *Understanding Gasification for PFAS Removal*. www.waterrf.org (2025).

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