White Paper

Supercritical Water Oxidation of PFAS

A Sustainable and Effective Pathway to Complete Mineralization of Per- and Polyfluoroalkyl Substances

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Aquarden TECHNOLOGIES
Because Water is Supercritical.

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Introduction

Per- and polyfluoroalkyl substances (PFAS) are a diverse group of over 15,000 synthetic organofluorine compounds that have been manufactured and used worldwide since the early 1950s. These compounds are characterized by the presence of multiple carbon-fluorine (C-F) bonds, which are among the strongest known in organic chemistry. This bond imparts extraordinary thermal, biological, and chemical stability, making PFAS compounds extremely useful in many industries, but persistent in the environment and difficult to be completely broken down by conventional technologies such as incineration. Below is a partial list containing some common PFAS applications.

Common PFAS applications include:

- Grease-resistant food packaging
- Food production lines
- Nonstick cook and bakeware
- Carpets
- Cosmetics
- Furniture
- Dental Floss
- Paints
- Aerospace
- Wire and cable insulation
- Water- and stain-repellent textiles
- Firefighting Foam (AFFF)
- Surface coatings and composites
- Hydraulic fluids, lubricants and Greases
- Pesticides
- Ski waxing
- Aerosols for fabric proofing
- Artificial grass
- Medical devices
- Electronics

Due to decades of extensive use and poor containment, PFAS have become ubiquitous in the global environment, threatening our drinking water supply and aquatic life. These compounds are now being detected in surface water, groundwater, rainwater, marine and freshwater sediments, soils, atmospheric particles, and even Arctic snow and wildlife. PFAS are also found in human blood serum, breast milk, and various tissues, indicating widespread and persistent exposure. Epidemiological studies have linked human PFAS exposure to a wide range of adverse health outcomes, as listed below.

Adverse health outcomes in humans linked to PFAS exposure include:

- Elevated cholesterol levels
- Developmental effects in infants and children (including lower infant birth weights)
- Liver enzyme changes
- Hormone disruption
- Kidney, ovarian, prostate, liver, breast, and testicular cancers[1]
- Non-Hodgkin's lymphoma[2]
- Suppression of immune response and reduced vaccine efficacy

As PFAS continue to accumulate in the environment and raise concerns for both human and ecological health, it has become clear that effective solutions must start early in the contamination pathway. At Aquarden Technologies, we are committed to addressing PFAS at the source to prevent the problem from escalating downstream. By using our SuperOx® SCWO technology, it is possible to completely break down PFAS to the simplest compounds such as carbon dioxide, water, fluoride and sulfate salts, without generating any toxic degradation products and comply with future environmental legislation.

[1] (2024) *PFOA, PFOS, and Related PFAS Chemicals*. American Cancer Society. Available at: https://www.cancer.org/cancer/risk-prevention/chemicals/teflon-and-perfluorooctanoic-acid-pfoa.html (Accessed: November 2025).
[2] (2020) *Study: PFAS Act Similar to Known Cancer-Causing Chemicals*. Environmental Working Group. Available at: http://www.ewg.org/news-insights/news-release/study-pfas-act-similar-known-cancer-causing-chemicals (Accessed: November 2025).

PFAS Waste Types

PFAS contaminated wastes sent for destruction usually originate from various industries and even environmental remediation efforts. Firefighting foams, for example aqueous film-forming foams (AFFF), have historically contained extremely high levels of PFAS. These compounds were added because they create a stable film that rapidly suppresses fuel-based fires. However, their use has caused widespread environmental contamination. When AFFF is used in training exercises, emergency responses, or accidentally released, PFAS is widely dispersed in significant quantities into our soil, groundwater, and surface waters.

As the background contamination of PFAS in nature typically found is in relatively lower concentrations compared to AFFF, many remediation technologies focus on separating and concentrating PFAS to lower the volume of contaminated waste prior to destruction. However, concentrating PFAS by e.g. adsorption, flocculation, membrane filtration or foam fractionation generates hazardous waste that still needs to be disposed of. Landfilling and incineration have hitherto been commonly used to dispose PFAS wastes. However, landfilling of PFAS contaminated material is not viewed as a proper solution as it simply relocates the problem to the landfills. Conventional incineration has also proven unreliable in achieving complete degradation of PFAS due to inadequate destruction temperatures.

As such, Aquarden Technologies offers SCWO as **the** sustainable alternative for the full destruction of PFAS contaminated waste. Aquarden Technologies has worked with PFAS wastes of various origins, including but not limited to the list in the following table.

PFAS wastes handled by Aquarden Technologies include:

- Concentrated AFFF
- Contaminated adsorbents from PFAS remediation (e.g. GAC, IX-resins)
- Sludge
- Decontamination water from cleaning PFAS contaminated equipment
- Industrial wastewater
- Membrane concentrate
- Foam fractionation foamate
- Regenerant from regeneration of PFAS contaminated adsorbents

PFAS Analysis

PFAS used in consumers everyday products, but especially AFFF firefighting foams, are known to contain not only the well-characterized PFAS compounds such as PFOS and PFOA or any of the other PFAS currently regulated, but also a large number of precursor-PFAS and other fluorinated substances. These ‘hidden PFAS’ often fall outside standard analytical methods, meaning they cannot be reliably quantified with routine PFAS tests. However, during environmental degradation or treatment processes, many of these precursor compounds transform into persistent and toxic PFAS end-products like PFOS and PFOA. Hence, even products marketed as ‘PFAS free’ may contain copious quantities of ‘dark’ PFAS in the form of precursors or unregulated PFAS compounds that are not included in the conventional PFAS analysis suite. As stated earlier, there is expected to be over 15,000 synthetic organic fluorine compounds, and targeted analysis for all is close to impossible.

Because of this, traditional PFAS analyses severely underestimate the true PFAS load present in legacy AFFF concentrates, foam runoff, contaminated water from firefighting sites, and in virtually all our PFAS contaminated wastes. This hidden PFAS fraction must be addressed to ensure proper regulation of existing consumer products and complete remediation of our waste. Therefore, Aquarden Technologies increasingly works with Total Organic Fluorine (TOF) analyses that can detect <u>all</u> fluorinated organics including the non-measurable PFAS fraction, rather than relying solely on targeted PFAS testing. As such, Aquarden Technologies has routinely encountered AFFF foams with TOF analyses that are ***orders of magnitude higher*** than what can be detected through current PFAS analysis.

The presence of non-measurable PFAS precursors also affects verification of complete PFAS destruction in processes like SCWO. Standard analytical methods only detect a limited set of PFAS, so even when these targeted compounds are removed, undetected precursors may still be present or form degradation products that are currently not included in regular PFAS analysis. For this reason, Aquarden Technologies firmly believes that assessing true destruction efficiency requires measuring total organic fluorine (TOF) to confirm that all fluorinated organics, not just the measurable PFAS in targeted analysis, have been eliminated.

Aquarden Technologies' SuperOx® Technology

There are multiple ways to utilize Aquarden Technologies' SuperOx® technology, but there is no doubt that it can handle everything PFAS. At Aquarden Technologies we differ between two methods as described below.

Supercritical Water Oxidation (SCWO): Use of oxidants mixed with supercritical water at temperatures above 374 ˚C and pressures above 22.1 MPa to break down PFAS in aqueous solution or slurry (of e.g. adsorbents). SCWO can completely break down PFAS, typically below detection limits depending on starting concentration. Though the destruction process may generate mineral acids such as hydrofluoric acid and sulfuric acid, proper acid management with base ensures only benign salts are released. In addition, salts created from the oxidation process are insoluble and can easily be flushed out of the process.

Subcritical Water Oxidation (subCWO): Oxidation of wastewater below the critical temperature of water (< 374 ˚C) and pressures above 22.1 MPa. This maintains most salts in solution and allows easier acid management with base, hence reducing reactor fouling and provides possibilities to treat waste with significant salt compositions. However, destruction rates are generally slower than for SCWO, requiring longer residence times to achieve high destruction rates.

With the SuperOx® reactor being fully electrically powered, the process avoids direct use of fossil fuels, reducing greenhouse gas emissions and simplifying energy management. Unlike traditional thermal or chemical treatments, SCWO generates no ash or sludge, eliminating secondary waste streams and associated disposal challenges. Additionally, the system allows operators to store and monitor effluents before discharge, ensuring that all PFAS and degradation products are fully treated, and regulatory compliance is met.

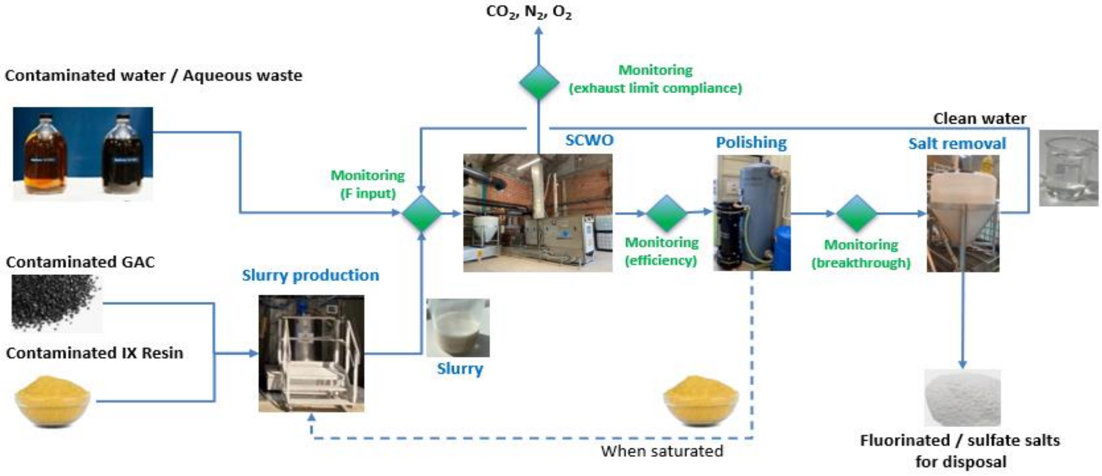

Figure 1 - Example of PFAS treatment pathway with the Aquarden Technologies' SuperOx® SCWO system.

Data from PFAS Destruction Tests

Below is an overview of PFAS destruction results from tests performed by Aquarden Technologies with the SuperOx® SCWO technology, proving efficient destruction of PFAS in various waste fractions and concentration ranges:

#	Test Specifics	Inlet	DRE
1	High TDS waste with short chained PFAS <C6	PFAS <C6: ~60,000 ppm	>99.998%
2	High TDS waste with short chained PFAS <C6	PFAS <C6: ~50,000 ppm	>99.99999%
3	High organic content waste with short chained PFAS <C6	PFAS <C6: 2,600 ppm COD: ~80,000 ppm	>99.9999%
4	IEX resins spiked with PFAS	PFAS: 12.4 – 14.6 ppm	>99.9999%
5	Flocculation sludge with PFAS	PFAS: >125 ppb	>99.50%
6	IEX resins spiked with PFAS	PFAS 22: ~21.5 ppm	>99.999%
7	IEX resins from landfill with PFAS	PFAS 22: ~3-5 ppm	>99.999%
8	PAC with PFAS	PFAS 22: ~10.5 ppm	>99.999%
9	Firefighting Foam, AFFF	PFAS 22: ~5,500 ppm	>99.999%
10	Firefighting Foam, AFFF	TOF: ~651 ppm	>99.99%
11	Firefighting Foam, AFFF	TOF: ~868 ppm	>99.99%
12	Wastewater with organics and PFAS	TOF: 26.6 ppm COD: ~40,000 ppm.	99.95%

Increasingly strict regulations on PFAS, including emerging restrictions on TFA (trifluoroacetic acid), are driving the need for proactive treatment of contaminated water and waste streams. Traditional containment or removal methods are no longer sufficient, as regulators expect permanent elimination of these persistent substances. Technologies like the SuperOx® SCWO, offer a sustainable solution by breaking down PFAS and their precursors completely, ensuring compliance with evolving legislation and minimizing environmental and health risks to provide a safer environment for future generations.

Aquarden Technologies has a close partnership with European aerospace leader ArianeGroup for the global commercialization of SCWO. Together we have full-scale systems in France for the destruction of PFAS, explosives, and other hazardous industrial wastes. Kindly contact Aquarden Technologies or ArianeGroup for more information about our SuperOx®.