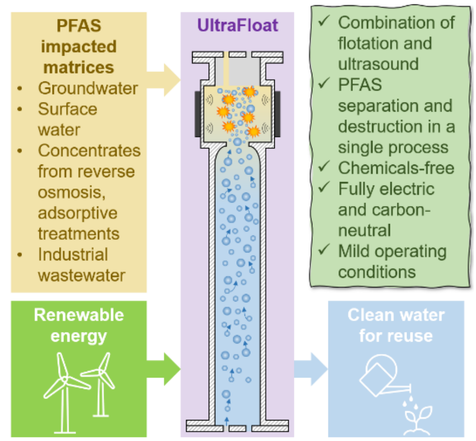
# Flotation-enhanced Ultrasonication ("UltraFloat") to Combine PFAS Separation and Destruction in a Unit Operation Process for Sustainable Water Treatment and Reuse

**Summary and Goal:** Contamination of ground- and drinking water with toxic PFAS is an imminent epidemiological and environmental concern and still lacks effective and affordable treatment options. We propose a novel treatment system that, for the first time, combines separation and destruction of PFAS in a unit operation process, synergistically interlacing flotation and ultrasonication. Combining the two processes sets free a trifold synergy, including enhanced cavitation intensity for high-rate degradation of PFAS, ultrasound (US) enhanced flotation through increased bubble surface area, and flotation-mediated PFAS trapping in the cavitation space. Trienens Seed Funding will allow for an impactful proof-of-concept, opening up new research directions towards practical, chemicals-free, and carbon-neutral PFAS treatment solutions for water reuse. The funding will furthermore establish interdisciplinary collaborations across schools at NU (Wells Lab and Dichtel Lab) and initiate an international collaboration with Technical University of Munich (TUM), Germany.




**Background:** *Per- and polyfluoroalkyl substances* (PFAS) are a class of synthetic chemicals that are used for many applications, ranging from aqueous film-forming foams (AFFFs) to consumer products like non-stick cookware, outdoor gear, or cosmetics [1]. Due to their widespread use and environmental persistence, PFAS are found in all environmental compartments and are estimated to be present in the drinking water of 200 million Americans [2]. Their ubiquitous presence and adverse health effects (*e.g.*, cancers, thyroid disease, high cholesterol [3]) call for urgent remediation efforts, especially at DOD and fire suppression training sites and in drinking water purification. Yet, commercially available treatment options (including reverse osmosis [RO] or adsorption using activated carbon or ion exchange resins) only *separate* PFAS, leaving large amounts of contaminated concentrates or spent media (up to 30% for RO). Destructive post-treatment of those wastes is oftentimes prohibitively expensive or challenged by the nascent state or extreme operating conditions of prospective destructive technologies [4].

**Description of Technological Innovation and Research Questions:** To address above challenges, we propose a novel approach that synergistically couples flotation-based PFAS separation with ultrasonic destruction (see Fig. 1A for the principle of ultrasonic PFAS destruction, and Fig. 1B for the UltraFloat reactor design). US requires only electricity and operates at ambient conditions, thus being potentially much more sustainable than other destructive processes; an innovative combination with flotation has furthermore not been reported in literature, underlining the novelty of the approach. In the proposed process, PFAS-impacted water enters the reactor through a cavitation chamber, in which PFAS are first adsorbed to cavitating bubbles and then mineralized via violent bubble implosions (with local hotspots of 5,000 °C and 500 bar). To improve the efficiency and rate of the process, flotation gas is pumped into the UltraFloat column from below, enabling three synergistic effects: 1) Ascending bubbles will adsorb PFAS that initially slipped through the cavitation chamber, thus routing them back into the cavitation zone (see purple flow line in Fig. 1B). 2) The "seeding" of the cavitation chamber with flotation bubbles dramatically increases the number of bubble implosions (see referenced research in Fig. 1C), thus promoting rapid PFAS destruction. 3) Flotation bubbles in the acoustic field are broken down into smaller bubble clouds, thereby increasing surface area and improving PFAS adsorption capacity. These synergistic effects were first demonstrated in a promising scoping experiment by our collaborators at TUM, using a similar flotation/ultrasonication setup, obtaining a trifold increase in PFOA degradation (see Fig. 1D). Yet, results were obtained with a low-frequency 25 kHz US reactor, which is not suitable for high-efficiency PFAS destruction (as mirrored by the low overall degradation rates of < 25%). Based on the nonetheless encouraging results, the Wells and Dichtel Labs at NU in collaboration with the team at TUM will investigate if the promising synergy can be reproduced in a high-frequency US system (~1,000 kHz) geared towards efficient PFAS degradation. More specifically, the research teams will investigate the system's capability to (i) destroy PFAS currently regulated in US EPA's drinking water standard (e.g., PFOA, PFOS, PFBS), (ii) fully mineralize PFAS without potential by-product formation, and (iii) elucidate performance impacts of different flotation gases (e.g., waste $O_2$ from green $H_2$ production instead of air), to potentially link PFAS destruction to energy storage and energy transition. To deepen mechanistic understanding, the experiments will be accompanied by a modeling approach.

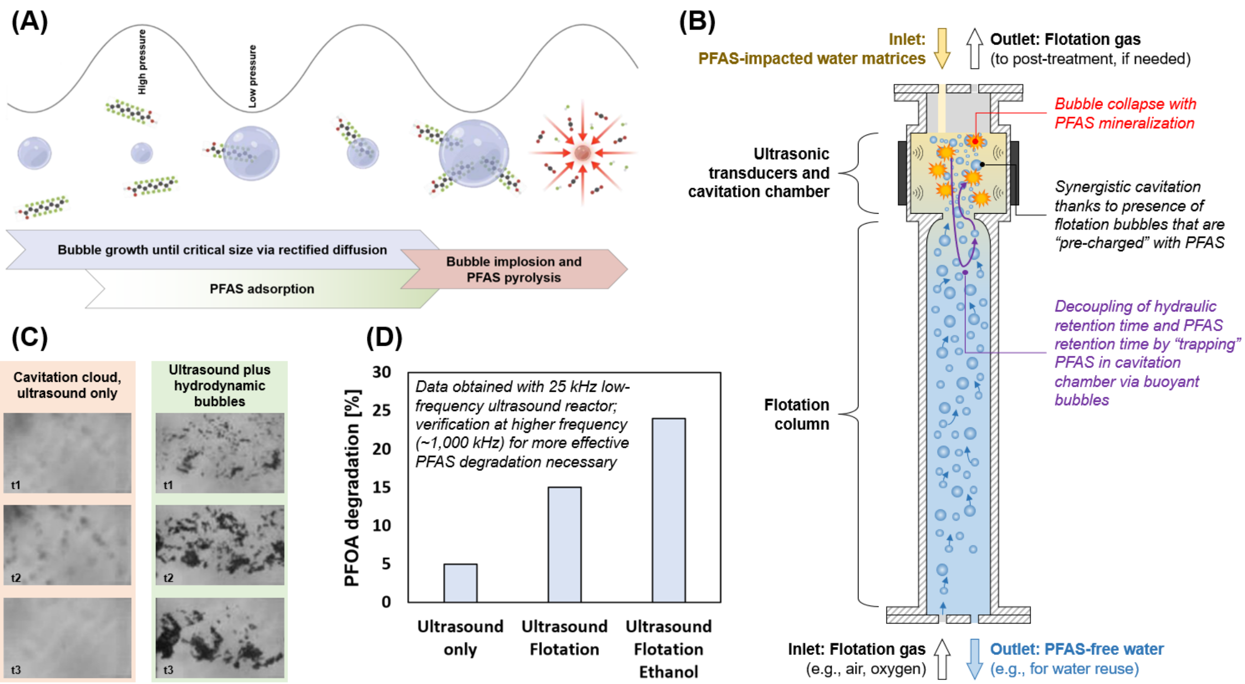



**Figure 1:** (A) Principle of ultrasonic destruction of PFAS (adapted from [5]), (B) schematic of the proposed "UltraFloat" reactor, (C) visualization of cavitation intensification via coupling of hydrodynamic and acoustic cavitation (adapted from [6]), (D) initial results for PFOA degradation obtained with a similar reactor design at Technical University of Munich (adapted from [7]).

**Research Plan, Milestones, and Impact:** The proposed research is organized in 4 tasks and 3 milestones.
*Task 1:* Fabricate custom-built UltraFloat platform with 960 kHz US reactor (PCT Systems Inc., San Jose, CA),
*Task 2:* Prepare model waters with EPA regulated PFAS (at least PFOA, PFOS, PFBS) at relevant concentrations.
*Task 3:* Quantify synergy (US vs. US + flotation) via analysis of PFAS effluent concentrations (incl. by-products).
*Task 4:* Develop mechanistic model for process optimization and scenario evaluation using COMSOL Multiphysics.
*Milestone 1:* Demonstrate at least 50% increase of PFAS degradation rates using UltraFloat compared to US only.
*Milestone 2:* Achieve 99% mineralization (all PFAS). Stretch: 4 ng/L for PFOA/PFOS (EPA drinking water standard).
*Milestone 3:* Communicate findings in a joint journal publication (NU labs + TUM).
The achievement of the above milestones will help establish a unique unit operation process for waste-free, chemicals-free, and fully electric, carbon-neutral PFAS remediation and is of broad interest for the scientific community, but also for practitioners and municipalities working towards sustainable, resilient communities. By addressing resilience in ecosystems through decarbonized water reuse technologies and by fostering interdisciplinary scholarship, we deem the proposed project closely aligned with the Trienens Institute's mission.

**Team and Resource Leverage:** Research will be carried out by an interdisciplinary and international team (Prof. Wells and Dr. Lippert [Dept. of Civil and Environmental Engineering], Prof. Dichtel and R. Monsky [Department of Chemistry], and Prof. Drewes as a new international collaborator from TUM, and will be further supported by graduate students from both NU and TUM. The proposed project leverages existing strengths at NU, including expertise in advanced wastewater treatment, ultrasonic technologies, and PFAS analysis, availability of wet chemistry equipment and COMSOL at the Wells Lab and far-ranging PFAS analysis capabilities (LC/MS/MS) of the Dichtel Lab / IMSERC.

**Budget and Duration:** We request \$85K for 1 year, including US reactor and lab supplies (\$15K), personnel costs (\$47K), PFAS analysis costs (\$18K), and travel costs for NU/TUM student mobility (\$5K).

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