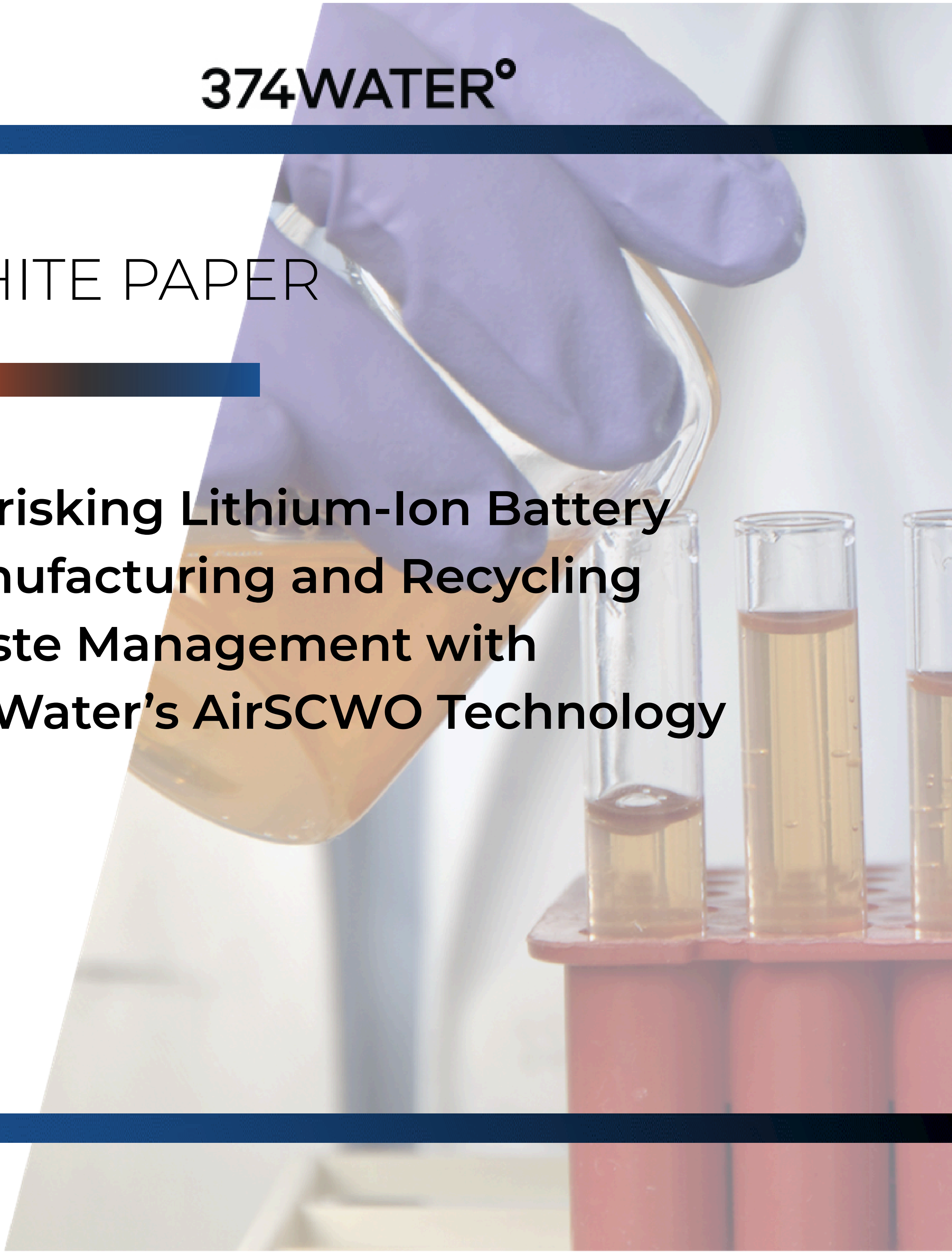

WHITE PAPER

De-risking Lithium-Ion Battery Manufacturing and Recycling Waste Management with 374Water's AirSCWO Technology

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Abstract

Lithium-ion batteries (LiBs) play a critical role in a plethora of major industries including transportation, electronics, and solar power. While performance, and longevity of LiBs is improved by the use of per- and polyfluoroalkyl (PFAS) additives, the incidental release of these additives to the environment through battery manufacturing and recycling operations can negatively impact the environment, human health, and financial outcomes. Current battery manufacturing and recycling waste treatment methods are not designed to eliminate PFAS, highlighting the need for advanced solutions. Supercritical water oxidation (SCWO) has been shown to destroy PFAS in a variety of complex waste streams, rendering it a promising solution. 374Water's AirSCWO technology was used to treat solutions containing HQ-115, an additive used commercially in Lithium-ion batteries. HQ-115, also known as Lithium bis(trifluoromethanesulfonyl)imide (LiTFSI), is a type of bis-perfluoroalkyl sulfonimides (bis-FASIs), which are a subclass of PFAS.The multi-lab verified results demonstrate that treatment with AirSCWO achieved >99.999% reduction in HQ-115 concentrations in under 30 seconds. These results suggest that 374Water's AirSCWO technology could be applied for the rapid destruction of PFAS-based LiB additives and may enhance sustainability in the manufacturing and recycling of LiBs, once commercialized.

The Challenge

The rising demand for Lithium-ion batteries (LiBs) is closely tied to the growth of industries reliant on electrification. A prominent example is the US automobile industry, where electric vehicles (EVs) are projected to account for 67% of all light-duty vehicles sales in 2032[1]. Recent and ongoing improvements to LiBs can in part be attributed to the development of fluorinated electrolyte additives, like bis-perfluoroalkyl sulfonimides (bis-FASIs). These additives improve battery performance[2], serve as flame retardants[3], increase the energy available from a single charge[4], and increase operational lifetime[4]. As shown in Figure 1, select examples include Lithium bis(trifluoromethanesulfonyl)imide (LiTFSI or HQ-115), 1,1,1-Trifluoro-N-(trifluoromethanesulfonyl)methanesulfonamide (TFSI), and Lithium hexafluorophosphate (LiPF6). The introduction of these PFAS-based additives during the manufacturing process adds new challenges in treating the waste generated.

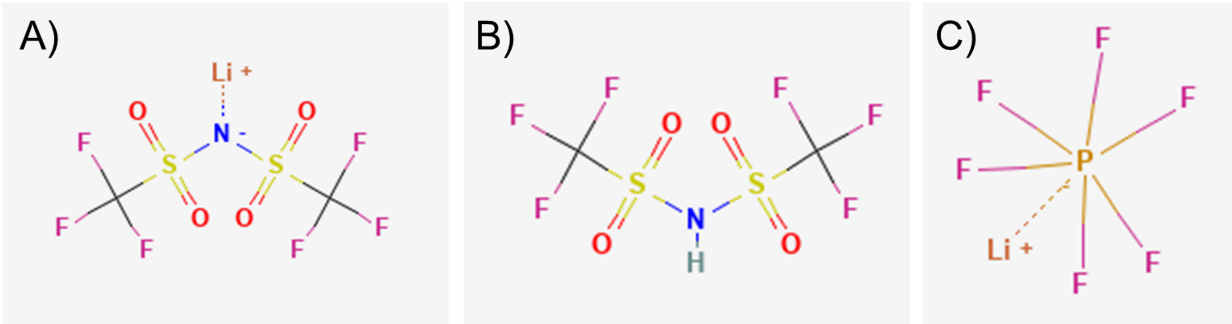

Figure 1. The structures of A) HQ-115 (also known as LiTSFI), B) TFSI, and C) LiPF6. Images taken from the NIH NCBI database [5,6,7]

The growth of the LiB industry is accompanied by a growth in the battery recycling industry; in 2020 the global supply for EV battery recycling alone was 250 kilotons, by 2040 that number is expected to increase by almost two orders of magnitude to about 20,000 kilotons per year.[8] While battery recycling processes differ, generally, batteries are broken down via mechanical means before valuable components are separated out. Some processes involve a submerged chemical reaction in which the energetic battery cells are discharged into a large tank of water. These processes generate wastewater streams contaminated with fluorinated electrolytes with bis-FASIs released from the batteries as well as various organic compounds from the battery recycling process.

While the environmental impact of LiB manufacturing and recycling remains to be fully understood, there is increasing evidence that this process may release various compounds to the environment, particularly PFAS. An article published in the newly released July 2024 edition of Nature Communications offers a glimpse of the extent and degree of environmental contamination by these fluorinated electrolytes.The authors of "*Lithium-ion battery components are at the nexus of sustainable energy and environmental release of per- and polyfluoroalkyl substances*" collected over 100 samples from various locations around the world near PFAS manufacturing facilities. They found PFAS including fluorinated electrolytes present in surface water, snow, and soils in the areas around EV battery factories.[9]

To prevent the environmental release of these PFAS compounds, LiB recycling operations must incorporate wastewater treatment technologies capable of destroying these and other organic contaminants. To date, relatively little attention has been paid to the fate of fluorinated electrolytes, especially those that fall into the bis-FASI class. No technology has been adopted at scale in the battery manufacturing or recycling industries to specifically target the elimination of these compounds in the wastewater.

In this study supercritical water oxidation (SCWO) was used to destroy HQ-115, a fluorinated electrolyte with chemical formula $C_2F_6LiNO_4S_2$. HQ-115 is of special interest because it is ubiquitous in batteries and is the only bis-FASI on the EPA's list of regional screening levels for PFAS compounds.[10]

The Solution

374Water offers air-based supercritical water oxidation (AirSCWO) as a waste treatment technology that can destroy challenging contaminants like PFAS including HQ-115. SCWO is a physical thermal process that is powered by water above its critical point (374°C and 221 bar) and an oxidant. This combination yields a highly effective oxidation reaction that completely eliminates organic compounds such as solvents and fluorinated electrolytes. Named the “3rd Generation of SCWO” by the U.S. EPA, 374Water's AirSCWO process uses a scalable tubular reactor, and air rather than pure oxygen. Multi-stream feed-stock mixing and preheating prevents fouling and charring, and an efficient energy recovery system minimizes the cost to heat and pressurize the treated waste in excess of 374°C and 221 bar.

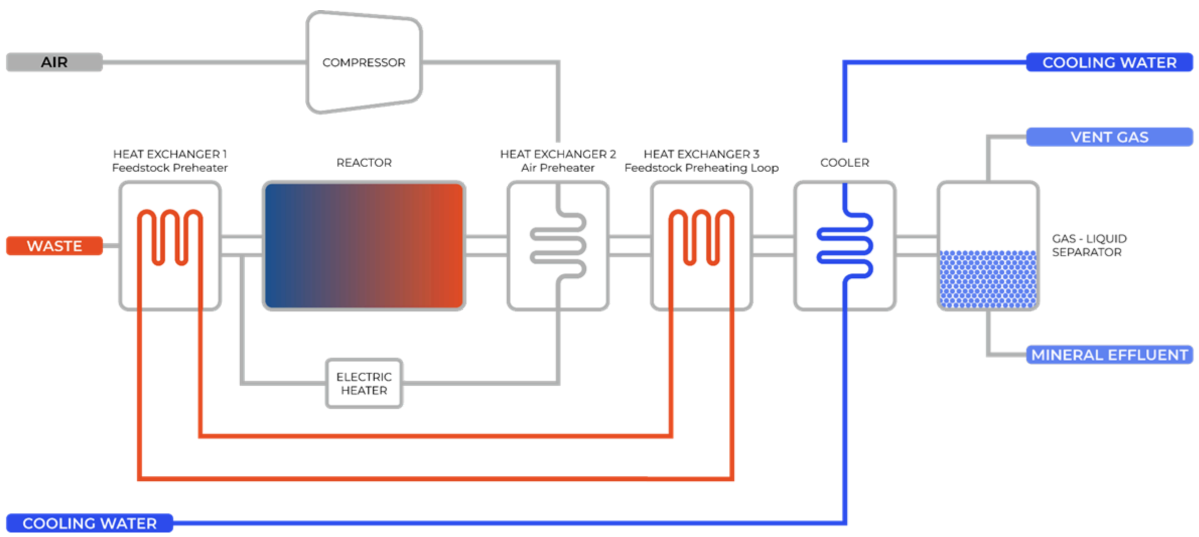

Figure 2. Schematic of 374Water’s SCWO system

374Water treated liquid solutions containing HQ-115, solvent (fuel), and water through the AirSCWO reactor. During these tests, the AirSCWO reactor was brought up to operating temperature and pressure, then fed with the solutions to be destroyed until adequate effluent volumes were collected for analysis. Several reaction conditions were examined. This research provides novel insights on the fate of the carbon-fluorine bonds in a complex PFAS electrolyte and the mineralization of HQ-115 under different SCWO operating conditions.

Testing was carried out using a solution of 5% isopropyl alcohol (co-fuel) and 0.1% HQ-115 in water, or 1,000,000,000 parts per trillion (ppt or ng/l). The reactor was operated at 570-600°C, with residence times between 19 and 30 seconds. Samples were collected and analyzed for HQ-115 and other byproducts by commercial labs. The reactor used for these tests has previously been used to run other fluorinated wastes and is regularly flushed and measured to ensure that no background contamination remains in the reactor.

The Results

Samples of the SCWO effluent were sent to two leading 3rd party independent laboratories PFAS analysis, where the presence of the HQ-115 was assessed using a cutting edge mass spectroscopy method. In every analysis, HQ-115 in the effluent was reduced by over 99.999%, resulting in a final concentration of 34-110 ppt, compared to 1,000,000,000 ppt in the feedstock.

Table 1. Details of the SCWO run on the HQ-115 solutions

Sample ID	Initial Concentration of LTFSI (HQ-115)	Run Conditions			Final Effluent Concentration (lab A)	Final Effluent Concentration (lab B)*	DRE*
		Temperature	Pressure	Residence time			
Sample A	1,000,000,000 ppt	600°C	3500 psi	21 sec	100 ppt	ND	99.99990%
Sample B	1,000,000,000 ppt	570°C	3500 psi	19 sec	110 ppt	ND	99.99989%
Sample C	1,000,000,000 ppt	600°C	3500 psi	27 sec	34 ppt	ND	99.99997%
Sample D	1,000,000,000 ppt	600°C	3500 psi	21 sec	42 ppt	ND	99.99996%

*The limit of quantification for lab B was 1000 ppt. DRE stands for Destruction and Removal Efficiency

The Future

Initial testing demonstrates AirSCWO as a promising technology for the elimination of fluorinated electrolytes containing bis-FASIs like HQ-115 from wastes generated by LiB manufacturing and recycling. 374Water has additional future tests planned to expand on the findings of this study. These include expanding the number of fluorinated electrolytes tested (especially in the bis-FASI class) and conducting comprehensive fluorine balances to demonstrate the complete mineralization of the organofluorine in the PFAS into inorganic fluoride. These tests are expected to further demonstrate the application of AirSCWO to mitigate PFAS contamination in industrial processes like LiB manufacturing and recycling. Once implemented on a commercial scale, the use of SCWO in the LiB manufacturing and recycling industries can help companies reduce disposal costs, avoid potential litigation, and contribute to a cleaner environment.

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