Novel Approaches to Separate and Destroy PFAS in Residual Waste Streams

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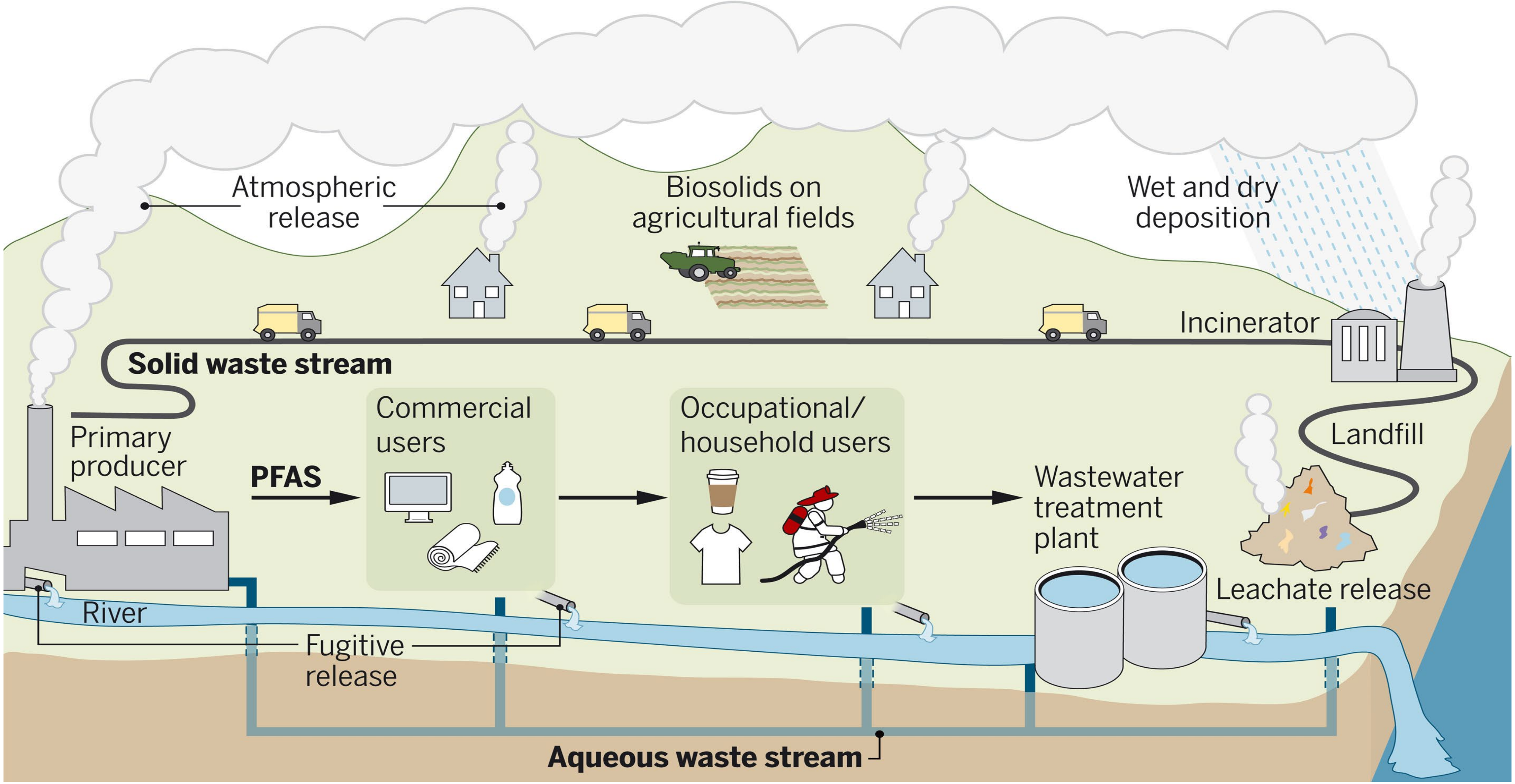
Objectives

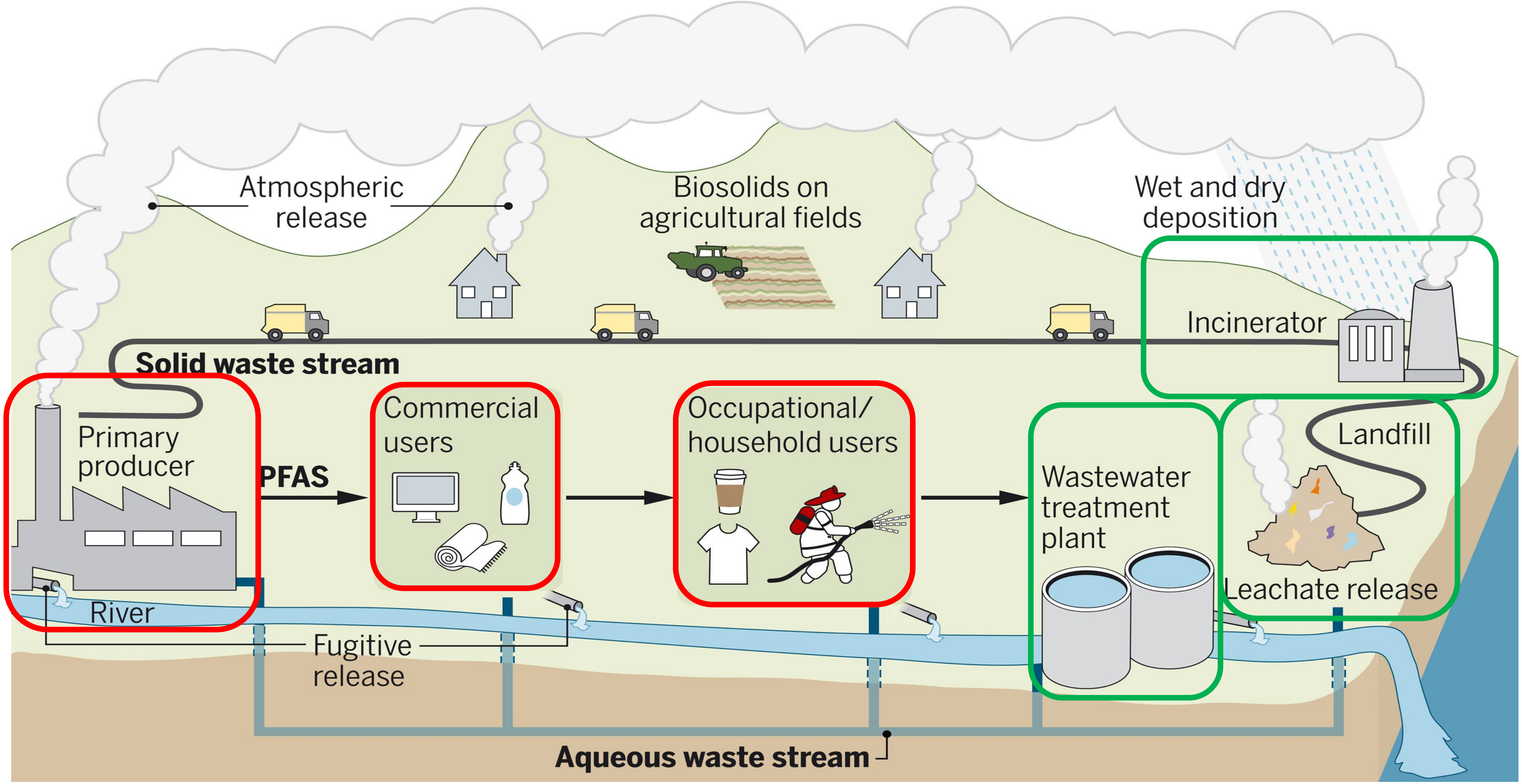
- Identify PFAS sources from residual streams
- Assess existing PFAS treatment technologies
- Review PFAS removal performance for novel adsorbents
- Propose an alternative PFAS treatment train for removal and destruction

The PFAS Cycle



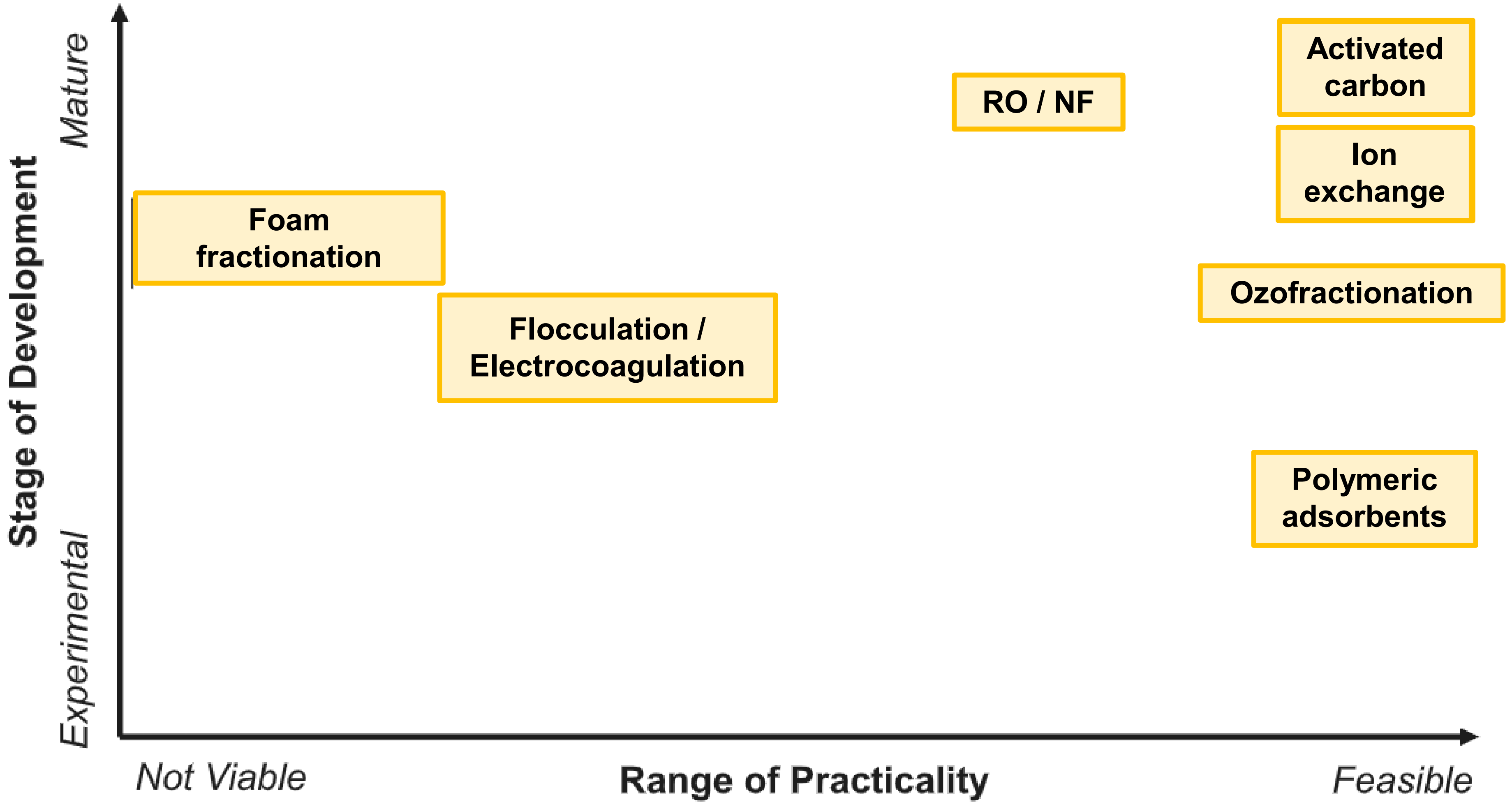
Evich et al., *Science* 2022

PFAS can enter the environment through residual waste streams.



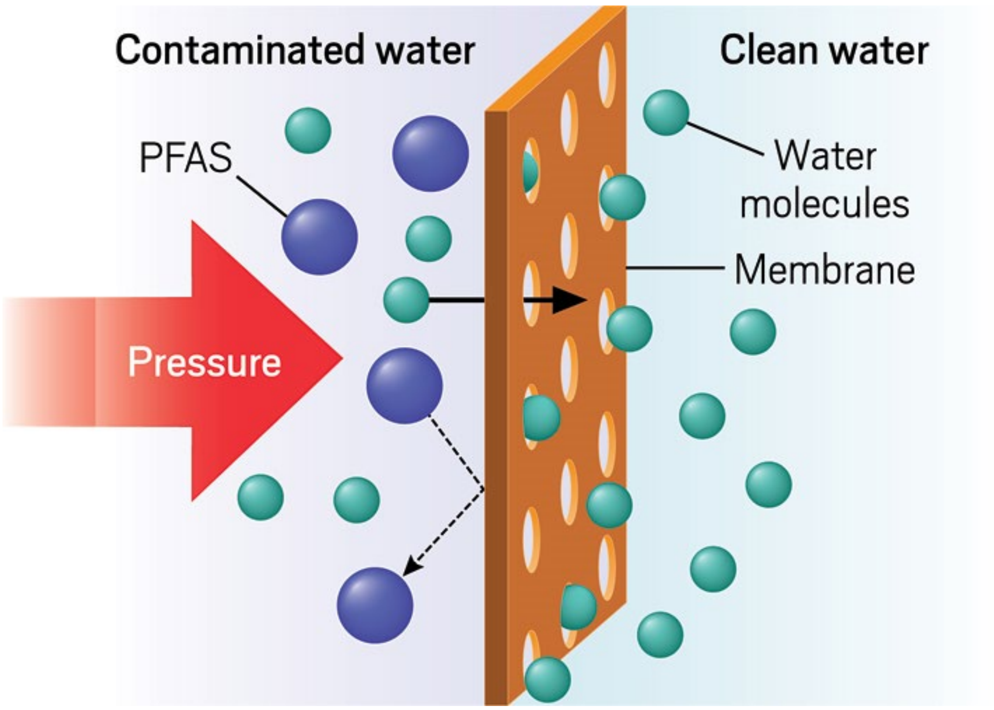
Evich et al., *Science* 2022

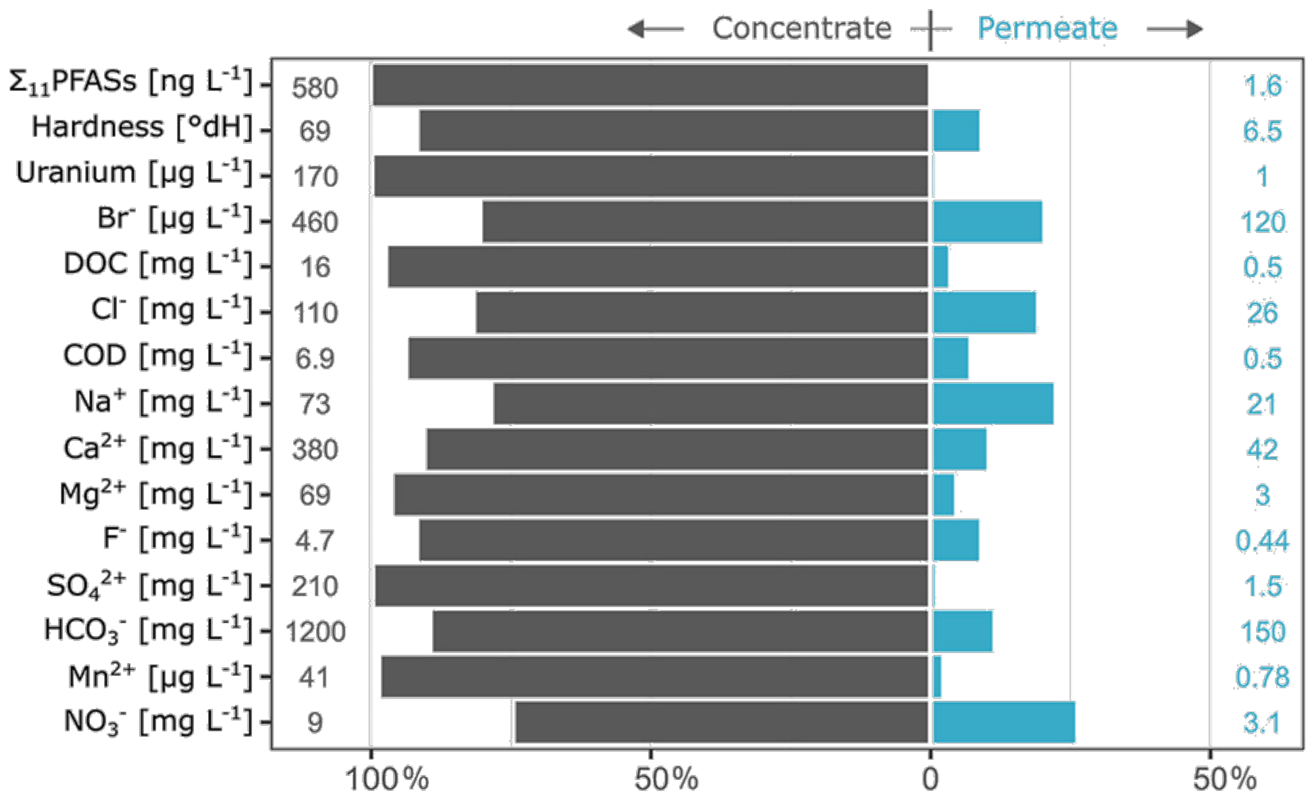
PFAS removal technologies vary in feasibility and development.



Modified from Ross et al., *Remediation* 2018, 28, 101-126

PFAS removal technologies produce complex waste streams.

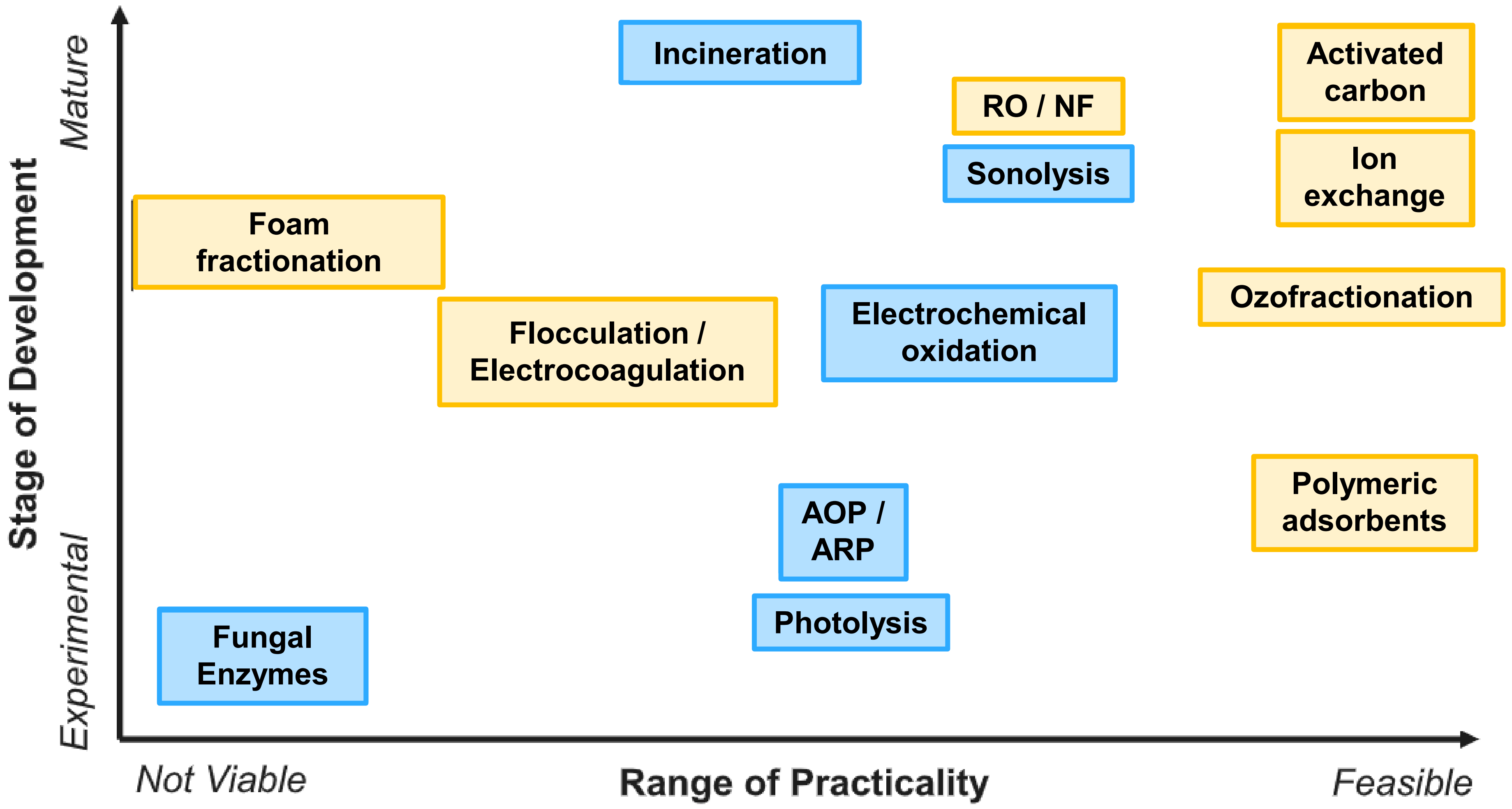




https://texasmembranerestoration.com/pfas-solutions

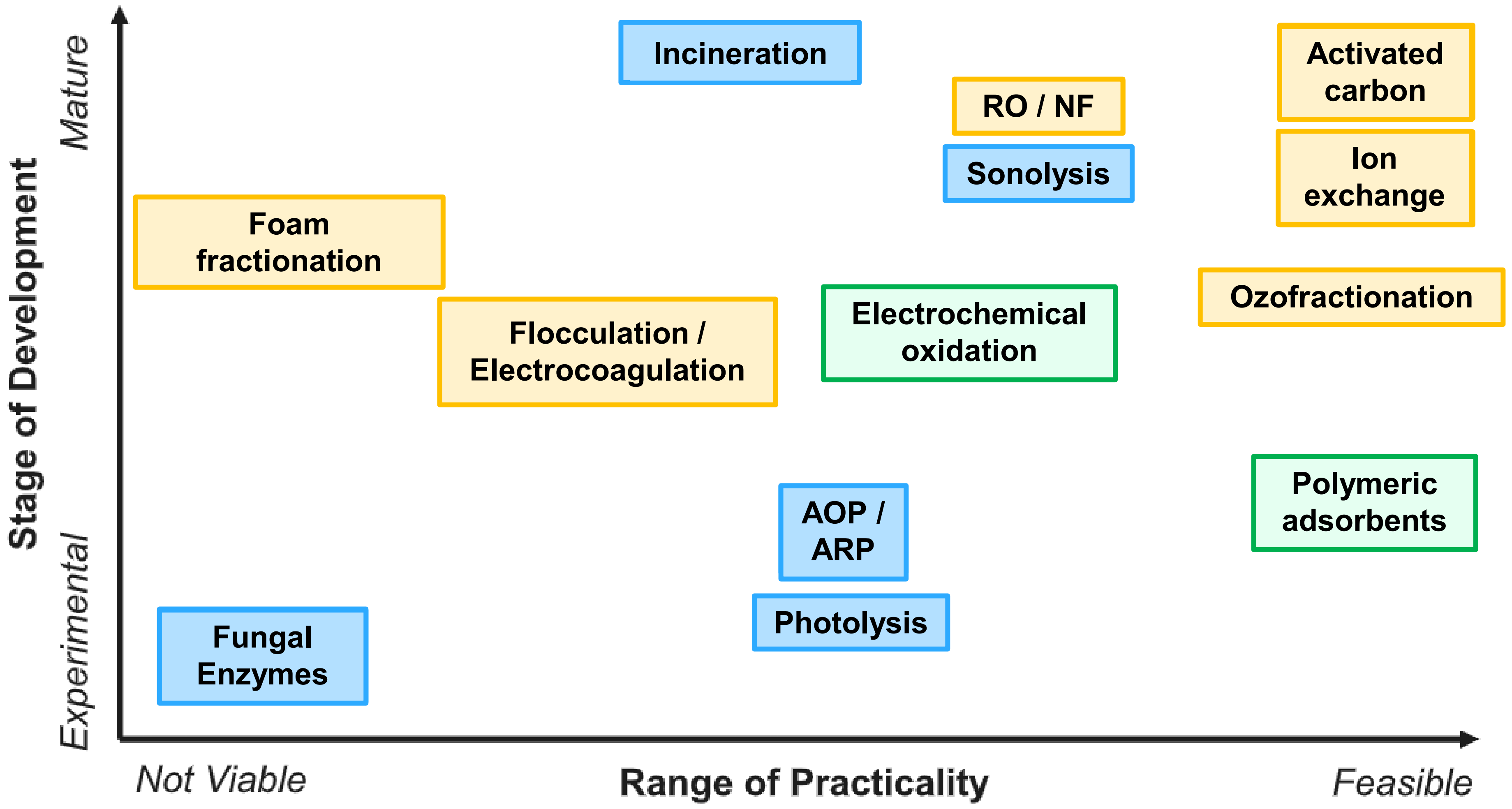
Franke, V. et al. *ACS EST Water* 2021, 1, 4, 782-795

PFAS degradation technologies vary in feasibility and development.



Modified from Ross et al., *Remediation* 2018, 28, 101-126

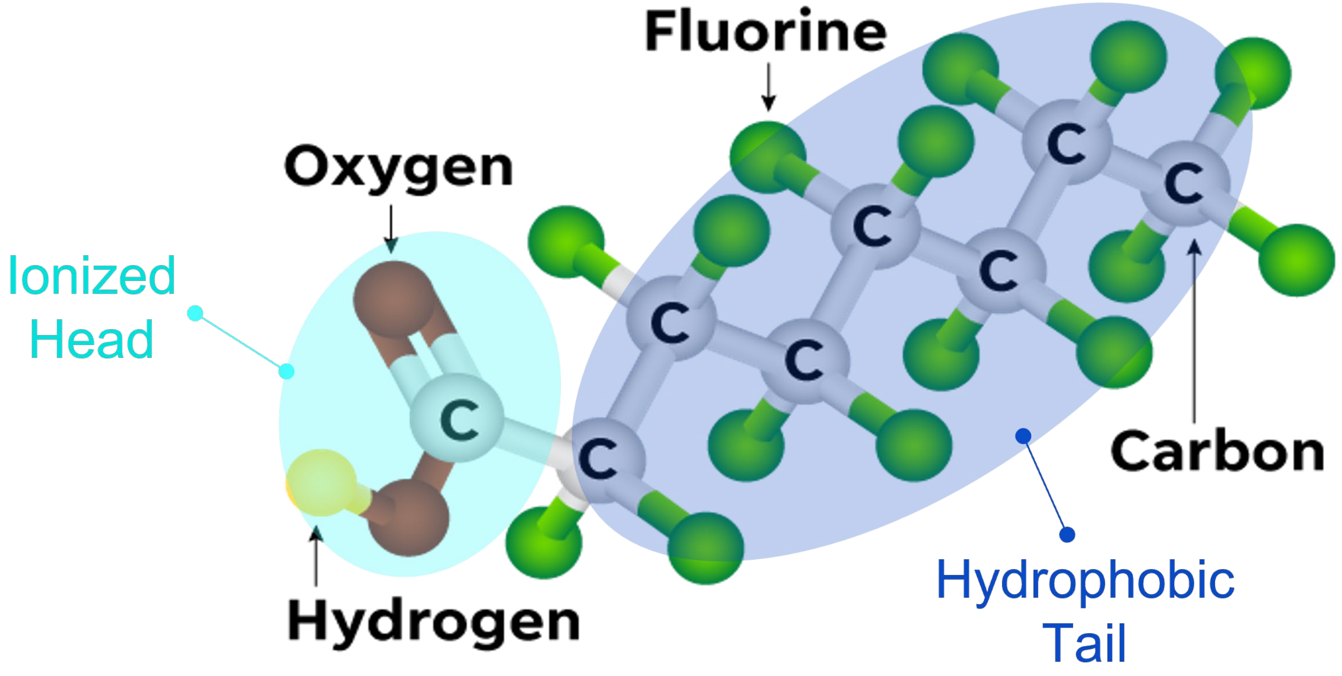
PFAS removal AND degradation technologies combined promise improved feasibility.

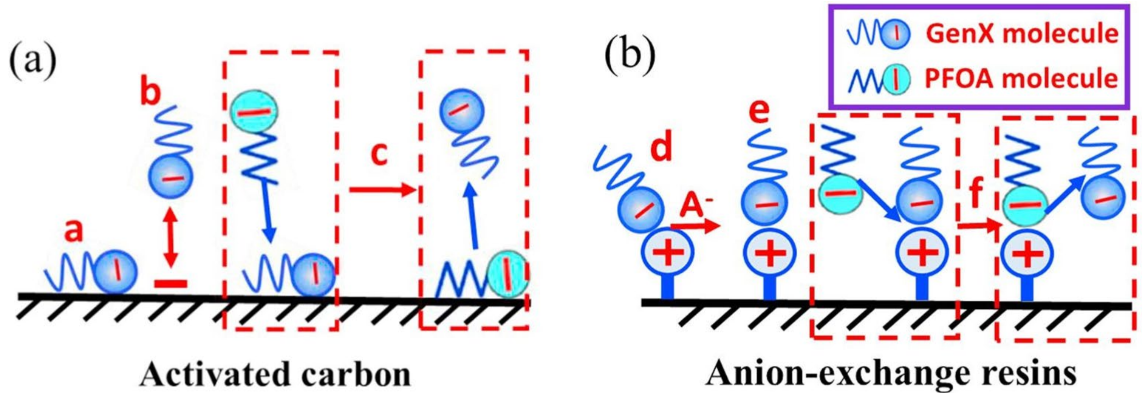


Modified from Ross et al., *Remediation* 2018, 28, 101-126

PFAS have unique properties that can result in varied removal via adsorption.

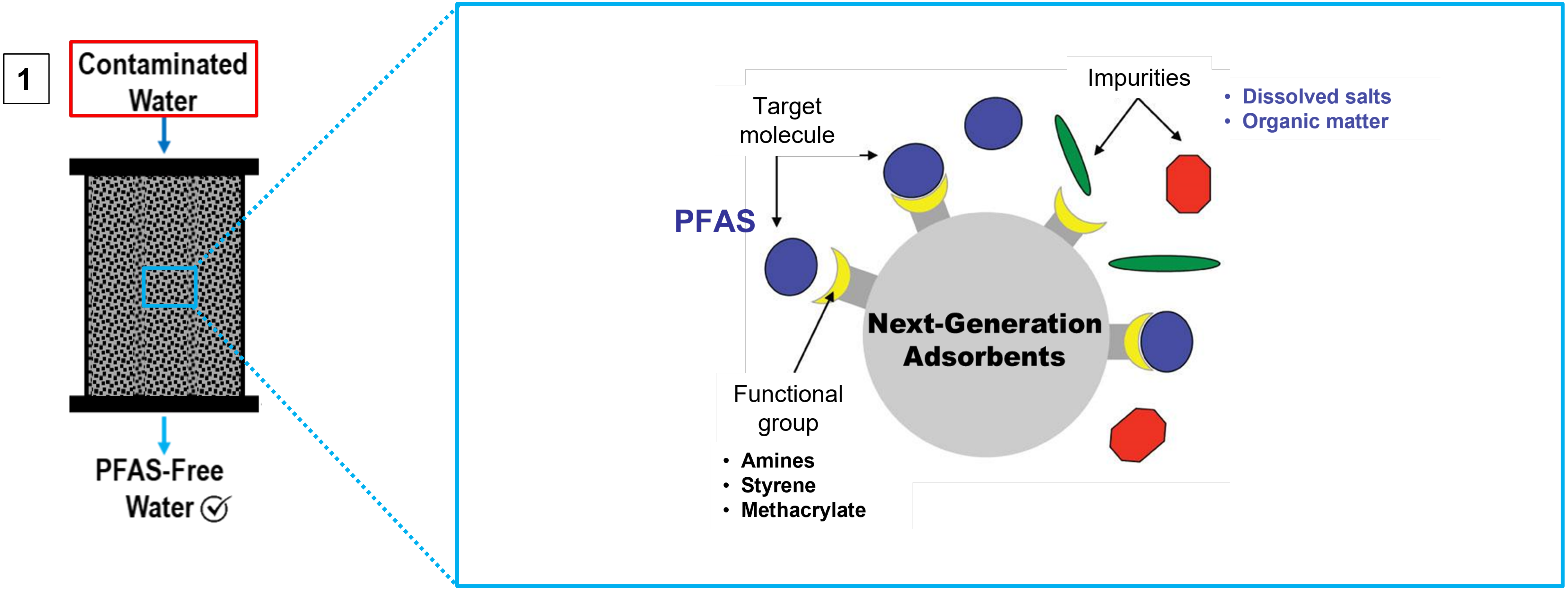
1 Contaminated Water





Wang, W. et al., *Chem Eng Journal* 2019

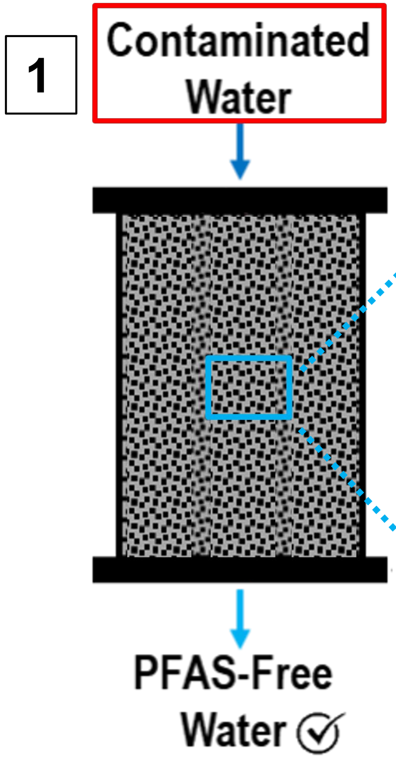
Polymeric adsorbents can be developed to target PFAS for effective removal.



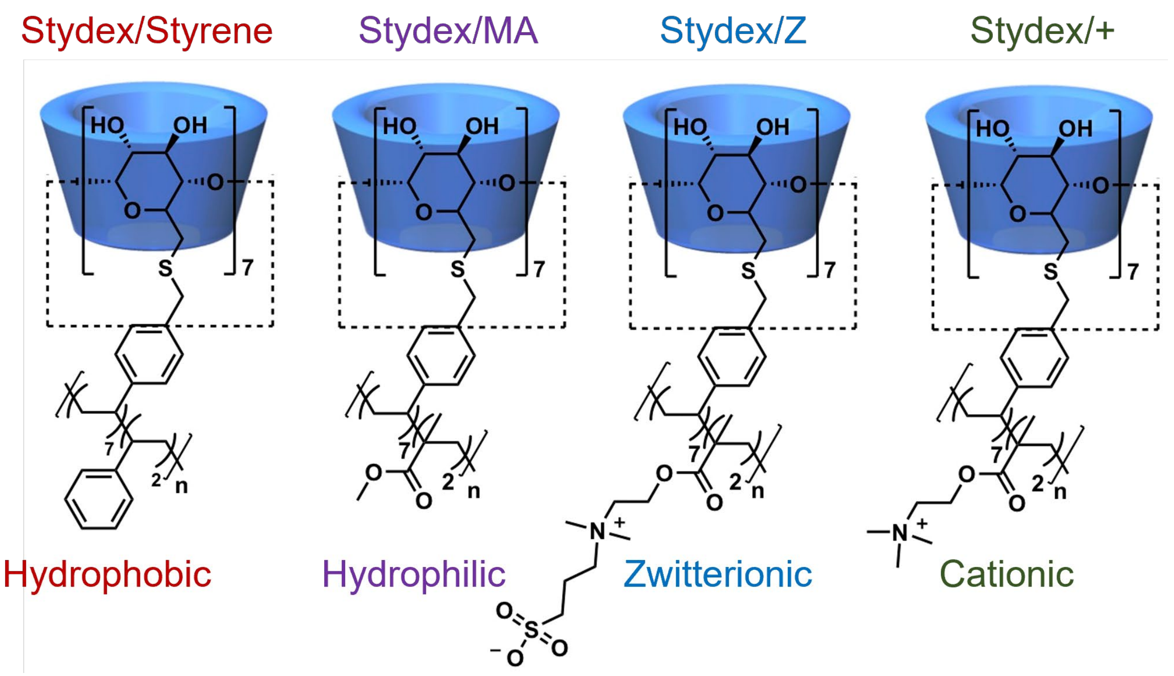
Ateia, M. et al., *ACS Materials Lett.* 2020

Figure courtesy of Mohamed Ateia, modified.

β-cyclodextrin adsorbents can be tailored to target PFAS for effective removal.



β-cyclodextrin

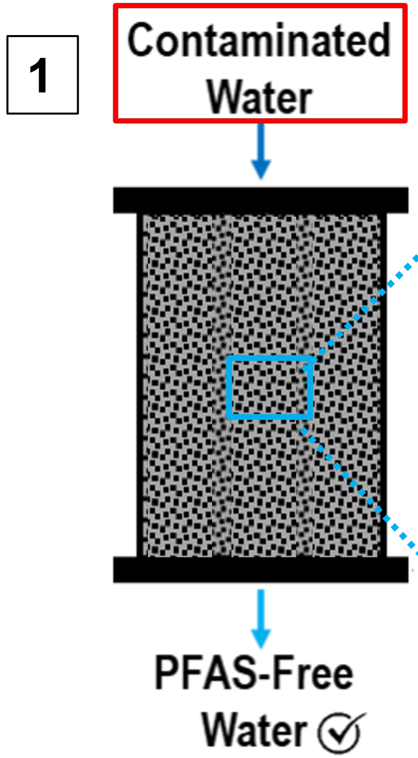


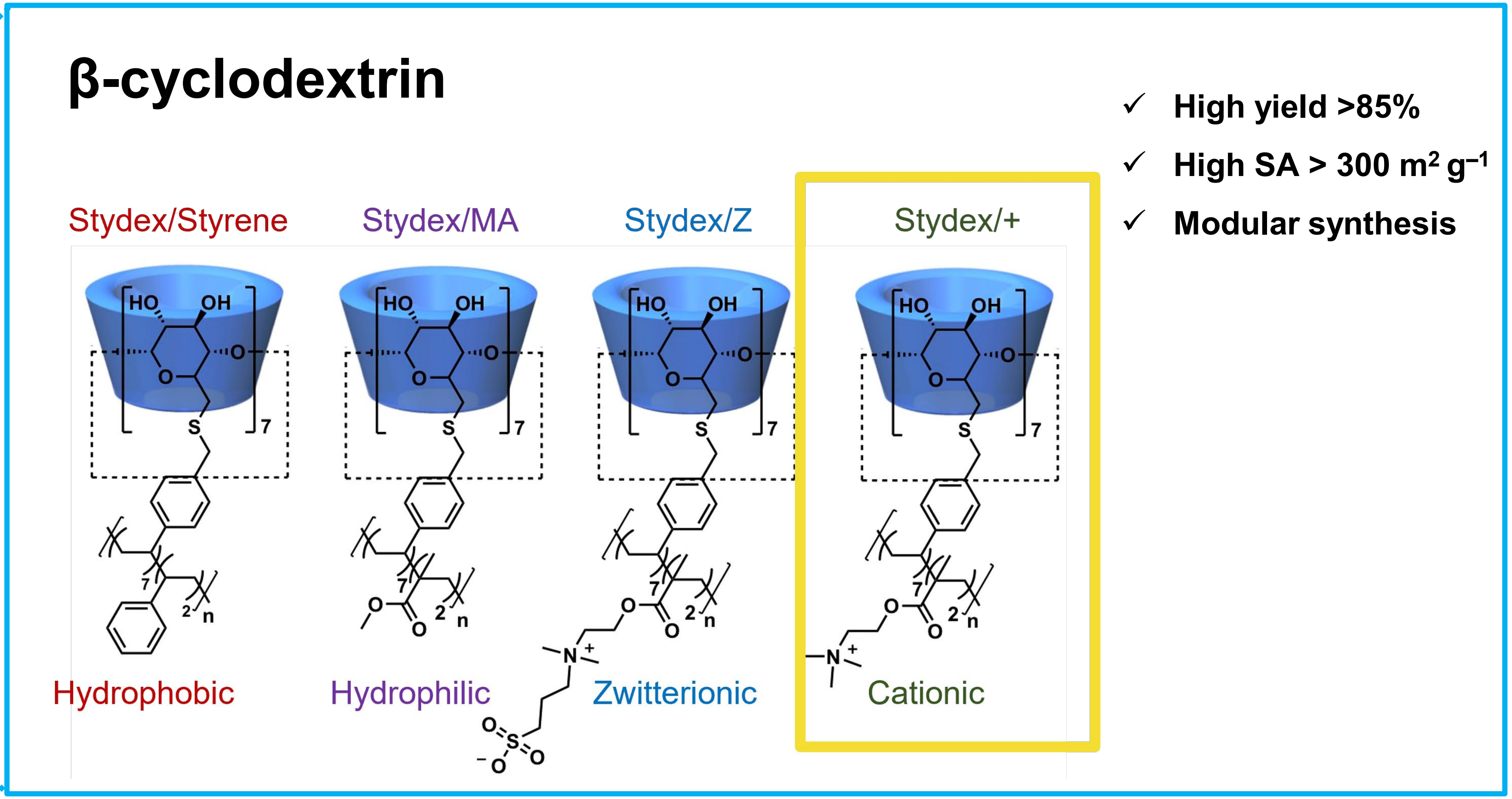
- ✓ High yield >85%
- ✓ High SA > 300 $m^2\,g^{-1}$
- ✓ Modular synthesis

Wang, R. et al., *ACS Central Science* 2022

Figure courtesy of Mohamed Ateia, modified.

β-cyclodextrin adsorbents can be tailored to target PFAS for effective removal. Cont.



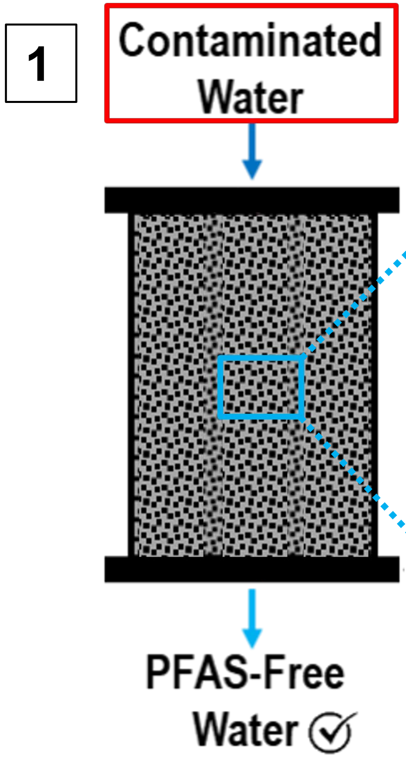


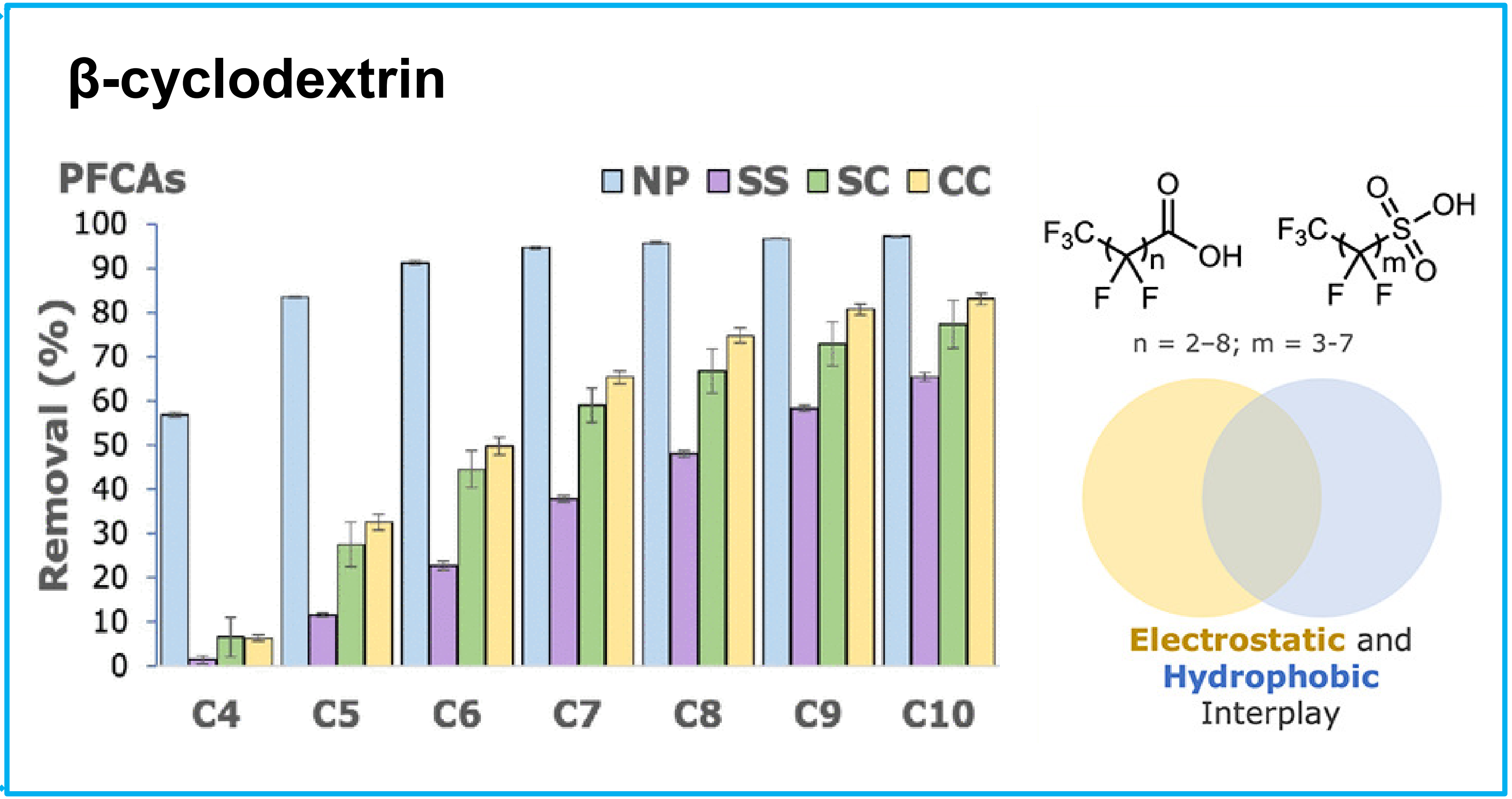
- ✓ High yield >85%
- ✓ High SA > 300 $m^2\,g^{-1}$
- ✓ Modular synthesis

Wang, R. et al., *ACS Central Science* 2022

Figure courtesy of Mohamed Ateia, modified.

Matrix components can impact interactions between the adsorbent and PFAS.



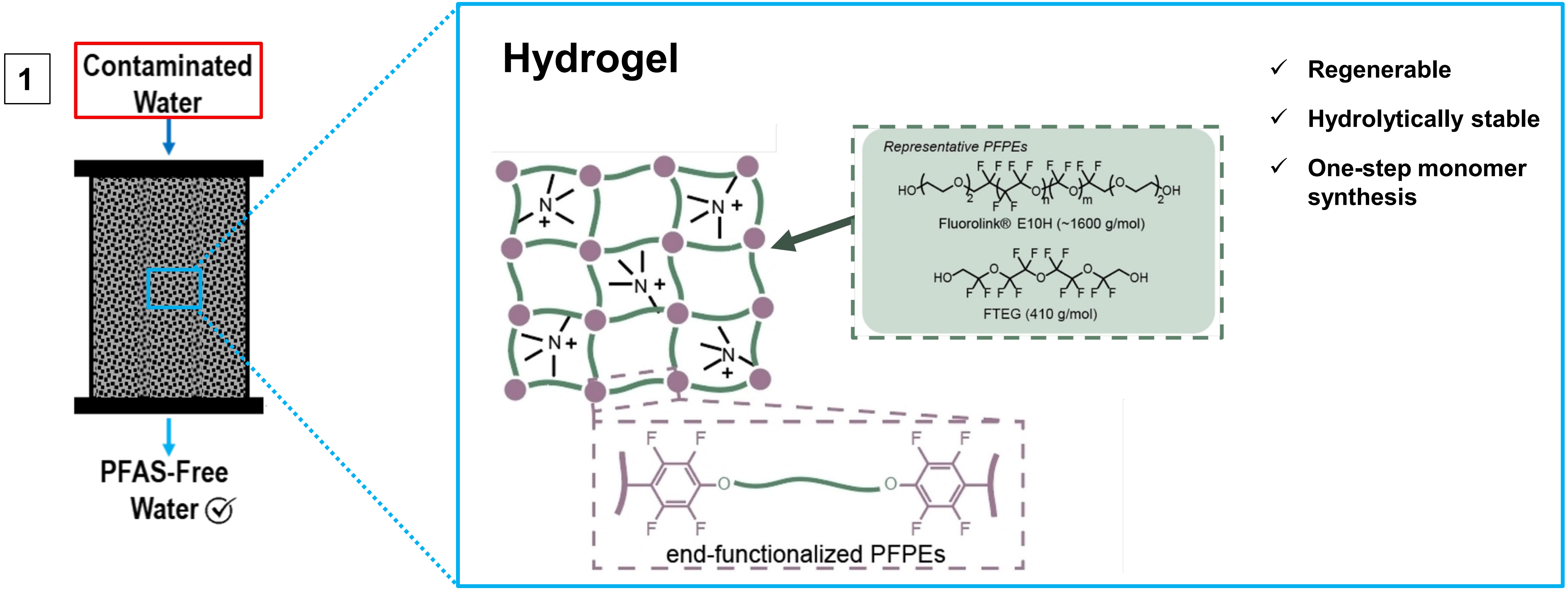


Experimental conditions. [PFCA] = 1 μg L^{-1}; Adsorbent loading: 1 mg L^{-1}; Matrices: nanopure water (NP), 1 mM Na_2SO_4 (SS), 2 mM NaCl (SC), and 1 mM $CaCl_2$ (CC); Contact time: 48 h.

Wang, R. et al., *ACS Central Science* 2022

Figure courtesy of Mohamed Ateia, modified.

Hydrogel adsorbents can be tailored to target PFAS for effective removal.

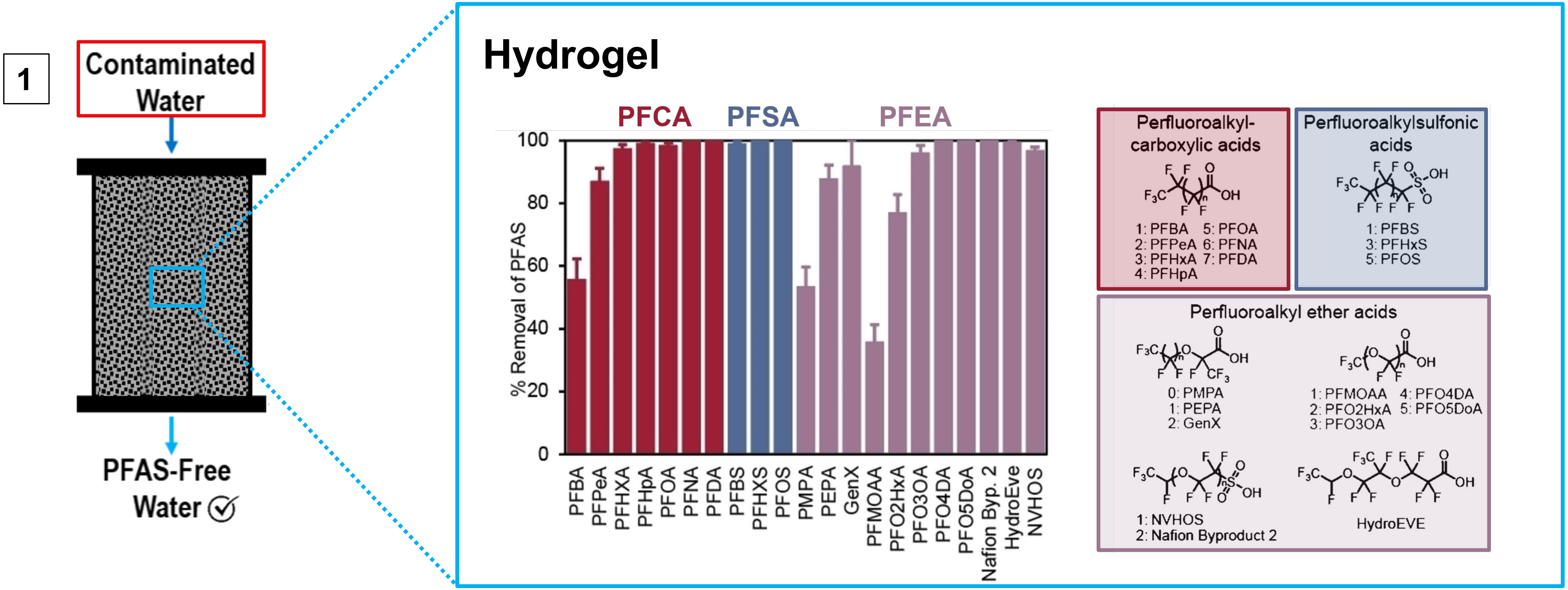


- ✓ Regenerable
- ✓ Hydrolytically stable
- ✓ One-step monomer synthesis

Manning, I. et al., *Angew. Chem. 2022,134*

Figure courtesy of Mohamed Ateia, modified.

Hydrogel adsorbents have high removal efficiency for a broad range of PFAS.



Experimental conditions. $[PFAS]_0$ = 1 µg L^{-1} each; Adsorbent loading: 100 mg L^{-1}; Matrix: conventional water; Contact time: 24 h.

Manning, I. et al., *Angew. Chem. 2022,134*

Figure courtesy of Mohamed Ateia, modified.

Polymer adsorbents may be regenerated…

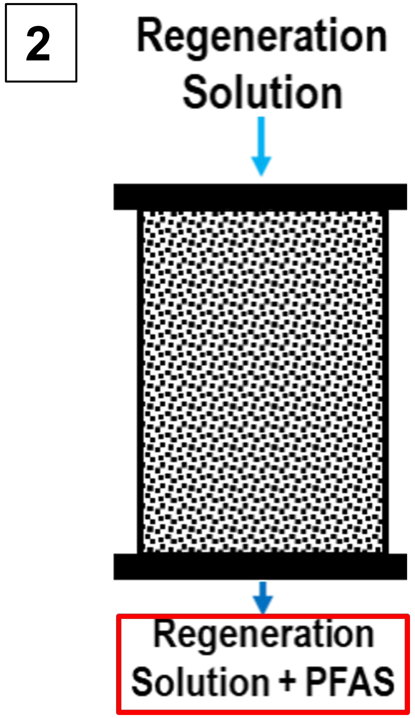


Figure courtesy of Mohamed Ateia, modified.

Polymer adsorbents may be regenerated…and regeneration solution recycled.

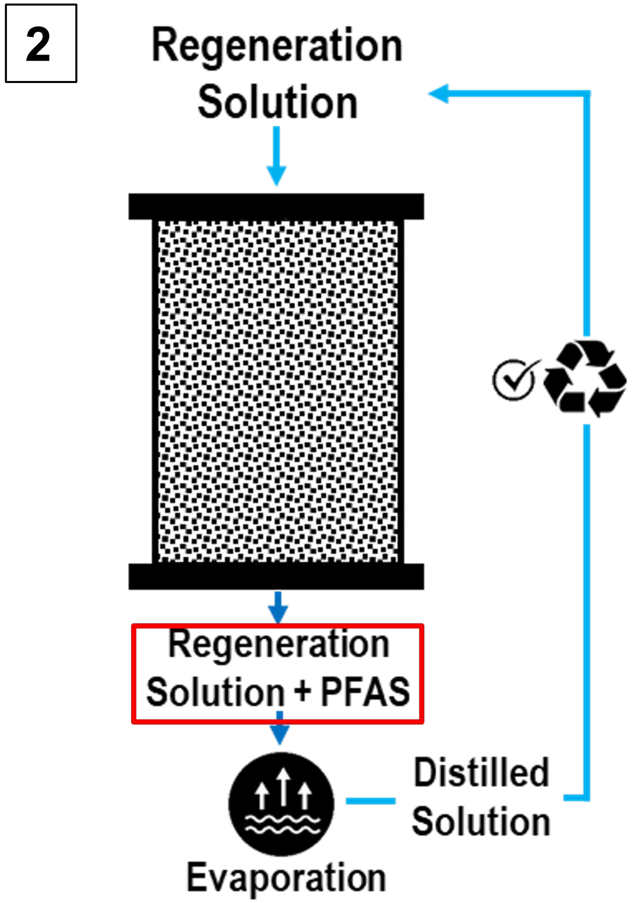


Figure courtesy of Mohamed Ateia, modified.

Polymer adsorbents may be regenerated… but produce concentrated waste streams.

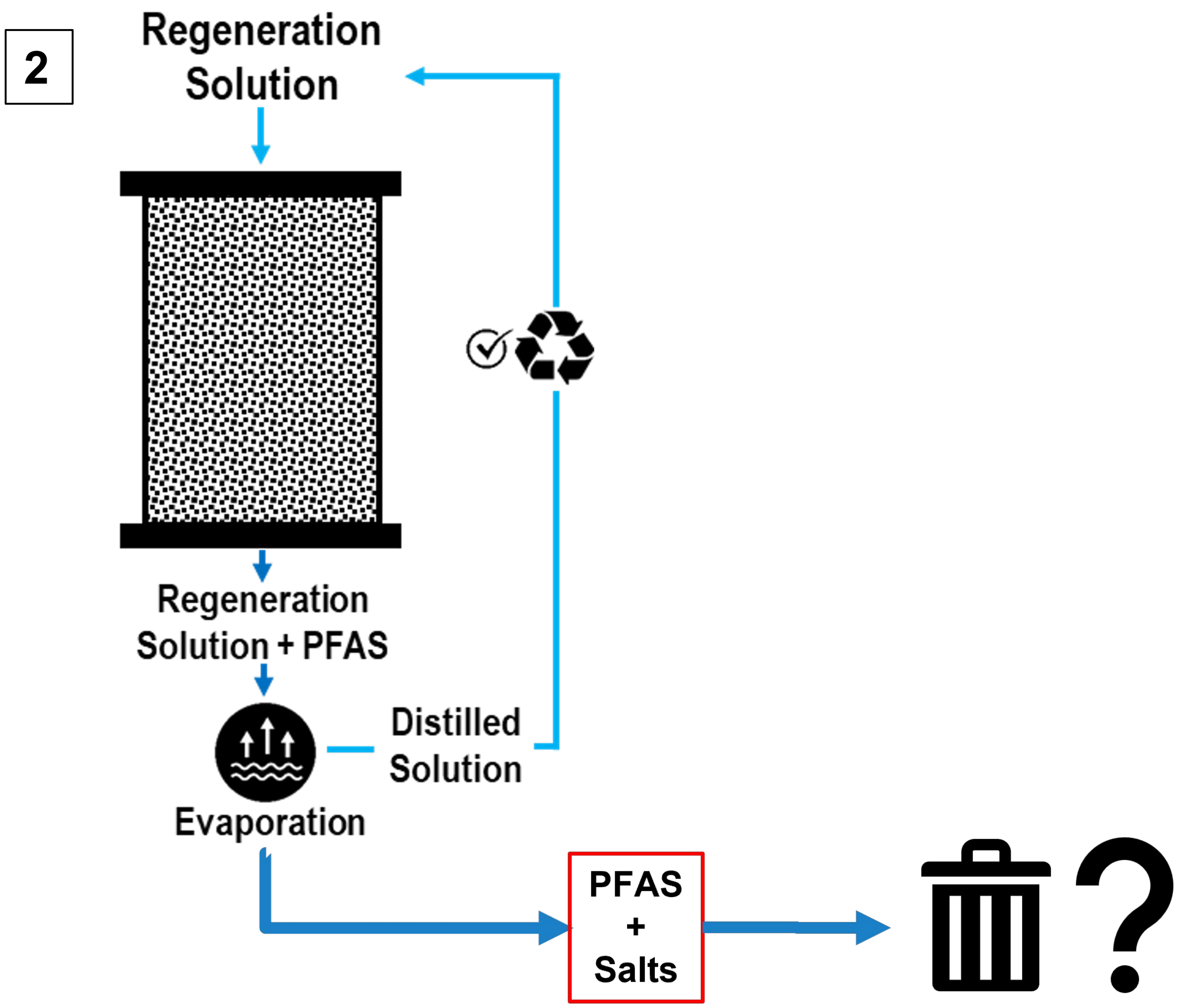


Figure courtesy of Mohamed Ateia, modified.

PFAS-laden regeneration streams can be redirected back to adsorbents for removal.

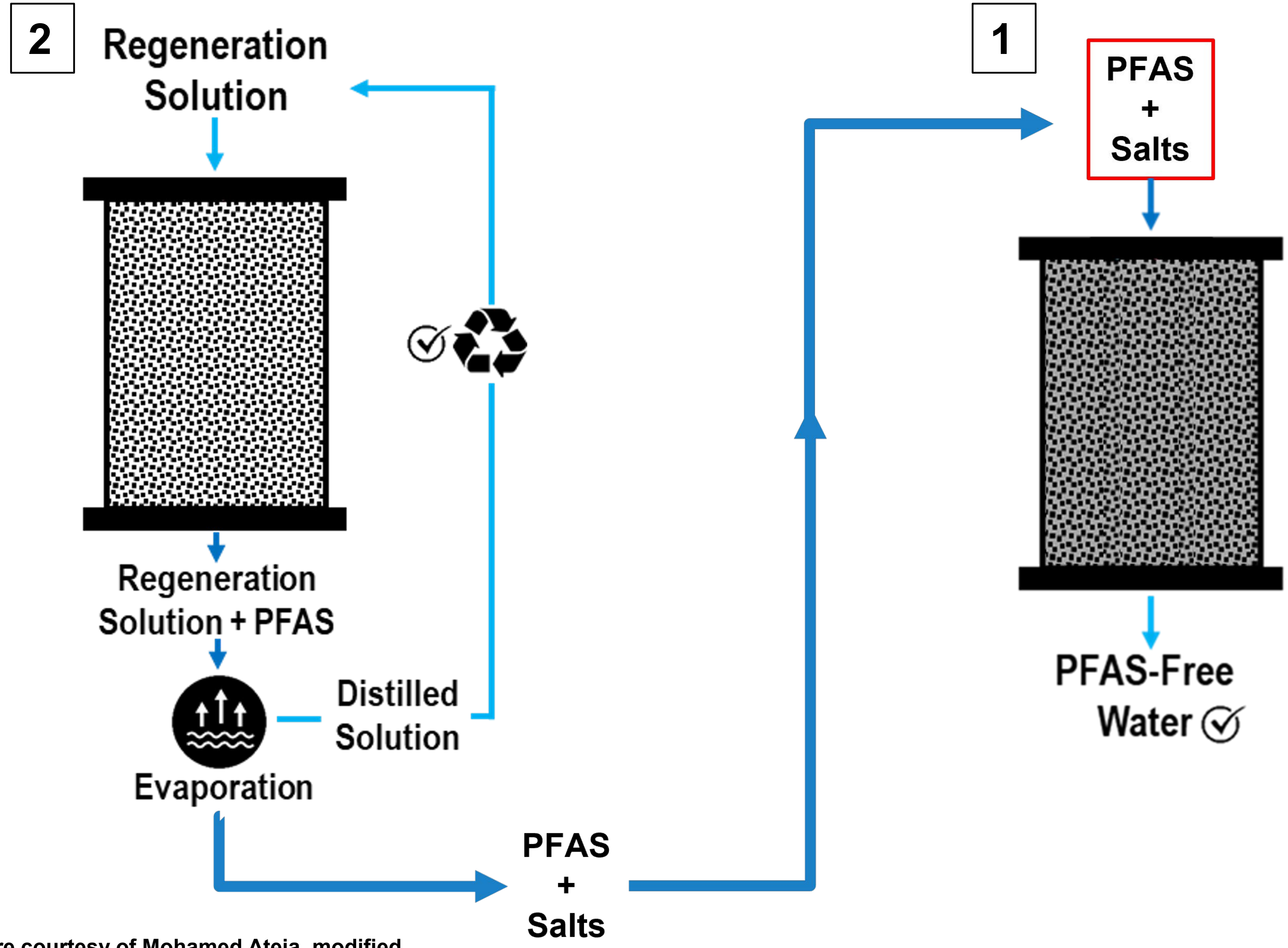


Figure courtesy of Mohamed Ateia, modified.

Treating PFAS-laden regeneration streams can decrease adsorbent performance.

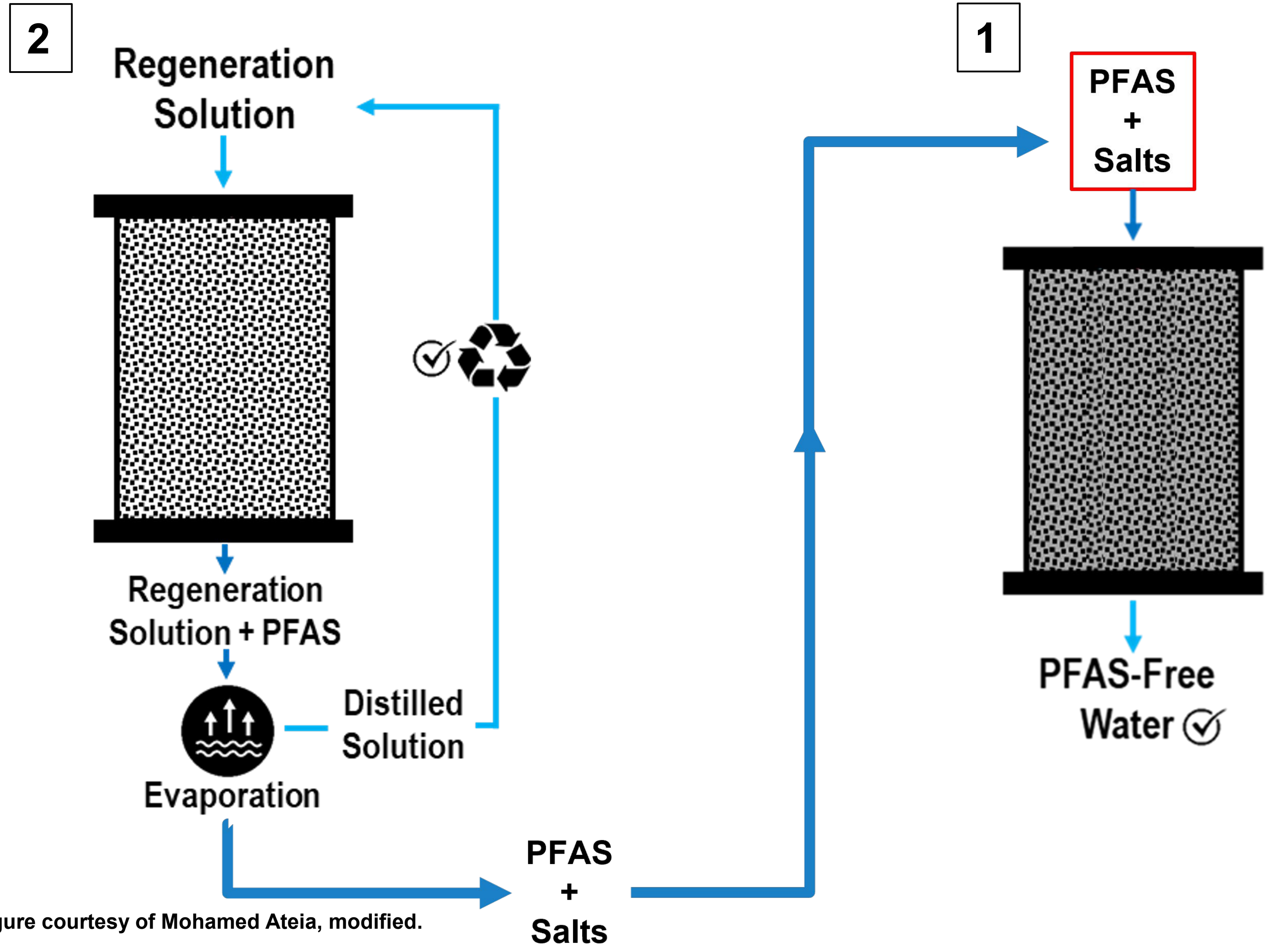


Figure courtesy of Mohamed Ateia, modified.

- ↓ **Adsorbent capacity**
- ↓ **Adsorbent lifetime**
- ↑ **Process cost**
- ↑ **PFAS concentration**
- ? **Matrix effects**
- ? **Ultimate disposal**

PFAS-laden regeneration streams can be eliminated with destruction technologies.

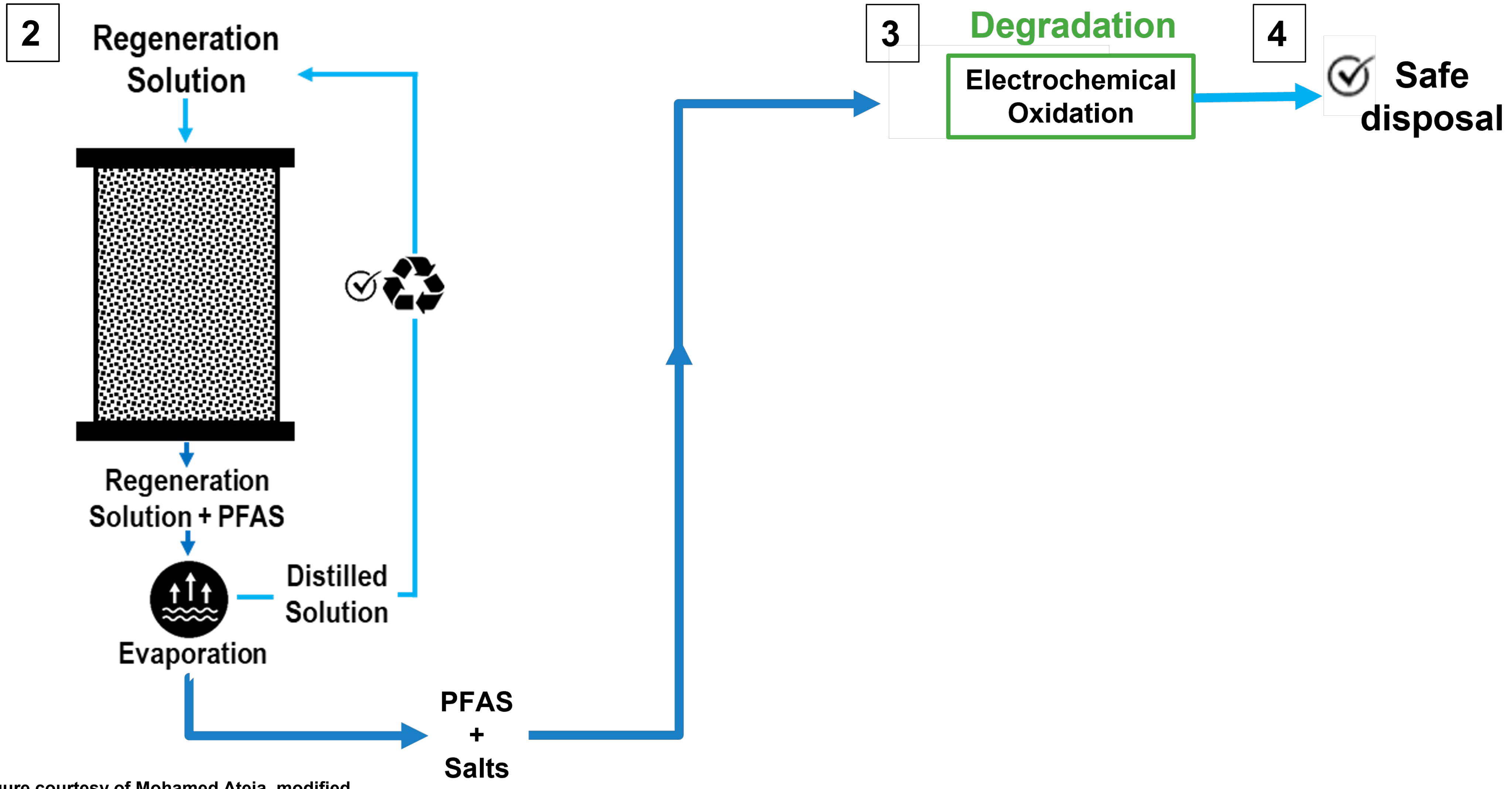


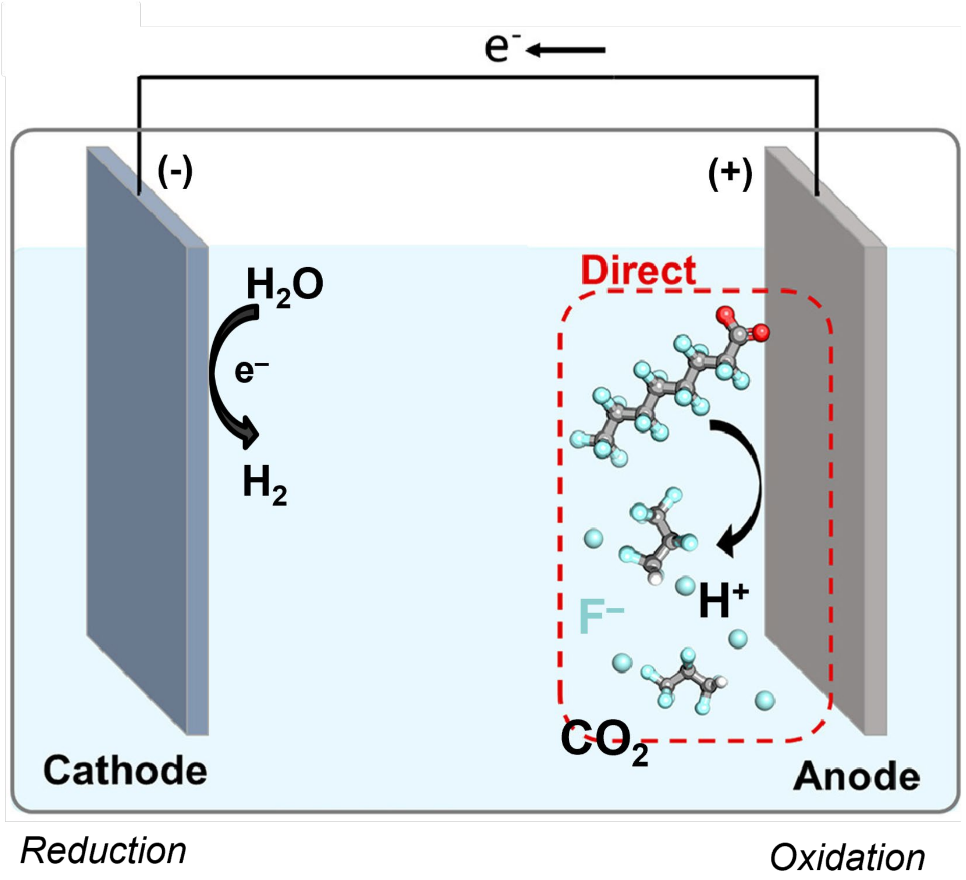
Figure courtesy of Mohamed Ateia, modified.

PFAS-laden regeneration streams provide opportunity for electrochemical degradation.

3

Degradation

Electrochemical Oxidation



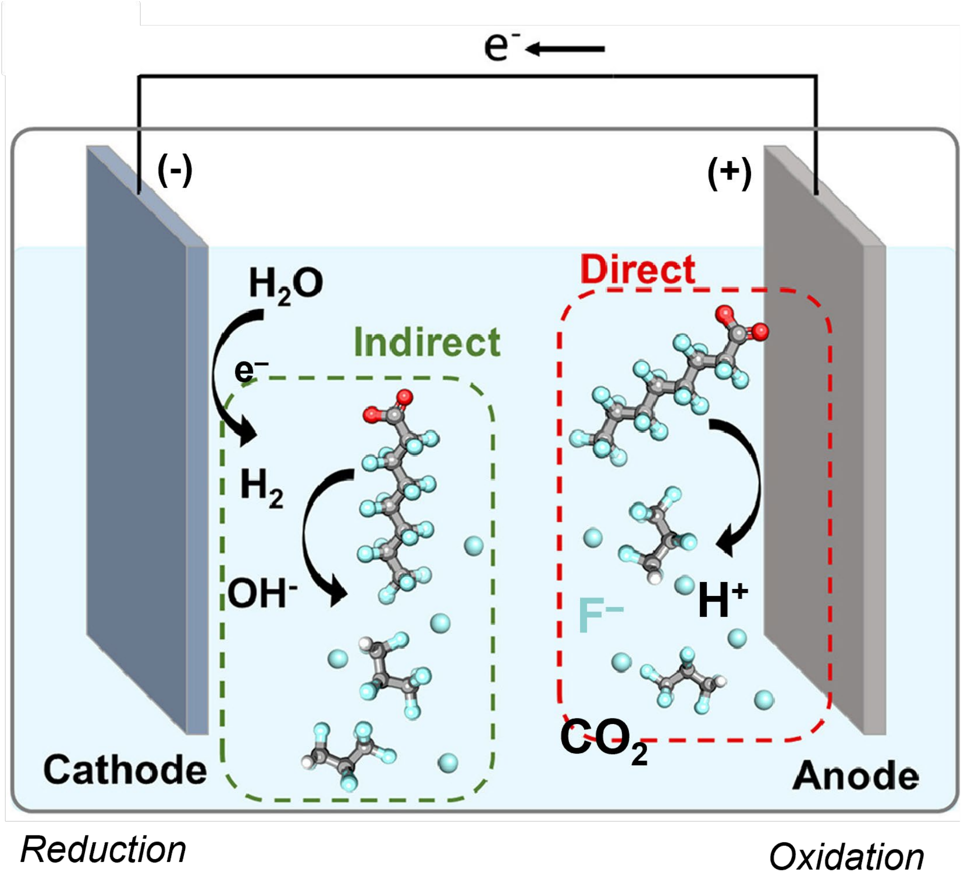
Santiago, A. et al. *Electrochimica Acta* 2022

PFAS can be electrochemically degraded via direct or indirect mechanisms.

3

Degradation

Electrochemical Oxidation



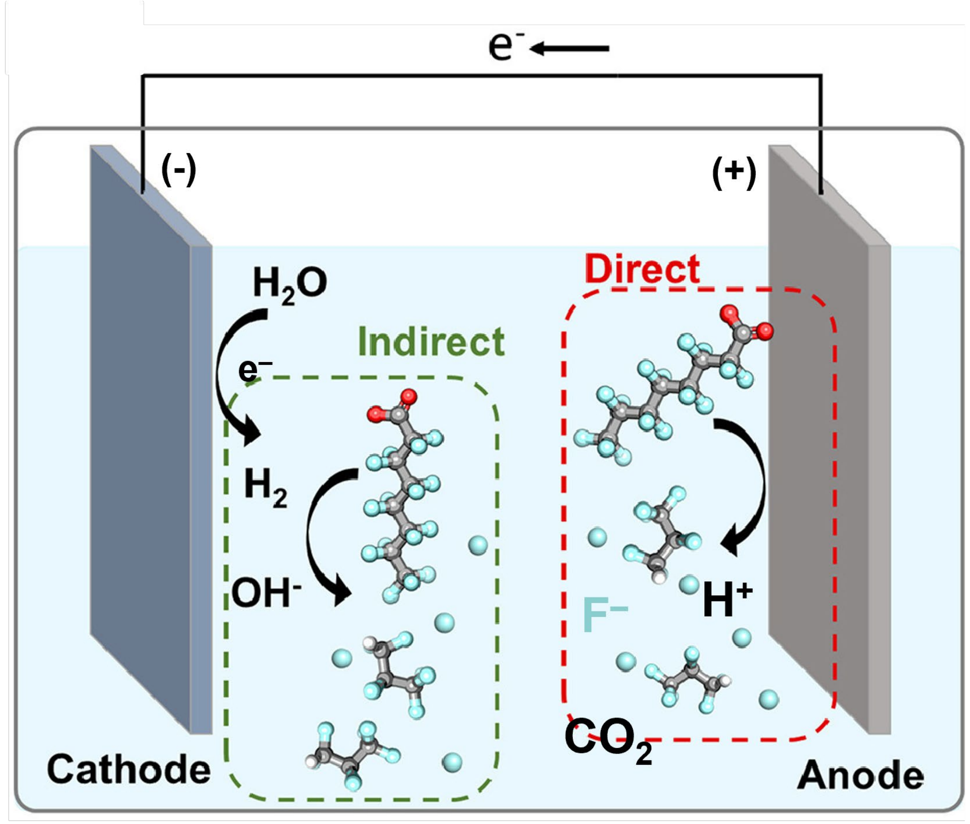
Santiago, A. et al. *Electrochimica Acta* 2022

PFAS electrochemical degradation mechanisms are complex and not well-defined.

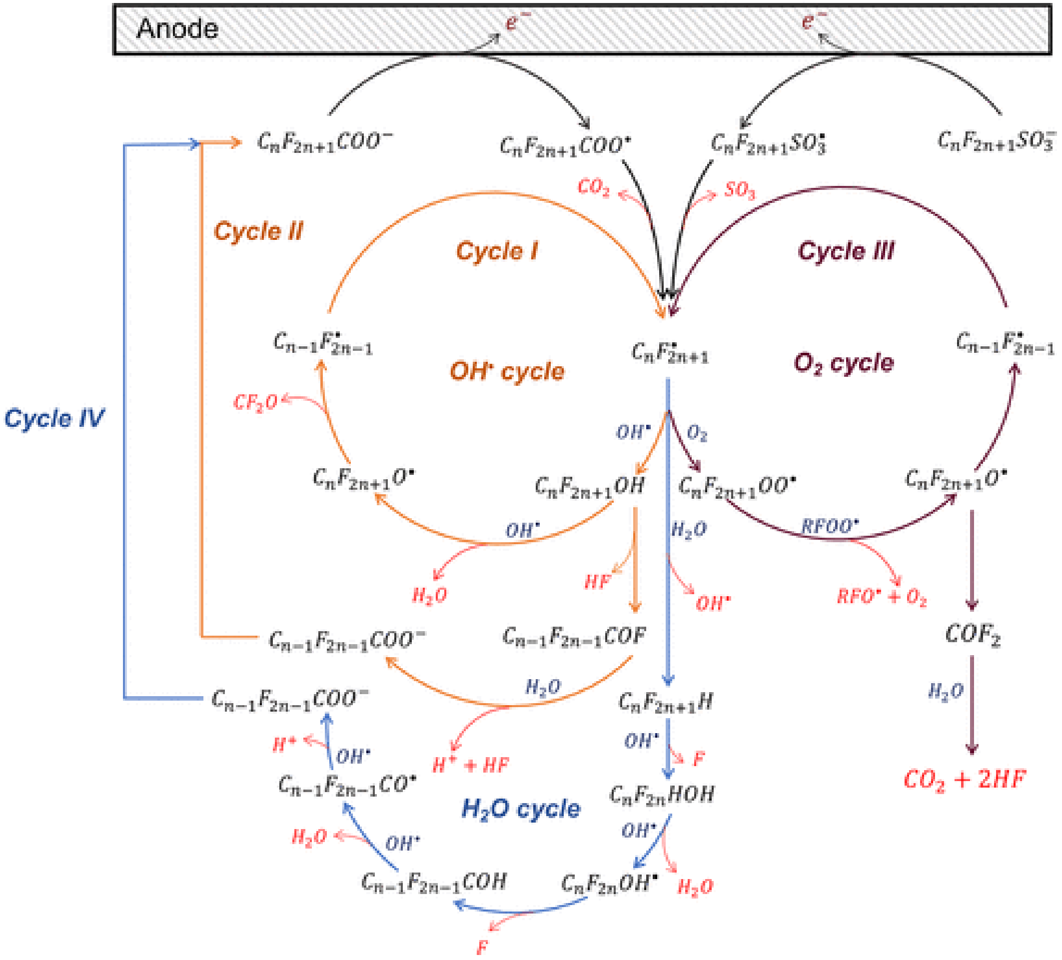
3

Degradation

Electrochemical Oxidation



Reduction *Oxidation*



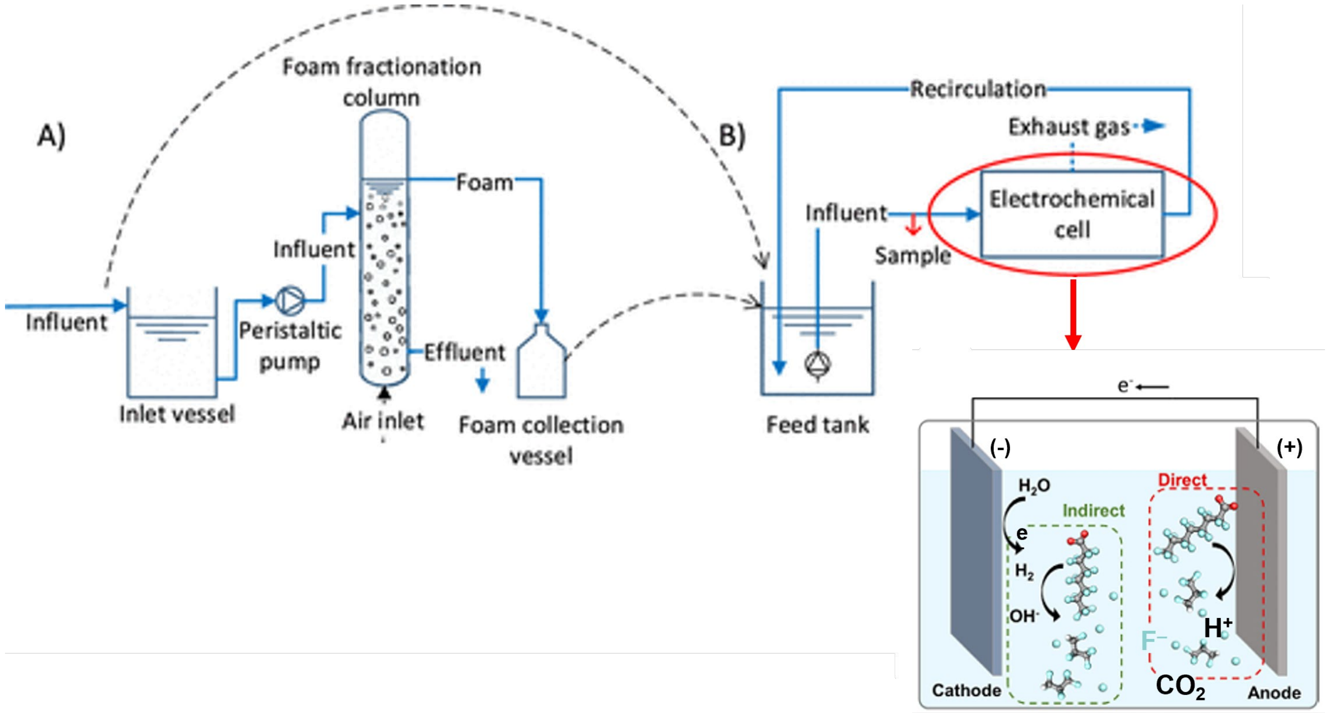
Santiago, A. et al. *Electrochimica Acta* 2022; Radjenovic, J. et al. *Environ. Sci. Technol.* 2020

Electrochemical PFAS degradation has been tested in other treatment trains.

3

Degradation

Electrochemical Oxidation



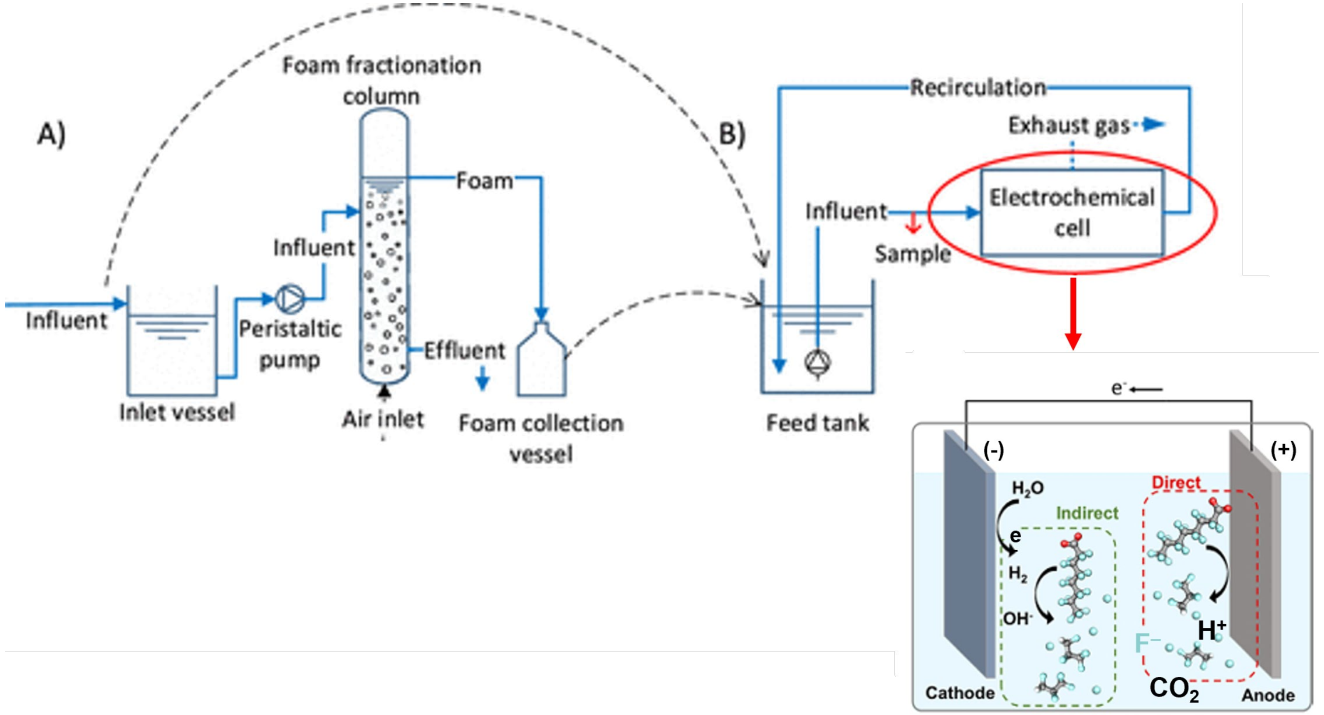
Santiago, A. et al. *Electrochimica Acta* 2022; Smith, S. et al. *ACS EST Water* 2023

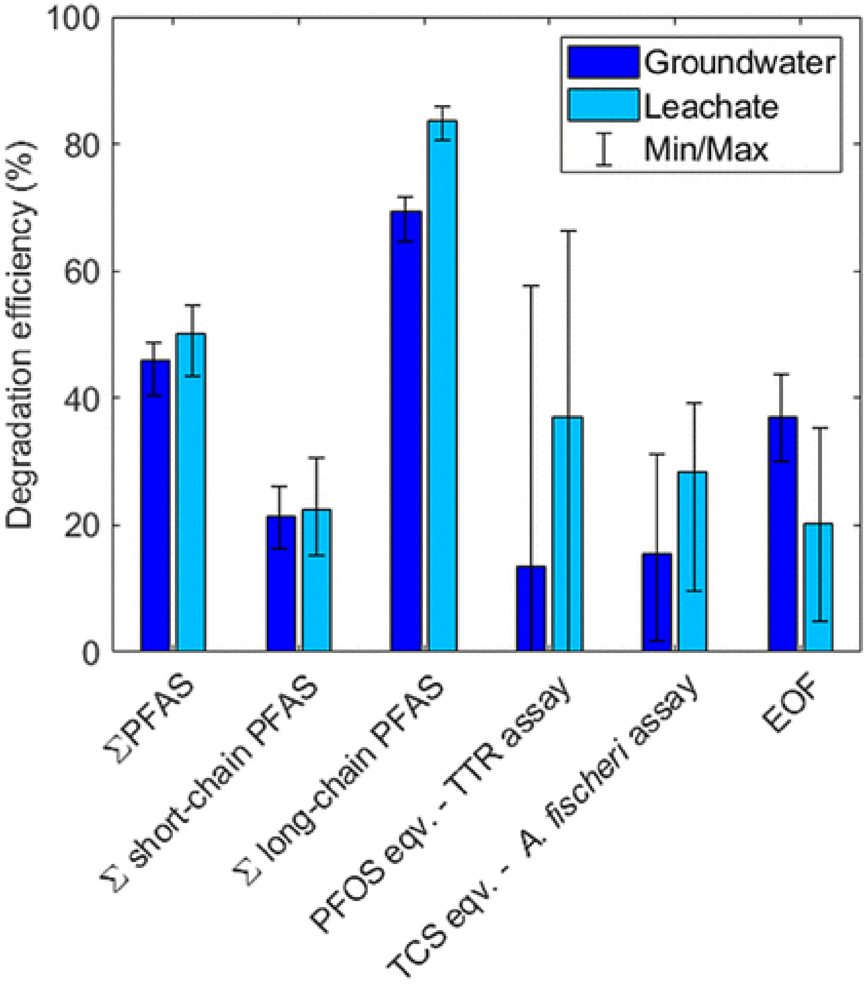
Electrochemical systems can achieve ~50% PFAS degradation in other treatment trains.

3

Degradation

Electrochemical Oxidation





Santiago, A. et al. *Electrochimica Acta* 2022; Smith, S. et al. *ACS EST Water* 2023

Novel adsorbents and electrochemical degradation provide a promising PFAS treatment train.

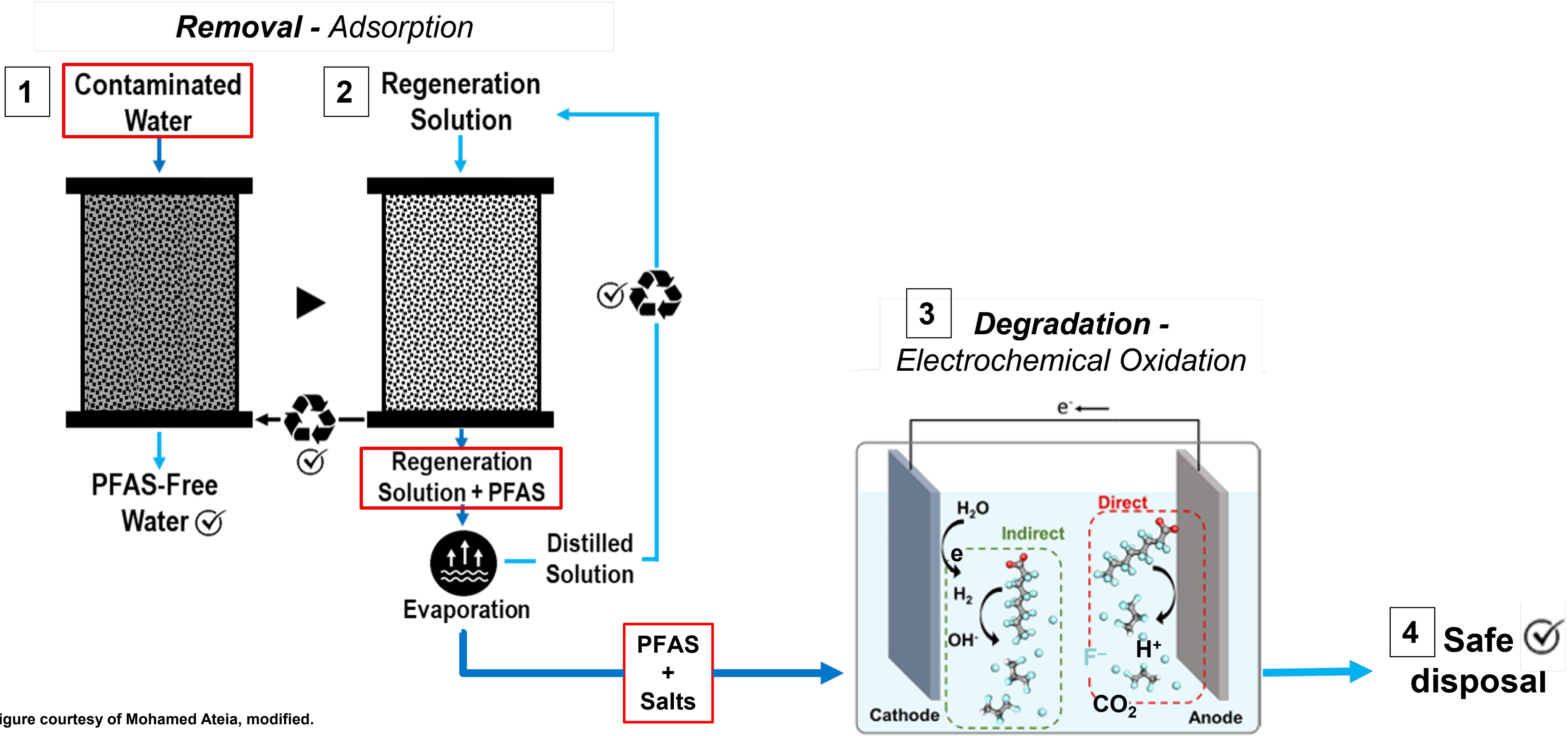


Figure courtesy of Mohamed Ateia, modified.

Conclusions

- Identified PFAS sources from residual streams
- Existing PFAS treatment technologies require continued development for improved performance and viability.
- Novel polymeric adsorbents can provide high PFAS removal efficiencies.
- Adsorbents require a complementary destruction technology to treat PFAS-laden regeneration streams.

Thank you!

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