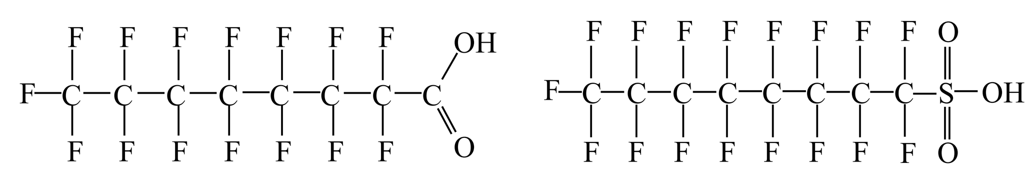
IEDO: Degradation of Poly-and Perfluoroalkyl Substances (PFASs) in Water via High Power, Energy-Efficient Electron Beam Accelerator

- Electron beam accelerators take electrons from a resting state and accelerate them to higher energies.
- The high energy electrons can be used for many applications such as to surface harden or cure materials, drive industrial chemistries, sterilize medical equipment or destroy environmental contaminants.

Concerns with PFAS Contamination in Water

What is PFAS?

- **Per and polyfluoroalkyl substances (PFAS) are a group of 1000s of different chemicals that have fluorine atoms attached to a carbon chain**



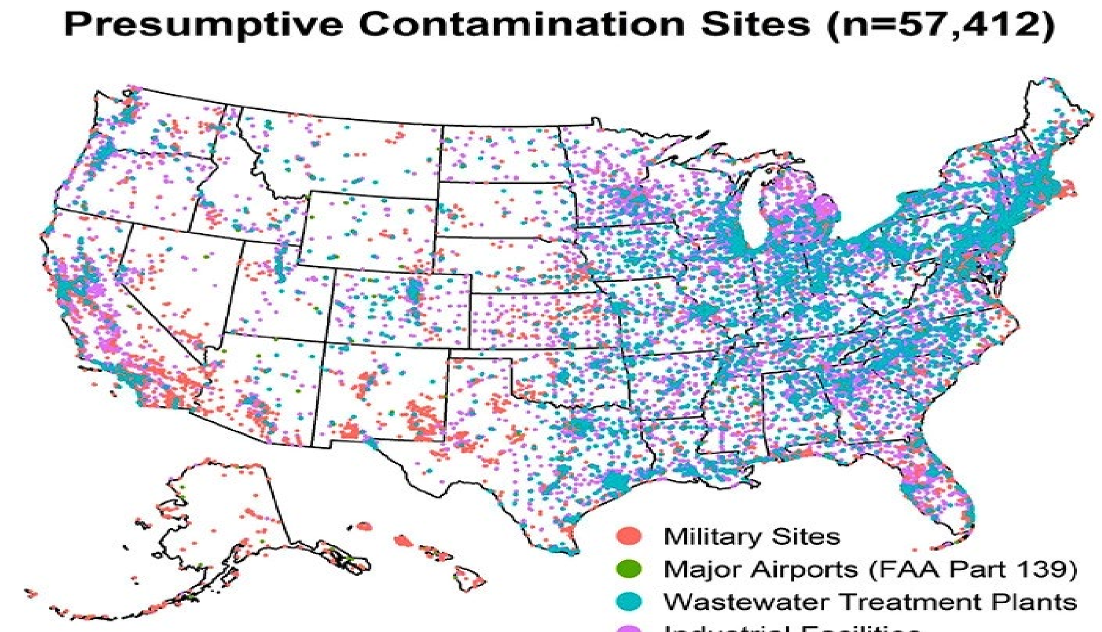
PFOA - Perfluorooctanoic acid PFOS - Perfluorooctyl Sulfonate

- **There are many PFAS of concern but PFOA and PFOS have received special attention because of their persistent nature and because of health concerns when ingested in small quantities.**

Sources for PFAS include:

- **Food packaging**
- **Fire Fighting Foams**
- **Surfactants**
- **Lubricants**
- **Paper and textile coatings**
- **Personal care products**
- **Photography**
- **Paints**
- **Pesticides**
- **Batteries**

Presumptive Contamination Sites (n=57,412)



The number of contamination sites and level of contamination at each site is still being understood. A recent study suggests 10's of thousands of sites based on sites that use or handle PFAS.

D. Salvatore, Environ. Sci. Technol. Lett. 2022, 9, 11, 983−990, October 12, 2022

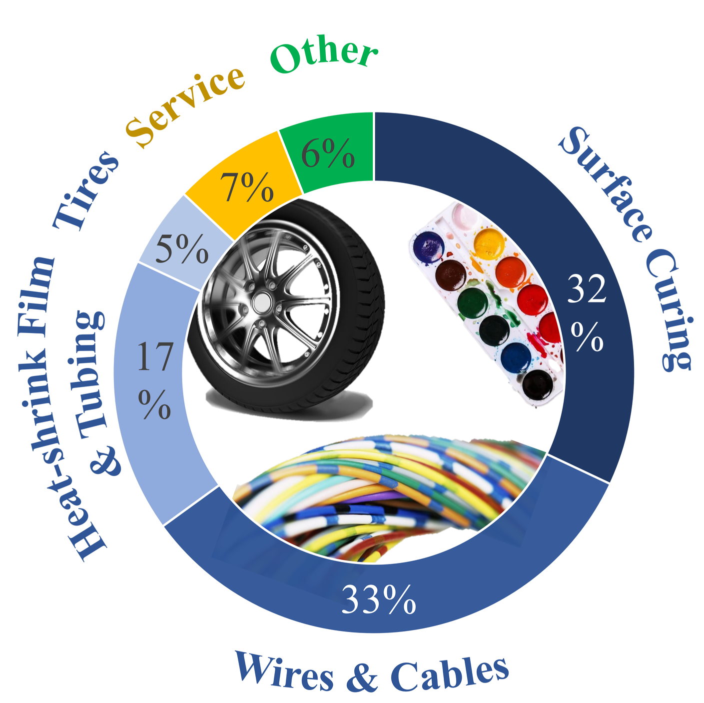
Problems with Conventional Treatment of PFAS in Water

- Conventional water treatment technology concentrates PFAS with no good way to handle the concentrated waste
- The concentrated waste created by these technologies can create secondary environmental contamination
- Electron beam directly destroys the contamination

Attribute	E-Beam	Activated Carbon Filtration	Ion Exchange Resins	Membranes (RO)	Hydotherm/ Electrochem
Treat PFOA/PFOS	✓	✓	✓	✓	✓
Treats short-chain PFAS	✓	No	No	✓	In Development
Destroys PFAS on-site	✓	No	No	No	No ✓
Treats PFAS in mixed-streams	✓	No	No ✓	No	✓
Cost	High	✓	✓	✓ High	High

Uses of Electron Beams Today and in the Future

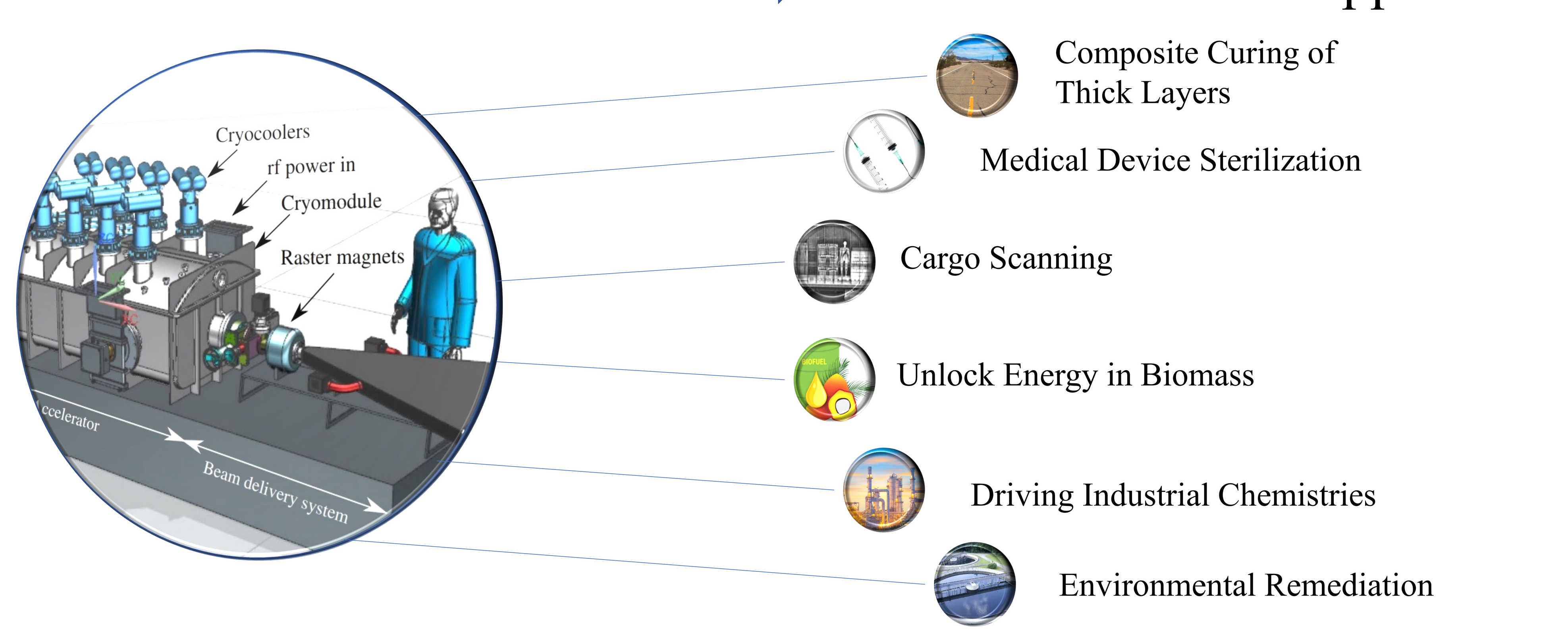
Electron Beam Applications Today



- Current end-use market distribution of electron beam industrial applications
- 87% of e-beam processes involve crosslinking, represented by the applications in blue segments

New Fermilab Tech

New Electron Beam Applications



New electron beam accelerator technology being developed at Fermilab allows for more throughput (higher flowrates), more energy efficiency, and a more compact footprint enabling new application areas.

New applications enabled can improve the U.S. economy, health, security and environment. Currently investigating improved roadways, medical sterilization, environmental remediation, and invasive species control.

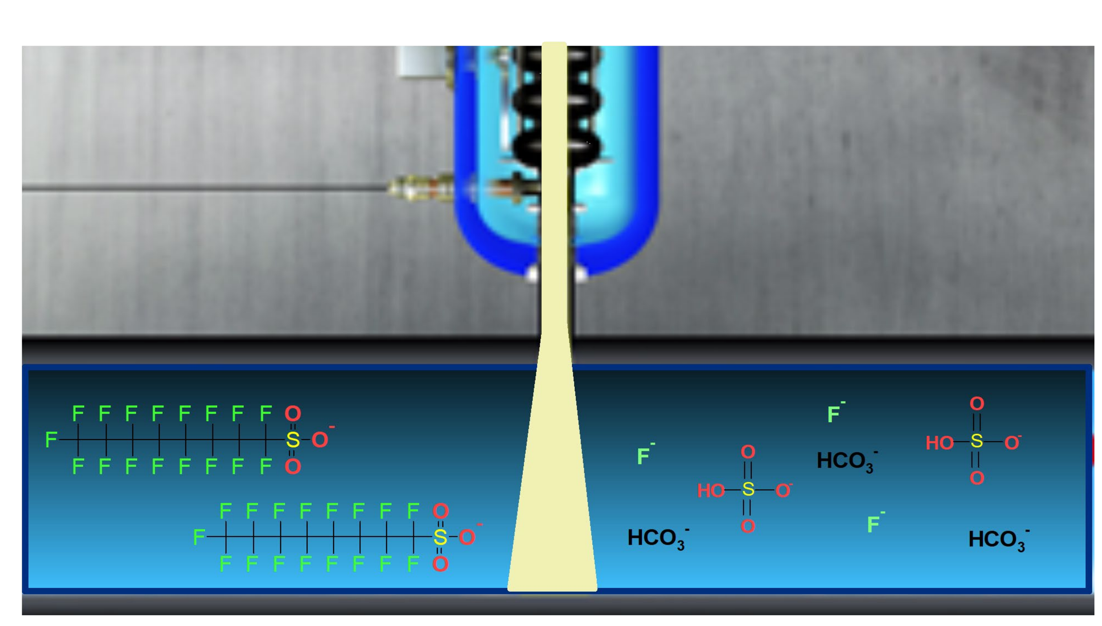
Electron Beam Destruction of PFAS in Water

TECHNOLOGY SUMMARY

- ***Effective and complete destruction of PFOA and PFOS has been demonstrated via e-beam at moderate energy costs for concentrations ranging from parts per billion to 10s of parts per million.***
- ***The destruction of the PFAS, and not just sequestration into another form, addresses one of the main issues in the area of remediation of contaminated PFAS water bodies.***
- Current work focuses on developing a novel e-beam accelerator that will have lower operation costs, treat greater flow rates and be compact enough so that it is portable. Process optimization is also being done to minimize energy consumption.
- While concentrated streams can be treated, flow rates are low and on the order of 10s of gallons per minute. Through process optimization and scaling up of the technology the goal is to get this to 100s of gallons per minute
- Electron beam destruction of PFOA and PFOS does not create any harmful byproducts.
- While the capital costs are currently high the operating costs for destruction of concentrated PFOA and POFS streams are favorable compared to conventional technologies.

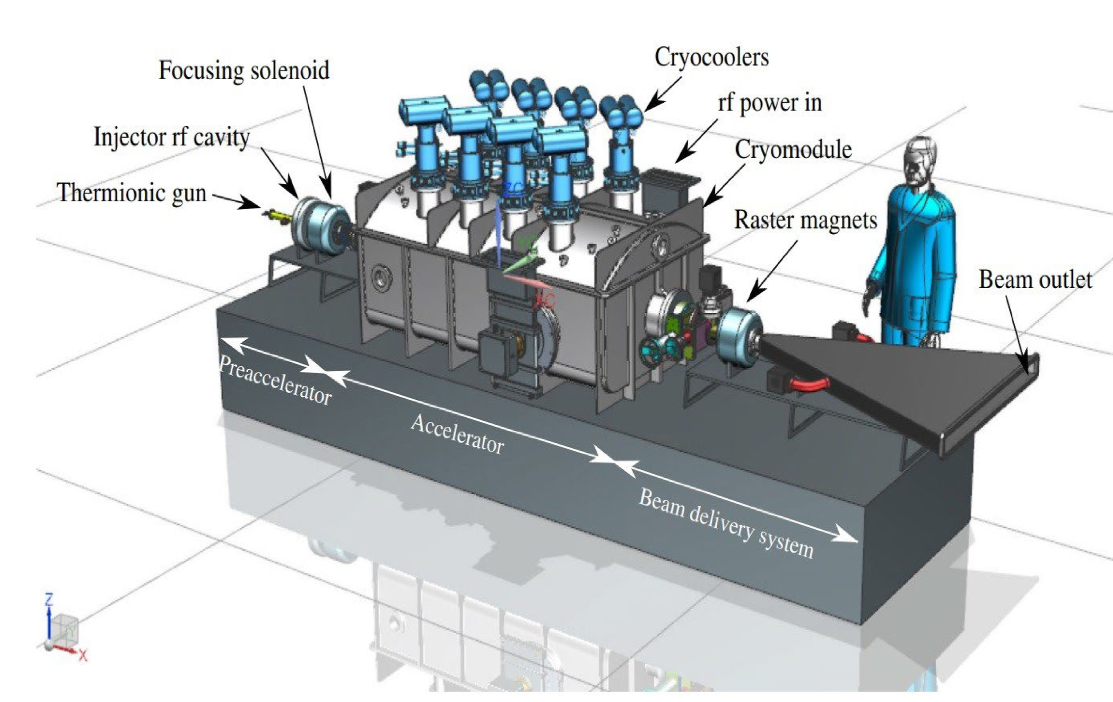
Next Steps

- ***We are looking for partners to scale up the system and integrate into a water treatment "plant demonstrator" to demonstrate/measure efficacy of operations and pursue R&D to investigate options for improved energy efficiency.***



$$H_2O \xrightarrow{\text{Electron Beam}} OH^-, H^+, e^-_{aq}, H_2, H_2O_2$$

- In a process called water radiolysis the electron beam creates active species that break down PFAS.
- The aqueous electron, e^-_{aq}, is thought to be the active species in PFAS destruction so the process is optimized to produce them.
- For high energy electrons (10 MeV), each electron will undergo roughly 100,000 interactions before coming to rest and each interaction has a good chance of producing the aqueous electrons needed for PFAS degradation
- All the active species are created and dissipate on microsecond timescales.



- Image shows superconducting, radio frequency, linear accelerator developed for PFAS degradation.
- It is as much as 50% more energy efficient, and therefore cheaper to operate than accelerators on the market today.

Charlie Cooper*, Slavica Grdanovska, Yichen Ji
Fermi National Accelerator Lab
Cleston Lange
3M Company
*ccooper@fnal.gov