

Scenarios for PFAS Destruction at Municipal Scale Water Treatment Facilities

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PFAS Destruction



**Hard to resist, even
when your nutritional
expectations are low**





Innovative Ways to Destroy PFAS

PER- AND POLYFLUOROALKYL SUBSTANCES

Hard to resist, even
when your **practical**
expectations are low

Raise
Your
Expectations



Raise
Your
Expectations



**“Right-size” our understanding of
destructive technologies for
municipal treatment**



Current Municipal-Scale BATs



GAC



IX Resin

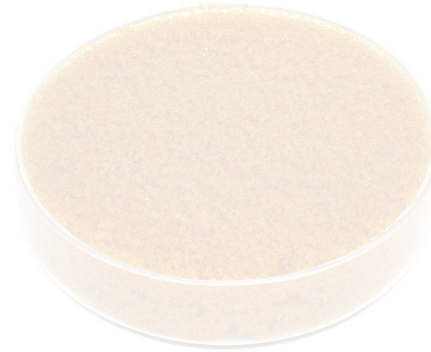


NF/RO

Current Municipal-Scale BATs

Advantages

- ✓ Substantial institutional knowledge
- ✓ Reasonable footprint
- ✓ Accommodate large flows
- ✓ Affordable (relatively)
- ✓ PFAS removal to non-detect*
 - ~ Design
 - ~ Influent concentrations
 - ~ Analytical methods
- ✓ Compatible with potable water



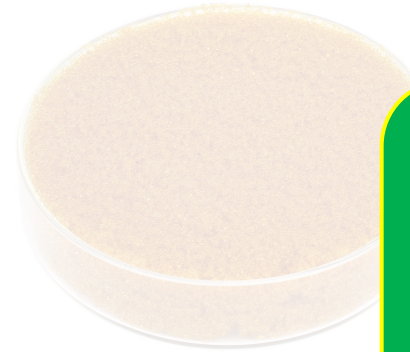
IX Resin



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IX Resin



Separation technologies

NF/RO

Current Municipal-Scale BATs

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Disadvantages

Residuals

IX Resin

NF/RO

Residuals Management Considerations



Residuals are not a formal aspect of the PFAS Rule.

Residuals Management Considerations



However, every system that installs treatment must consider the impact of potential & pending regulations that could affect PFAS residual management.

Residuals Management Considerations



**USEPA has
acknowledged this.**

Residuals Management Considerations

“A facility that has spent carbon or other media from treating PFAS and/or other contaminants must determine whether the material is a regulated waste. If the material was only used to treat PFAS, it is likely not considered hazardous waste (under federal statutes). EPA published [‘Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances’](#) that describes the options of landfilling, injection and thermal treatment for disposing PFAS laden materials. The guidance notes that thermal treatment techniques, including carbon reactivation, may allow PFAS to migrate to the environment. EPA and partners are undertaking research to further address the subject. EPA is also working to update this guidance in 2023. Materials used to treat PFAS may become hazardous if there are additional contaminants that are hazardous removed along with PFAS.”

- USEPA FAQs for Drinking Water Primacy Agencies

Residuals Management Considerations

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- USEPA FAQs for Drinking Water Primacy Agencies

...YET

Residuals Management Considerations

Potential Residuals Regulations

| Regulation | Applicable / Potential Areas of Purview | Concerns |
|--|---|----------|
| Clean Water Act (CWA) | | |
| Resource Conservation and Recovery Act (RCRA) | | |
| Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) | | |

Residuals Management Considerations

Potential Residuals Regulations

| Regulation | Applicable / Potential Areas of Purview | Concerns |
|--|--|----------|
| Clean Water Act (CWA) | Facility Discharges | |
| Resource Conservation and Recovery Act (RCRA) | Solid Waste (Hazardous & Non-Hazardous) | |
| Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) | Hazardous Waste Remediation | |

Residuals Management Considerations

Potential Residuals Regulations

| Regulation | Applicable / Potential Areas of Purview | Concerns |
|---|--|---|
| Clean Water Act (CWA) | <ul style="list-style-type: none">• Residuals discharge permits• Management and disposal of residuals | <ul style="list-style-type: none">❑ Installation of additional treatment❑ More limited land application / beneficial use❑ Restrictions for sanitary sewer discharge |
| Resource Conservation and Recovery Act (RCRA) | | |
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Residuals Management Considerations

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| Resource Conservation and Recovery Act (RCRA) | <ul style="list-style-type: none">• Management and disposal of residuals• Transport of residuals | <ul style="list-style-type: none">❑ Management costs (landfill, incineration, etc.)❑ More limited land application / beneficial use❑ Fewer alternatives |
| Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) | | |

Residuals Management Considerations

Potential Residuals Regulations

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| Clean Water Act (CWA) | <ul style="list-style-type: none">• Residuals discharge permits• Management and disposal of residuals | <ul style="list-style-type: none">❑ Installation of additional treatment❑ More limited land application / beneficial use❑ Restrictions for sanitary sewer discharge |
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| Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) | <ul style="list-style-type: none">• Management and remediation of sites with land-applied residuals | <ul style="list-style-type: none">❑ Potential liability❑ More limited land application / beneficial use❑ Fewer alternatives |

Residuals Management Considerations

Potential Residuals Regulations

| Regulation | Applicable / Potential Areas of Purview | Concerns |
|--|--|---|
| Clean Water Act (CWA) | <ul style="list-style-type: none">• Residuals discharge permits• Management and disposal of residuals | Cost Compliance Liability |
| Resource Conservation and Recovery Act (RCRA) | <ul style="list-style-type: none">• Management and disposal of residuals• Transport of residuals | |
| Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) | <ul style="list-style-type: none">• Management and remediation of sites with land-applied residuals | |

Can Destructive Technologies be a Viable Alternative...?



**Primary
PFAS Treatment**

Parsing PFAS Destructive Technologies: 1°

| Destructive Technologies <i>Examples</i> |
|--|
| Ball Milling |
| Dimethyl sulfoxide (DMSO) dissolution |
| Catalytic electrochemical oxidation |
| Electron beam degradation |
| Enzymatic defluorination |
| Microbial defluorination |
| Photocatalytic degradation |
| Plasma reactor degradation |
| Sonolysis |
| Supercritical Water Oxidation |
| Thermolysis |

And Many More!

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**Many destructive technologies
have been demonstrated to
effectively degrade PFAS...**



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...but are they viable for
municipal treatment
applications?

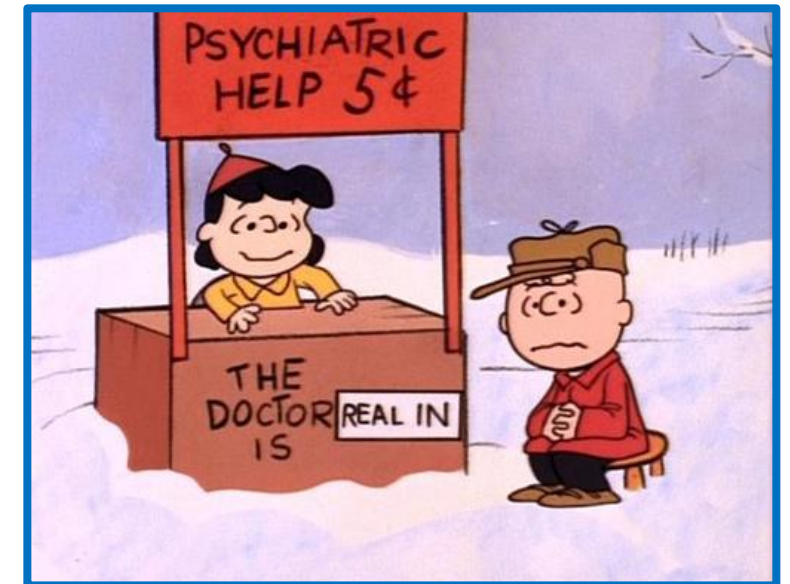


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Translation Factors

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- ☐ Adaptability
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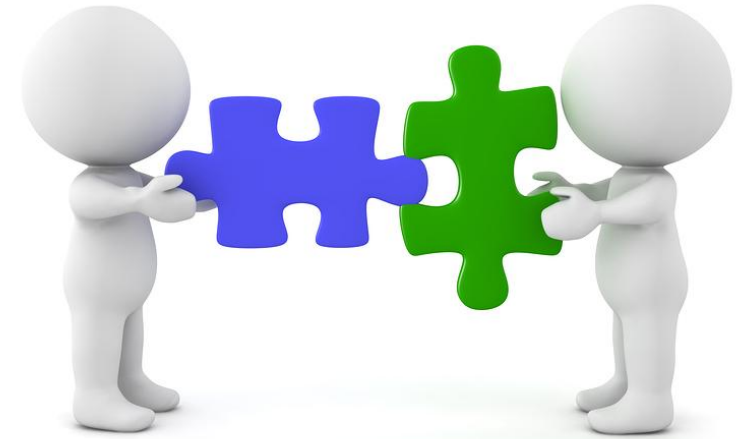
We have issues!

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Materials must be
compatible with potable
water production

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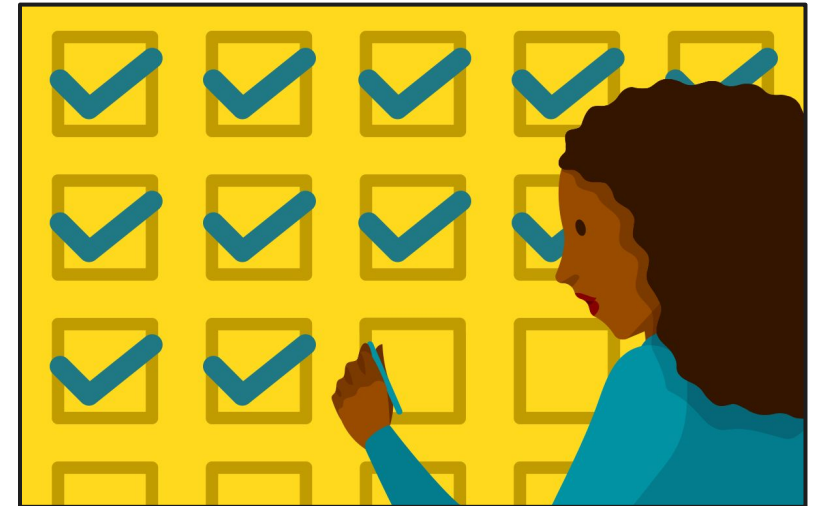
**Cannot trade one
environmental justice
issue for another**

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**Viable technologies
must check
all the boxes**

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Barriers are high

Can Destructive Technologies be a Viable Alternative...?



**Secondary
PFAS Treatment**

Can Destructive Technologies be a Viable Alternative...?



**Residuals
Management**

Parsing PFAS Destructive Technologies: 2°

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**How can we lower
the barriers?**

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**Focus on
liquid residuals**

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**Smaller flows increase
potential for scale-up
and reduce footprint**

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Smaller systems
have lower capital
and O&M cost

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**Smaller systems
consume less power
and chemicals (as appl.)**

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Smaller flows reduce
the importance of
reaction kinetics

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Any by-products
will not form in the
treated water flow

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**Materials compatibility
is not an issue
for waste flows**

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Permitting may not be
an issue for treatment
of residuals flows

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**Adaptability for
municipal scale
continuous flow is
process-specific**

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GOAL:
Lower Barriers

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**Barriers are not
necessarily
eliminated**

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**Focus on
liquid residuals**

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How?



Generating Liquid Residuals

| Liquid Separation Technologies |
|----------------------------------|
| Coagulation |
| Electrocoagulation |
| Foam fractionation |
| Ozofractionation |
| Reverse osmosis / nanofiltration |

Generating Liquid Residuals

| Liquid Separation Technologies | Well-Understood | Common Use in Municipal Applications |
|----------------------------------|-----------------|--------------------------------------|
| Coagulation | ● | ● |
| Electrocoagulation | ● | ● |
| Foam fractionation | ● | ● |
| Ozofractionation | ● | ● |
| Reverse osmosis / nanofiltration | ● | ● |

Generating Liquid Residuals

| Liquid Separation Technologies | Well-Understood | Common Use in Municipal Applications | Highly Efficient Primary Removal |
|----------------------------------|-----------------|--------------------------------------|----------------------------------|
| Coagulation | ● | ● | ● |
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| Reverse osmosis / nanofiltration | ● | ● | ● |

Generating Liquid Residuals

| Liquid Separation Technologies | Well-Understood | Common Use in Municipal Applications | Highly Efficient Primary Removal | Flow Minimization |
|----------------------------------|-----------------|--------------------------------------|----------------------------------|-------------------|
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| Electrocoagulation | ● | ● | ● | ● |
| Foam fractionation | ● | ● | ● | ● |
| Ozofractionation | ● | ● | ● | ● |
| Reverse osmosis / nanofiltration | ● | ● | ● | ● |

Generating Liquid Residuals

No ideal options

| Liquid Separation Technologies | Well-Understood | Common Use in Municipal Applications | Highly Efficient Primary Removal | Flow Minimization | Cost |
|----------------------------------|-----------------|--------------------------------------|----------------------------------|-------------------|------|
| Coagulation | ● | ● | ● | ● | ● |
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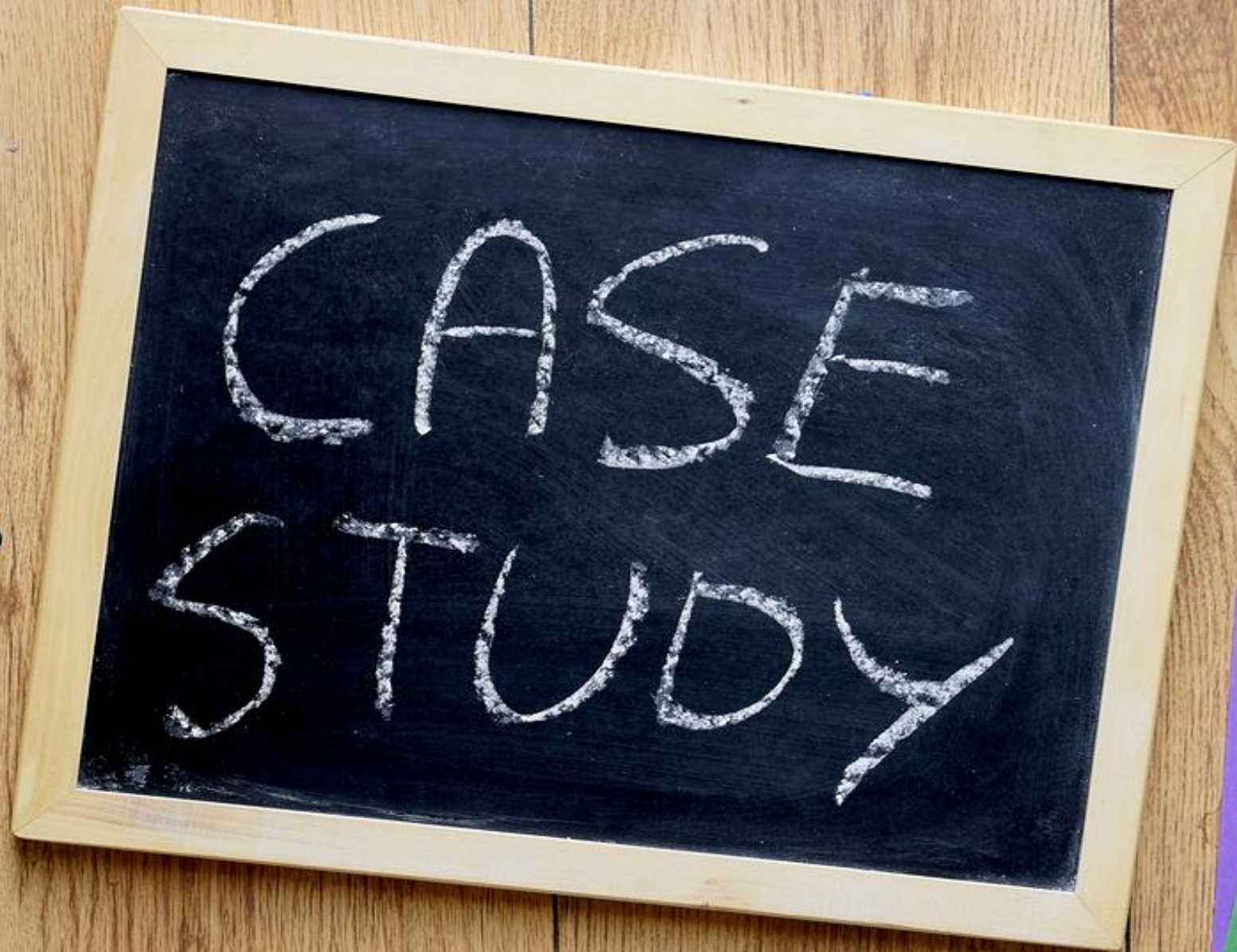
💧 Color assignment are debatable... but useful for relative comparison.

**Effectively leveraging
destructive technologies
is challenging.**



...but not impossible.





Case Study: Sonolysis

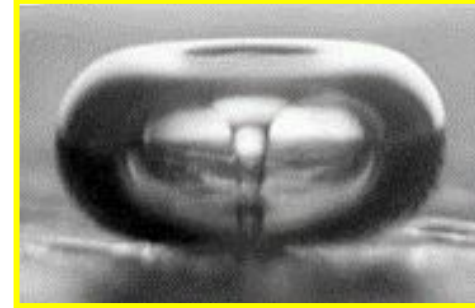
How it works...

Ultrasound-induced rarefaction / compression of microbubbles, yielding cavitation at extremely high temperatures on bubble surfaces



Specific energy consumption:
~1,000 kWh/kgal

f(x): target compound, concentration,
and water quality matrix



**Bubble
cavitation**



**Resonator
(reactor)
in a flow cell**

Case Study: Sonolysis

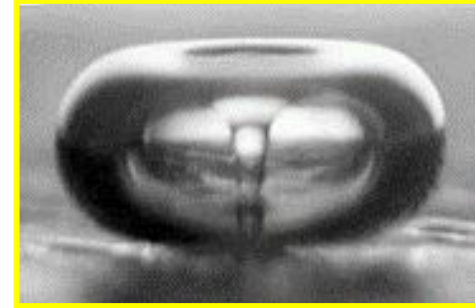
How it works...

Ultrasound-induced rarefaction / compression of microbubbles, yielding cavitation at extremely high temperatures on bubble surfaces



Specific energy consumption:
~1,000 kWh/kgal

f(x): target compound, concentration,
and water quality matrix



**Bubble
cavitation**



**Resonator
(reactor)
in a flow cell**

Case Study: Sonolysis

Credit: Ed Helmig (Arcadis)

Example of an Installed System

| System Attribute | | Value(s) | Notes |
|---------------------|------------|---|--|
| Application | | Industrial waste | Applied to concentrated residuals |
| Target Contaminants | | 17 β -Estradiol, Trimegestrone | Two very potent hormones |
| Flow | | 3 gpm | Very low flow |
| Treatment Goal | | 100% destruction | No mass transport of hormones off site |
| Cost | Capital | ~ \$1 million | Includes design, procurement, and construction |
| | Life Cycle | \$80,000 / year | Amortized capital + operating costs (power, chemicals) |

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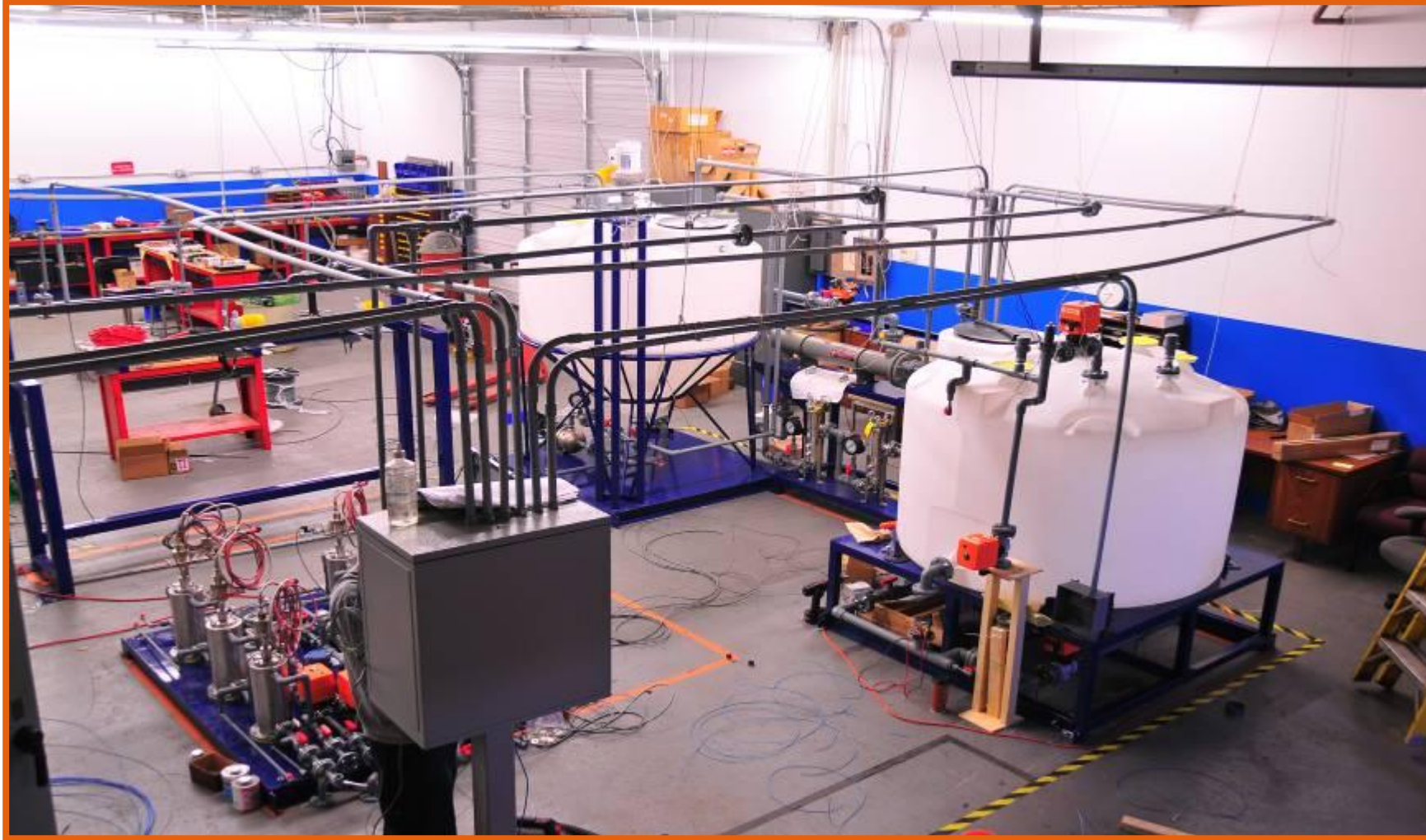
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**Not designed for PFAS,
but applicability is analogous**

Case Study: Sonolysis

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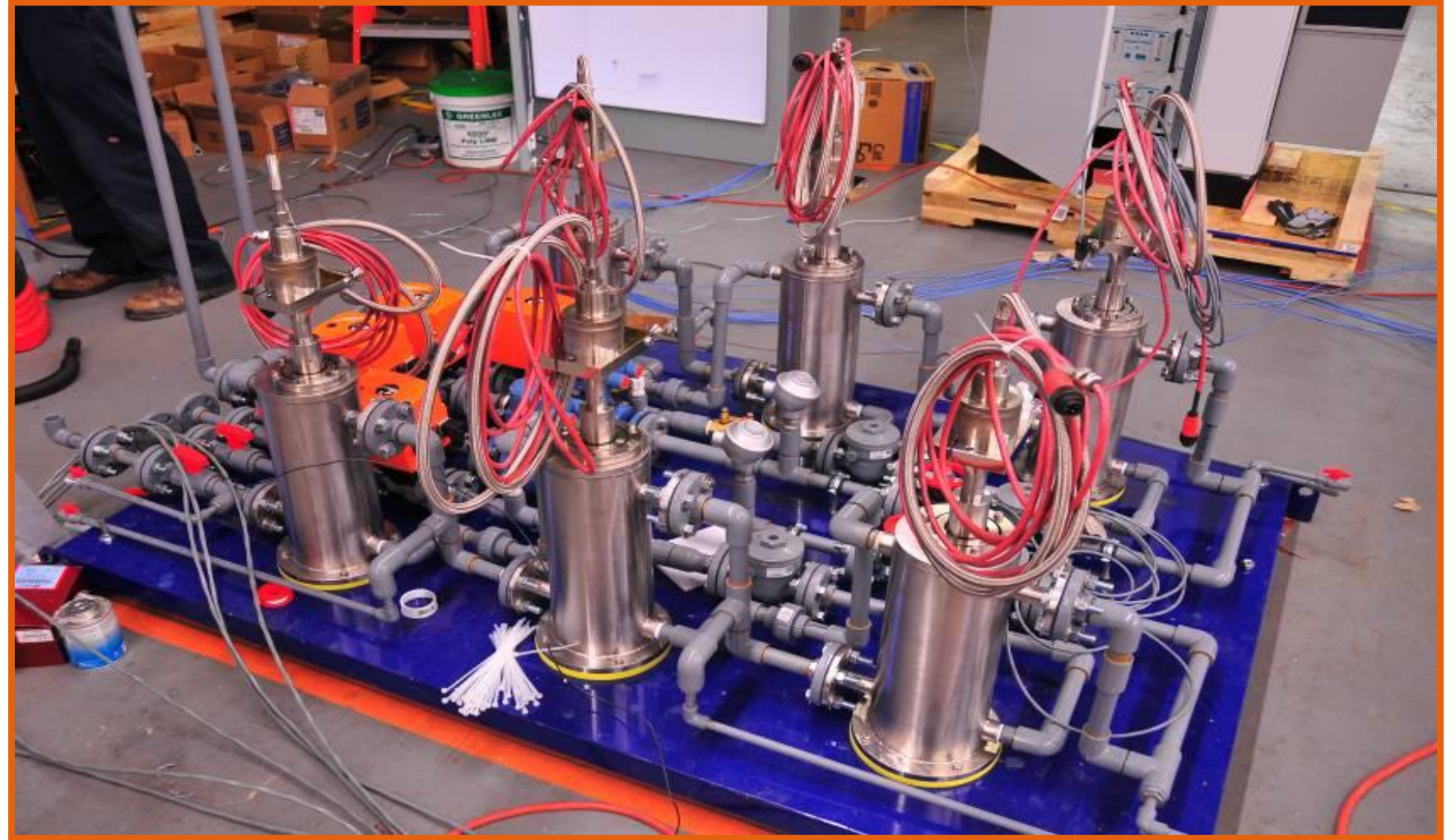


**System fabrication,
nearing completion**

Case Study: Sonolysis

Credit: Ed Helmig (Arcadis)

**Transducers
and flow cells**



Case Study: Sonolysis

Credit: Ed Helmig (Arcadis)

**Transducers
and flow cells**



Case Study: Sonolysis

Credit: Ed Helmig (Arcadis)



**Noise attenuation
enclosure**

Case Study: Sonolysis

Example of an Installed System

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| Treatment Goal | | 100% destruction |
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Facilitating Conditions

- ✓ Applied to concentrated waste
- ✓ Very low flow
- ✓ Health & environmental concerns
- ✓ Discharge prohibitions
- ✓ Lower cost than alternatives

**Sanity check
for destructive
technologies**



Sanity Check for Destructive Technologies

- Many potential options exist
- Many are not (yet) commercially available
- There are significant barriers for municipal application
- Some options may be feasible under the right circumstances...
- ...but these circumstances may be **very rare**
- Implementation will be **expensive**



Thanks for your attention!



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