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The Energy Cost of PFAS Destruction Across the Range of Commercially Available Technologies

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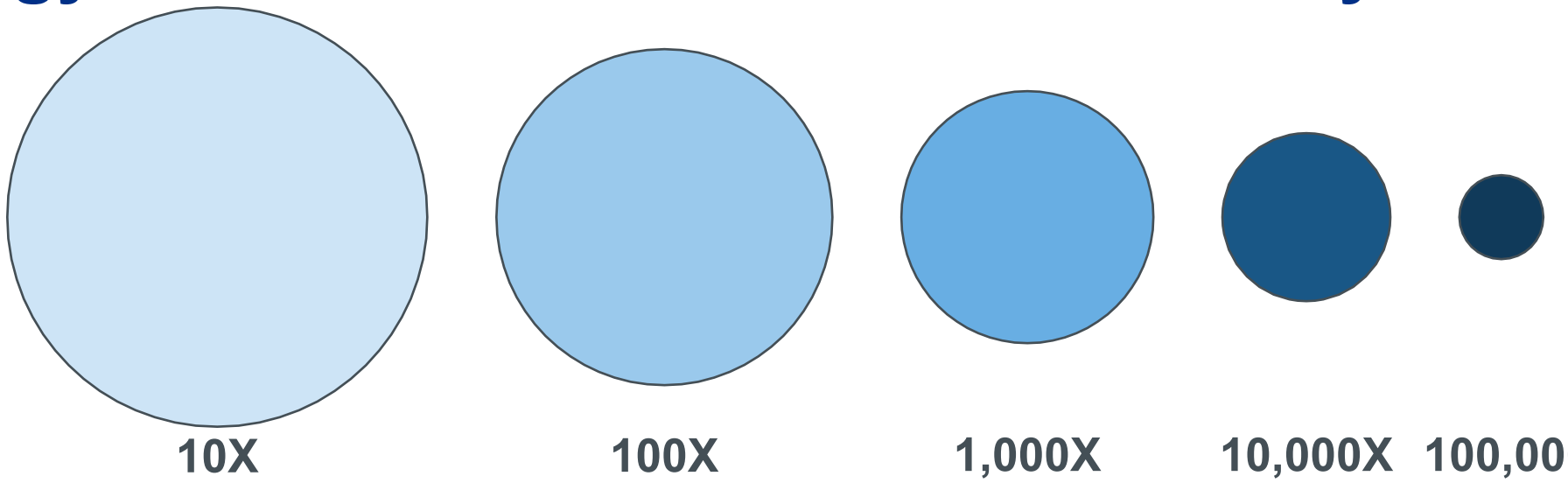
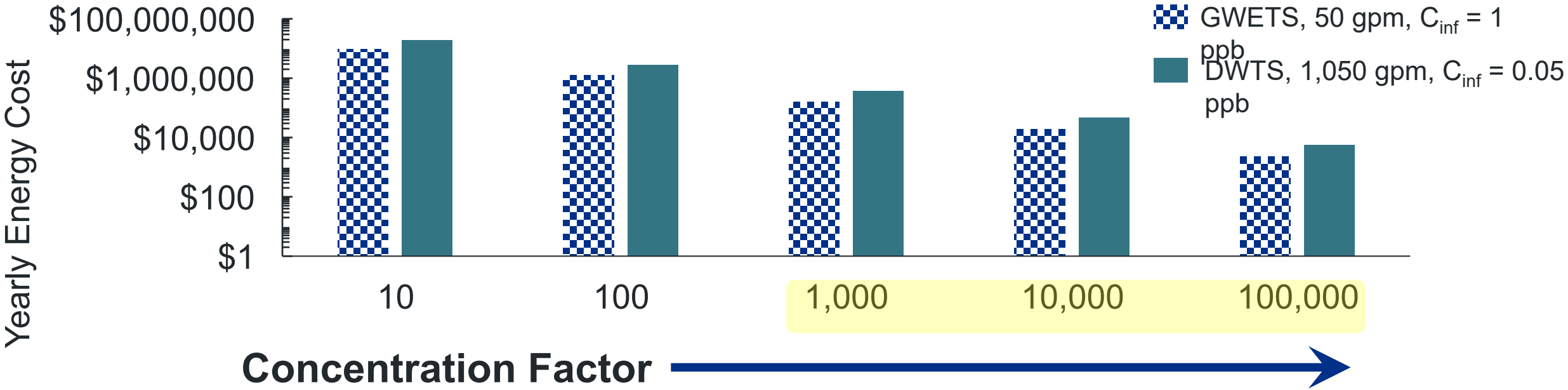
Energy for PFAS Destruction Means Money for OPEX





Take Away Points from Presentation

- In isolation, energy may be a limited comparative indicator among technologies
- Large return on investment for concentrating PFAS ahead of destruction; C_0 influences energy usage per mass (EEM) of PFAS
- Energy “penalty” for complex matrices; **still worth it!**
- More data from actual waste streams! Technology providers doing a great job
- EEM: potential metric for comparing technology performance in waste concentrates

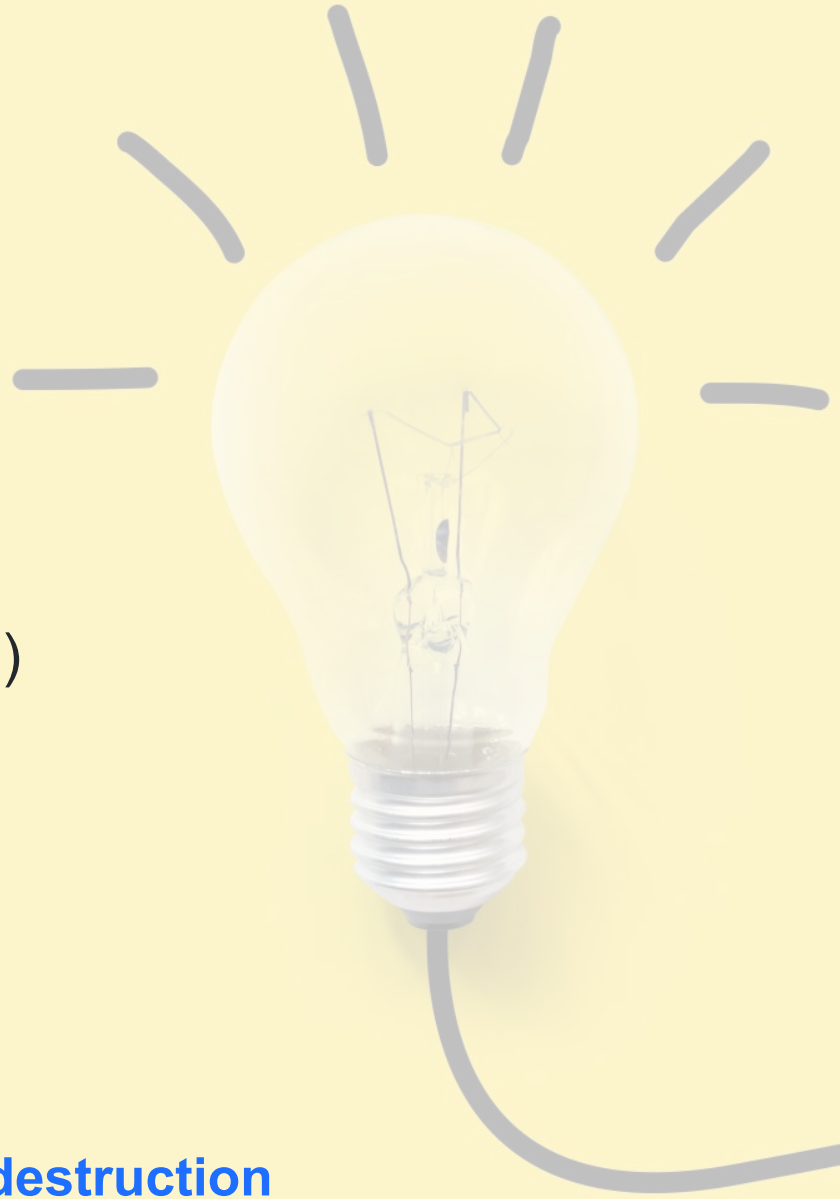
Motivation and Agenda

- Motivation for this work:
  - Scrutinize the focus on energy for PFAS destruction
  - Compare energy per order of magnitude versus energy per mass
  - Investigate sensitive parameters around these expressions of energy

1. Introduce Electrical Energy per Order (EE/O) and Electrical Energy per Mass (EEM)

2. Literature review and observations

3. Technology provider survey and observations



NOT an effectiveness review of individual PFAS destruction technologies

Electrical Energy per Order is Different than Electrical Energy per Mass

$$EE/O = \frac{P \times t \times \frac{1{,}000\,L}{m^3}}{Vol \times \log\left(\frac{C_0}{C_t}\right)}$$

Energy required per unit volume per order of magnitude reduction in concentration (kW-hr/m^3/OoM)

$$EEM = \frac{P \times t \times \frac{10^9 \mu g}{kg}}{Vol \times (C_0 - C_t)}$$

Energy required per unit mass destroyed (kW-hr/kg)

P = Power (kilowatts [kW])

t = time (hour [hr])

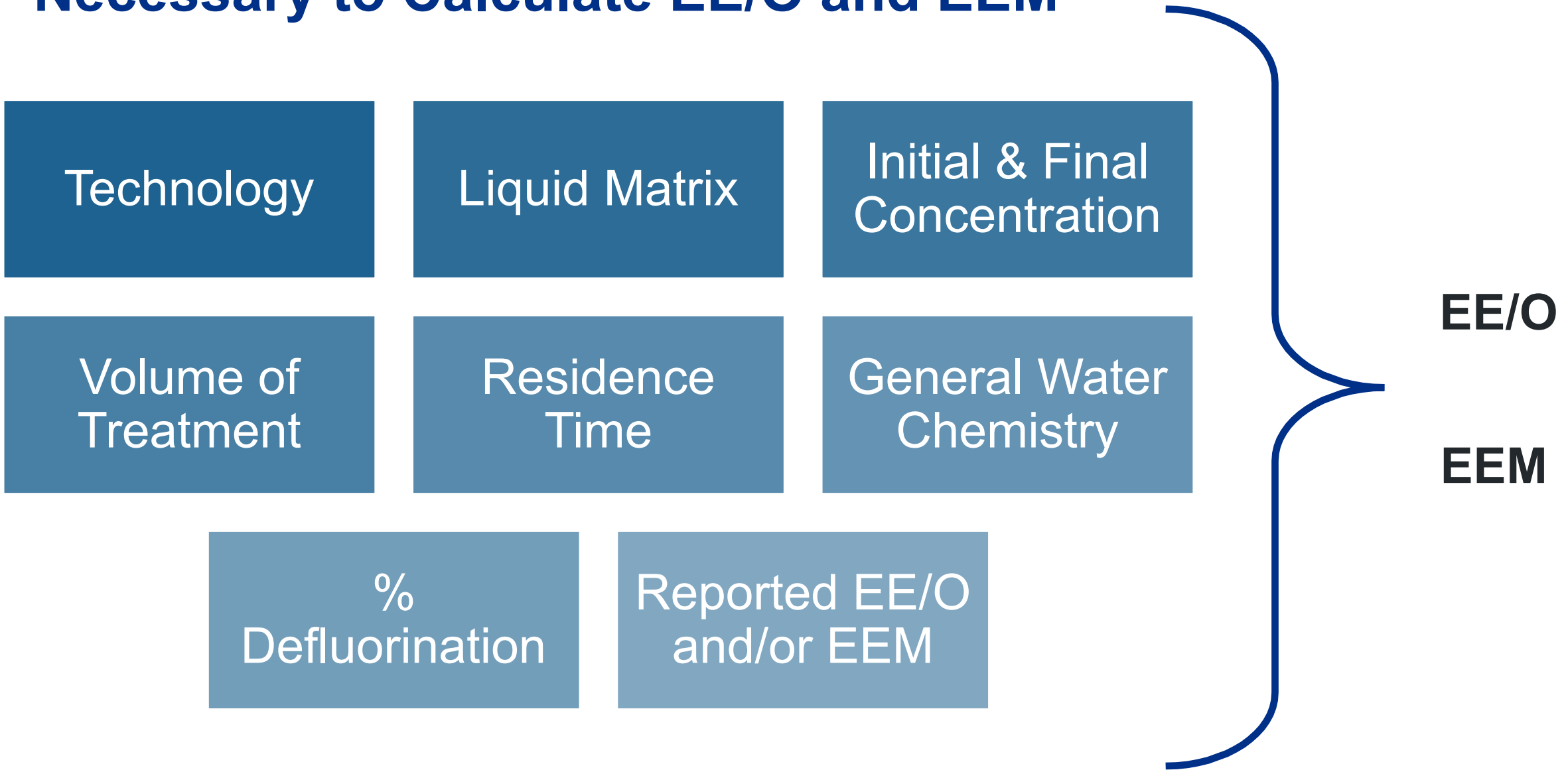
Vol = Treatment Volume (liters [L])

C_0 = Initial concentration (micrograms per liter [µg/L])

C_t = Concentration at time t (µg/L)

After Bolton et al., 2001

We Reviewed Peer-Reviewed Studies to Extract Parameters Necessary to Calculate EE/O and EEM



Attempt to Standardized EE/O and EEM Calculations

$$EE/O = \frac{P \times t \times \frac{1{,}000\,L}{m^3}}{Vol \times \log\left(\frac{C_0}{C_t}\right)}$$

$$EEM = \frac{P \times t \times \frac{10^9 \mu g}{kg}}{Vol \times (C_0 - C_t)}$$

- Power used was **inlet power** (“from the wall”)
- Time used based on **mineralization**, not sequential defluorination
- **C_t** matched to **time of trial**
- Units selected:
  - Calculated EE/O = kW-hr/m^3/OoM
  - Calculated EEM = kW-hr/kg

What Did We Find? Basic Descriptive Statistics

Studies = 78
Experiments (n) = 1,090

SW, DW, GW = Surface, Drinking, Ground Water

WW Eff = Wastewater Effluent

LL = Landfill Leachate

Mem = Membrane Concentrate

Foam = Foamate

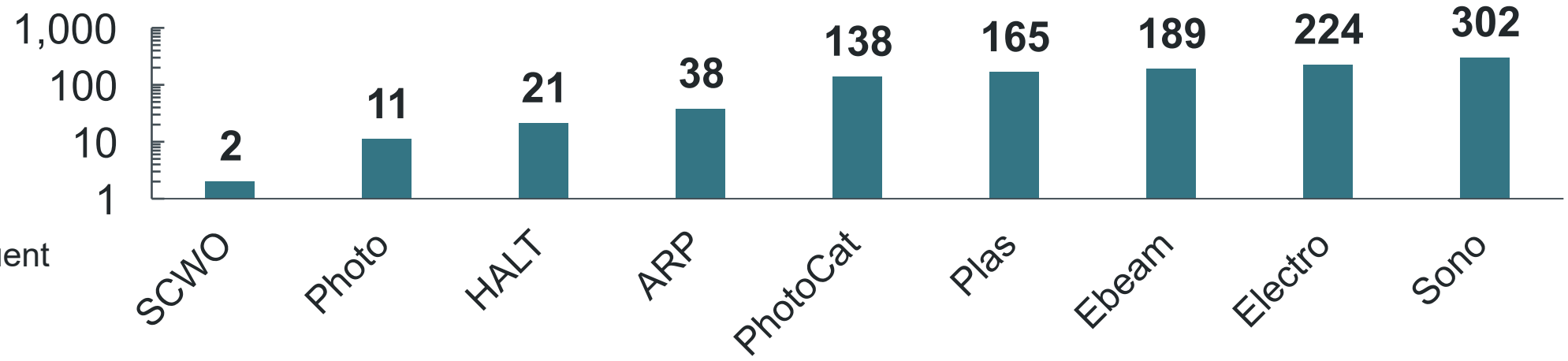
Dil AFFF = Dilute AFFF

Salt = High Salinity

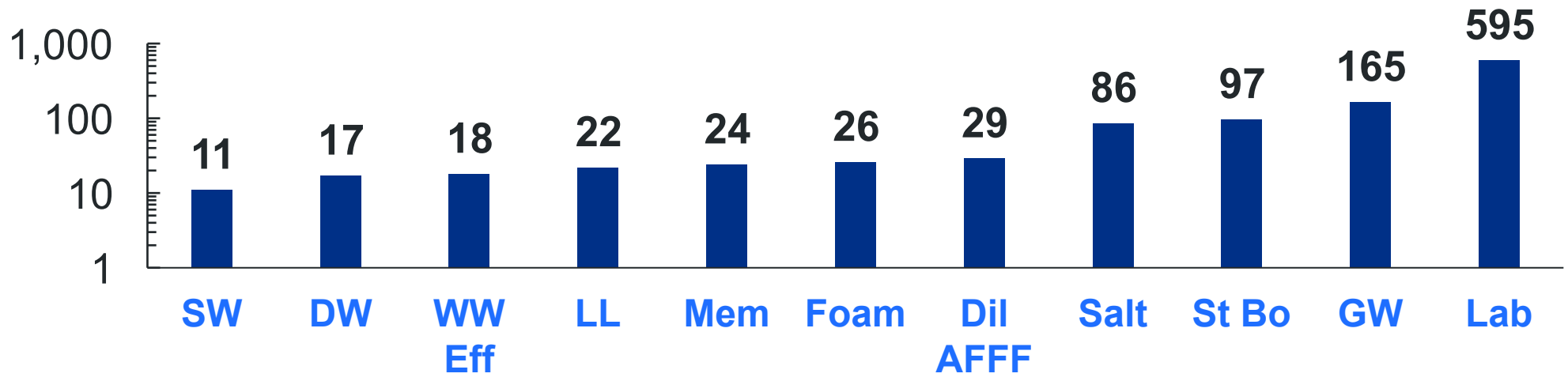
St Bo = Still Bottom

Lab = Laboratory Water

Technologies – Number of Experiments

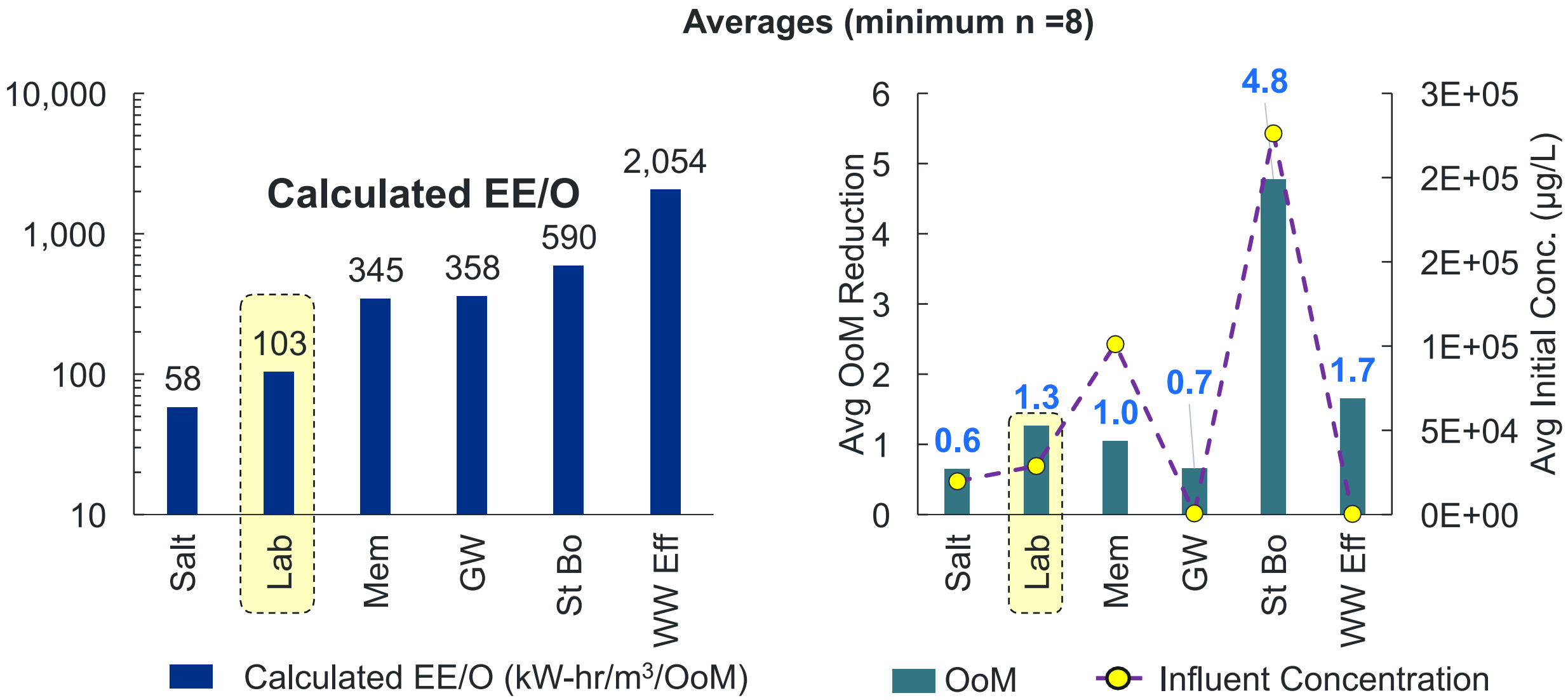


Matrices – Number of Experiments



Matrix Influences EE/O; Pay Back for Concentrating PFAS

Electrochemical Oxidation (variable experimental conditions)

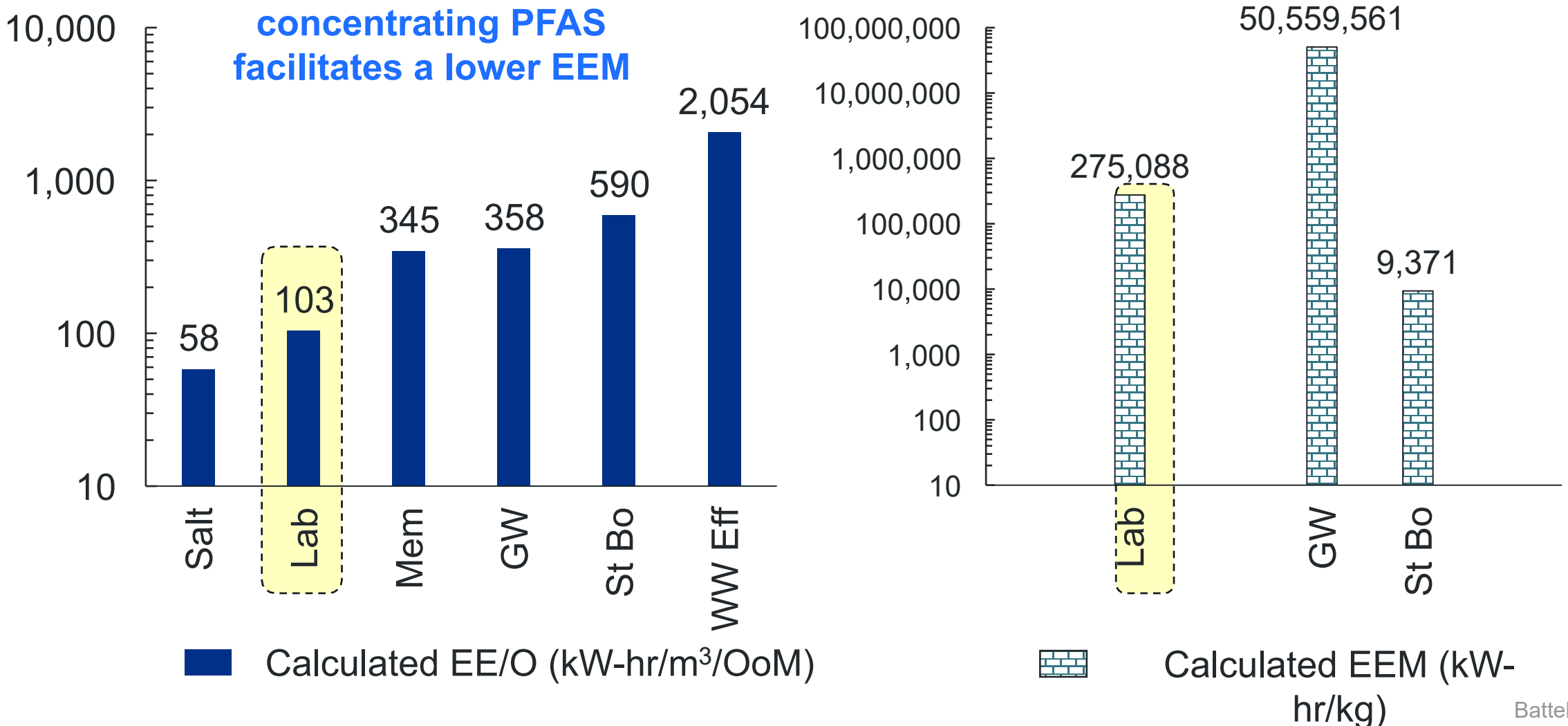


Matrix Influences EE/O; Pay Back for Concentrating PFAS

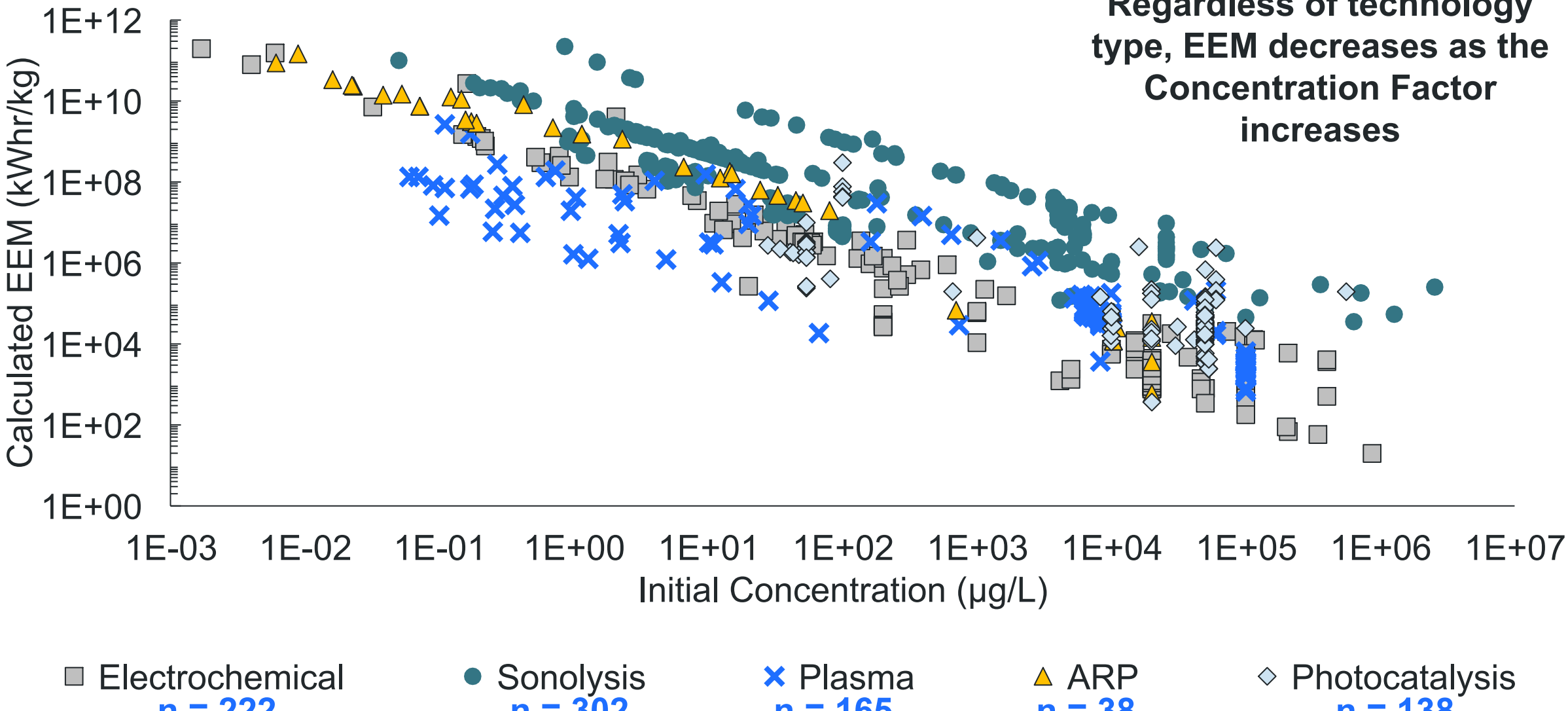
Electrochemical Oxidation (variable experimental conditions)

Despite the higher EE/O, concentrating PFAS facilitates a lower EEM

Averages (minimum n = 8)

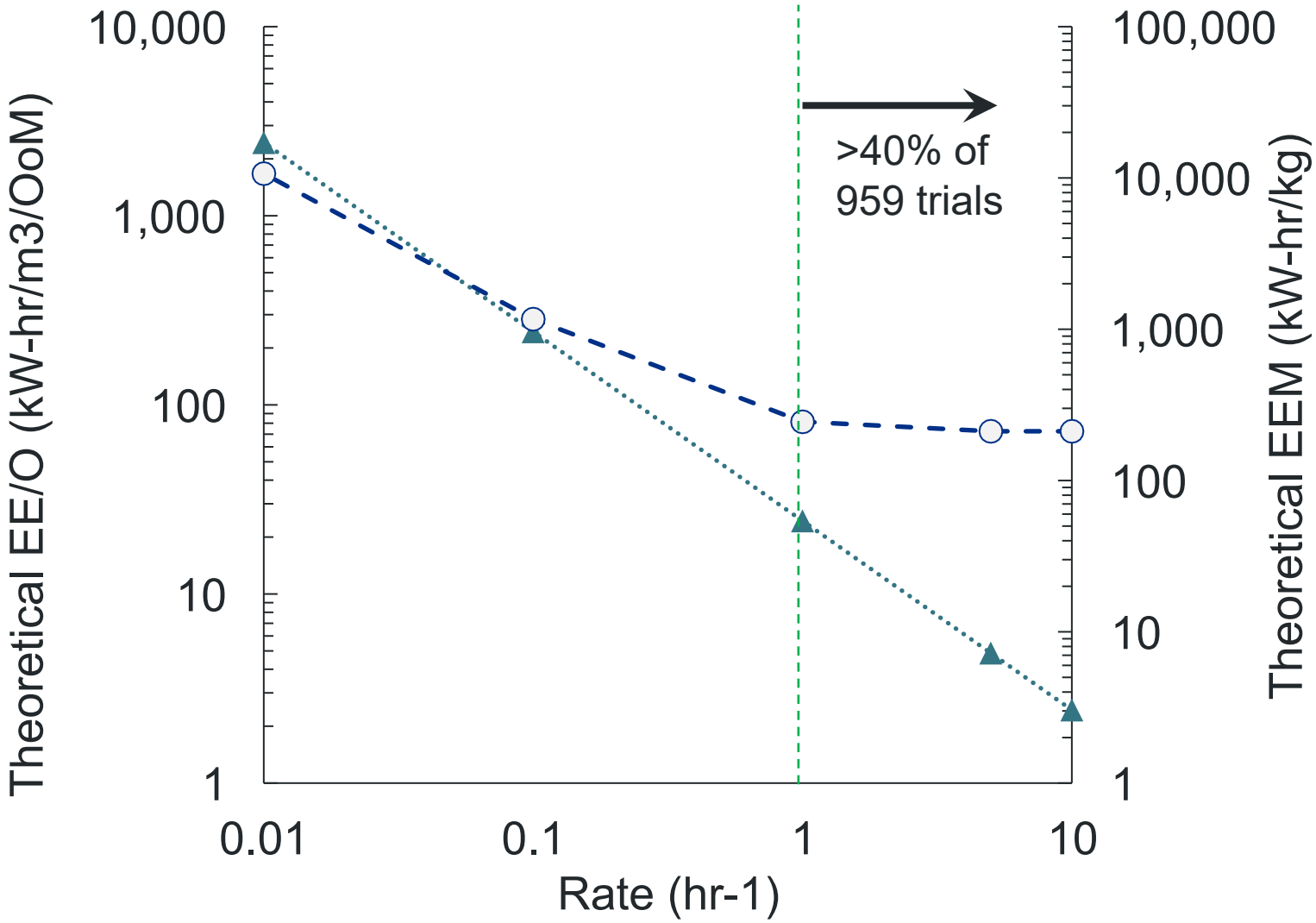


Initial Concentration Appears to Influence the Energy per Mass of PFAS Destroyed



Rate Kinetics Influence Energy Expressions, A Thought Experiment

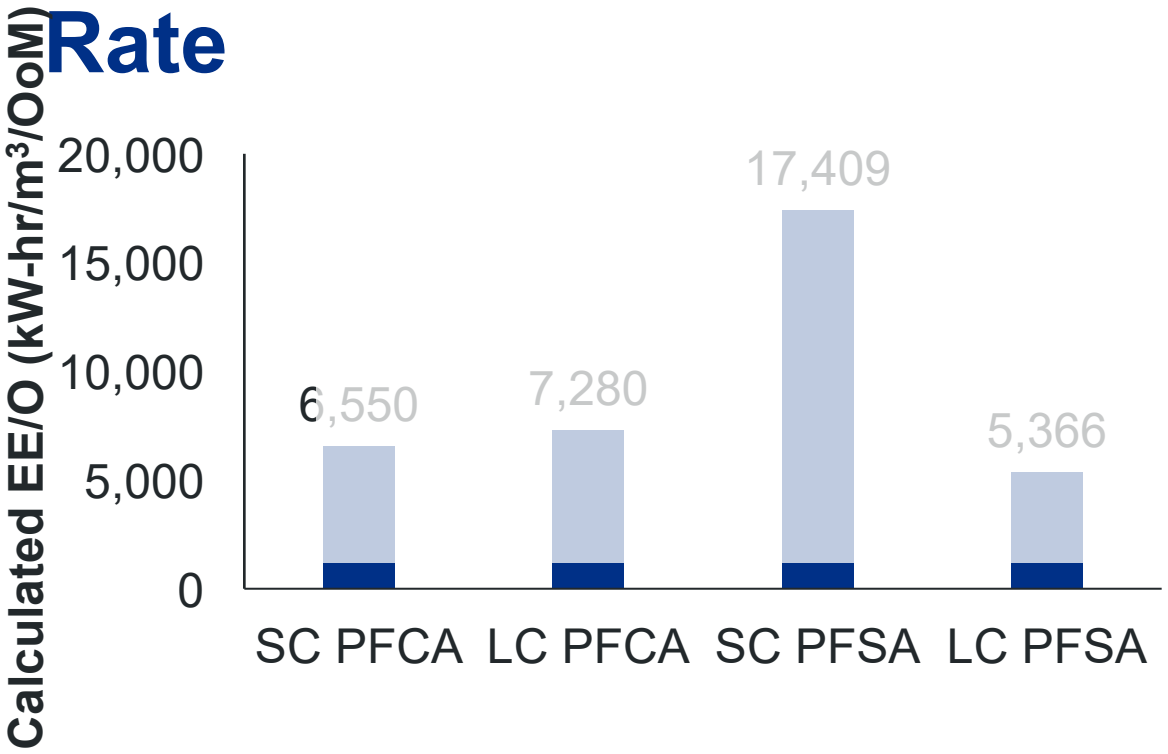
- Rate of reaction influences both EE/O and EEM at slower rates
- At faster rates, EEM is less influenced (**math trick!**)
- Rates >1 hr^{-1} observed in more than 40% of trials reviewed

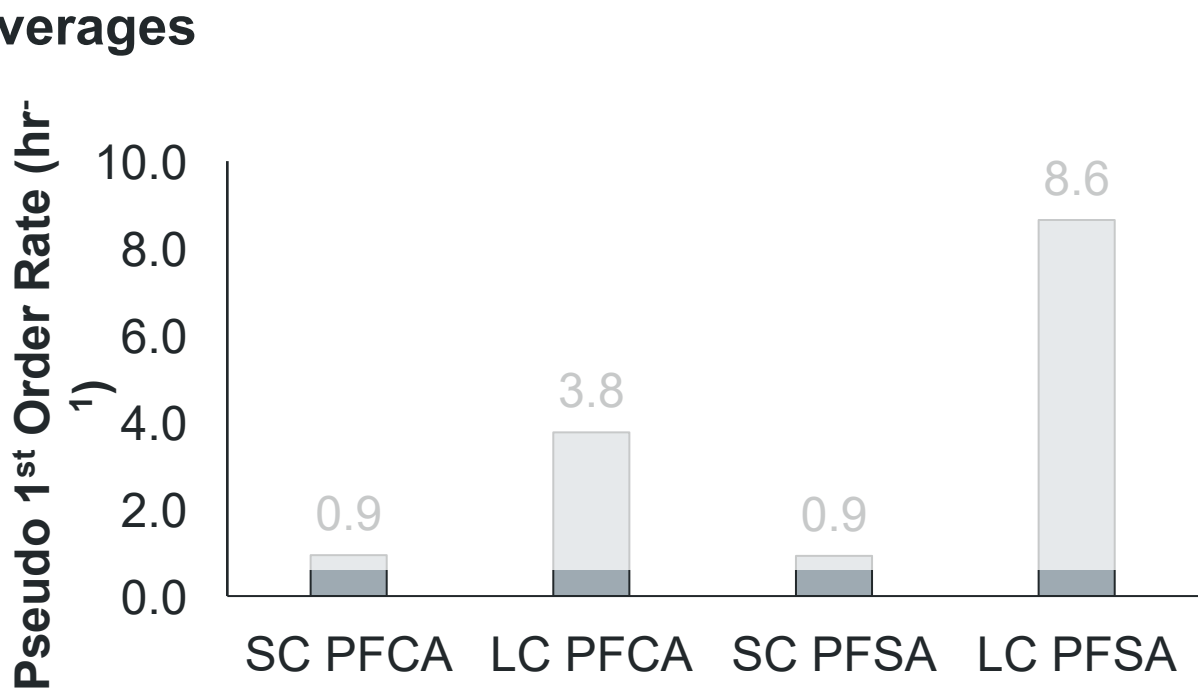


Conceptual Calculation

(*t = 2 hr, C_0 = 100,000 µg/L, Vol = 18.9 L, P = 0.2 kW*)

PFAS Type & Characteristics May Influence Destruction Rate

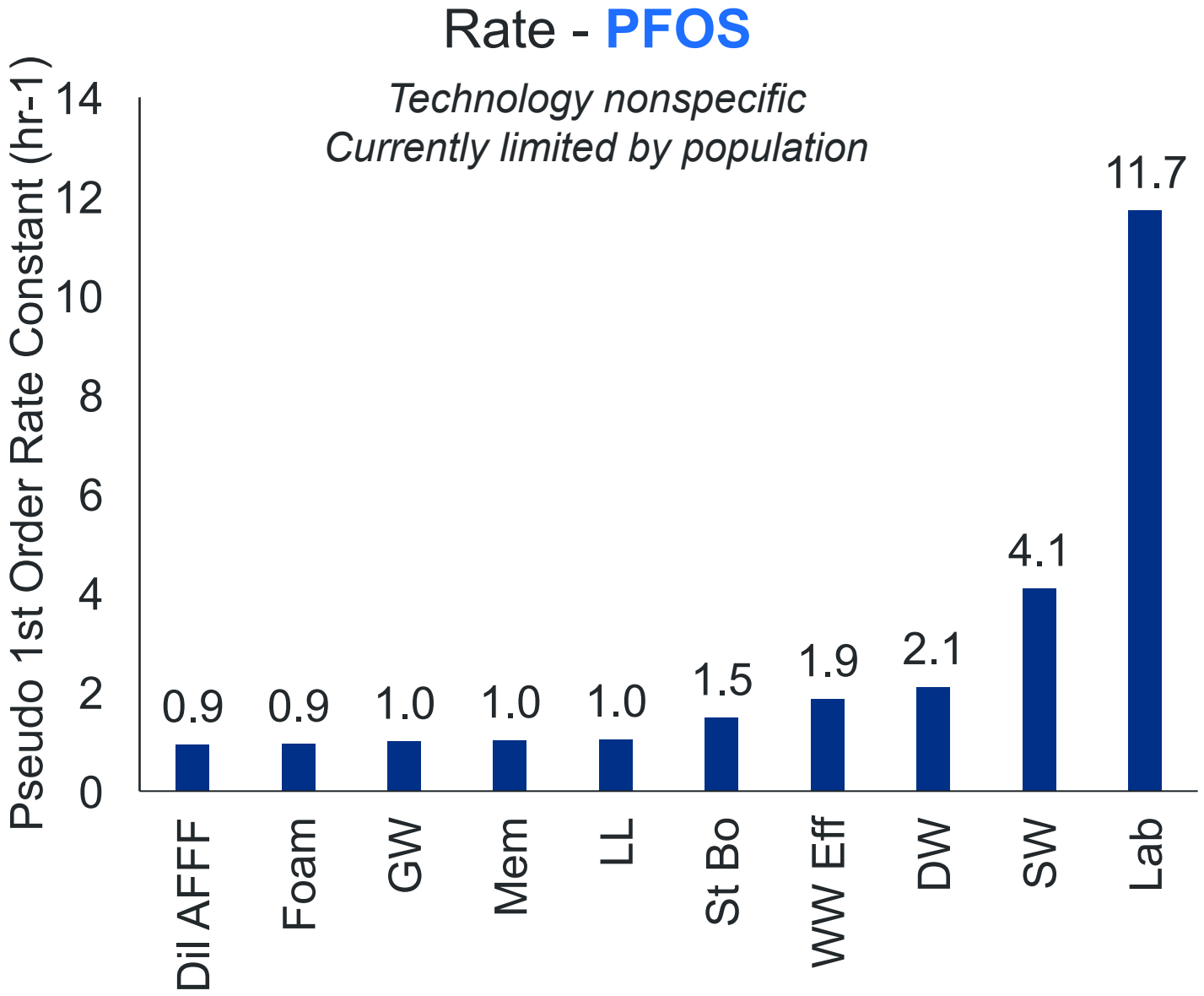




- PFSA: EE/O and rate constant relationship as expected
- PFCA: EE/O and rate constant relationship not intuitive; limited by study-specific analyte lists (PFSAs → PFCAs during destruction)

Rate constants vary based on functional group and chain length and therefore will influence energy expressed as EE/O

Treated Matrix Influences the Reaction Rate



- Complex matrices = slower reaction rates
- Less complex matrices = faster rate kinetics
- **PFOS**-specific because PFAS type and chain-length influences rate constants

Practicality and Energy Evaluation: Survey of PFAS-Relevant Liquid Phase Destruction Treatment Providers

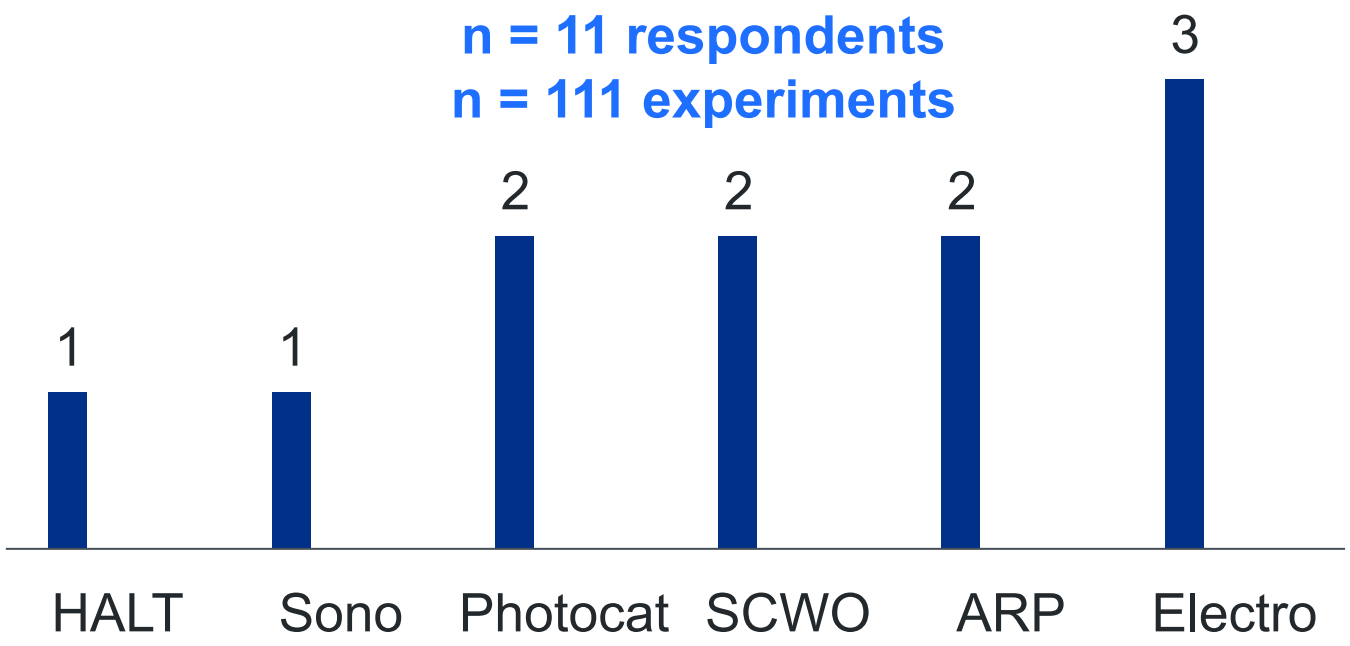
Special Thank You

Survey Question Summary

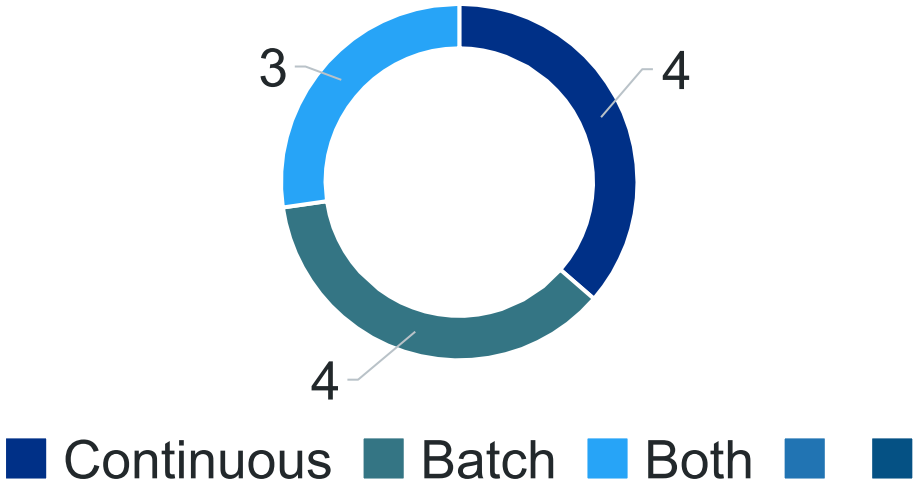
- Batch or continuous?
- Typical residence time?
- Number of trials (bench-scale, field-scale, full-scale)?
- Energy measurements/expression (w/units)?
- Differences in energy for higher/lower OoM changes?
- Trials where defluorination was not the goal?
- Primary component that dictates energy usage?
- Observed influence of treatment matrices?
- Considerations of energy transformation efficiency?

Responses included case studies of PFAS destruction (C_0, C_t, time, volume, energy, and % defluorination) to standardize EE/O and EEM

Survey Summary



Only 1 technology without stated plans for future continuous throughput



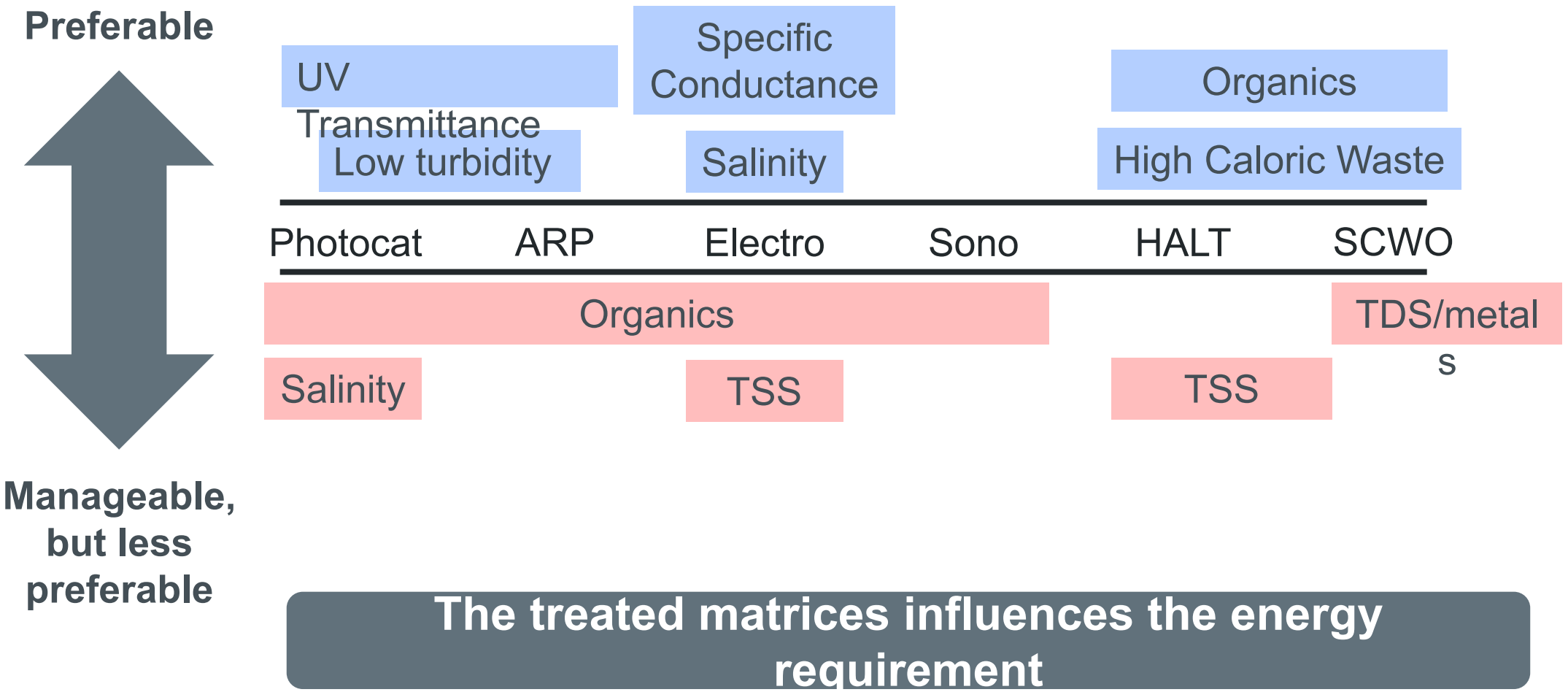
0.0006 hr — **Residence Times** — 48 hr

Avg = 7.6 hr

Energy Units:

- kWhr/gal
- kWhr/flowrate
- kWhr/m^3
- kWhr/m^3/OoM (special for PFAS)
- kWhr/kg

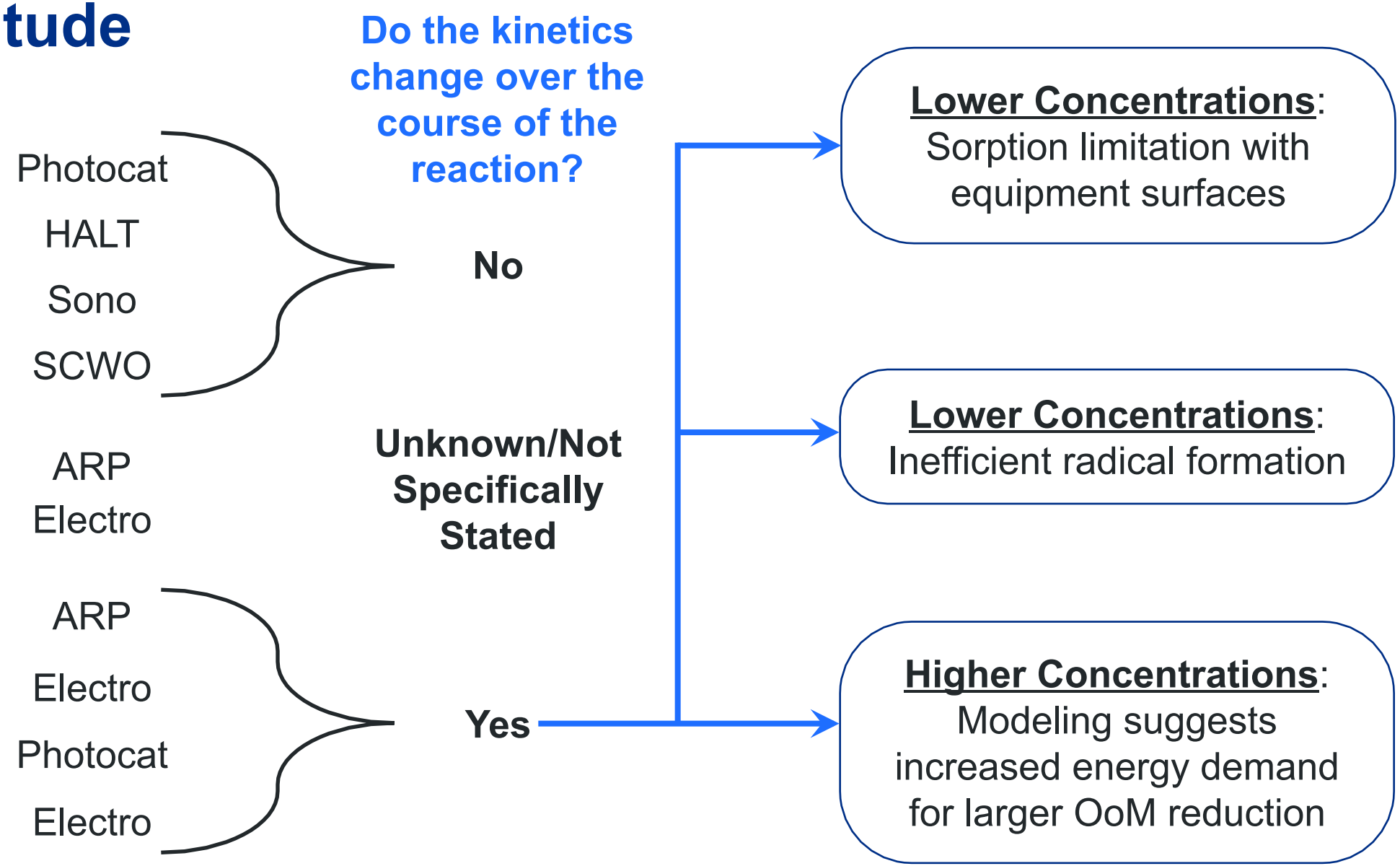
Survey Summary



The treated matrices influences the energy requirement

TDS = total dissolved solids
TSS = total suspended solids

Mixed Response on Linearity of Energy Usage per Order of Magnitude



Limitations of this Summary and Future Work

Little information on TOF/TOP Assay

Little information on <C4 PFAS

Influence of reactor configuration on EE/O

Volatile fluorinated intermediates (widely acknowledged)

Destruction focused; what about the concentration steps?

Multiple influences on rate kinetics unexhausted

Inconsistent “system boundaries” for determining power

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To learn more, contact:

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