PFAS treatment techniques – Needs for the future?

Lutz Ahrens

Department of Aquatic Sciences and Assessment, SLU, Uppsala, Sweden

September 18, 2023

Webinar on PFAS in the Nordic Region

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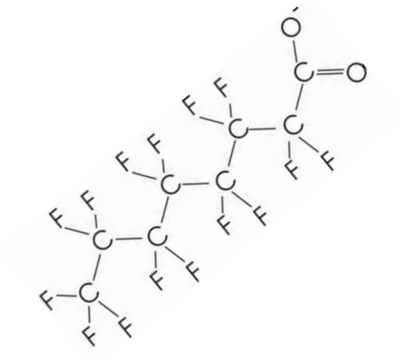
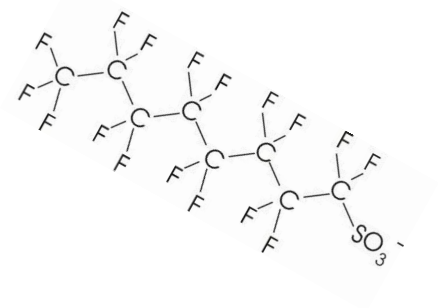
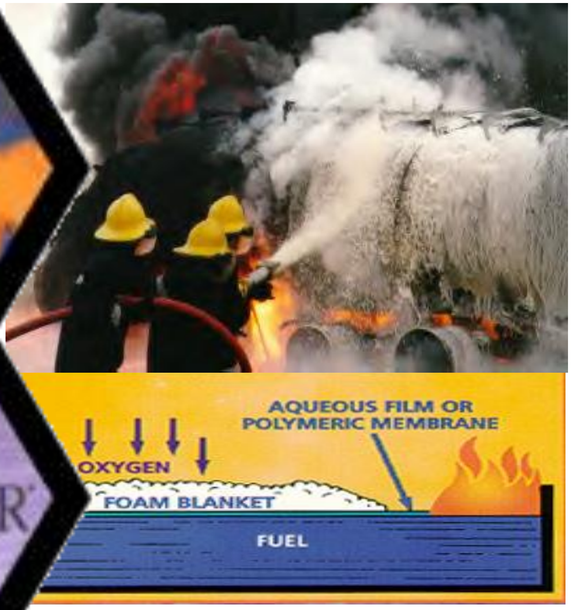
Per- and polyfluoroalkyl substances (PFASs)







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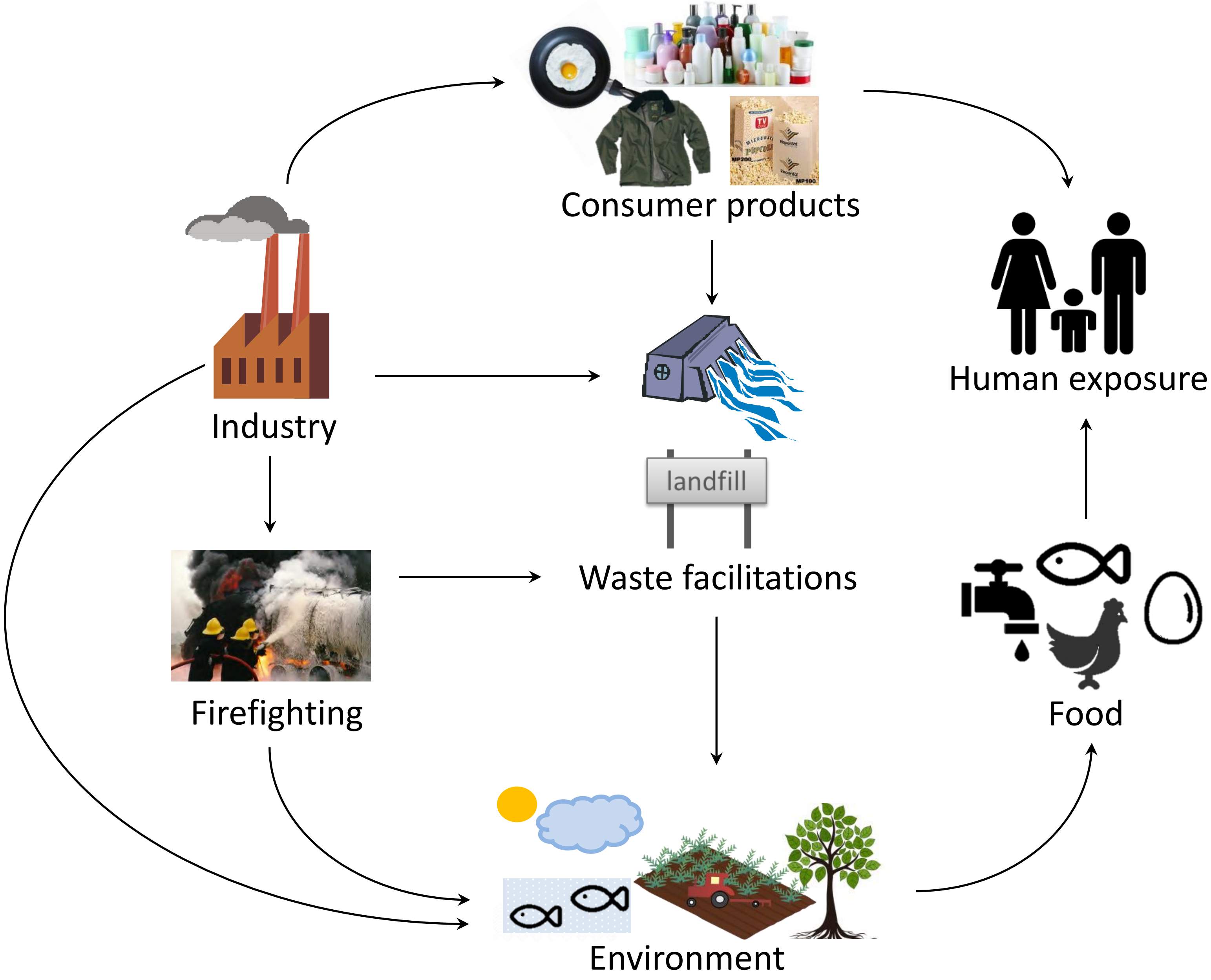
Circulation of PFASs in the Environment



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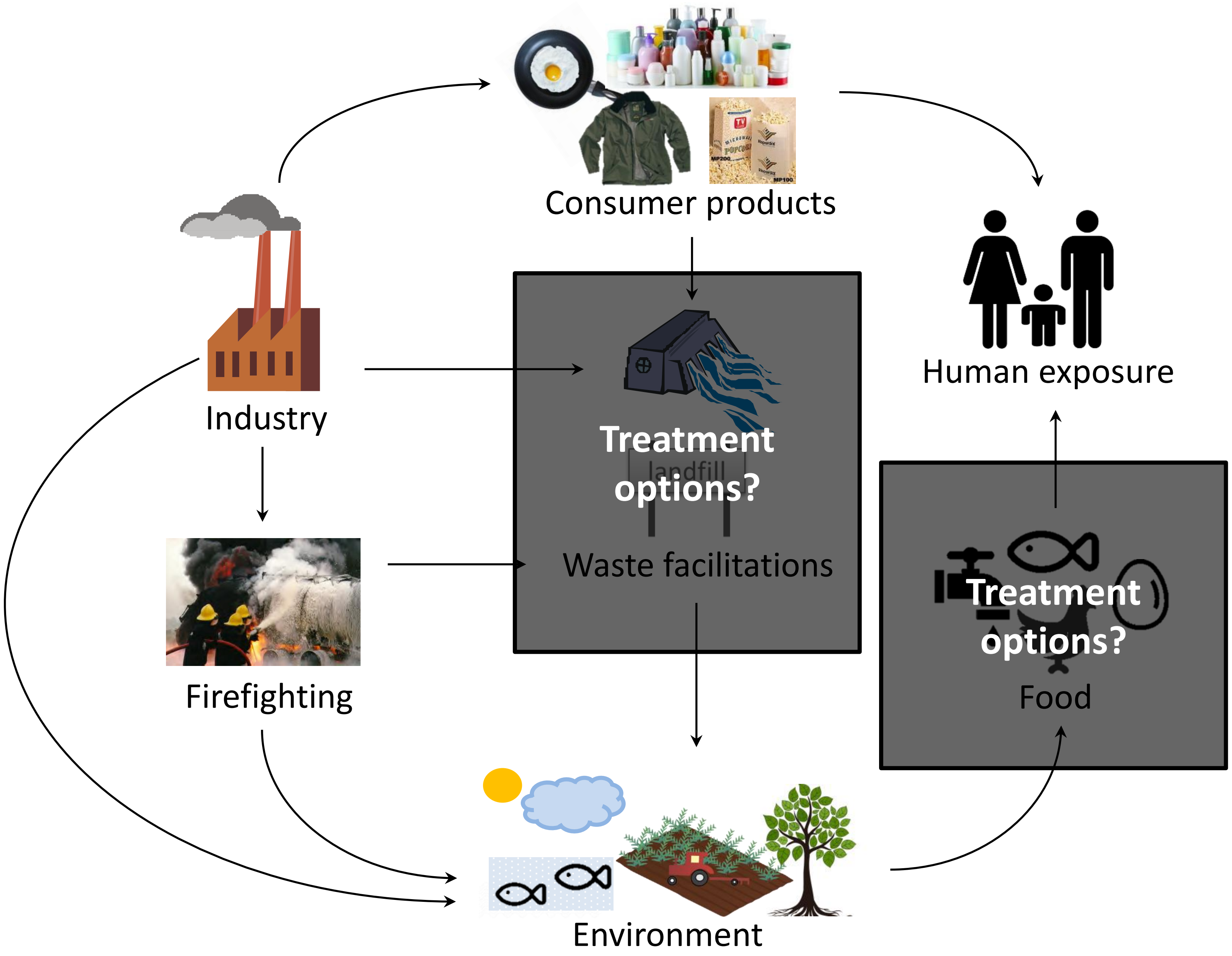

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Guideline Values for PFASs in Drinking Water

2013

National Food Agency

$\sum PFAS_7 \leq 90$ ng L^{-1}

$\sum_7$PFASs
PFPeA - C_4
PFHxA - C_5
PFHpA -C_6
PFOA - C_7
PFBS - C_4
PFHxS - C_6
PFOS - C_8

2016

National Food Agency

$\sum PFAS_{11} \leq 90$ ng L^{-1}

$\sum_{11}$PFASs
PFBA - C_3
PFPeA - C_4
PFHxA - C_5
PFHpA -C_6
PFOA - C_7
PFNA - C_8
PFDA - C_9
PFBS - C_4
PFHxS - C_6
PFOS - C_8
6:2 FTSA

2020

$\sum PFAS_{20} \leq 100$ ng L^{-1}

Total PFASs ≤ 500 ng L^{-1}

$\sum_{20}$PFASs
C_4–C_{13} PFSAs
C_4–C_{13} PFCAs

Total PFASs

2023

National Food Agency

Sampling required

$\sum PFAS_{21} \leq 100$ ng L^{-1}

Total PFASs ≤ 500 ng L^{-1}

$\sum PFAS_4 \leq 4$ ng L^{-1}

$\sum_{21}$PFASs
C_4–C_{13} PFSAs
C_4–C_{13} PFCAs
6:2 FTSA

Total PFASs

$\sum_4$PFASs
PFOA - C_7
PFNA - C_8
PFHxS - C_6
PFOS - C_8

2026 ?

National Food Agency

Treatment required

$\sum PFAS_4 \leq 4$ ng L^{-1}

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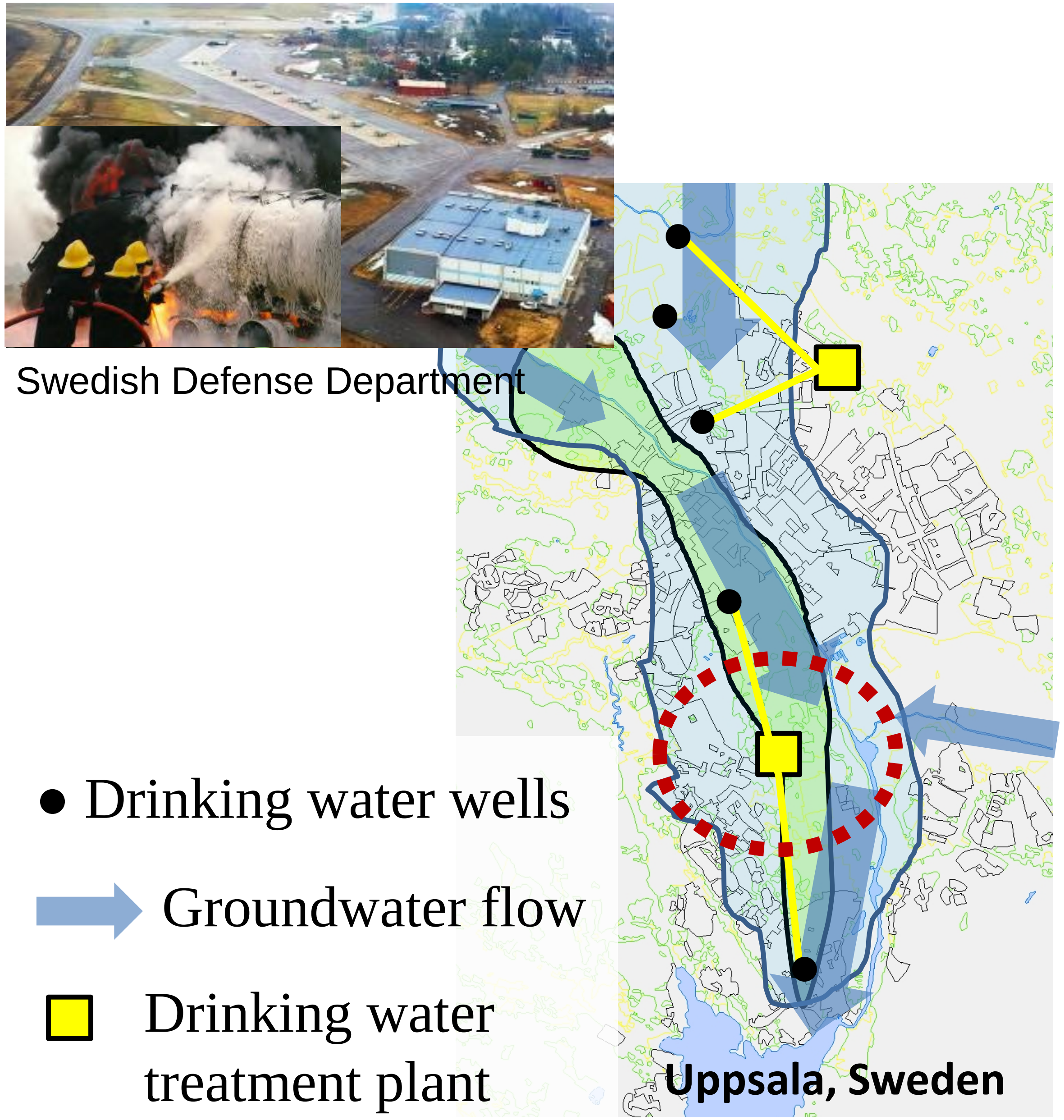
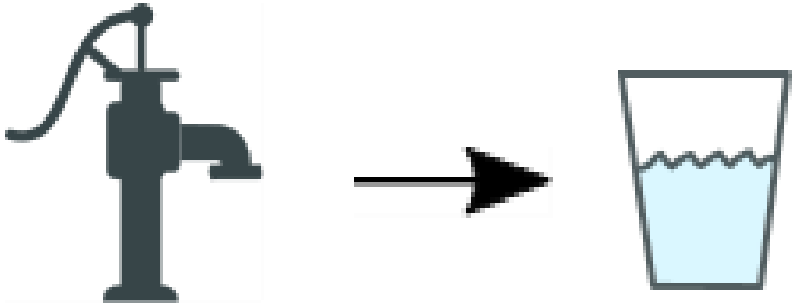
PFASs in Drinking Water



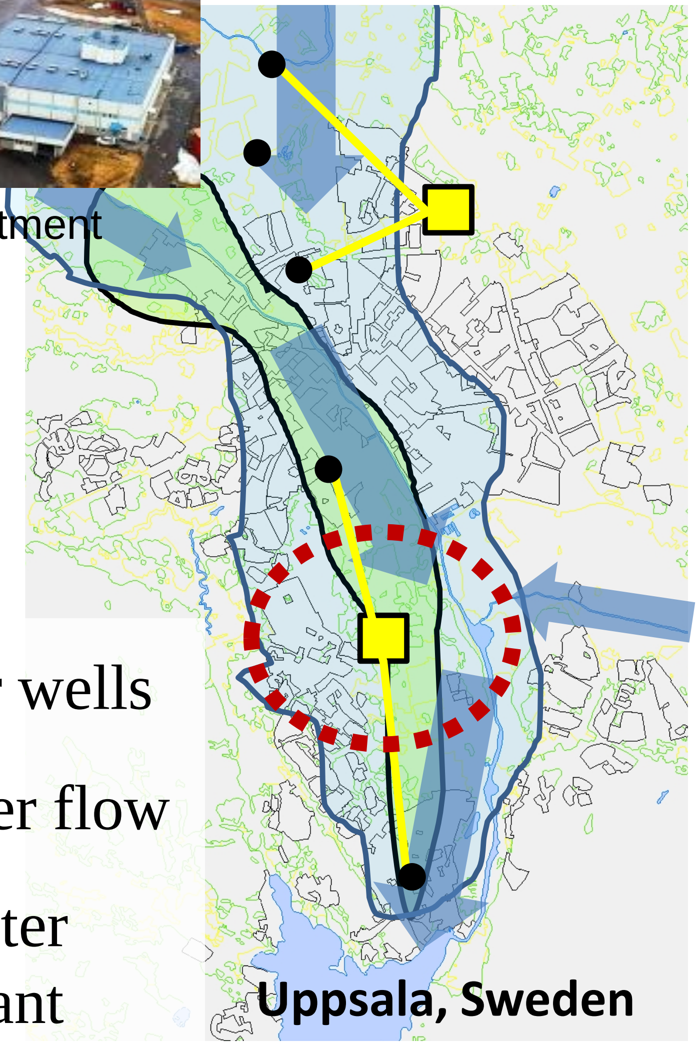


$PFAS_{in} \approx PFAS_{out}$

Sörengård M, Bergström S, McCleaf P, Wiberg K and Ahrens L, 2022. *Environ. Pollut.*, 311, 119981.

PFASs in Drinking Water

Swedish Defense Department



Raw water

- 100-200 ng/L for $\sum_{21}$PFAS
- ~80 ng/L for $\sum_{4}$PFAS

Drinking water limits

- $\sum PFAS_{21} \leq 100$ ng/L
- $\sum PFAS_{4} \leq 4$ ng/L

Sörengård M, Bergström S, McCleaf P, Wiberg K and Ahrens L, 2022. *Environ. Pollut.*, 311, 119981.

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What can we do?

PFASs in Drinking Water

Swedish Defense Department

- Drinking water wells
- Groundwater flow
- Drinking water treatment plant

Raw water

- 100-200 ng/L for $\sum_{21}$PFAS
- ~80 ng/L for $\sum_{4}$PFAS

Drinking water limits

- $\sum PFAS_{21} \leq 100$ ng/L
- $\sum PFAS_{4} \leq 4$ ng/L

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PFAS Treatment Options for Water

Concentration

Adsorption treatment

Degradation

PFAS Treatment Options - Concentration

Environmental Science
Water Research & Technology

COMMUNICATION

Cite this: DOI: 10.1039/c9ew00286c

Received 6th April 2019,
Accepted 11th June 2019

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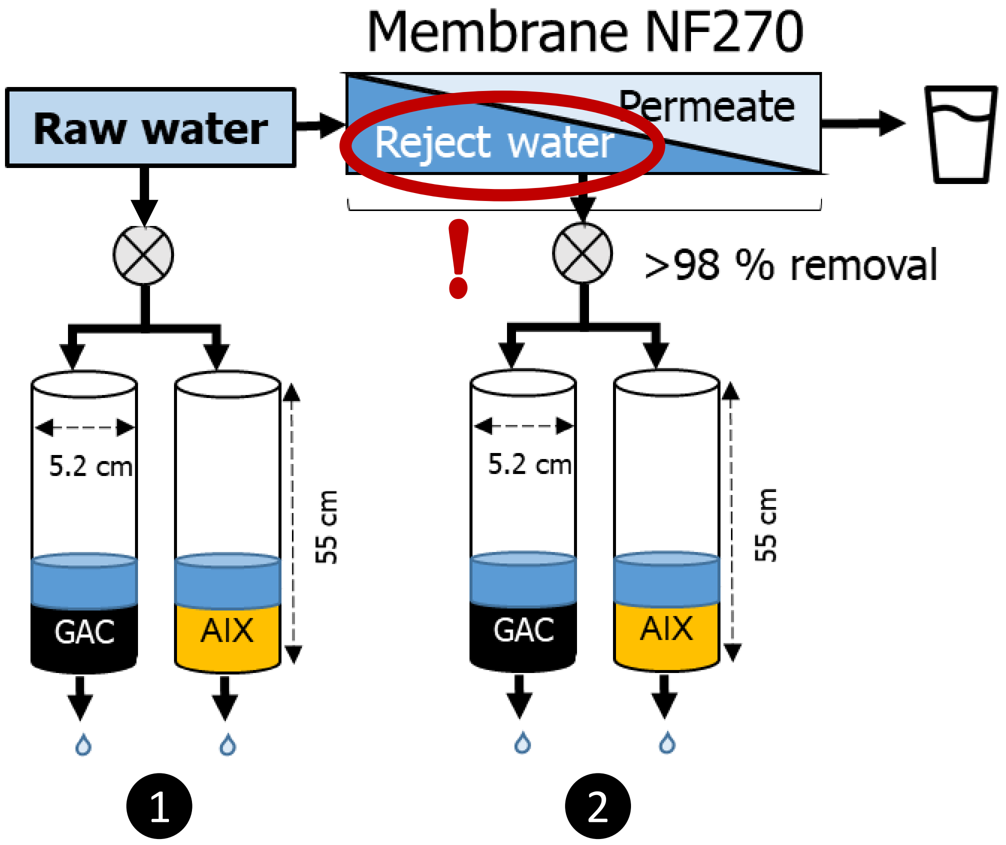
Efficient removal of per- and polyfluoroalkyl substances (PFASs) in drinking water treatment: nanofiltration combined with active carbon or anion exchange†

Vera Franke,[*a] Philip McCleaf,[b] Klara Lindegren‡[a] and Lutz Ahrens[a]

Concentration

Membranes
- NF, RO



Franke V, McCleaf P, Lindegren K, Ahrens L. 2019. *ESWRT*, 5, 1836–1843

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PFAS Treatment Options - Concentration

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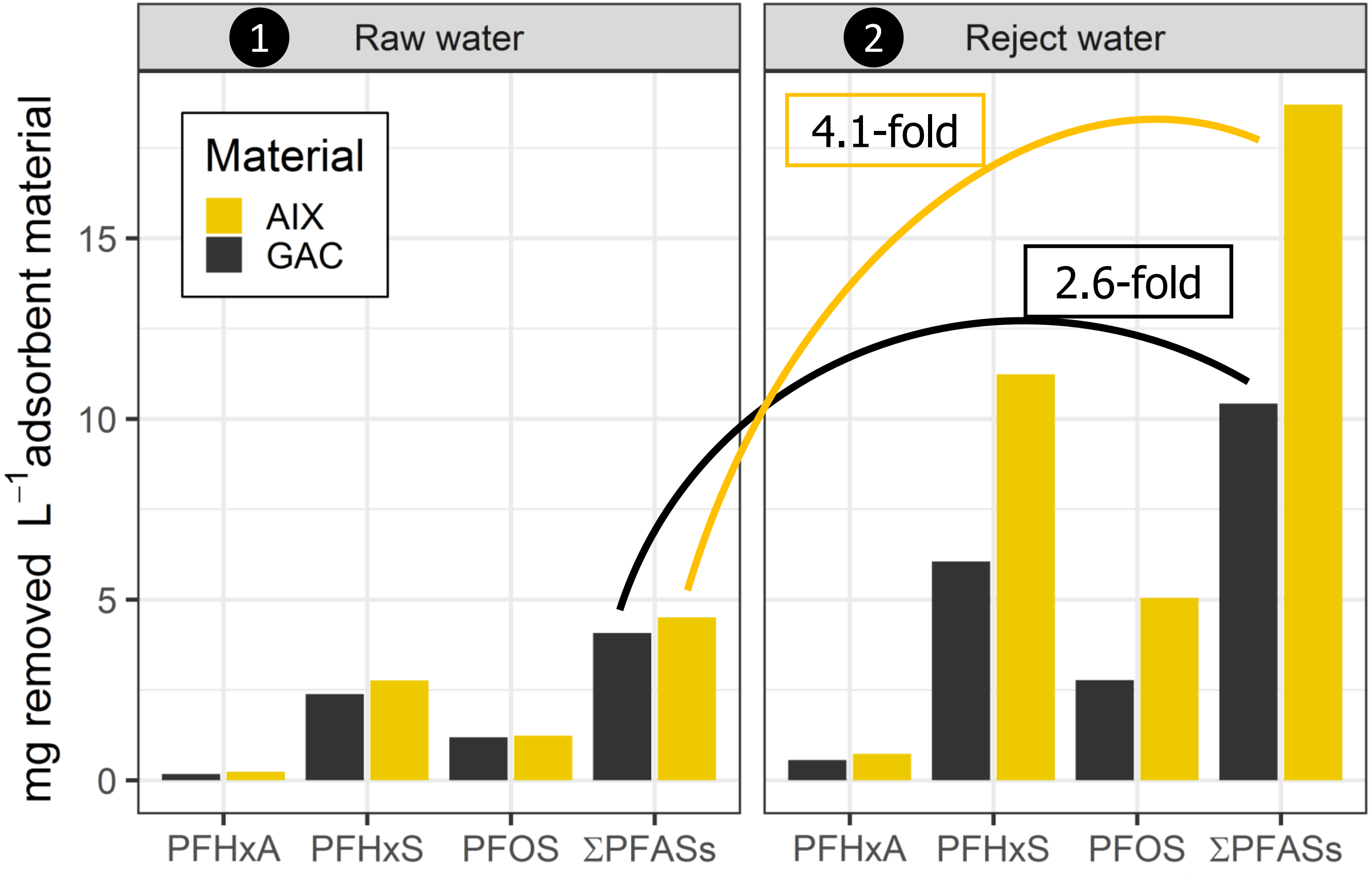

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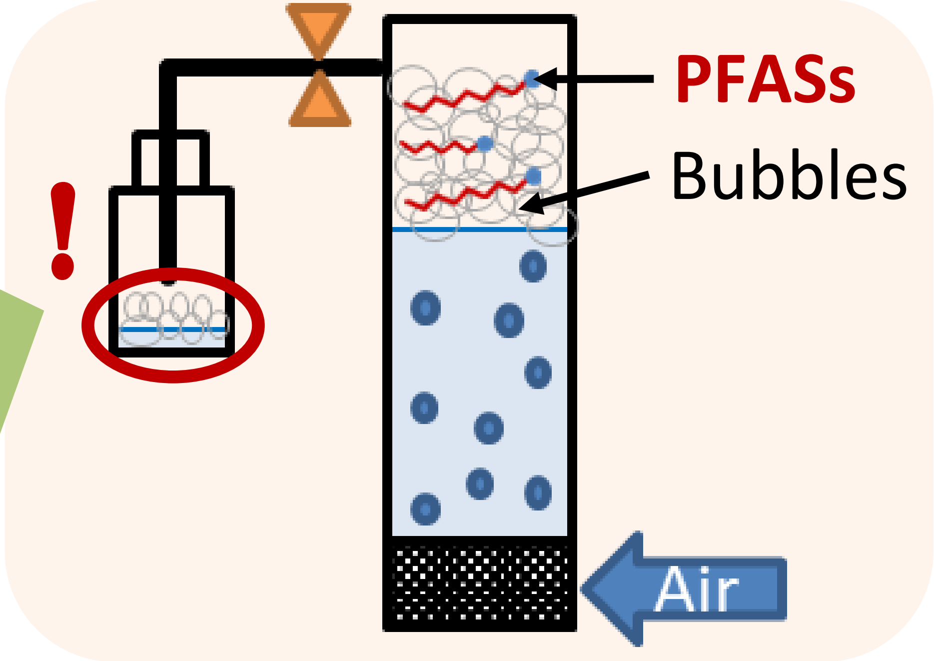
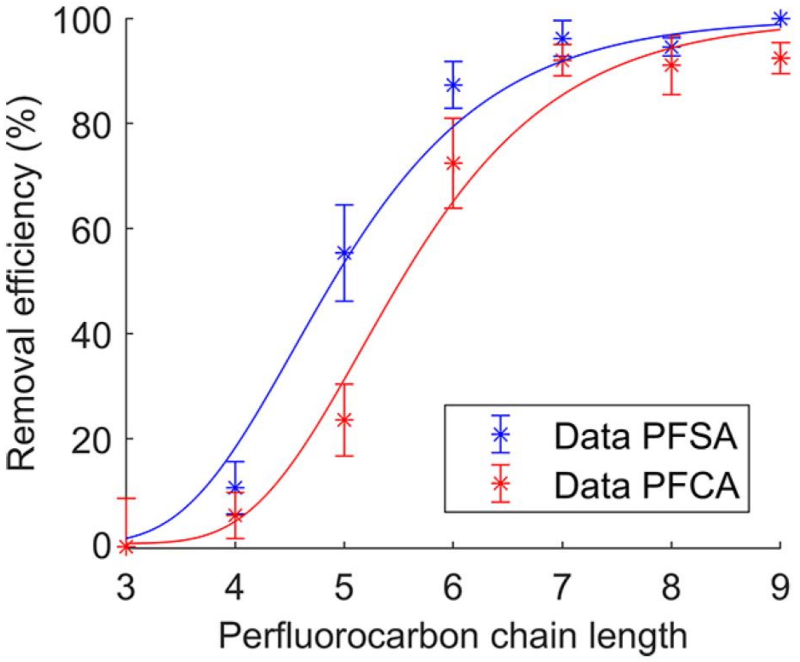
PFAS Treatment Options - Concentration

Concentration

Membranes
- NF, RO

Foam fractionation





Smith, Wiberg, McCleaf, Ahrens. 2022. ES&T Water, 2, 841-851 McCleaf P, Kjellgren Y, Ahrens L. 2021. AWWA, e1238

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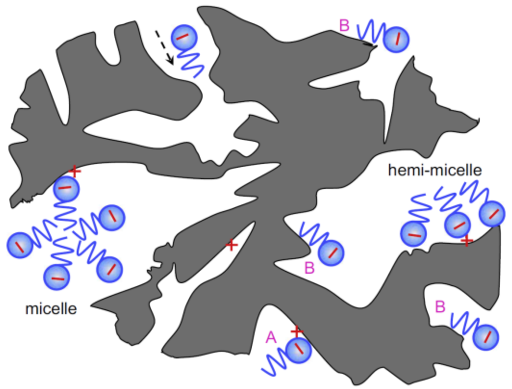
Adsorption Treatment

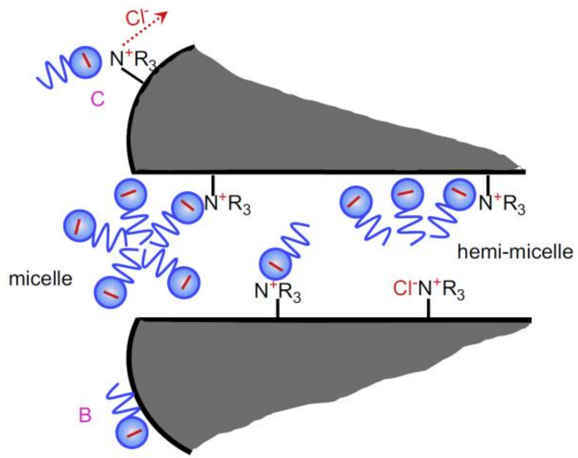
Adsorption treatment

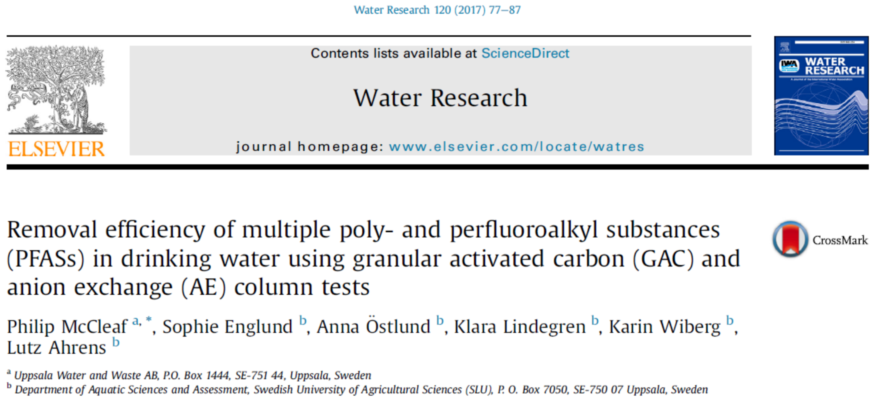
Activated carbon (AC)
- GAC
- PAC

Anion exchange (AIX)

Other sorbents







Water Research 120 (2017) 77–87
Contents lists available at ScienceDirect
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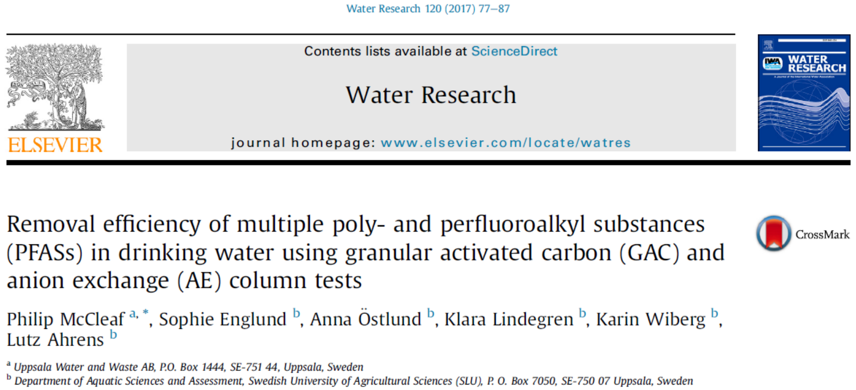
Removal efficiency of multiple poly- and perfluoroalkyl substances (PFASs) in drinking water using granular activated carbon (GAC) and anion exchange (AE) column tests

Philip McCleaf [a, *], Sophie Englund [b], Anna Östlund [b], Klara Lindegren [b], Karin Wiberg [b], Lutz Ahrens [b]

[a] Uppsala Water and Waste AB, P.O. Box 1444, SE-751 44, Uppsala, Sweden
[b] Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences (SLU), P. O. Box 7050, SE-750 07 Uppsala, Sweden



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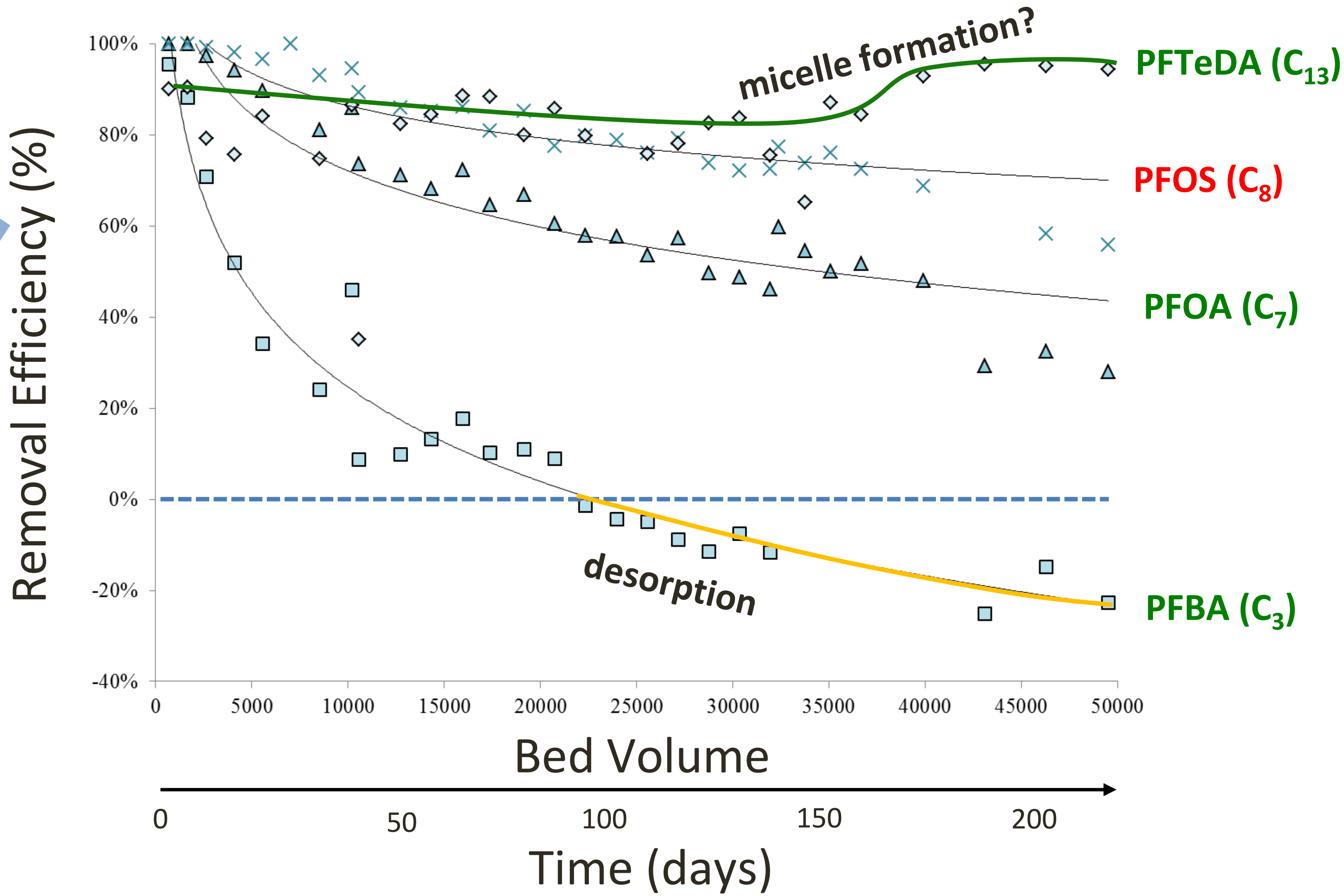
Belkouteb N, Franke V, McCleaf P, Köhler S, Ahrens L. 2020. Water Res, 182, 115913
Yu, Zhang, Deng, Huang, Yu, 2009. Water Res, 43,1150-1158

PFAS Treatment Options - Adsorption Treatment

Adsorption treatment

- **Activated carbon (AC)**
  - GAC
  - PAC
- Anion exchange (AIX)
- Other sorbents



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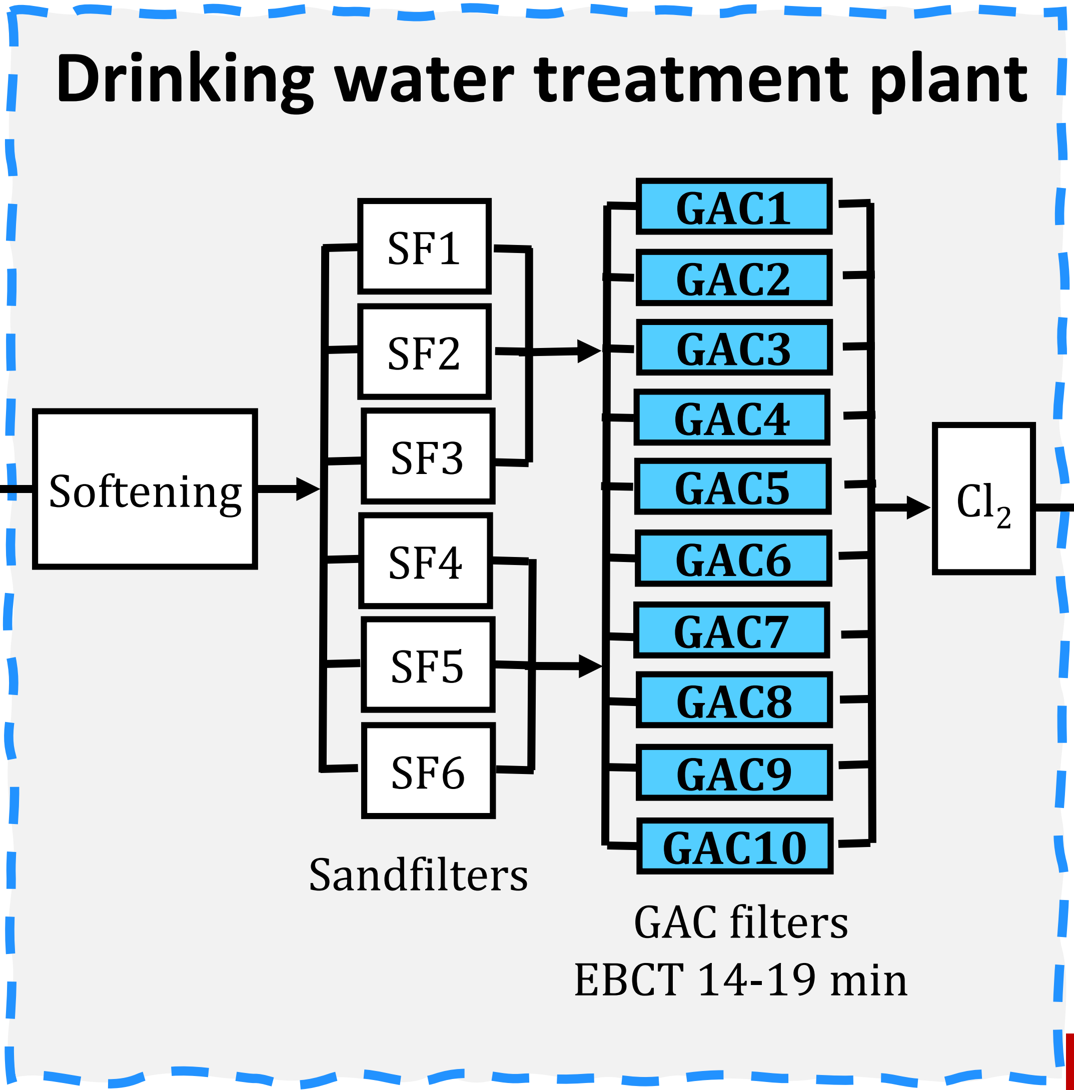
PFAS Treatment Options – Uppsala's Drinking Water Plant

Adsorption treatment

- Activated carbon (AC)
  - GAC
  - PAC
- Anion exchange (AIX)
- Other sorbents

Raw water

- 100-200 ng/L for $\sum_{21}$PFAS
- ~80 ng/L for $\sum_{4}$PFAS



Drinking water

- ~25 ng/L for $\sum_{21}$PFAS (since 2015)
- 4-5 ng/L for $\sum_{4}$PFAS (since 2023)

Drinking water limit
$\sum PFAS_{21} \leq 100$ ng/L
$\sum PFAS_{4} \leq 4$ ng/L

Belkouteb N, Franke V, McCleaf P, Köhler S, Ahrens L. 2020. Water Res, 182, 115913

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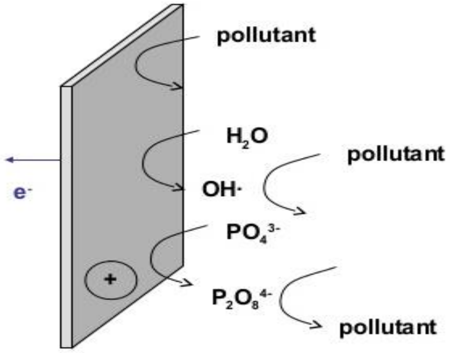
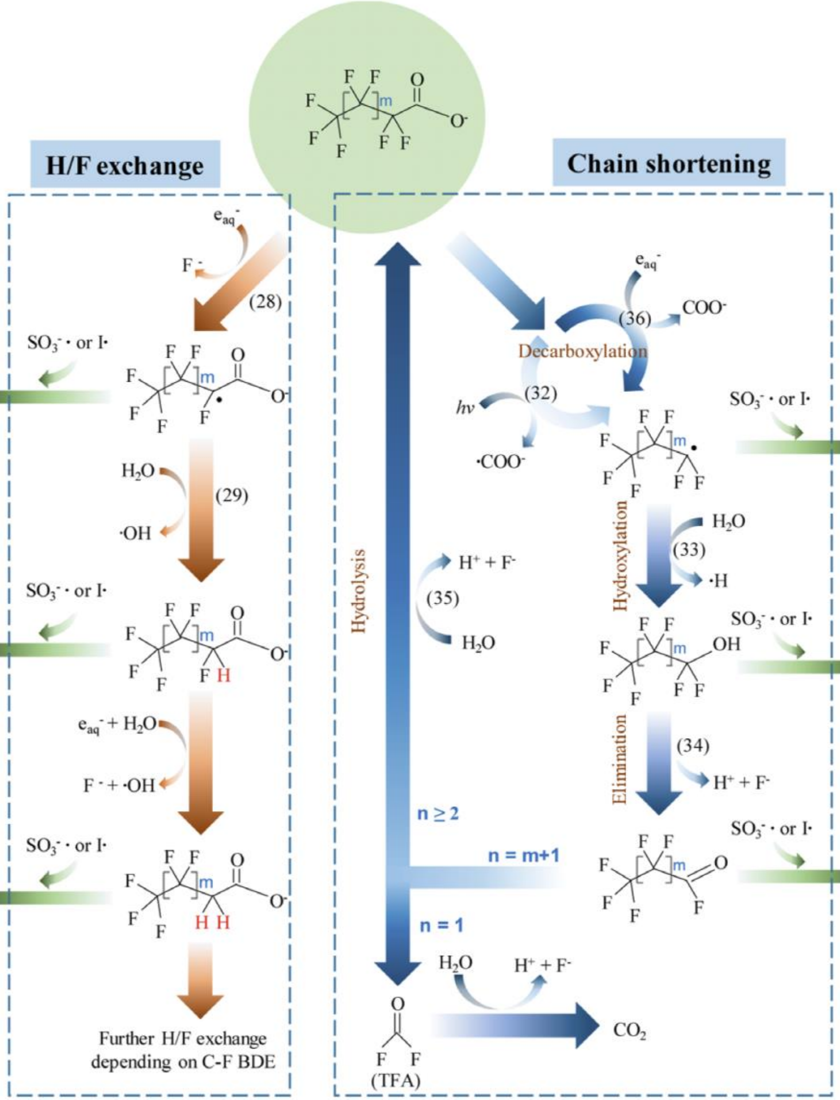
PFAS Treatment Options - Degradation

Degradation

- **Electrochemical oxidation**
- Super critical water oxidation
- Sonochemical
- Plasma reactor
- Microbial degradation





By-products

By-products

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By-products

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Cui, Gao, Deng, 2020, *ES&T*, 54, 3752–3766

PFAS Treatment Options - Degradation

Degradation

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- Super critical water oxidation
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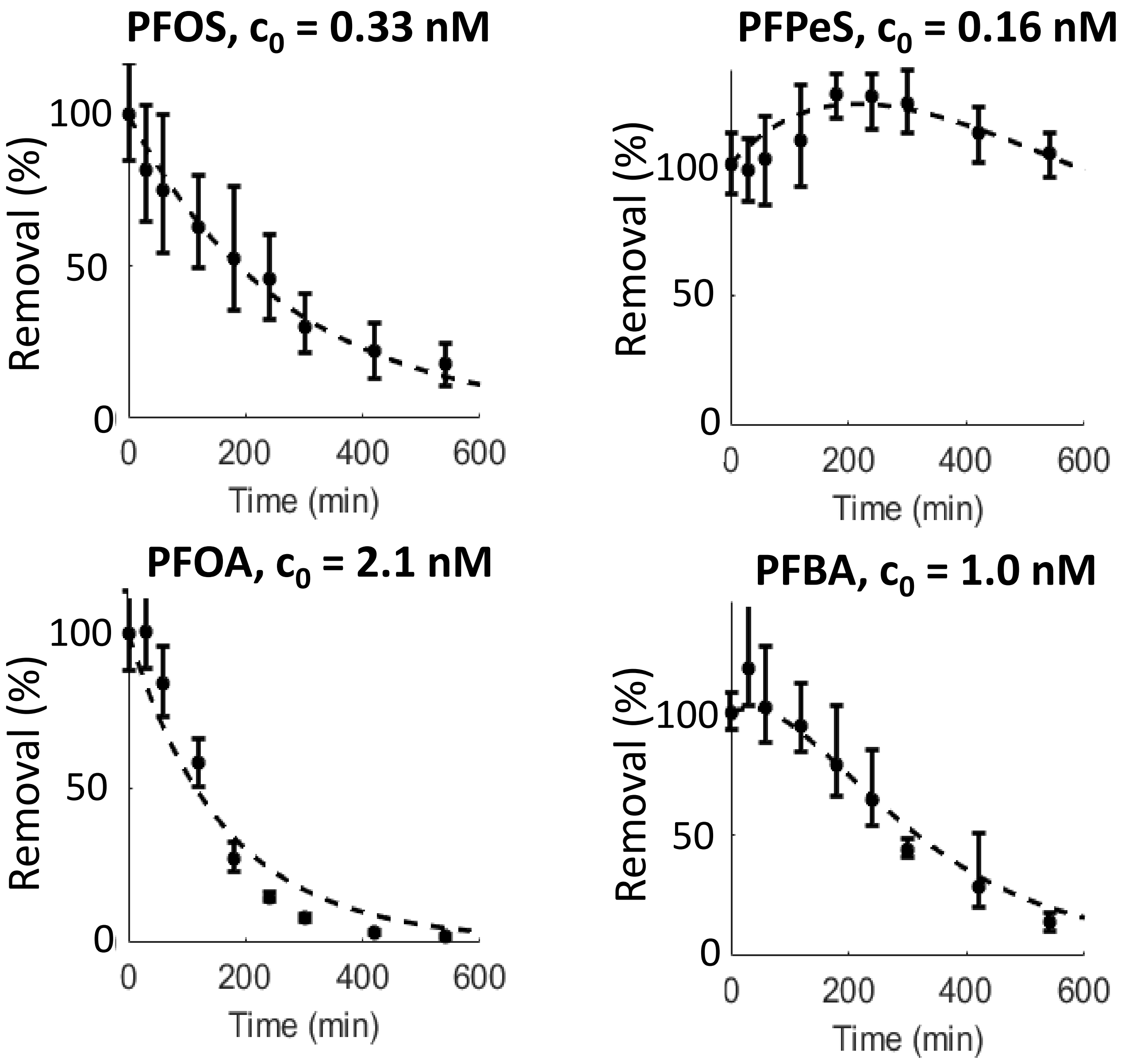
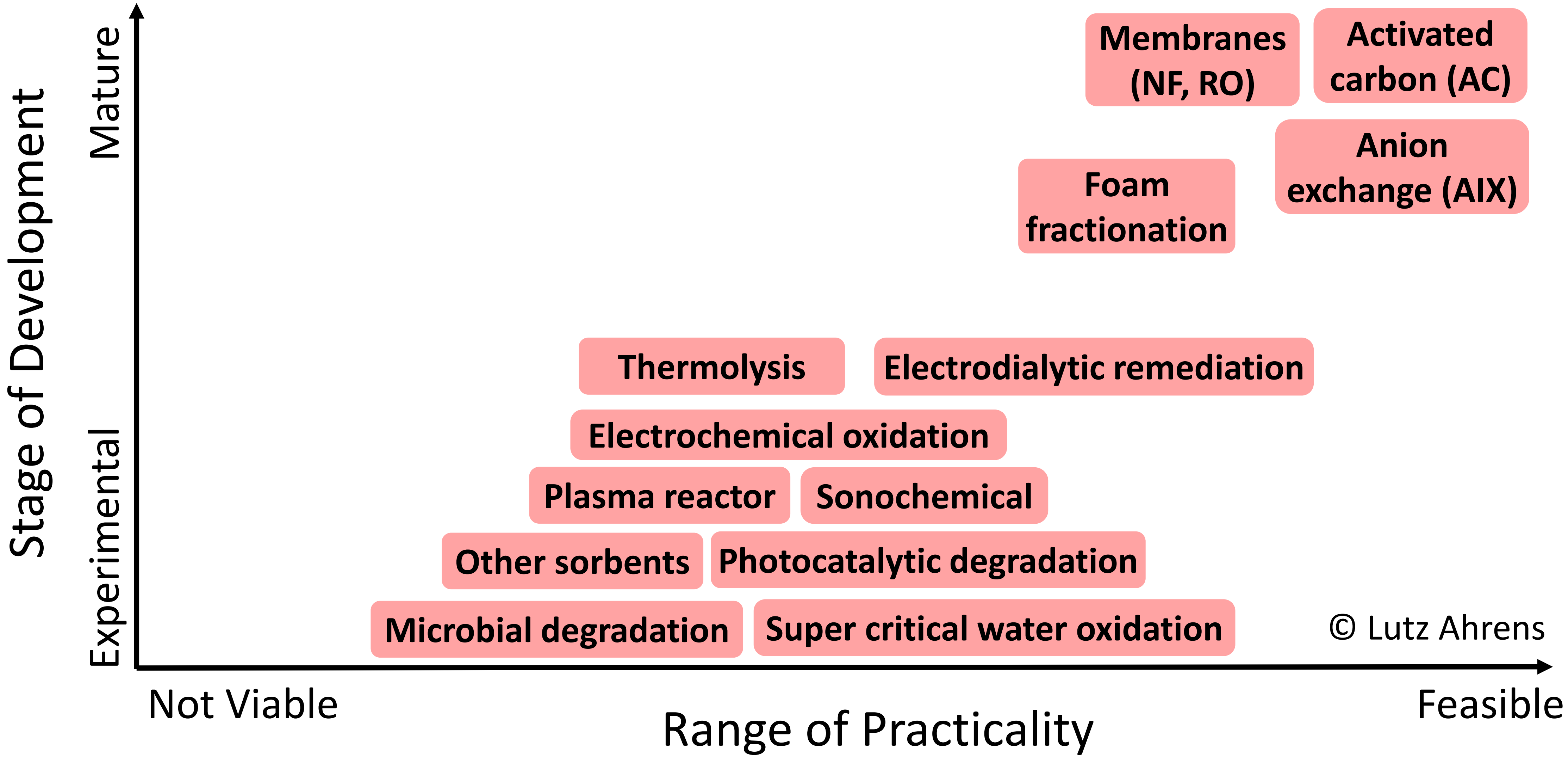
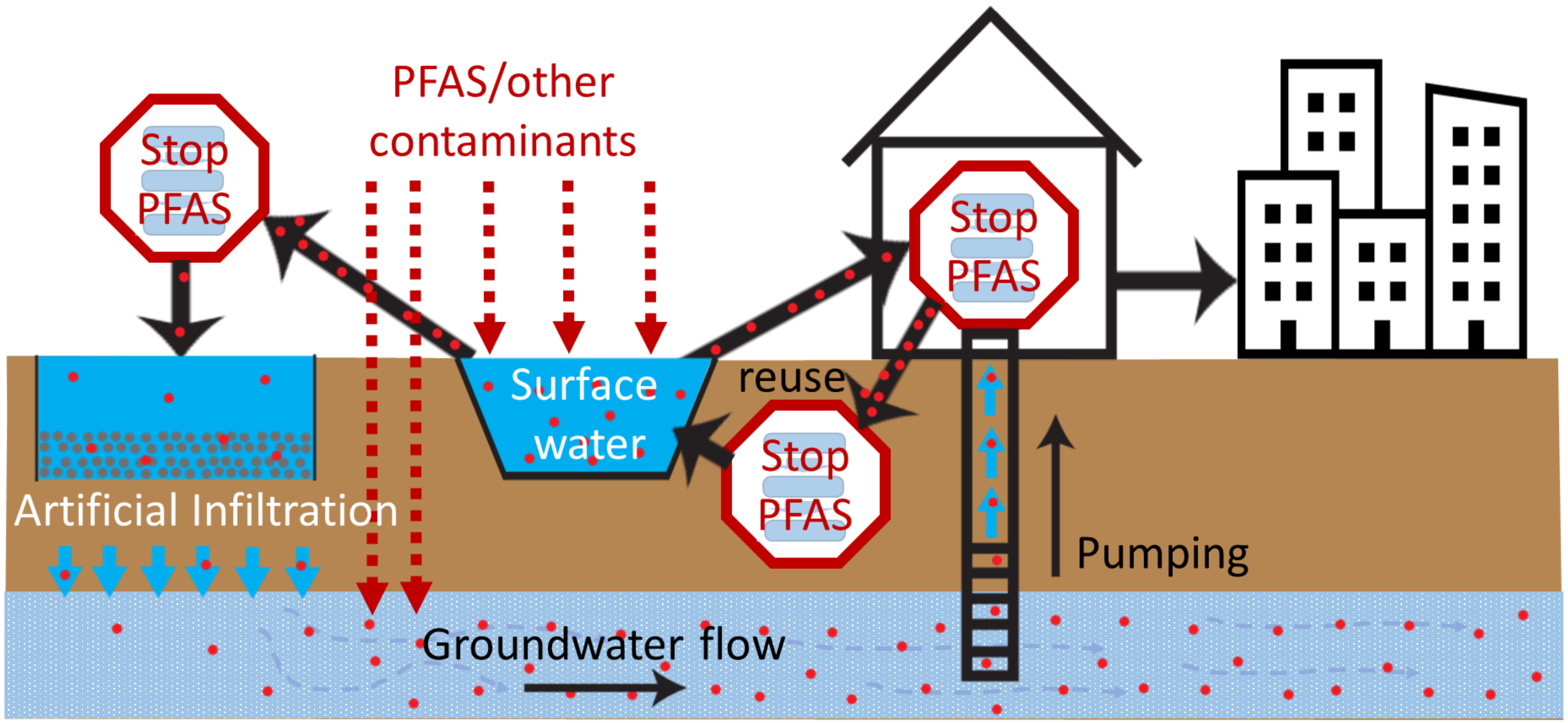


Smith SJ, Lauria M, Ahrens L, McCleaf P, Hollman P, Bjälkefur Seroka S, Hamers T, Arp HPH, Wiberg K, 2023. ES&T Water, 3, 1201-1211.

PFAS Treatment Options for Water



Sustainable innovative drinking water treatment solutions for large-scale water supply and reuse (SIDWater)



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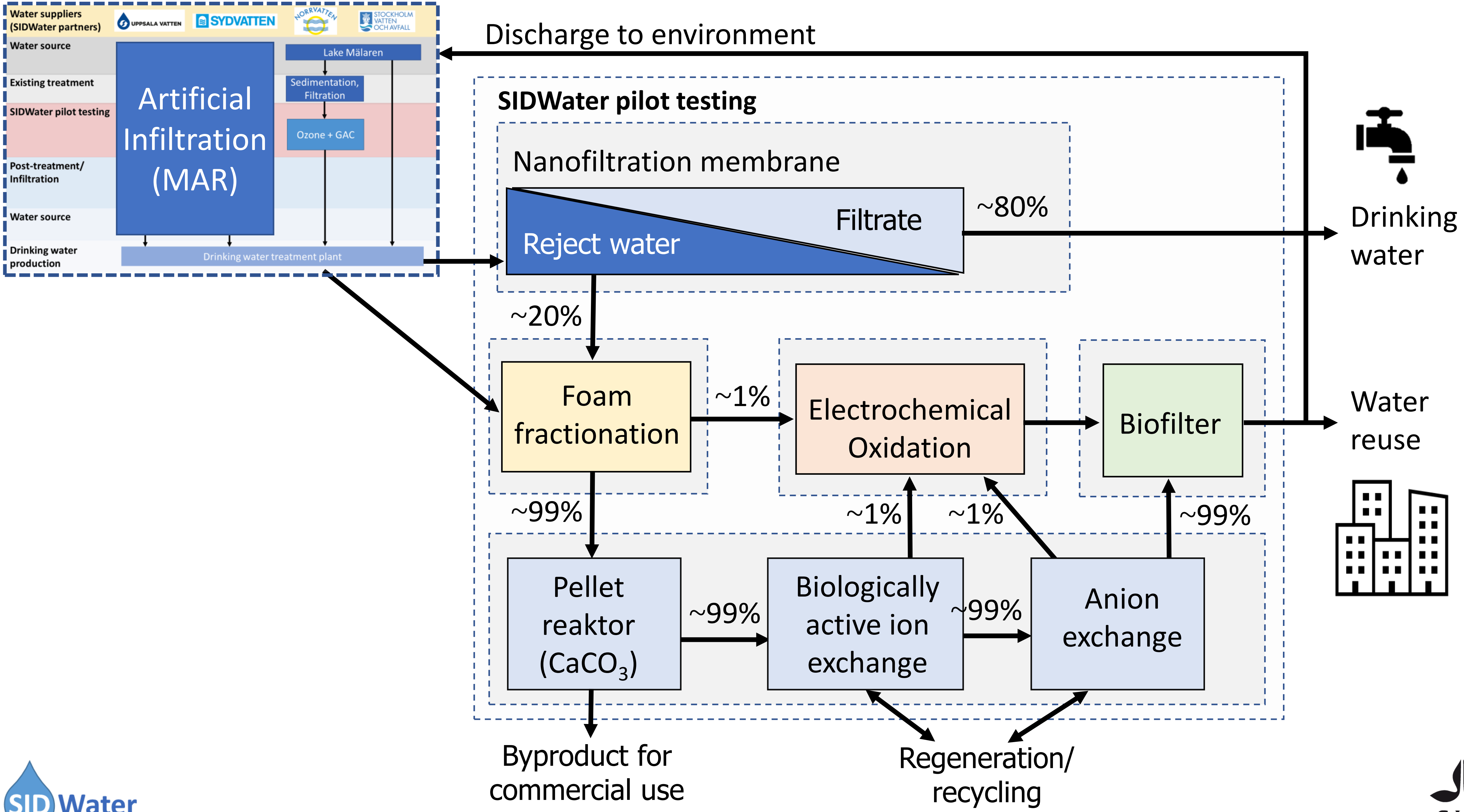
SIDWater

FORMAS



SIDWater

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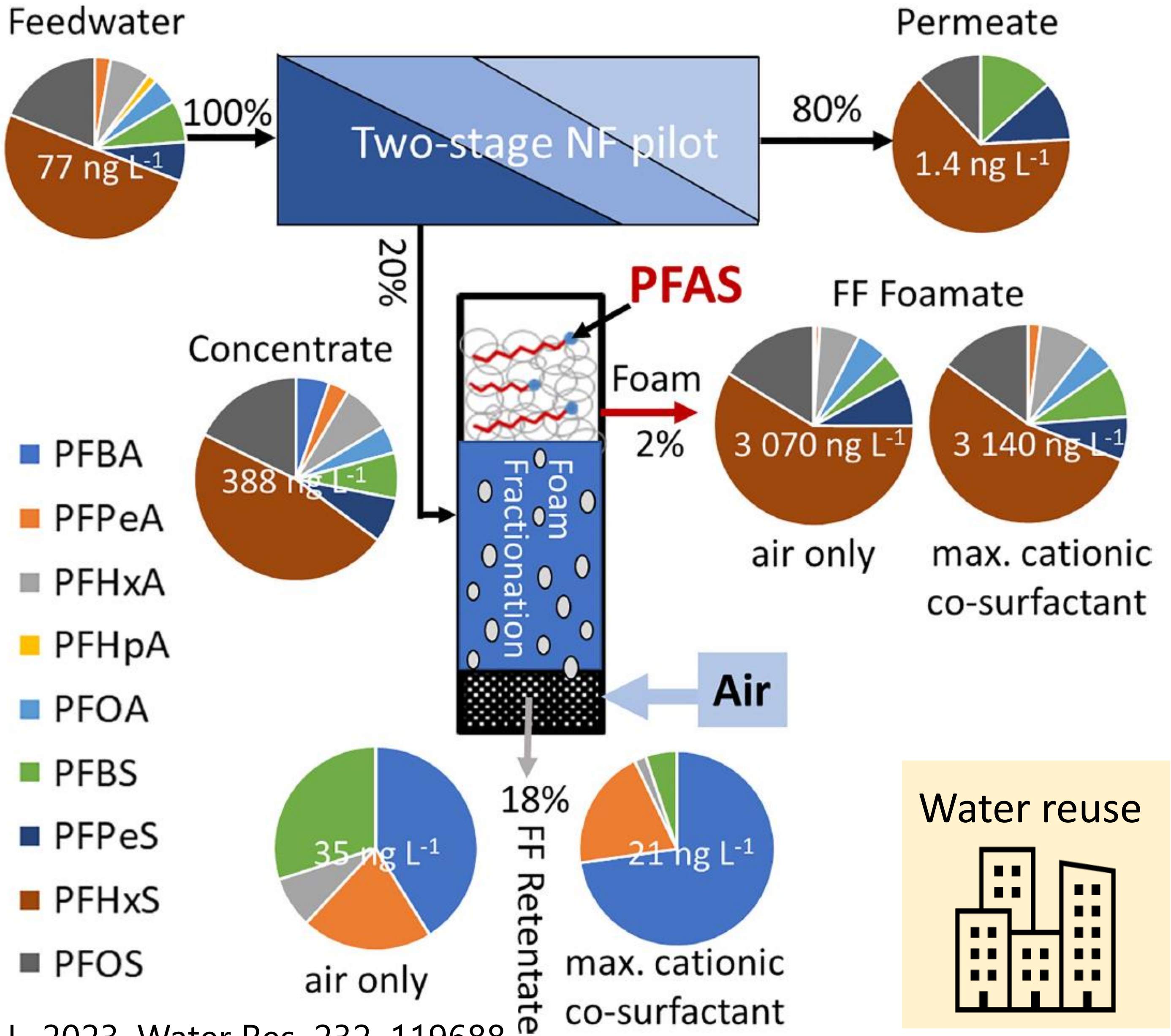
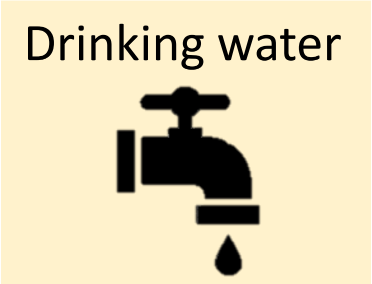
Combination of Nanofiltration + Foam Fractionation





McCleaf P, Stefansson W, Ahrens L. 2023. Water Res, 232, 119688

Take Home Message

- Each treatment technique has their **advantage** and **disadvantage**, so **combination of different treatment techniques is often the best solution**

Thank you!

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