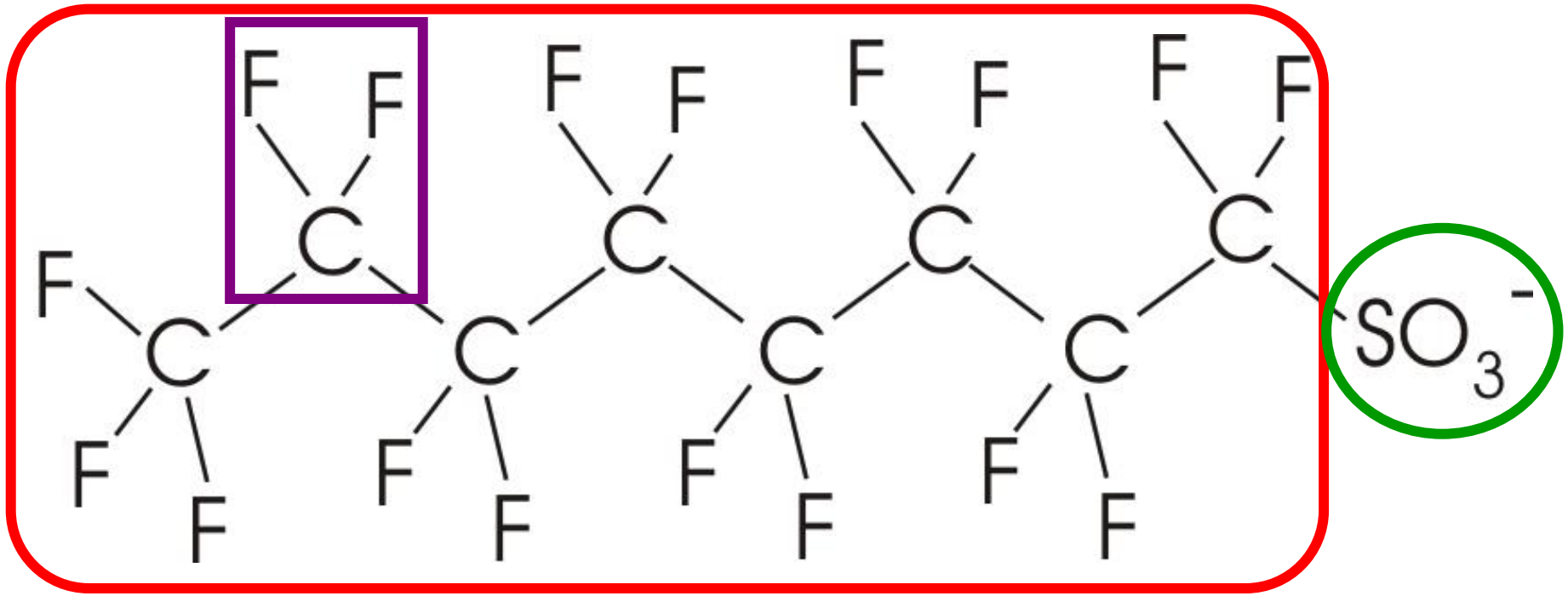
Biokol och PFAS – hur går det ihop?

Lutz Ahrens

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

May 5, 2023

Characteristics of Per- and Polyfluoroalkyl Substances (PFASs)



Perfluorooctane sulfonate (PFOS)

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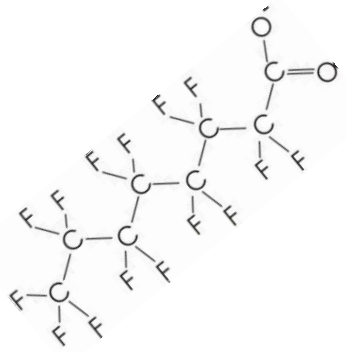
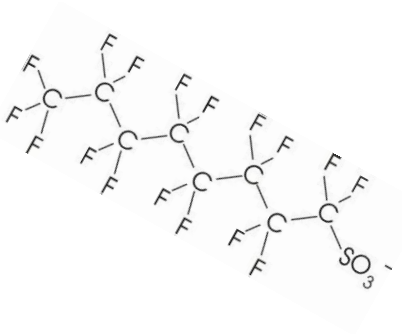
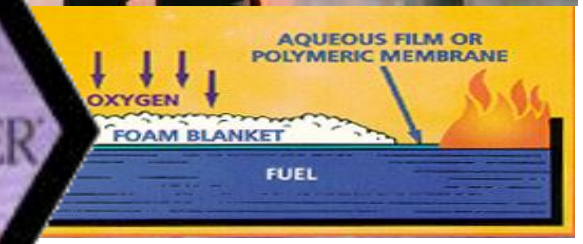
Per- and polyfluoroalkyl substances (PFASs)







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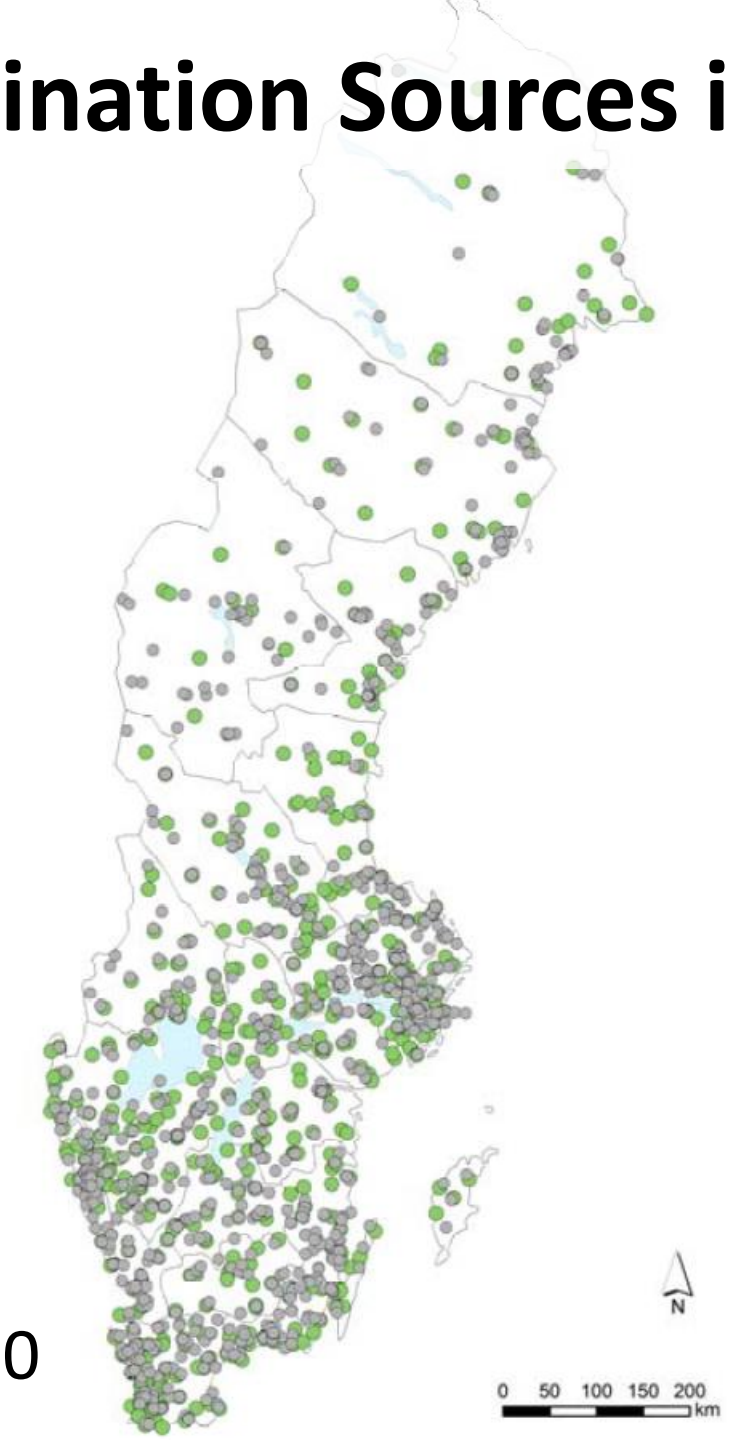
PFAS Contamination Sources in Sweden



>2000

Swedish EPA

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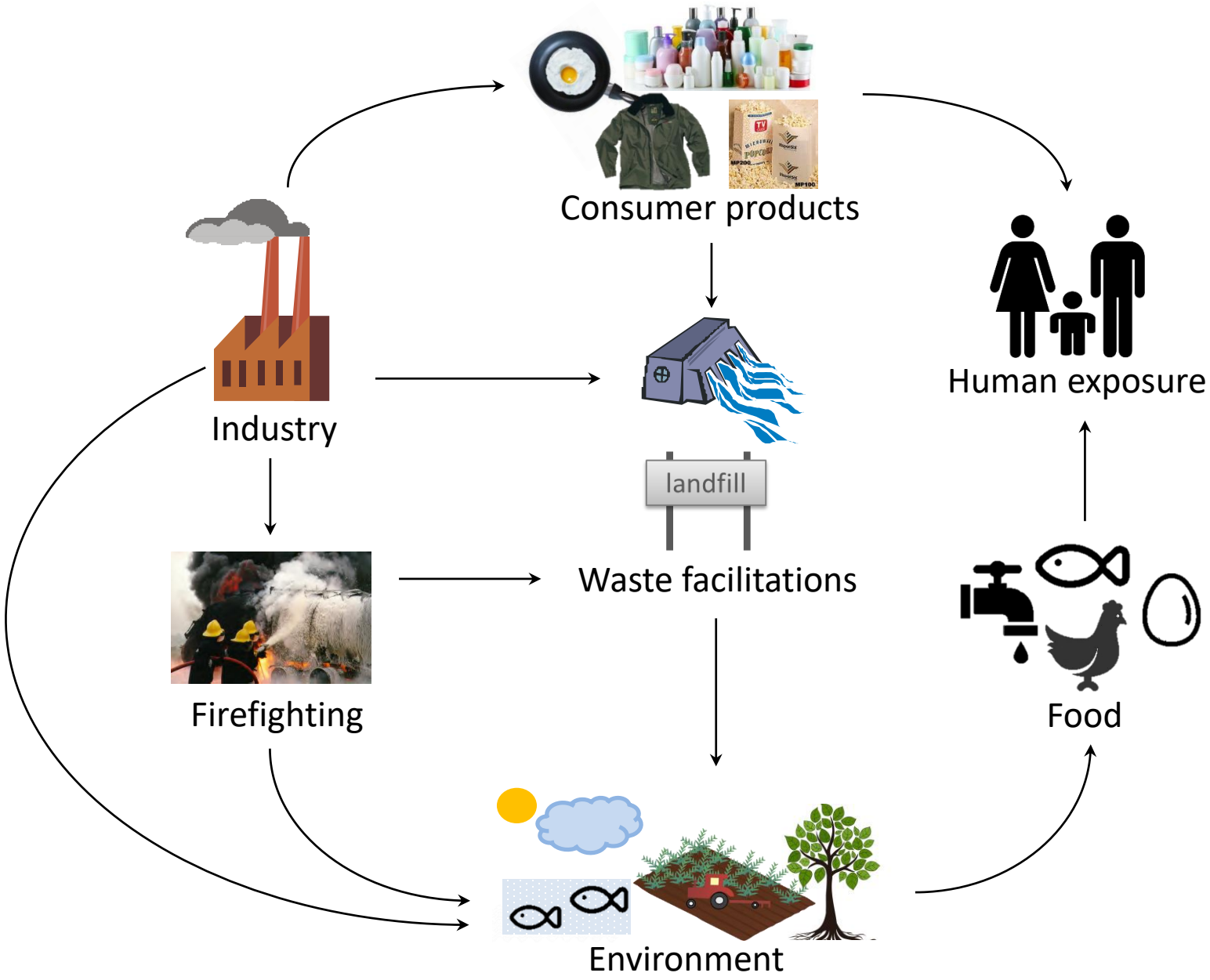
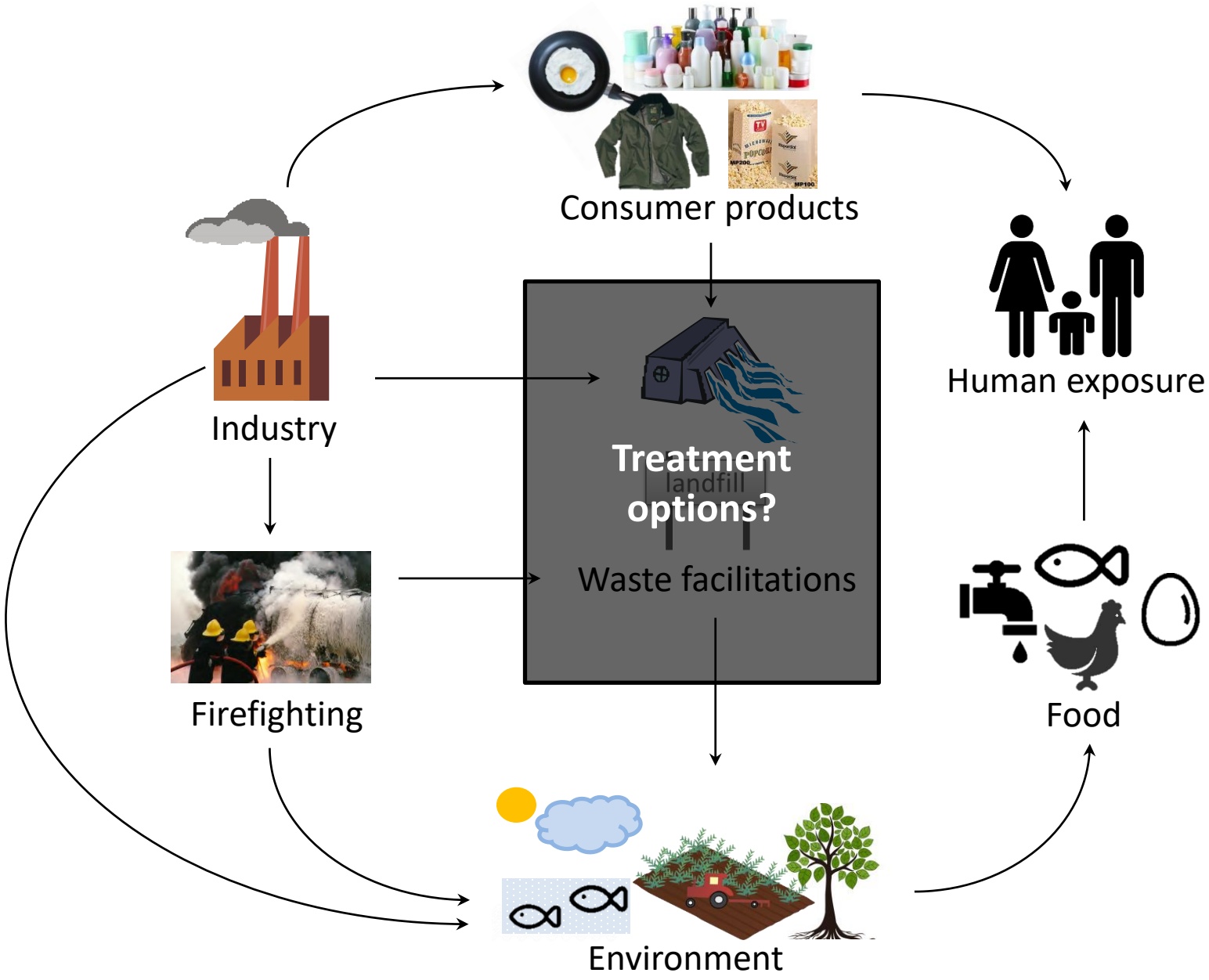
Circulation of PFASs in the Environment



Circulation of PFASs in the Environment



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
TOP?
EOF-CIC?
PIGE?
...?

20??

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

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

20??

?

PFAS Treatment Options for Water

Concentration

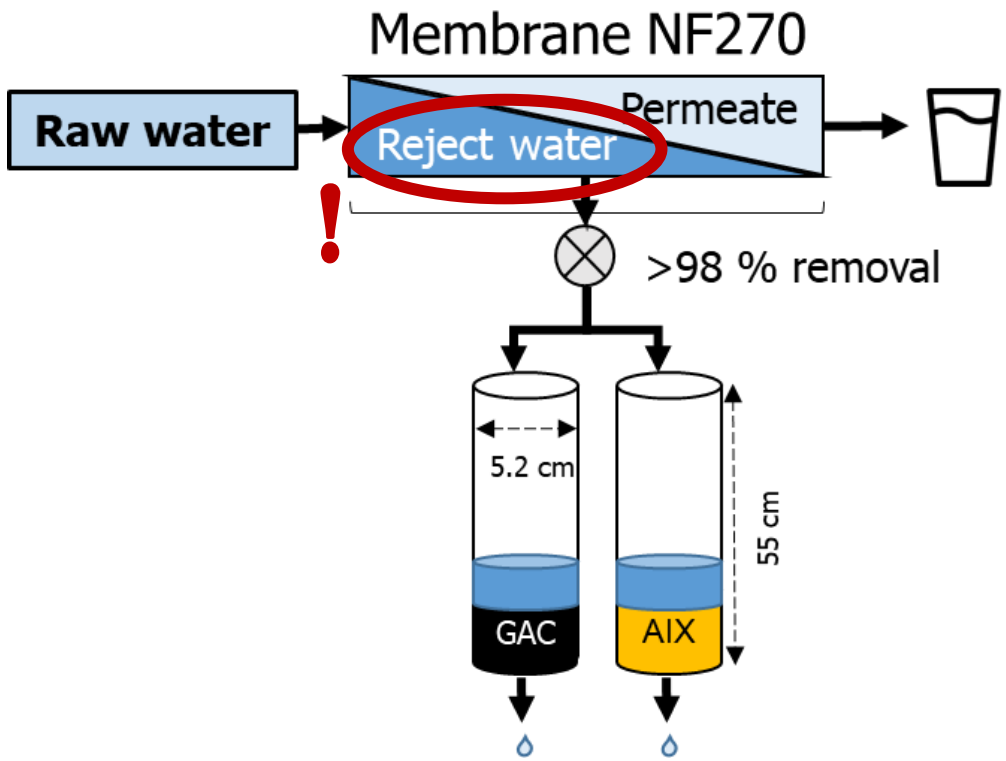
Adsorption treatment

Degradation

PFAS Treatment Options - Concentration

Concentration

Membranes
- NF, RO



Environmental Science
Water Research & Technology

COMMUNICATION

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

Cite this: DOI: 10.1039/c9ew00286c
Received 6th April 2019,
Accepted 11th June 2019
DOI: 10.1039/c9ew00286c

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

- Combination of NF with GAC/AIX is more efficient than only GAC/AIX
- AIX better than GAC

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

PFAS Treatment Options - Concentration

Concentration

Membranes
- NF, RO

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

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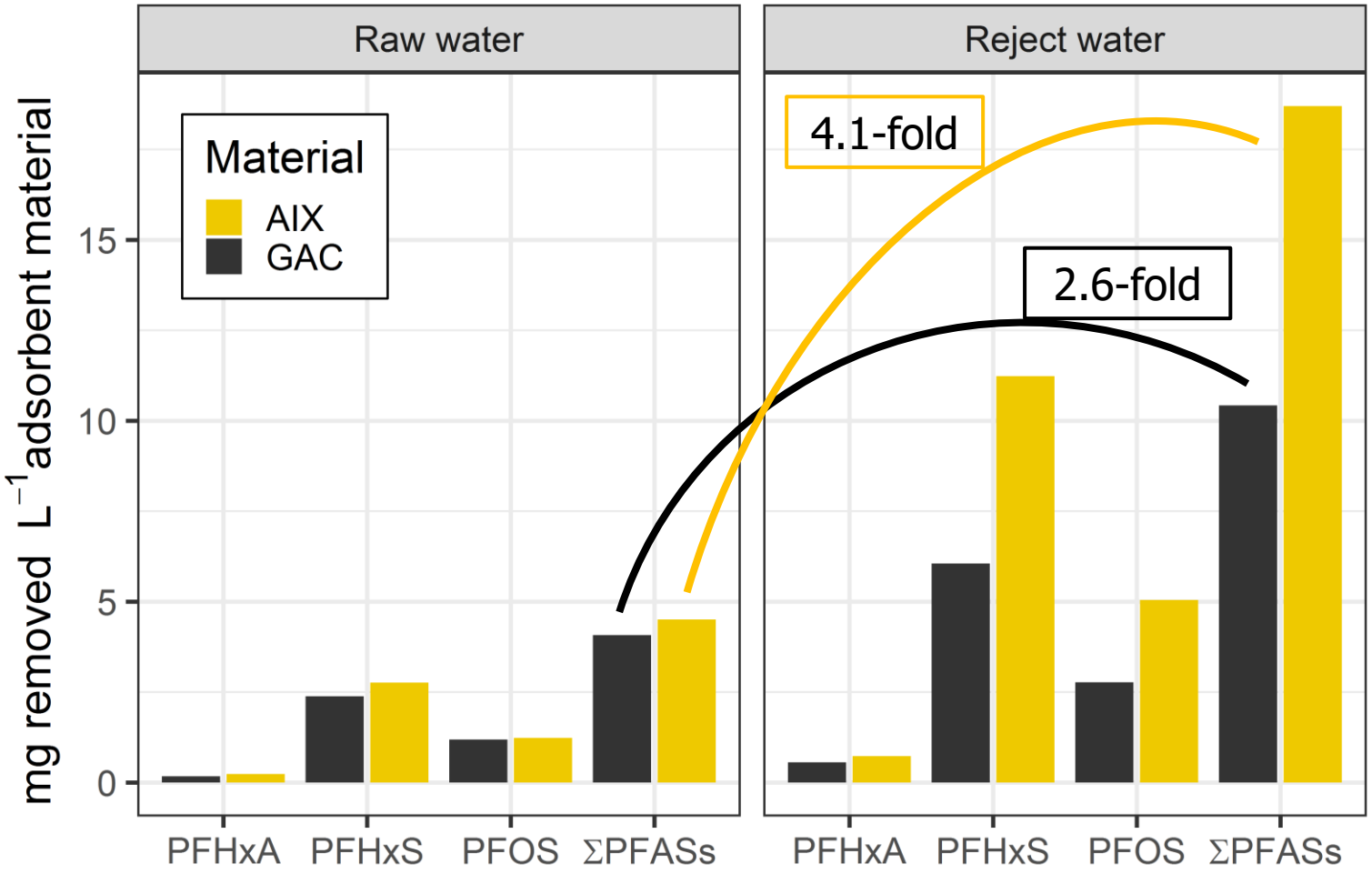


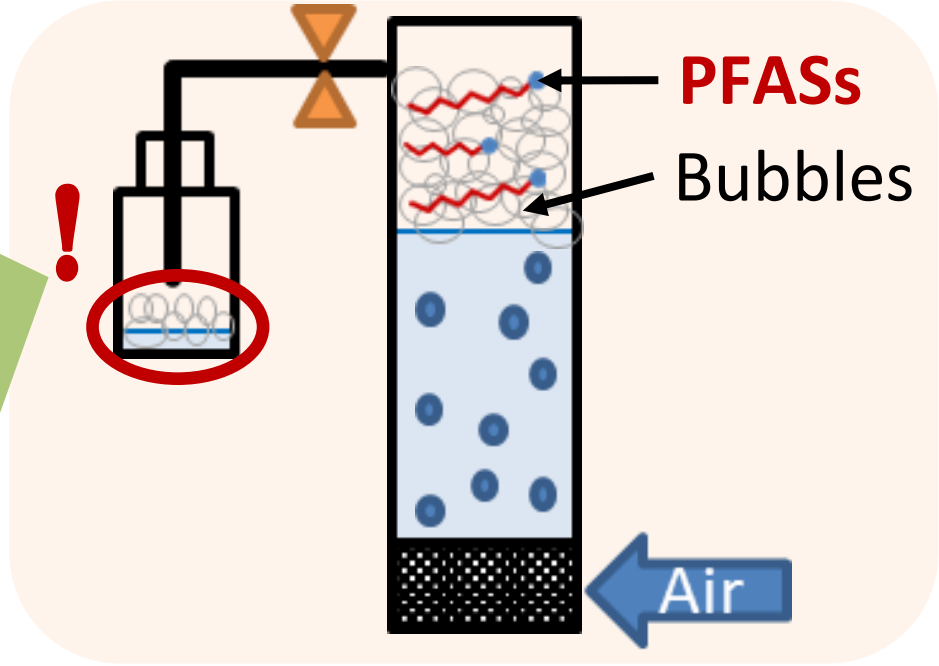
Franke V, McCleaf P, Lindegren K, Ahrens L. 2019. *ESWRT*, 5, 1836–1843

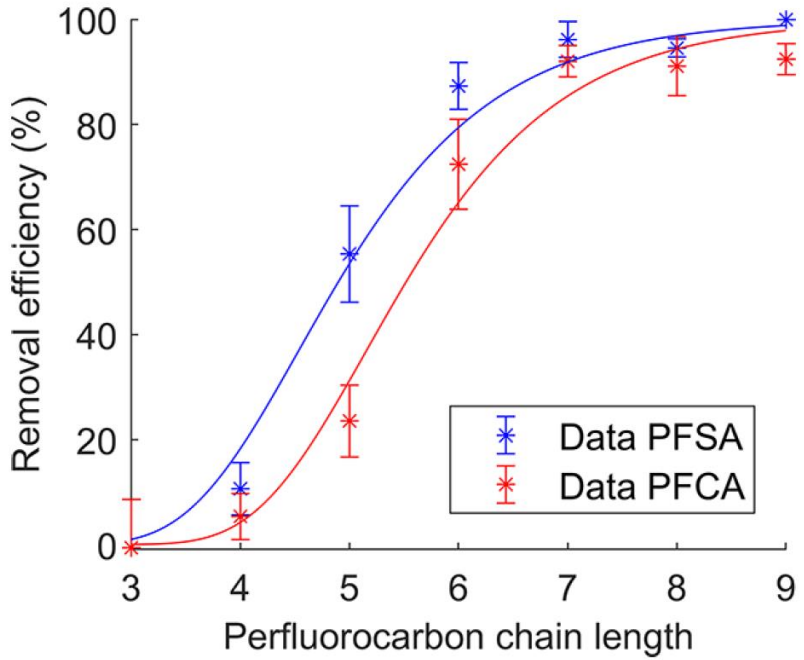
PFAS Treatment Options - Concentration

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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PFAS Treatment Options - Concentration

Concentration

Membranes
- NF, RO

Foam fractionation

Phyto-remediation
- Constructed
- Natural

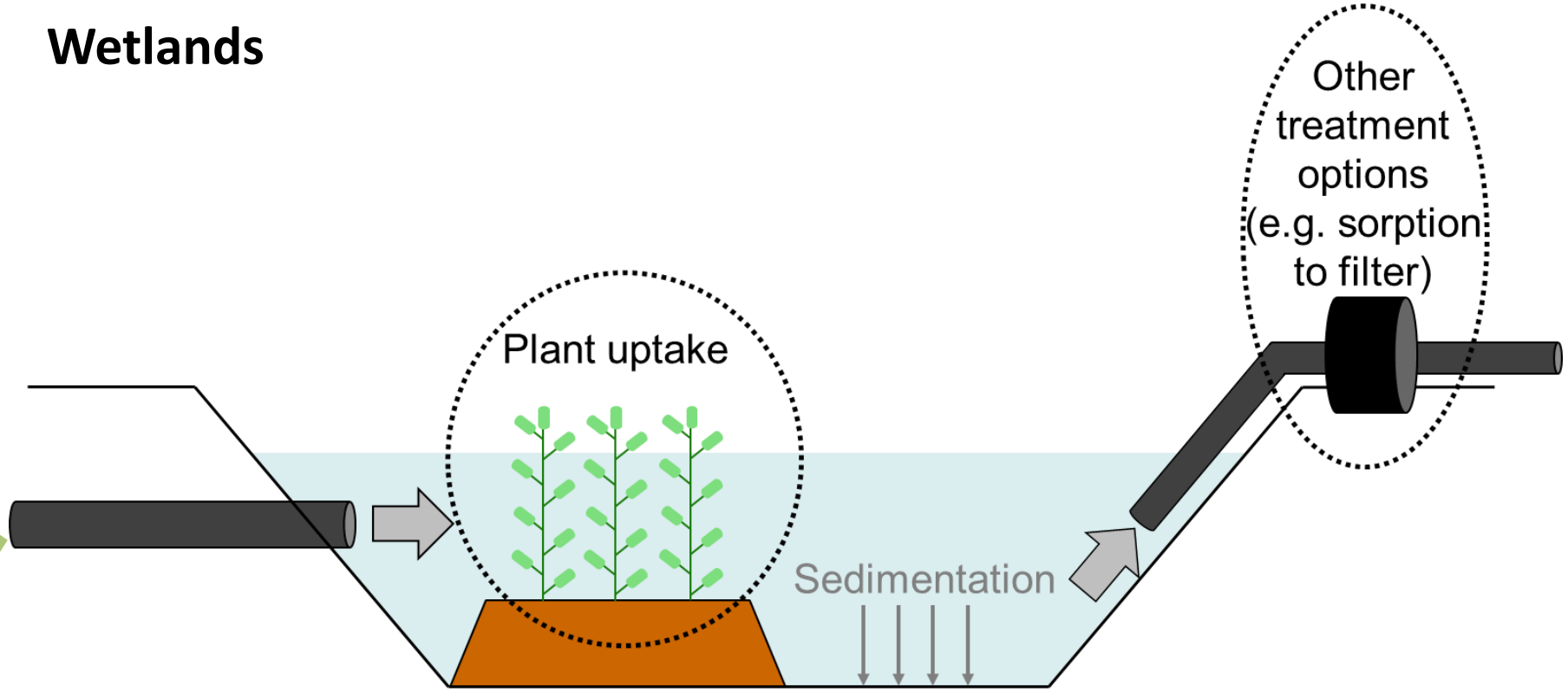
ENVIRONMENTAL Science & Technology
Article
Cite This: Environ. Sci. Technol. 2017, 51, 12602-12610
pubs.acs.org/est

Plant Uptake of Per- and Polyfluoroalkyl Substances at a Contaminated Fire Training Facility to Evaluate the Phytoremediation Potential of Various Plant Species

Laura Gobelius,[†] Jeffrey Lewis,[‡] and Lutz Ahrens*[,†]

[†]Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences (SLU), Box 7050, SE-750 07 Uppsala, Sweden
[‡]Tyréns AB, Västra Norrlandsgatan 10B, 903 27 Umeå, Sweden

Wetlands



Gobelius L, Lewis J., Ahrens L. 2017, *ES&T*, 51, 12602-12610

SLU

PFAS Treatment Options - Concentration

Concentration

- Membranes
  - NF, RO
- Foam fractionation
- Phyto-remediation
  - Constructed
  - Natural

Plant tissue	Burden (%)	
	Birch	Spruce
Foliage	8 - 63	20
Twigs	20	26
Stem	14 - 88	53
Roots	1 - 4	23

Biomass

→ **Incineraion (>1000 °C)**
Taylor P et al., 2014, *Chemos.* 110, 17-22

→ **Calcium catalysed defluorination (~350°C)**
Wang et al., 2015, *ES&T*, 49, 5672-5680

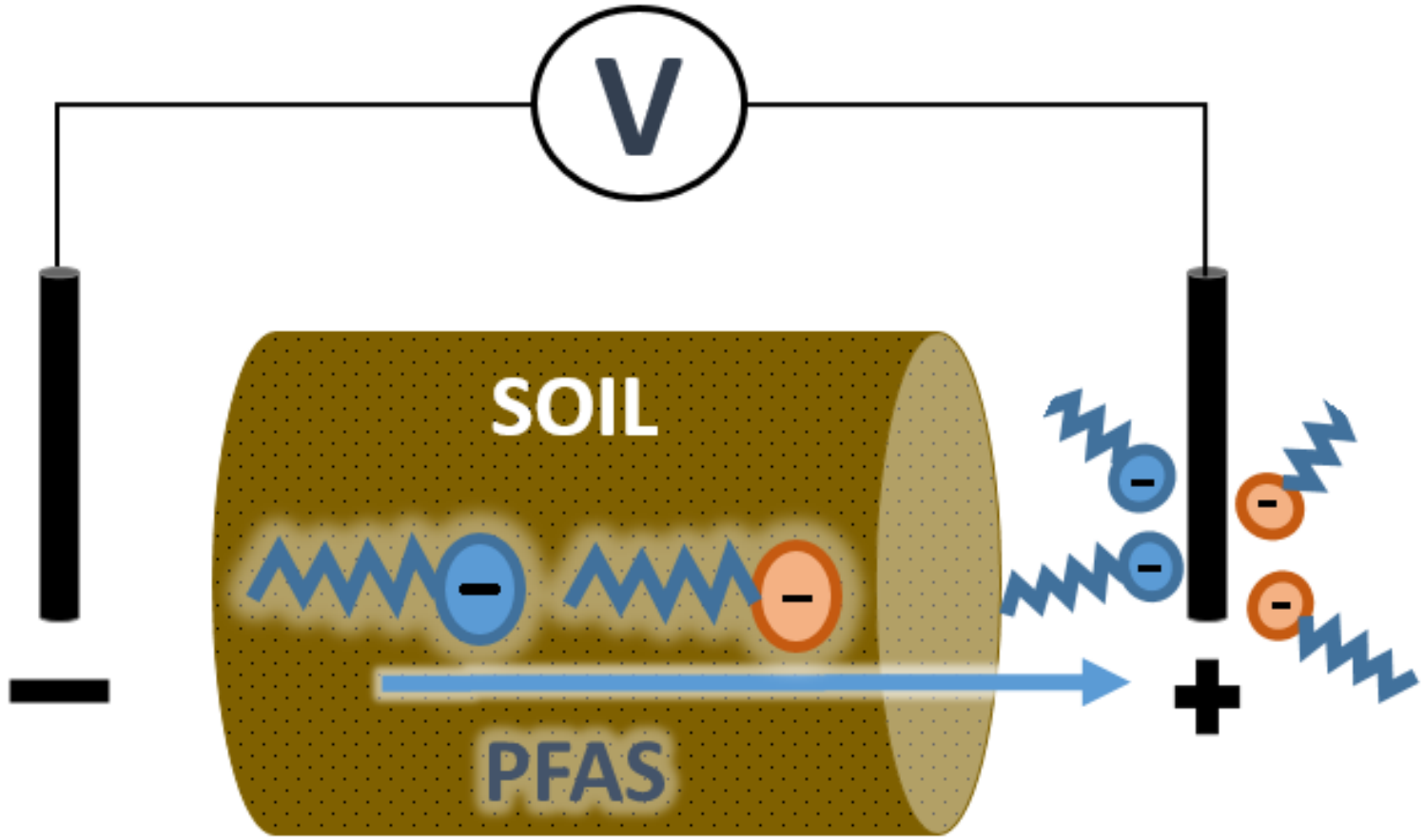
Gobelius L, Lewis J., Ahrens L. 2017, *ES&T*, 51, 12602-12610

SLU

PFAS Treatment Options - Concentration

Concentration

- Membranes
  - NF, RO
- Foam fractionation
- Phyto-remediation
  - Constructed
  - Natural
- **Electrodialytic remediation**

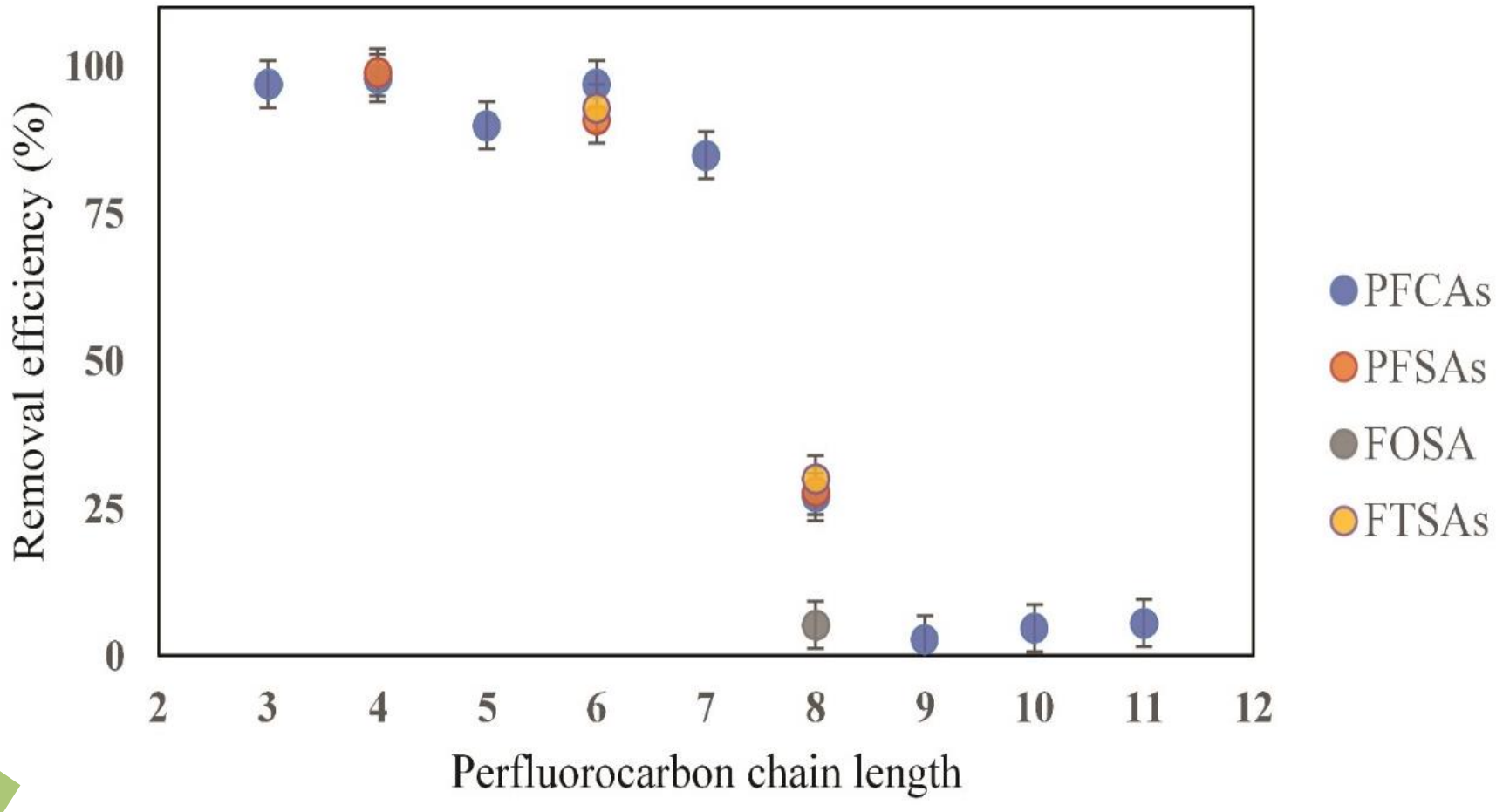


Sörengård M, Niarchos G, Ahrens L. 2019. *Chemosphere*. 232. 224-231
Niarchos G, Sörengård M, Fagerlund F, Ahrens L. 2022. *Chemosphere*. 291. 133041

PFAS Treatment Options - Concentration

Concentration

- Membranes
  - NF, RO
- Foam fractionation
- Phyto-remediation
  - Constructed
  - Natural
- **Electrodialytic remediation**



*two-compartment, 0.19 mA cm^{-2}

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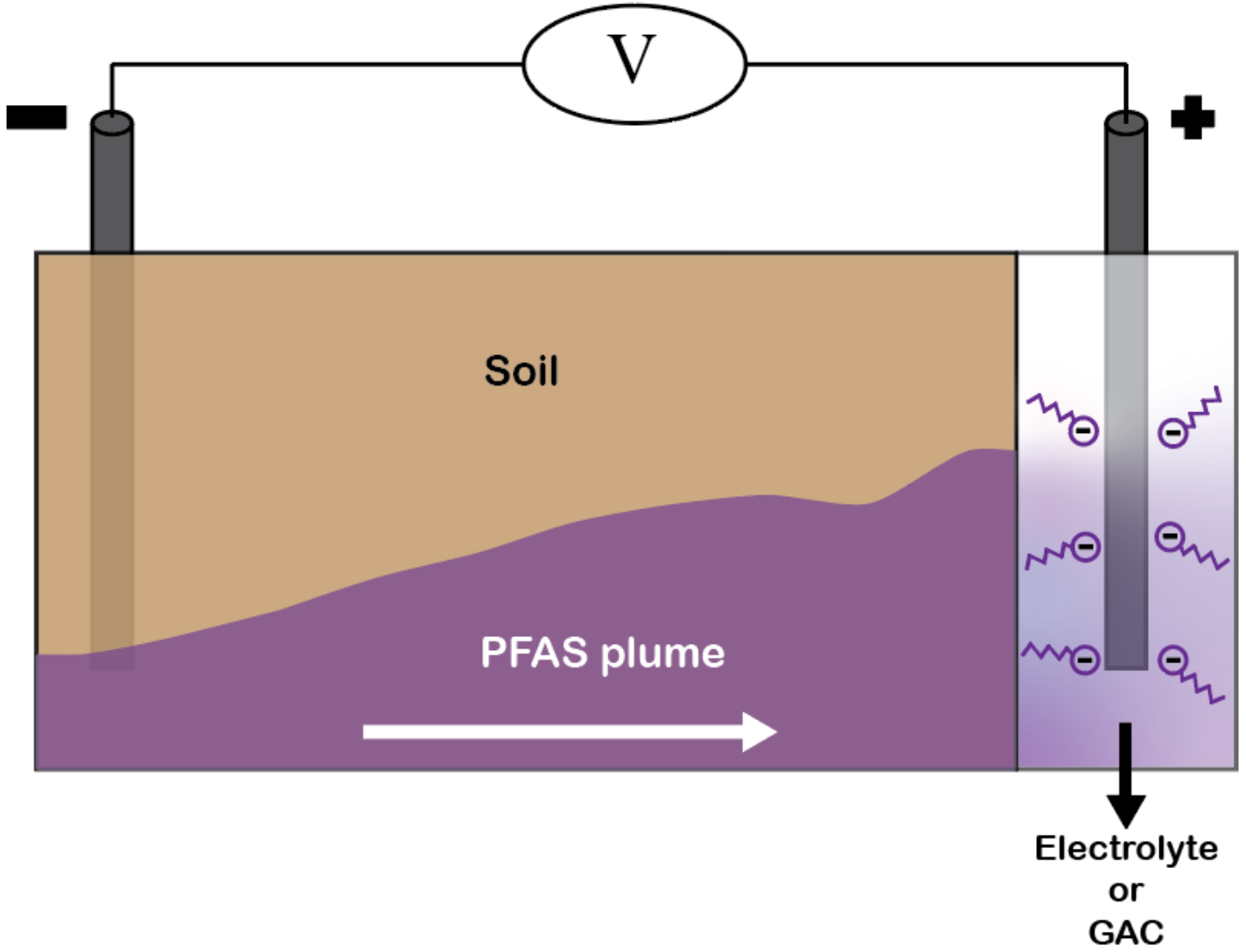
PFAS Treatment Options - Concentration

Concentration

- Membranes
  - NF, RO
- Foam fractionation
- Phyto-remediation
  - Constructed
  - Natural
- **Electrodialytic remediation**



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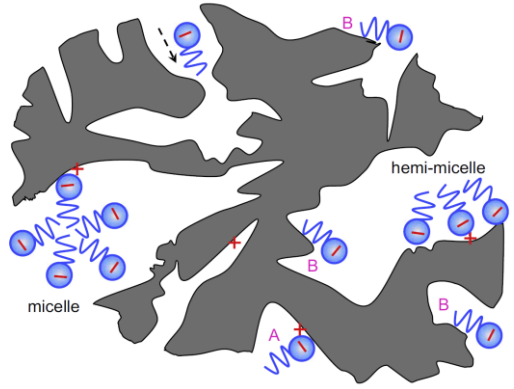
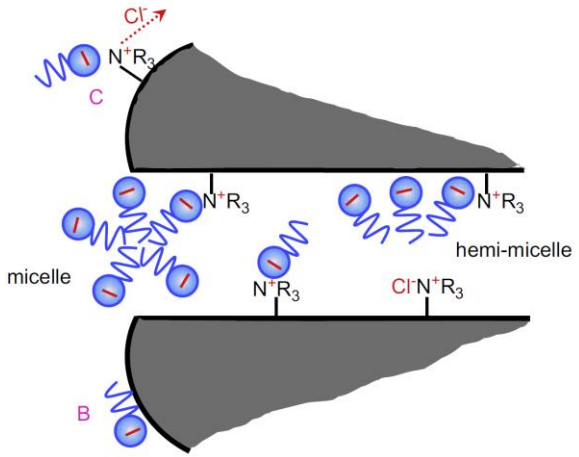
Adsorption Treatment

Stabilization/ solification

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





Water Research 120 (2017) 77–87

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

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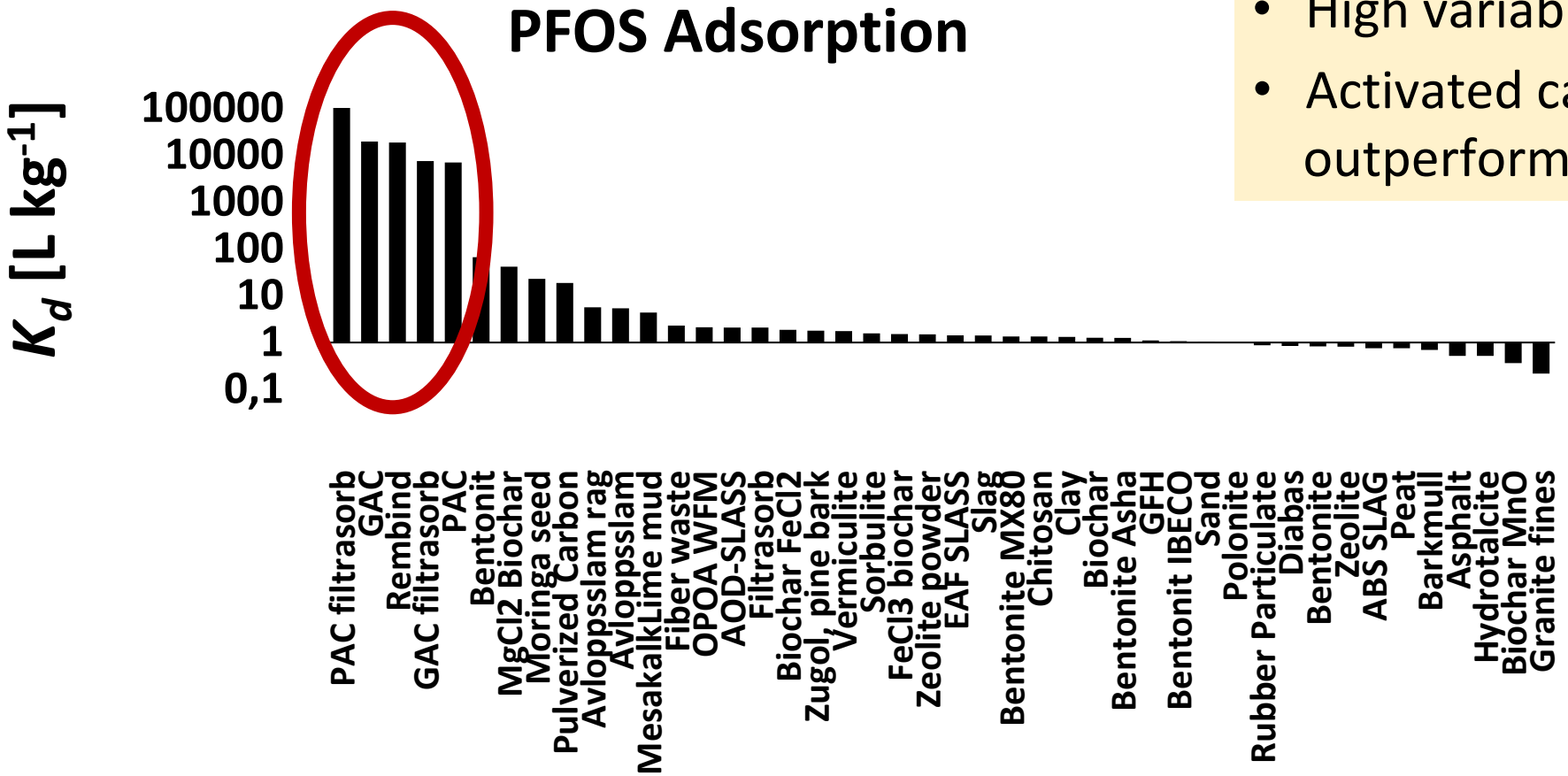
Belkouteb N, Franke V, McCleaf P, Köhler S, Ahrens L. 2020. Water Res, 182, 115913
Yu, Zhang, Deng, Huang, Yu, 2009. Water Res, 43,1150-1158

Screening of 44 Different Sorbents

Stabilization/ solification

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



- High variability
- Activated carbons outperformed

Sörengård M, Östblom E, Köhler S, Ahrens L. 2020. *J Environ Chem Eng*. 8, 103744

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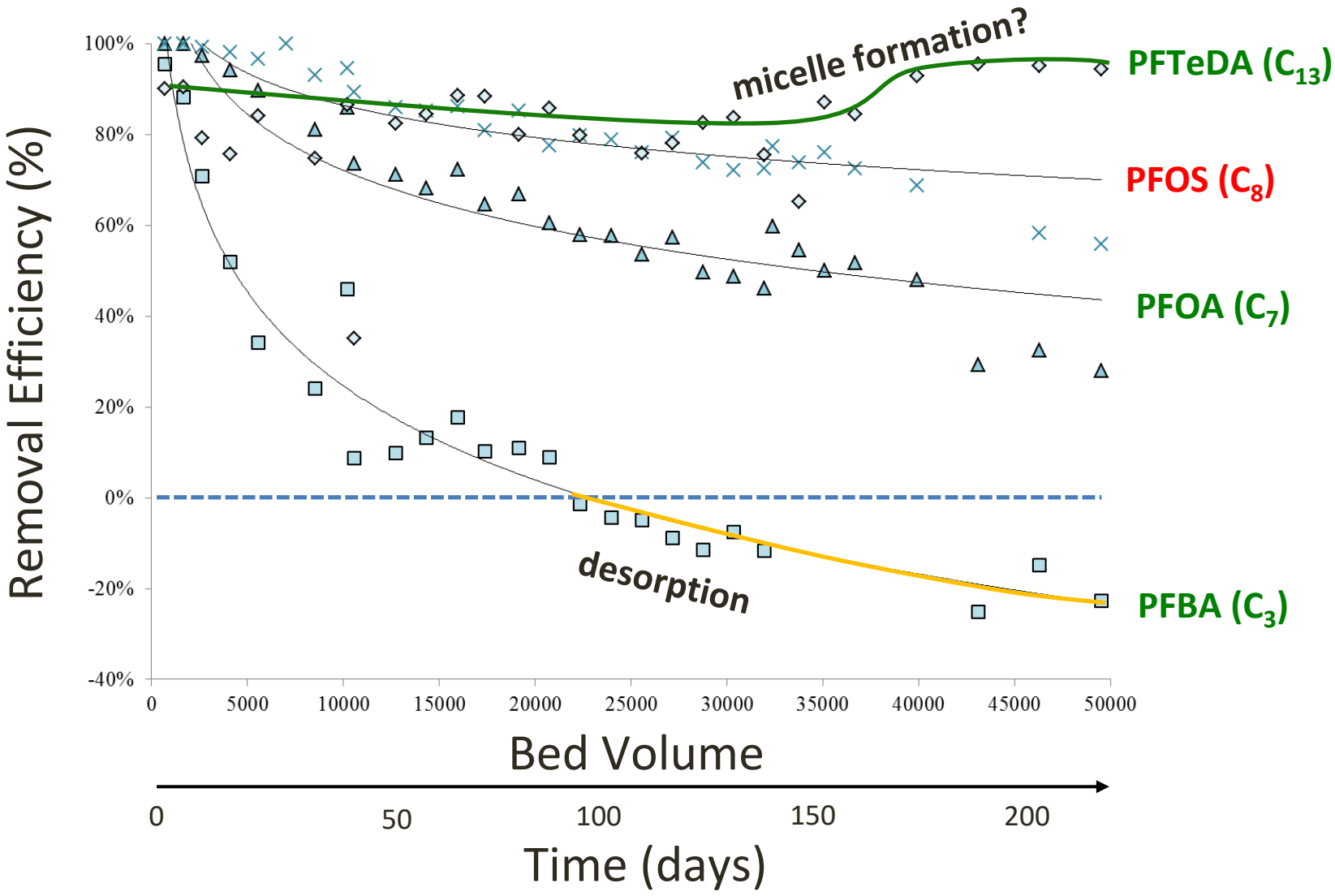
PFAS Treatment Options - Adsorption Treatment

Adsorption treatment

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



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

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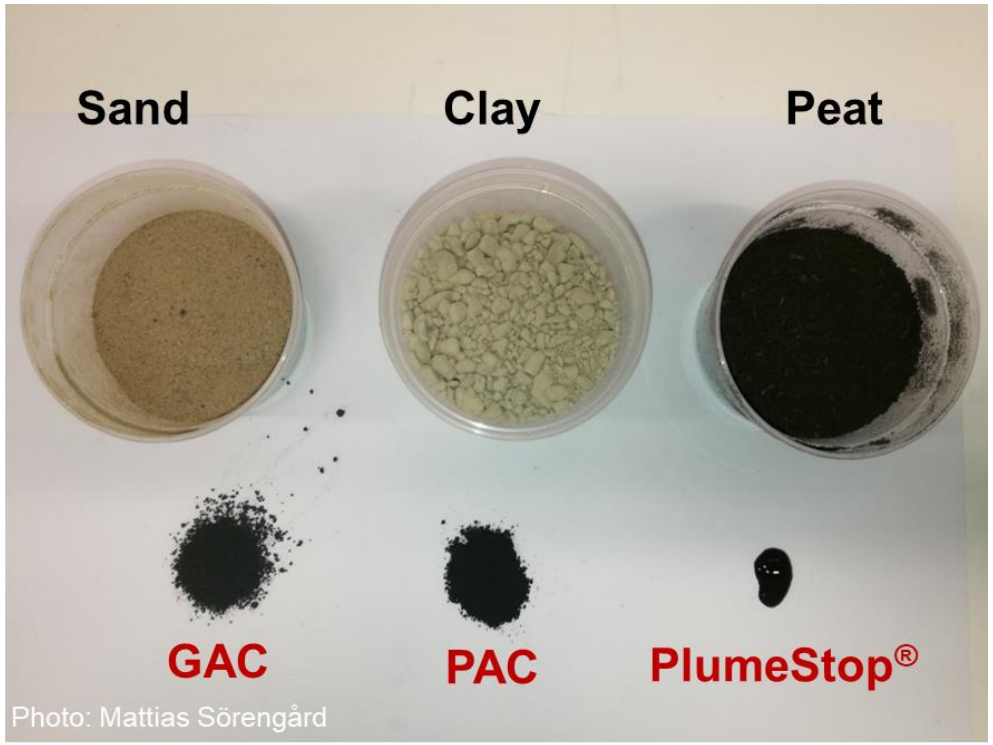
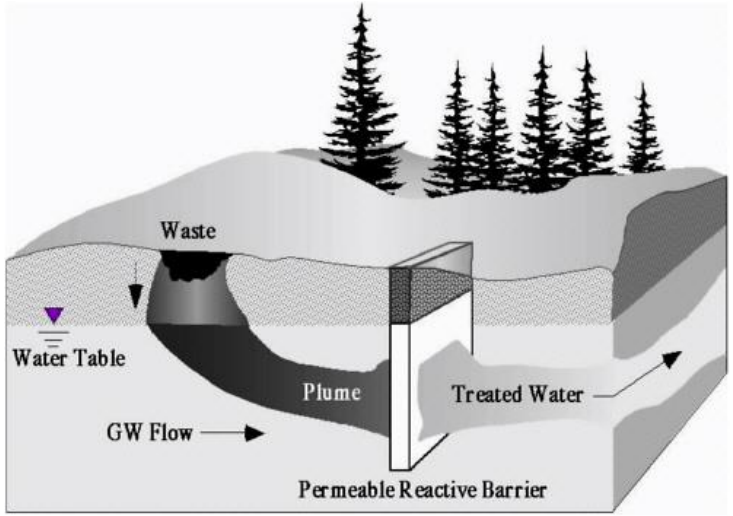
In-Situ Remediation: Barriers/Stabilization

Stabilization/ solification

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

In-Situ Remediation: Barriers





Geoengineer.org

Sörengård M., Berggren Kleja D, Ahrens L. J. Hazard. Environ., 367, 639–646

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In-Situ Remediation: Barriers/Stabilization

Stabilization/ solification

- Activated carbon (AC)
  - GAC
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- Anion exchange (AIX)
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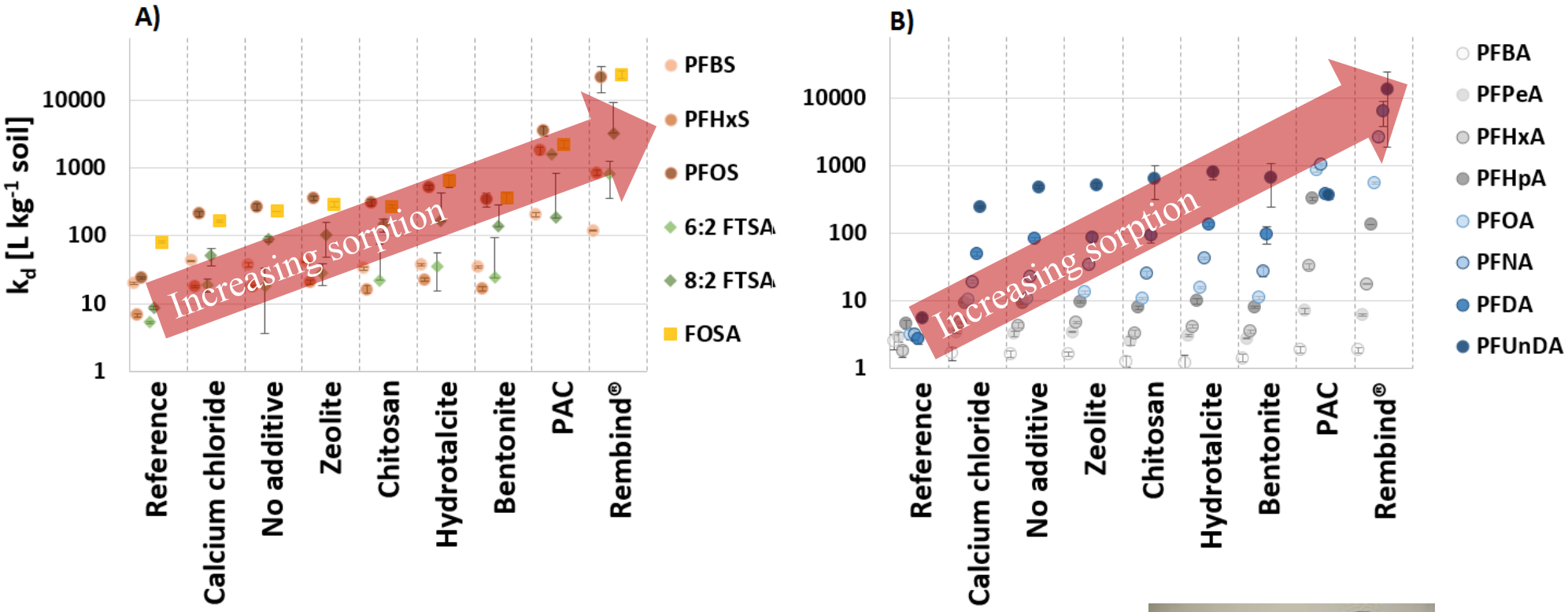

Sörengård M., Berggren Kleja D, Ahrens L. J. Hazard. Environ., 367, 639–646

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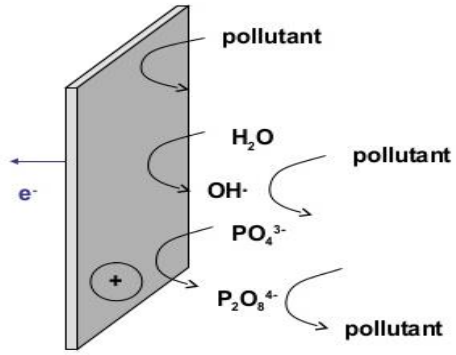
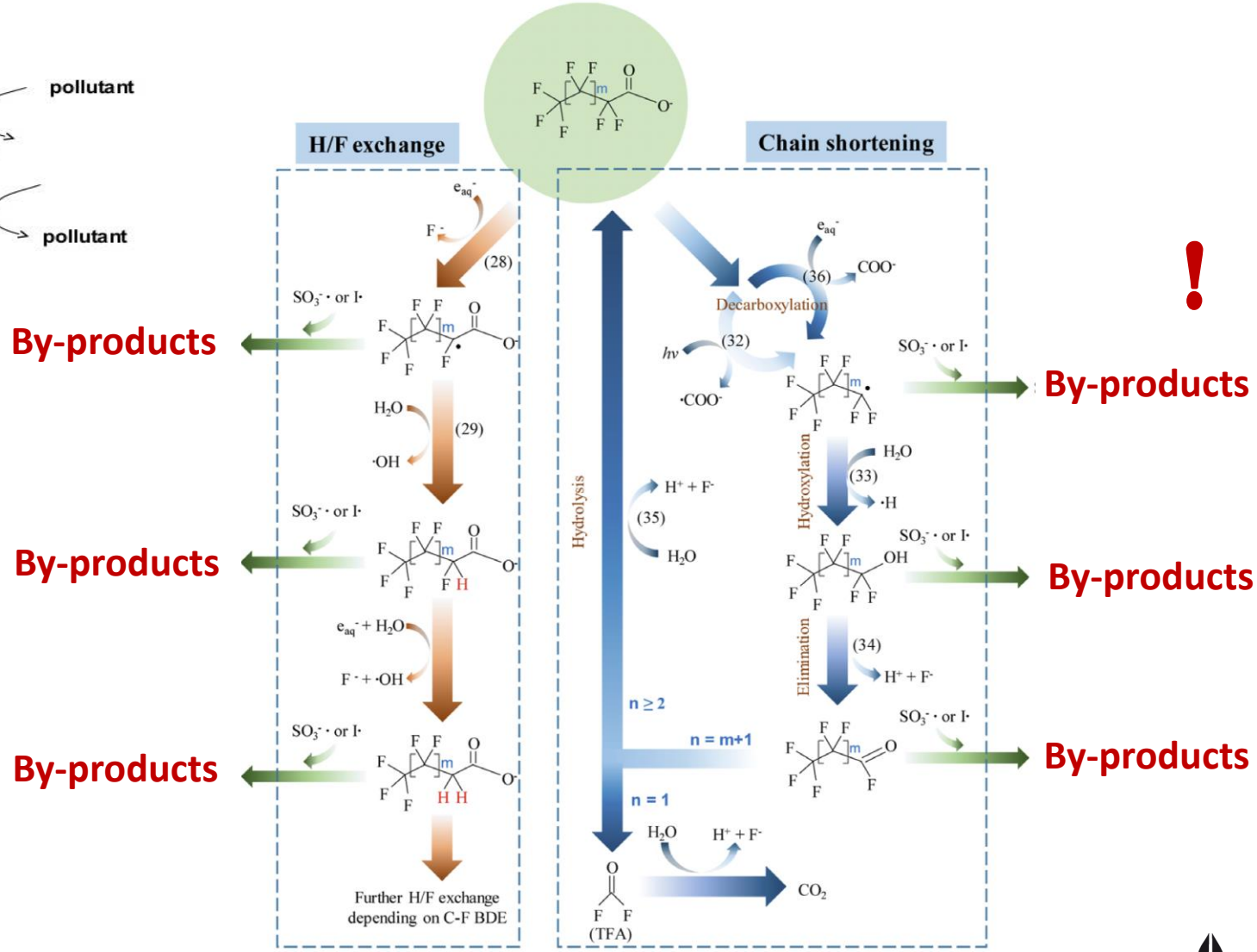
PFAS Treatment Options - Degradation

Degradation

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





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

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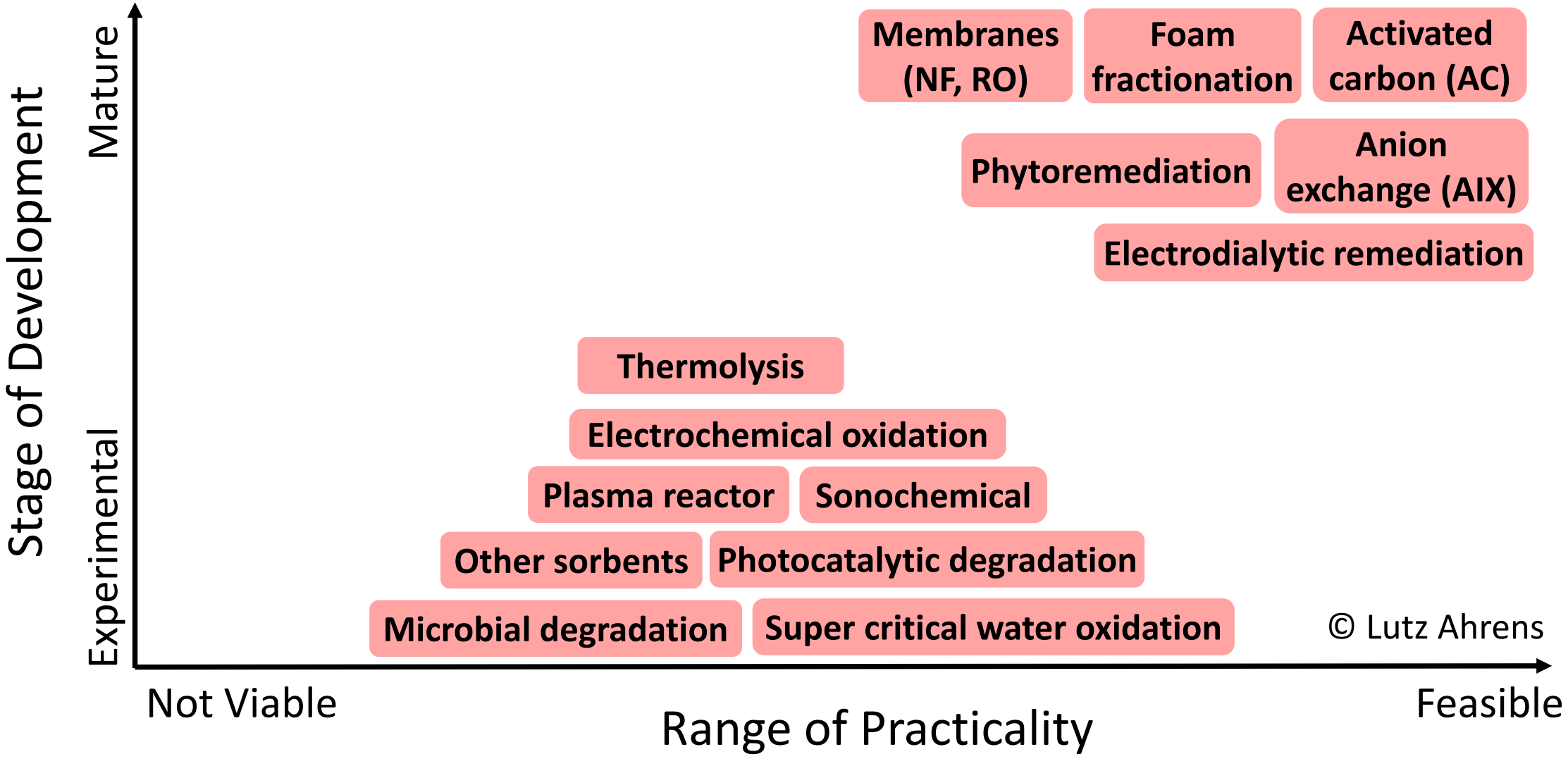
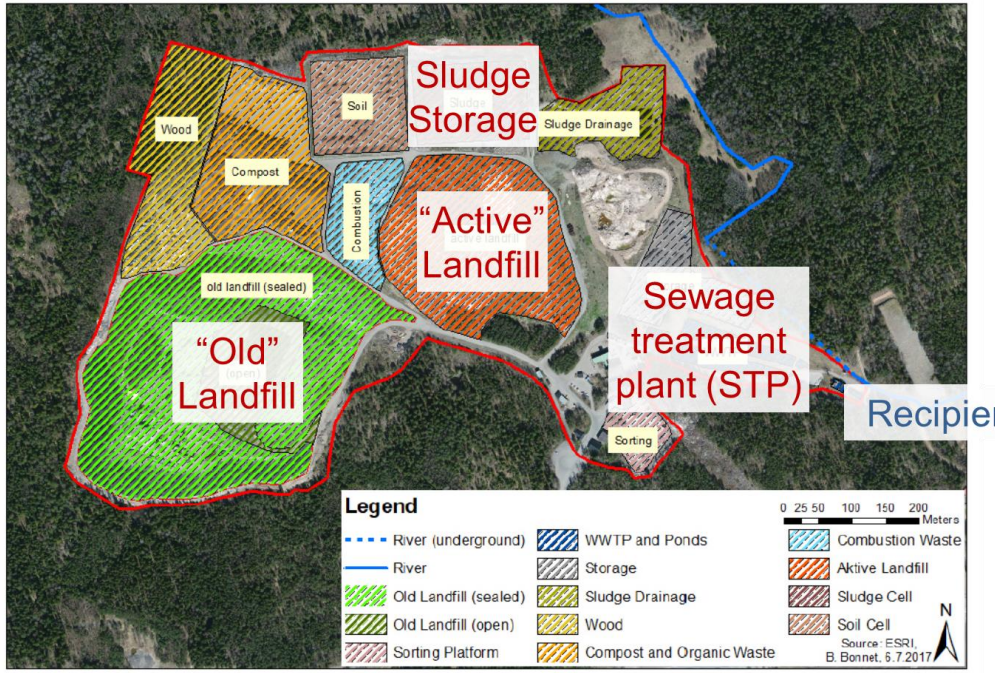
PFAS Treatment Options for Water



LIFE SOuRCE – PFAS Treatment of Groundwater (2021-2025)

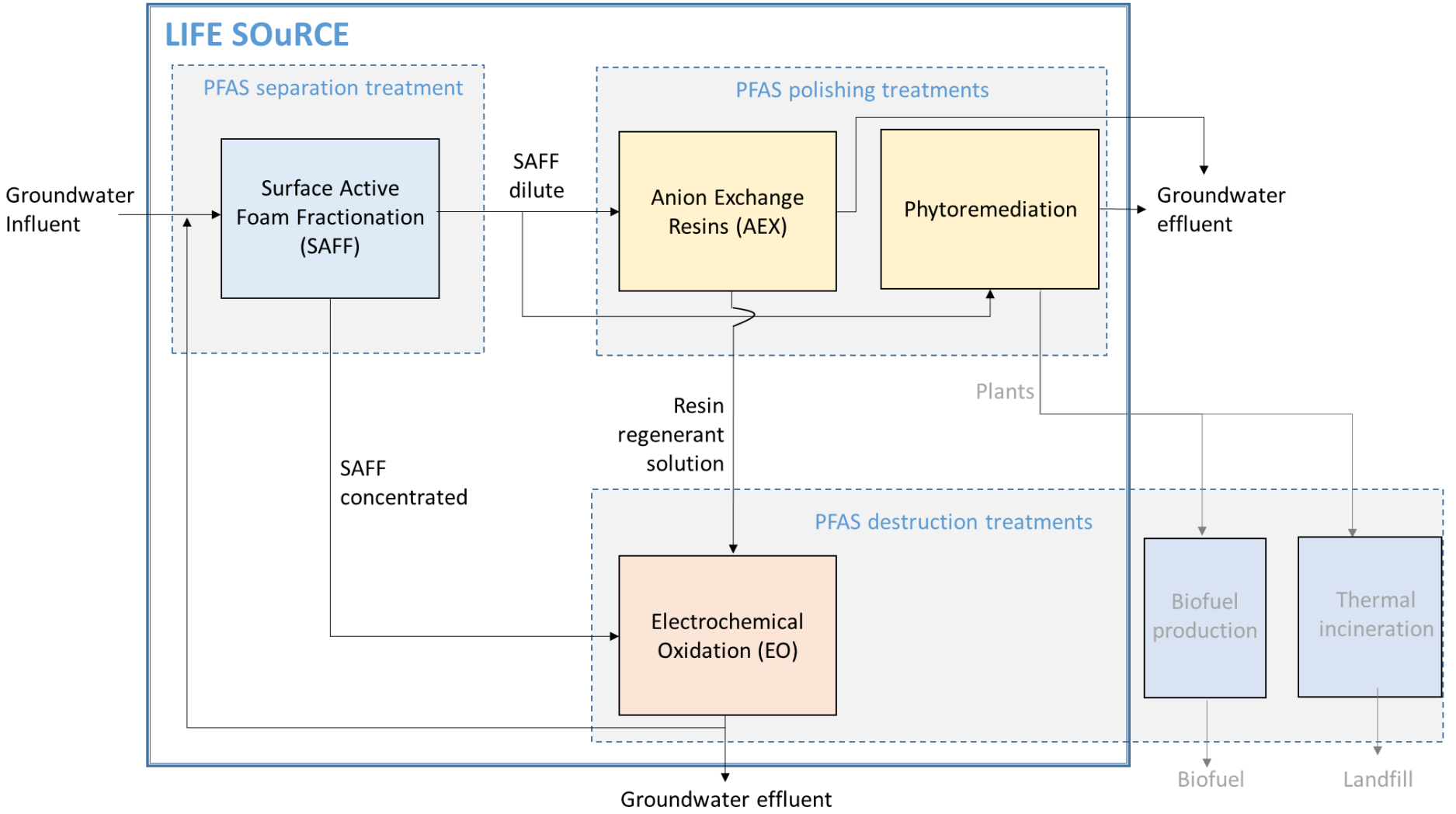
Landfill, Sweden



Industrial site, Spain

LIFE SOuRCE – PFAS Treatment of Groundwater (2021-2025)

Treatment train for removal of PFASs in groundwater



Take Home Message

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

Thank you!

The LIFE SOuRCE project (LIFE20 ENV/ES/000880) has received funding from the LIFE Programme of the European Union

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