Challenges for PFAS remediation

(…with only a slight bias towards ultrasound technology….)

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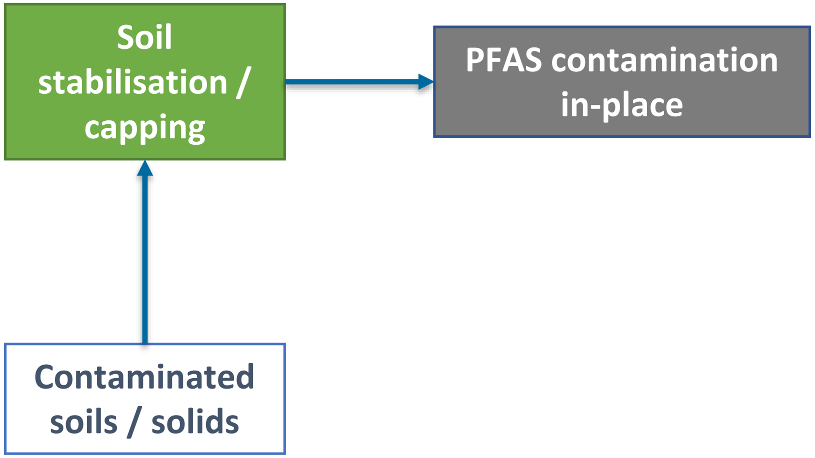
@madbuss

Soil remediation



Soil Stabilisation

- Add a sorbent such as activated carbon
- Prevent leaching

Soil capping

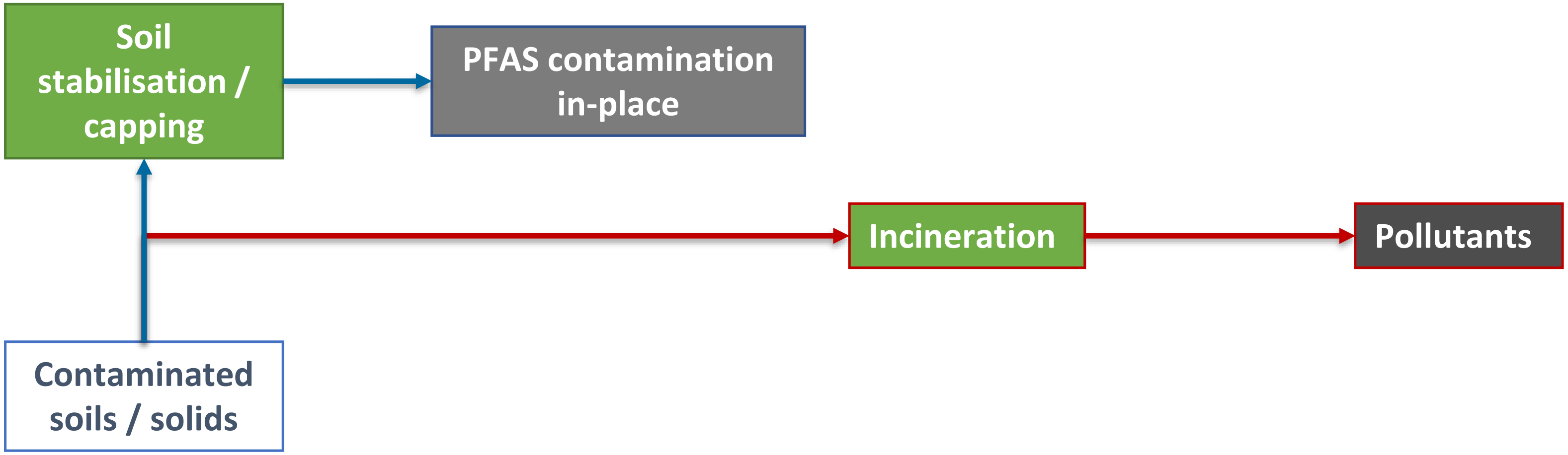
- Physical barrier to prevent PFAS leaching

Transfer to landfill

- Potential enter as leachate

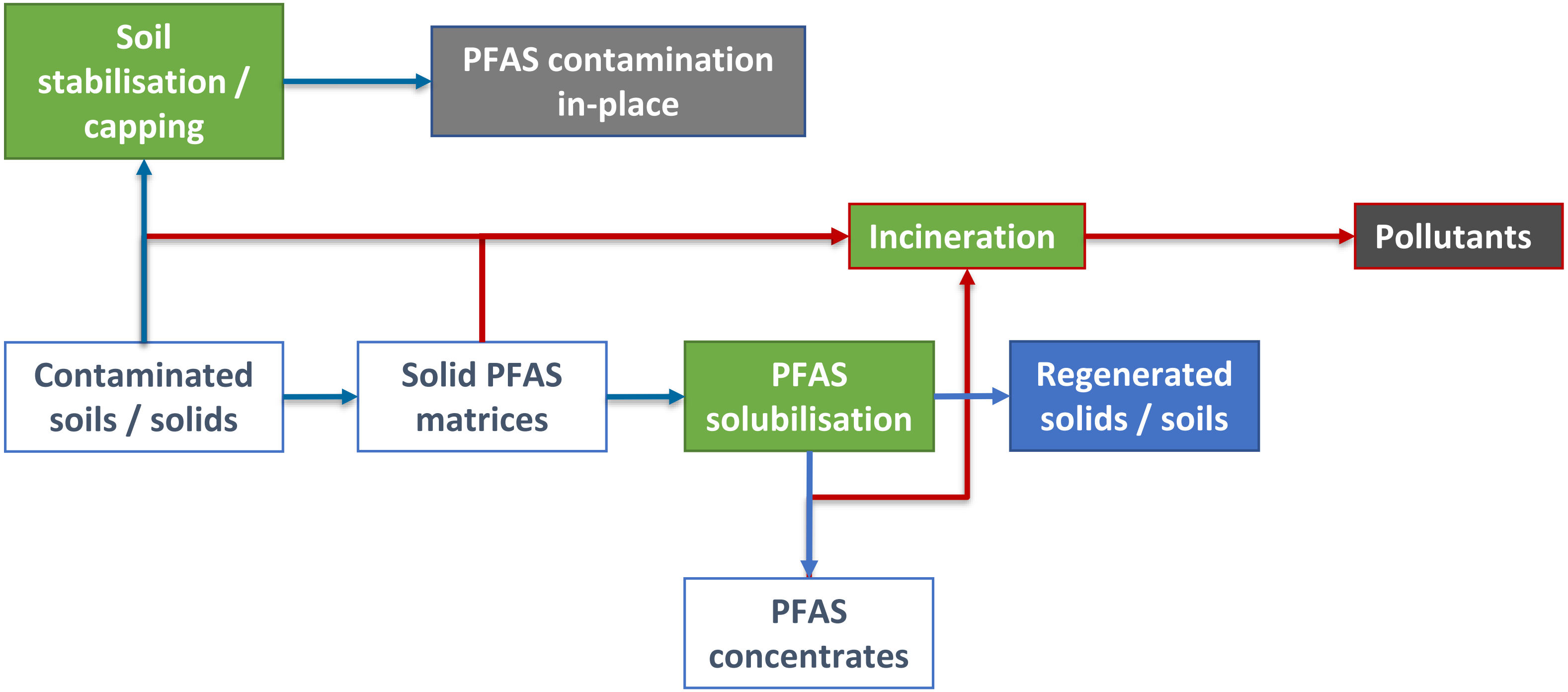
Ball milling?

Soil remediation



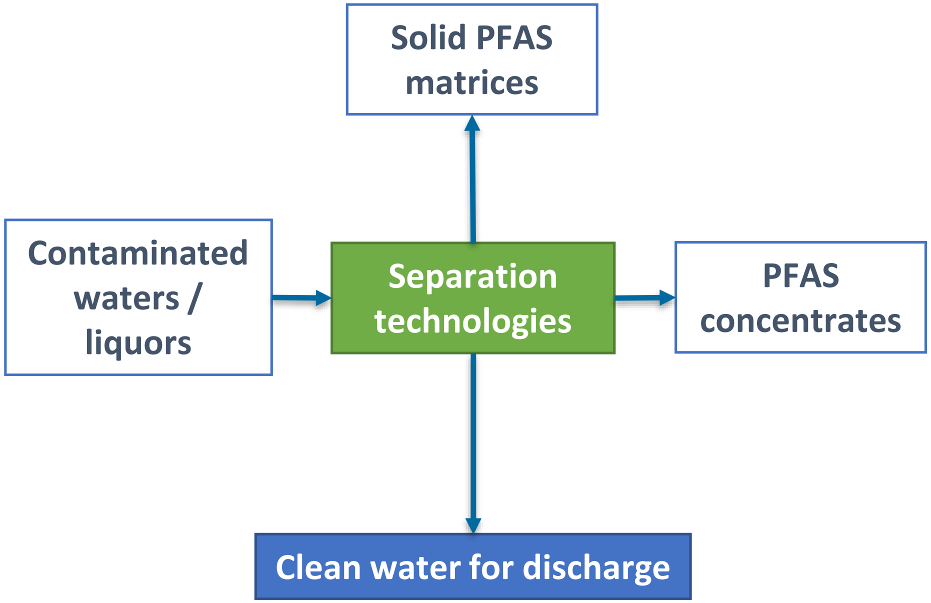
Soil remediation

The treatment train approach



Water / liquor remediation

The treatment train approach



Separation technologies

- Activated carbon
- Ion exchange/silicas
- Membrane
- Foam fractionation

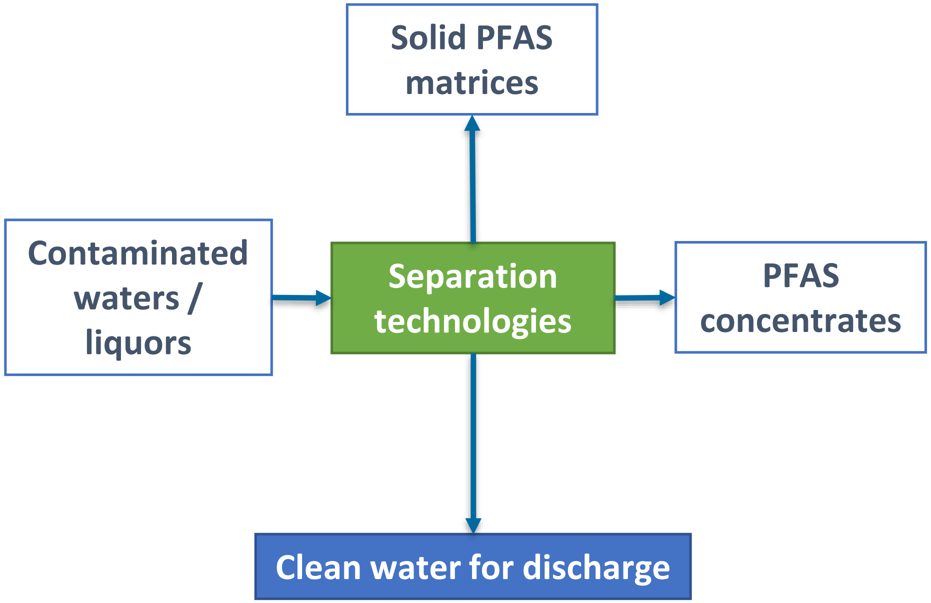
Separation Technologies

TREATMENT: Status	Efficacy for different PFASs			Solution composition		Waste/side streams
	PFEAs	SCs*	LCs*	Matrix	PFAS	
GAC / PAC: GAC implemented in the US for remediation	None - medium	None- Medium	Medium (not all)	Organics compete	Can remove ~90% PFOS, at ppb (µg/L)	Contaminated solid (PAC), solid for regeneration (GAC)
RESINS / SILICAS: Large scale available for IX resins. Silicas at lab stage.	NR	IX is less efficient	Yes	Depends on absorbent chemistry	Can remove ~99% PFASs at ppb (µg/L)	Regenerate solutions, e.g. 70% CH_3OH and 1% NaOH with ppm (mg/L) PFAS
MEMBRANES: Expensive, polishing step, mostly lab scale.	NR	Yes	Yes	Rejection impacted by organics	Reported range up to ppm (mg/L)	Membrane rejectate, spent membranes
FOAM FRACTIONATION: implemented for sludge, leachate remediation	NR	Yes	Yes	Unlikely	Input in ppb (µg/L) range, output can need polishing	Concentrated (oxidised) PFAS solution (ppm range), sedimentation

*PFSAs with 6 or more carbons in a carbon chain and PFCAs with 7 or more carbons are defined as long chain (LC) and short chains (SCs) have 5 or fewer and 6 or fewer carbons, respectively.

Water / liquor remediation

The treatment train approach



Separation technologies

- Activated carbon
- Ion exchange
- Silicas
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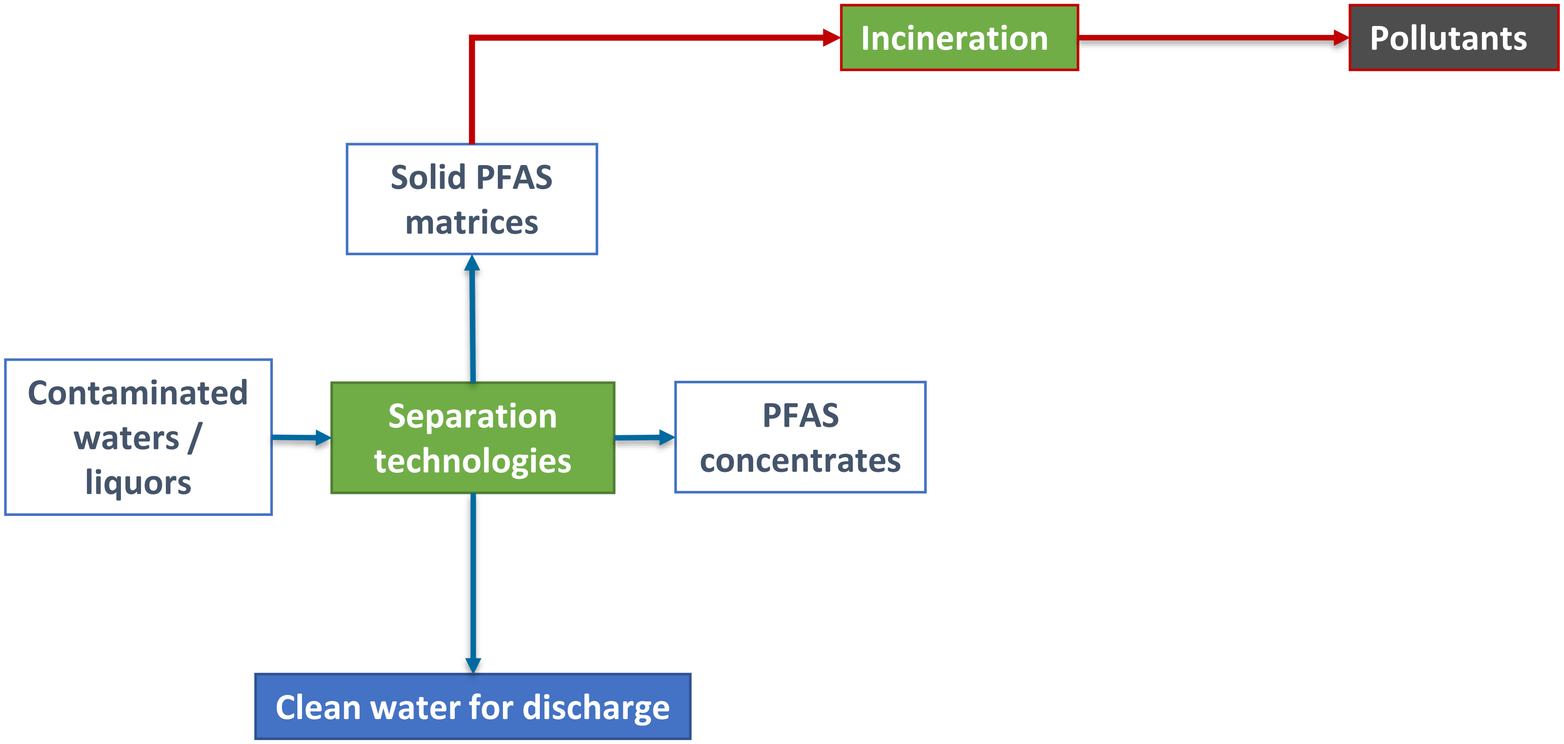
Challenged by

- Solid matrix / PFAS concentrate to deal with
- New and emerging PFAS
- Shorter chain PFAS

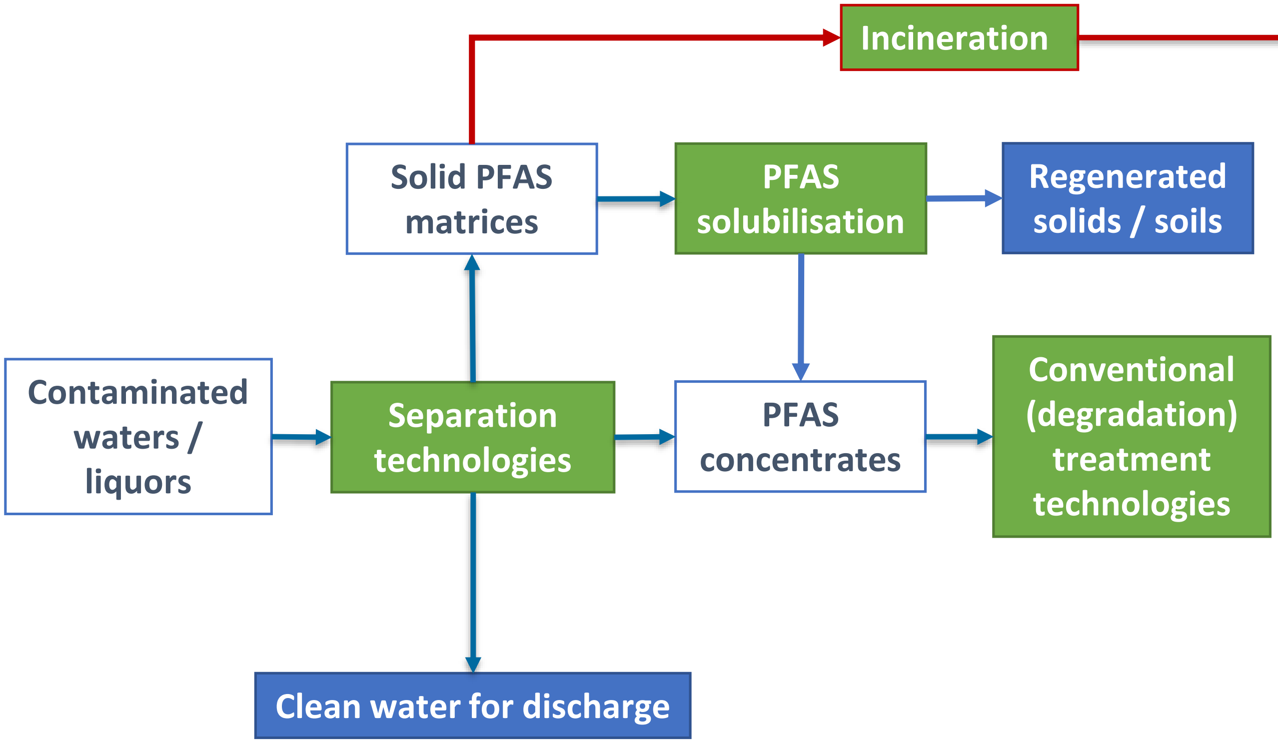
Water / liquor remediation

The treatment train approach



Water / liquor remediation

The treatment train approach



Chlorination, ozonoation, UV & biological are ineffective/ incomplete mineralisation

AOPs don't work on PFSAs, short chains

Water / liquor remediation

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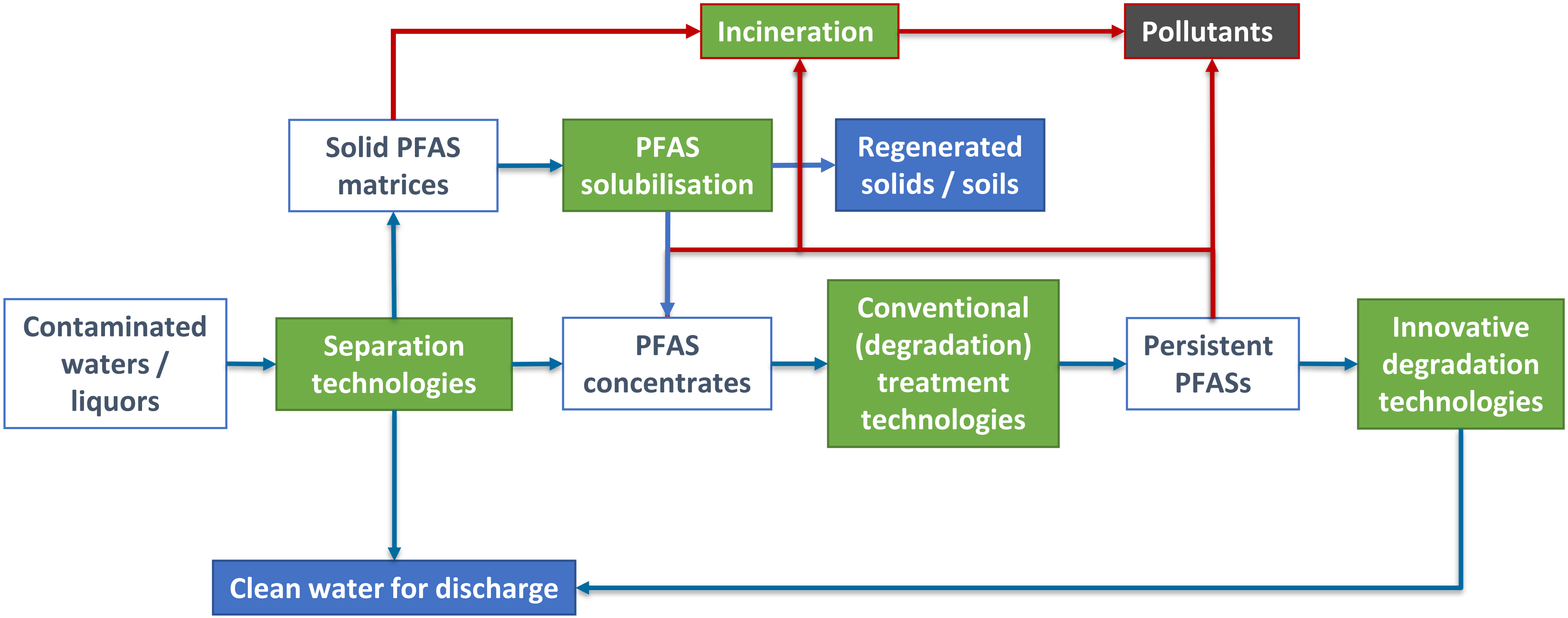

Mineralisation via hydrated electron and / or pyrolytic processes

Innovative degradation technologies

TREATMENT	Mechanism	Specific Challenges
Electron Beam	Water radiolysis using a electron beam of 1-10 MeV	• Small treatment area / depth • Practicalities of implementation
Ultrasound / Sonolysis	Cavitation collapse generates high temperature / non equilibrium plasma	• Ubiquity of application / understanding (best at high frequencies) • Complex bubble dynamics
Plasma	Surface or submerged plasma to create reactive species to degrade pollutants	• SC degradations / productions debated
Electrochemical (via e_{aq}^{-})	Uses electron transfer from customised anode to the PFAS	• Production of reduced matrix elements
Photochemical	UV irradiation with reductants (sulphite, iodide, dithionite) or catalysts	• Use of environmentally unfriendly catalysts / reductants • Scavenging of e_{aq}^{-} by matrix elements

Comparing degradation technologies (PFOS)

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Technology (Reaction time)	C_0 (mg L^{-1})	Efficiency ($x10^{-3}$ g $kW^{-1}h^{-1}$)	Short chains prod?
Photochemical (240 hours)	20.0	1.33	Observed, significant quantity indicated (71% F^- release)
Photochemical, ferric ion (60 hours)	10.0	2.90	≈14% of initial mass
Sonication, 618 kHz (3 hours)	5.00	8.01	Almost none implied (≈100% F^- release)
Photochemical, persulfate (2 hours)	10.0	9.00	Observed, significant quantity indicated (76% F^- release)
Photochemical, propanol (24 hours)	20.0	15.2	Not discussed
Sonication, 400 kHz (4 hours)*	9.42	15.5	1% of initial mass
Plasma (4 hours)	50.0	26.0	Not discussed, none implied
Sonication, 400 kHz (2 hours)*	9.42	26.1	13% of initial mass
Sonication, 358 kHz (3 hours)	59.5	41.7	Not discussed
Plasma (0.5 hours)	0.0001	69.0	Observed, 5.65% of initial mass after 40 minutes
Plasma (1 hour)	100	621	Observed, significant quantity indicated (≈30% F^- release)

*Reference - https://doi.org/10.1016/j.ultsonch.2020.105196

Implementation challenges

Scale up

- Difficult to replicate bench top efficiency for larger scales
- Efficacy reported varies and is often debatable
- Variation in analytical techniques

Variety in solution compositions

- Concentration of PFAS – effects efficiency
- Other contaminants / species can scavenge the e_{aq}^{-} - pretreatment??

Emerging PFAS issues

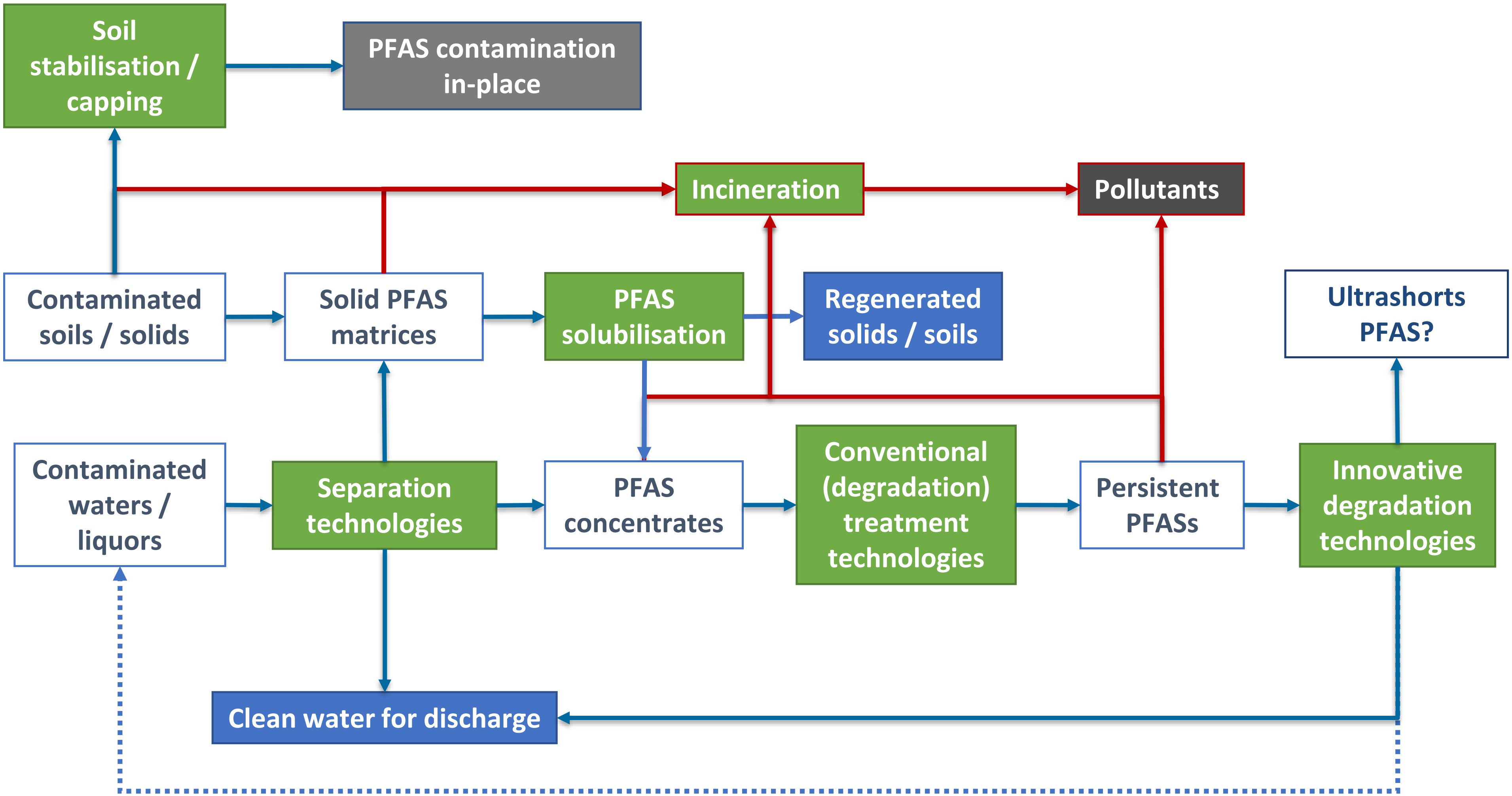
- Shorter chains / next gens
- Ultrashorts

How does it fit in the context of the treatment train?

- For better efficiency likely need a “polishing” step
- Cost / benefit analysis in the whole context – systems engineering?

A view of PFAS remediation

The treatment train approach



A view of PFAS remediation

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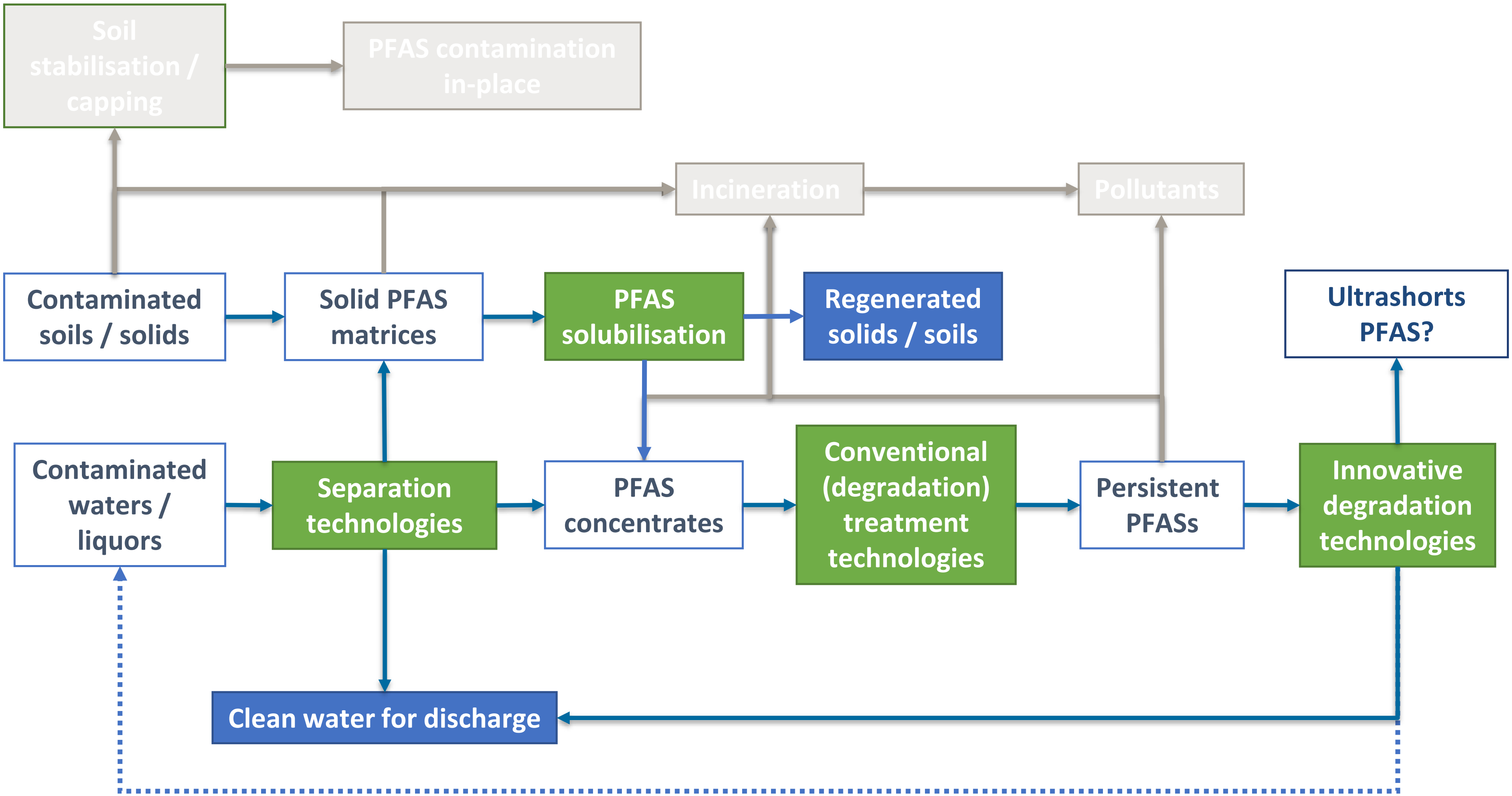
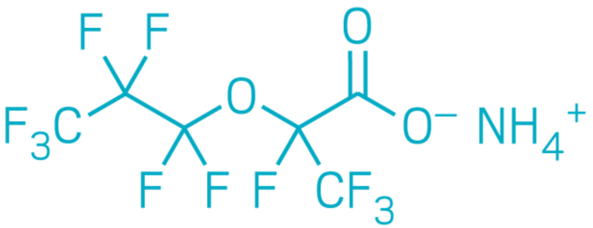


The future questions…

- Next-gen PFAS, ultrashorts…
- What about other solid PFAS wastes?
- How to piece it all together?
- Funding for research!



GenX

THANK-YOU