PER-AND POLY FLUOROALKYL SUBSTANCES (PFAS) in SEWAGE SLUDGE

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KEY TERMS

PFAS – Perfluoro And Polyfluoro Alkyl Substances

PFCA – Perfluoro Alkyl Carboxylic Acids

PFOA - Perfluorooctanoic Acid

PFBA - Perfluorobutanoic Acid

PFHxA - Perfluorohexanoic Acid

PFHpA - Perfluoroheptanoic Acid

PFNA - Perfluorononanoic Acid

PFDA - Perfluorodecanoic Acid

PFUnA - Perfluoroundecanoic Acid

PFDoDa - Perfluorododecanoic Acid

PFTreA - Perfluorotridecanoic Acid

PFTA - Perfluorotetradecanoic Acid

PFPA - Perfluoropropanoic Acid

PFPeA - Perfluoropentanoic Acid

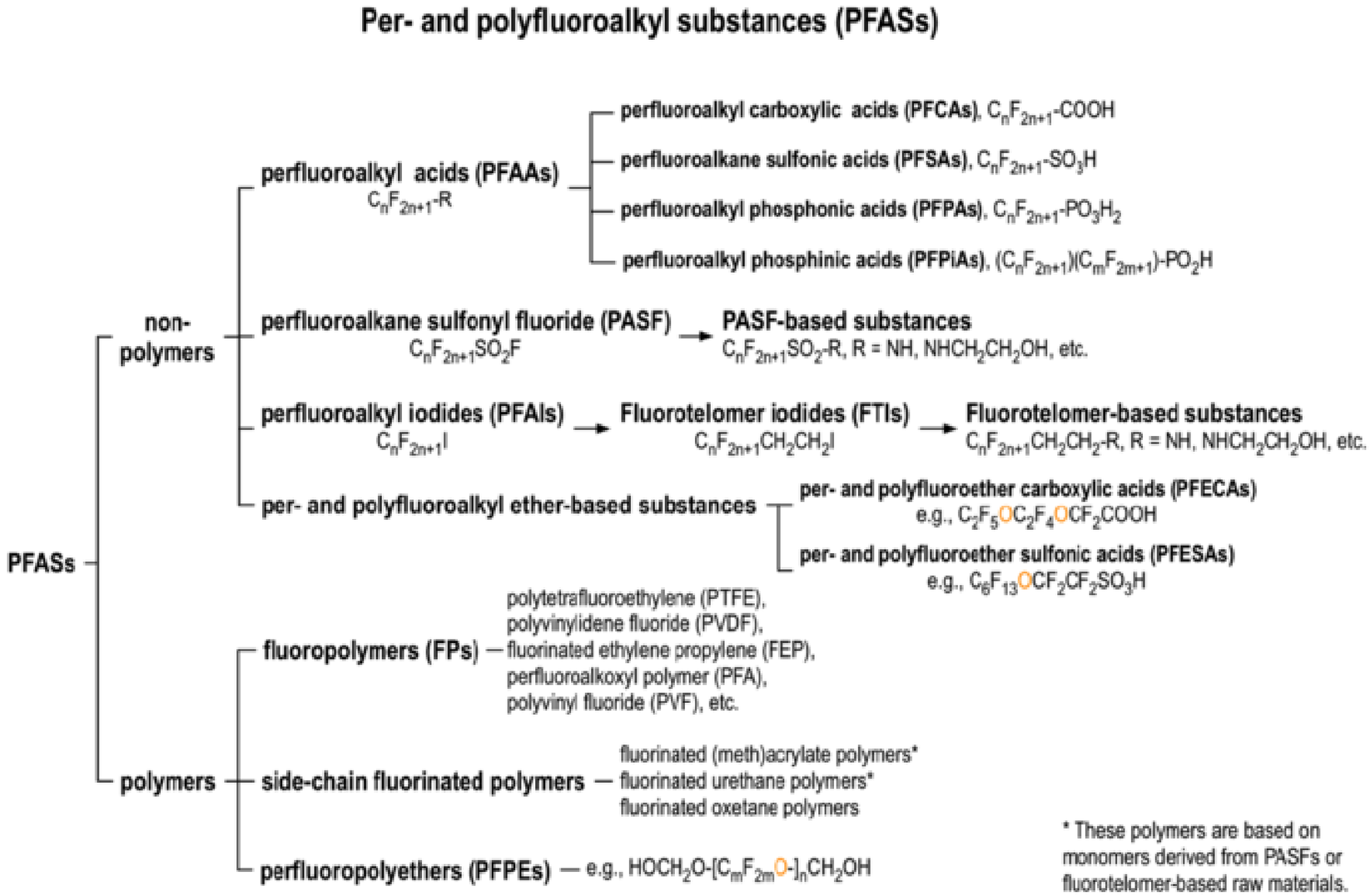
PFSA- Perfluoro Alkane Sulfonic Acids

PFOS - Perfluorooctane Sulfonic Acid

PFBS - Perfluorobutane sulfonic acid

PFHxS - Perfluorohexane sulfonic acid

PFDS - Perfluorodecane sulfonic acid



Source: OECD, 2015

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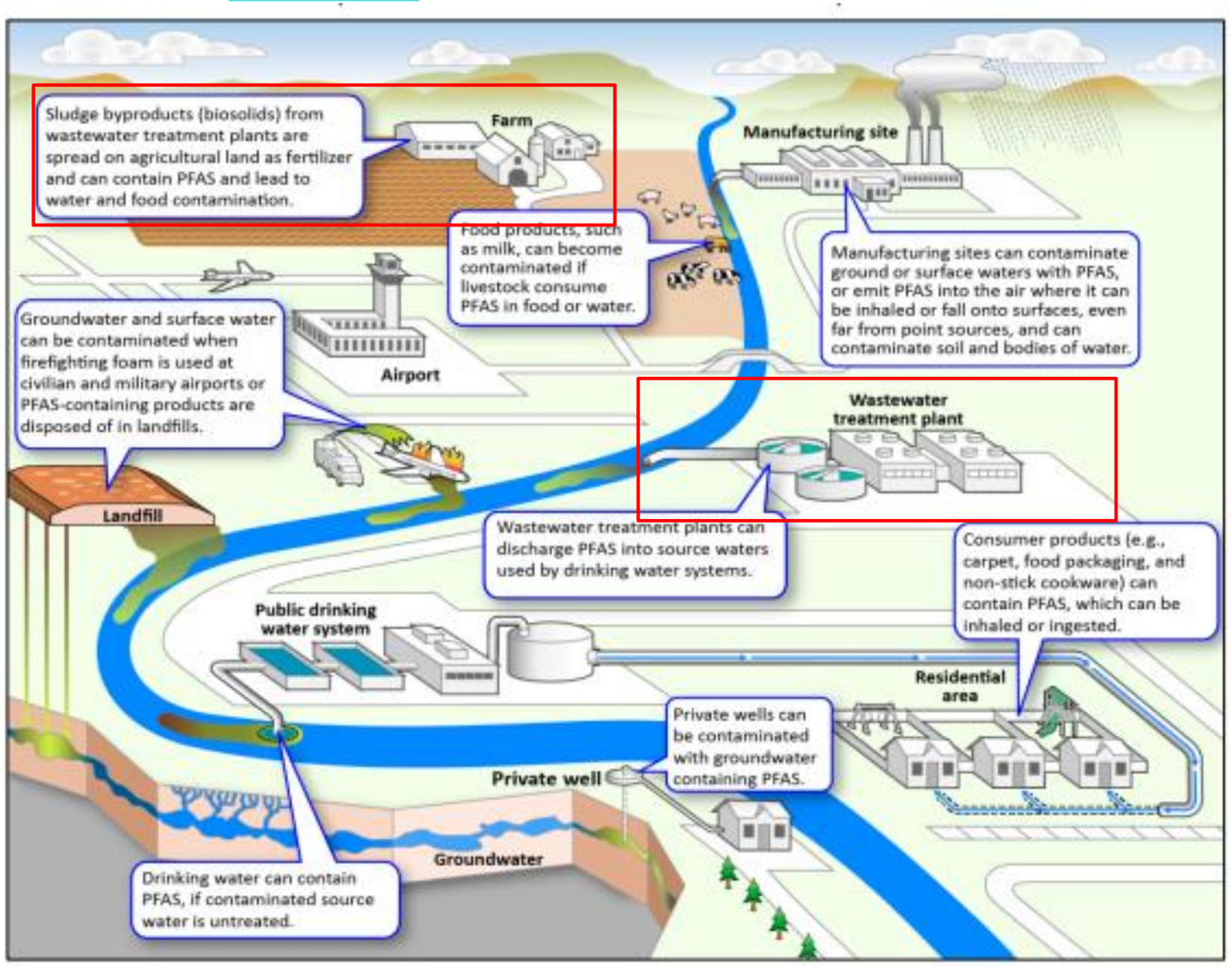
01 INTRODUCTION



Possible Routes For PFAS Release Into The Environment
Source: United States Government Accountability Office, 2022

- ✓ Highly Persistent
- ✓ Long Range Transport Potential
- ✓ Bioaccumulation Potential
- ✓ Endocrine Activity
- ✓ Human Health Effects

2009 **PFOS -Restriction**

2019 **PFOA - Elimination**

2022 **PFHxS – Elimination**

"A perfluorocarbon chain bonded to fluorine atoms at most (polyfluoroalkyl) or all available bonding sites (perfluoroalkyl) and connected to functional groups on both ends ."

Buck et al. (2011) and the OECD (2018)

PFAAs (PFOA,PFOS, PFNA and PFHxS) are found at ppb level in bloods of 97 % residents in industrialized nations.

Source: TWI Limited

PFAS SAFE LIMITS (US EPA)

DRINKING WATER

2016

US EPA established non-regulatory health advisories of 70 ng/L (C8 PFAAs)

2022

Updated the health advisory

- PFOA – 0.004 ng/L*
- PFOS – 0.02 ng/L*
- Gen X – 10 ng/L
- PFBS – 2 µg/L

2024

Announced the final National Primary Drinking Water Regulation for six PFAS

- PFOA – 4 ng/L
- PFOS – 4 ng/L
- Gen X – 10 ng/L
- PFHxS – 10 ng/L
- PFNA – 10 ng/L
- PFAS mixtures – Hazard Index 1

(At least 2 or more of PFHxS, PFNA, GenX, and PFBS)

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), PFOA and PFOS are classified as hazardous substances. (April,2024)

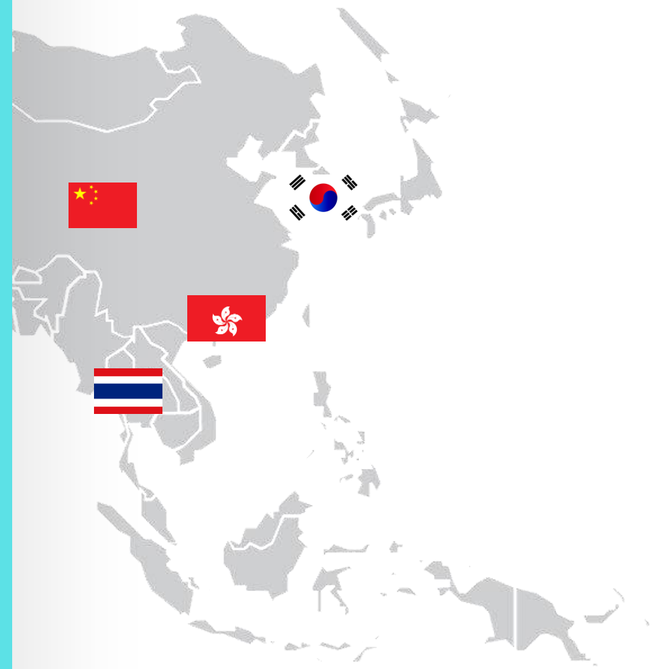
PFAS LIMITS (SOIL & SLUDGE)

Media	Country	PFAS	Regulation value
			(ng/g dw)
Soil	Queensland,	PFOS	1
	Australia	PFOS+PFHxS	2
		PFHxS	3
		PFOA	4
		PFBA, PFPeA	1
		PFHxA	
		Sum C9 -C14	10
		PFCA	
		PFSA	1
		n:2 FTS	4
	USA	PFOS	5.2
		PFOA	2.5
		PFBS	1900
	Canada	PFOS	10
	Norway	PFOS	100
	The Netherlands	PFOS	2.3
	Denmark	PFOS	390
		PFOA	1300
		PFOSA	390
Sewage	United Kingdom	PFOS	46
Sludge	Austria	PFOS+PFOA	100
Soil	Germany	PFOS+PFOA	100

Source: Zhou et al., 2024

02 PFAS OCCURRENCE IN SLUDGE (ASIA)

Studies	Location	Year	WWTP	No of PFAS	Perfluoroalkyl Carboxylic Acids													
					PFOA	PFBA	PFHxA	PFHpA	PFNA	PFDA	PFUnA /PFUdA	PFD0A/ PFDoD A	PFTreA	PFTA/ PFTeDA	PFTrDA/ PFTriA	PFPA	PFPeA	PFPrA
This Study	Thailand	2024	Municipal	11	☑		☑		☑	☑	☑	☑	☑					
(Kunacheva et al., 2011)	Thailand	2011	Industrial	10	☑		☑	☑	☑	☑	☑	☑				☑		
(Kwon et al., 2017)	South Korea	2017	Combined	12	☑			☑	☑	☑	☑	☑			☑			
(Ruan et al., 2015)	China	2010	Municipal	15	☑	☑	☑	☑	☑		☑	☑		☑		☑	☑	☑
(Ma & Shih, 2010)	Hong Kong	2010	Municipal	14	☑	☑	☑	☑	☑	☑	☑	☑		☑	☑		☑	



Globally, PFAS in sludge ranges from 2.1 to 500,000 ng/g (Saliu & Sauvé, 2024; Zhou et al., 2024)

At least 10 analytes of PFAS were detected in sewage sludge.

02 PFAS OCCURRENCE IN SLUDGE (ASIA) (Cont.)

Studies	Location	Year	WWTP	No of PFAS	Perfluoroalkyl Sulfonic Acids					PFOS precursor	PFOA alternative	PFOA precursor	Ultra short-chain PFCA
					PFOS	PFBS	PFHpS	PFHxS	PFDS	NEt FOSAA	Gen X	FOUEA	TFA
This Study	Thailand	2024	Municipal	11	☑	☑		☑			☑		
(Kunacheva et al., 2011)	Thailand	2011	Industrial	10	☑			☑					
(Kwon et al., 2017)	South Korea	2017	Combined	12	☑			☑	☑	☑		☑	
(Ruan et al., 2015)	China	2010	Municipal	15	☑	☑		☑					☑
(Ma & Shih, 2010)	Hong Kong	2010	Municipal	14	☑	☑	☑						

Gen X, introduced in 2009 as a replacement for PFOA, has been detected in Thailand's sewage sludge, reflecting the growing use of newer PFAS compounds.

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PFAS IN SOLID TREATMENT TECHNOLOGIES

- Solidification and Stabilization

(Addition of Binders, Sorbents)

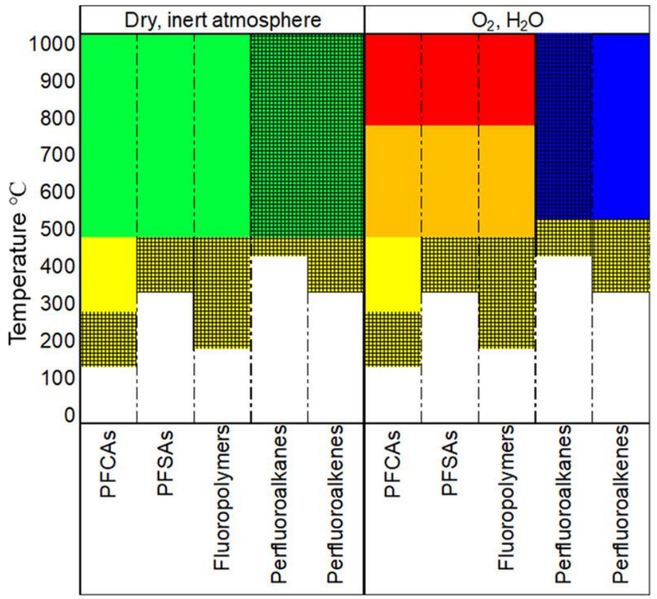
- Separation Technologies

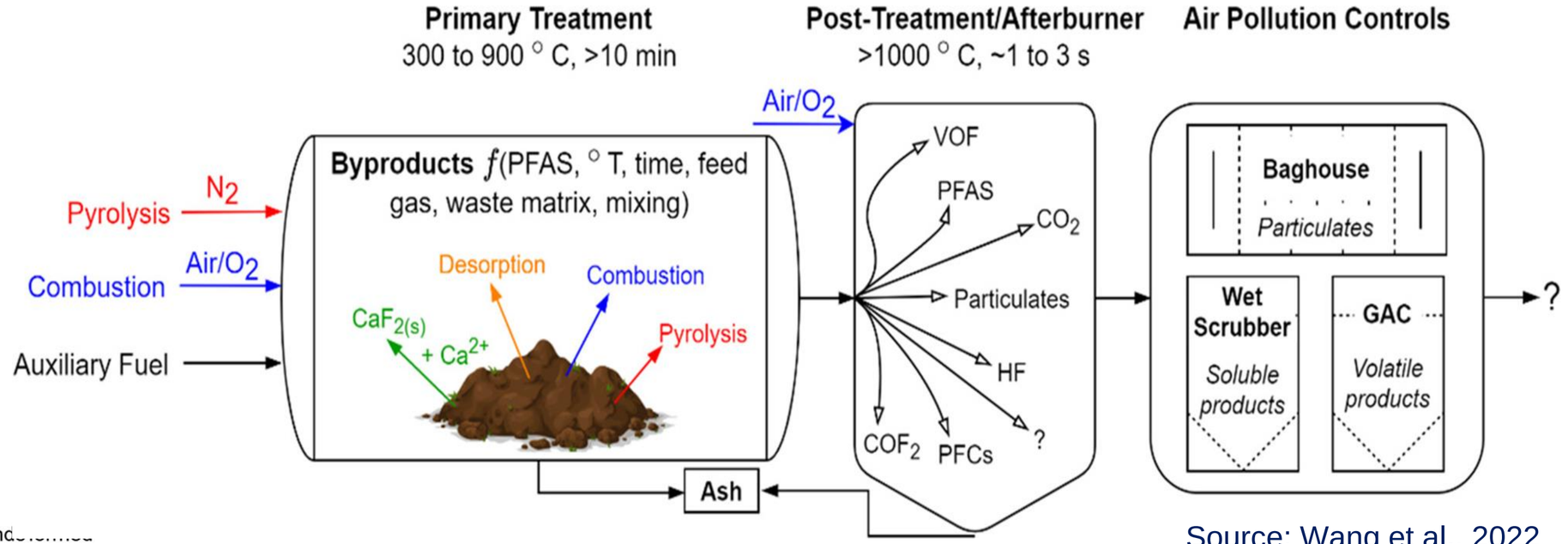
(Soil Washing or Solvent Extraction)

- **Thermal Destruction**

(Commercial Incinerators, Municipal Waste Combustors, Soil Desorbers, Pyrolyzers)

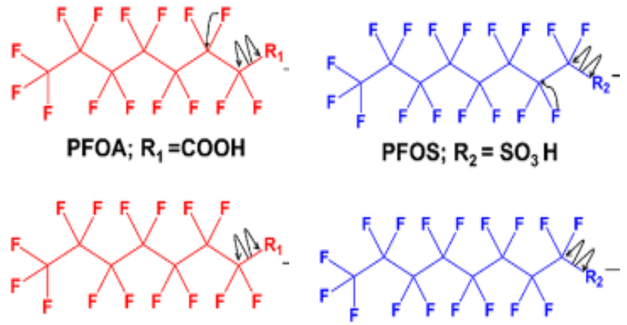
THERMAL DEGRDATION OF PFAS IN SOLIDS





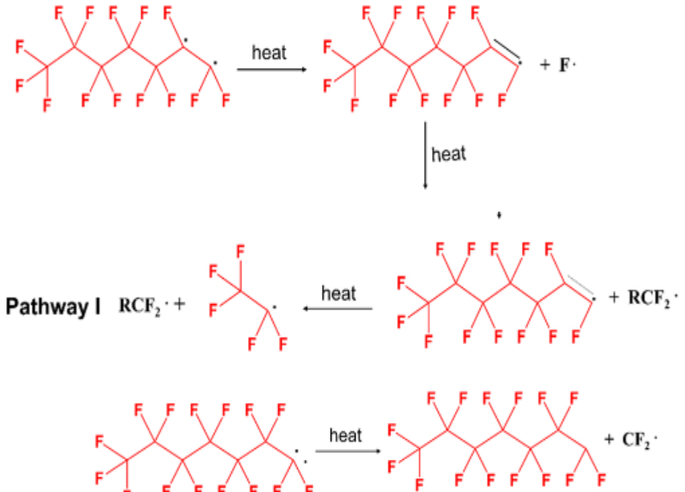
Source: Wang et al., 2022

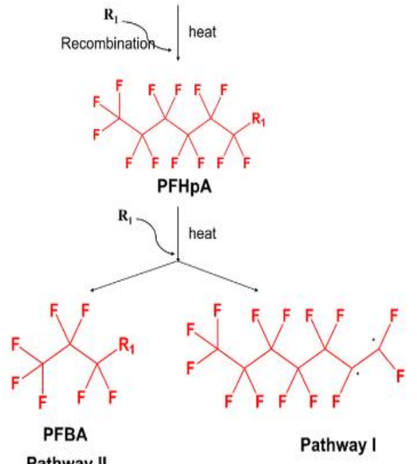
Initiation



Chain Propagation

Radical - defluorination
Shorter chain radicals
Intermediate PFCAs





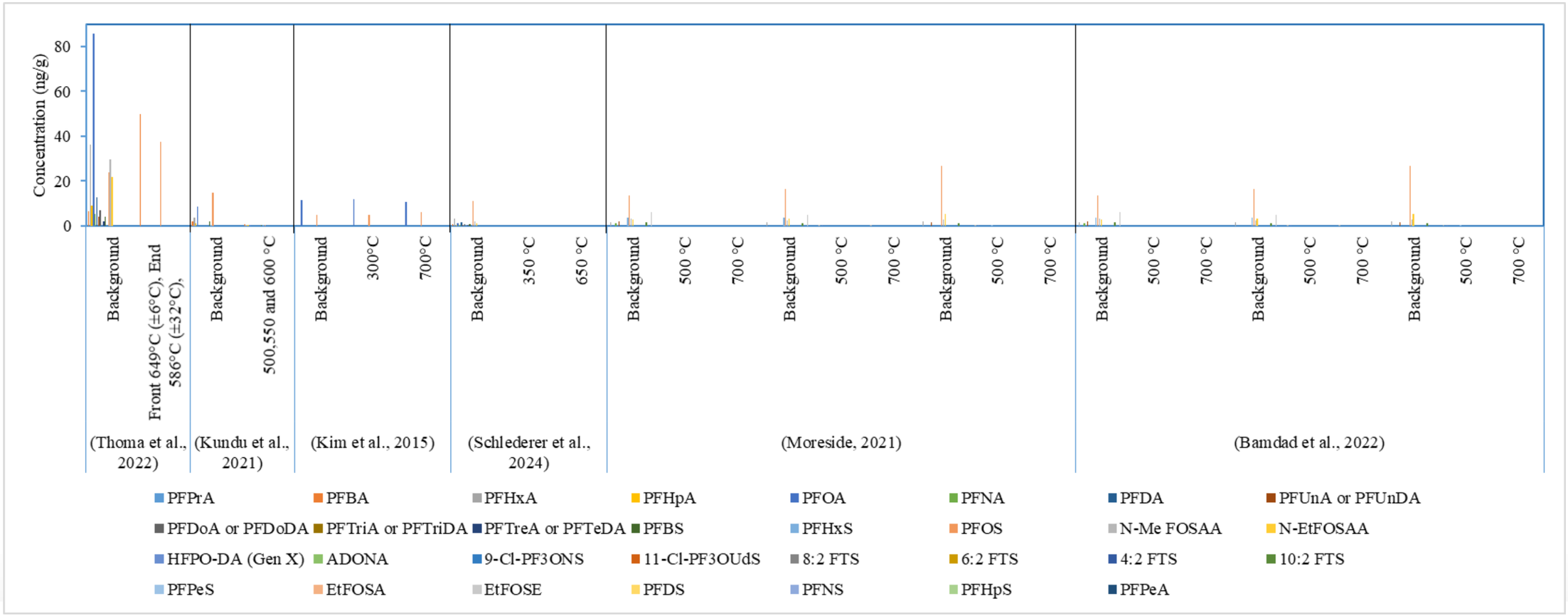
Termination

Very short fluorinated end products

$2RCF_2 \cdot \longrightarrow$ Final product

Source: Kumar et al., 2023

PYROLYSIS OF PFAS SLUDGE (SOLID RESIDUES)



- ✓ **High temperatures (700–800°C):** PFAS in solids effectively decrease but are detected in liquid and gas by-products.
- ✓ **Low temperatures (300–500°C):** Several PFAS persists at trace level across all end products.
- ✓ **Short-chain PFAS and PFOS:** Frequently detected, often at higher concentrations than initially present.

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CHALLENGES

- ✓ There is significant potential to better understand PFAS in thermal degradation
- ✓ More research is needed to optimize thermal treatment conditions for PFAS
- ✓ Non-catalytic pyrolysis is well-studied, but catalytic approaches have been less explored
- ✓ Analytical methods are needed to close the fluorine mass balance

OPPORTUNITIES

- ✓ Deepening Understanding of PFAS Fate
- ✓ Catalyst Development
- ✓ Analytical Advancements
- ✓ Optimization of Thermal Techniques

Q & A