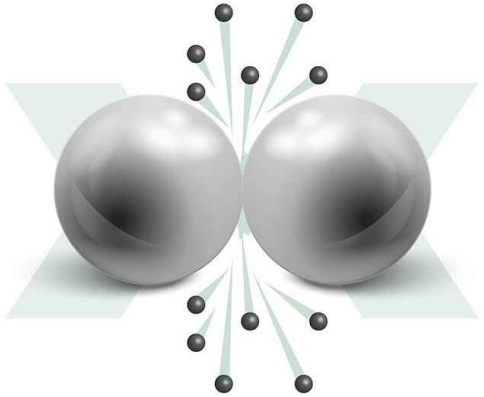
Environmental Decontamination (NZ) Limited



Ball Milling as an Emerging Destruction Technique for PFAS Contaminated Soils

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June 2024

13th International Conference on the Remediation of Chlorinated and Recalcitrant Compounds

Solution Focused

Technology Supplier

R&D facility in Auckland, New Zealand

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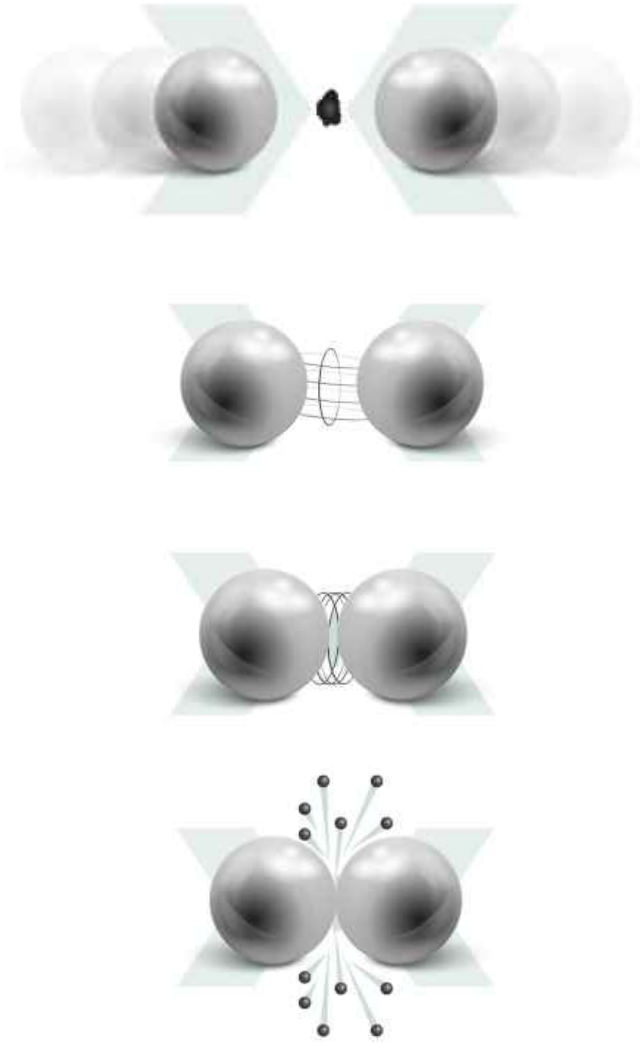
What is Mechanochemistry?

"Mechanochemistry is a less well-known division of chemistry that explores the physical and chemical transformation of substances that have been mechanically stressed or have undergone mechanical fractures."

Underlying Science

Collision Profile



High Velocity Impact

Elastic Deformations

Plastic Deformations

Fracture

- Ball bearings in reactors collide at incredibly fast speeds.
- Mechanical energy input induce physical and structural transformations.
- Particles are subject to intense conditions at the point of collision.
- Optimizing mechanical activation results in improved destruction of target organics.

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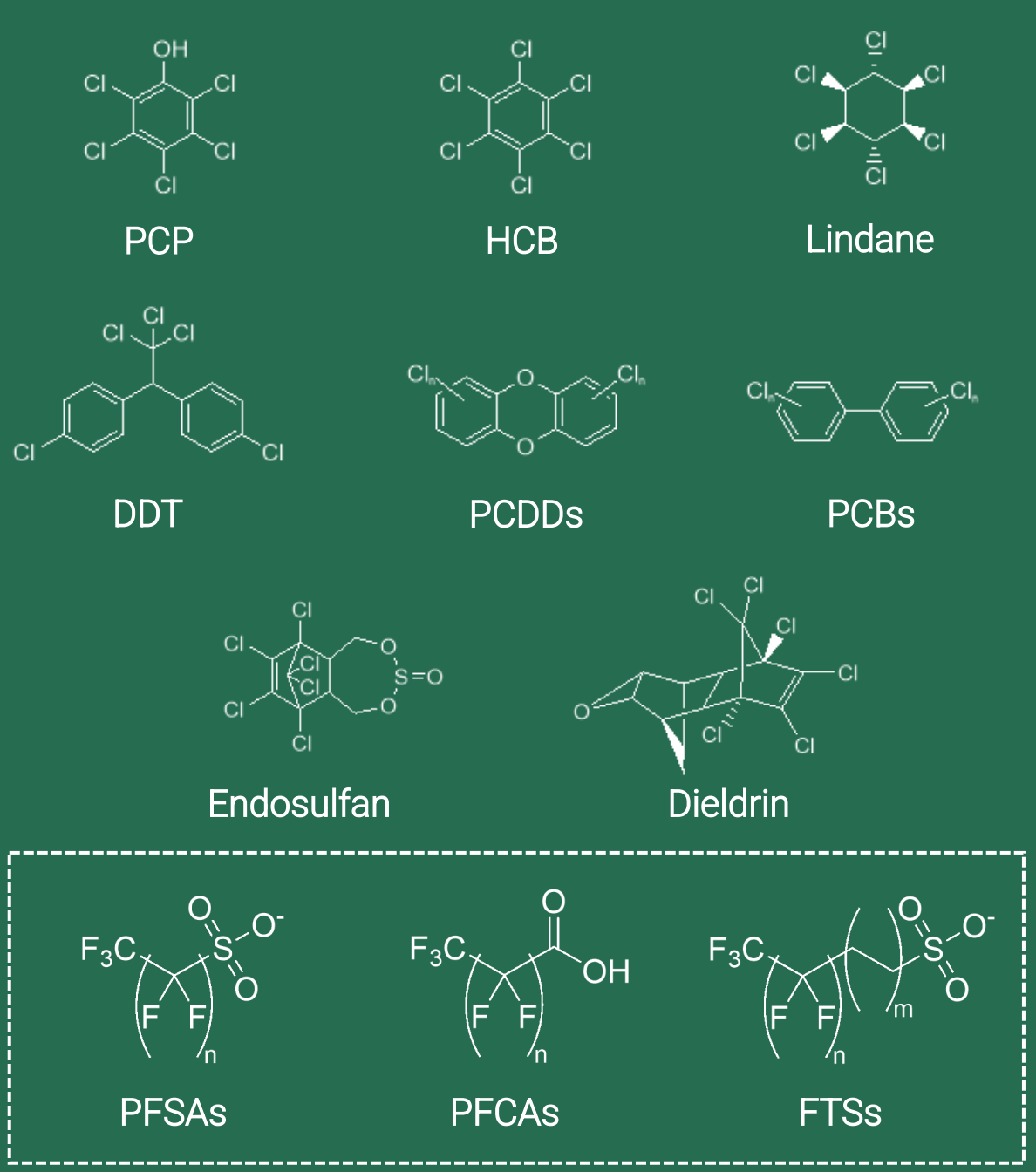
Gobindlal et al. The Mechanism of Surface-Radical Generation and Amorphization of Crystalline Quartz Sand upon Mechanochemical Grinding. *J. Phys. Chem C, 2021.*

Technology Capabilities

Ball milling, or mechanochemical destruction (MCD), as a hazardous waste treatment process.

- Emerging solution for multicomponent wastes.
- A *Green Chemistry* approach.
- Solid state technique.
- Scalable.
- Modular.

<u>Requires progressive validation for PFAS.</u>



R&D Strategy

Reaction Fundamentals

- Mechanisms.
- Kinetics.
- Fluorine fate.

Technology Application

- Contaminated soils.
- AFFF concentrates.
- Spent sorbents.

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Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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New Zealand DEFENCE FORCE
Te Ope Kātua O Aotearoa

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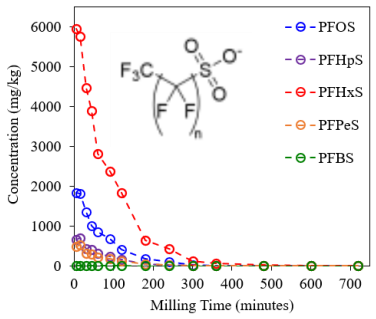
Fundamentals of PFAS Destruction

Procedure

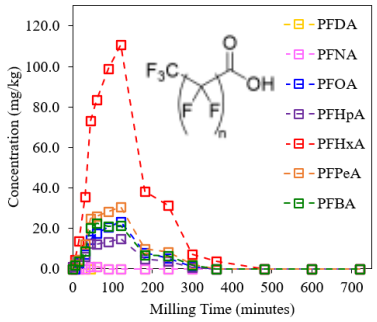
PFAS Standard(s)
~0.05 g

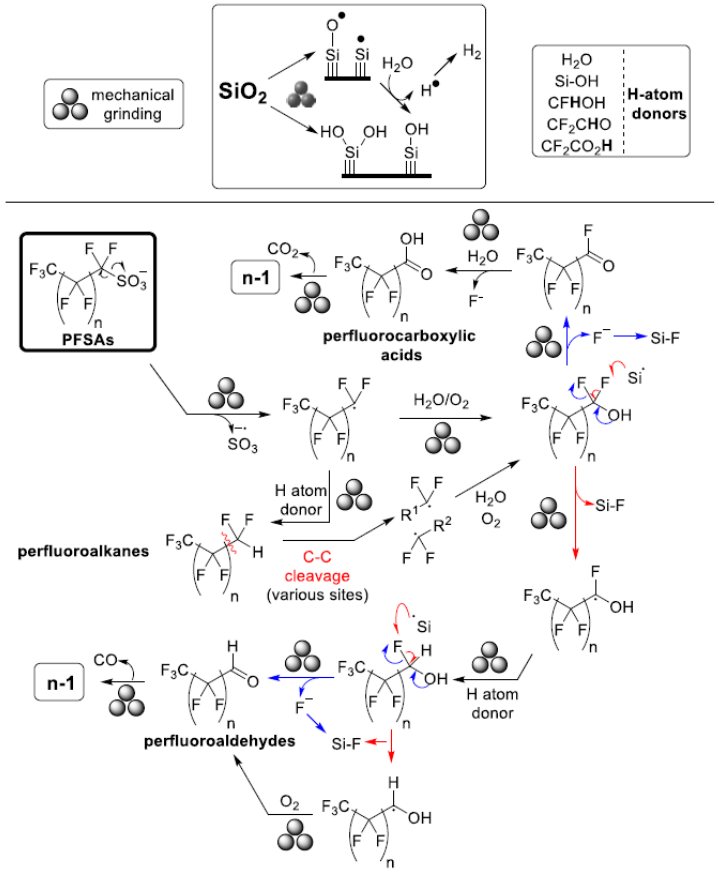
Quartz Sand
~5.00 g

Perfluorosulfonic Acids



Perfluorocarboxylic Acids





- LC-MS/MS
- HRMS
- Solid-State NMR
- CIC
- EPR
- FTIR
- Powder XRD
- XPS
- BET

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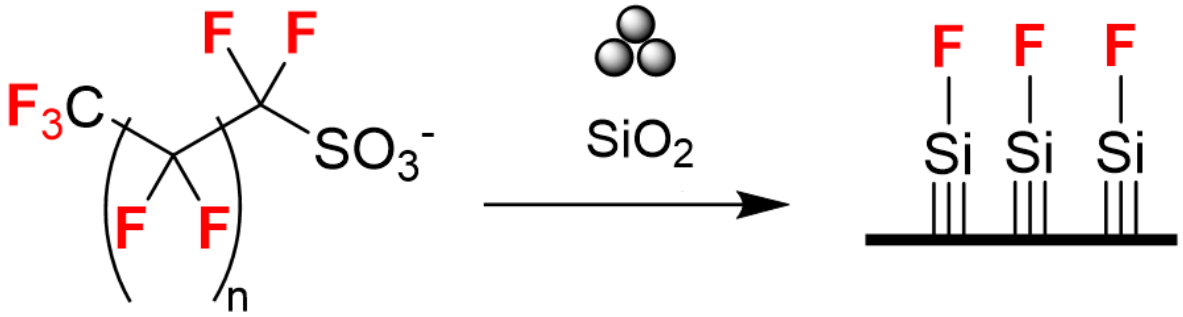
Gobindlal et al. Solvent-Free, Ambient Temperature and Pressure Destruction of Perfluorosulfonic Acids under Mechanochemical Conditions: Degradation Intermediates and Fluorine Fate. *Environ. Sci. Technol., 2023.*

Overall Reaction

High destruction efficiencies achieved (below levels of detection).

Comprehensive destruction mechanism developed for the first time.

Treated matrix characterised. Fluorine fate established.



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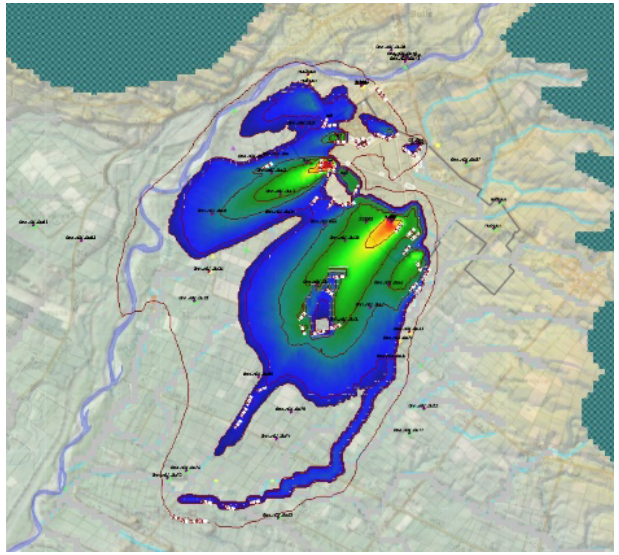
PFAS-Contaminated Soil

Authentic sample derived from a New Zealand Airforce site.

Complex PFAS profile due to decades of foam use.



Characterization:

Sandy soil with low level organic matter.

602 hits on PFAS suspect screening databases (NIST, EPA, OECD).

Method	Major PFAS
HRMS	- 6:2 FTS, 8:2 FTS, 10:2 FTS, + FTS derivatives. - PFOS.
LC-MS/MS	- 6:2 FTS, 8:2 FTS. - PFOS.

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PFAS-Contaminated Soil

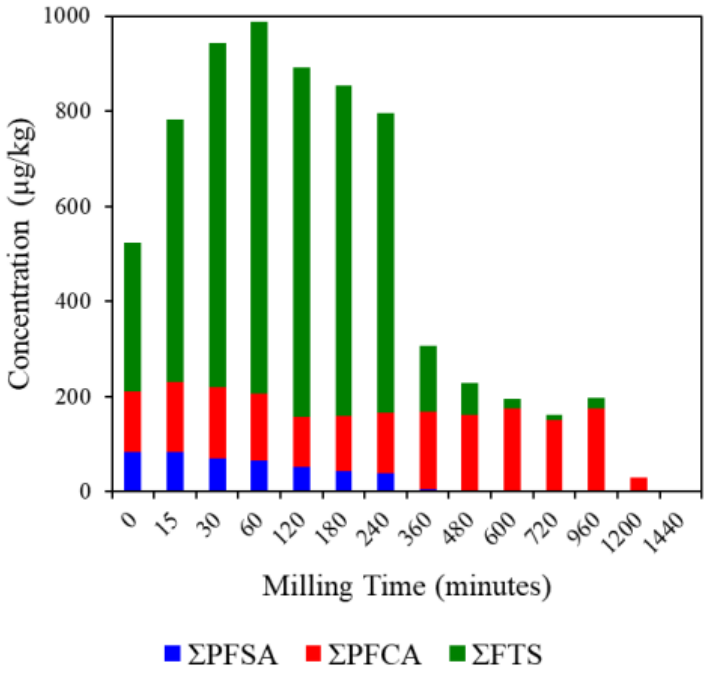
	PFSA (µg/kg)			FTS (µg/kg)		PFCA (µg/kg)									
	PFHxS C6	PFHpS C7	PFOS C8	6:2 FTS C6	8:2 FTS C8	PFBA C4	PFPeA C5	PFHxA C6	PFHpA C7	PFOA C8	PFNA C9	PFDA C10	PFUnDA C11	PFDoDA C12	PFTrDA C13
Before (t = 0)	3.93	2.83	61.97	71.77	239.53	5.13	16.17	13.67	7.83	14.63	23.13	22.53	10.67	7.27	2.97
During (t = 600)	< 1	< 1	1.30	9.20	10.30	7.20	12.30	32.90	37.10	36.20	27.90	11.10	5.90	3.00	1.20
End (t = 1440)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Highlights:

Conversion of FTS derivatives into stable target PFAS, followed by rapid degradation.

Growth of some PFCAs in line with mechanism, followed by degradation.

Short-chain PFAS destroyed alongside long-chain PFAS. All PFAS reduced to below LoD.



Gobindlal et al. Mechanochemical Destruction of Per- and Polyfluoroalkyl Substances in Aqueous Film-Forming Foams and Contaminated Soil. *Environ. Sci.: Adv., 2023.*

Other PFAS-Containing Materials

Product Stockpiles

AFFF and other obsolete products require effective destruction treatment.

Published work describes effective destruction by ball milling, in the order of >99% for total PFAS in AFFF.

Spent Sorbents

GAC, resins, and other materials present challenging disposal issues.

Preliminary trials have revealed high rates of PFAS destruction in spent sorbents subjected to ball milling.

Active research underway by EDL and the University of Auckland

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ESTCP Project 2024 -

2.5-year R&D programme focused on scaling up MCD.

Develop technical **AND** commercial case.

All work to be conducted in NZ.

- University of Auckland
- US EPA
- Analytica Part of ALS
- GSI Environmental, Inc. USA
- Eurofins USA & Aus

Evaluation of Ball Milling as a Destruction Technique for PFAS in Impacted Soil

Expected Outcomes

- Scalability of ball milling technology established for first time (PFAS).

- Technology optimisation to inform implementation.

- In depth feasibility study (technical and commercial).

- On site demonstration in USA.

Scale-Up & Process Flow

1. 

Benchtop

5 - 50 g.

Tech capability.

Efficacy, kinetics.

2. 

Small MCD

10 - 50 kg.

Scalability.

Efficacy.

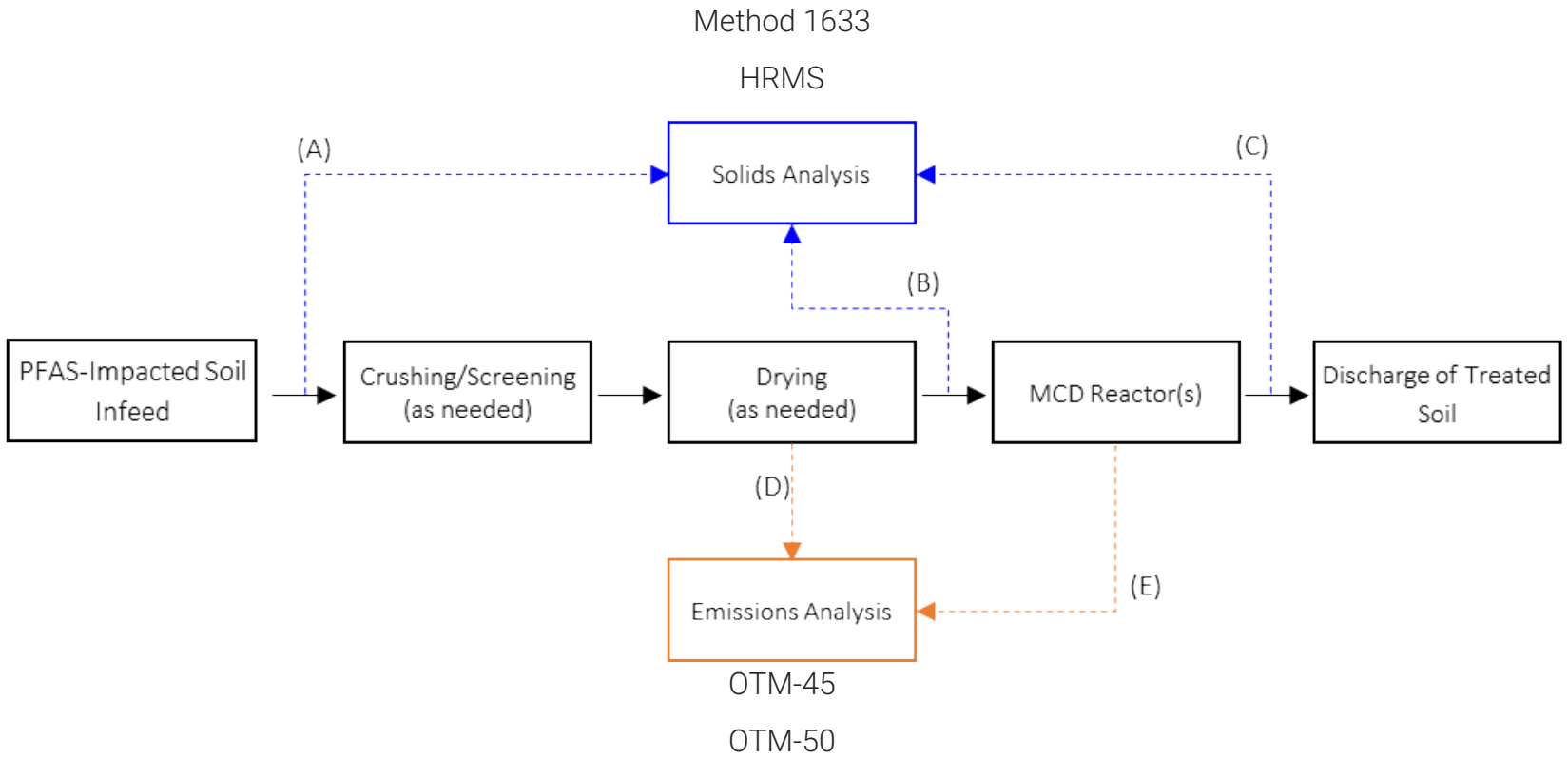
3. 

Intermediate MCD

250 - 2,000 kg/h.

Scalability.

Recirculation.



(Full characterisation suite: TOF, EOF, SVOCs, TCLP HMs, metal speciation, soil properties)

Operational Plants

Next Steps

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