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Persistent Organic Pollutants (POPs) in Waste: Emerging Treatment Technologies

Executive Summary

Scottish Government
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1. Introduction

Persistent Organic Pollutants (POPs) are synthetic chemicals that persist for decades, accumulate in food chains and pose risks to human health and the environment. In Scotland, their presence in household and industrial products—ranging from upholstered seating to electronics and construction materials—creates a barrier to advancing a circular economy.

The UK is a party to the Stockholm Convention on POPs, which requires destruction or irreversible transformation of these substances above regulatory thresholds. Enforcement is difficult. The volume of waste requiring testing far exceeds current capacity and screening technologies cannot reliably distinguish between regulated and non-regulated compounds.

Scotland's carbon footprint is dominated by the lifecycle of products and services, with around 80% linked to material use. Current waste management guidance requires that POP-contaminated waste exceeding Low POP Content Limits (LPCLs) be destroyed, usually through incineration. This prevents recycling of potentially valuable materials, locks Scotland into high-carbon disposal routes and undermines progress toward net zero and circular economy goals.

SEFARI Gateway supported a Specialist Advisory Group (SAG) to review and examine current and emerging technologies for the identification, separation, and treatment of POPs in waste. The objectives of the POPs SAG were to:

Objective 1. Identify technologies to improve Scotland's ability to identify and separate POPs in waste.

Objective 2. Identify technologies to treat POP-containing waste and enable movement up the waste hierarchy.

Objective 3. Summarise benefits, limitations and readiness of technologies.

Objective 4. Identify opportunities for Scotland to build an effective R&D and implementation environment.

This review highlights opportunities for Scotland to build a stronger research and implementation environment for identifying, separating and treating POPs in waste.

2. Research Undertaken

Evidence review

We conducted a structured review of peer-reviewed and grey literature on POPs in waste streams. Search terms combined specific waste categories (e.g. "construction and demolition," "WEEE," "furniture," "end-of-life vehicles") with "Persistent Organic Pollutants" or "POPs," and relevant treatment technologies (e.g. "separation," "bioremediation," "thermal"). Articles were included if they described separation or treatment of POPs in waste materials. Environmental remediation studies (soil, water, air) were excluded unless directly relevant to waste recycling.

Where Scottish data were unavailable, estimates from England, Wales, or Ireland were applied pro-rata, given regulatory and market similarities (Drage et al., 2018; Drage et al., 2022).

Technology assessment

Each technology was assessed against standard Technology Readiness Levels (TRLs) (UKRI, 2025). Key information extracted included: process description, benefits, limitations, cost implications, international application, and potential for scale-up or future-proofing.

Stakeholder engagement

A workshop was held in Edinburgh (March, 2025) with industry representatives, academics, and policymakers. Evidence boards summarised technologies with the highest TRLs, followed by round-table "World Café" discussions. Insights were used to sense-check literature findings, assess feasibility in the Scottish context, and identify barriers and opportunities for implementation.

3. Key Findings

Objective 1. Identify technologies to improve Scotland's ability to identify and separate POPs in waste

Evidence:

Studies in Ireland and the UK show that the main POPs of concern in waste streams are brominated flame retardants (PBDEs, HBCDD) and selected PFAS (PFOA, PFOS, PFHxS). These occur in construction and demolition materials, end-of-life vehicles, furniture foams and fabrics, mattresses, carpets, curtains, and electronic equipment (Drage et al., 2018; Drage et al., 2022).

Technologies identified:

- Density separation (sink-float): Low-cost, mature technology (TRL 9). Separates heavier, POP-rich plastics from lighter fractions. Effective for WEEE but IS crude and limited in discrimination (Stubbings et al., 2021).
- X-ray fluorescence (XRF): Hand-held devices detect bromine as a proxy for brominated POPs. Faster and cheaper than conventional chemical analysis, but cannot distinguish regulated from non-regulated flame retardants, leading to false positives (Harrad et al., 2019; Harrad et al., 2023b).

Workshop insights:

UK recyclers already use XRF and density separation but raised concerns about throughput, lack of established verification labs in the UK, and inability to screen chlorinated or fluorinated POPs.

Policy implication recommendations:

Scotland should expand testing and verification capacity and invest in complementary methods (e.g. spectroscopy, near-infrared scanning) to strengthen compliance and reduce reliance on incineration.

Objective 2. Identify technologies to treat POP-containing waste and enable movement up the waste hierarchy

Evidence:

A wide range of physical, chemical, thermal, and microbial methods are under development, with most at laboratory or pilot stage. Only incineration is widely deployed at scale.

Technologies identified:

- Physical/chemical extraction: Creasolv (TRL 7) can extract POPs from polystyrene insulation foam, allowing recycling of cleaned plastic (Minet et al., 2021). Soxhlet, supercritical fluids, and microwave-assisted extraction show promise but remain at lab stage (TRL 3–5).
- Thermal processes: Pyrolysis, gasification, and smouldering offer potential for partial POP destruction and production of by-products but face challenges of toxic residues, high energy demand, and lack of infrastructure (Hamlin & Hamlin, 2025).
- Advanced oxidation processes (AOPs): Photochemical and hydrothermal oxidation can destroy POPs under controlled conditions, but risks of persistent by-products remain (Foteinis et al., 2018; Rapti et al., 2023).
- Biological methods: Microbial and plant-based remediation are promising but untested at scale for waste streams. Bioleaching has been used to recover metals from WEEE, though not to treat POPs directly (Khalid et al., 2021).

Workshop insights:

Industry representatives noted that some recyclers are piloting AOPs for PFAS in firefighting foams, but large-scale treatment of solid waste remains undeveloped. Pre-sorting and clean feedstocks are critical, yet often unrealistic for composite products such as sofas.

Policy implication:

Investment in pilot-scale testing and infrastructure is required to evaluate which technologies can realistically replace incineration and enable safe recycling.

Objective 3. Summarise benefits, limitations, and readiness of technologies

Evidence:

Technology Readiness Levels (TRLs) vary widely:

- TRL 9: Incineration, density separation, XRF.
- TRL 6–7: Creasolv, some AOP applications.
- TRL 3–5: Pyrolysis, supercritical fluids, microwave-assisted extraction, bioleaching.

Benefits:

Options like XRF and density separation are relatively cheap, non-destructive, and already used commercially (Harrad et al., 2023b).

Creasolv enables plastic recycling rather than destruction.

Pyrolysis and gasification could create secondary products and reduce landfill.

Limitations:

- High cost and energy demand for many processes.
- Risk of toxic by-products (e.g. from pyrolysis, AOPs).
- Limited applicability beyond specific waste streams.
- Lack of UK-based verification labs and specialised facilities.

Workshop insights:

Industry stakeholders stressed that current business models and regulatory frameworks make innovation unattractive compared to low-cost incineration or export. Technologies remain fragmented, with no "one size fits all" solution currently available.

Policy implication:

Scotland can support innovation by funding demonstration projects, creating demand through regulation (e.g. product passports), and reducing reliance on overseas testing.

Objective 4. Identify opportunities for Scotland to build an effective R&D and implementation environment

Workshop insights:

Stakeholders highlighted systemic barriers:

- Regulation: Current LPCL thresholds push most POP-containing materials directly to incineration, limiting incentives for innovation.
- Transparency: Lack of chemical disclosure in products makes it impossible for recyclers to plan treatment.
- Resources: Too few facilities, insufficient skilled staff, and reliance on overseas labs for verification.
- Business models: High uncertainty and low profitability in recycling POP waste without stronger policy support.

Opportunities identified:

- Integration: Better coordination between industry, research, and government to accelerate innovation (Sharkey et al., 2022).
- Funding: Targeted support for scaling technologies from lab to pilot stage, potentially through polluter-pays models.
- Testing capacity: Establish domestic verification labs to reduce reliance on EU facilities.
- Product passports: Require chemical disclosure through digital labelling or confidential repositories to manage future POPs (Gluge et al., 2020).

Policy implication:

Scotland could position itself as a leader in circular economy innovation by piloting these approaches, aligning with international obligations under the Stockholm Convention and reducing reliance on high-carbon incineration.

4. Recommendations

Strengthen integration across sectors

- Create structured forums linking industry, research and government to accelerate solutions for POPs waste (Sharkey et al., 2022).
- Support joint platforms so new tools and practices are interoperable rather than fragmented.

Invest in facilities and pilots

- Fund pilot-scale testing of promising technologies (e.g. Creasolv, pyrolysis, AOPs) to assess feasibility beyond lab conditions.
- Establish UK-based verification laboratories to support compliance with LPCLs and reduce reliance on overseas testing.

Mandate chemical transparency

- Introduce digital product passports or confidential chemical registries to track substances in goods throughout their lifecycle (Gluge et al., 2020).
- Require labelling or online disclosure of chemicals in imported products to support recyclers and regulators.

Secure innovation funding

- Provide targeted funding streams for scaling technologies from TRL 3–5 to operational use.
- Explore "polluter pays" mechanisms, similar to the Landfill Tax Credit, to finance POPs treatment innovation.

Shift incentives away from incineration

- Review UK/EU guidance to enable recycling options where technologies can safely remove or destroy POPs.
- Support business models that make recycling POP-containing materials more viable than low-cost incineration or export.

Align with international obligations

- Ensure all approaches comply with the Stockholm Convention's requirement that POPs be destroyed or irreversibly transformed (Drage et al., 2022).
- Position Scotland as a leader in circular economy innovation by demonstrating compliance alongside sustainable material recovery.

5. Conclusion

Persistent Organic Pollutants (POPs) remain a major obstacle to the development of Scotland's circular economy. Current reliance on incineration protects health but destroys resources and locks in high-carbon pathways. Evidence shows that emerging technologies—while not yet ready at scale—offer opportunities to recover value safely if barriers of cost, infrastructure, and regulation are addressed.

By investing in pilot facilities, requiring chemical transparency, and strengthening collaboration across industry, research, and policy, Scotland can move from containment to innovation. Acting now will not only ensure compliance with international obligations but also position Scotland as a leader in sustainable waste management and circular economy solutions.

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SEFARI works across six Research Institutes who deliver the Scottish Government funded Strategic Research Programme.