Repository

Section 15 - Hydrogen, Sustainability & Circularity

Topic 105 – Recycling Processes

Dissemination Level: Public

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1. Repository Introduction

This document is part of the H2VE Repository, a structured collection of learning resources and materials developed to support Centres of Vocational Excellence (CoVEs) and training providers in delivering high-quality, up-to-date hydrogen education. The thematic clusters and sub-topics covered in this repository were jointly compiled by all H2VE project partners as part of Deliverable D5.1 - Educational Training Material Specification Document. Each document corresponds to a specific sub-topic within a broader thematic cluster and follows a standardized structure comprising a document header, learning context, core content, curated digital tools, and assessment guidance, where applicable. The aim is to provide trainers and educators with general resources as well as modular content that can be integrated into existing curricula or adapted to specific training contexts. A list of underlying resources and sources is provided at the end of each document to allow for further exploration and verification of the material presented.

2. Topic Overview

Mechanical, hydrometallurgical, and pyrometallurgical methods each offer different pathways for recovering materials from hydrogen technology components. This topic provides an overview of these technical recycling processes and explains how they differ in terms of material recovery rates, energy intensity, and applicability to specific hydrogen components and materials. Learners are introduced to the current state of process development and the trade-offs involved in selecting recycling routes for different hydrogen technologies. By focusing on the underlying process technology that enables material recovery, this topic complements the component-specific and material-specific documents in this cluster.

3. Learning Resource Overview

1. Learning Context	**Prerequisites**: • Completed Topics 100 and 103 (R-strategies and component recycling pathways) • Basic chemistry knowledge (acid-base reactions, redox processes) for EQF 5+ learners
2. Content	• **Three Process Families** Recycling approaches fall into three families: mechanical (physical separation), pyrometallurgical (thermal treat-

	ment), and hydrometallurgical (chemical/aqueous processing), each suited to different materials and recovery goals. • **Hydrometallurgical Recovery** Platinum-group metals can be recovered via acid leaching, typically using hydrochloric acid combined with an oxidant, to dissolve and selectively extract the catalyst material. • **Pyrohydrometallurgy** This combined route incinerates the PFSA membrane and other organic material first, then applies hydrometallurgical refining to recover the remaining metals, often achieving higher yields at the cost of higher energy use and emissions. • **Emerging Alternatives** Acid dissolution and electrochemical dissolution are lower-energy, lower-toxicity alternatives currently at an earlier stage of industrial readiness compared to established hydrometallurgical and pyrometallurgical routes. • **Recovery Yields and Industrial Integration** Platinum recovery from PEMFC via hydrometallurgy ranges from roughly 64–99%, with combined methods reaching 97%+. Scaling these processes industrially requires integrated collection, pre-processing, and refining infrastructure. • **Worked Example: Trinh et al. (2024)** This open-access study demonstrates oxidative leaching in hydrochloric acid achieving around 97% platinum recovery under mild conditions, offering students a concrete process to analyze in detail, including kinetics and scale-up considerations.
3. Digital Tools	FCH-LCA Tool, Recycling Process Modelling: Model the environmental impact of different recycling pathways using the FCH-LCA Tool's end-of-life templates. Compare GWP and energy use across hydrometallurgical vs. pyrohydrometallurgical routes.
4. Assessment Guidance	**Assessment Methods** • Multi-criteria scoring exercise: students complete the 5-technology x 4-criteria table and write a 200-word rec-

	ommendation for which process should be prioritised for PEMWE Ir recovery at industrial scale. • Process flowchart: students draw the hydrometallurgical Pt recovery process (Trinh et al., 2024) as a labelled flowchart with key process conditions annotated. • **Sample Questions** 1. Describe the hydrometallurgical process for platinum recovery from PEMFC MEAs. What are the advantages over pyrohydrometallurgy? 2. Why does pyrohydrometallurgy achieve higher PGM yields than hydrometallurgy in some scenarios, and what environmental trade-offs does this involve? 3. An electrochemical dissolution process achieves 95% Pt selectivity but requires 3 hours per batch. A pyrohydrometallurgical process achieves 99% Pt yield in 45 minutes but generates HF precursors. Which would you recommend for a European facility and why? **Evaluation Criteria** • Accuracy of process description and chemistry (35%) • Correct identification of trade-offs across yield, energy, toxicity, and readiness (40%) • Quality of justified recommendation referencing real data (25%)
5. References	Uekert, T., et al. (2024). Electrolyzer and fuel cell recycling for a circular hydrogen economy. Advanced Sustainable Systems. https://docs.nrel.gov/docs/fy24osti/87146.pdf Clean Hydrogen Partnership. (2020). Life cycle assessment of hydrogen and fuel cell technologies. https://www.clean-hydrogen.europa.eu/media/publications/life-cycle-assessment-hydrogen-and-fuel-cell-technologies_en **Trinh et al. (2024): Pt Recovery from PEMFC via Oxidative Leaching in HCl, Cleaner Engineering & Technology (Open Access)**: Detailed process paper. 97% Pt recovery under mild conditions. Includes full kinetics and industrial scale-up analysis. Open access. **ACS Applied Energy Materials (2025): Sustainable PGM Recovery for FC & Electrolyzer Applications**: review of advanced PGM recovery strategies with circular economy linkages. For EQF 7–8 learners.