

Demonstrating circularity for critical materials in proton exchange membrane (PEM) hydrogen technologies.

Summary

Johnson Matthey and Syensqo have successfully recovered and recycled critical materials from industrial scrap fuel cell catalyst coated membranes (CCMs), including both the platinum group metals (PGMs) and the ionomer. These kilo-scale demonstrations show high yield recoveries for both materials that can be reused to manufacture new CCMs, demonstrating circularity and with lower carbon footprint to existing processes. The recovered ionomer, which is destroyed in conventional recycling processes, has shown equivalent performance to fresh materials in testing, with no evidence of degradation products or trace metals.

The coordinated approach from Johnson Matthey and Syensqo exemplifies the industry-wide action needed to effectively implement circularity for PEM electrolysis for fuel cells and electrolyzers. But future commercial and policy frameworks must evolve to support widespread adoption, including:

- clearer regulatory direction for fluorinated membrane recycling.
- end-of-life infrastructure being developed in parallel with increasing PEM deployment.
- industry wide product stewardship to maximise ionomer recovery and ensure degraded residues are safely destroyed.

This can only be successful with cross-company collaboration across the supply chain.

Introduction

Proton exchange membrane (PEM) technologies are key to enabling the energy transition towards a sustainable and secure future. Hydrogen produced by water electrolysis has the potential to decarbonise “hard-to-abate” sectors, acting either as an energy vector (for example, as fuel for fuel cell trucks (FCEVs), energy storage, hydrogen-based e-fuels, etc.) or as a sustainable chemical feedstock. This hydrogen can be fully “green”, depending on the source of electricity. PEM technology is particularly well suited to this scenario due to its high power density and rapid response to fluctuations in electricity supply from renewable sources.

It is vitally important that, in developing sustainable technologies, the environmental burden is not shifted to other areas, such as critical material efficiency and ecotoxicity. PEM technologies use platinum group metals (PGMs) as catalysts. These materials are essential due to their unique properties, including high activity and durability under device operating conditions. Because of the limited geographical distribution of primary sources, PGMs are classified as critical minerals by the US, UK, and EU. However, established

recycling routes and robust secondary supply chains already exist for these materials, driven by both economic and sustainability considerations compared with primary supply.¹ Concerns that PGM availability could limit the growth of the PEM industry are largely unfounded, provided that PGMs are used efficiently and recycled.^{2,3}

Challenge

PGMs contained in catalyst-coated membranes (CCMs) used in PEM technologies have historically been recycled via standard routes, in which the material is first incinerated to remove organics before being introduced into pyrometallurgical and hydrometallurgical processes to separate and purify the PGMs. However, this approach does not address the circularity of other key materials within the CCM.

The membrane is made from perfluorosulfonic acid-based polymers (ionomers), which are selected for their unique properties. These materials are designed to conduct protons, provide optimal gas and water permeability, remain stable under the electrochemical conditions in the fuel cell or water electrolyser, and maintain high mechanical durability. Previously described recycling routes destroy these highly valuable materials, contributing to the CO₂ footprint of recycling and necessitating the management of hydrogen fluoride off-gas.

Fluorinated materials have attracted increased regulatory attention in recent years due to the presence of carbon-fluorine bonds, which classify them as PFAS (per- and polyfluoroalkyl substances). These strong bonds contribute to the exceptional durability and chemical resistance of all fluoropolymers, including ionomers. While PFAS have raised concerns regarding adverse effects on human health and the environment, it is important to note that not all PFAS are the same. In particular, high-molecular-weight fluoropolymers are stable, inert, and non-bioaccumulative. To maintain forward momentum in the journey towards a more sustainable and secure energy future, in which hydrogen plays a key role, it is therefore imperative that, alongside PGM recycling from PEM technologies, ionomer use is tightly controlled and that materials are recovered and reused wherever possible. New recycling processes are required to achieve this.

Despite strong progress in PGM recycling, the circularity of fluorinated membranes and ionomers remains limited by current device design and the absence of mature end-of-life infrastructure. Complex, tightly bonded stack assemblies make efficient disassembly difficult, and while PGM circularity is long established, equivalent pathways for fluoropolymers remain in early development. Policy frameworks are only beginning to recognise the strategic importance of these materials, leaving a gap between deployment rates and circular recovery models.

A Path to Circularity

Johnson Matthey (JM) was founded in 1817 and has been refining PGMs for over 100 years. Today, it is the largest recycler of PGMs globally and is a key supplier of catalysts and CCMs for PEM fuel cells and water electrolyzers. The research team at JM developed a new, purely chemical **HyRefine™** process for recovering PGMs, avoiding the incineration and smelting steps which destroy the ionomer and allowing it to be recovered and recycled, as illustrated in Figure 1.

Initial life cycle assessment studies comparing the **HyRefine** process with the use of fresh ionomer and conventional PGM recycling routes showed that the carbon footprint was reduced by approximately 80%,⁴ with:

- 65% less water used
- 80% less energy used
- 84% less waste produced

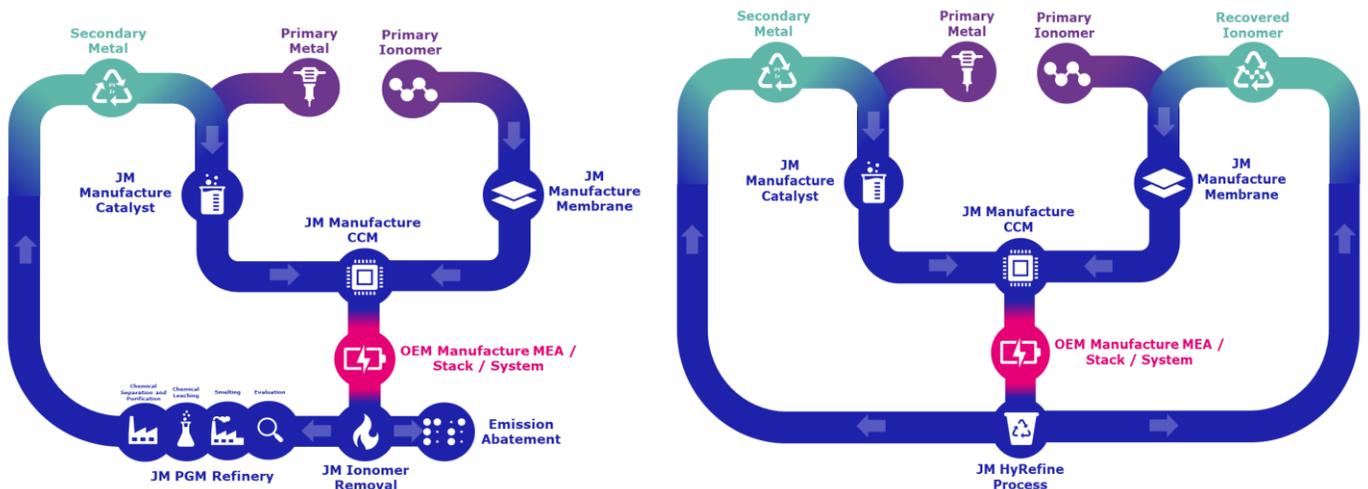


Figure 1: Conventional recycling route of CCMs (left) compared to **HyRefine** process (right).

Syensqo builds on decades of expertise in advanced polymer science and is a leading supplier of high-performance ionomers for PEM fuel cells and water electrolyzers, with global manufacturing and R&D capabilities. Today, it supports the electrochemical energy sector with specialty polymer technologies designed to meet stringent requirements for conductivity, durability and processability.

In line with this commitment to circularity and sustainable innovation, Syensqo’s research team has developed a process for the leaching of ionomers from various articles (membranes, electrodes, MEAs, etc.), followed by purification and reconditioning to obtain ready-to-use ionomer dispersions. Pilot-scale validation has demonstrated that this process has no negative impact on the ionomer performance.

Recognising that full circularity requires collaboration across the supply chain, Johnson Matthey and Syensqo have demonstrated what is possible within the industry. On a kilogram scale, PGMs have successfully been recovered from industrial scrap fuel cell

CCMs, achieving yields comparable to those of existing processes, and could be reintegrated into the catalyst manufacturing process.

Virtually all of the ionomer from these materials has been recovered, as the recycling process itself does not cause any degradation or material loss. Analysis showed that the recovered ionomer met the original specification for virgin material, with no evidence of degradation products or trace metals. After recasting the ionomer into a membrane, the proton conductivity showed a profile equivalent to that of fresh material.

Importantly, electrochemical performance remained stable under operational conditions. As illustrated in Figures 2, 3 and 4, in situ electrochemical testing and accelerated stress tests confirmed comparable durability and performance retention between recycled and virgin ionomer-based membranes, including structural integrity, proton transport performance, and electrochemical durability.

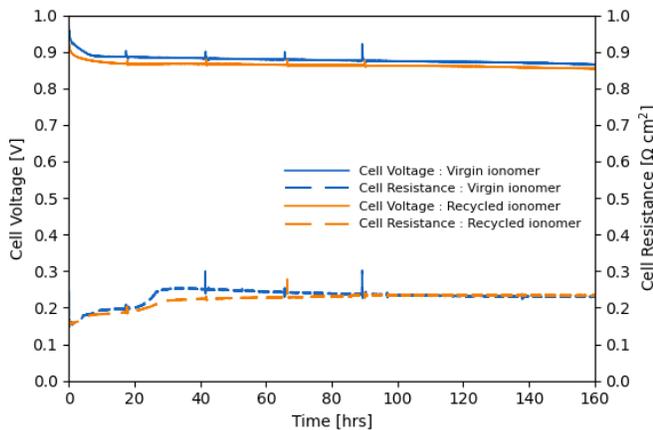


Figure 2: OCV accelerated stress testing demonstrating comparable voltage stability and resistance evolution over time.

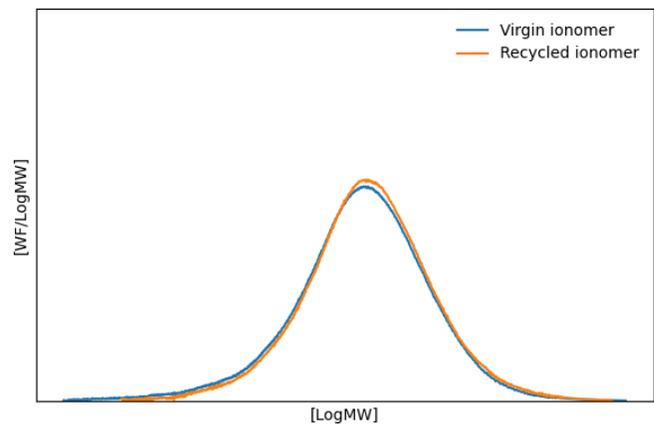


Figure 3: GPC molecular weight distribution profiles confirming preservation of polymer architecture after recycling

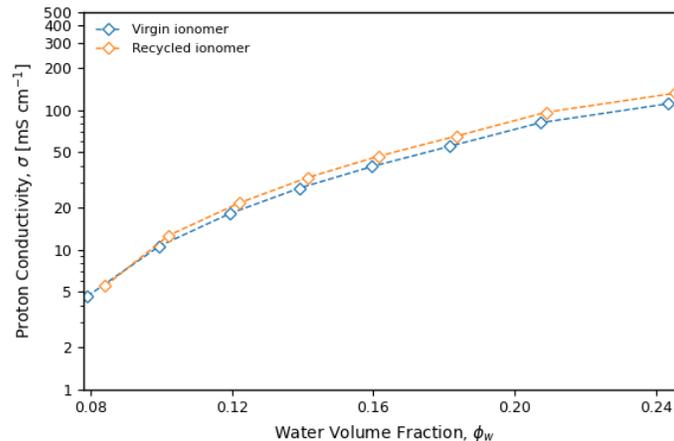


Figure 4: Proton conductivity as a function of membrane hydration at 80 °C, showing equivalent transport properties for recycled and virgin materials.

These results align with broader assessments that the future of circular hydrogen technologies depends not only on efficient end-of-life processes but also on integrating circularity into component design from the outset. As new materials are introduced, their recyclability will need to be engineered into the system to prevent future recovery barriers.

Conclusion and Outlook

Johnson Matthey and Syensqo were able to demonstrate a viable pathway for recycling both PGMs and perfluorosulfonic acid-based ionomers from CCMs used in PEM fuel cells and water electrolyzers.

This route has a lower carbon footprint compared to conventional processes, yet does not compromise PGM recycling efficiency. Research to date suggests that ionomer can be recovered in high yield from manufacturing scrap, meets virgin material specification, and matches performance when recast into a new membrane.

Challenges remain in understanding how much ionomer can be recovered from end-of-life materials. In this context, analytical techniques to assess the quality of the remaining material will be crucial in determining the appropriate recycling route.

Strong product stewardship — maximising ionomer recovery while ensuring that degraded residues are safely destroyed — will support a sustainable energy transition. Industry voices increasingly highlight that scaling fuel cell circularity requires coordinated action across design, processing, and policy. While PGM circularity is mature, fluorinated membrane recycling requires clearer regulatory direction and the parallel development of end-of-life infrastructure alongside increasing deployment. Demonstrations show that full-system circularity is technically achievable and that future commercial and policy frameworks must evolve to support widespread adoption.

Established supply chains already enable collection, recycling, and refining of PGMs and could be leveraged to support ionomer recovery. However, OEMs, ionomer suppliers, and component manufacturers will need to collaborate to achieve full circularity.

¹ [“The Life Cycle Assessment of Platinum Group Metals”](#), International Platinum Group Metals Association 2022 (accessed Feb, 2026)

² M. Clapp, C. M. Zalis, M. Ryan, *Catal. Today*, 2023, **420**, 114140

³ M. Clapp, C. M. Zalis, M. Ryan, *ECS Trans.*, 2023, **111**, 21

⁴ J. Lord, R. White, R. Murphy, J. Sadhukhan, *Green Chem.*, 2025, **27**, 14577