Sustainability in the hydrogen economy

RECYCLING AS A KEY FACTOR FOR RESOURCE EFFICIENCY

The hydrogen economy as a crucial technology for replacing fossil resources is subject to high expectations in terms of sustainability. Hardly any other growth area is the subject of such controversial discussions about how "green" it really is. In the context of resources, the hydrogen economy however is about more than just ideological considerations. Electrolyzers and fuel cells contain rare and valuable raw materials, such as the precious metals iridium and platinum. From economic and strategic perspectives, they must be recovered after the end of their life. Recycling is a must—and should be considered from the outset, not only when the end of life of the plants and vehicles is reached. But where does the circular economy stand today in the context of hydrogen? We provide an overview using the example of PEM technology. **Authors:** Ole Rauber-Wagner, Gisela Mainberger

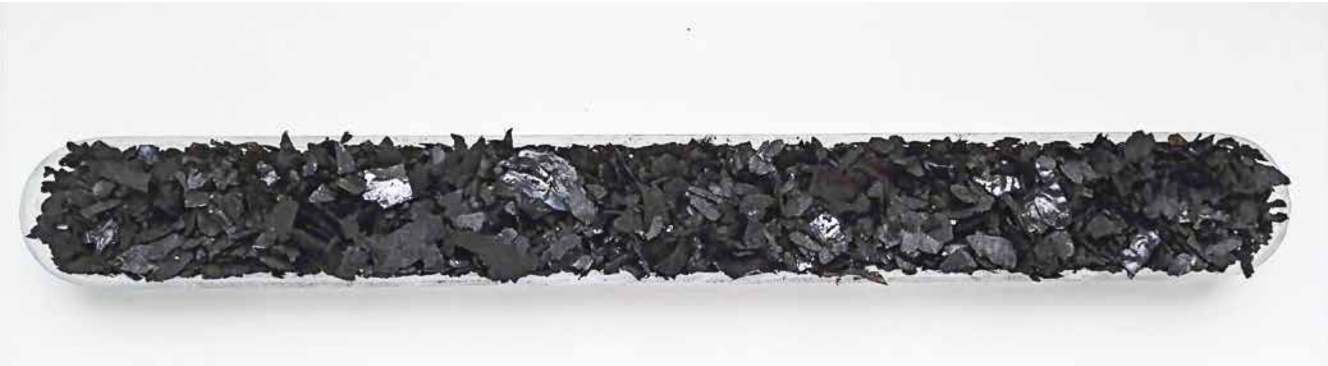

Fig. 1: Shredded material [Source: Heraeus]

Many valuable raw materials go into the stacks of electrolyzers and fuel cells. When considering the weight, one could almost overlook the value drivers. It is only when looking at the value of the raw material components of a PEM stack (proton-exchange membrane) that it becomes clear that the focus is primarily on the CCM (catalyst-coated membrane). It consists of an ionomer that is coated with precious metal.

VALUABLE AND RARE: RAW MATERIALS IN THE HYDROGEN ECONOMY Precious metals are not only valuable, some of them are also extremely rare. This is particularly true for iridium, which is indispensable in PEM electrolysis. In May 2022, the Hydrogen Council [1] spoke of announced 175 gigawatts of electrolyzer capacity by 2030. Since then, the goals have become even more ambitious. According to experts' estimates, 40 percent of this is expected to be realized with PEM technology. Based on the average amounts of iridium currently used per gigawatt, this would require around 28 tonnes of iridium—more than will be available during the same period.

The experts at the precious metal specialist Heraeus Precious Metals in Hanau, Germany, whose core business includes trading, products, and recycling of precious metals, estimate that, out of the very low annual production quantities of iridium, a maximum of cumulative twelve tonnes can be used for the hydrogen economy by 2030.

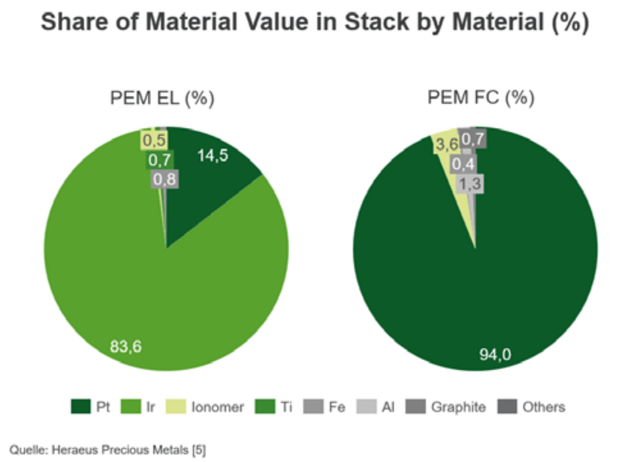

Fig. 2: Even though the composition of the stacks is constantly being optimized and therefore these 2016 data no longer completely correspond to reality, the precious metals on the membrane remain the value driver. [Source: Heraeus]

CIRCULAR ECONOMY AS A LEVER FOR GROWTH

The industry is primarily addressing this challenge with technological innovations. The experts at Heraeus are doing this with catalysts that require significantly less iridium, reducing the required amount to seven tonnes by 2030. This however clearly demonstrates how important the establishment of a circular economy for raw materials will be for further growth, as an increase in production quantities of iridium is not considered realistic from the experts' perspective.

In addition to considerations regarding raw material supply, the value of precious metals naturally plays a significant role. Typically, the recovery of the installed precious metals is part of the plan from the outset because they represent a significant share of the investment costs (CapEx). Reuse reduces the total cost of ownership by supplying future systems. Furthermore, the CO_2 footprint of recycled precious metals is up to 98 percent lower compared to primary materials [2].

Recycling of non-precious metal components, such as titanium, steel, or aluminum, also contributes to reducing the total cost of ownership, even if the material value is lower. A higher value is created when it is possible to reuse them, but many questions still remain unanswered.

ESTABLISHMENT OF STRUCTURES AND PROCESSES

To establish a sustainable and efficient hydrogen economy, efficient and economically viable structures and processes are needed. In principle, the recycling value chain can be divided into four major areas: return structure, processing & pre-treatment, recycling & refining and reutilization. The benefits of the circular economy can only unfold when all four components of the value chain are effectively designed, organized and implemented.

STEP 1: RETURN STRUCTURE

The return structure includes the processes and infrastructure required to return electrolyzers and fuel cells at the end of their life cycle. This involves collection, logistics, and also the tracking of materials. It is essential to develop a clear concept here before the materials enter circulation. Once they are lost sight of, it becomes difficult to ensure widespread return.

A central issue here is the uncertainty about how the recycling infrastructure will develop in the future. Who should be responsible and accountable for the return? The manufacturer? The operator? The recycler? To avoid missing the opportunity to regulate in a timely manner, close collaboration along the entire value chain and supporting regulatory requirements are needed.

STEP 2: PROCESSING AND PRE-TREATMENT

Once the stacks have been successfully collected, the next step is to process and pre-treat them. This is essential because a good yield for the materials can only be achieved if they are as homogeneous as possible before recycling.

Science and industry are still searching for the best method for the efficient and scalable separation of materials. One option is disassembly. In this approach, the stack is dismantled and broken down into components, specifically those for which processes already exist. For instance, the MEA (membrane electrode assembly) has been processed in existing recycling and refining processes at Heraeus Precious Metals for more than ten years.

However, this approach is associated with a high procedural effort and is limited in terms of scaling. Therefore, methods for automated or semi-automated disassembly are being considered, similar to those already widely used in traction batteries from electric vehicles.

In particular, for fuel cells, there is also the option to crush them as a whole using industrial shredding facilities. However, the resulting material mixture must then be separated in downstream separation and sorting processes, requiring careful attention. The by far most valuable components are the fragments which are destined for precious metal recycling. When separating and sorting these, certain impurities that would lead to more complex treatment or poor yields should be removed.

Therefore, pre-treatment and subsequent recycling steps are ideally carried out by a single source.

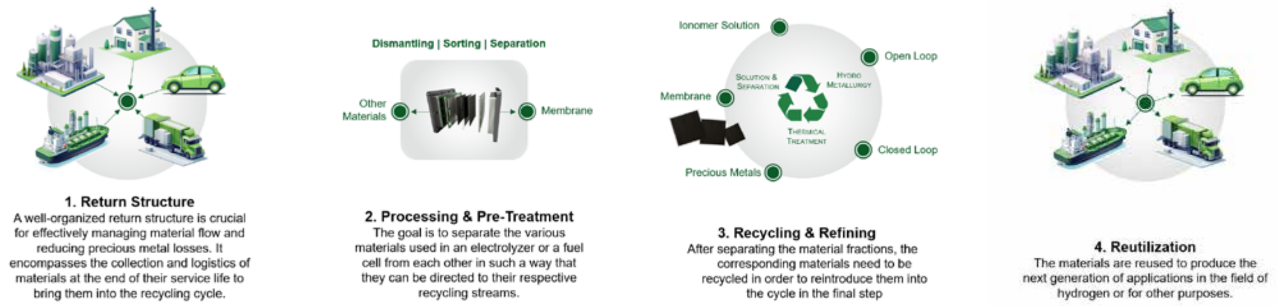

Fig. 3: Various steps of a circular economy [Source: Heraeus]

CHALLENGES FOR PRE-TREATMENT Overall, many questions remain unanswered. A major challenge is posed by the different designs of the stacks, particularly with regard to the automation mentioned. Agreement on standards and consideration of the entire life cycle, including recycling, already in the design, would significantly contribute to the solution. For example, a screw connection is easier to detach than an adhesive surface or a weld seam. Manufacturers, policymakers, and associations should address this issue.

Furthermore, the different components enter very different post-processing streams with very different requirements. With precious metals and membranes, (raw) materials are recovered, while for other components such as bipolar plates, a possible reuse of the component itself is on the table. Such functional recycling goes far beyond material value. Currently, it is not yet clear what is possible and economically feasible. This also leads to a lack of requirements for reutilization, which could serve to adjust the disassembly processes so that the components are not damaged and reuse remains realistic.

STEP 3: RECYCLING & REFINING

For precious metals, well-established processes have existed for decades to recover the valuable material. Initially, the material is thermally treated to remove non-metallic residues and the water. Subsequently, the material is carefully homogenized, and a representative sample for material analysis is drawn before further processing. This sample serves to analytically determine the precious metal content of the material and forms the basis for the calculation of the amount of precious metal that will be compensated. In hydrometallurgy and refining, the precious metal is then recovered and highly purified.

Materials from the hydrogen economy are some of the more demanding materials in precious metal recycling. Iridium is chemically challenging, and the thermal treatment of fluorinated membranes requires special care in the safe post-treatment of emissions. Precious metal specialist Heraeus Precious Metals is one of the few companies that can efficiently process these material streams for its customers. Iridium has been processed on a tonne scale for years, and significant investments have been made in the necessary facilities for the hydrogen economy.

SPECIAL PROCESSES FOR SPECIAL MATERIALS For the ionomer membranes, there is another possibility. Ionomers are special fluoropolymers that, due to their unique properties, significantly contribute to the functionality of fuel cells and PEM electrolyzers. They are complex to manufacture and therefore expensive. In addition, their handling after end-of-life is currently the subject of controversial discussions in the EU due to a proposal to regulate PFAS (per- and polyfluoroalkyl substances). Therefore, increased efforts are being made to find solutions for their reutilization. Work is underway to chemically separate the ionomers from the precious metals and process them separately.

To develop cycles for such demanding materials as fluoropolymers, collaboration among manufacturers, users,

Fig. 4: Platinum-containing material after incineration [Source: Heraeus]

and recyclers is necessary, as demonstrated in the H2Circ funding project of the US Department of Energy: In this consortium, companies along the entire value chain work on the recovery of materials, especially ionomers. [3]

STEP 4: REUTILIZATION

After the recovery process is completed, the material is ready to be reused. This is not a problem for precious metals, as recycling provides high-purity materials according to internationally certified standards, which do not differ in their properties from primary materials.

In contrast, for ionomers, there are neither established recycling processes nor defined requirements for the recyclate. Unlike with precious metals, the recycled material here differs from that produced in primary manufacturing. Therefore, it requires not only the development of recovery processes, but also applications and markets for consumption.

Similar to the functional reuse of components, the ecosystem faces a chicken-and-egg problem here: Before the requirements for the use of the recycled material are clarified, the recycling processes cannot be meaningfully developed, also with regard to a possible business model. This is because only when the value of the output is clear can the costs of the process be calculated to determine if they will be worthwhile.

SETTING THE STAGE FOR THE FUTURE The Hanau-based precious metal company Heraeus Precious Metals systematically employs collaboration. For example, the company works with manufacturers of fluoropolymers to establish closed cycles for ionomers. Heraeus begins considering the value chain, including recycling, in the early stages of development together with its customers. It is also working on developing holistic solutions in public projects such as the aforementioned Department of Energy research project.

Even though the recycling of fuel cells and electrolyzers is currently limited in volume, its importance for the development of the hydrogen economy and the promotion of a circular economy should not be underestimated. Experts anticipate significant amounts of precious metals from the hydrogen economy by the end of this decade. It is important to take advantage of this window of opportunity to develop efficient processes across all parts of the value chain and to build corresponding recycling capacities. •

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Sources:

1. Hydrogen Council, Hydrogen Insights 2023
2. International Platinum Group Metals Association e.V, 2022, The Life Cycle Assessment of Platinum Group Metals (PGMs)
3. American Institute of Chemical Engineers, 2024, AIChE Selected by DOE to Lead New Hydrogen Electrolyzer and Fuel Cell Recycling Consortium
4. H. Stahl et al., Ableitung von Recycling- und Umweltanforderungen und Strategien zur Vermeidung von Versorgungsrisiken bei innovativen Energiespeichern, Umweltbundesamt, 2016
5. Kalkulation durch Heraeus Precios Metals, basierend auf Materialanteilen basierend auf H. Stahl et al., Ableitung von Recycling- und Umweltanforderungen und Strategien zur Vermeidung von Versorgungsrisiken bei innovativen Energiespeichern, Umweltbundesamt, 2016