Securing the ramp-up of PEM electrolysis by thrifting

By **Dr. Christian Gebauer,** Head of R&D Hydrogen Systems at **Heraeus**

Capacities for hydrogen generation by means of PEM electrolysis are skyrocketing, as the world is witnessing an unprecedented momentum behind the formation of a hydrogen economy. Around 70GW capacity of PEM electrolysis has been announced for 2030 and the figure is rising[1].

But will we really be able to produce those gigantic capacities more or less from scratch? One obstacle is the availability of raw materials. All available electrolyser technologies are requiring materials that are scarce, and for PEM EL (Proton Exchange Membrane Water Electrolysis) the most scarce material is iridium.

Will this be a bottleneck for the ramp up? The answer is no, if iridium consumption by PEM electrolysis is further reduced by means of thrifting.

What is the point of iridium thrifting?

Iridium is a very rare metal, and the mining of primary material depends on the mining of platinum. Only about 9 tonnes of iridium are mined annually and used in existing applications.

Assuming that about 1.5 tonnes of iridium can be shifted to the hydrogen economy by using alternative materials in the other already existing application segments and by bringing additional material streams into the recycling loop, in total about 12 tonnes could be made available from 2023-2030.

This amount would not be enough, if we built the planned capacities with the today's typical loadings of in average 400kg/GW. Around 175GW electrolyser capacity are announced until 2030[1] and 40% thereof (70GW) expected to be built with PEM.

With the today typical loadings, cumulative 28 tonnes would be needed, but here is where thrifting comes in play.

There are already solutions available, which need only 100kg/GW, like the Heraeus low-loading catalyst. Thereby only seven tonnes of iridium would be needed until 2030, which is realistic. With other similar catalysts, as well as new material combinations even iridium-loadings below this already impressive number are by now demonstrated.

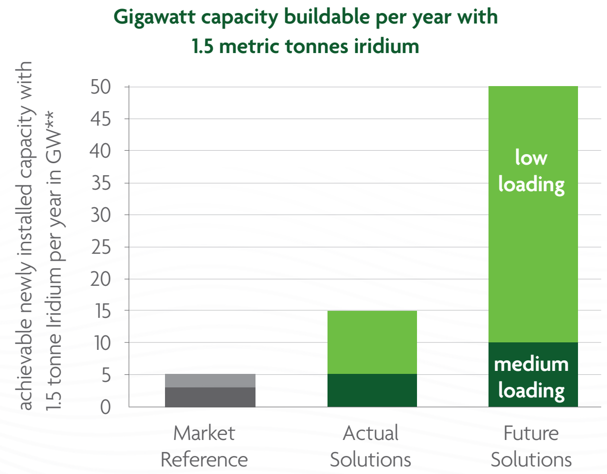
Iridium is no bottleneck for the hydrogen ramp up; we just have to use the available technology.

How does thrifting work?

How do we achieve the same or higher hydrogen output with less material? While there are numerous levers from improved cell design over improving membrane properties to the overall system efficiency and operating conditions, one of the most important levers is the electrocatalyst itself and its application in the electrode.

By fine-tuning the structure, morphology, and composition of iridium-based electrocatalysts, catalytic activity with respect to the oxygen evolution reaction (OER) can be optimised towards lower iridium loadings in the PEM EL anode. Most importantly, maintaining high stability must be guaranteed to ensure a long-term efficient operation of the electrolyser.

Especially for the sake of the latter, first generation catalysts are based on 'Iridium Black', i.e. bulk iridium metal. They show good performance and rather high stability. However, the mismatch in the ratio of iridium on the surface (catalysis is happening only on the surface) versus iridium in the bulk of the catalyst is tremendous and limits the potential savings in iridium use.



* various Ir loadings (45 to 10%) possible
** based on state of the art components

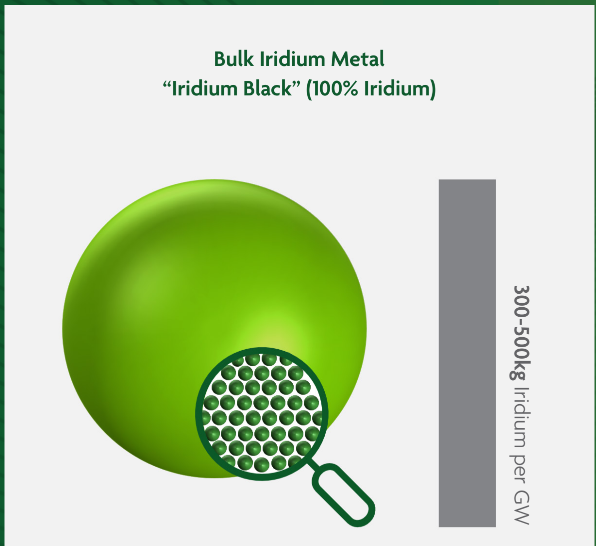
© Heraeus, data-based assumptions

Step 1: From bulk metal to iridium oxide

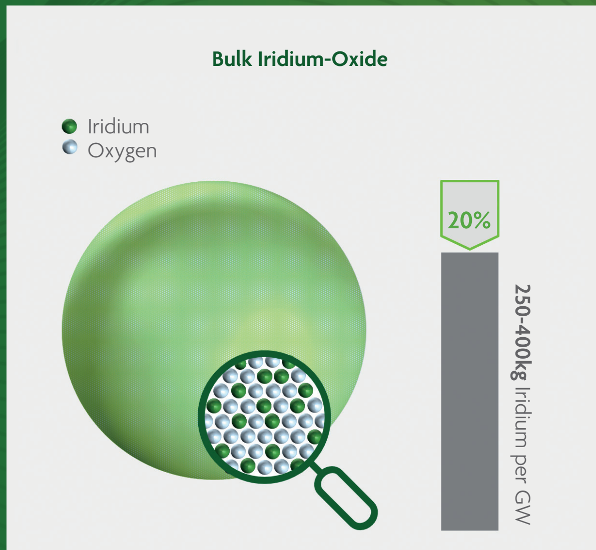
The first improvement, which is well established already today, is working with iridium oxide instead of pure iridium, whereby IrO_2 15% less iridium (based on the total mass of the material) is used. Additional impact factors are the material properties like surface area, chemical state as well as chemical and electrochemical stability. This leads to an even higher saving of iridium in the anode. Here, a minimum of 20% less of this scarce metal can be used to achieve high quality electrode layers while maintaining long-term performance at the level of bulk iridium.

Step 2: Leverage the potential of supported catalysts

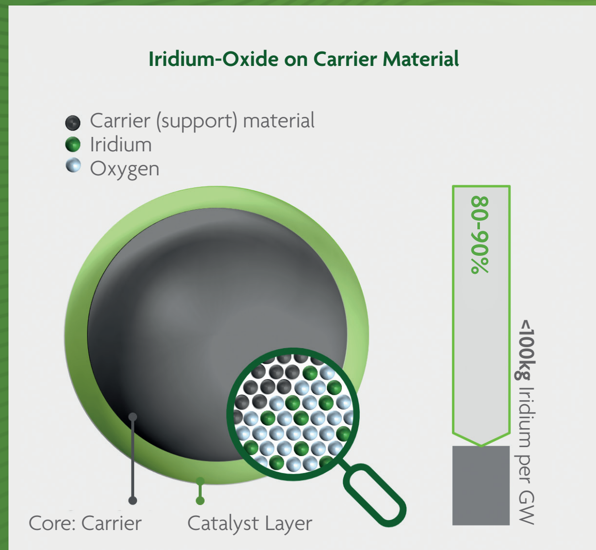
Still the surface to bulk ratio is only slightly improved. With supported catalysts well dispersed iridium-based nanoparticles or iridium-containing layers are placed on a carrier material. The target is to maximise the Iridium mass or atom-based efficiency in the oxygen evolution reaction, i.e. how efficient the catalytic reaction can run per gram of iridium. >>



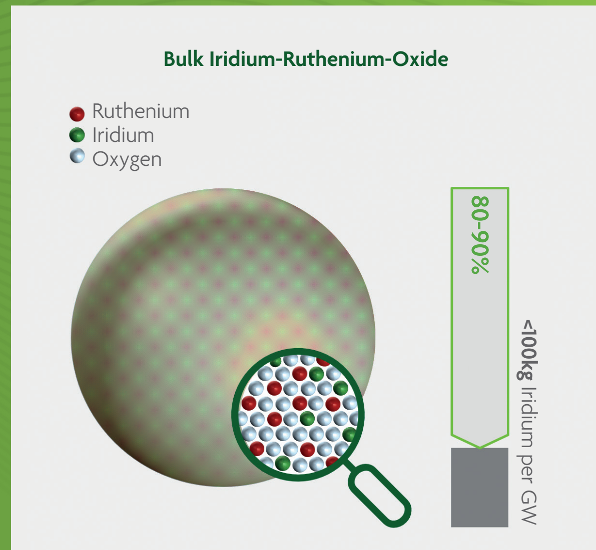
© Heraeus



© Heraeus



© Heraeus



© Heraeus

Various coating and deposition methods are possible and are defining the iridium species and efficiencies as well as the stability. Usually, tremendous increase of activity is often leading at the same time to serious stability issues, especially under harsh conditions as present on the anode of a PEM electrolyser (high oxidation potential and strongly acidic environment).

The Heraeus supported catalyst, developed in the publicly funded Kopernikus P2X project, was specifically designed for the purpose of minimising the amount of iridium while maintaining its stability, and at the same time enabling also a rather low amount of iridium in the electrode – at least 50% less iridium in the electrode can do the job.

A stability study impressively validated the material concept and proved the long-term stability under operation conditions[2]. With a superior performance compared to the benchmark over more than 40,000 operating hours, the Heraeus low-loading next gen materials are well tested for the long-term stability and have proven to fulfil the industrial application requirement.

Step 3: New ways with mixed oxides

A further path in development is to leverage other materials to partially substitute iridium. Ruthenium not only can substitute a significant part of the scarce iridium; it also can increase the material activity. Unfortunately, so far ruthenium alone has failed to bring the necessary long-term stability.

A mutual project of Sibanye-Stillwater and Heraeus strives to solve this challenge. A concept of an oxide, integrating both iridium and ruthenium in the material is showing very promising results in respect to stability.

At the same time the new materials provides the ruthenium induced significantly increased activity at the same low loadings of iridium as described before.

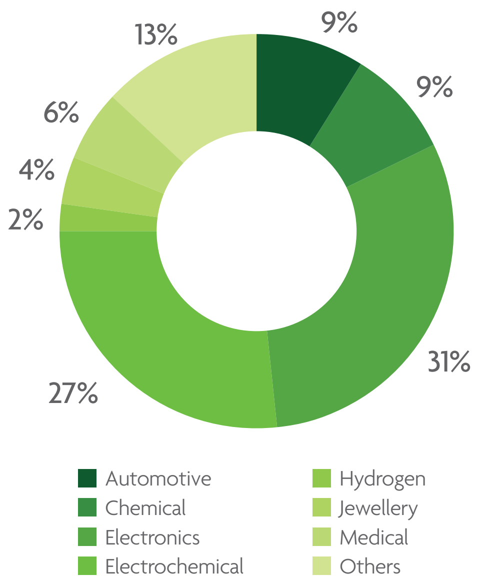
This achievement not only serves as development basis for further optimisations, but also provides an alternative to the supported material, more suitable for other requirements. Thus, the toolset for development and industrial implementation grows.

Bring together all levers for thrifting

Equally important to catalyst optimisation are other stack components, their interplay, as well as the operation mode of an electrolyser system.

In the cell design flow fields and transport layers, especially the so-called PTL – porous transport layer – are optimised to reduce cell resistances and mitigate component degrading input factors in the whole system. An even stronger lever is the membrane, which can significantly reduce the cell resistance by applying an operation-optimised membrane thickness.

Demand for Iridium in 2021 per Segment



© SFA (Oxford) Ltd

> "...the Heraeus low-loading next gen materials are well tested for the long-term stability and have proven to fulfil the industrial application requirement"

By working on these levers, researchers and industry experts collectively work towards minimising the impact of iridium PEM electrolysers.

The combined optimisation of catalysts, stack design, balance of plant components, operating conditions, and recycling methods paves the way for more cost-effective and sustainable hydrogen production. The journey has just begun and has still a lot of potential.

So the prerequisites for the ramp-up are very good. Scarce raw materials need a strategy, but the technological solutions are not only readily available but also well tested to bring the needed stability already today.

If we use the different levers of thrifting, iridium will not be a bottleneck to the energy transition. H2V

References

1. McKinsey & the Hydrogen Council
2. Möckl et al. JECS 2022