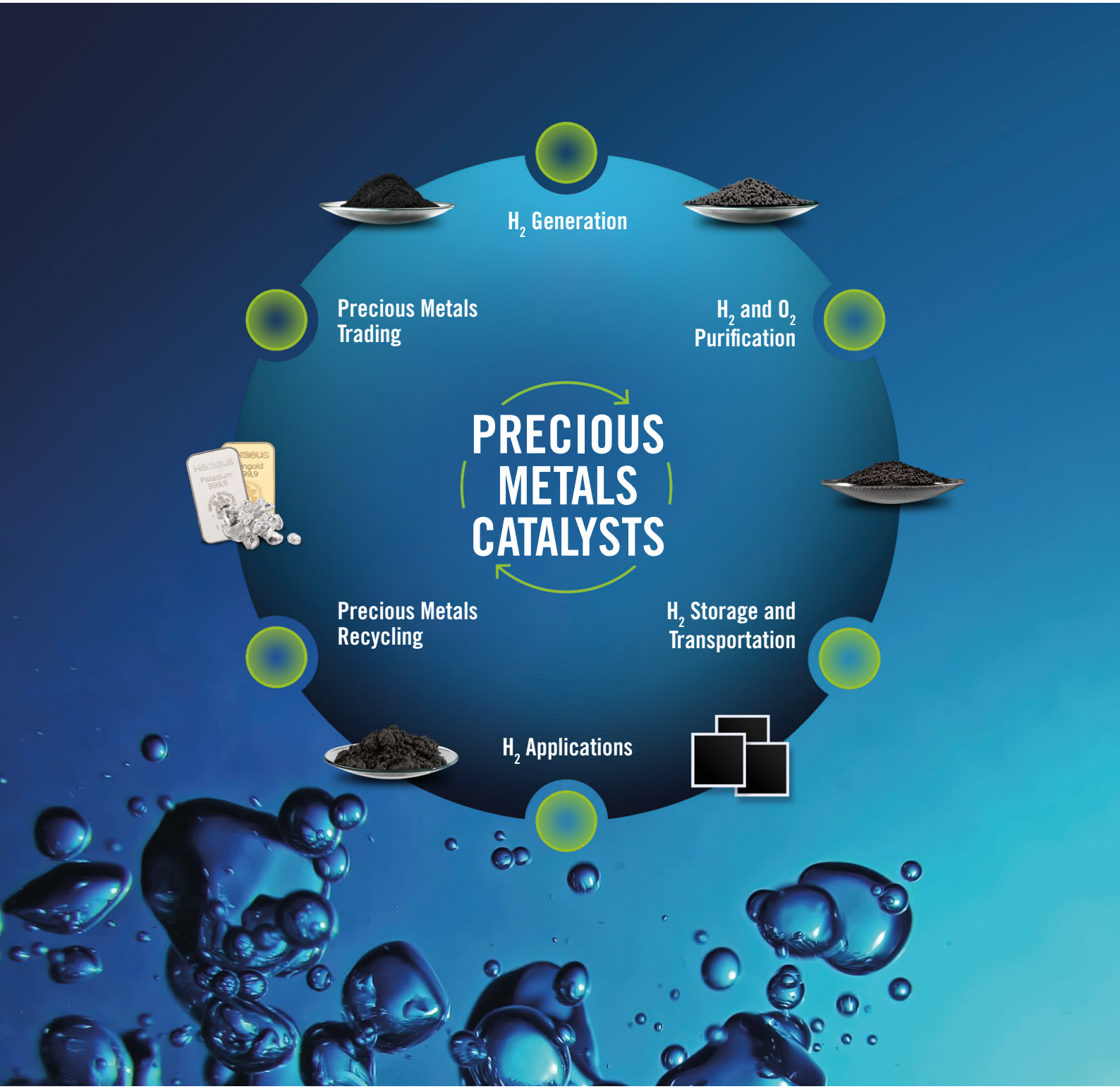


Catalyzing the Hydrogen Revolution

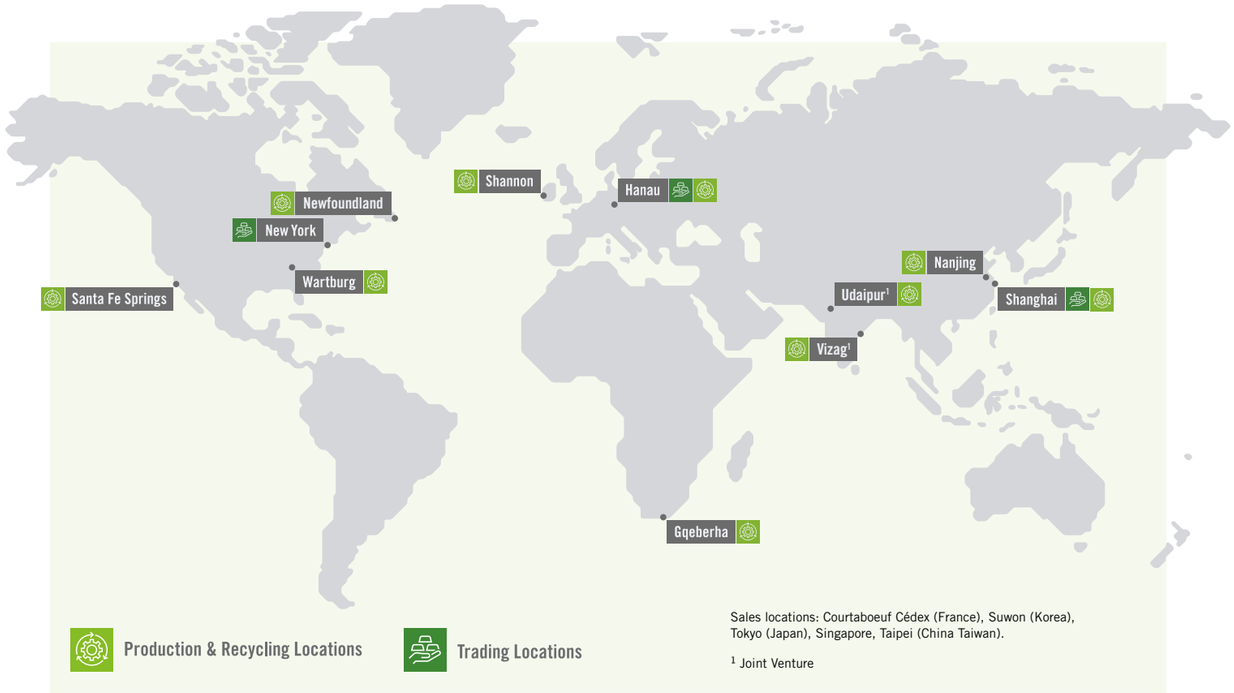
Heraeus Precious Metals
A tradition of innovation

In 1856 Wilhelm Carl Heraeus, a pharmacist and chemist, **was the first to melt platinum on an industrial scale**. The revolutionary process brought with it a new era in the precious metal industry and laid the foundation of the present Heraeus Group.

Heraeus Precious Metals is **one of the world's leading players in the precious metals industry.** As part of the Heraeus Group, the company covers the value chain **from trading to precious metals products to refining and recycling.** It has extensive expertise in all platinum group metals as well as gold and silver.

With about **2,500 employees at 11 sites worldwide**, Heraeus Precious Metals offers a broad portfolio of products that are essential for many industries such as the automotive, chemicals, semiconductor, aerospace, pharmaceutical and hydrogen industry.

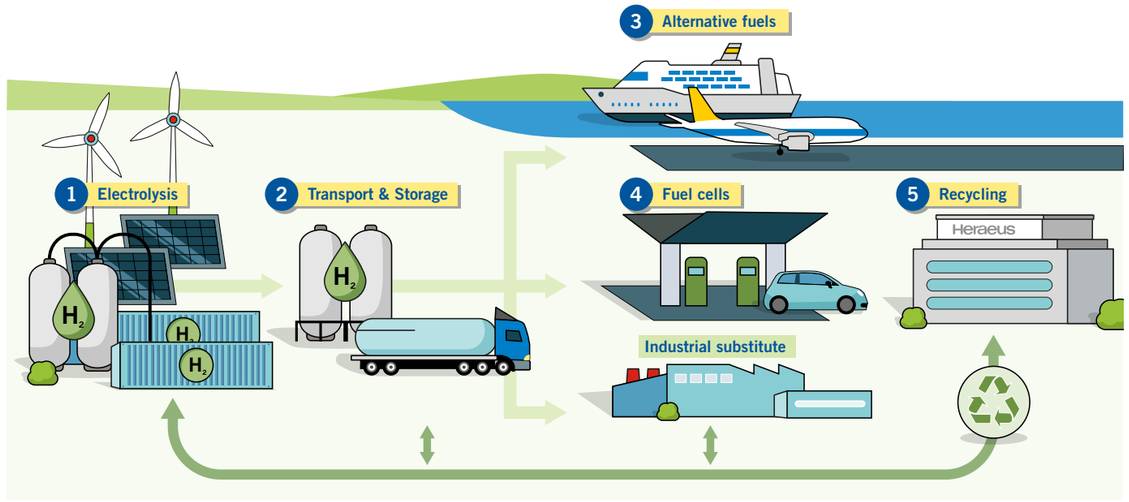
From the company's humble beginnings in Hanau, Germany to its strong global footprint today, Heraeus is guided by a single purpose: to **continually strive to improve the businesses of every customer we serve**.



Sales locations: Courtaboeuf Cédex (France), Suwon (Korea), Tokyo (Japan), Singapore, Taipei (China Taiwan).

[1] Joint Venture

The Hydrogen Economy
Precious metals support key steps



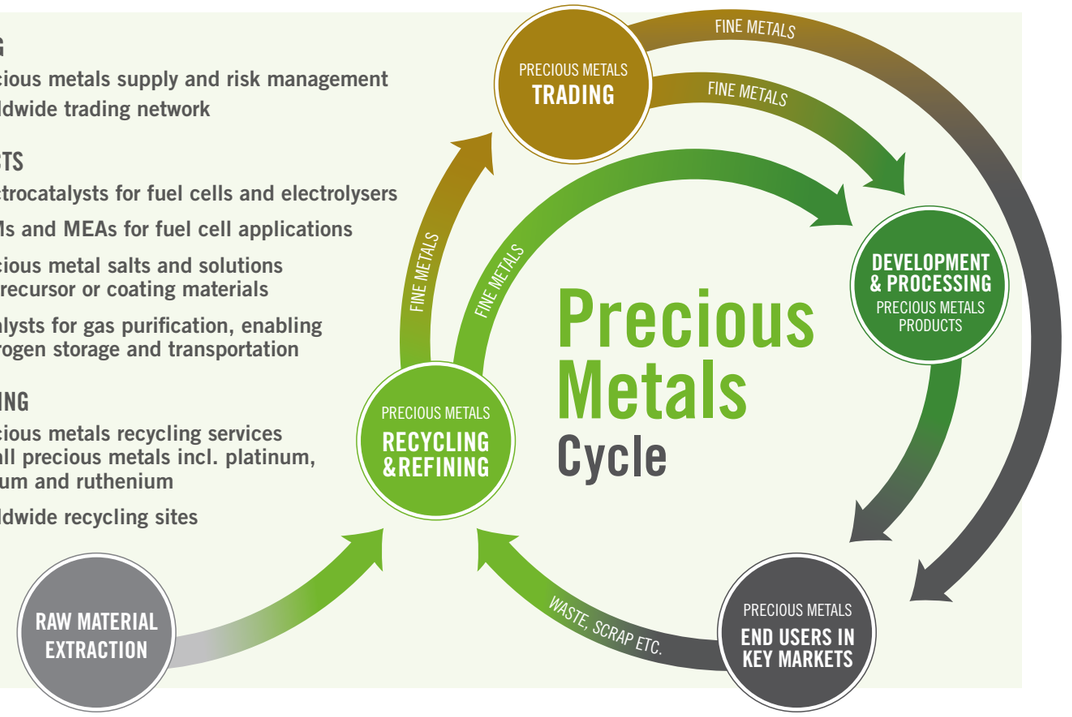
Precious metals support the hydrogen value chain in many ways: from production via electrolysis (1) and purification, through transport and storage (2), industrial application, for example for the production of alternative fuels (3), and transport-related use as an energy source for fuel cells (4), to precious metal recycling (5).

The Heraeus Precious Metals offer for the Hydrogen Economy

TRADING
- Precious metals supply and risk management
- Worldwide trading network

PRODUCTS
- Electrocatalysts for fuel cells and electrolysers
- CCMs and MEAs for fuel cell applications
- Precious metal salts and solutions as precursor or coating materials
- Catalysts for gas purification, enabling hydrogen storage and transportation

RECYCLING
- Precious metals recycling services for all precious metals incl. platinum, iridium and ruthenium
- Worldwide recycling sites



Precious Metals Trading
Available across the globe, offering customized solutions

With three trading desks around the world, Heraeus can make precious metals available wherever needed:

Precious metals are scarce and valuable, and their prices volatile: real expertise is needed to deal with them. This is even more important for dynamic markets like hydrogen, with a rapidly growing demand for critical raw materials.

Partnerships with mines to secure precious metals supply

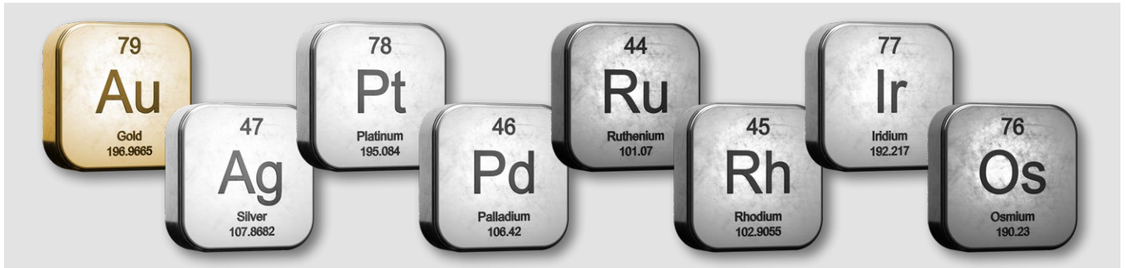
Comprehensive trading services covering all time zones

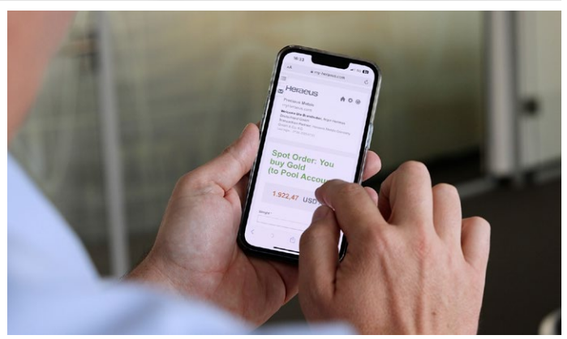
Flexible pricing / hedging options and advanced financing models

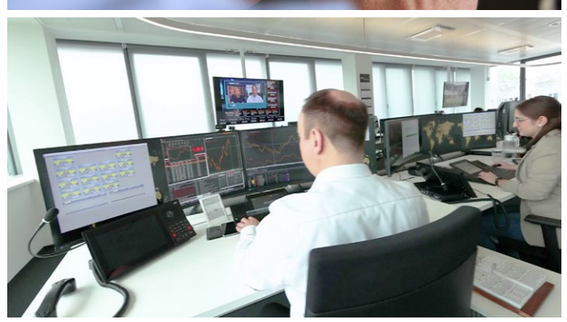
Pool Account Management

Physical Supply as LBMA / LPPM approved supplier

Digital real-time access to your assets







Recycling & Refining of Precious Metals:
Actydon | Loop: Circularity for the hydrogen economy

Depending on the metal, the industry average emission factor of secondary platinum group metals (PGMs) are 98.2% to 98.8% lower than those of primary PGMs.*

Heraeus is a specialist in the recovery and recycling of precious metals. With worldwide sites, capacity and capabilities are available to handle complex materials, including the waste streams of the hydrogen economy.

But Actydon | Loop intends to go beyond the recovery of precious metals, as the stack contains further valuable and reusable materials, such as the ionomer used in the membrane. Heraeus is therefore developing solutions to offer the recovery of ionomers as well as taking in complete stacks, separating re-usable components.

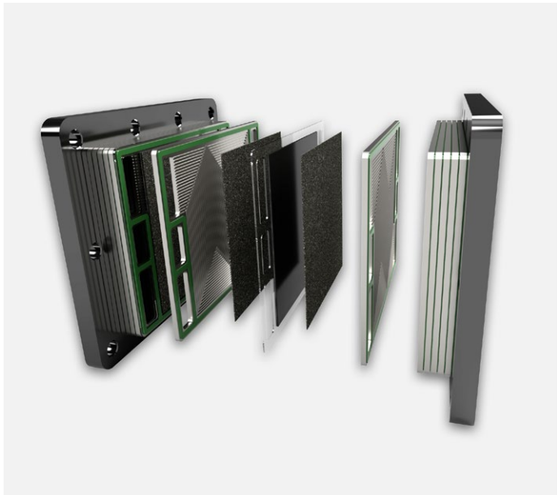
* Comparisons are based on data from International Platinum Group Metals Association, “The Life Cycle Assessment of Platinum Group Metals”, 2025 (reference year 2022).

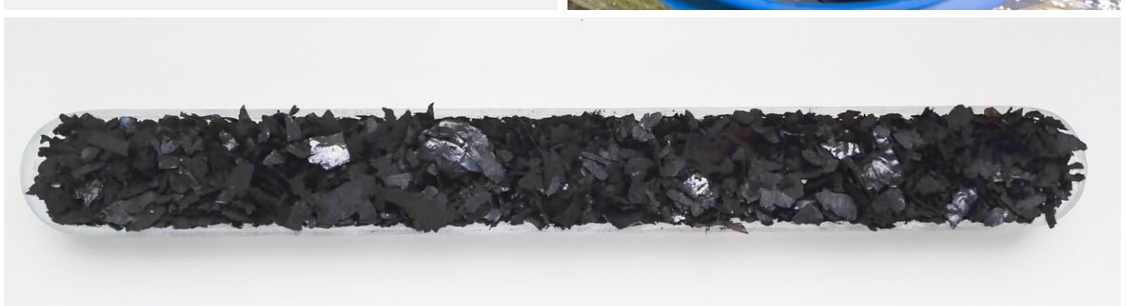
Supporting the hydrogen economy

With the ramp-up of the hydrogen economy, the demand for the recycling of important metals like platinum, iridium or ruthenium from production scrap as well as end-of-life materials will rise.

Already today, Heraeus recycles precious metals in the fuel cell and electrolyzer sector with high precious metal return rates by processing end-of-life materials as well and production scraps and productions wastes, like inks and pastes. Transparent and auditable sampling processes can be witnessed by you or a designated representative.

Recycling will help to secure the supply of scarce precious metals. Equally important, it maintains your investments in precious metals for future projects. With an increase in PEM electrolyzer capacities, the amount of end-of-life material will increase and Heraeus is already prepared for this GW-scale.





Hydrogen Generation
PEM water electrolysis

PEM electrolysis will play a **pivotal role** in producing **Green Hydrogen** from fluctuating renewable energy sources. At the same time, the **cost-efficient production** of Green Hydrogen on an industrial scale will be an important component in enabling industries to reduce their greenhouse gas emissions.

Heraeus **electrolyzer catalysts** enable a **decrease in iridium content** while **increasing efficiency** and performance. The comprehensive product portfolio includes **Iridium Black, Iridium Oxide**, and **novel solutions** with low iridium content such as supported catalyst or mixed oxides.

They deliver the benefits needed in the important areas for efficient electrolyzer operation and to scale-up of electrolyzer production:

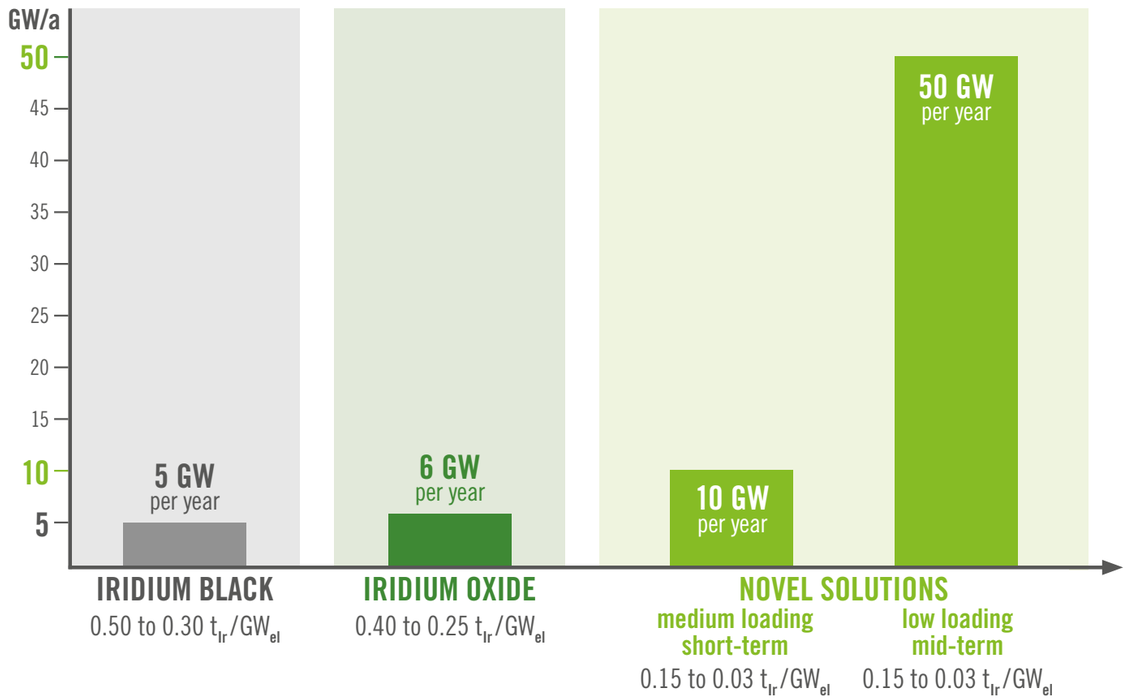
ACTIVITY - Several catalyst concepts available to increase performance and reduce costs.

STABILITY - With stability comes reliability; these catalysts will contribute to a high lifetime in your application.

IRIDIUM SAVING - Ideal for large-scale application due to significant savings in precious metal content.

ELECTRODE AREA SAVING - Strong decrease in capital expenditure due to iridium and catalyst material savings.

Maximum new electrolyzer capacity (GW) for 1.5 t iridium availability per year



Fuel Cells
Catalysts with different precious metal loadings

Fuel Cells are becoming more prominent in energy generation **for mobility or stationary applications** using **Green Hydrogen** from renewable energy sources. PEM fuel cell technology will have a **significant impact on the integration** of Green Hydrogen.

You **benefit from an extensive portfolio** of precious metal services which increases the planning reliability of your business. Achieve higher margins and focus on your core business by trusting the leading precious metal experts.

Heraeus' fuel cell catalysts provide dedicated solutions for PEM fuel cells addressing the various requirements of anode and cathode. Complementing this, Heraeus also offers CCMs and MEAs tailored for PEM fuel cell applications:

ACTIVITY – Efficient use of platinum in different catalyst concepts helps to gain high performance performance.

STABILITY – Achieve long lifetime for your application by using catalyst designed for best stability and reliability.

CELL REVERSAL TOLERANCE – This feature protects the anode by reducing damage over time.

Most suitable applications

The increasing use of fuel cell as a power source in all those applications and the increasing demand for fuel cell production capacity makes a strong supply chain partner paramount for your success.

Heraeus delivers as **your partner** for the **future up-scaling of this business**, serving as a fully industrialized catalyst producer and precious metal supplier.

Heraeus fuel cell catalysts can be used in a variety of applications:

Aviation · Drones · Marine vessels · Rail transportation · Heavy duty vehicles · Passenger vehicles · MHV · Stationary

Electrocatalysts for Electrochemical Applications
Beyond low temperature PEM electrolyzer and fuel cell

Precious metals offer **significant advantages** in technologies also other than PEM electrolyzers and fuel cells. In many applications the use of precious metals **can improve operating efficiency** and lifetime. Precious metals are used simply because it pays off.

Heraeus offers precious metal catalysts suitable for the use in **AEM water electolyzers, Direct Methanol Fuel Cells** and **High-Temperature PEM Fuel Cells** and also precursors for **electrode coatings** in the alkaline water electrolyzer technology. Choose from a diverse portfolio of tailor-made solutions for the growth of your specific application and benefit from the proven track record in materials and upscaling.

Optimizing an electrolyzer or a fuel cell system is not only about catalyst efficiency. **Precursors for coating** of stack components, such as **bipolar plates** or **PTLs help to achieve** optimal performance and durability.

Also, the interplay of all stack components and its operation conditions affect the efficiency of electrolyzer and fuel cell systems. Heraeus provides the material solutions to optimize your stack and balance of plant components.

System Integration of Solid Oxide Cells: The Critical Role of BoP Components

Solid oxide cells (SOCs) in particular offer enhanced efficiency and unique feedstock flexibility, making them ideal for integrated energy and chemical systems. Operating at elevated temperatures, **SOFCs** enable the direct use of different fuels such as methane, ammonia, methanol, or hydrogen, while **SOECs** cannot only produce hydrogen but allow direct routes to syngas or synthetic fuels.

However, transforming a single **solid oxide cell (SOC)** into a fully functional system involves substantial complexity. At the heart of this challenge lie the **balance-of-plant (BoP)** components – including **catalysts, absorbents, and functionalized hardware** such as heat exchangers. These components directly impact system efficiency, lifetime, and cost. Selecting the right components—and tailoring them to specific process conditions—is essential for achieving technical and economic viability.

Heraeus Precious Metals and Hulteberg Chemistry & Engineering are **jointly developing and commercializing** a portfolio of advanced catalysts and functional materials for fuel processing specifically designed to meet the demanding conditions of high-temperature SOC operation.

The portfolio consists of catalysts for the

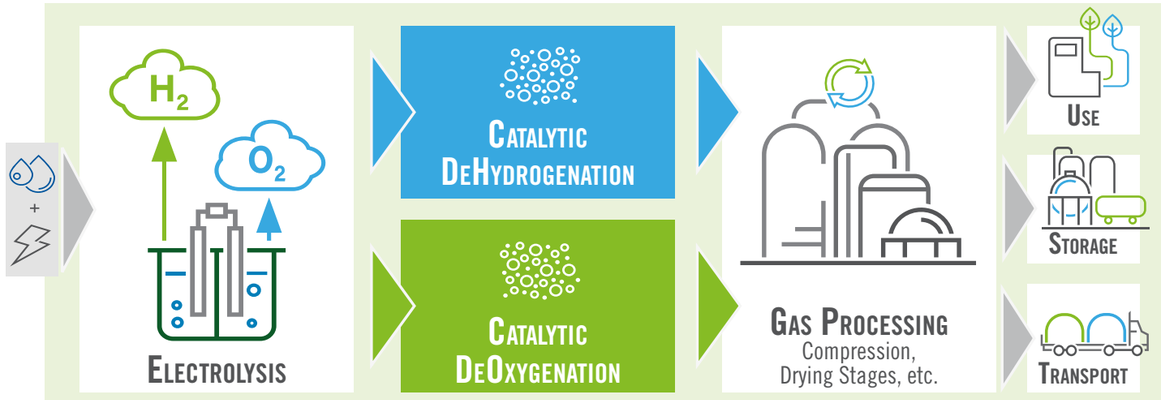
- targeted pre-reforming of hydrocarbons and alternate fuels
- generation of syngas (H_2/CO) via reforming or catalytic partial oxidation (CPOX)
- purification of syngas via the water-gas shift reaction (WGS)
- preferential oxidation (PROX) and selective methanation reactions to yield pure hydrogen (H_2)
- reverse water-gas shift (rWGS), methanation or Fischer-Tropsch (FT) processes for Carbon Capture and PtX
- absorbents and getter materials
- tail-gas combustion

Hydrogen Purification
Safely process, transport and use the gases

While electrolysis is an efficient method for producing hydrogen, the **separation of gases** is not perfect, resulting in a **small amount of slip** at the ppm level of **one gas into the other**, for example, O_2 in the H_2 stream and vice versa. In order to safely process, transport, and utilize the gases, these **impurities need to be removed**.

Since decades, Heraeus' HeraPur® gas purification catalysts have **reliably fulfilled** the task of **removing O_2 from H_2 streams** by converting it to H_2O – operating at **low temperatures** and with an **efficient use** of the applied Platinum Group Metals (PGM).

With the emergence of new electrolysis technologies and applications, a **new generation of deoxygenation and high-performance dehydrogenation catalysts** has been developed.



No matter which method is used to generate hydrogen:
it is always followed by a purification process which is enabled by precious metals catalysts.

Heraeus catalyst portfolio offers the **efficient solutions** to meet your **purification requirements**. Gas purification catalysts are available with **different active metal combinations and loadings**. The **various geometries of catalyst** provide the possibilities and flexibilities to align your purification system.

For hydrogen or oxygen sources other than electrolysis, various impurities may apply. These challenges can be tackled by a **tailor-made proven catalyst** from the Heraeus toolkit.

Storage, Transportation and Recovery of Hydrogen
Ammonia, LOHC, methanation and Biogas upgrading

The direct **storage of hydrogen** requires significant amounts of energy for compression and/or liquefaction. With the rise of the hydrogen economy, better and easier manageable **hydrogen carriers** are needed.

Ammonia synthesis

Ammonia is considered as an excellent possibility to **store hydrogen**, as it can be stored in liquid form in simple pressure vessels at approximately 8 bar akin to natural gas. Most commonly, ammonia is produced via the Haber-Bosch process where hydrogen reacts with nitrogen in an energy intensive catalytic reaction. By using novel **ruthenium-based catalysts**, ammonia synthesis is feasible even on small scale and decentrally, and with less required energy.

Ammonia cracking

Hydrogen can be released from ammonia through **ammonia cracking** for industrial processes, for ammonia combustion engines or for use in a fuel cell. **Catalysts containing ruthenium** provide high activity already at low operating temperatures. The robustness and low poison sensitivity are key characteristics of the catalyst that enable them to withstand dynamic operating conditions.

Emission control and boil-off management

Hydrogen and the various hydrogen storage media can be **used in a fuel** cell or also as a **direct energy source**, simply by combusting it. The later has the advantage that also existing infrastructure can be used. But also here the exhaust gas must be cleaned from hazardous emissions - unburned fuels or byproducts such as N_2O must be removed by **gas purification or emission catalysts**. Further any hydrogen if vented from liquid hydrogen fuel systems must be abated for environmental and health and safety reasons. **Boil-off catalysts** are an important safety measure. In each case platinum / palladium catalysts provide an efficient solution.

Methanation

The Power-to-X (PtX) concept of methanation to **Synthetic Natural Gas (SNG)** uses hydrogen from electrolysis combined with captured carbon dioxide to produce methane via a **catalytic methanation process.** This SNG can be injected into the existing natural gas grid or used as fuel directly. The process enables long-term energy storage and sector coupling. If the SNG is produced is used by renewable energy sources, it supports of energy, transport and industrial sectors. **Base metals or ruthenium-based catalysts** play an important part here.

Biogas upgrading

An alternate root to Methane for injection into the gas grid is via **upgrading of raw biogas**. In combination with the separation of CO_2 and the absorption of contaminants such as H_2S, **catalytic oxygen removal** plays a decisive role in obtaining gas with the required quality of near-pure biomethane. **Platinum and palladium catalysts** fulfill this task efficiently at low temperatures.

LOHCs

Liquid Organic Hydrogen Carrier (LOHC) can be stored or transported at ambient conditions, very similarly to petrol or diesel. The hydrogenation of the LOHCs substrate as well as the dehydrogenation to then release the hydrogen require an efficient and selective catalyst. **Heterogeneous catalysts** in these applications are typically based on platinum, ruthenium or palladium, combined with various catalyst support. These catalysts must be tailored specifically for the respective LOHC molecule and process to deliver optimal performance.

Precious Metal Catalysts and the Hydrogen Economy

Renewable Energy

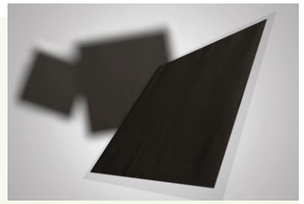
H_2 Generation

Distribution & Transport
Hydrogen Carriers

Applications

Heraeus Products & Services

Precious Metals Catalysts and Precursors for ...

... Water Splitting	... H_2 Transport and Storage	... H_2 Utilization
		
Pt Platinum · Ir Iridium · Ru Ruthenium	Pt Platinum · Pd Palladium · Ru Ruthenium	Pt Platinum · Pd Palladium · Ir Iridium · Rh Rhodium · Ru Ruthenium
▪ Electrocatalysts for the **Water Electrolysis**: H_2 & O_2 Generation ▪ O_2-removal Catalysts for the **Purification of Hydrogen** ▪ H_2-removal Catalysts for the **Purification of Oxygen**	▪ **Ammonia** – Synthesis, Oxidation, Cracking & Emission Abatement from NH_3 Fuel ▪ **Methanol** – CCU of CO_2 ▪ **Synthetic Natural Gas** – Methanation of CO_2 ▪ **LOHC** – Hydrogenation & Dehydrogenation	▪ **Electrocatalysts** for PEM-FC ▪ **CCMs and MEAs** for PEM-FC ▪ Solutions for **Component Plating** ▪ **Gas Purification Catalysts** (WGS, PROX,...) ▪ **Reforming** Catalysts & Coatings for SOFCs ▪ Catalyst for **Gas Sensors** ▪ Catalysts for **Off-Gas Burners** ▪ **And more**...

Precious Metals Management

Precious Metals Recycling

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