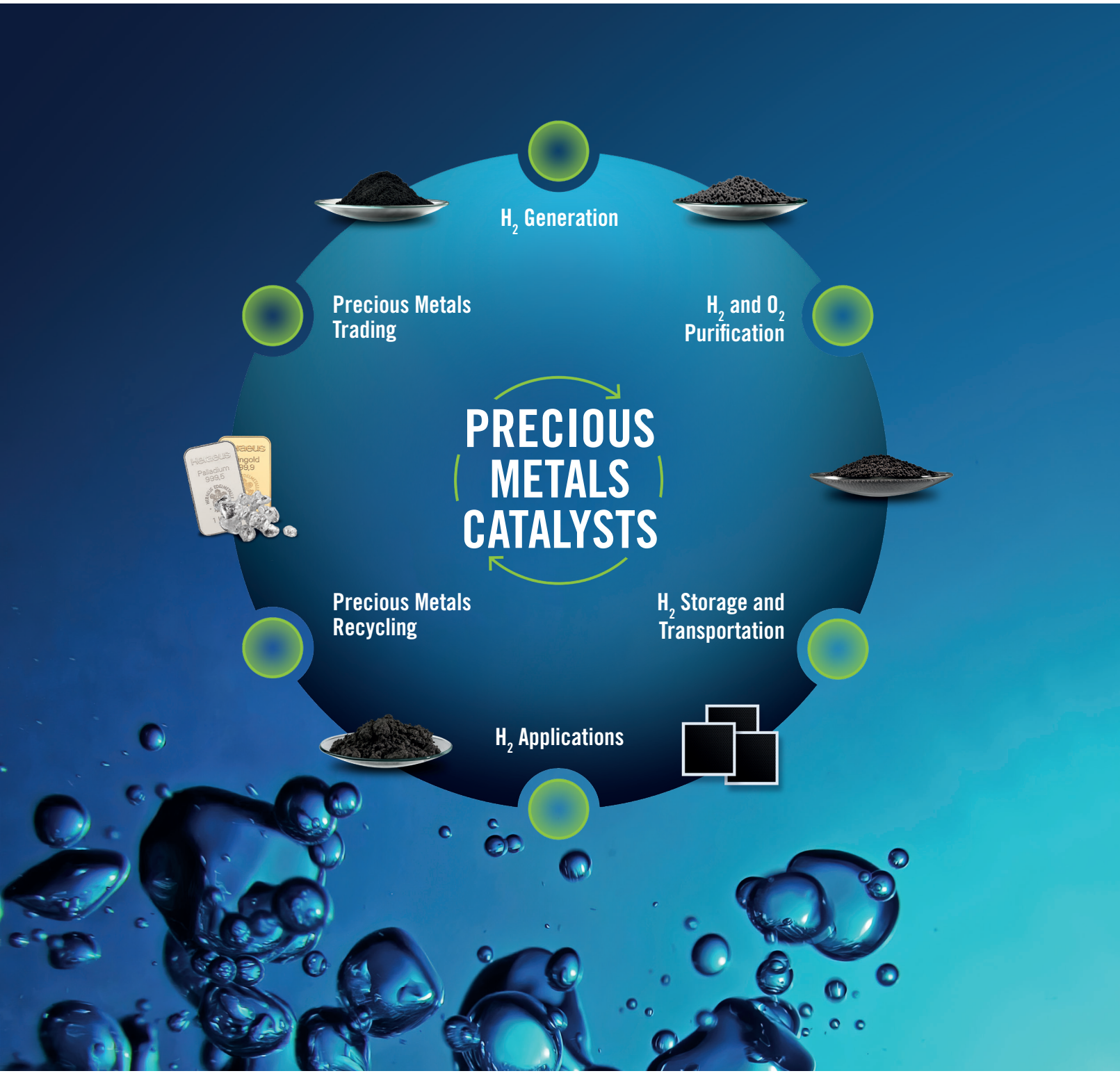


Catalyzing the Hydrogen Revolution

Heraeus Precious Metals
A tradition of innovation

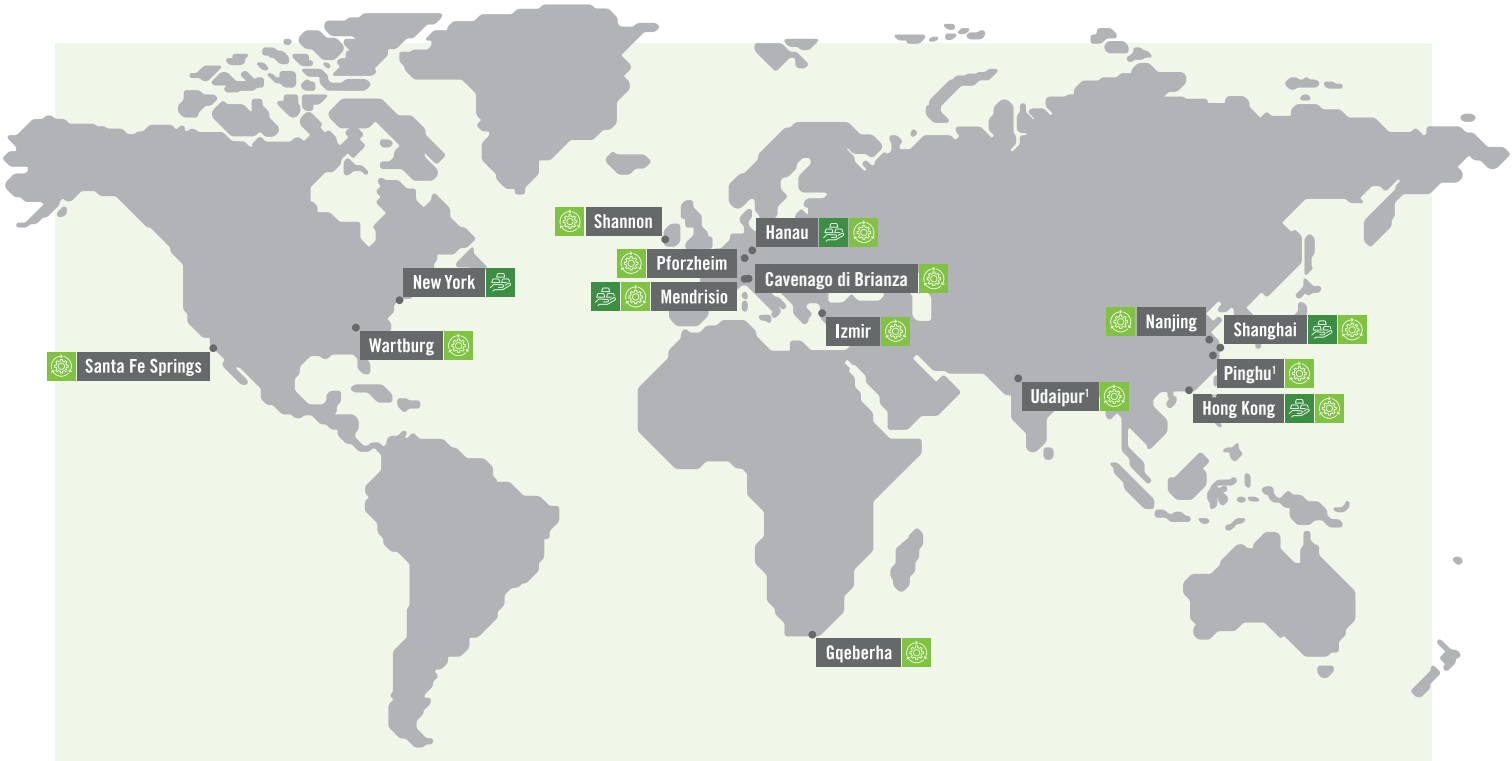
In 1856 Wilhelm Carl Heraeus, a pharmacist and chemist, **was the first to melt platinum on an industrial scale**. The revolutionary process brought with it a new era in the precious metal industry and laid the foundation of the present Heraeus Group.

Today, Heraeus Precious Metals is **globally leading in the precious metals industry**. The company is part of the Heraeus Group and covers the value chain **from trading to precious metals products to recycling**. It has extensive expertise in all platinum group metals as well as gold and silver.

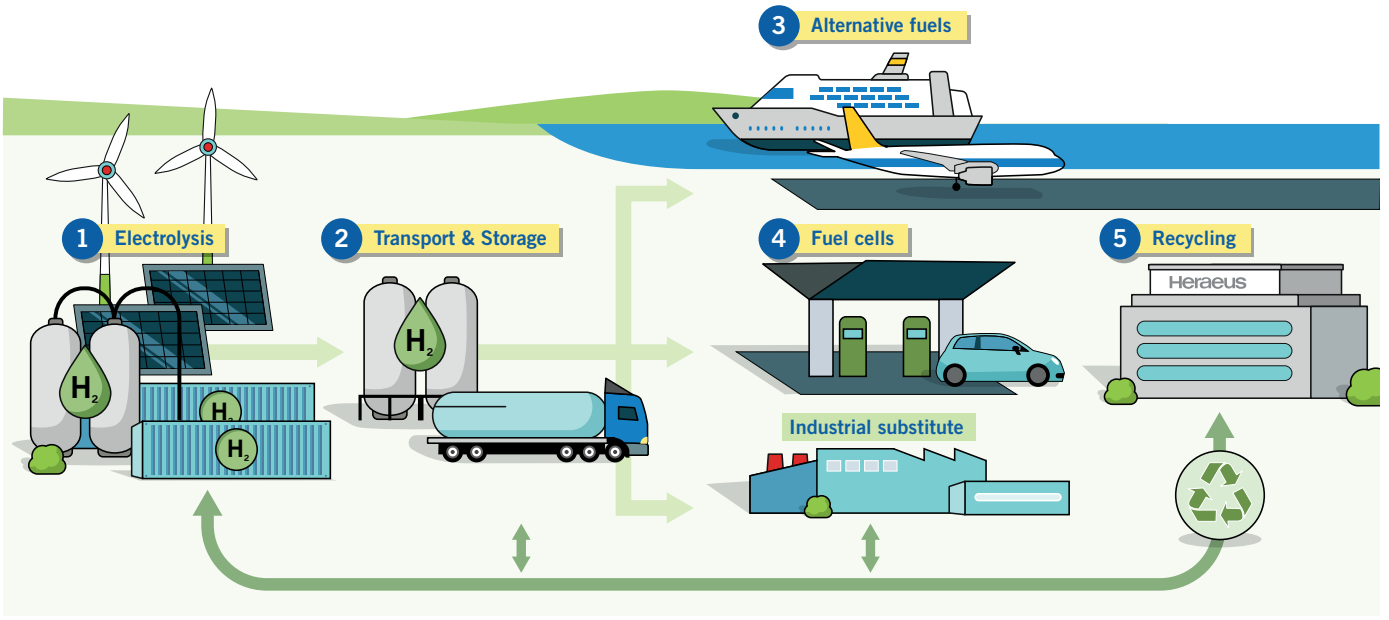
With about **3,000 employees** at **15 sites worldwide**, Heraeus Precious Metals offers a broad portfolio of products that are essential for many industries such as the automotive, chemicals, semiconductor, pharmaceutical, hydrogen and jewelry industry.

By 2025 Heraeus Precious Metals will be **the first company in the industry that operates carbon neutral**.

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**.



The Hydrogen Economy
Precious metals support every step



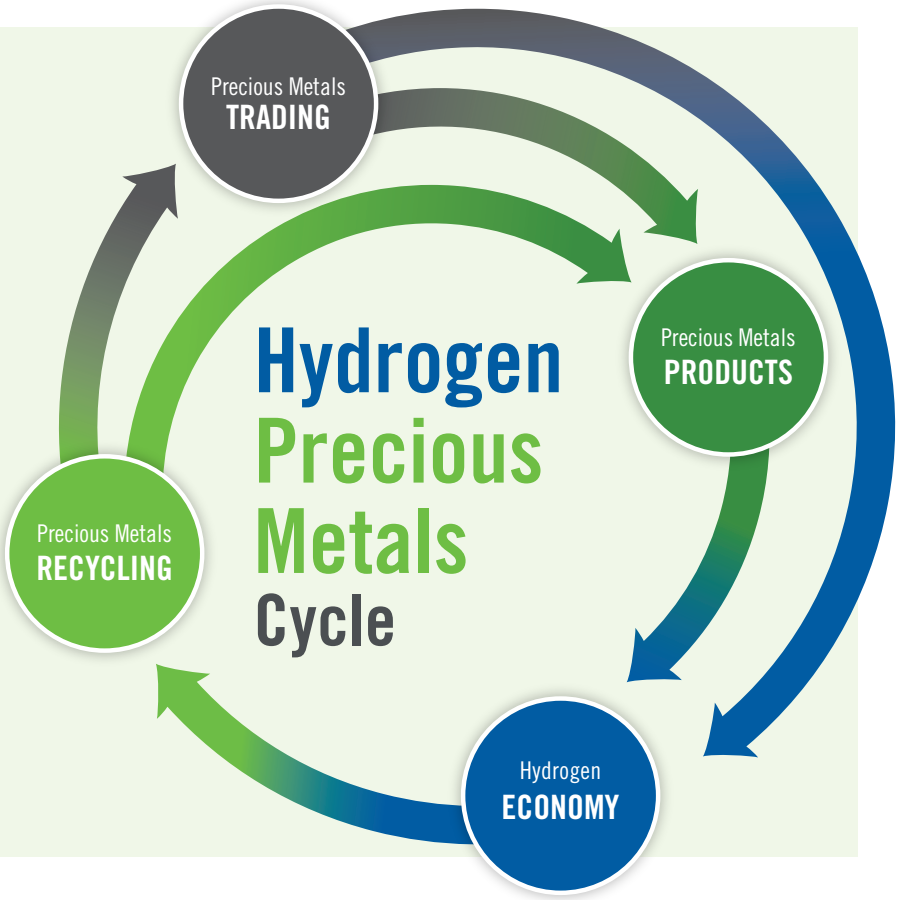
Heraeus supports the hydrogen value chain in many ways: from production via electrolysis (1) and purification, through transport and storage (2), industrial application, for example for the production of alternative fuels (3), and transport-related use as an energy source for fuel cells (4), to precious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

The Heraeus Precious Metals offer for the Hydrogen Economy

TRADING
- Sustainable precious metals supply and risk management
- Worldwide trading network

PRODUCTS
- Electrocatalysts for applications in electrolysis and fuel cells
- 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 five 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

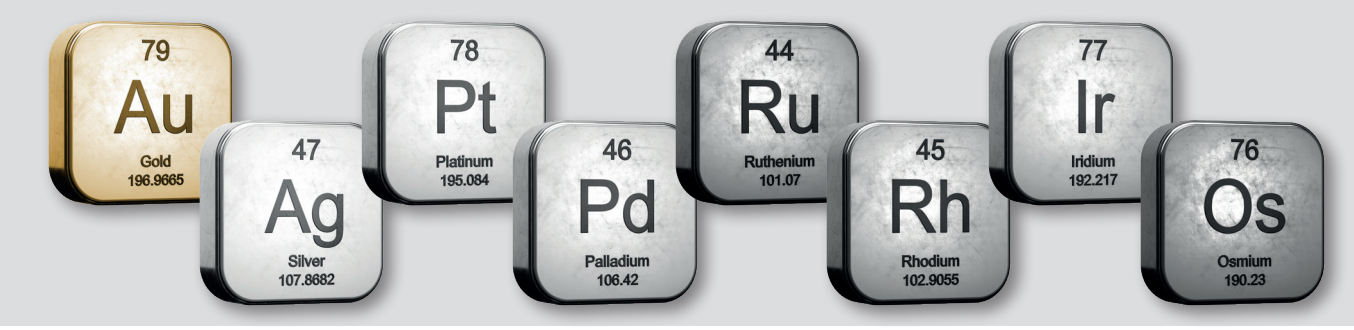
Comprehensive trading services covering all time zones

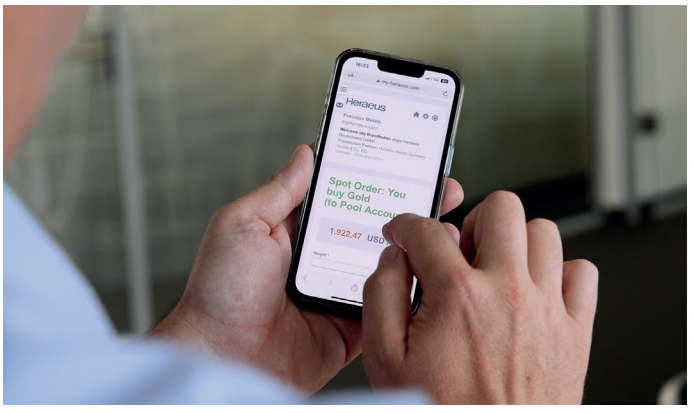
Flexible pricing / hedging options and advanced financing models

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

Compared to primary material, the carbon footprint of recycled precious metals is up to 98% lower. Thus, recycling contributes significantly to a lower carbon footprint of industrial applications.

Additionally, Heraeus has developed an eco-friendly, sustainable process through which the byproduct of most of our refining processes is used in the water purification industry – significantly reducing landfill waste.

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

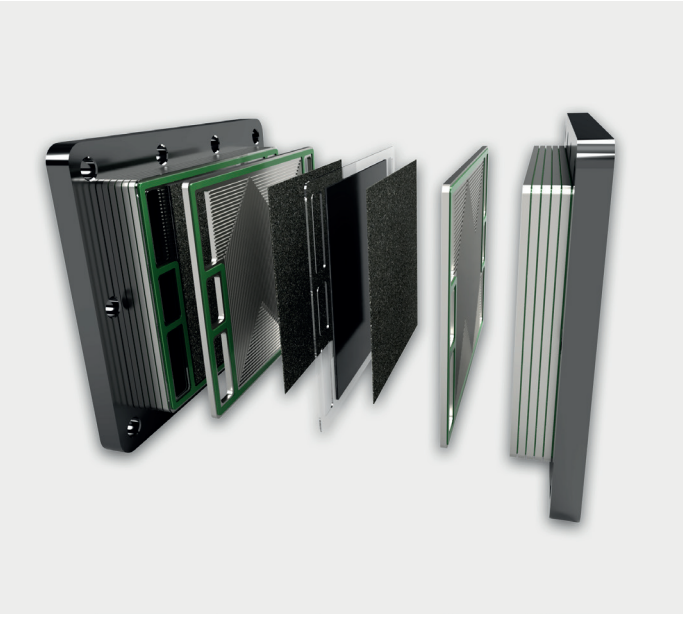
But Heraeus goes beyond: The aim is not only to maximize the use of precious metals, but of all secondary raw materials. For example, the valuable ionomer used in fuel cells and electrolyzers can be recovered and Heraeus also offers the service of disassembling/process complete stacks (electrolyzer and fuel cells).

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 dramatically.

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 production 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 significantly 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 the decisive component on our way towards a **zero-emission** society.

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:

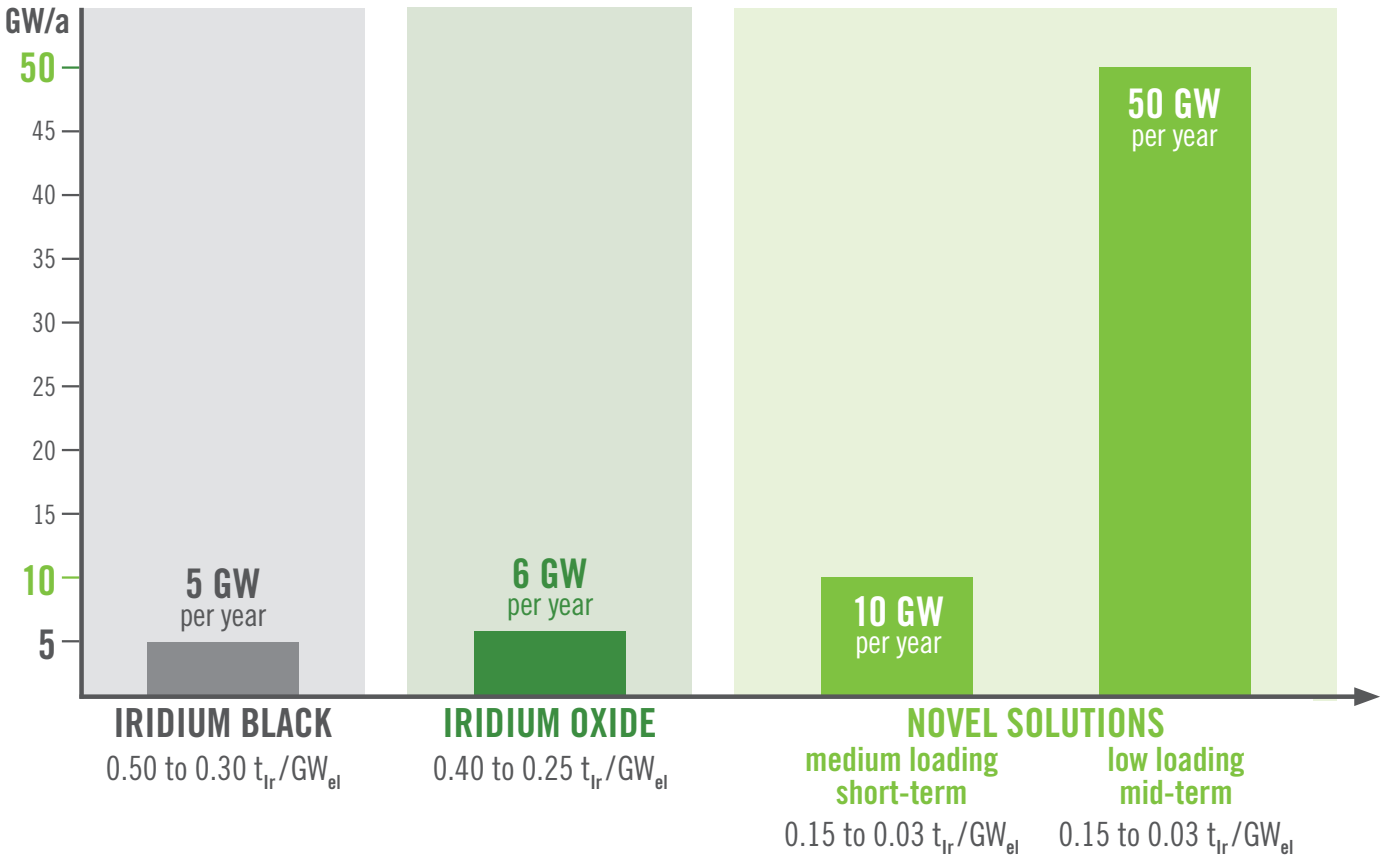
ACTIVITY - Several catalyst concepts available to increase performance and reduce costs.

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:

ACTIVITY – Efficient use of platinum in different catalyst concepts helps to gain highest 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 allowing significantly lower damage throughout 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
- 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 **increases the operation efficiency** and lifetime significantly. 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.

For the operation of **Solid Oxide Fuel Cells (SOFC),** Heraeus Precious Metals and Hulteberg Chemistry & Engineering AB jointly develop and commercialize a dedicated portfolio. The toolkit includes solutions for the **(pre-)reforming of hydrocarbons**, the **generation of syngas** (H_2/CO) via catalytic partial oxidation (CPOX), the **purification of syngas** via water-gas-shift, **preferential oxidation** (PROX) and **selective methanation reactions** to yield pure hydrogen (H_2), as well as **tail-gas combustion**.

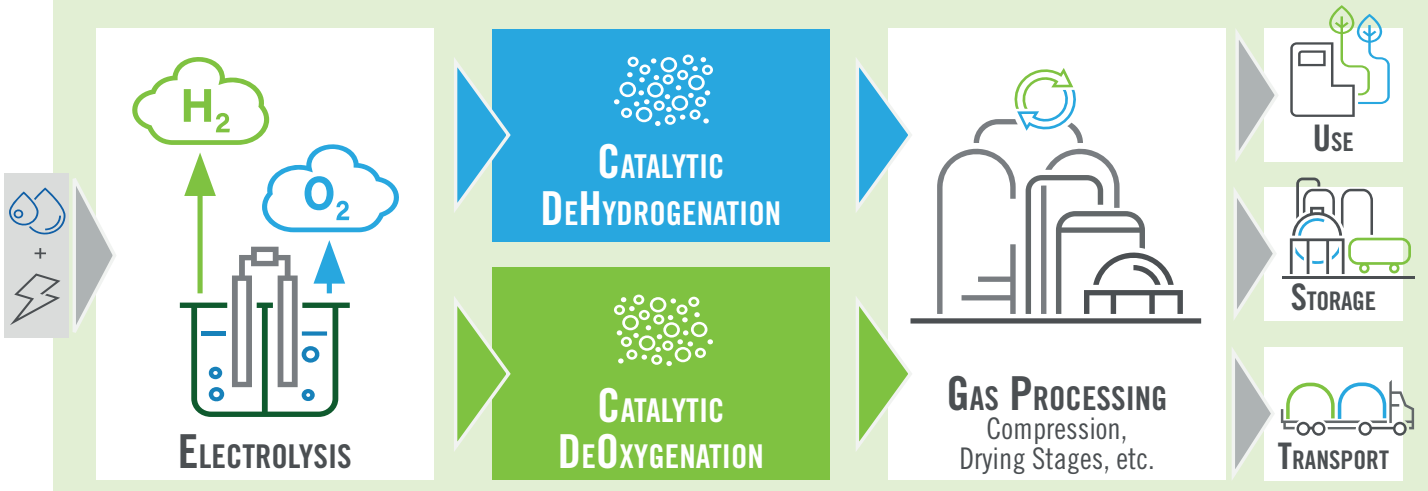
Optimizing an electrolyzer or a fuel cell system is not only about catalyst efficiency. **Precursors for coating** of stack components, such as **bipolar plates** or **PTLs help to achieve** optimal performance and durability. Also, the interplay of all stack components and its operation conditions affect the efficiency of electrolyzer and fuel cell systems. Heraeus provides the material solutions to optimize your stack and balance of plant components.

Hydrogen Purification
Safely process, transport and use the gases

While electrolysis is an efficient method for producing green 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 **most 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.**

Exhaust abation

Ammonia can be used as a direct energy source (simply by burning it) also with the advantage, that existing infrastructure can be used. If so, the **exhaust gas** must be cleaned from hazardous emissions such as N_2O by **gas purification catalysts** or **emission catalysts**.

Ammonia cracking

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

Boil-off abatement

For the process of recovery and application, Heraeus also offers **boil-off catalysts** to control the **hydrogen slip**.

Methanation

If we follow the nature, hydrogen can also directly be combined with CO_2. This is what happens in photosynthesis and ultimately is the principle that provided us with fossil feedstocks. These chemical substances, namely methane, can also be synthesized. In the **power to gas concept**, the generated H_2 is combined with CO_2 and reacts to CH_4 and H_2O via the Sabatier reaction. This **Synthetic Natural Gas** (SNG) is a promising option to store and transport hydrogen, as it allows the use of the already existing natural gas grids.

Biogas upgrading

Additionally, raw biogas can be **upgraded** to near-pure **biomethane**.

LOHCs

Liquid Organic Hydrogen Carrier (LOHC) can be stored or transported at ambient conditions, very similarly to petrol or diesel. Both charging of LOHC with hydrogen and dehydrogenation to release the hydrogen require a catalyst. **Heterogeneous catalysts** in these applications are typically based on platinum, ruthenium or palladium, combined with various catalyst support, e.g., aluminum oxide or active carbon. Heraeus **tailors the catalyst 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

Pt Platinum | **Ir** Iridium | **Ru** Ruthenium

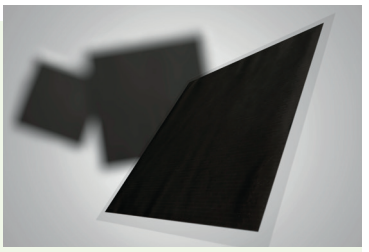
- Electrocatalysts for the **Water Electrolysis**: H_2 & O_2 Generation
- O_2-removal Catalysts for the **Purification of Hydrogen**
- H_2-removal Catalysts for the **Purification of Oxygen**

... H_2 Transport and Storage

Pt Platinum | **Pd** Palladium | **Ru** Ruthenium

- **Green Ammonia** – Synthesis, Oxidation, Cracking & Emission Abatement from NH_3 Fuel
- **Green Methanol** – CCU of CO_2
- **Synthetic Natural Gas** – Methanation of CO_2
- **LOHC** – Hydrogenation & Dehydrogenation

... H_2 Utilization



Pt Platinum | **Pd** Palladium | **Ir** Iridium | **Rh** Rhodium | **Ru** Ruthenium

- **Electrocatalysts** 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

We are committed to realize the potential of precious metals as responsibly as possible.

We underline this commitment with our pledge to responsibility: **precious to us.**

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