PRECIOUS METALS – SUSTAINABLE DEVELOPMENTS IN HEALTHCARE, HYDROGEN ECONOMY AND RECYCLING

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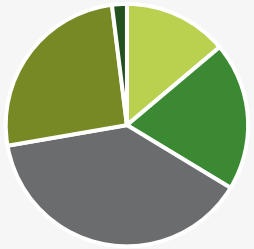
WHO WE ARE

29.5 bn. €
(34.9 bn. US$)
TOTAL REVENUE
in 2021



Germany 14%
Rest of Europe 20%
Asia 39%
America 26%
Africa/Australia 2%

US$ calculated with 2021 average exchange rate (1€ = 1.1827 US$)

Region breakdown based on revenues excl. Precious Metals

6% expenditures
for RESEARCH &
DEVELOPMENT

based on revenues excl. Precious Metals

12 market-oriented
GLOBAL BUSINESS UNITS

TOP 10
FAMILY-OWNED COMPANIES
in Germany

Listed in
FORTUNE
Global **500**

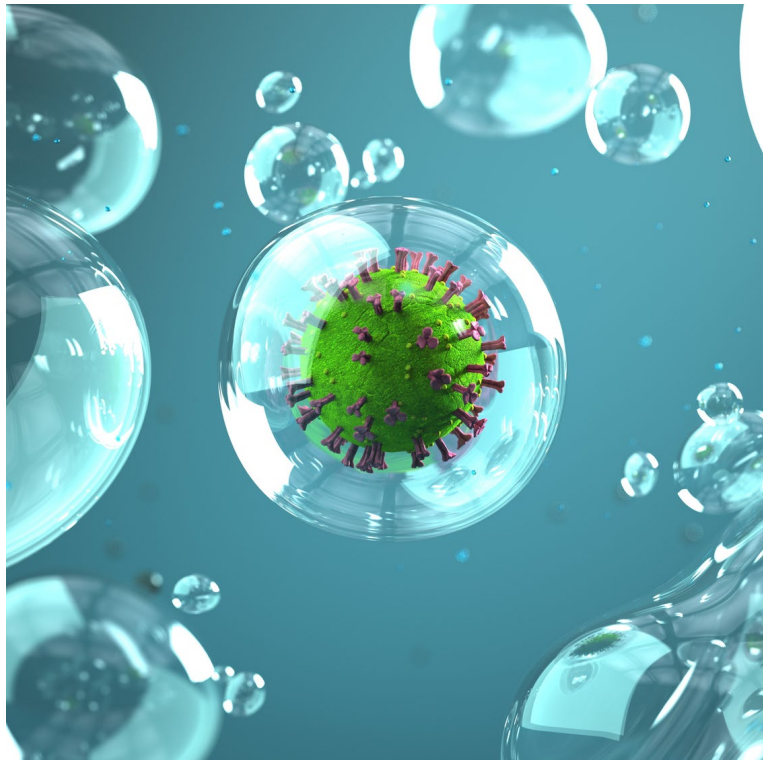
More than
100 SITES in
40 COUNTRIES

Approx.
16,200
EMPLOYEES
in 2021

Germany 33%
Rest of Europe 16%
Asia 27%
America 24%
Africa/Australia 1%

including staff leasing

THREE EVENTS SHAKING OLD BELIEFS



Covid Pandemic

Pharmaceutical Efficiency

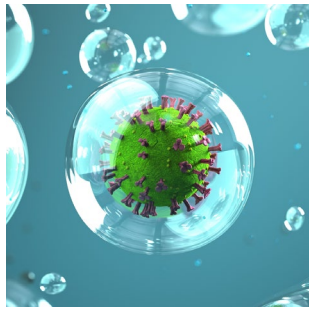
Geopolitical Developments

Urgency for Hydrogen Economy

Global Warming

Recycling & Sustainability

LESSONS LEARNED



Covid Pandemic:

- long and tedious procedures in pharma production are not sufficient
- demand for fast and efficient pharmaceutical syntheses

  → renewed push for efficient & specialized precious metal catalysts

Geopolitical Developments:

- reduce dependence on oil & gas as our primary sources of energy
- make solar power electricity storable and transportable

  → efficient precious metal catalysts for hydrogen generation and usage are a key factor

Global Warming:

- minimize the carbon footprint of each part of the value chain
- the mining of precious metal is quite energy intensive

  → the recycling of precious metals has become even more important

PHARMACEUTICAL EFFICIENCY

COVID PANDEMIC INCREASES NEED FOR PHARMACEUTICAL EFFICIENCY

Lesson learned during the pandemic:

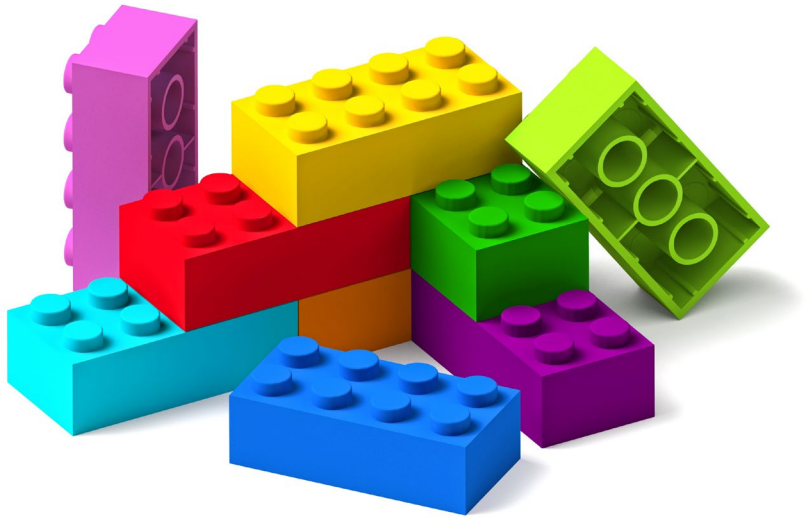
- Need for rapid and efficient pharma syntheses

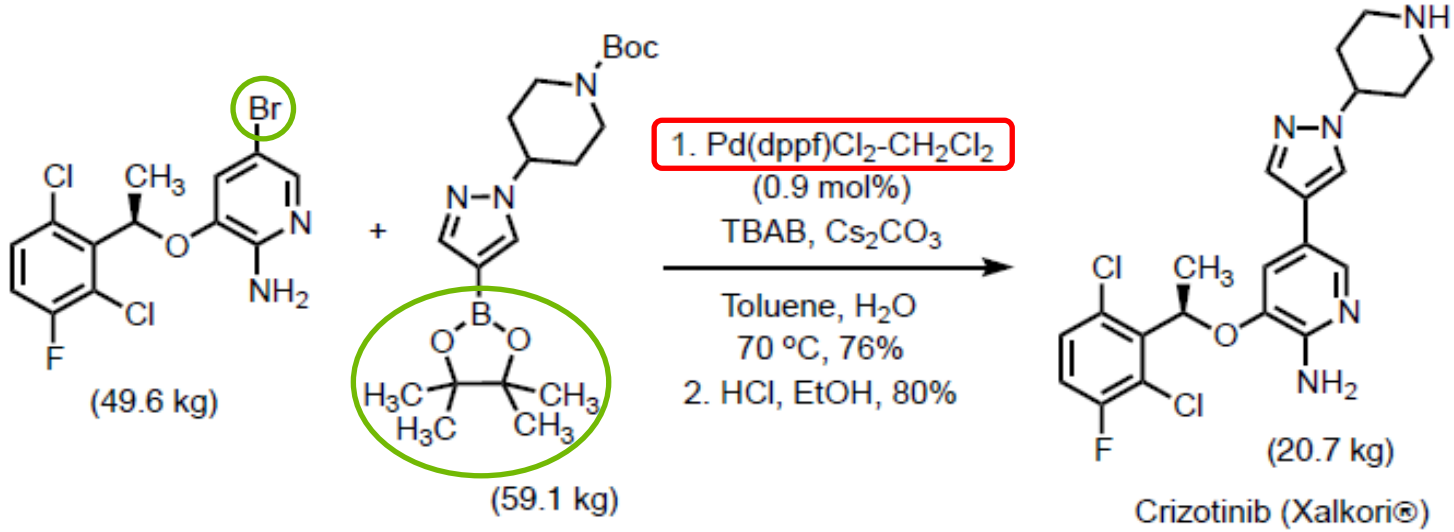
What does that mean for the PGM-world?

- Rising: soluble homogeneous PGM catalysts
- Iridium, Rhodium and Ruthenium complexes for asymmetric hydrogenations
- Osmium compounds for the synthesis of hormone-like molecules
- Palladium complexes for C-C coupling reactions:
  - Enable the direct creation of carbon-to-carbon bonds between building blocks of an API (active pharmaceutical ingredient)

PHARMACEUTICAL SYNTHESIS: C-C COUPLING REACTIONS

Instead of long linear syntheses with low overall yields researchers can now use convergent syntheses starting from two or more building blocks, almost like building with LEGO®





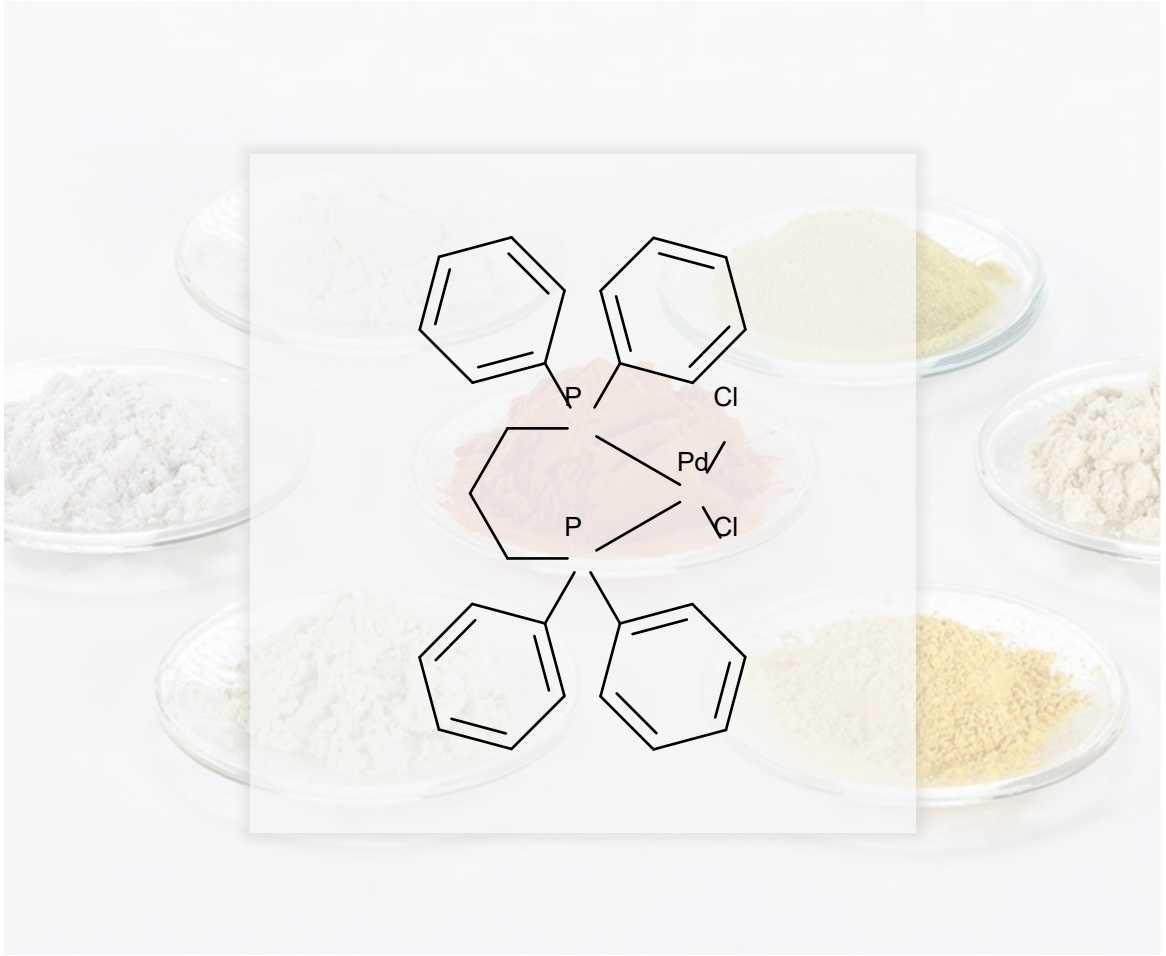
de Koning, P. D. *et. al. Org. Proc. Res. Dev.* **2011**, *15*, 1018–1026.

PALLADIUM COMPLEXES: FIRST CHOICE FOR C-C COUPLING REACTIONS

- Palladium complexes (so-called phosphines) are particularly good at catalyzing C-C couplings
- They are built with a certain class of phosphorous containing ligands
- One example is Pd(dppp)Cl_2 (see illustration), dozens of palladium phosphines exist

Working Principle:

- modify the electron density on the palladium
- enable access to catalytic center only from one side
  - the reaction can run only in one way
  - side products are avoided



PD-PHOSPHINE COMPLEXES: MAGIC POWDER COLLECTION

HYDROGEN ECONOMY

HYDROGEN ECONOMY: REPLACE FOSSIL FUELS

Renewable Energy

H_2-Generation

Distribution & Transport

Hydrogen Carrier

NH_3 CH_4 CH_3OH LOHC

Application

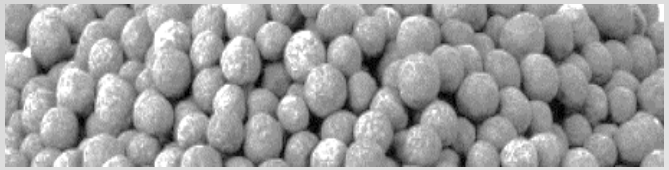
Precious Metal Products & Services

Precious Metal Catalysts and Precursors for:

Water Electrolysis

- Electrocatalysts for H_2 & O_2 Generation
- De-Oxo / De-Hydro Catalysts

H_2 Transport and Storage



- Ammonia Synthesis and Cracking
- Methane/Methanol from CO_2
- De-/Hydrogenation of LOHCs

Hydrogen Utilization

- Electrocatalysts for PEMFC
- Catalyst Coated Bipolar Plates
- Reforming Catalysts for SOFC

Precious Metal Management

Precious Metal Recycling

HYDROGEN ECONOMY: PRECIOUS METALS ARE INDISPENSABLE

Ir	Pd	Pt	Rh	Ru
Iridium	Palladium	Platinum	Rhodium	Ruthenium

PEM Electrolysis Catalysts

Bipolar Plating

De-Oxo and De-Hydro Catalysts

Ammonia splitting

Methan / Methanol LOHC

PEM Fuel Cell Catalysts

Catalysts for SOFC
Gas Purification
O_2/CO_2 removal

HYDROGEN ECONOMY: WHAT IS NEEDED FOR THE RAMP UP?

Innovative catalysts for efficient use of Ir and Pt in PEM electrolyzer & fuel cells

- Variety of catalysts with different Pt loadings and carbon supports
- Special catalysts for long life performance
- Innovative Ir-catalysts for electrolysis with significantly reduced Ir content

Recycling of precious metals from production scrap and end-of-life

- High return rates for sustainable use of Ir & Pt
- Global capabilities
- Broad range of recycling technologies to fit the requirements of the waste stream

Metal Management of price volatility and financing of precious metals

- Precious metal trading and PM-containing material in one hand
- Supply security for metals / strategic sourcing by partnerships
- Risk management & mitigation of price volatilities

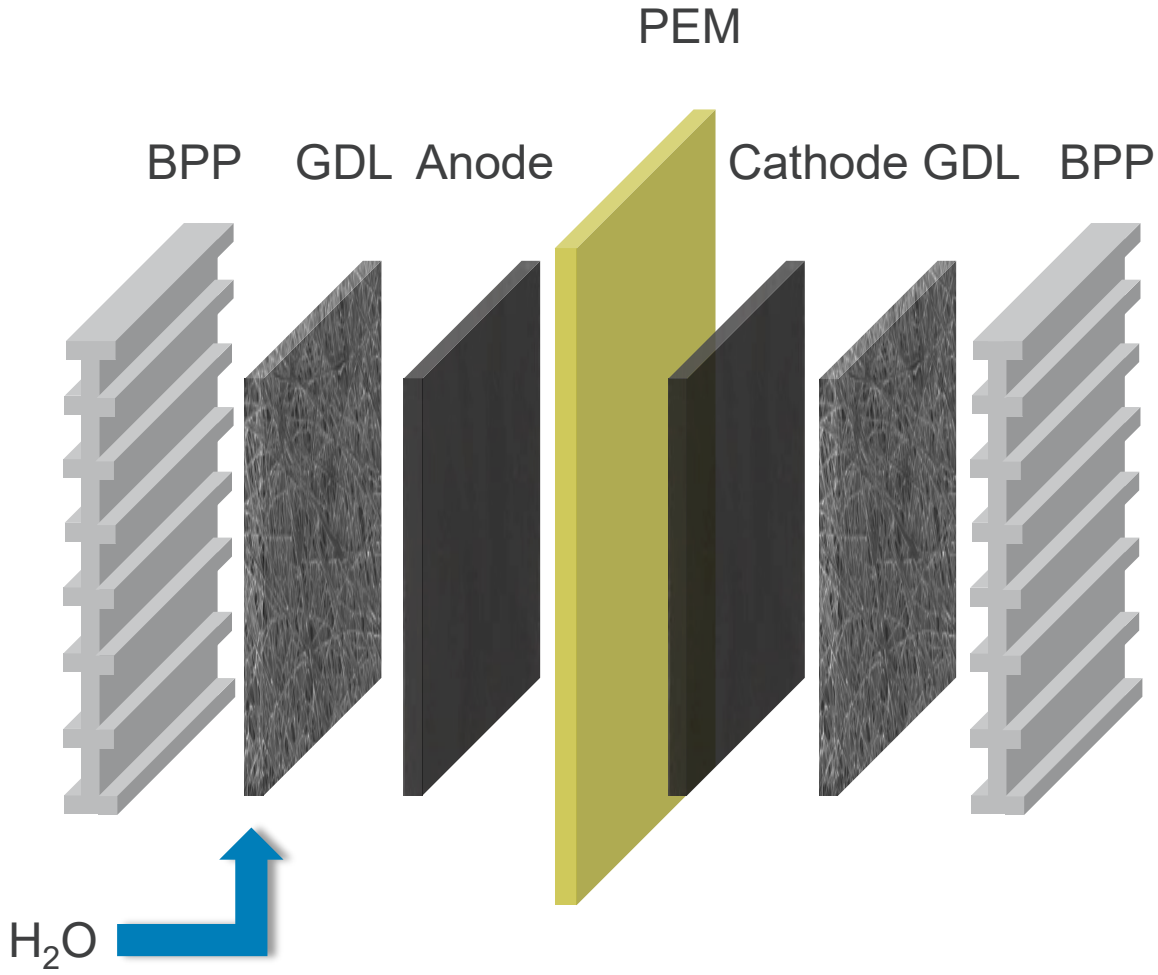
HYDROGEN GENERATION: MATERIALS FOR PEM ELECTROLYZERS

Anode Catalysts – different catalyst classes

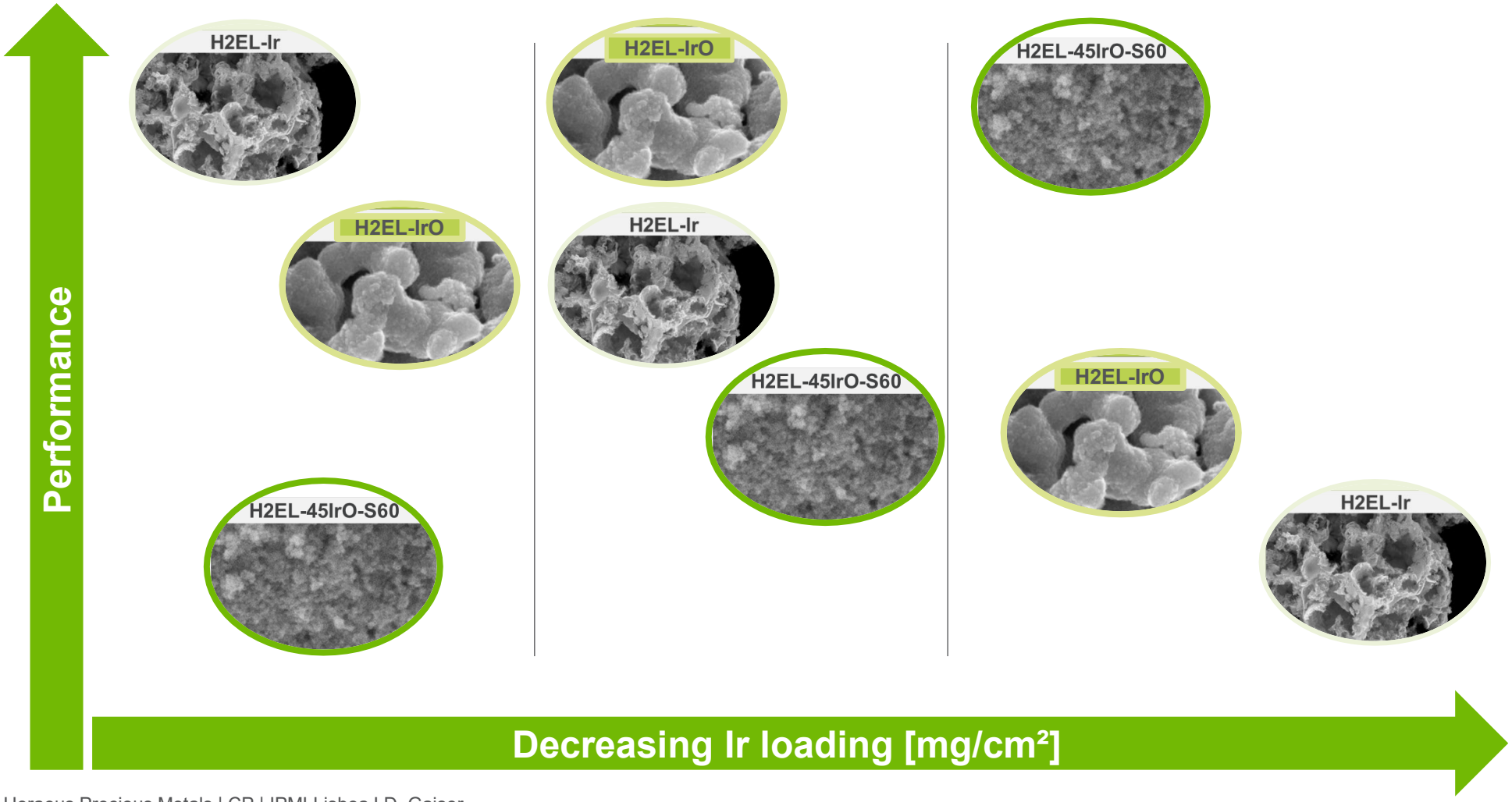
- H2EL-Ir
  - Iridium black catalysts with high surface area and high intrinsic conductivity
- H2EL-IrO
  - IrO_2 catalyst with high surface area and good intrinsic conductivity
  - Medium volumetric density
- H2EL-xxIrO-Sxx
  - Highly variable catalyst on high surface area TiO_2 support
  - High activity and variable conductive
  - High volumetric density for extremely low Ir loadings
- H2EL-xxIrRu
  - Highly active Ir-Ru mixed oxides for low Ir loadings

Bipolar Plates

- Precursors for stable conductive electroplated coatings



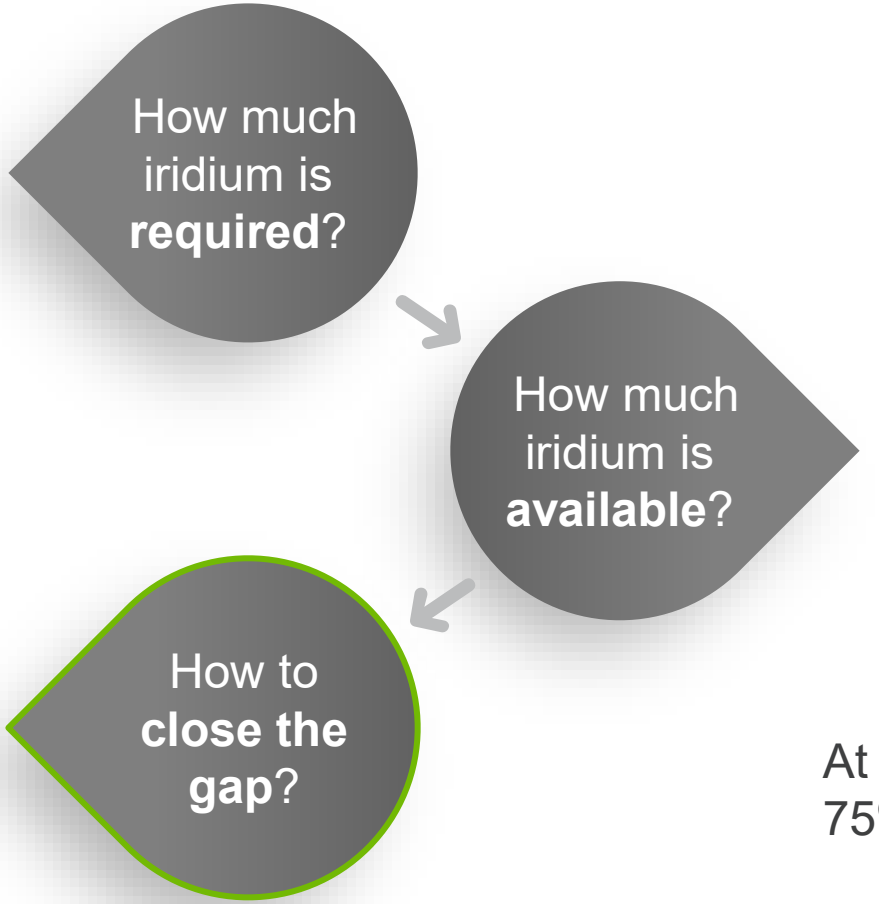
INNOVATIVE MATERIALS SHOW OPTIMAL PERFORMANCE AT LOW LOADINGS



- Iridium black shows best performance at high loadings.
- Iridium oxide is optimal for the middle area.
- Innovative materials balance low iridium content with high performance

FOR THE HYDROGEN RAMP-UP THE IRIDIUM GAP NEEDS TO BE CLOSED

With current catalysts
→ 27 mt of iridium required from 2022 until 2029

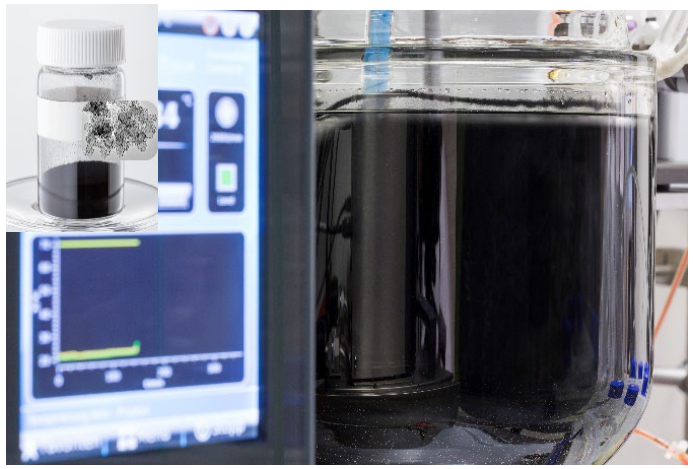


Estimated available iridium quantities for PEM: 1.5 mt/a
→ 12 mt until 2030

Reduction of iridium with next gen catalysts for PEM:
→ Demand for iridium until 2030 is reduced from 27 to 7 mt

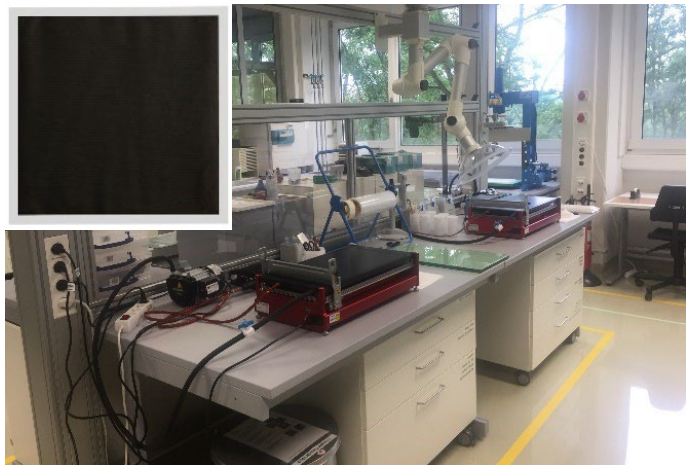
At the same time, this leads to 75% cost saving on iridium metal

FULLY EQUIPPED TEST LABS SUPPORT THE CATALYST ADOPTION PROCESS



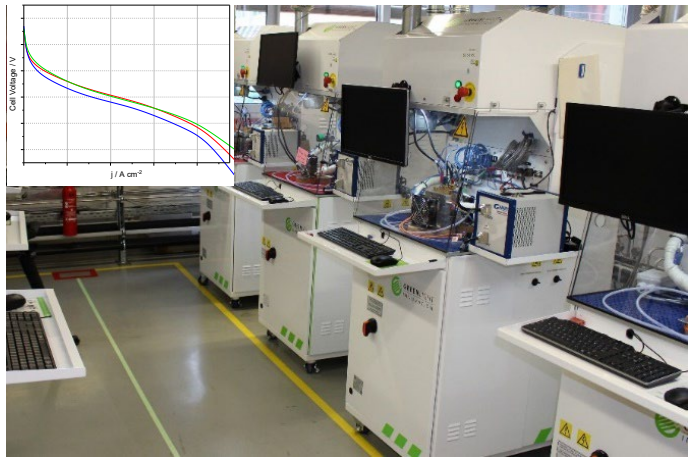
Catalyst Synthesis & Characterization

- Automated catalyst synthesis for high reproducibility
- Tailoring catalysts for various customer applications



CCM manufacturing

- Established coating process for catalyst benchmarking
- Ink-formulation expertise to support customer directly

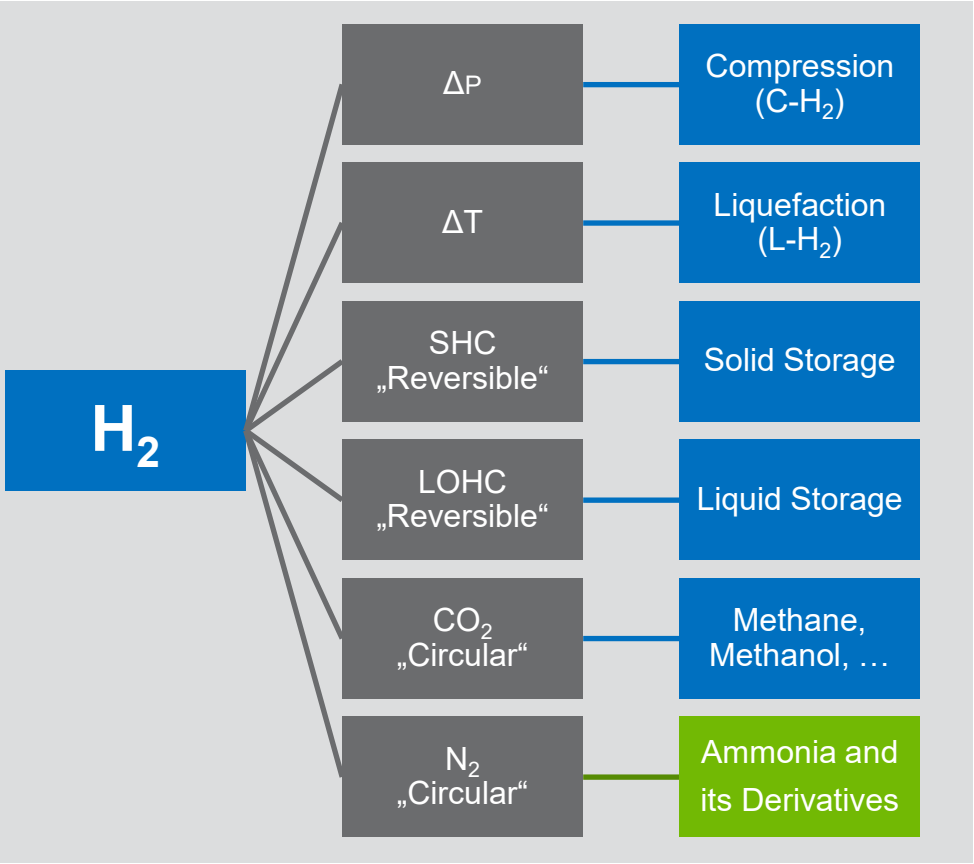


Single Cell Testing

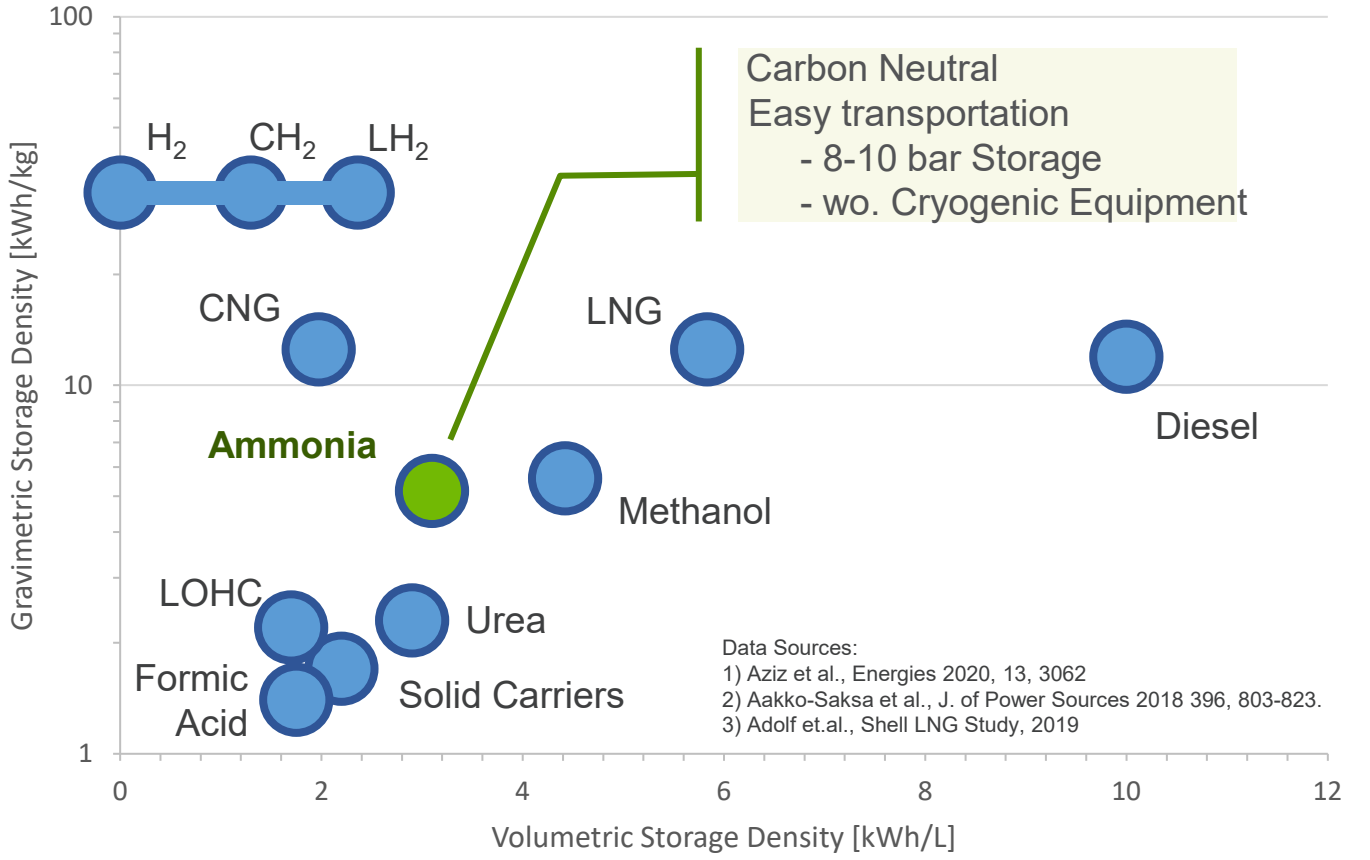
- Testing under various realistic conditions
- Fast implementation of customer requirements
- Detailed assessment of electrode stress events

HYDROGEN STORAGE & TRANSPORT: THE ROLE OF AMMONIA

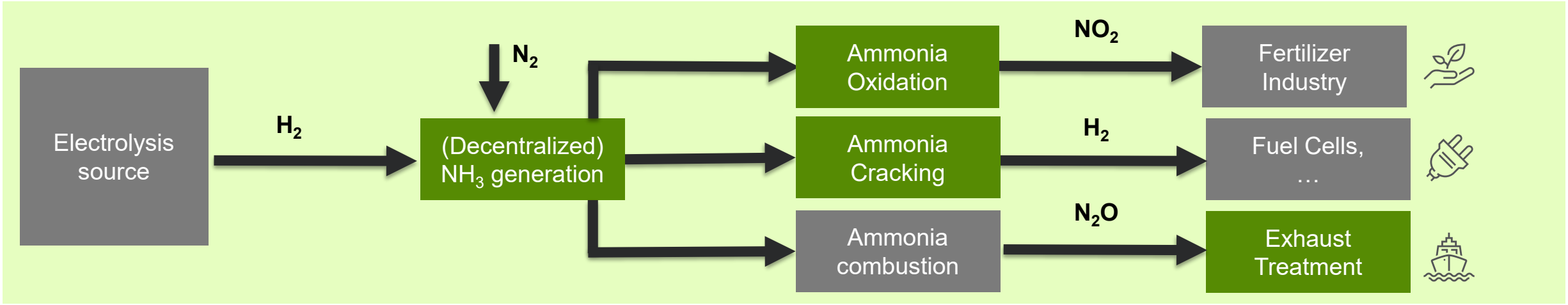
Hydrogen Storage Options



Storage densities



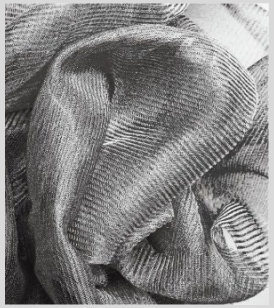
HYDROGEN STORAGE & TRANSPORT: GREEN AMMONIA



Catalysts

Chemical Products

Ruthenium Salts KAA Process, …



Catalytic Gauzes

FTC Gauzes, Ostwald process

Process Catalysts

Bulk Catalysts, Ammonia Cracking

Emission Catalysts

Coated Substrates, N_2O Abatement

HYDROGEN UTILIZATION: PEM FUEL CELL

Cathode Catalysts

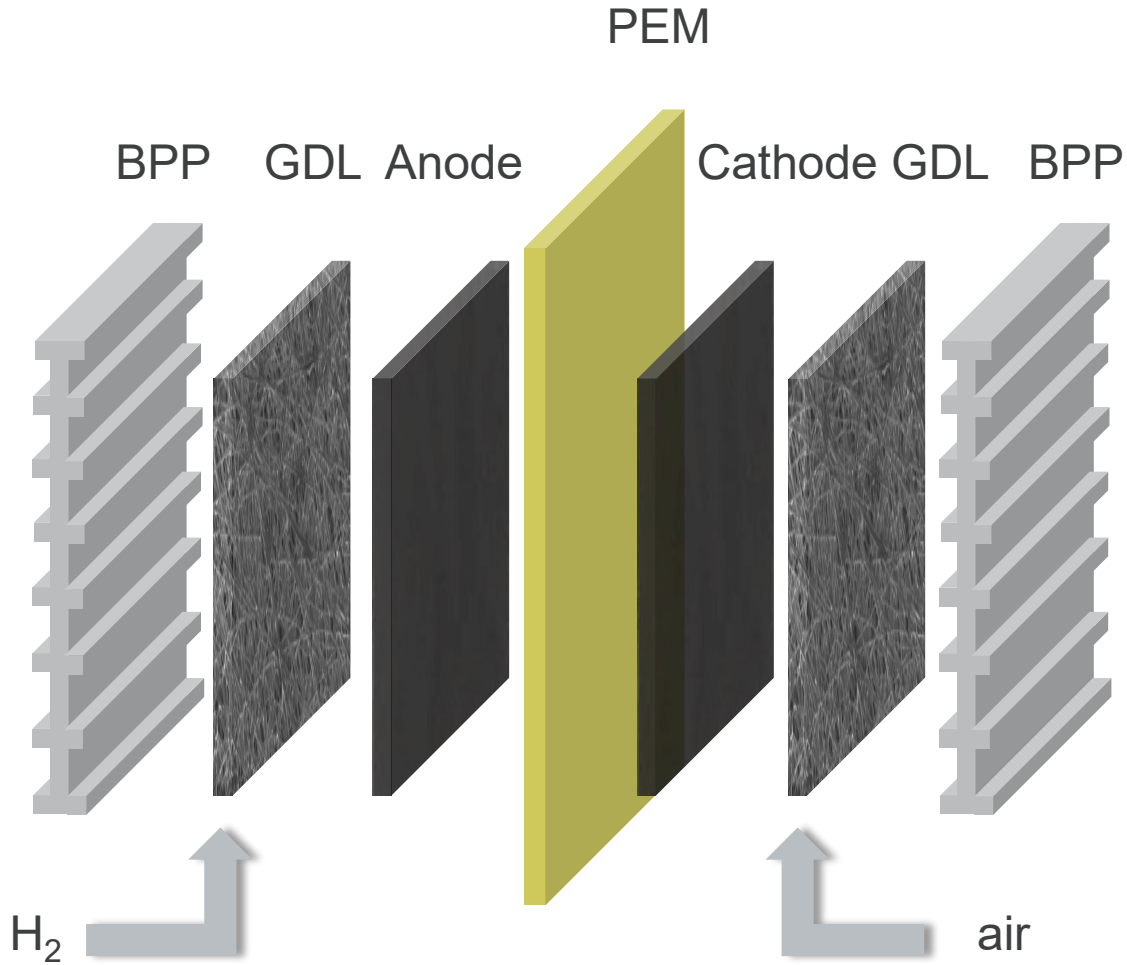
- Tailormade solutions for high and low humidity and current operations
- Optimized Pt surface area utilization
- Stability optimized catalysts
- High surface area to medium surface area carbon support

Anode Catalysts

- Solutions for cell reversal tolerant anode recipes
- IrO_2 OER (oxygen evolution reaction) catalyst

Bipolar Plates

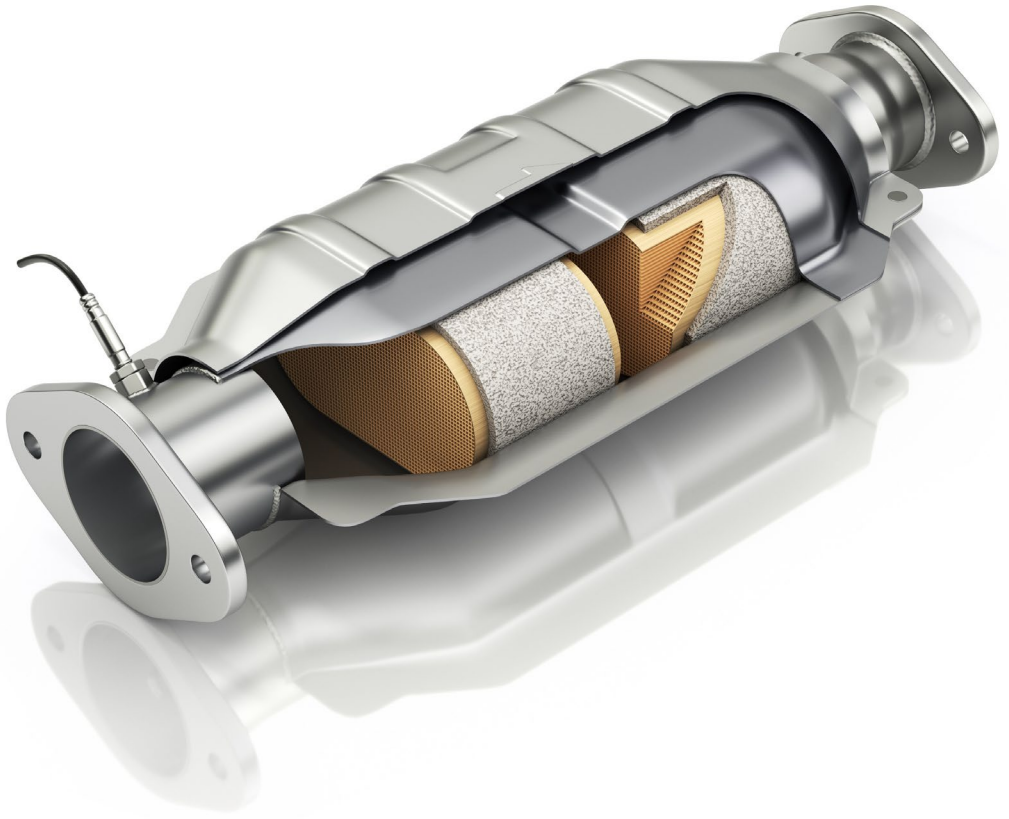
- Precursors for stable conductive electroplated coatings



RECYCLING OF PRECIOUS METALS & SUSTAINABILITY

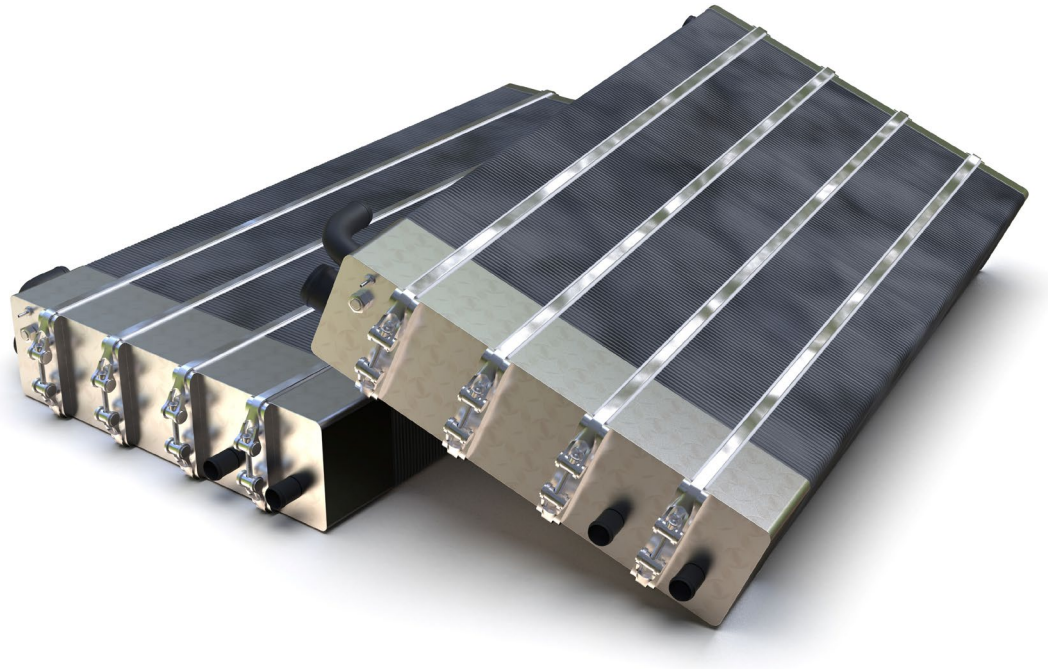
RECYCLING OF CATALYTIC CONVERTERS

- End of lifetime: catalytic converters containing several grams of precious metals are dismantled
- The housing is removed “de-canning”
- The PGM-coated monolithic honeycomb ceramic is ground up
- The ceramic powder is molten in an electric arc furnace and separated into a slag phase and a metal phase
- The precious metals are extracted from the metal phase



CCM RECYCLING

- End of lifetime: electrolyzer or fuel cell stacks consisting of hundreds of CCMs (catalyst coated membranes) which contain the precious metal
- Stacks have to be dismantled and CCMs have to be extracted
- In most cases membranes are fluorinated polymers and the catalyst coating is carbon based
- New concepts will have to be developed on how to process CCMs:
  - Total Incineration
  - Mechanical removal of catalyst coatings
  - Chemical separation of membrane and coating

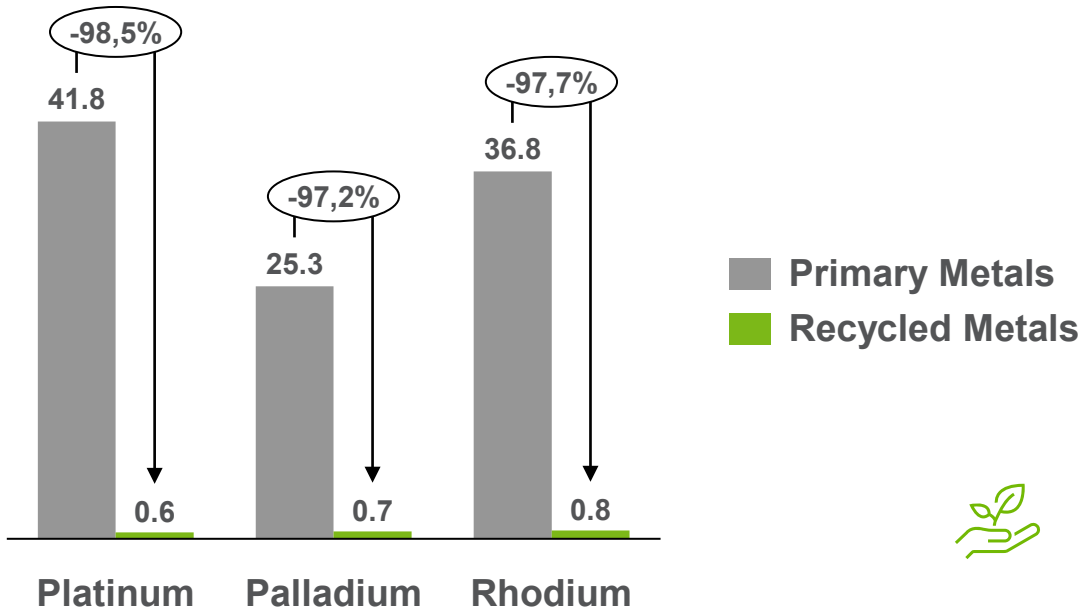


SUSTAINABILITY ADVANTAGE: MASSIVE CO_2 SAVING POTENTIAL

Recycled Precious Metals show a much lower carbon footprint than mining material

- Precious metals can either originate from mines (primary metals) or from recycling of used precious metal products (secondary metals).
- Primary metals account for roughly 67-76 % of annual precious metal (Pt, Pd, Rh) supply while only 24-33 % is coming from recycled metals.
- Although recycled metals can only cover a fraction of total PGM demand, their contribution is significant:
  Recycled metals provide a massive CO_2 saving potential compared to primary metals by reducing the carbon footprint up to 98.5 %!

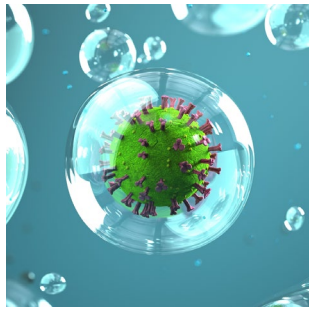
Carbon footprint of primary vs. recycled precious metals in kg CO_2-eq per gram precious metal:



Source: International Platinum Group Metals Association

SUMMARY

SUMMARY



Pharmaceutical Efficiency:

- Need for new and more efficient syntheses for pharmaceutical, agro- and finechemical ingredients → homogeneous precious metal catalysts

Urgency for Hydrogen Economy:

- generation of hydrogen in electrolyzers → Iridium
- transformation of hydrogen into other fuels (mostly ammonia) → various coated catalysts
- usage of hydrogen in fuel cells → Platinum

Recycling & Sustainability:

- Massive CO_2 saving potential compared to primary metals by reducing the carbon footprint up to 98.5 %! → Recycled metals