Heraeus

Precious Metals

SUSTAINBILITY - IRIDIUM AND THE HYDROGEN ECONOMY

IPMI, Dublin, November 28th – 30th, 2021 / Philipp Walter

CONTENT

Introduction to Heraeus

The next Innovation Cycle is „Green“

Hydrogen Generation by Means of PEM Electrolysis

Next Generation electrocatalysts for the GW-Scale

A GLOBALLY SUCCESSFUL PORTFOLIO COMPANY

TOTAL REVENUE
31.5 bn €
in 2020

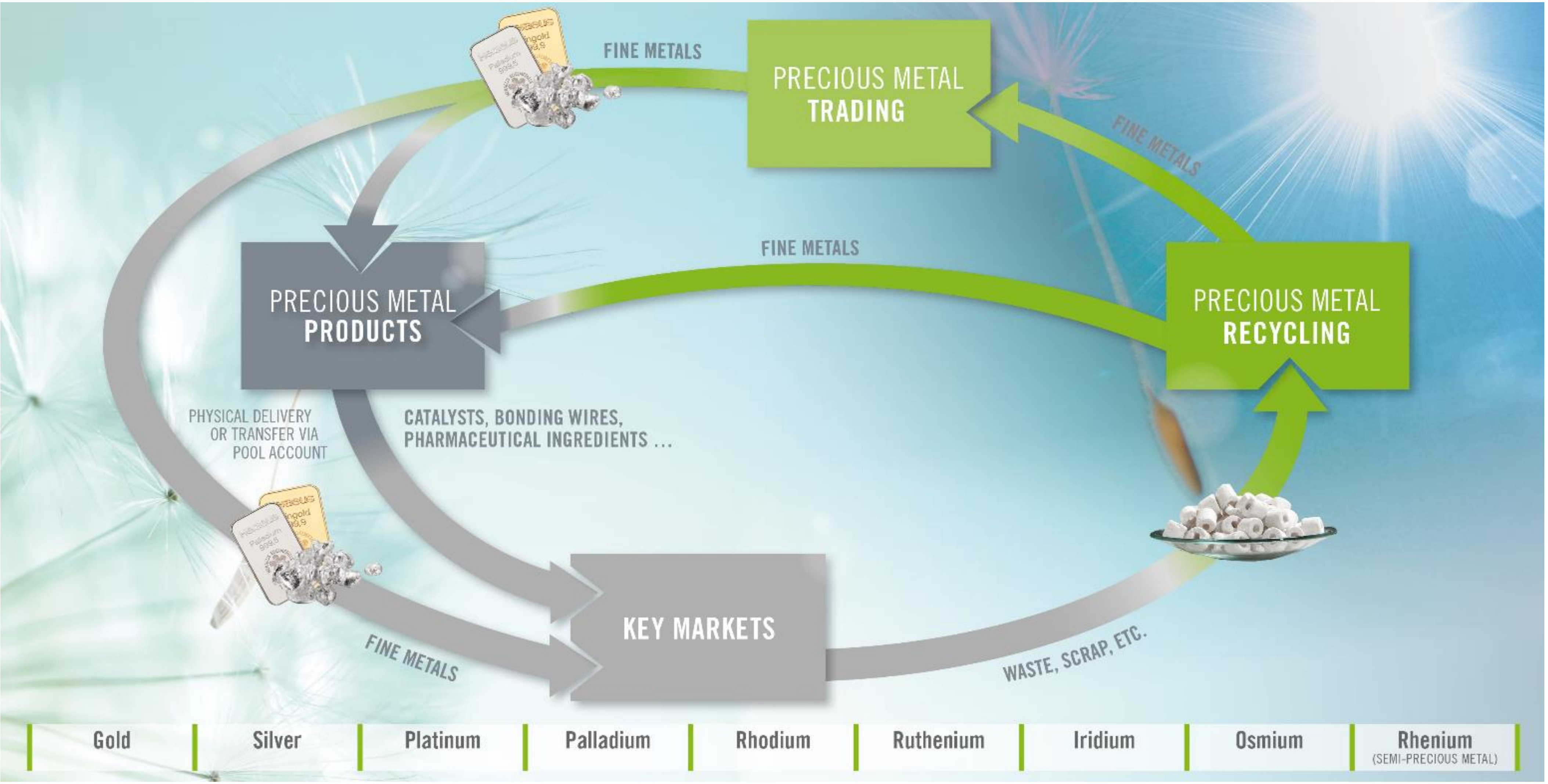
Market-oriented distribution
in **11** GLOBAL BUSINESS UNITS

7% R&D EXPENDITURES
Based on revenues excl. Precious Metals

TOP 10 FAMILY-OWNED COMPANIES
in Germany

FORTUNE 500
COMPANY

HERAEUS PRECIOUS METALS OFFERS INTEGRATED SOLUTIONS



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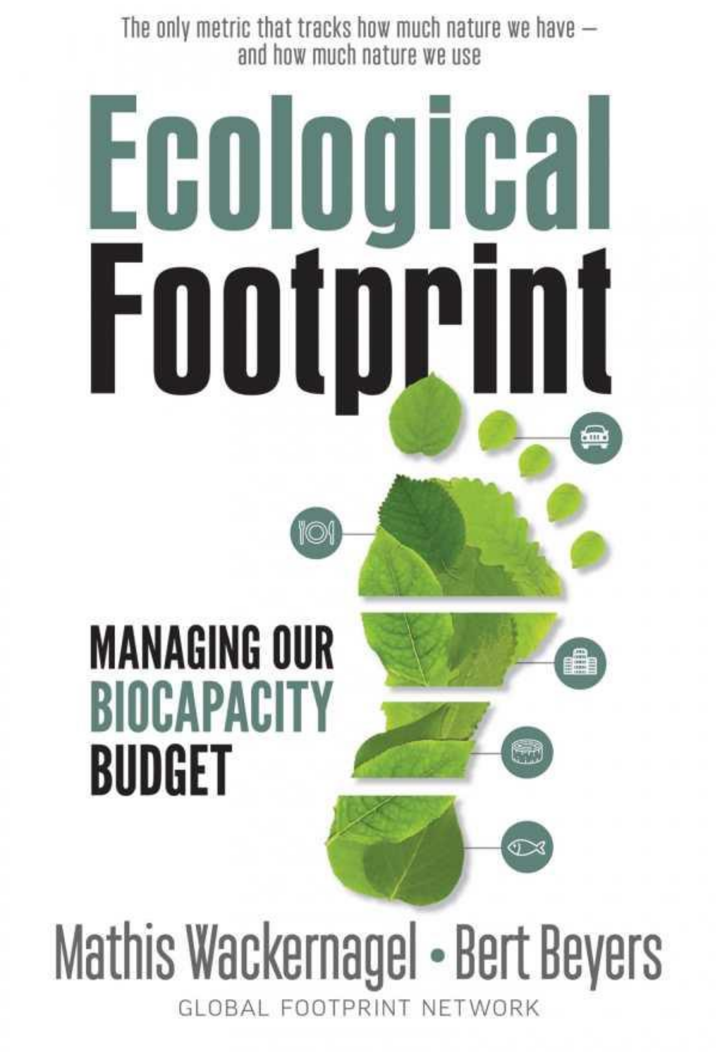
THE ECOLOGICAL FOOTPRINT AND BIOCAPACITY



Ecological Footprint

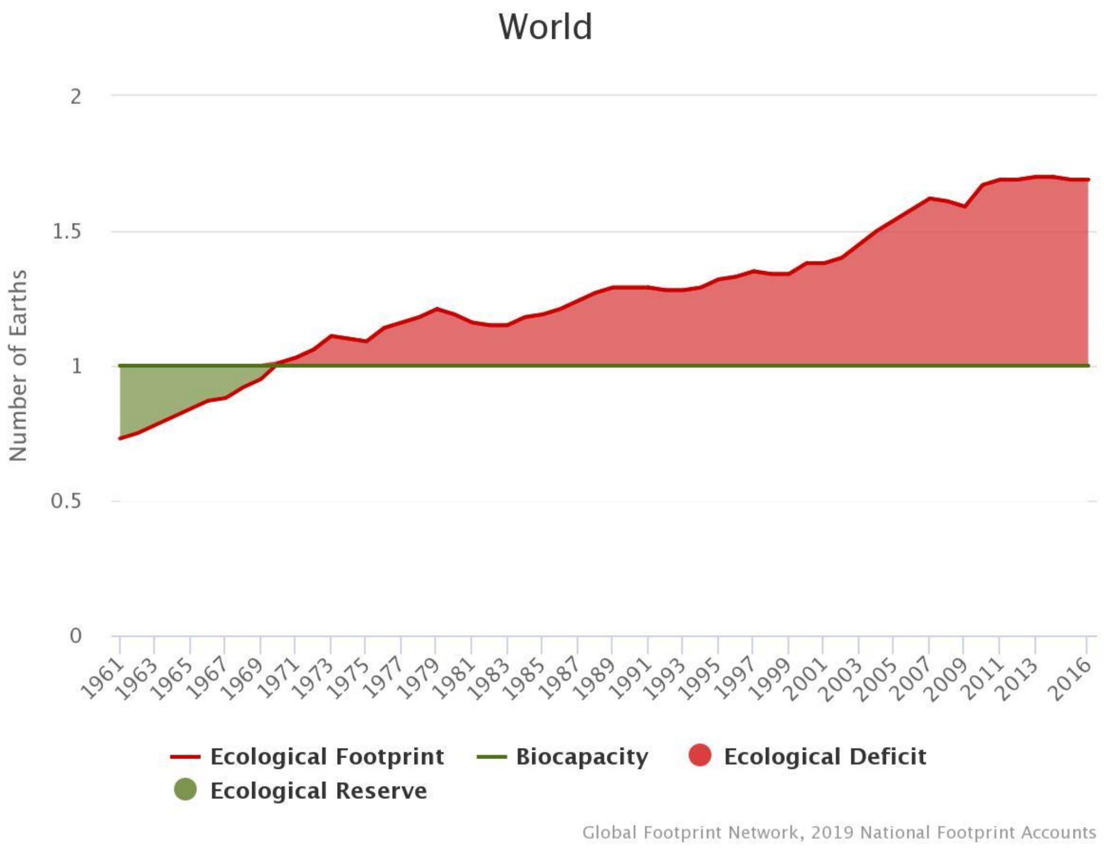
…measures **how fast we consume resources** and **generate waste** compared to **how fast nature can absorb our waste and generate new resources**

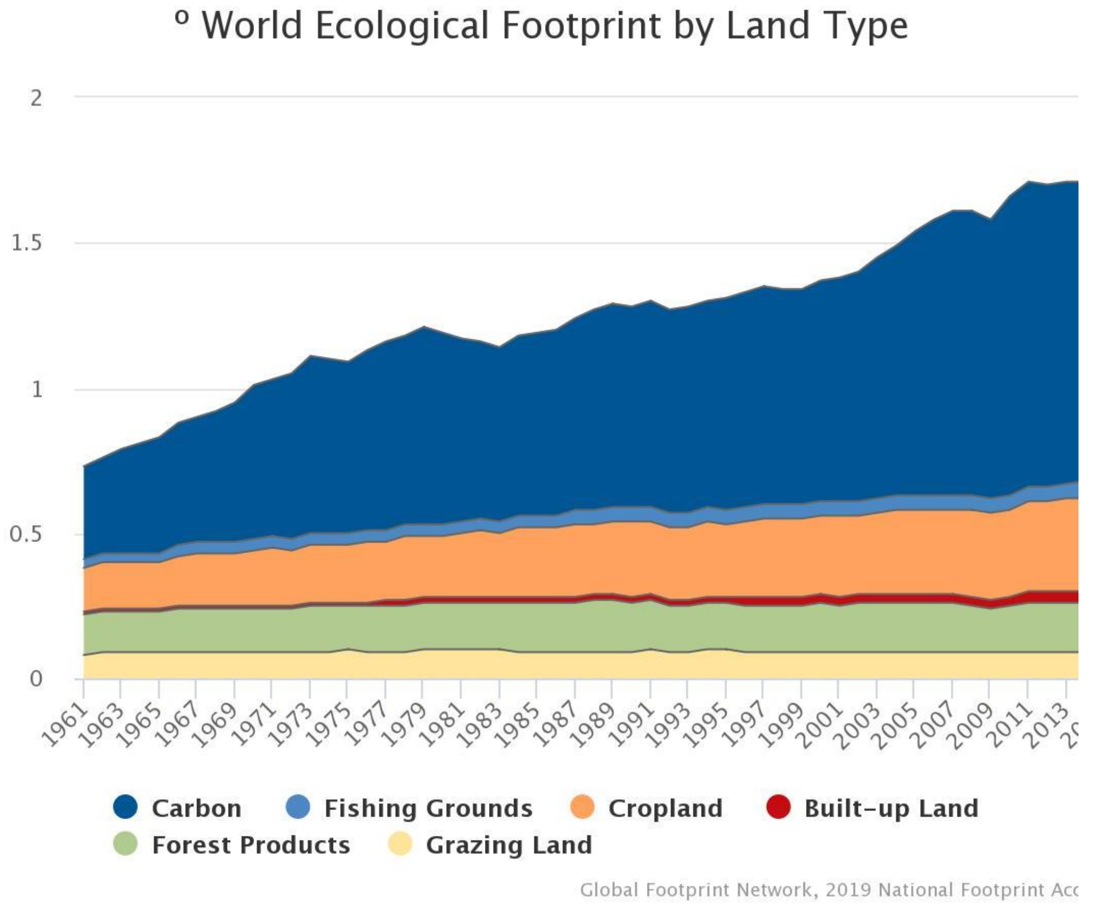
Biocapacity

…is the **capacity of ecosystems to regenerate what people demand** from particular surfaces. Life, including human life, competes for space. The **biocapacity of a particular surface represents its ability to renew what people demand.**

www.footprintnetwork.org - Global Footprint Network,

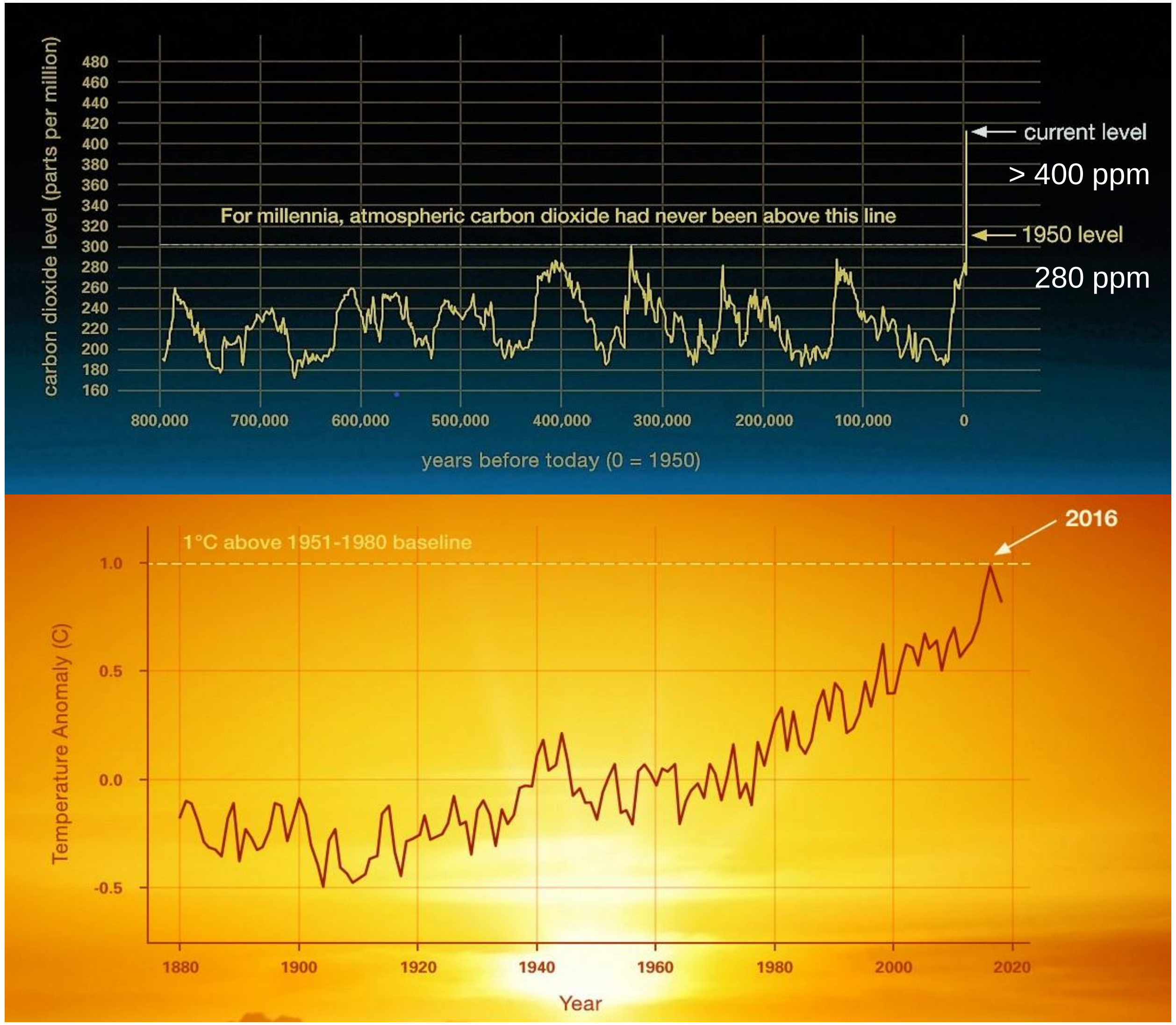
ECOLOGICAL FOOTPRINT EXCEEDS BIOCAPACITY SINCE THE 70TH WITH CARBON FOOTPRINT INCREASING MOST PROMINENTLY





ANTHROPOGENIC CO_2 AS ONE MAJOR CAUSE FOR GLOBAL WARMING

- **Combustion of fossil resources** are the primary cause for a **steep increase of atmospheric CO_2** since the 1950th
- **Heat-trapping nature of CO_2** (and other gases) drives global warming
- **Temperature anomaly** of + 1 °C in 2016 and + 6 °C predicted by IPCC until 2100
- The **need for reducing CO_2 emissions** has been globally recognized – by society and industry



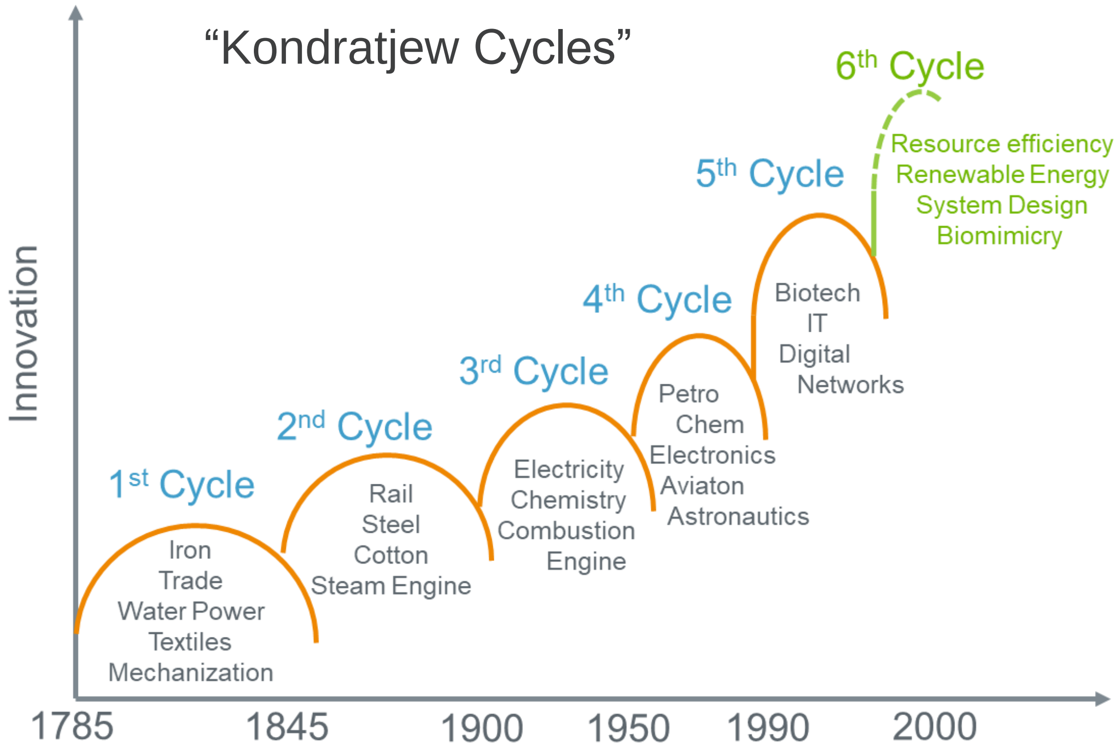
IPCC = Intergovernmental Panel on Climate Change

Climate.nasa.gov

5 GROWTH AND INNOVATION CYCLES AND 1 HYPOTHETICAL FUTURE CYCLE

Signs for a wave of "green technology", marking the next Kondratjew cycle*:

- **Resource productivity**
- **System Design:** Optimization of resource efficiency for entire systems
- **Biomimicry:** Nature's principles as model, measure and teacher
- **Renewable Energy**



Source: Weizsäcker et al. „Faktor Fünf"

Prediction and request: The 6th cycle is "green"

* Hargroves et Smith, „Risks of Inaction on Sustainable Development" (2005)

HOW PRECIOUS METAL BASED CATALYSTS CONTRIBUTE TO SUSTAINABILITY

Renewable Feedstocks		Products	Applications
	**Biomass** Conversion of Biomass into Chemicals	**Biobased Chemicals**	- Organic chemicals - Fuel and Fuel additives - …
	**Water** Electrolysis using renewable energy	**Green Hydrogen**	- Replacement of Grey H_2 - Energy Storage - …
	**CO_2** Conversion of CO_2 and H_2	**Green Hydrocarbons & functionalized HC**	- Fuels and Fuel additives - Surfactants - …
	**Hydrogen** Energy generation from H_2 and O_2	**Energy**	- Fuel Cell Electric Vehicles - Stationary Fuel Cells - …

1) www.wri.org - World Resource Institute

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Hydrogen Economy is on the rise due to need for decarbonization

Massive Capital Deployment on multiple levels

10’s of bn. € of subsidies (roadmaps)[1)]
>10 bn. € of Corporate CAPEX[1)]
> 1 bn. € of Venture Capital[1)]

End-consumer pull and inter-industry alliances

Willingness to pay premium for decarbonized products
New business models to improve return scenarios

Technologies ready for scale-up to mass

Technologies are basically existent but need ‘economy of scale’ to be cost competitive

Energy Storage and Transport

Renewable Energy requires high-capacity storage options

Existing H_2 applications

Petrochemical H_2 generates CO_2 during production (SMR)[2)]

Fuels and Chemicals

Direct fuel for turbines or fuel cells or through reaction with CO2

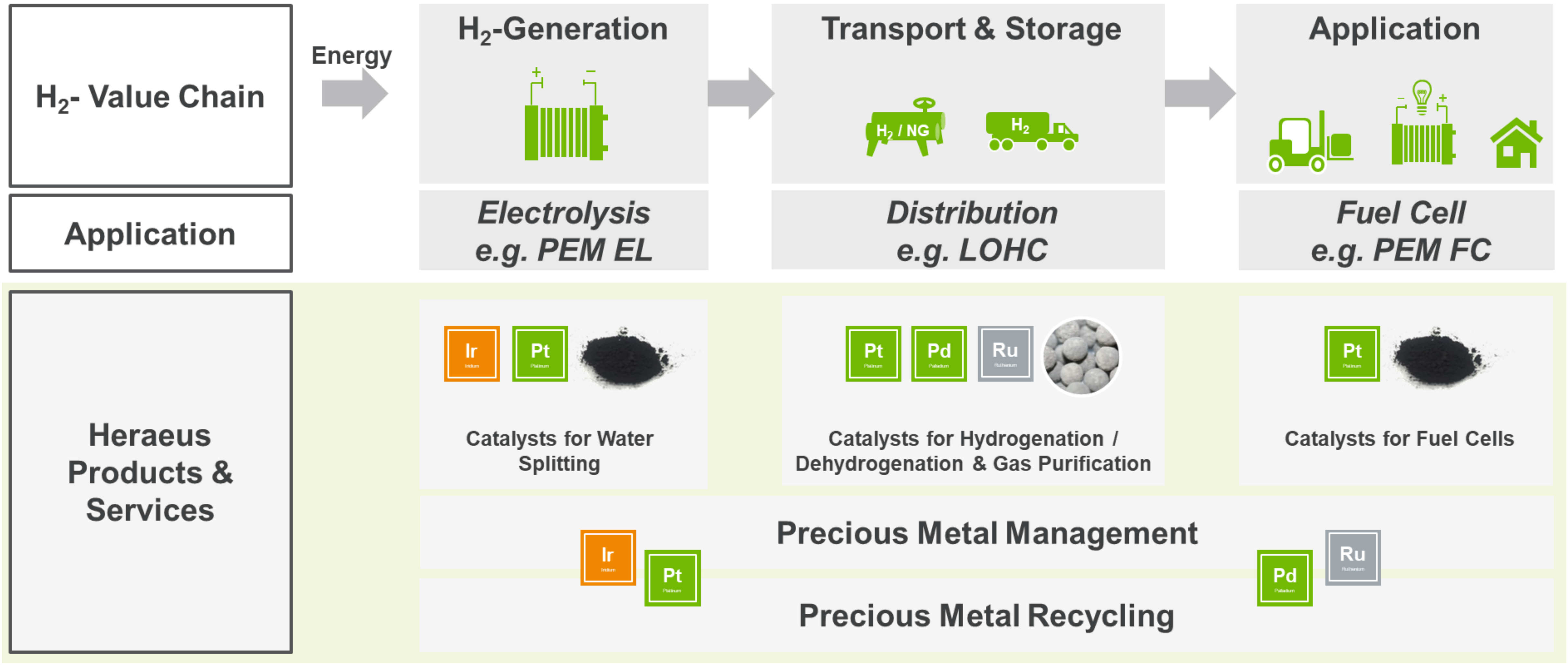
New H_2 applications

e.g. Replacement of coke in steel manu-facturing

Hydrogen is more than fuel cells and offers significant CO_2 reduction potential → 5 Gt/a until 2050[3)]

[1)] Own estimations from public announcements. [2)] SMR = Steam Methane Reforming, [3)] Barclays, *Hydrogen – a climate megatrend*, May 2020

PRECIOUS METALS AND THE HYDROGEN ECONOMY



The “Colors” of Hydrogen

Petrochemical processes with methane as feedstock

GREY	Steam **Methane** Reforming → CO_2
BLUE	Steam **Methane** Reforming → CO_2 captured
TURQUOISE	**Methane** Pyrolysis → Carbon by product

- **Carbon or carbon dioxide** as byproduct
- **Capturing and storage or valorization** of products is targeted
- **Blue and Turquoise as transition** towards a hydrogen economy

Electrolysis with water as feedstock

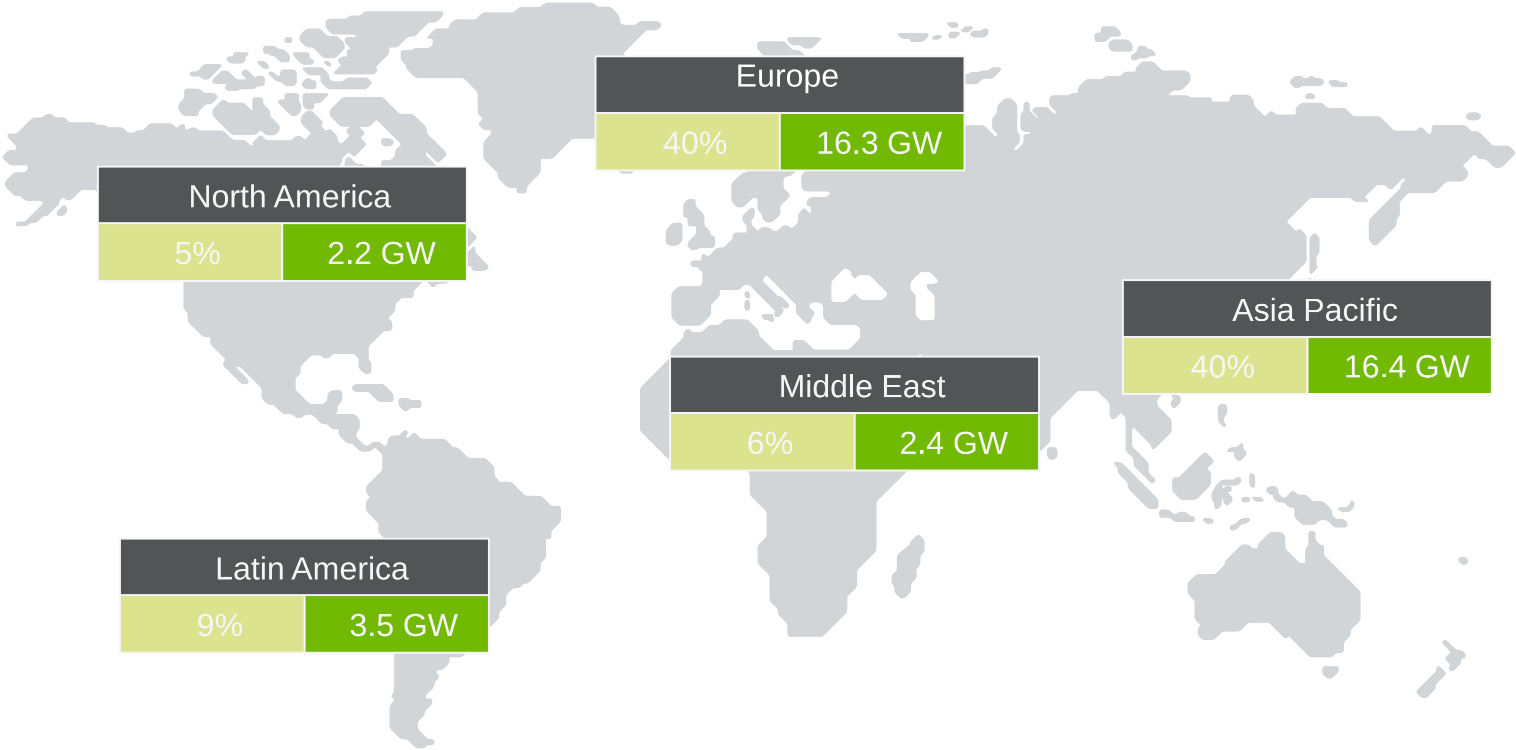
GREEN	**Water** Electrolysis using renewable energy
YELLOW	**Water** Electrolysis using nuclear energy

- **Cost competitive “CO_2-free” energy** required (wind, solar, water)
- **Nuclear Energy less preferred** due to safety concerns and nuclear waste

Green Hydrogen from water electrolysis as technology for the hydrogen future depends on renewable energy

GLOBAL ELECTROLYSIS PROJECT ANNOUNCEMENTS UNTIL 2030[1)]

- **Approx. 40 GW electrolyzer capacity announced until 2030** (Jan 2021) and increasing
- **National and regional roadmaps** pave the way
- **Massive capital deployment** from corporate world and governments
- Several **different use cases for hydrogen**
  - Enable the **renewable energy system**
  - Decarbonize end uses (**hard-to-abate sectors**)



1) McKinsey & Company Analysis, May 2021, incl. early stage capacity deployment with full commission after 2030

Announcements of > 40 GW are made globally, with highest momentum in APAC and EMEA

Electrolyzer technologies differ in maturity and strengths

	Alkaline	Proton exchange	Solid Oxide
Cost (USD/kW) 2020	750 - 770	800 - 1,400	2,500 - 3,500
Cost (USD/kW) 2030	440 - 555	345 - 460	300 - 500
+	› Established technology › Easy scalability › **No PGM catalysts**	› Simple cell design › High current density › Small footprint	› Low Power demand → "waste" steam › Potential for co-electrolysis › **No PGM catalysts**
-	› Larger footprint › Low output pressure › Highly flexible loads	› Scalability tbc › Lifetimes still below alkaline › **Catalysts w/ still high PGM loads**	› Still immature › Heat/steam source required to be competitive › Low output pressure

- **Cost of electrolyzer technologies to decrease** to < 550 USD/kW until 2030 (scale-up and industriali-zation of production)
- **Alkaline Electrolysis (AEL) most mature** technology
- With performance converging, **AEL and Proton Exchange Membrane (PEM) Electrolysis to be relevant across application segments**
- **Solid Oxide** Electrolysis **(SOE) for applications with process heat access** (e.g. synfuels, steel plants)
- **PEM** Electrolysis requires **platinum and iridium as electrode catalysts**

PEM and AEL to share market equally long-term - SOE limited to special applications

Source: CAPEX Median-values from Hydrogen Cost Roadmap, SOEC from IEA 2019, McKinsey

OVERVIEW OF ELECTROCATALYSTS FOR PEM ELECTROLYSIS

Anode

	Compound	g Ir per kW	Mass Activity
Standard	Ir Black	0.8 – 1.2	
Advanced	IrO_2	0.35 – 0.6	
Next Gen	$IrO(OH)_x/TiO_2$	0.08 – 0.2	
Future	Mixed Oxides	< 0.08	

- **Combination of IrO_x film on a low-corrosive support material** allowed for up to factor 15 lower Ir use (loading and activity)
- **Future approaches target mixed oxides**
- **Ir-free technology leads** are explored by the industry as long-term perspective

Cathode

	Compound	g Pt per kW	Mass Activity
Standard	Pt Black	0.3 – 0.5	
State-of-the-Art	Pt /Carbon	0.05 – 0.25	

- **Anode is seen as bigger cost and performance lever**
- Pt loadings can be reduced by **moving from standard Pt black to Pt on carbon catalysts**

Development focus in on anode side with significant progress in reducing Ir loading and improving performance

Standard electrolyzer catalysts for PEM Electrolysis

Standard catalysts are based on 100% PGM still

	Loading	Cumulative Demand till 2030[1)]	Supply
Pt Platinum	0.4 mt/GW	40 x 50% x 0.4 → **8 mt** *800 kg of Pt for 10 y*	190 mt/a[2)]
Ir Iridium	1.0 mt/GW	40 x 50% x 1.0 → **20 mt** *2 mt of Ir for 10 y*	8 mt/a[3)]

[1)] Based on announced global capacity in 2030 of 40 GW, 50% share for PEM

- **Primary supply of iridium is not sufficient to accompany the growth scenario for PEM Electrolysis** (2 mt/a additional demand vs. 8 mt/a supply)
- **Additional demand might evolve** due to additional electrolyzer projects
- **Platinum demand** from electrolyzers **can be digested**

PGMs contribute significantly to electrolyzer cost

1,100 USD/kW

6% PGM

$/oz
841 Pt
1,635 Ir

May 19th, 2020

1,350 USD/kW

17% PGM

$/oz
1,245 Pt
6,750 Ir

May 3rd, 2021

- **Price changes of PGMs have a significant impact**
- Since competing with AEL, **securing a cost advantage and stability** is important

Low PGM (in particular iridium) catalysts are needed to ensure the success of PEM Electrolysis long-term

[2)] Source: SFA Oxford, Quarterly Report Q1-2021, [3)] Estimation by Heraeus

Next Generation electrolyzer Catalysts for PEM Electrolysis from Heraeus

Next generation catalysts with lower PGM loading

	Loading	Cumulative Demand till 2030[1]	Supply
Pt Platinum	**0.1 mt/GW**	40 x 50% x 0.1 → **2 mt** *200 kg of Pt in 10 y*	**190 mt/a[2]**
Ir Iridium	**0.15 mt/GW**	40 x 50% x 0.15 → **3 mt** *300 kg of Ir in 10 y*	**8 mt/a[3]**

[1] Based on announced global capacity in 2030 of 40 GW, 50% share for PEM

- **Platinum and iridium loading reduced** by factor 4 and 5, respectively, at same or better performance.
- **Iridium market less impacted in the near term** and further reduction of iridium loadings necessary

Significantly lower impact of PGMs on electrolyzer cost

1,030 USD/kW

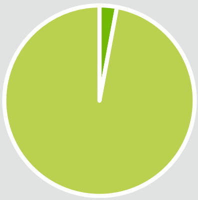
1% PGM

$/oz
841 Pt
1,635 Ir

May 19th, 2020

1,100 USD/kW

3% PGM



$/oz
1,245 Pt
6,750 Ir

May 3rd, 2021

- **Price hikes impact** the competitiveness of PEM Electrolysis **to a lesser extent**
- **Improved cost competitiveness** with AEL

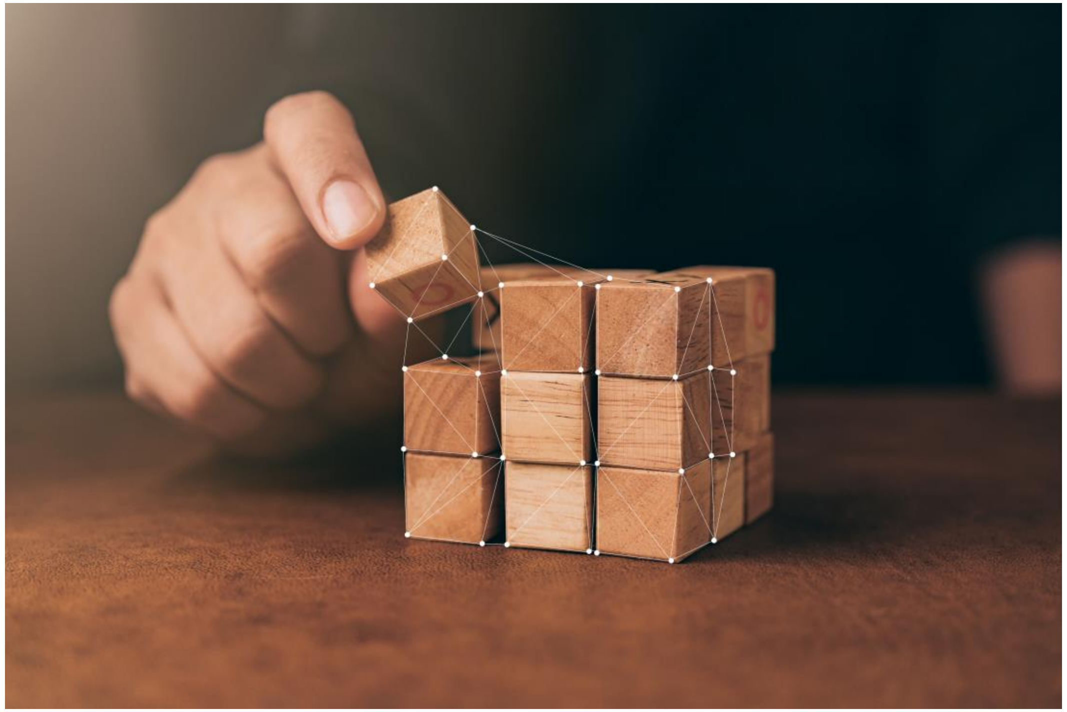
Next generation catalysts for PEM Electrolysis to make PEM Electrolysis successful exist and are at qualification stage

[2] Source: SFA Oxford, Quarterly Report Q1-2021, [3] Estimation by Heraeus

A HYDROGEN STRATEGY REQUIRES A RAW MATERIAL STRATEGY

European and National Hydrogen Strategies do not consider requirements for critical raw materials for the generation and use of hydrogen sufficiently! **We plead for…**

- Increase R&D for further **reduction of Iridium loadings**
- Increase R&D for **Recycling of Iridium**
  - Open up new recycling streams
  - Higher recycling rates
  - Subsidies for investments in recycling operations for precious metals from hydrogen applications
- Introduction of **“Top-Runner” Programs**
  - Link subsidies for PEM Electrolyzers to an efficient use of Iridium
- **Stronger involvement of producers of critical components** for electrolyzers in the political discussion concerning the ramp-up of an hydrogen economy



SUMMARY

- **The current Innovation Cycle is “green”** (Alternative feedstocks and circularity)
- **A Hydrogen economy is on the rise** and PEM Electrolysis will play a significant role
- **Platinum and Iridium are pivotal** elements of the PEM technology
- PEM Electrolysis in **GW scale requires low PGM catalysts**
- Heraeus has developed **next generation platinum and iridium catalysts**
- To explore the **full potential of PEM Electrolysis, further PGM reduction (especially iridium) and a raw material strategy (sourcing and recycling)** are needed long-term
- **Heraeus is committed to leverage its capabilities and** know-how around precious metals to accompany the growth of PEM Electrolysis

COMMITTED TO YOUR PRECIOUS NEEDS!

DISCLAIMER