Les enjeux des minéraux critiques et stratégiques dans la filière hydrogène

Bruno G. Pollet

President of the Green Hydrogen Division of the International Association for Hydrogen Energy (IAHE)

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Member of the Council of Engineers for the Energy Transition (CEET): An Independent Advisory Council to the United Nations' Secretary-General (UN)

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Director of the UQTR Green Hydrogen Lab

Journée bretonne Hydrogène R&D - Industries - formations

Piliers du développement de la filière hydrogène et piles à combustible en Bretagne

Jeudi 29 mai 2024 sur le campus de l'IUT et l'ENSM 38-40 Rue de la croix Desilles 35400 Saint Malo

NSERC CRSNG

UQTR Université du Québec à Trois-Rivières

IAHE Green Hydrogen Division

COUNCIL OF ENGINEERS FOR THE ENERGY TRANSITION
An independent advisory council to the United Nations Secretary-General

GREEN H2YDROGEN LAB

INNERGEX Renewable Energy

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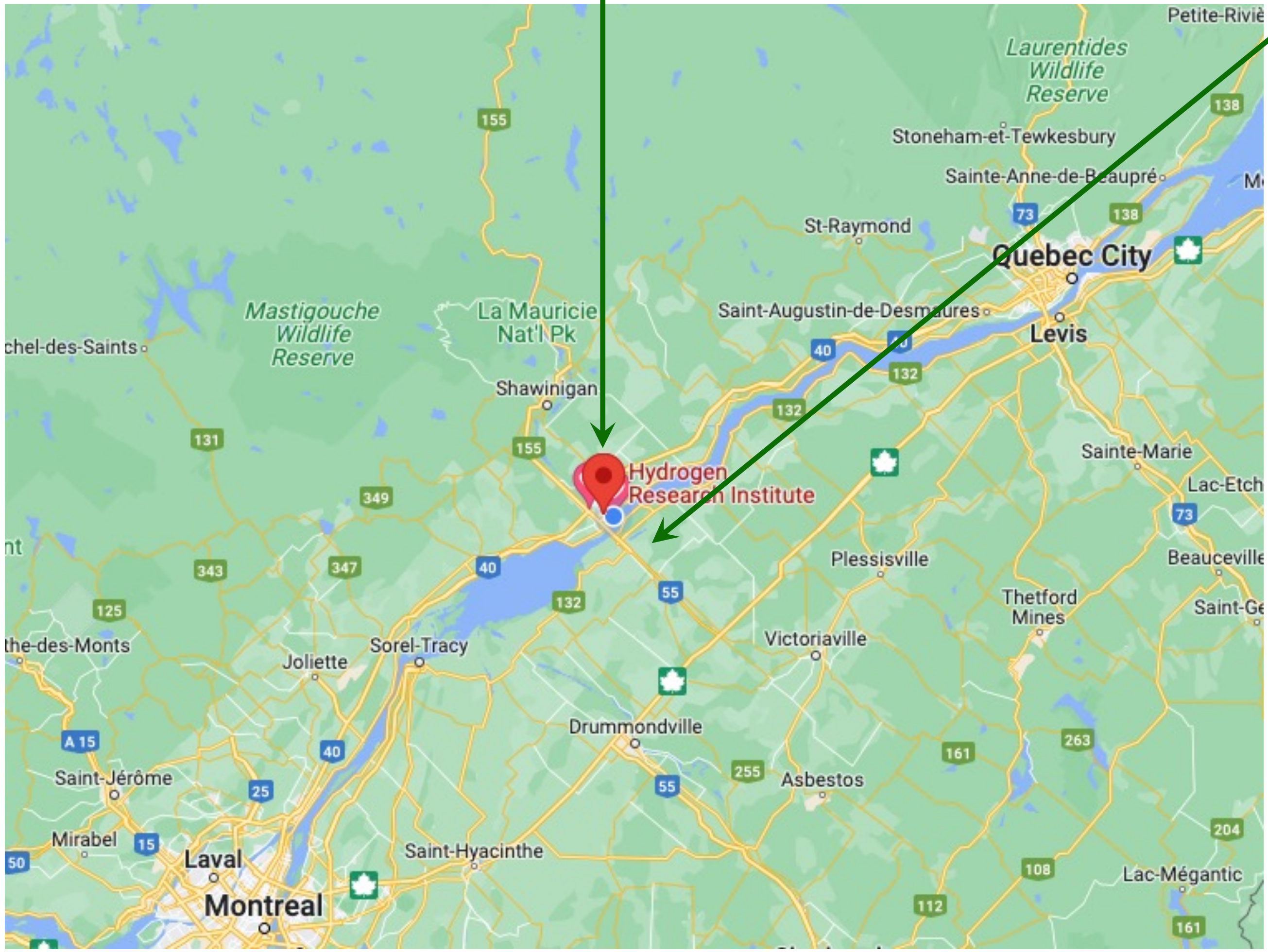
HRI HYDROGEN RESEARCH INSTITUTE UQTR



- **Air Liquide Hydrogen plant** – Home of the largest PEMWE electrolyser capacity (20MW, Cummins/Hydrogenics) in the world.
- **Innovation Zone** - Industrial Park on Decarbonation and Electrification.

RESEARCH AREAS

ELECTROLYSERS

Catalysts containing non-critical and strategic metals mined in Canada, Membranes, Electrodes, Transport layers, Bipolar plates, etc

PEM FUEL CELLS

Catalysts containing non-critical and strategic metals mined in Canada, Membranes, Electrodes, Bipolar plates, etc

TECHNO-ECONOMICS

Environmental Life Cycle Assessment and Techno-Economic Analysis

GREEN H_2YDROGEN LAB UQTR

IRH INSTITUT DE RECHERCHE SUR L'HYDROGÈNE UQTR

MATERIAL DISCOVERY

DFT Modeling, Artificial Intelligence

CO_2 VALORIZATION

Production of methanol and other green chemicals, CO2 conversion into value-added products

TRAINING

Academic, collegial and industrial

Research Funding

GREEN H2YDROGEN LAB

Government of Canada / Gouvernement du Canada

Canada

Chairholder	University	Chairholder title	Agency	Tier	Chair type
Pollet, Bruno	Université du Québec à Trois-Rivières	Canada Research Chair in Green Hydrogen Production	NSERC	Tier 1	New

NSERC Tier 1 Canada Research Chair in Green Hydrogen Production (7 years, $1.4m)

INNOVATION
Canada Foundation for Innovation / Fondation canadienne pour l'innovation

>$0.5m

INNERGEX Renewable Energy

INNERGEX Research Chair in Green Hydrogen Production (5 years, >$0.6m)

Québec
Ministère de l'Économie et de l'Innovation

3 years, >$0.5m

Chem Soc Rev

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REVIEW ARTICLE

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Water electrolysis: from textbook knowledge to the latest scientific strategies and industrial developments†

Marian Chatenet,[a] Bruno G. Pollet,[bc] Dario R. Dekel,[de] Fabio Dionigi,[f] Jonathan Deseure,[a] Pierre Millet,[gh] Richard D. Braatz,[i] Martin Z. Bazant,[ij] Michael Eikerling,[kl] Iain Staffell,[m] Paul Balcombe,[n] Yang Shao-Horn[o] and Helmut Schäfer*[p]

Replacing fossil fuels with energy sources and carriers that are sustainable, environmentally benign, and affordable is amongst the most pressing challenges for future socio-economic development. To that goal, hydrogen is presumed to be the most promising energy carrier. Electrocatalytic water splitting, if driven by green electricity, would provide hydrogen with minimal CO_2 footprint. The viability of water electrolysis still hinges on the availability of durable earth-abundant electrocatalyst materials and the

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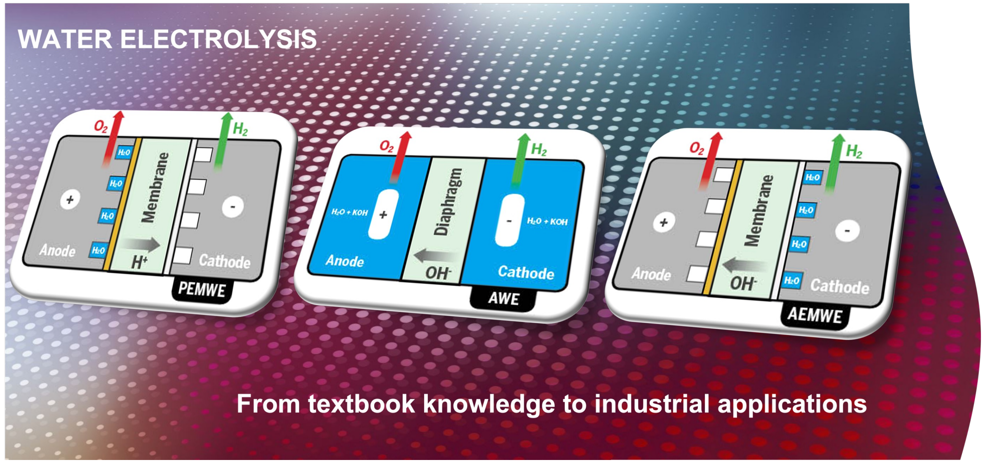

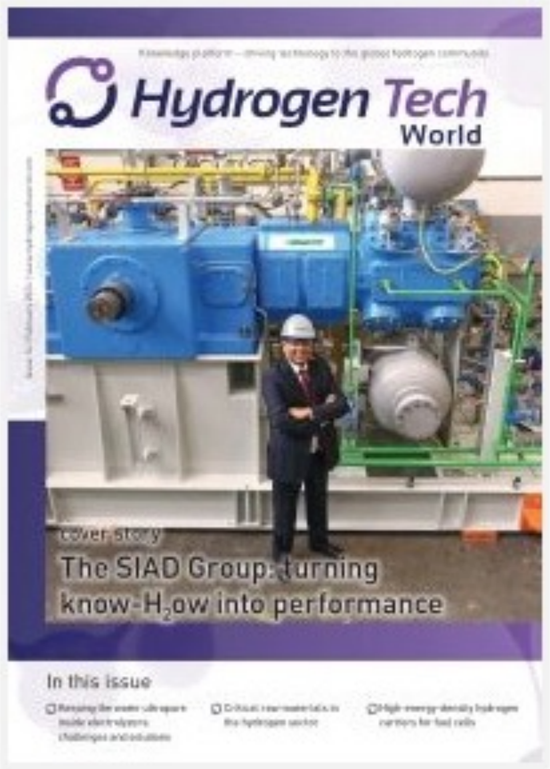

Critical raw materials in the hydrogen sector

Although the implementation of global renewable electricity generation capacity is increasing exponentially, with the goal of tripling it by 2030 as established by COP28, the world's renewable hydrogen production capacity is lagging behind. The International Energy Agency (IEA) has recently lowered its five-year forecast for renewable power capacity dedicated to renewable hydrogen production (2023–2028) to 45 GW. It goes without saying that the hydrogen sector will require a substantial amount of critical raw materials (CRMs), for instance, for fuel cells, electrolysers, hydrogen separation, hydrogen storage, and hydrogen transport.

By Bruno G. Pollet, Director of the Hydrogen Research Institute at the Université du Québec à Trois-Rivières

The equation is simple:
no CRM = no renewables and
no hydrogen revolution!

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Review Article

Critical and strategic raw materials for electrolysers, fuel cells, metal hydrides and hydrogen separation technologies

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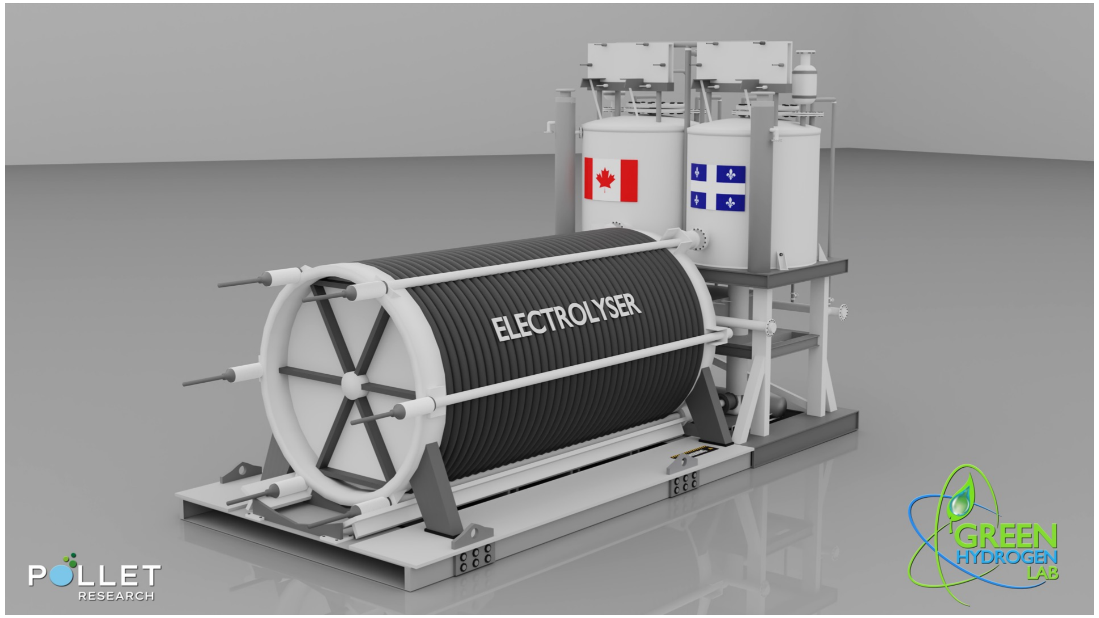
Fuel cell technologies
Sustainable energy

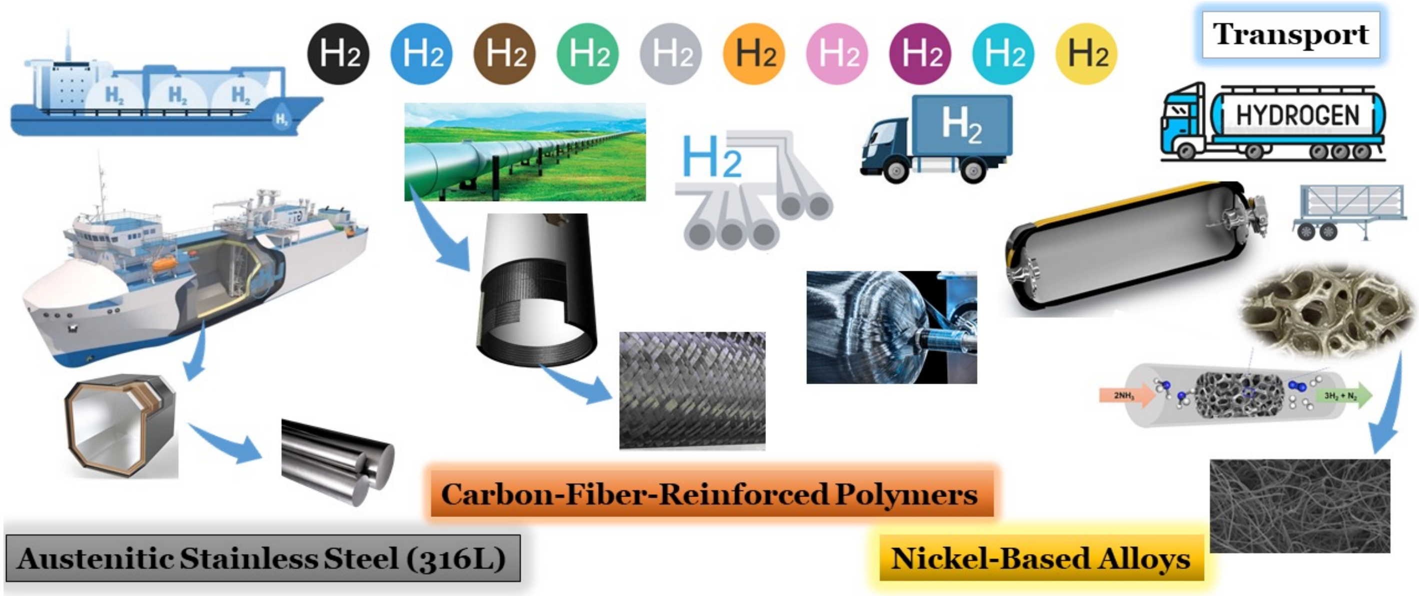
ABSTRACT

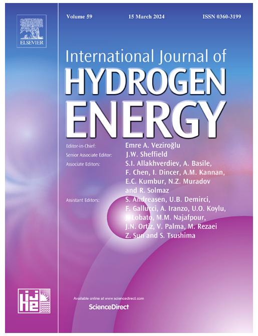
This paper provides an in-depth examination of critical and strategic raw materials (CRMs) and their crucial role in the development of electrolyzer and fuel cell technologies within the hydrogen economy. It methodically analyses a range of electrolyzer technologies, including alkaline, proton-exchange membrane, solid-oxide, anion-exchange membrane, and proton-conducting ceramic systems.

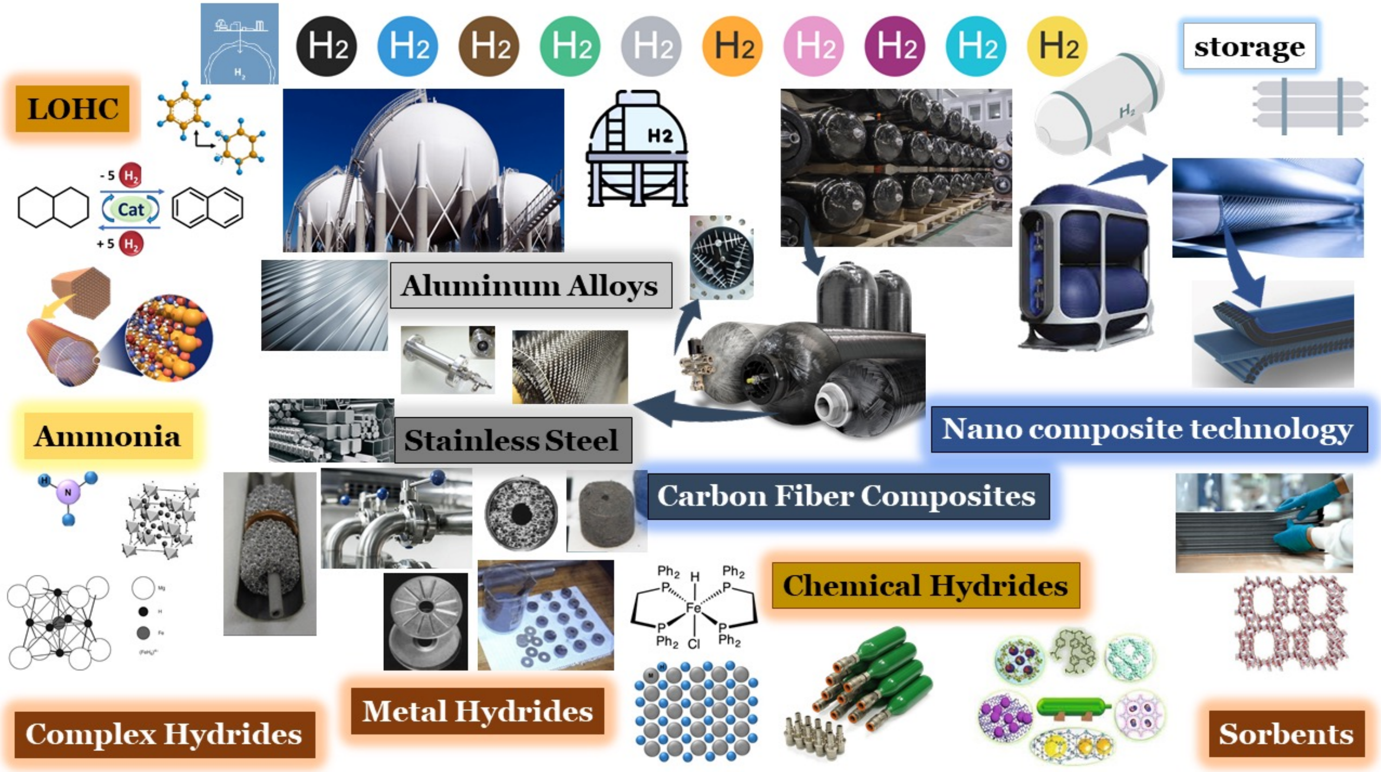
Each technology is examined for its specific CRM dependencies, operational characteristics, and the challenges associated with CRM availability and sustainability. The study further extends to hydrogen storage and separation technologies, focusing on the materials employed in high-pressure cylinders, metal hydrides, and hydrogen separation processes, and their CRM implications.

A key aspect of this paper is its exploration of the supply and demand dynamics of CRMs, offering a comprehensive view that encompasses both the present sttate and future projections. The aim is to uncover potential supply risks, understand strategies, and identify potential bottlenecks for materials involved in electrolyzer and fuel cell technologies, addressing both current needs and future demands as well as supply. This approach is essential for the strategic planning and sustainable development of the hydrogen sector, emphasizing the importance of CRMs in achieving expanded electrolyzer capacity leading up to 2050.


ELECTROLYSER
POLLET
RESEARCH
GREEN
HYDROGEN
LAB


Transport
HYDROGEN
H2
Carbon-Fiber-Reinforced Polymers
Austenitic Stainless Steel (316L)
Nickel-Based Alloys


International Journal of
HYDROGEN
ENERGY


storage
H2
LOHC
Cat
Aluminum Alloys
Ammonia
Stainless Steel
Nano composite technology
Carbon Fiber Composites
Chemical Hydrides
Complex Hydrides
Metal Hydrides
Sorbents

Main Barriers

- Production, transportation, and distribution costs as well as infrastructure development;
- Policy and regulatory framework development and harmonization between regions;
- Lack of market structure and off-takers (demand uncertainty);
- Lack of financial support in the early stage of deployment;
- Access to natural resources;
- Environmental and safety issues.

Hydrogen has no colour…This is a fact!

INSTITUTE FOR HYDROGEN RESEARCH

The Hydrogen Colour Spectrum

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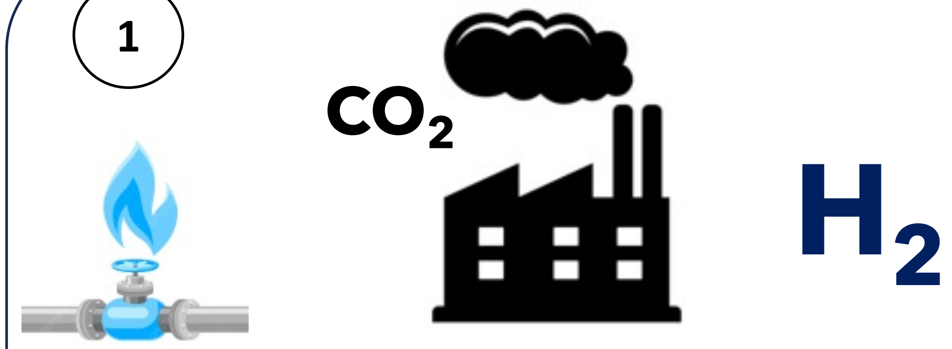
	Colour	Primary Energy / Source of Electricity	Technology	Technology Readiness Level (TRL)	Efficiency	Carbon Footprint	Terminology
Production -Fossil Fuels-	Blue Hydrogen	Natural Gas, Coal + Carbon Capture Sequestration (CCS)	Steam Reforming / Gasification	5-9	80%	Low < 3 kg CO_2-eq / kg H_2	Low-carbon Hydrogen
	Brown Hydrogen	Lignite	Gasification	Mature	<60%	Very High > 20 kg CO_2-eq / kg H_2	High-carbon Hydrogen (Fossil Hydrogen)
	Black Hydrogen	Bituminous Coal		Mature	<60%	Very High > 20 kg CO_2-eq / kg H_2	High-carbon Hydrogen (Fossil Hydrogen)
	Grey Hydrogen	Natural Gas	Steam Reforming	Mature	<85%	Medium to High <15 kg CO_2-eq / kg H_2	High-carbon Hydrogen (Fossil Hydrogen)
			Autothermal Reforming	Mature	<95%	Medium to High <15 kg CO_2-eq / kg H_2	High-carbon Hydrogen (Fossil Hydrogen)
			Partial Oxidation	6-9	<75%	Medium to High <15 kg CO_2-eq / kg H_2	High-carbon Hydrogen (Fossil Hydrogen)
	Turquoise Hydrogen	Natural Gas Biomethane Refuse Derived Fuels	Pyrolysis	6-8	<50%	Low < 3 kg CO_2-eq / kg H_2 + Carbon Black (CB)	Low-carbon Hydrogen
Production -Biomass-	Green Hydrogen	Biomass	Thermolysis	3	<50%	Low < 3 kg CO_2-eq / kg H_2	Renewable Hydrogen
		Biomethane	Steam Reforming	9	<85%	Low < 3 kg CO_2-eq / kg H_2	Renewable Hydrogen
Production -Electricity-		Renewable Energies (Solar, Wind, Hydro etc)	Water Electrolysis	6-9	<50%	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
	Pink Hydrogen	Nuclear		8	<70%	Minimal < 1-2 kg CO_2-eq / kg H_2	Low-carbon Hydrogen
	Yellow Hydrogen	Electrical Network		Mature	<50%	Depending on source for producing electricity	Depending on source for producing electricity

Hydrogen has no colour…This is a fact!

Production -Others-	Unclassified	Water	Photoelectrolysis	3	15%	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
			Photochemical	3	15%	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
			Thermochemical	3-5	<50%	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
		Biomass	Bioelectrolysis	3	-	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
			Biophotolysis	4	-	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
			Dark Fermentation	8	50-70%	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
			Photo Fermentation	8	30-50%	Minimal 0 kg CO_2-eq / kg H_2	Renewable Hydrogen
Naturally Occurring	White Hydrogen						

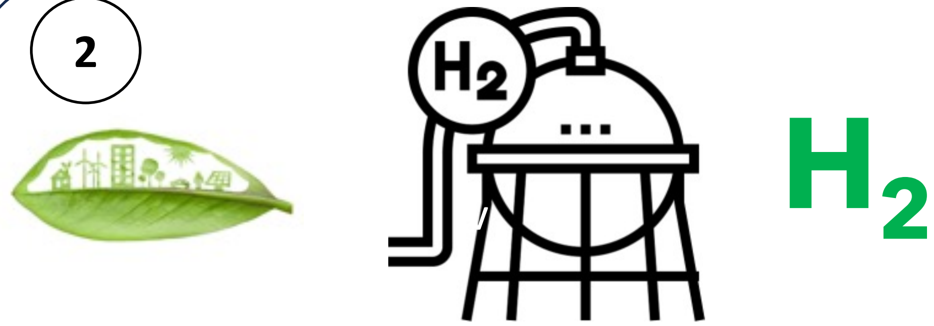
Main LCH_2/RH_2 Production

1



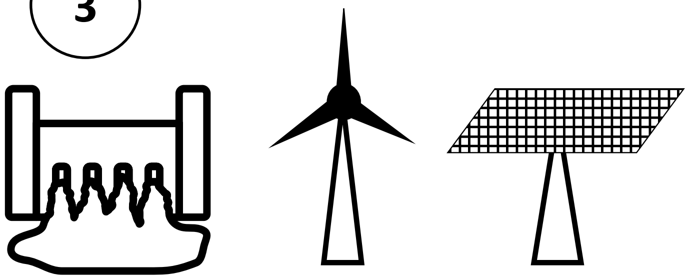
NATURAL GAS REFORMING WITH CARBON CAPTURE AND STORAGE (CCS)

2



BIOMASS GASIFICATION

3

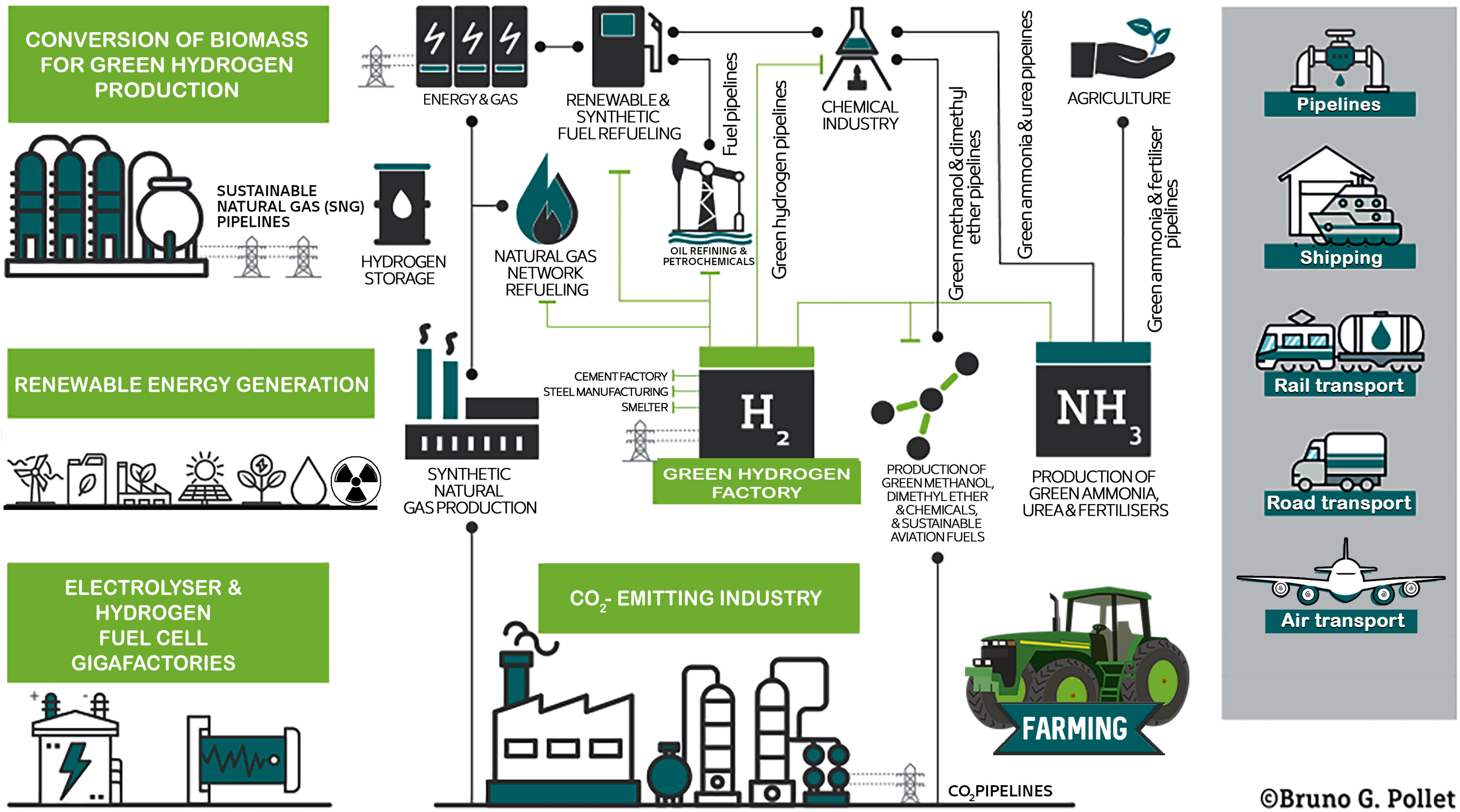


RENEWABLE ENERGY

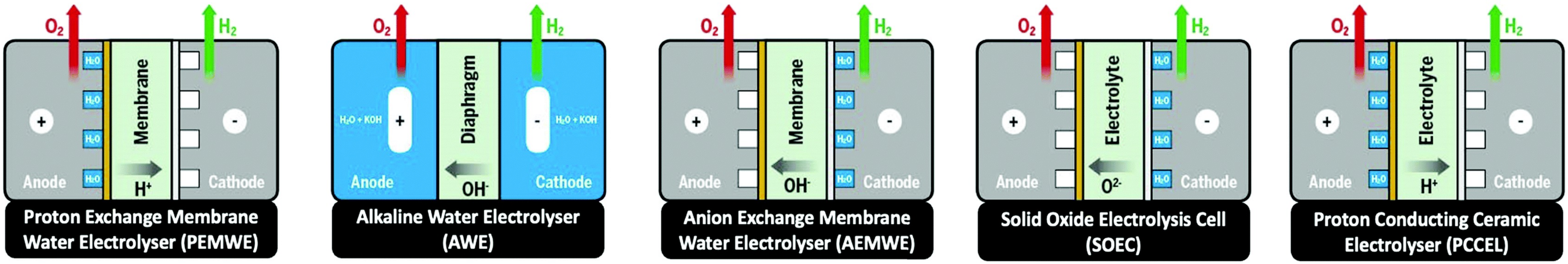
$H_2O + e^- \rightarrow H_2 + \frac{1}{2}O_2$

ELECTROLYSER

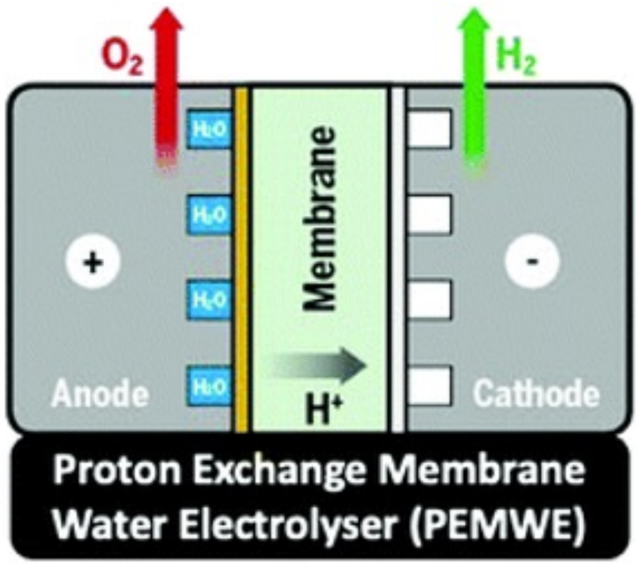
LCH2 and RH2 VALUE CHAIN

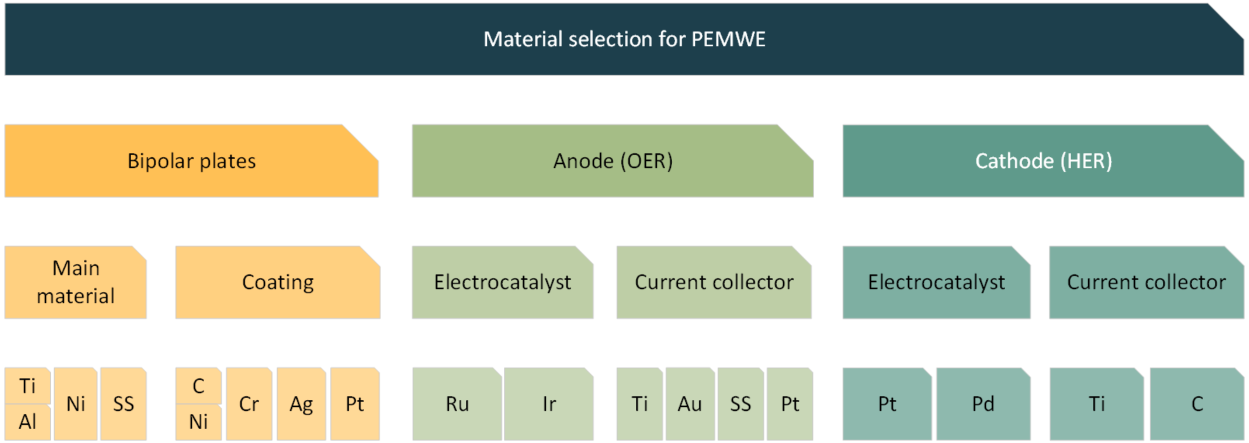


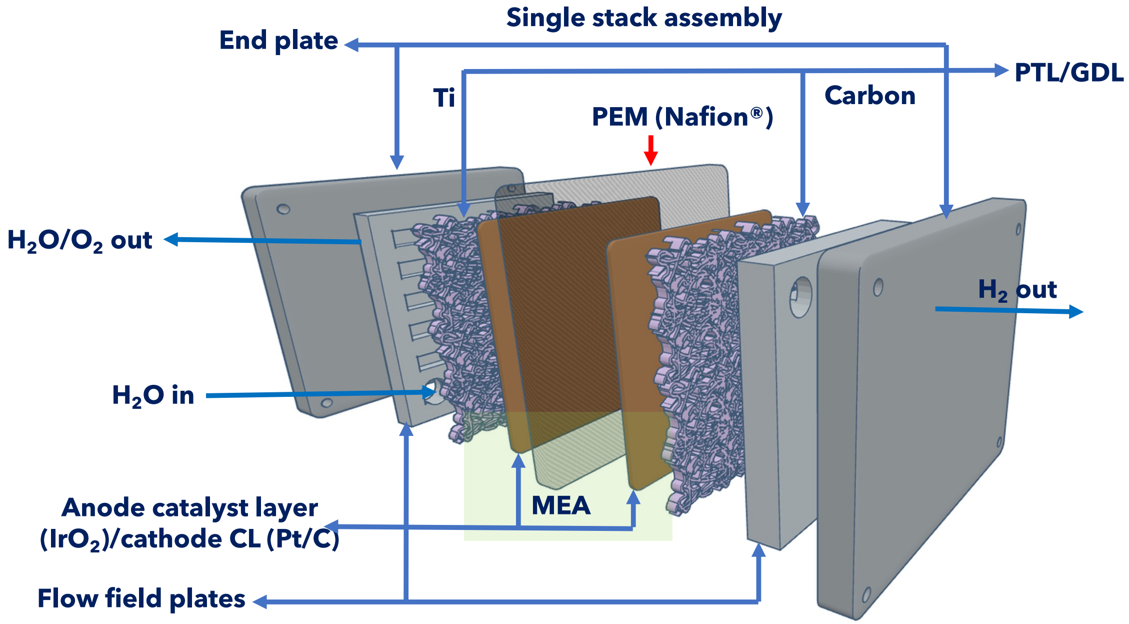
WATER ELECTROLYSERS

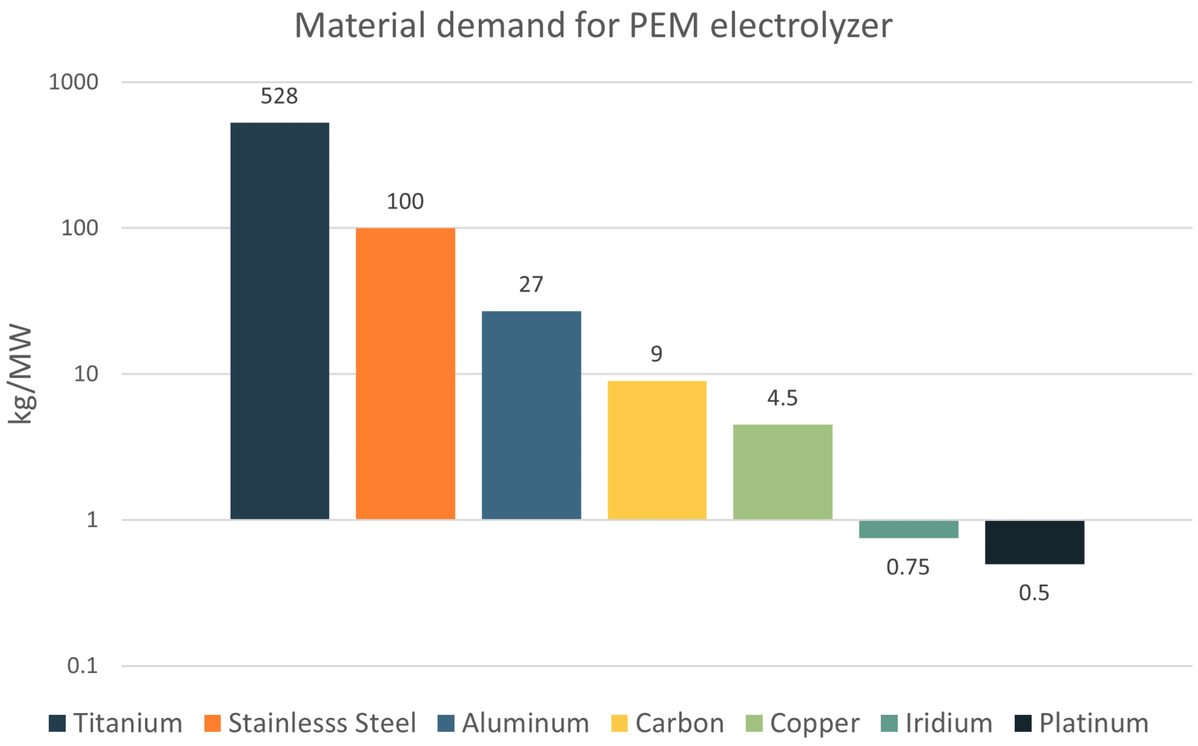


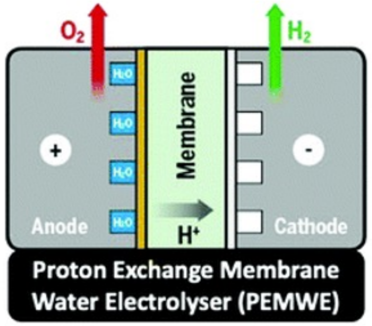
	PEMWE	AWE	AEMWE	SOEC	PCCEL
Operating temperature	50–80 °C	70–90 °C	40–60 °C	700–850 °C	300–600 °C
Operating pressure	<70 bar	1–30 bar	<35 bar	1 bar	1 bar
Electrolyte	PFSA membranes	Potassium hydroxide (KOH) 5–7 mol L^{-1}	DVB polymer support with KOH or $NaHCO_3$ 1 mol L^{-1}	Yttria-stabilised zirconia (YSZ)	(Y,Yb)-Doped-$Ba(Ce,Zr)O_{3-\delta}$
Separator	Solid electrolyte (above)	ZrO_2 stabilised with PPS mesh	Solid electrolyte (above)	Solid electrolyte (above)	Solid electrolyte (above)
Electrode/catalyst (oxygen side)	Iridium oxide	Nickel coated perforated stainless steel	High surface area nickel or NiFeCo alloys	Perovskite-type (*e.g.*, LSCF, LSM)	Perovskite-type (*e.g.*, LSCF, LSM
Electrode/catalyst (hydrogen side)	Platinum nanoparticles on carbon black	Nickel coated perforated stainless steel	High surface area nickel	Ni/YSZ	Ni/YSZ, Ni-BZY/LSC, BCFYZ
Porous transport layer anode	Platinum coated sintered porous titanium	Nickel mesh (not always present)	Nickel foam	Coarse nickel-mesh or foam	Coarse nickel-mesh or foam
Porous transport layer cathode	Sintered porous titanium or carbon cloth	Nickel mesh	Nickel foam or carbon cloth	None	None
Bipolar plate anode	Platinum-coated titanium	Nickel-coated stainless steel	Nickel-coated stainless steel	None	None
Bipolar plate cathode	Gold-coated titanium	Nickel-coated stainless steel	Nickel-coated stainless steel	Cobalt-coated stainless steel	Cobalt-coated stainless steel
Frames and sealing	PTFE, PSU, ETFE	PSU, PTFE, EPDM	PTFE, silicon	Ceramic glass	Ceramic glass


O2
H2
H2O
Membrane
+
-
Anode
H+
Cathode
Proton Exchange Membrane
Water Electrolyser (PEMWE)


Material selection for PEMWE
Bipolar plates
Anode (OER)
Cathode (HER)
Main material
Coating
Electrocatalyst
Current collector
Electrocatalyst
Current collector
Ti
Al
Ni
SS
C
Ni
Cr
Ag
Pt
Ru
Ir
Ti
Au
SS
Pt
Pt
Pd
Ti
C

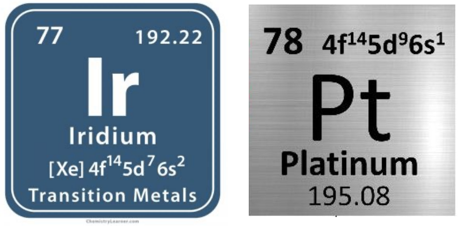

Single stack assembly
End plate
PTL/GDL
Ti
Carbon
PEM (Nafion®)
H2O/O2 out
H2 out
H2O in
MEA
Anode catalyst layer
(IrO2)/cathode CL (Pt/C)
Flow field plates

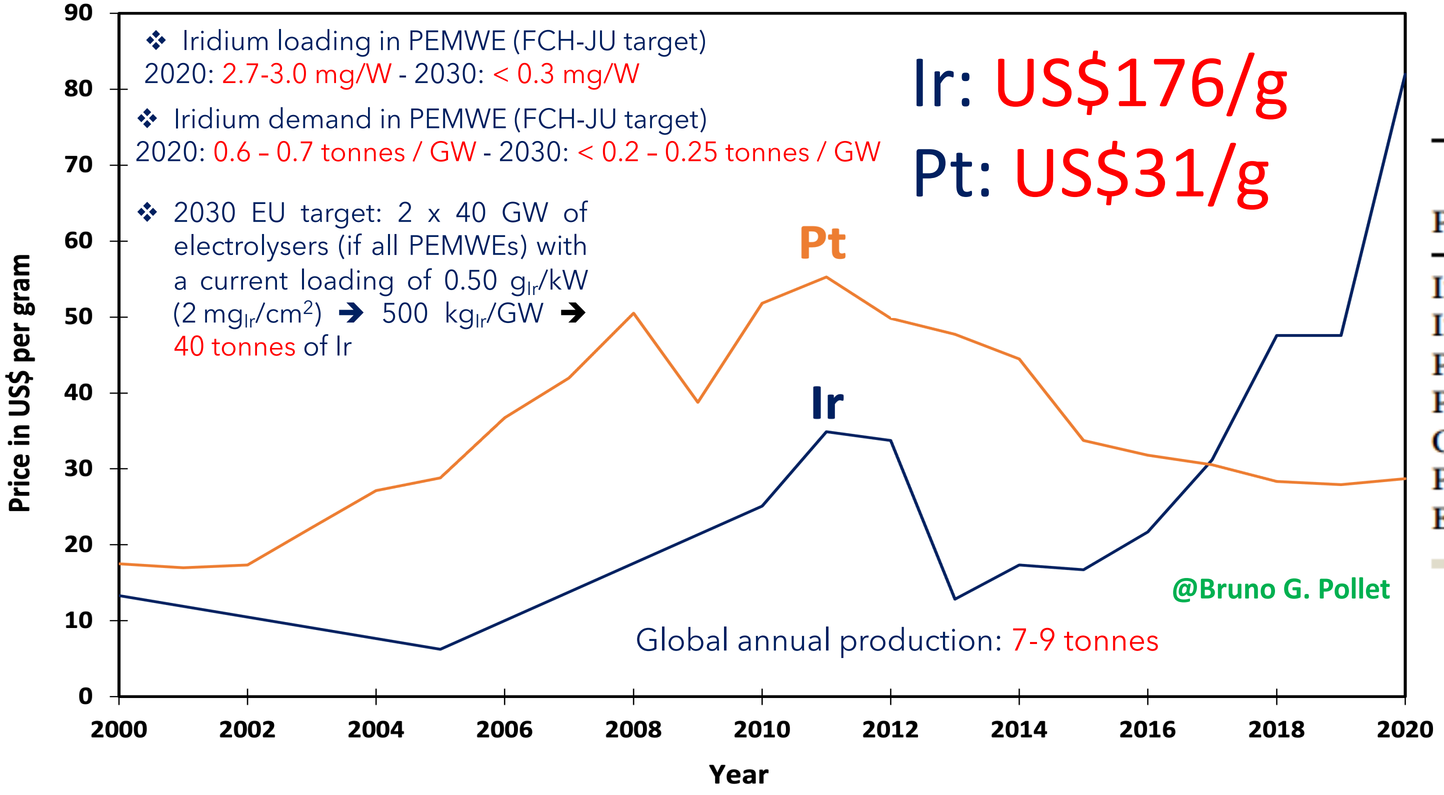

Material demand for PEM electrolyzer
kg/MW
1000
100
10
1
0.1
528
100
27
9
4.5
0.75
0.5
Titanium
Stainlesss Steel
Aluminum
Carbon
Copper
Iridium
Platinum



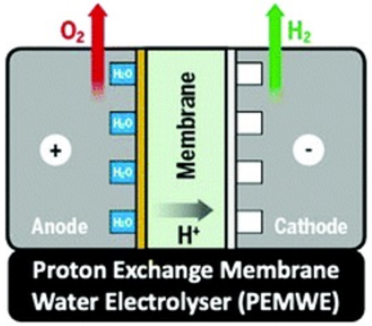
Critical and Strategic Minerals (CSM)

PGM – Platinum Group Metals



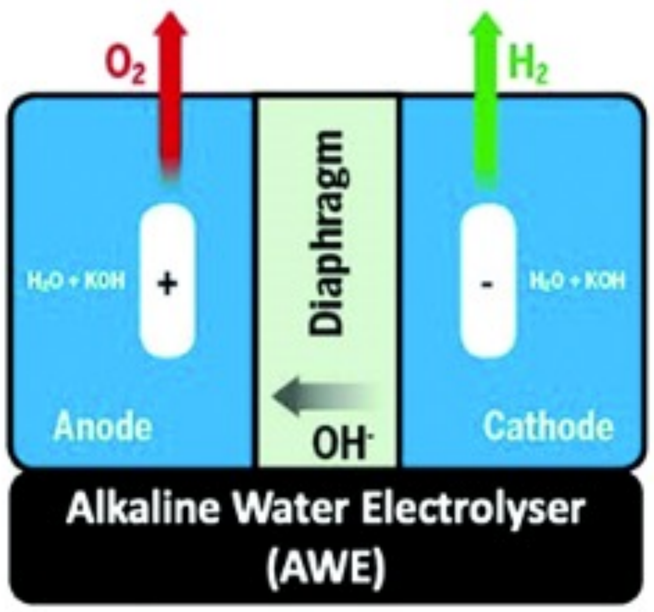


Parameter	2020 status	2020 target	2035 target	Future
Ir (mg cm^{-2})	2–5	1	0.2–0.40	0.05–0.2
Ir (g kW^{-1})	<2.5 (0.33/0.5/0.67)	0.40	0.05–0.4	0.01–0.4
Pt (mg cm^{-2})	1–2	1	0.5	0.05
Pt (g kW^{-1})	0.5–1	0.5	0.25	0.1
Current density (A cm^{-2})	2	2	3	5
Power density (W cm^{-2})	3	3	8	10
Electrode area (m^2)	0.12	—	—	0.50

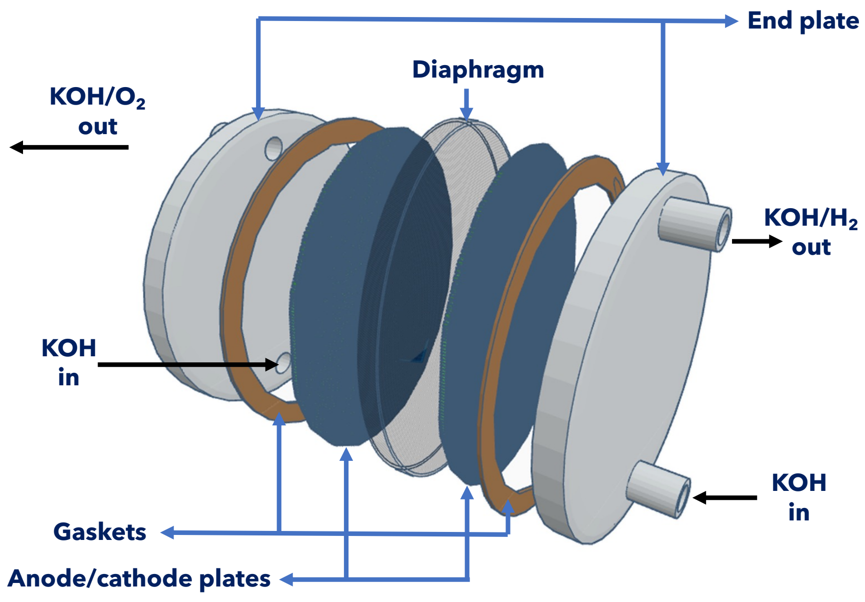


Iridium (Ir) in PEMWE

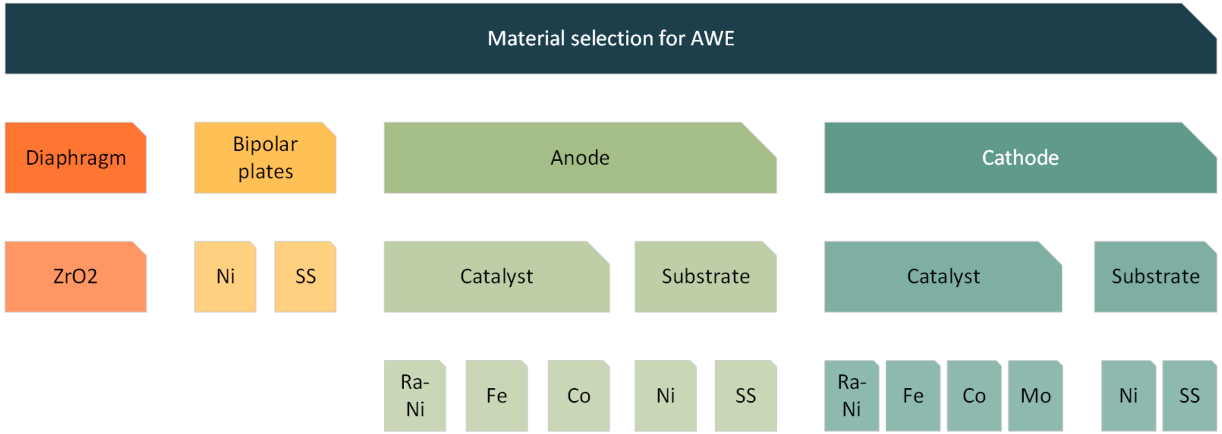
- 0.2 - 0.5 kg of Ir per MW.
- 200 - 500 kg of Ir per GW.
- **US$100 000** of Ir in 1 MW.
- **US$100 000 000** of Ir per 1 GW.
- To produce **6 000 000 tonnes of hydrogen require 40 GW of PEMWE and 20 tonnes of Ir!**



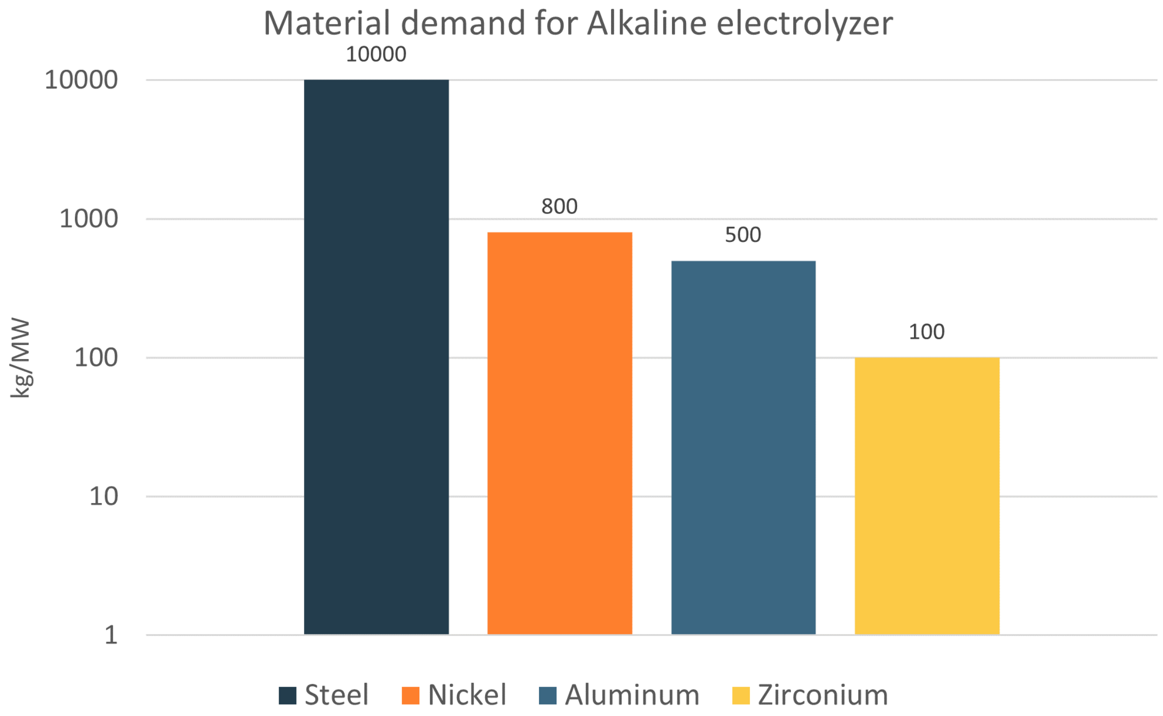
O_2
H_2
Diaphragm
$H_2O + KOH$
+
-
$H_2O + KOH$
Anode
OH^-
Cathode
Alkaline Water Electrolyser
(AWE)



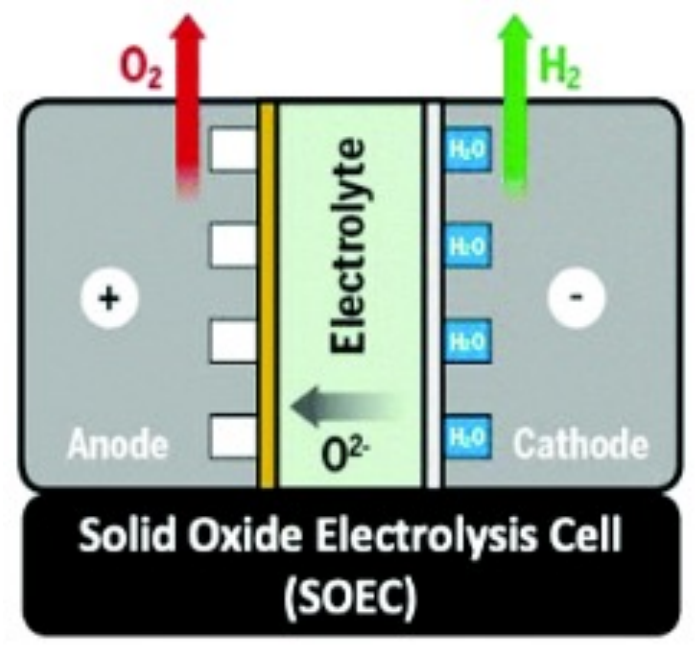
End plate
Diaphragm
KOH/O_2 out
KOH/H_2 out
KOH in
KOH in
Gaskets
Anode/cathode plates

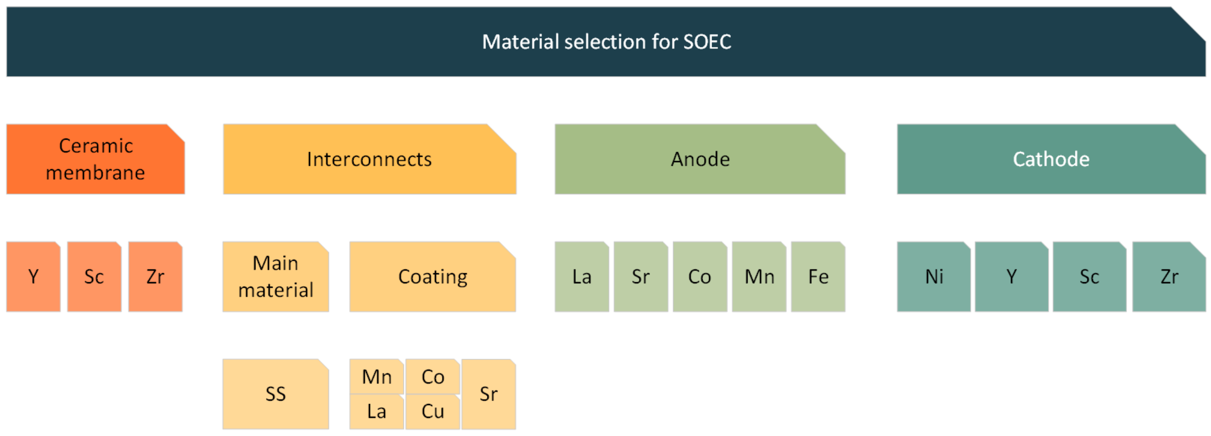


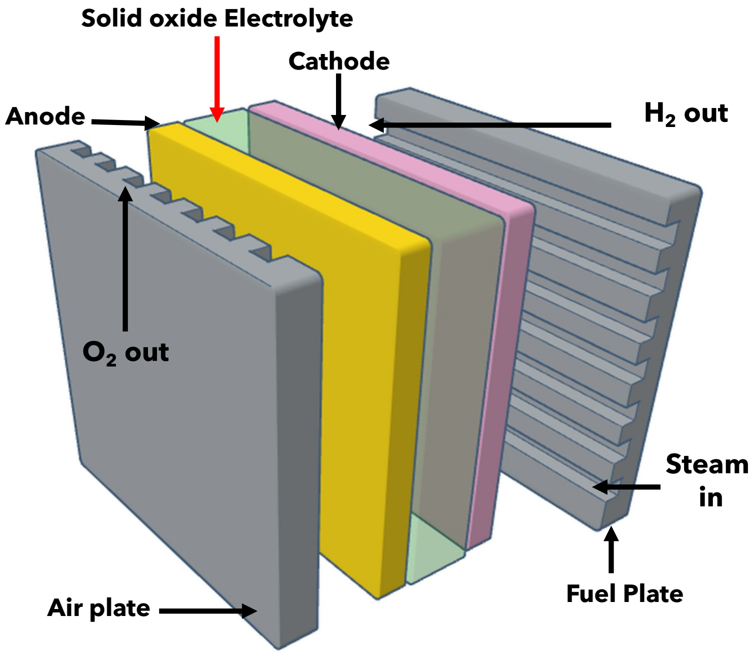
Material selection for AWE
Diaphragm
Bipolar plates
Anode
Cathode
ZrO2
Ni
SS
Catalyst
Substrate
Catalyst
Substrate
Ra-Ni
Fe
Co
Ni
SS
Ra-Ni
Fe
Co
Mo
Ni
SS

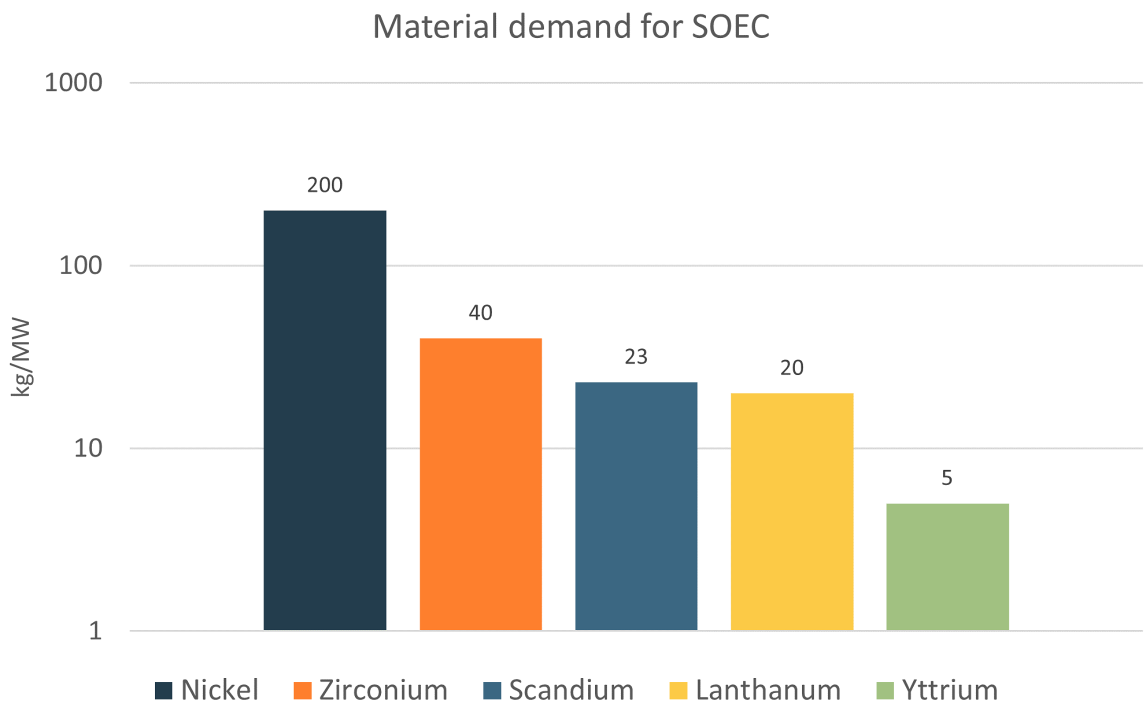


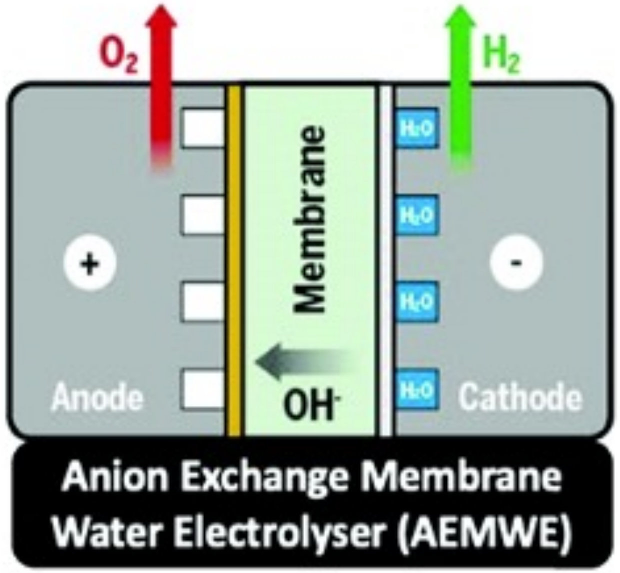
Material demand for Alkaline electrolyzer
kg/MW
10000
1000
100
10
1
10000
800
500
100
Steel
Nickel
Aluminum
Zirconium

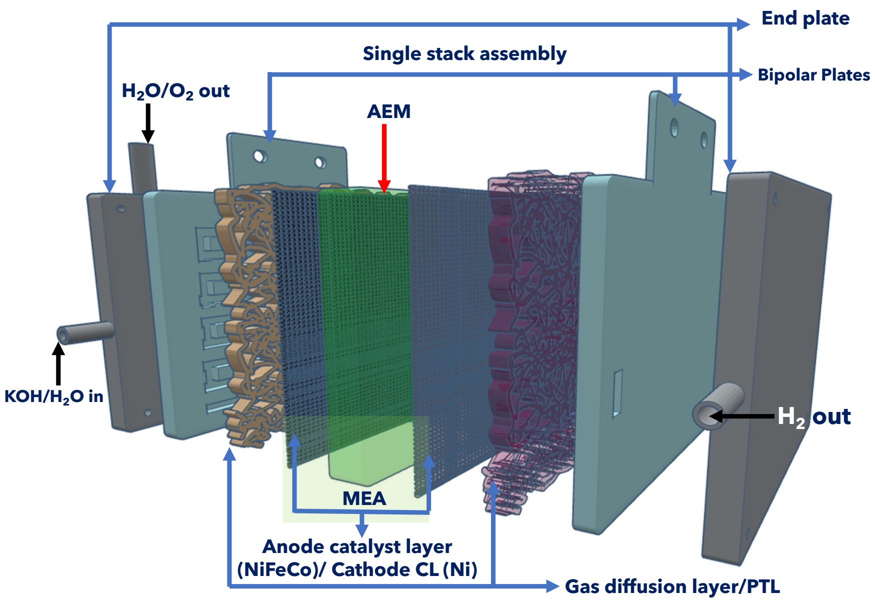

O_2
H_2
Electrolyte
+
-
H_2O
Anode
O^{2-}
Cathode
Solid Oxide Electrolysis Cell
(SOEC)

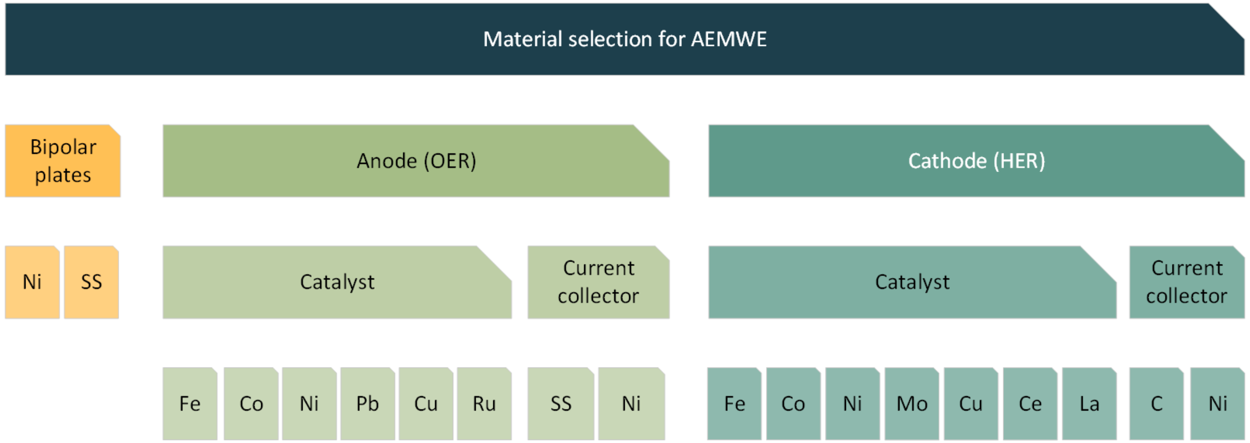

Material selection for SOEC
Ceramic membrane
Interconnects
Anode
Cathode
Y
Sc
Zr
Main material
Coating
La
Sr
Co
Mn
Fe
Ni
Y
Sc
Zr
SS
Mn
Co
La
Cu
Sr

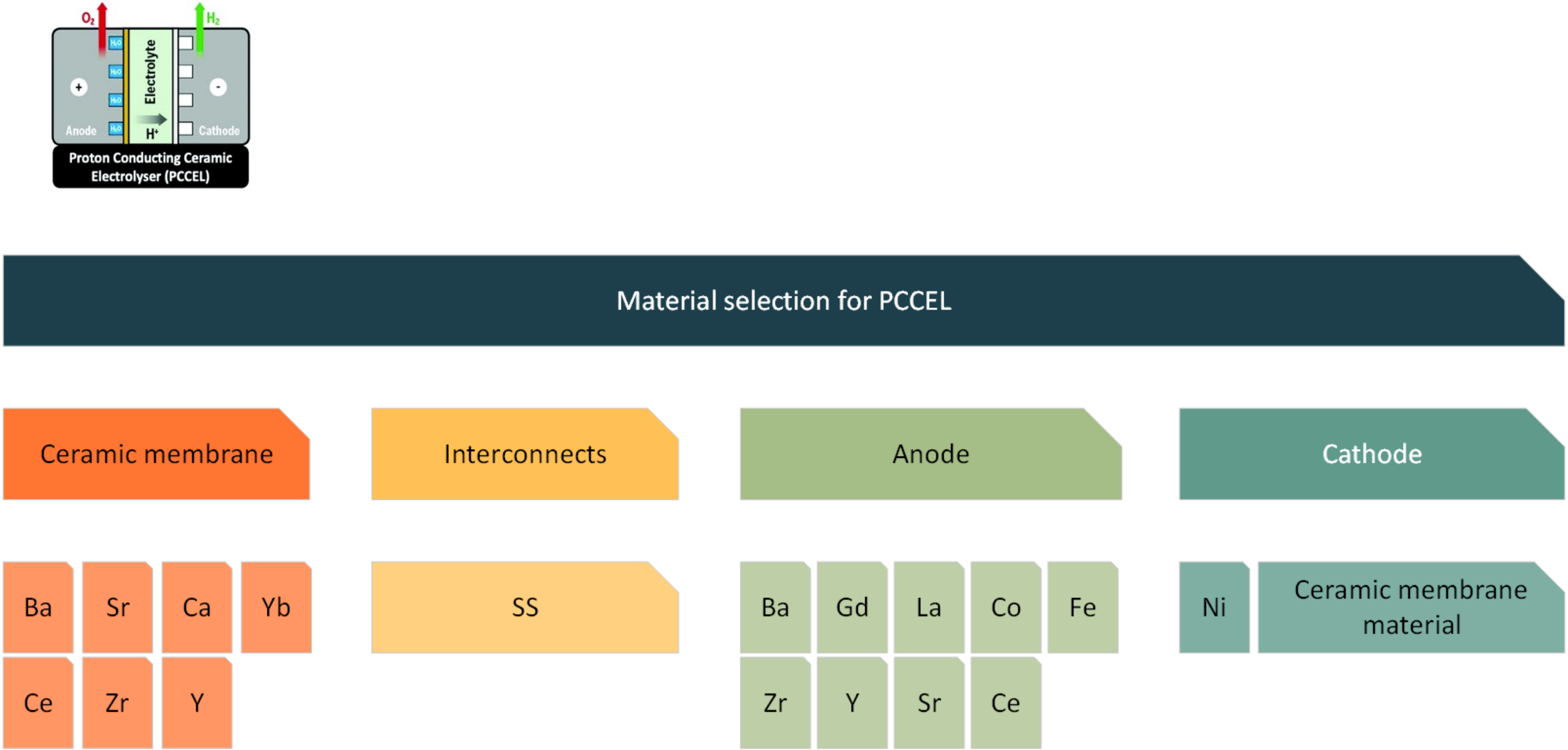

Solid oxide Electrolyte
Cathode
Anode
H_2 out
O_2 out
Steam in
Air plate
Fuel Plate


Material demand for SOEC
1000
100
10
1
kg/MW
200
40
23
20
5
Nickel
Zirconium
Scandium
Lanthanum
Yttrium


O2
H2
Membrane
H2O
+
-
Anode
OH-
Cathode
Anion Exchange Membrane
Water Electrolyser (AEMWE)

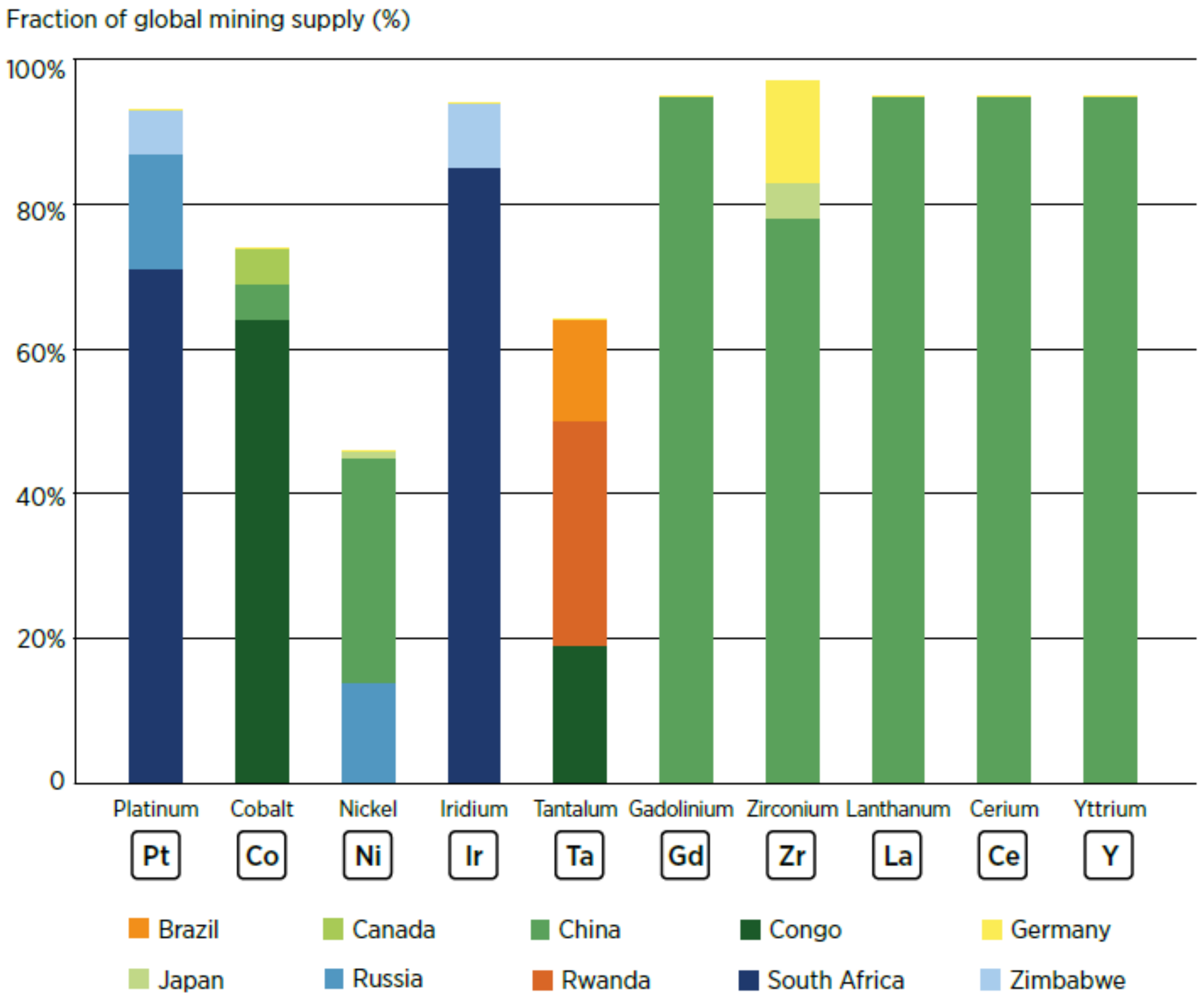

End plate
Single stack assembly
Bipolar Plates
H2O/O2 out
AEM
KOH/H2O in
H2 out
MEA
Anode catalyst layer
(NiFeCo)/ Cathode CL (Ni)
Gas diffusion layer/PTL


Material selection for AEMWE
Bipolar plates
Anode (OER)
Cathode (HER)
Ni
SS
Catalyst
Current collector
Catalyst
Current collector
Fe
Co
Ni
Pb
Cu
Ru
SS
Ni
Fe
Co
Ni
Mo
Cu
Ce
La
C
Ni



O2
H2
H2O
Electrolyte
+
-
Anode
H+
Cathode
Proton Conducting Ceramic Electrolyser (PCCEL)
Material selection for PCCEL
Ceramic membrane
Interconnects
Anode
Cathode
Ba
Sr
Ca
Yb
Ce
Zr
Y
SS
Ba
Gd
La
Co
Fe
Zr
Y
Sr
Ce
Ni
Ceramic membrane material

Top Producers of Critical Materials in Electrolysers

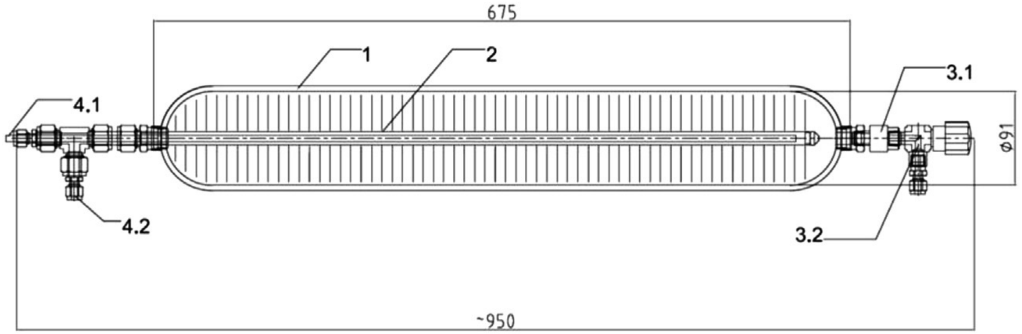


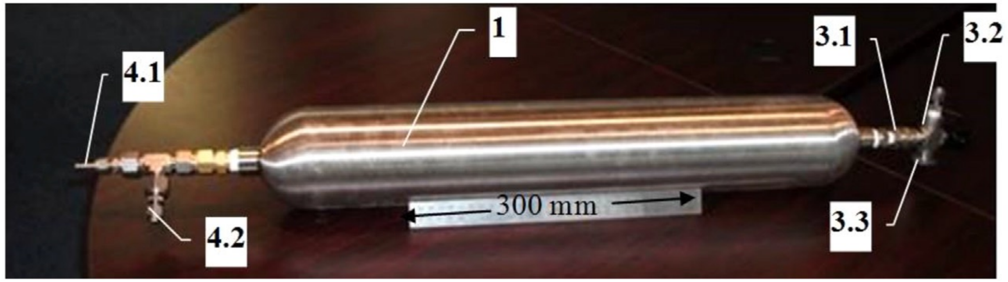
Extract from: **IRENA (2022), Geopolitics of the Energy Transformation: The Hydrogen Factor, International Renewable Energy Agency, Abu Dhabi.**

Hydrogen (MH) storage materials

Ni
Co
Al
Mn
Zr
Cr
Cu
Ti
La
V

METAL HYDRIDE (MH)





Assembly line for hydrogen storage materials

(A fully functional production line to produce metal hydride materials)

HySA Systems
Hydrogen South Africa

METAL HYDRIDE MATERIALS

In March 2014 HySA Systems Competence Centre plans to launch a production facility for the manufacturing of Metal Hydride (MH) materials for hydrogen storage and thermally-driven compression, as well as for NiMH batteries

The facility based on locally developed induction melting and annealing furnaces will be able to daily produce up to 25 kg of the MH materials to be used for HySA Systems MH hydrogen storage / supply units and hydrogen compressors, as well as to be exported to various customers.

The facility will manufacture the MH materials from the abundant South African feedstock, according to new technology recently developed at HySA Systems (Patents ZA2012/03824, ZA2012/08851).

Metal Hydride Materials

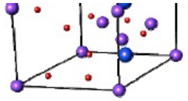
Metal Hydride Hydrogen Compressors

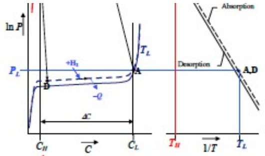
FEATURES

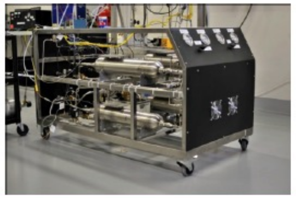
MH materials: AB_5-, A_2B_7- and AB_2-type alloys

Customized compositions according to customers' specifications, including target Pressure/Concentration/ Temperature performances for Hydrogen absorption / desorption

Load capacity (melting & annealing) 25 kg







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South African Institute for Advanced Materials Chemistry
MAKING RESEARCH WORK

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Metal Hydride Hydrogen Storage and Supply Containers

Metal Hydride Materials

Availability of mineral deposits for the manufacturing MH alloys in South Africa

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 3577–3596

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Review

Hydrogen South Africa (HySA) Systems Competence Centre: Mission, objectives, technological achievements and breakthroughs

Bruno G. Pollet*, Sivakumar Pasupathi, Gerhard Swart, Kobus Mouton, Mykhaylo Lototskyy, Mario Williams, Piotr Bujlo, Shan Ji, Bernard J. Bladergroen, Vladimir Linkov

10,000 ton magnesium-based hydrides manufacturing plant under construction in China

The vehicle contains 12 hydrogen storage containers, each of which is filled with high-capacity magnesium alloy hydrogen storage materials.

In addition, the selective adsorption of hydrogen by magnesium alloy can also be used to purify hydrogen. The released hydrogen can reach the standard of high-purity hydrogen or even ultra-pure hydrogen.

HyFun now has a 1,000 ton production capacity of magnesium alloy in **Jiangsu** province, expanding 10-fold of capacity may signal that the company expects rapid growth of magnesium-based hydrogen storage material application in China.

Main Elements in Electrolysers (and Hydrogen Fuel Cells), Metal Hydrides and Lithium-ion Batteries

@Bruno G. Pollet

PEMWE
Proton Exchange Membrane Water Electrolyser

AWE
Alkaline Water Electrolyser

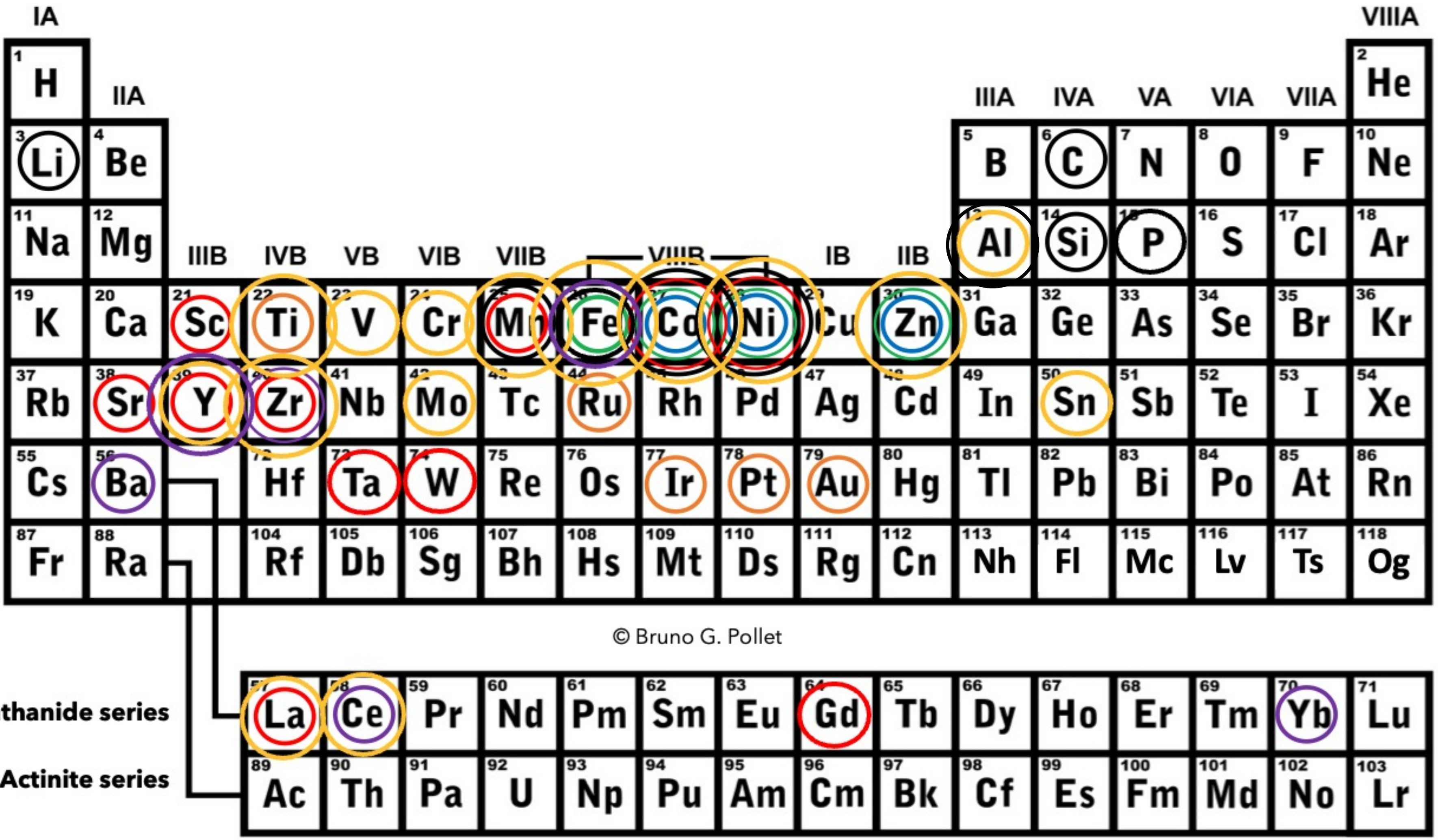
AEMWE
Anion Exchange Membrane Water Electrolyser

SOEC
Solid Oxide Electrolysis Cell

PCCEL
Proton Conducting Ceramic Electrolyser

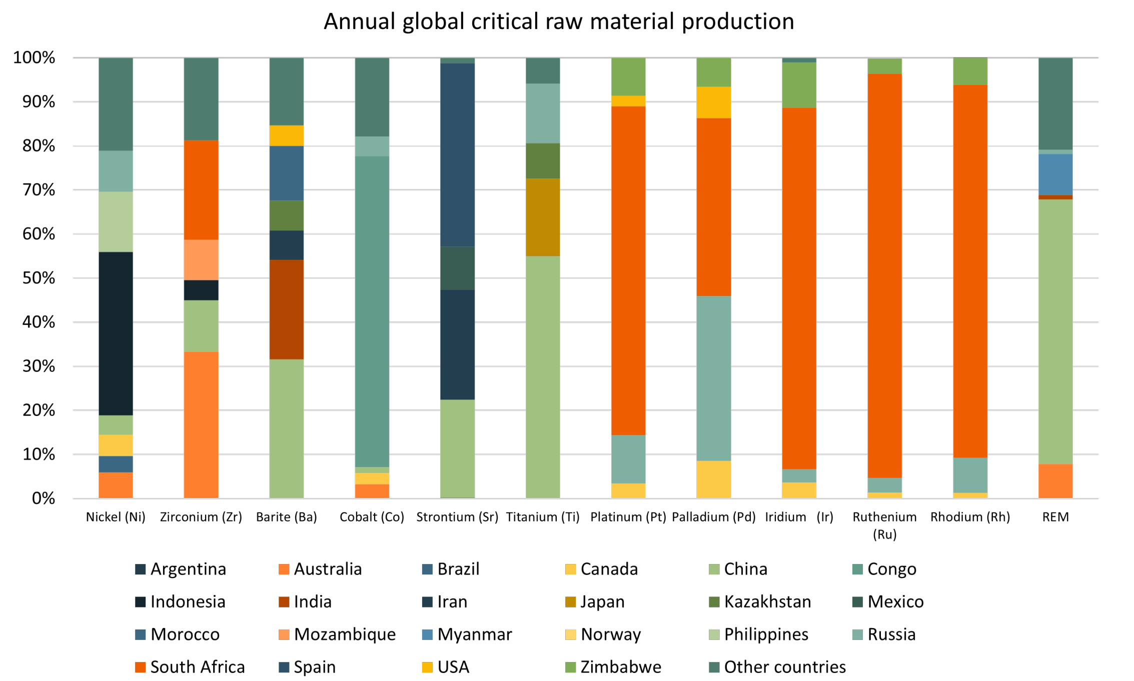
MH
Metal Hydride
inc. AB-, AB_2-, AB_5-types & IMC
- InterMetallic Compound

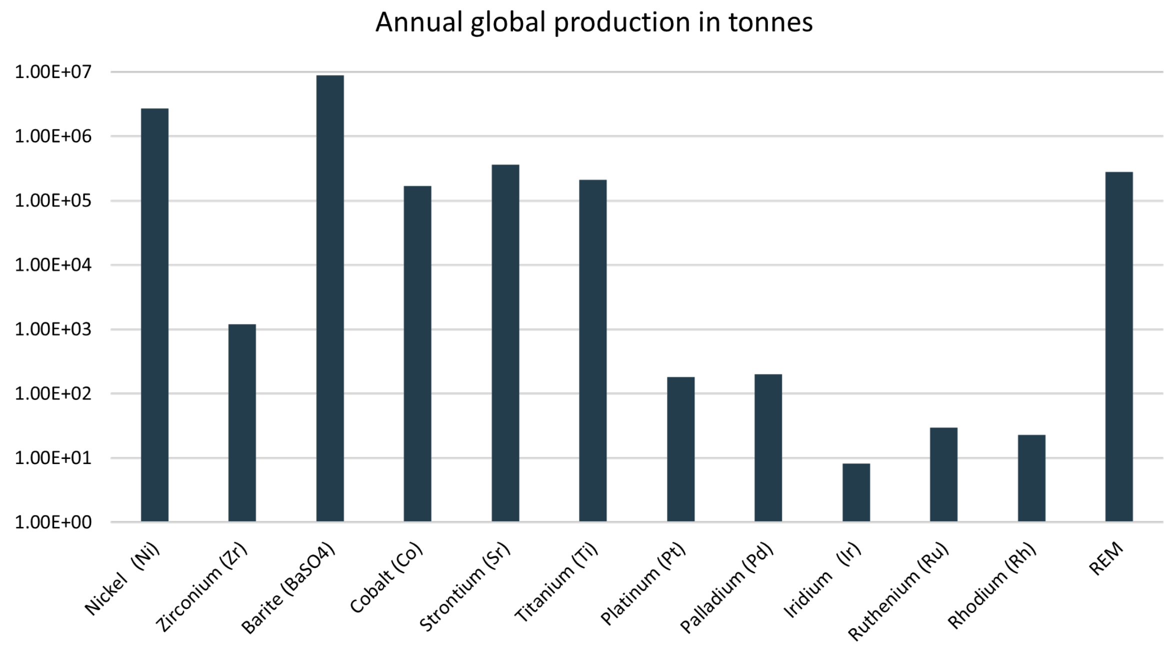
LIB
Lithium-ion Battery
inc. LCO, LMO, NMC & LFP



Lanthanide series

Actinite series





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Review Article

Critical and strategic raw materials for electrolysers, fuel cells, metal hydrides and hydrogen separation technologies

Erik Eikeng [a], Ashkan Makhsoos [b,*], Bruno G. Pollet [b]

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ARTICLE INFO

Keywords:
Green hydrogen
Critical raw materials
Strategic raw materials
Electrolyzer technologies
Fuel cell technologies
Sustainable energy

ABSTRACT

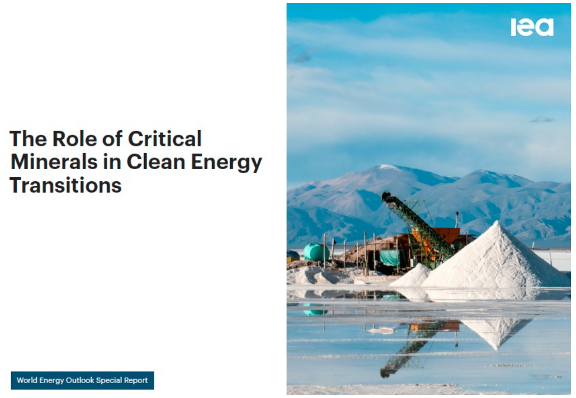
This paper provides an in-depth examination of critical and strategic raw materials (CRMs) and their crucial role in the development of electrolyzer and fuel cell technologies within the hydrogen economy. It methodically analyses a range of electrolyzer technologies, including alkaline, proton-exchange membrane, solid-oxide, anion-exchange membrane, and proton-conducting ceramic systems.

Each technology is examined for its specific CRM dependencies, operational characteristics, and the challenges associated with CRM availability and sustainability. The study further extends to hydrogen storage and separation technologies, focusing on the materials employed in high-pressure cylinders, metal hydrides, and hydrogen separation processes, and their CRM implications.

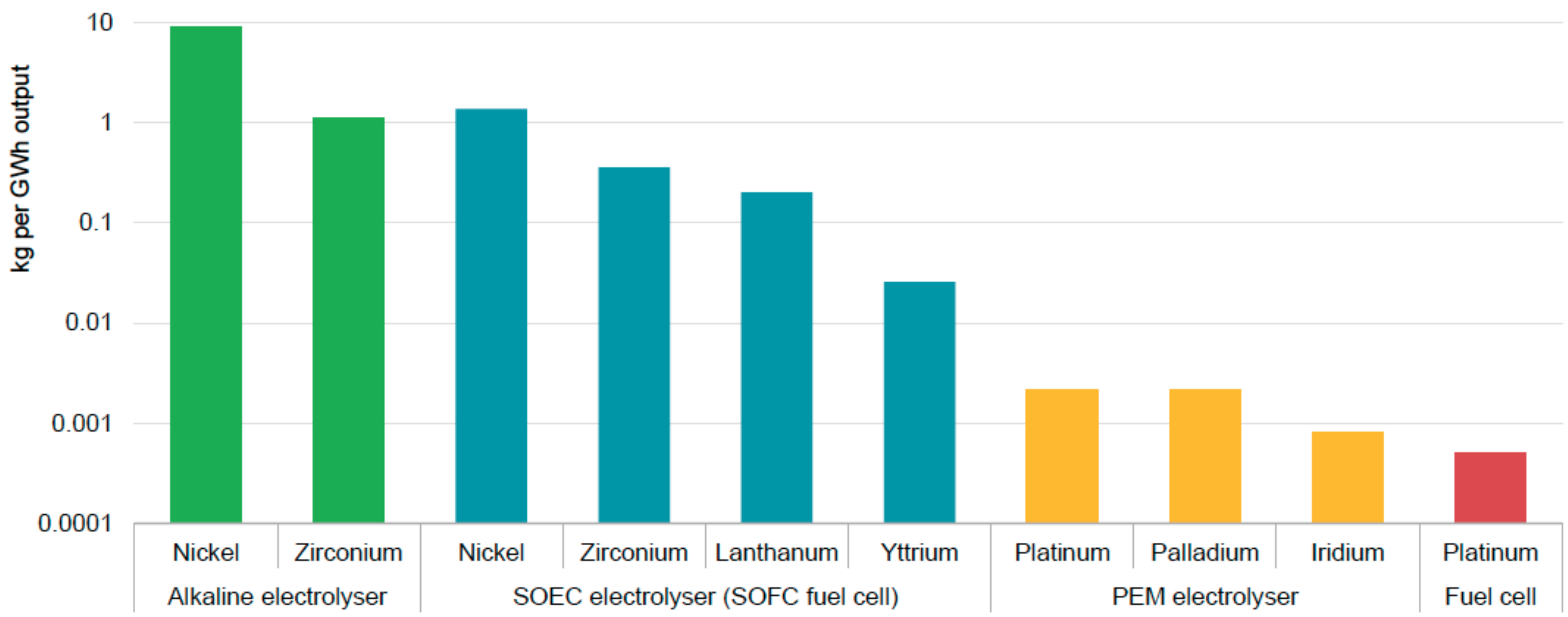
A key aspect of this paper is its exploration of the supply and demand dynamics of CRMs, offering a comprehensive view that encompasses both the present state and future projections. The aim is to uncover potential supply risks, understand strategies, and identify potential bottlenecks for materials involved in electrolyzer and fuel cell technologies, addressing both current needs and future demands as well as supply. This approach is essential for the strategic planning and sustainable development of the hydrogen sector, emphasizing the importance of CRMs in achieving expanded electrolyzer capacity leading up to 2050.

CRM Supply Risk

- PEMWE and AWE use PGMs typically as catalysts – Iridium and Platinum which are considered to have high supply risk.
- Out of 5 critical materials, only titanium is considered to have low to medium supply risk.
- Yttrium and Scandium used in SOEC are considered to have a high supply risk.
- Recycling may not play an important role in relaxing the supply chain situation of these CRMs because of overall market growth rate.

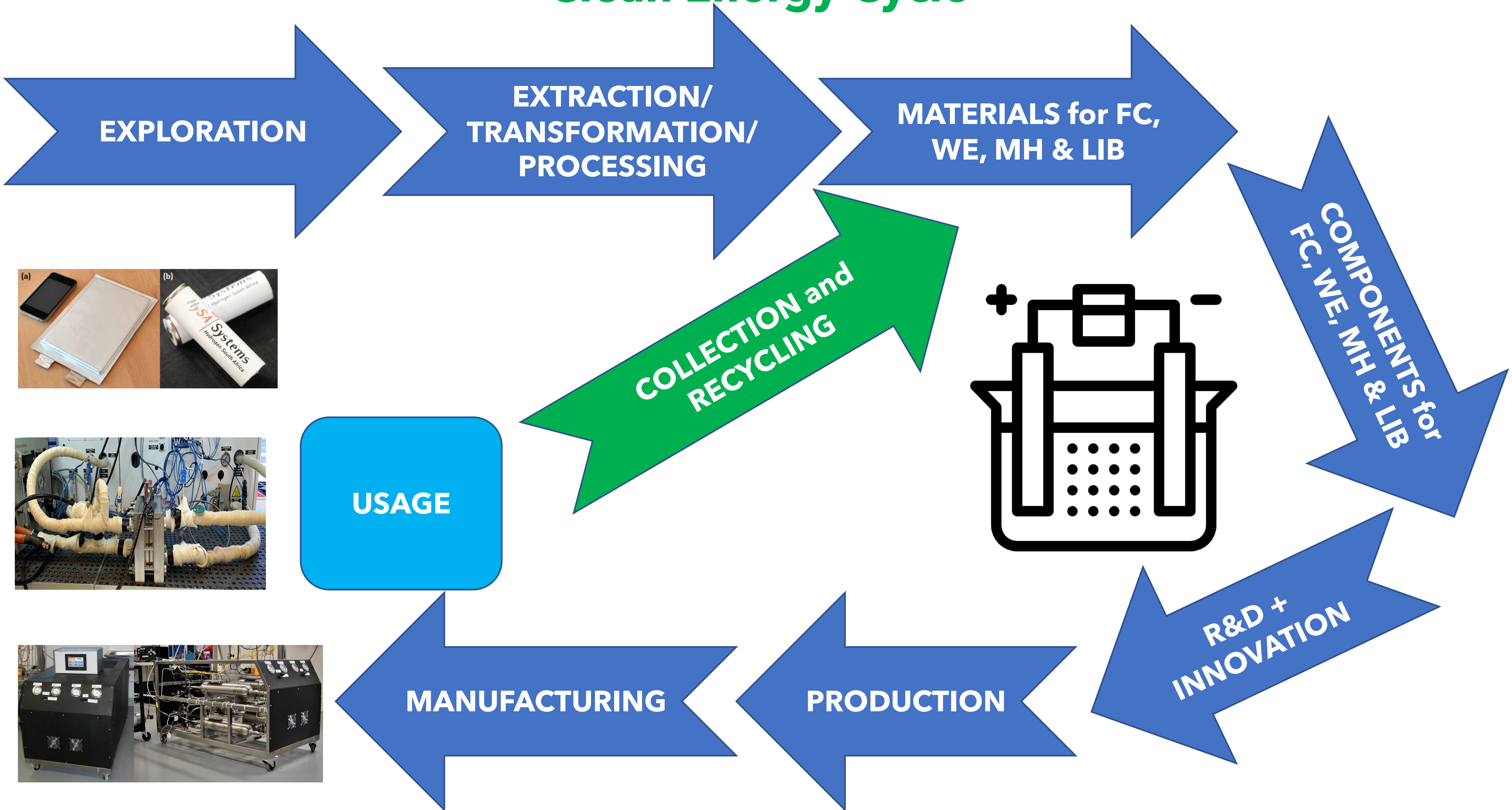


Hydrogen electrolysers and fuel cells could drive up demand for nickel, platinum and other minerals, but the market effects will depend on the shares of the different electrolyser types



Notes: PEM = proton exchange membrane; SOEC = solid oxide electrolysis cells; SOFC = solid oxide fuel cell. Normalisation by output accounts for varying efficiencies of different electrolysis technologies. Full load hours of electrolysers assumed to be 5 000 hours per year.
Sources: Bareiß et al.(2019); Fuel Cells and Hydrogen Joint Undertaking (2018); James et al. (2018); Kiemel et al. (2021); Koj et al. (2017); Lundberg (2019); NEDO (2008); Smolinka et al. (2018); US Department of Energy (2014; 2015).

Clean Energy Cycle



Conclusions

- Increasing concerns about the future availability of CRMs e.g., Li, Co, Ni and rare earths but also processed materials and components.
- The bottleneck is not caused by **physical scarcity**.
- The bottleneck is caused by **geopolitical aspects** - extraction + processing of CRM are concentrated in a small number of countries – although China + Russia dominate most of the markets.
- Countries (mainly US, EU + Japan) with a large demand for CRMs for their clean energy industry depend on a small group of suppliers.
- This is going to create disputes and possible regional conflicts!

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Acknowledgement
Erik Eikeng
Ashkan Makhsoos

NSERC CRSNG

UQTR Université du Québec à Trois-Rivières

IAHE Green Hydrogen Division

Prof. Dr. Bruno G. Pollet

President of the Green Hydrogen Division at International Association...

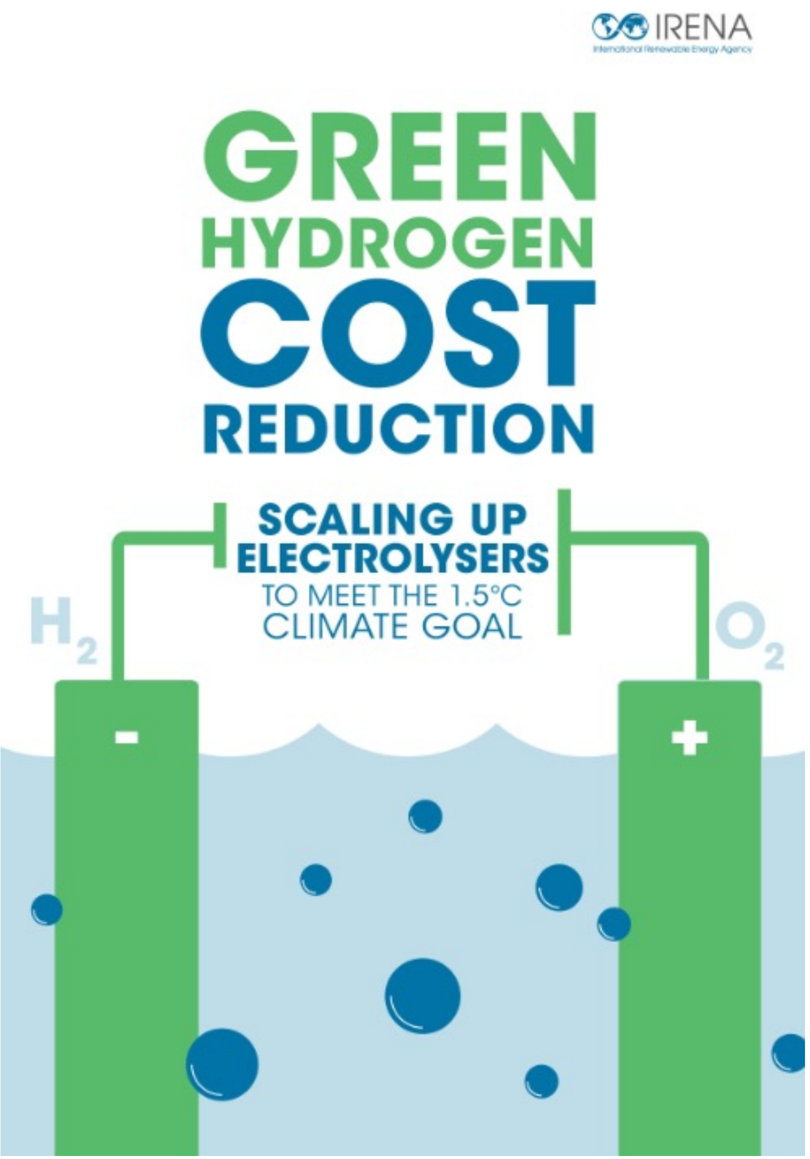
HOSTING PARTNER

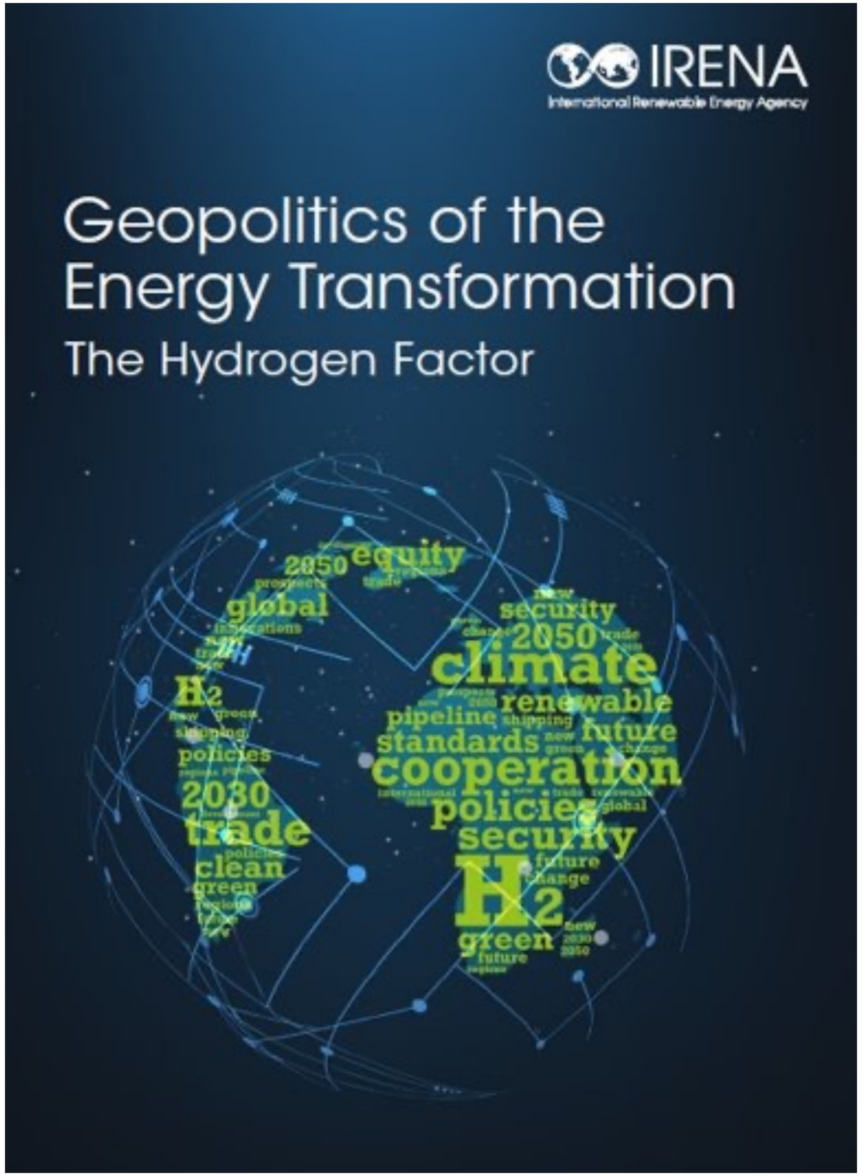
Cipher Neutron

SUPPORTING PARTNER

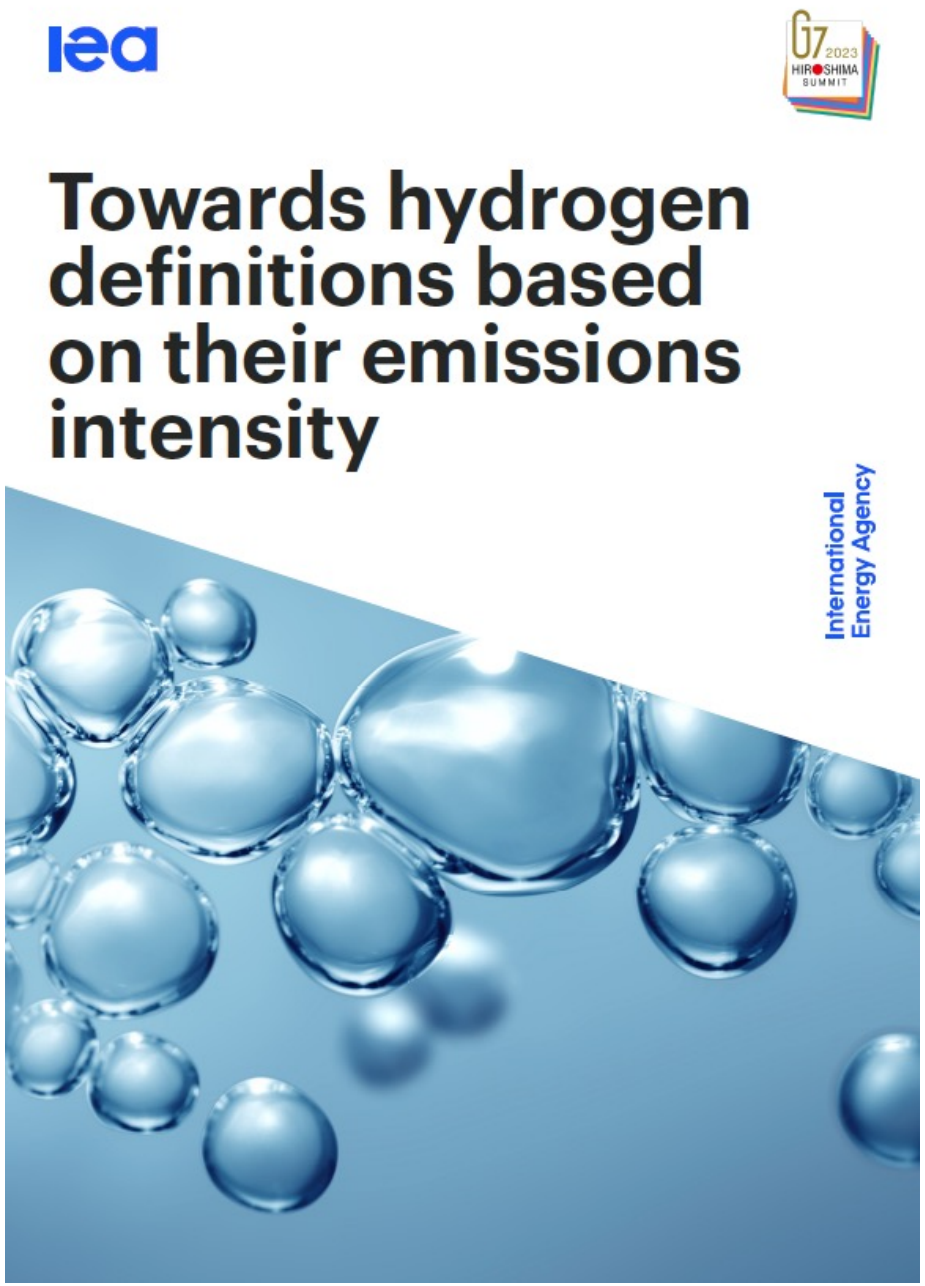
CHFCA
Clean. Efficient. Energy.

Global Critical Minerals Outlook 2024





IRENA – International Renewable Energy Agency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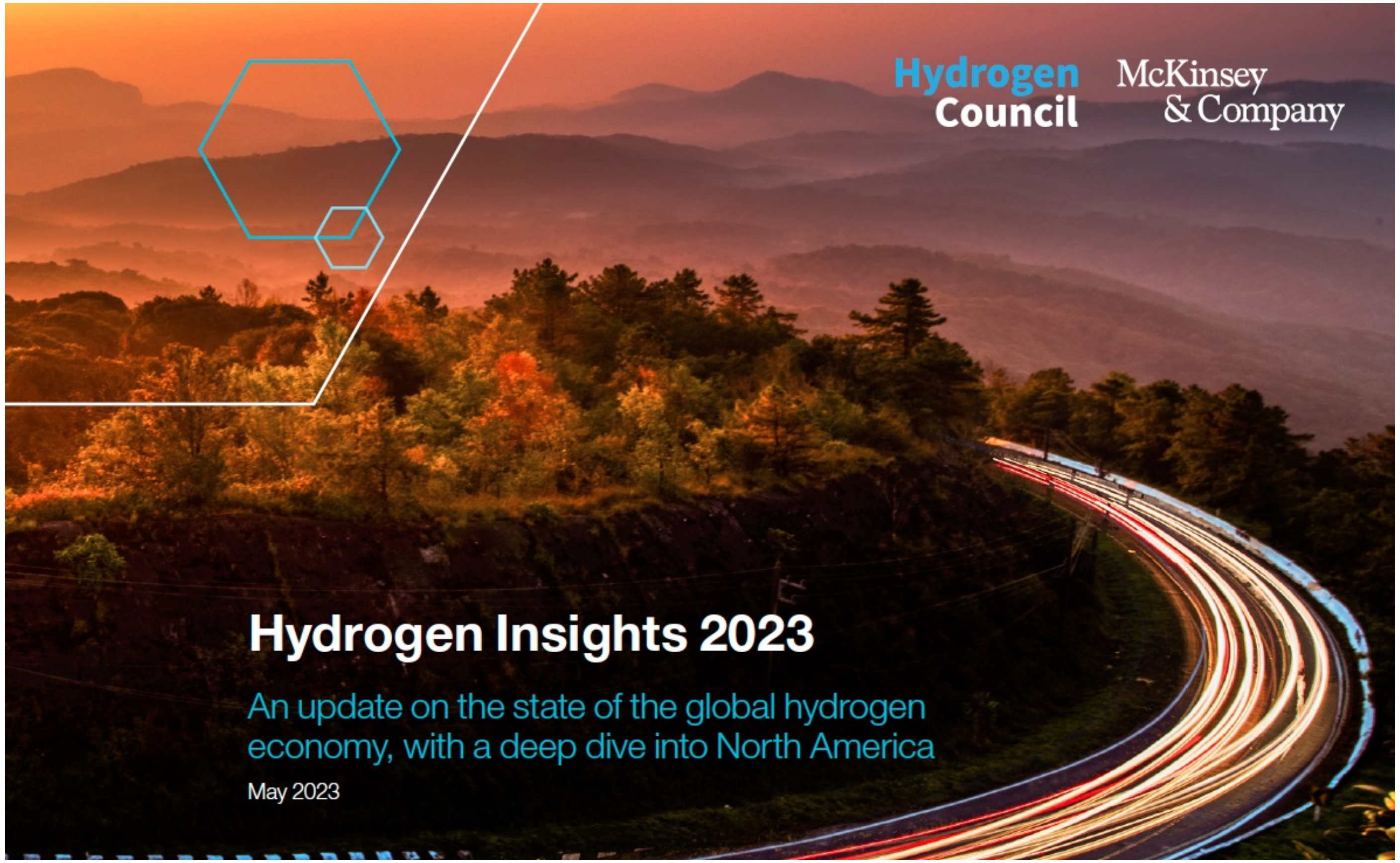
Towards hydrogen definitions based on their emissions intensity
International Energy Agency


Hydrogen Council
McKinsey & Company
Hydrogen Insights 2023
An update on the state of the global hydrogen economy, with a deep dive into North America
May 2023

The Role of Critical Minerals in Clean Energy Transitions

World Energy Outlook Special Report

Global Hydrogen Review 2023

International Energy Agency