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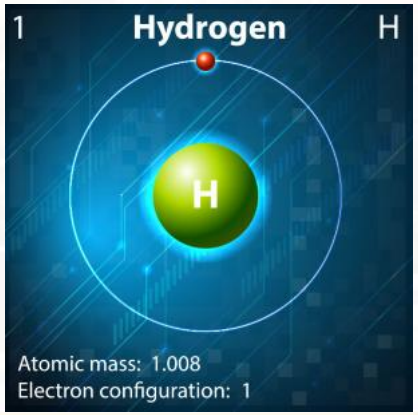
Green Hydrogen Value Chain

Dr. Zivayi CHIGUVARE

Acting Director – Namibia Green Hydrogen Research Institute

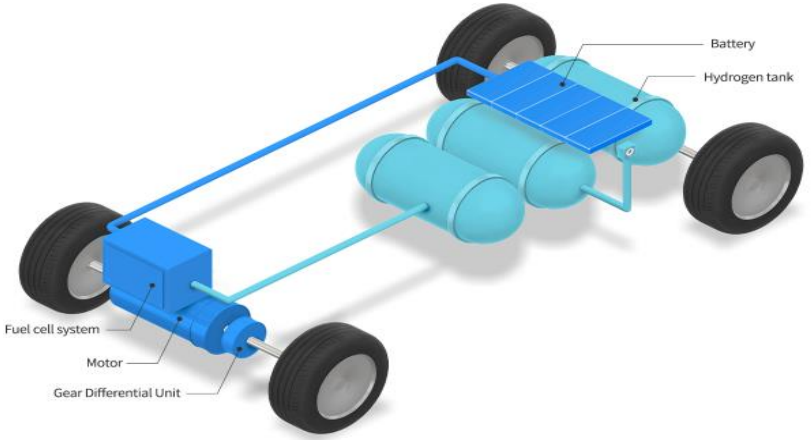


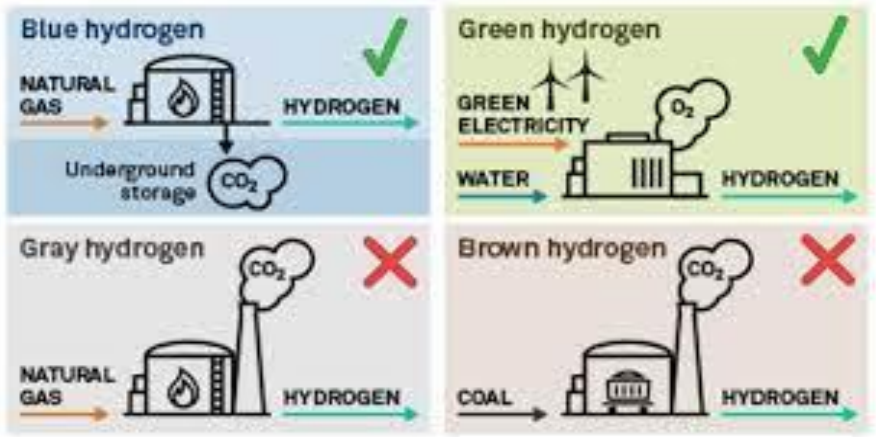
GREEN HYDROGEN MASTERCLASS 2023

21 NOVEMBER 2023

Outline

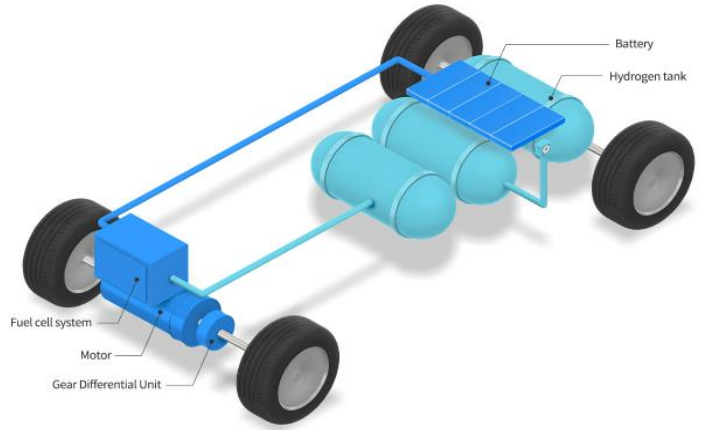
- The Need for Energy
- What is Green Hydrogen?
- Hydrogen Energy System
- National Context and International Context
- UNAM's Response
- Namibia Green Hydrogen Research Institute
- Outlook
- Conclusions



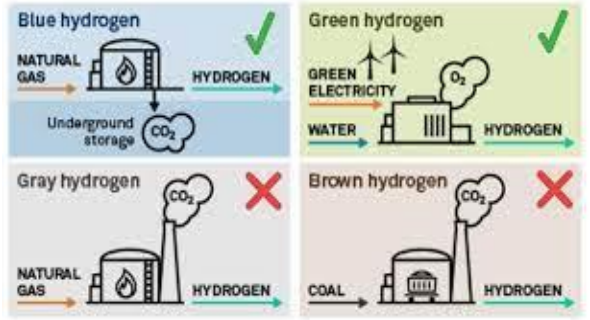


Hydrogen can smoothen the transition to a more sustainable energy economy

The Need for Energy

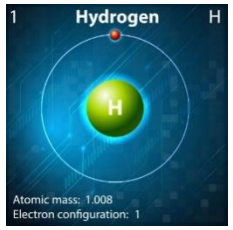


- Man needs **food** and **thermal comfort**;
- Man works for these – from birth to death;
- Man harnesses these locally and from afar;
- Man shows love through provision of food and thermal comfort;
- Man fights, and protects these with all they have;
- Technology eases their harnessing, storage, transmission, protection, and provision;
- Irresponsible technology threatens man's **livelihood**.



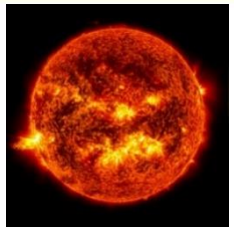
Hydrogen is an effective energy carrier

What is Hydrogen?



Hydrogen is the lightest & the most abundant element found in the universe

On Earth, Hydrogen is found in greatest quantities in water



The sun is essentially a giant ball of hydrogen gas under-going fusion into helium.

Energy density	MJ/kg	MJ/L
European gas mix	33.5	0,040
Gaseous hydrogen	142	0,015
LPG	49	27
Gasoline	46	34
Diesel	46	38
Kerosene	43-50	35
Ammonia	16.9	11.5
Stone- and Lignite	23	34-43

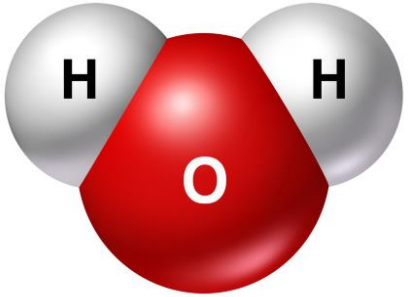
- Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline) but also the lowest energy content by volume (about four times less than gasoline).

- Hydrogen supports a gradual transition towards lower-carbon sources of energy as it can be generated from natural gas and other non-renewable by-products. It can be used as an energy carrier; i.e., a medium to store energy from renewable and other sources. It can be generated at scale with a zero-carbon footprint by using renewable energy to split water (electrolysis).

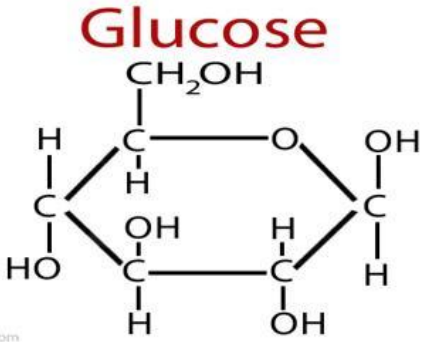
- Global hydrogen demand in 2020 was about 100 million metric tons, and this is set to double by 2030. According to the IEA, the demand for hydrogen could reach 528 million metric tons globally by 2050.

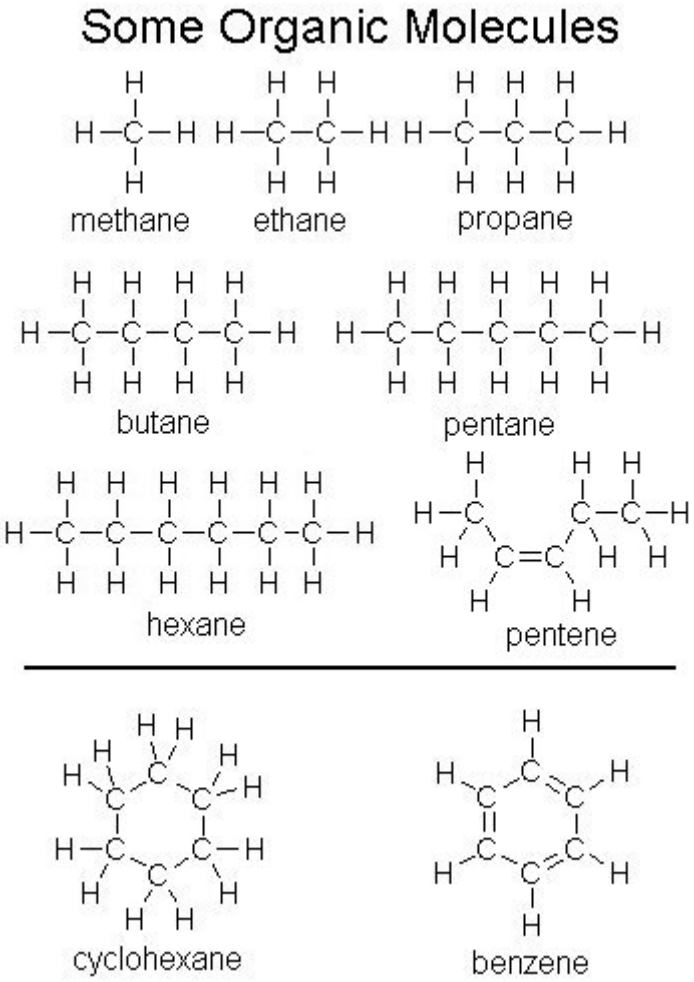
What is Hydrogen?

- Hydrogen is the lightest & the most abundant element found in the universe
- Hydrogen and derivative e-fuels like ammonia or methanol can be used as fuel for transportation.
- Hydrogen is stored and used for stationary power, building heat, and industrial and manufacturing sectors.
- Fuel cells can provide non-stop power for critical load functions, such as data centres, telecommunication towers, and emergency response systems.

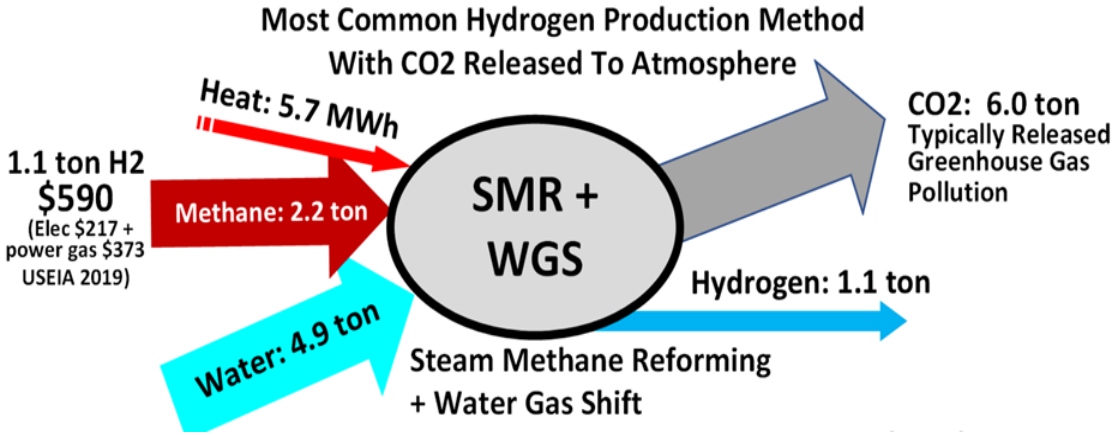


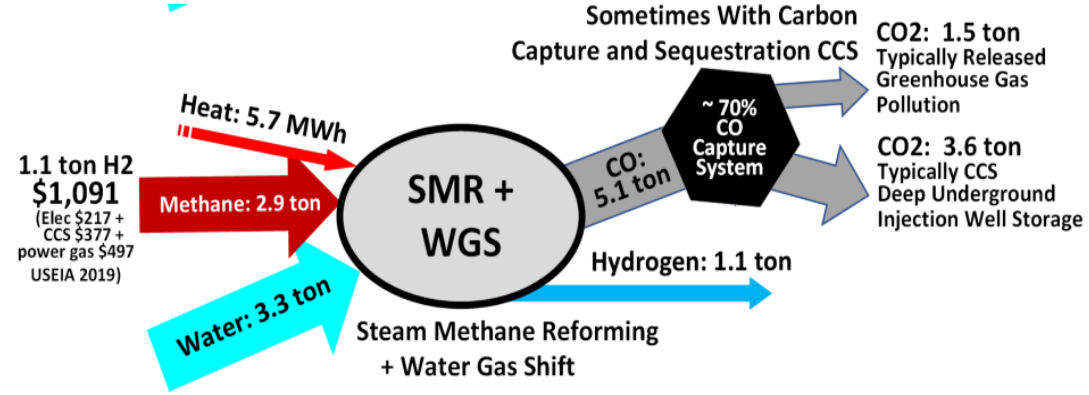
WATER MOLECULE





Inputs and Outputs of Hydrogen Production Methods





GREY HYDROGEN

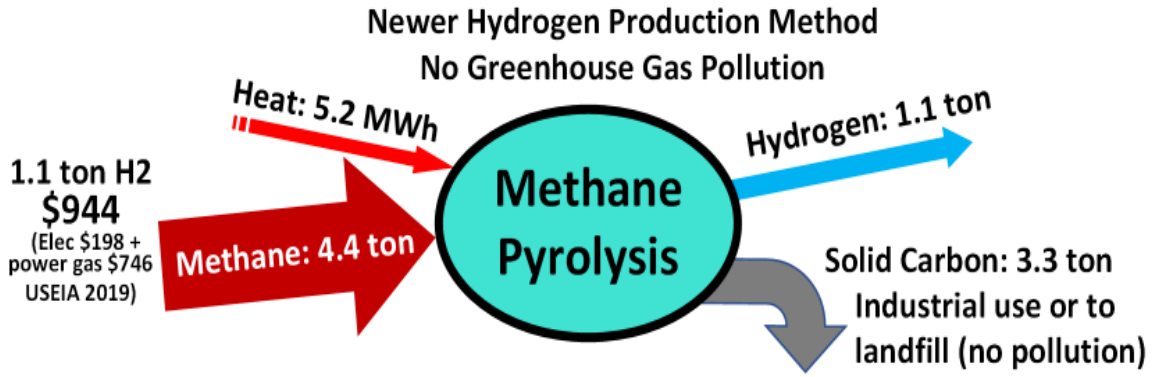
Methane reacts with steam under 3-25 bar pressure in the presence of a catalyst to produce hydrogen and carbon monoxide (with a small amount of carbon dioxide). Steam reforming is endothermic and uses steam at 700 °C to 1000 °C.

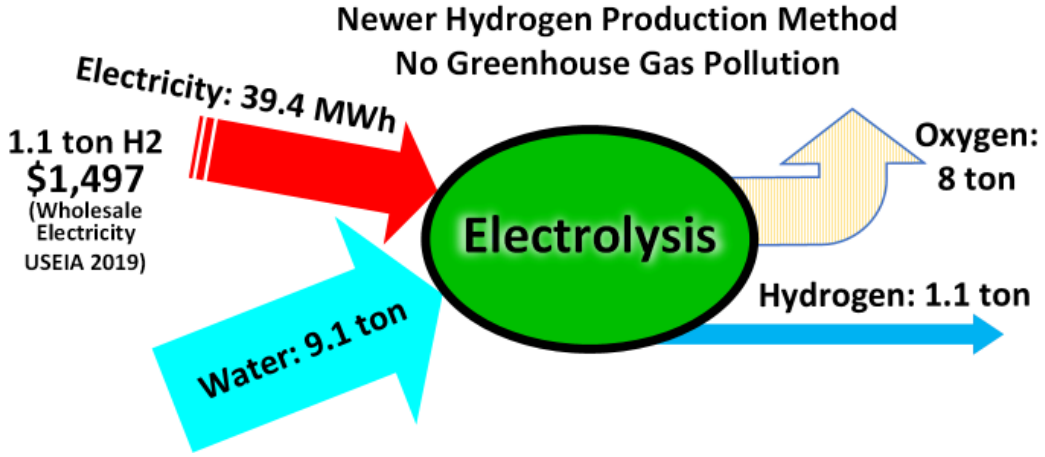
$2CH_4 + 2H_2O \rightleftharpoons 2CO + 3H_2$ ΔH +206 kJ/mol (endothermic)

$CO + H_2O \rightleftharpoons CO_2 + H_2$ ΔH -41 kJ/mol – water-gas shift reaction (exothermic)

As of 2020, the carbon sequestration step was not in commercial use

Inputs and Outputs of Hydrogen Production Methods

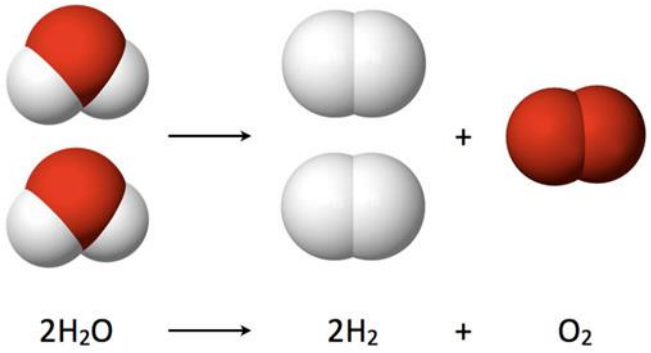




BLUE HYDROGEN

GREEN HYDROGEN

- The electricity required for electrolysis can be tied directly to a non-renewable or renewable source of energy.
- 9.1 kg of deionized water is required to produce 1.1kg of H_2 through the electrolysis process.



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Does Hydrogen Have a Colour?

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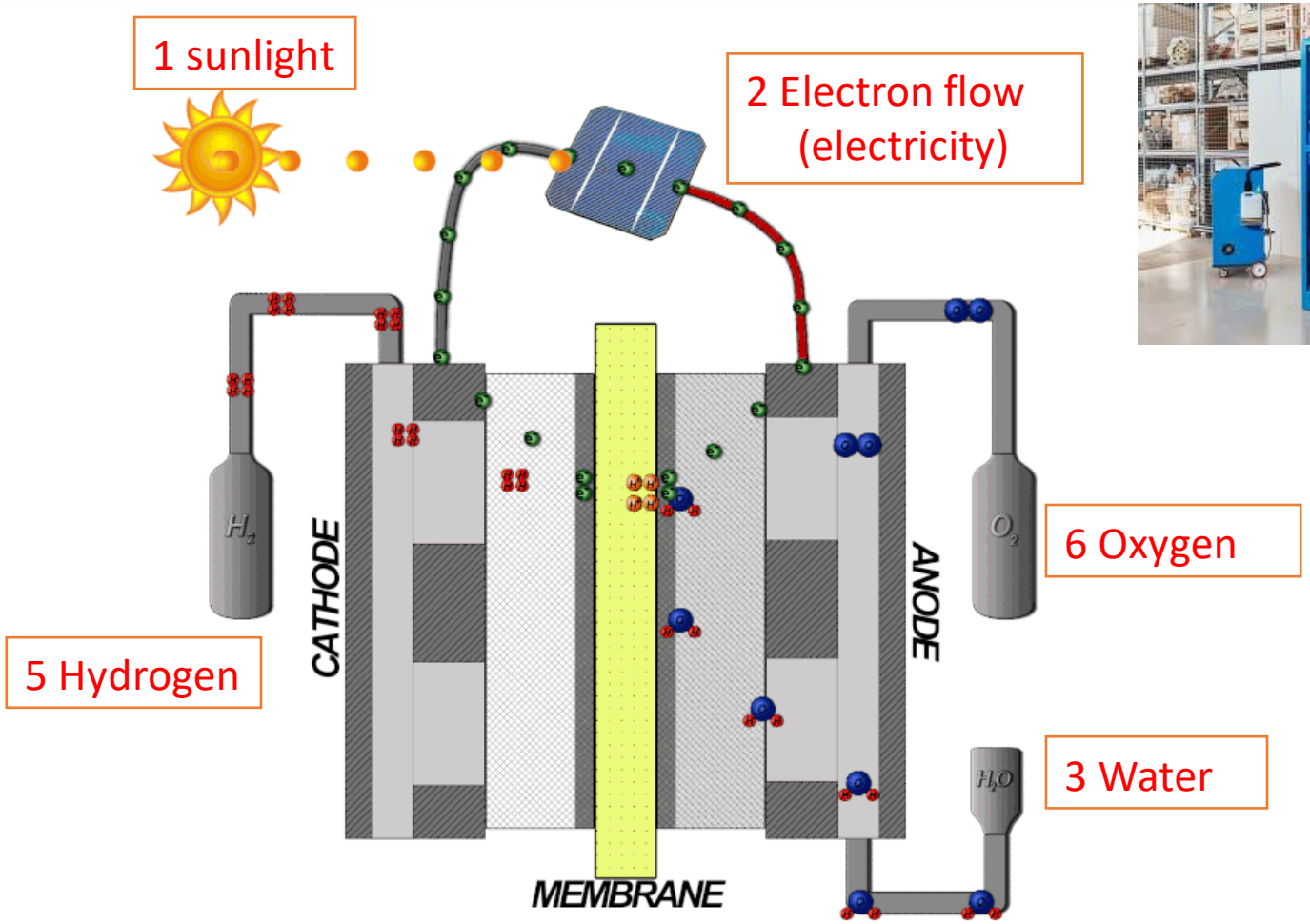
Colour	Production source	Notes	References
Green	Renewable energy and electricity	via electrolysis of water	[38]:28
Turquoise	Thermal splitting of methane - pyrolysis of molten metal, fuelled by natural gas.	via methane pyrolysis	[38]:28 [39]:2
Blue	Hydrocarbons, with carbon capture and storage	CCS networks required	[38]:28
Grey	Steam reforming of natural gas	CO_2 emissions	[38]:28 [40]:10 [39]:2
Brown or black	Hydrocarbon-rich feedstocks, such as coal or other fossil fuels.	CO_2 emissions	[41]:91
Purple or pink or red	Nuclear power electricity for electrolysis	Fairly stable hydrogen	[39]:2
Yellow	Electricity used for electrolysis comes from mixed sources, from renewable energies to fossil fuels.	Green hydrogen from photovoltaics.	[37]
Gold	Naturally occurring hydrogen within Earth's crust	obtained by mining	[42]
White	Medical hydrogen	naturally occurring hydrogen	[43]

Electrolysis - Green Hydrogen Production Mechanism



$2H_2O$ + electrical energy → $2H_2$ + O_2

Electrolysers can be for small or large-scale hydrogen production.

In a polymer electrolyte membrane (PEM) electrolyzer, the electrolyte is a solid specialty plastic material.

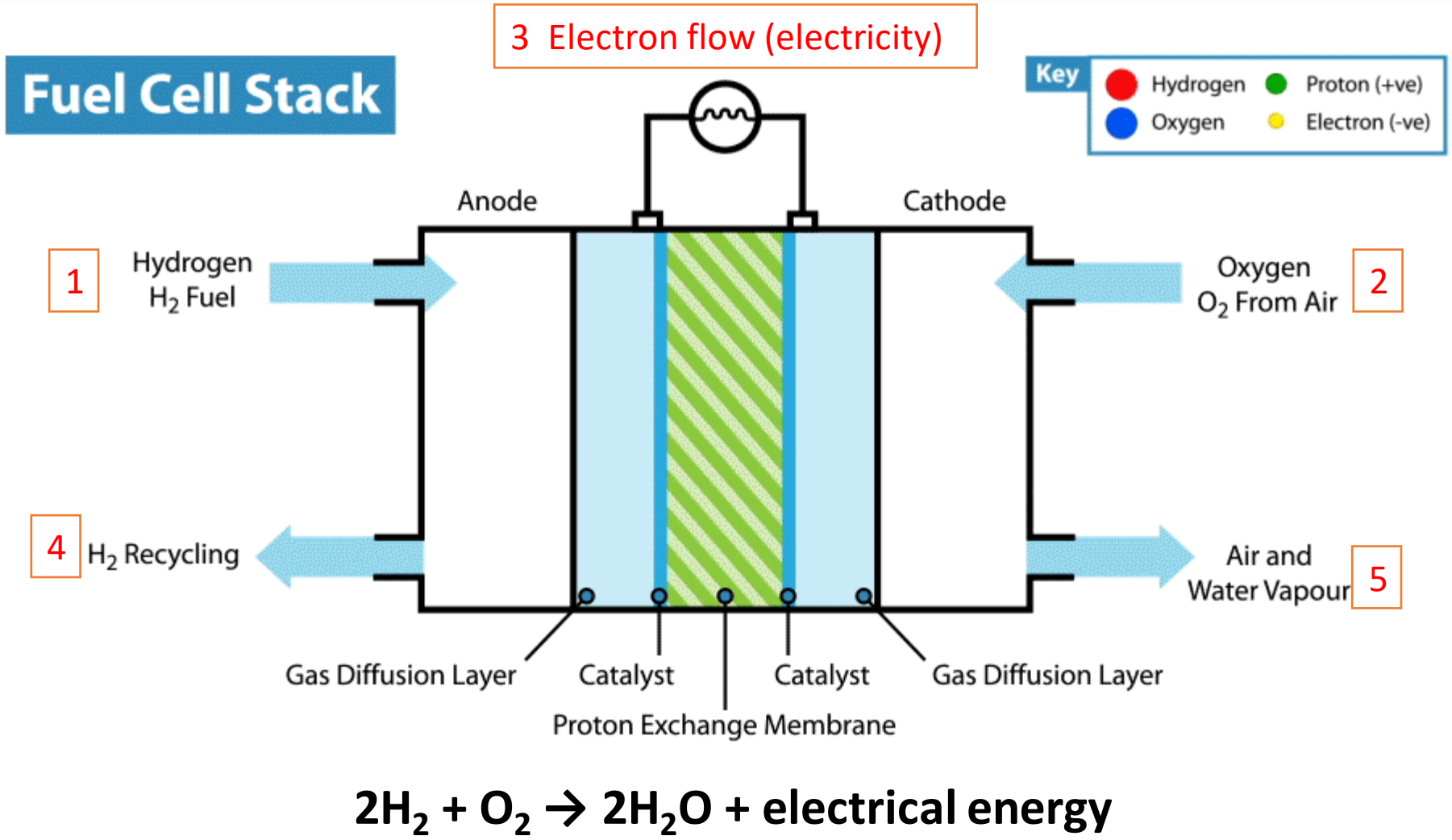
- Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons).
- The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode.
- At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas.

Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$

A Water elecrolyser produces hydrogen by supplying electrical energy that splits the water molecule into hydrogen and oxygen

Fuel Cell - Electricity Production Mechanism



The reactions which takes place in hydrogen-oxygen fuel cell are,

At cathode:

$$2H_2(g) + 4\,OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$$

At cathode:

$$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$$

Overall reaction:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

$$2H_2 + O_2 \rightarrow 2H_2O + \text{electrical energy}$$

A polymer electrolyte fuel cell (PEFC or PEM fuel cell) generates electricity and heat by the chemical reaction between hydrogen and oxygen. Byproducts: Water and heat.

Green Hydrogen Energy System

Energy Harnessing from Renewable, Environmentally friendly Sources

Electricity generation using sustainable, environmentally friendly, renewable energy technologies

Excess electricity for local use

Desalination of Water

Electrolysis of Water

Air separation

Brine

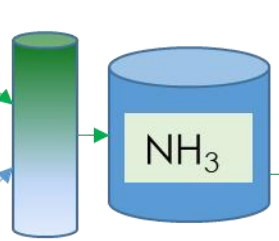
H_2O

O_2

H_2

N_2

O_2 rich air



NH_3

Ammonia Synthesis and Storage

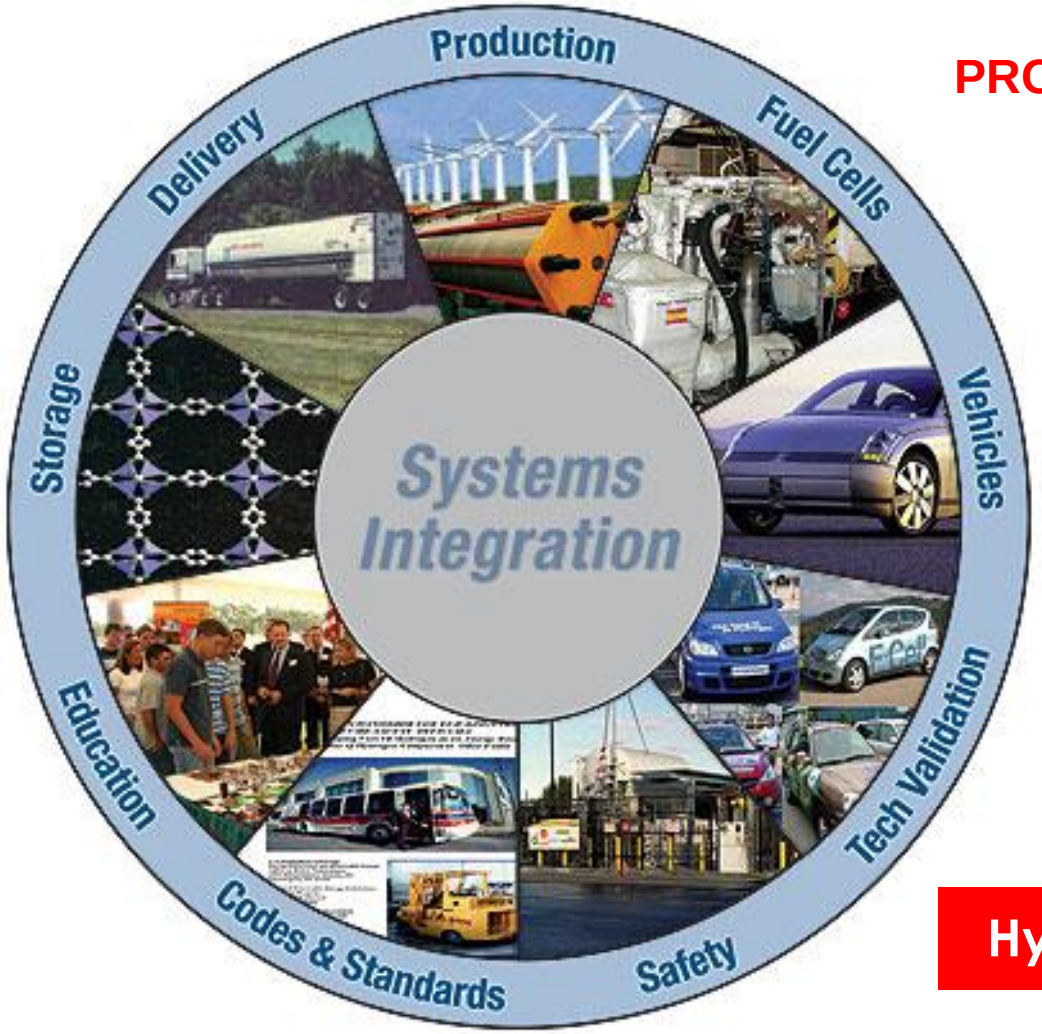
- Refrigerant
- Hydrogen carrier
- Power generators
- Cleaning chemicals
- Energy production
- Fertilizer
- Feedstock/ chemicals
- Fuel Cell systems
- Ammonia engines

- Chemical
- Public
- Commercial
- Residential
- Remote communities
- Agricultural
- Industrial
- Utility
- Transportation

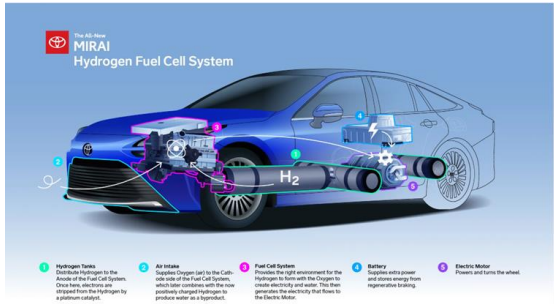
Energy Sourcing | **Hydrogen production** | **Distribution system** | **Utilization** | **Sector**

Local opportunities? Raw material sourcing… Production … Storage … Transport … Utilization (must be economically, and environmentally, viable and safe)

Elements of the Hydrogen Economy



PROJECTS: Planning - Initiation - Execution - Monitoring - Closing

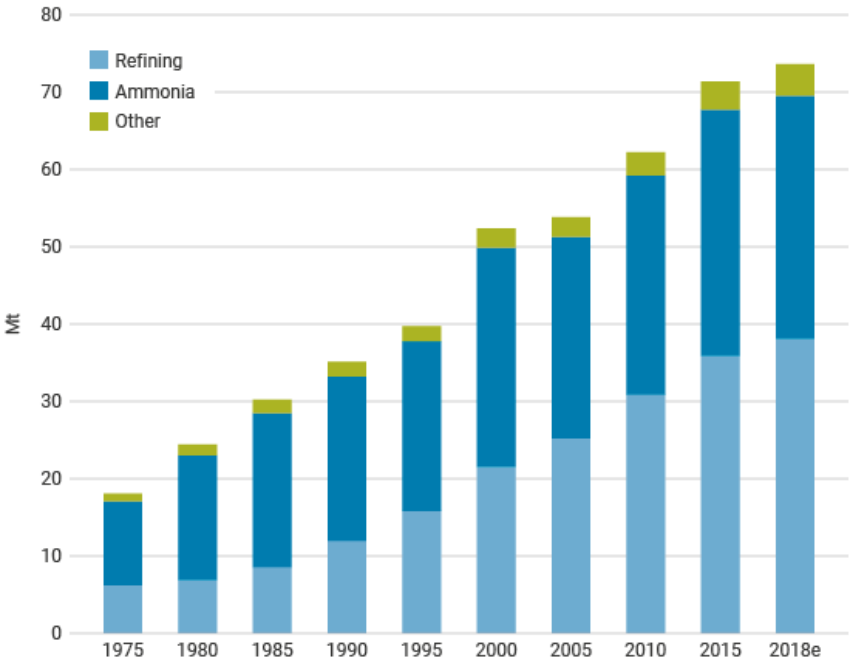


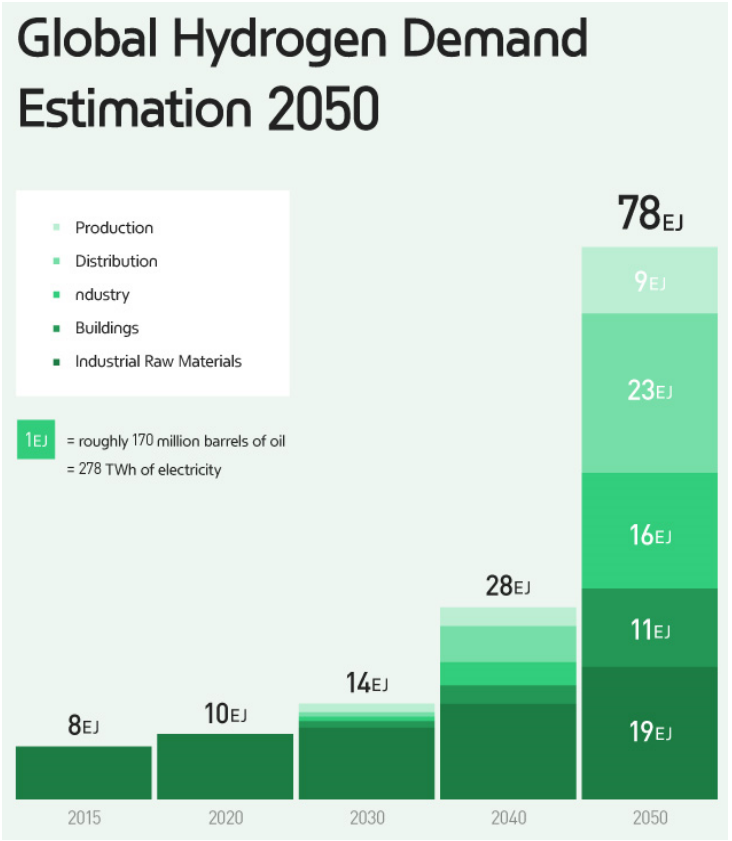
Hy-tech; Hy-economy; Hy-fuels; Hy-…do not be left behind…

Local opportunities? Energy … Raw material sourcing… Production … Storage … Transport … Utilization (must be economically, and environmentally, viable and safe)

Green Hydrogen energy system

Global annual demand for pure hydrogen (source: IEA)



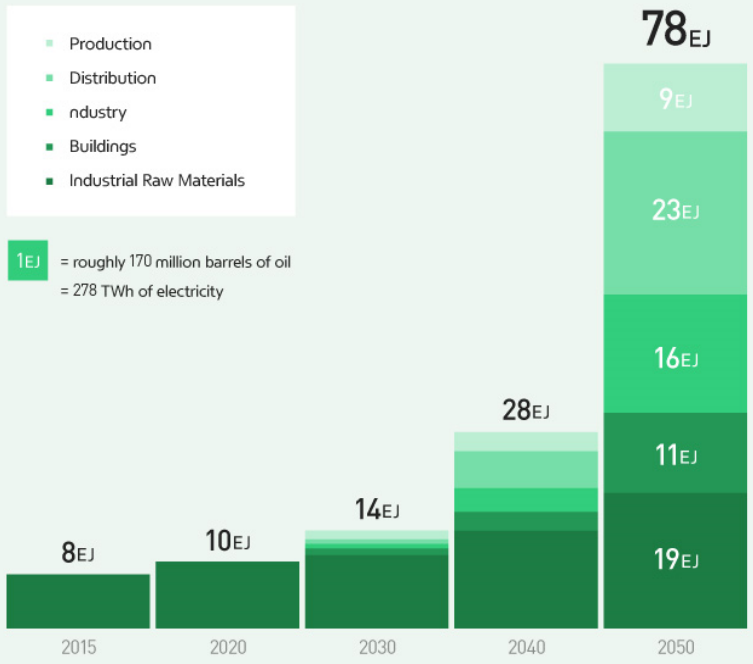


- **Production of hydrogen could meet 18% of the total final energy demand by 2050.** And with its environmental benefits, the hydrogen economy could create opportunities for sustainable economic growth.
- **An envisioned market for hydrogen and hydrogen technologies with revenues of more than $2.5 trillion per year, and jobs for more than 30 million people globally.** Half of this revenue would come from hydrogen sales, the other half from sales of vehicles, trains, boats, machinery, drones, and fuel cell batteries.
- **Achieving this vision would create significant benefits for the energy system, the environment, and the global economy.**

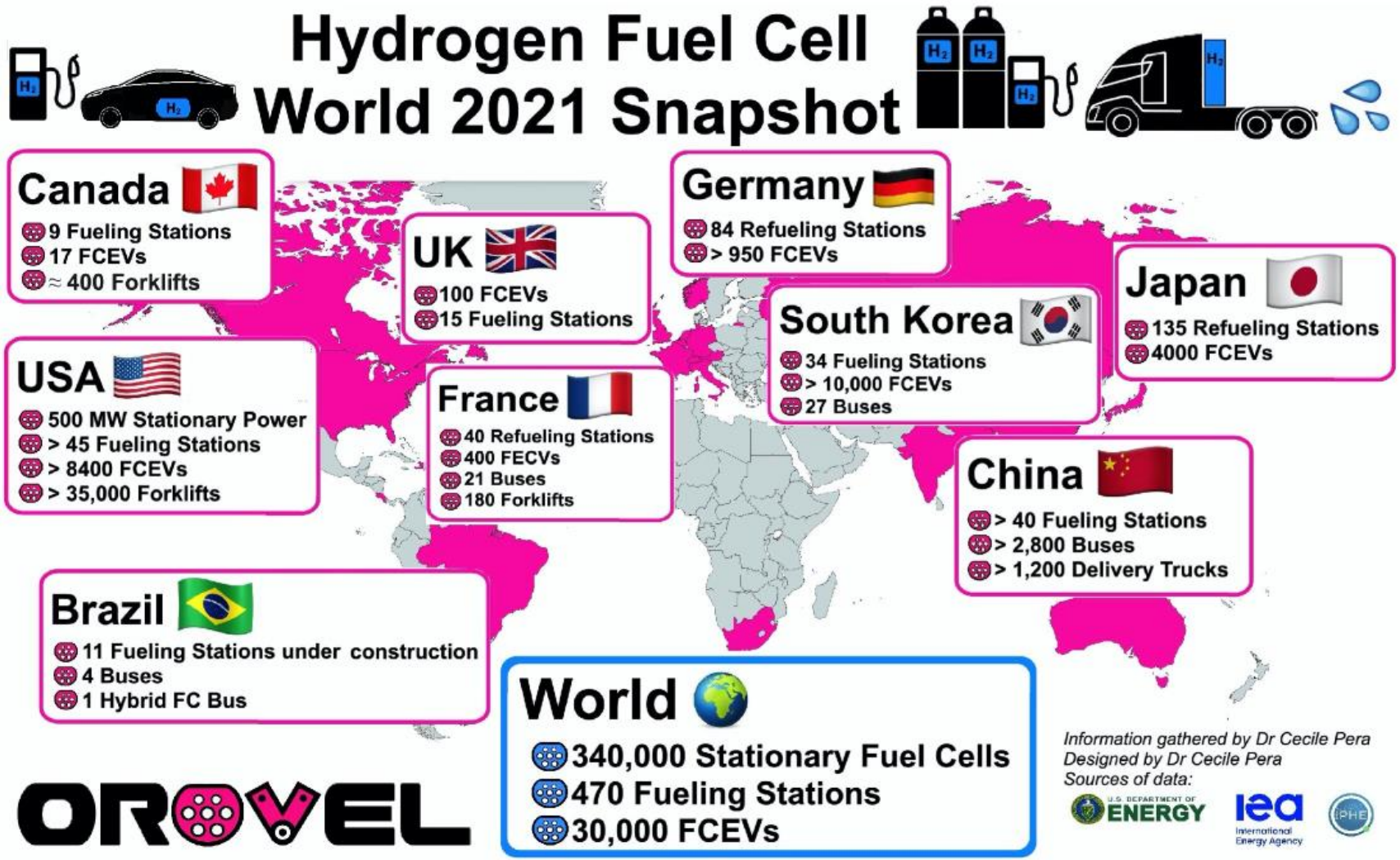
Hydrogen is a major fuel that can replace fossil fuels

Green Hydrogen Energy System

Global Hydrogen Demand Estimation 2050



Hydrogen Fuel Cell World 2021 Snapshot



OROVEL

Hydrogen is a major fuel that can replace fossil fuels

National Context

- Namibia's Harambee Prosperity Plan II (HPPII) lists as priority Goal 3: "the development of complementary engines of growth," with two activities that promote the initiation of research and development into the green and blue economy:

Activity 1	Develop an implementation plan to attract private sector investment into the Green and Blue Economy.
Activity 2	Investigate the feasibility of Green Hydrogen and Ammonia as a transformative strategic industry.

- The HPP II further outlines actions to be carried out to unlock the potential of the green economy including the research and development of hydrogen as an energy source, culminating in the establishment of hydrogen production, storage, delivery, and usage infrastructure.

- One such action is to establish an Inter-Ministerial National Green Hydrogen Council.

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National Context: Government Green Hydrogen Lead

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Honourable Obeth M Kandjoze		**Green Hydrogen Council Chair**	Director General of the National Planning Commission Former Minister of Mines and Energy
Mr James Mnyupe		**Green Hydrogen Commissioner**	Economic Advisor to the Namibian President Former Allan Gray Namibia Managing Director and a 2022WEF Young Leader.
Honourable Iipumbu W Shiimi		**Green Hydrogen Council Member**	Minister of Finance Former Governor of the Bank of Namibia from 2010 until 2020.
Honourable Thomas K Alweendo		**Green Hydrogen Council Member**	Minister of Mines and Energy In 2003, he became the first Namibian Governor of the Bank of Namibia
Honourable Pohamba P Shifeta		**Green Hydrogen Council Member**	Minister of Environment, Forestry and Tourism Minister of Environment and Tourism in the Cabinet of Namibia since 2015
Honourable Carl-Hermann G Schlettwein		**Green Hydrogen Council Member**	Minister of Agriculture,Water and Land Reform Former Minister of Finance
Mr Johannes !Gawaxab		**Green Hydrogen Council Member**	Central Bank Governor Former Head of Old Mutual Africa and Chair of EOS Capital
Mrs Nangula N Uaandja		**Green Hydrogen Council Member**	CEO : Namibia Investment Promotion and Development Board (NIPDB) Former Country Partner of PriceWaterhouse Coopers in Namibia.

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Hydrogen costs from hybrid solar PV and onshore wind systems

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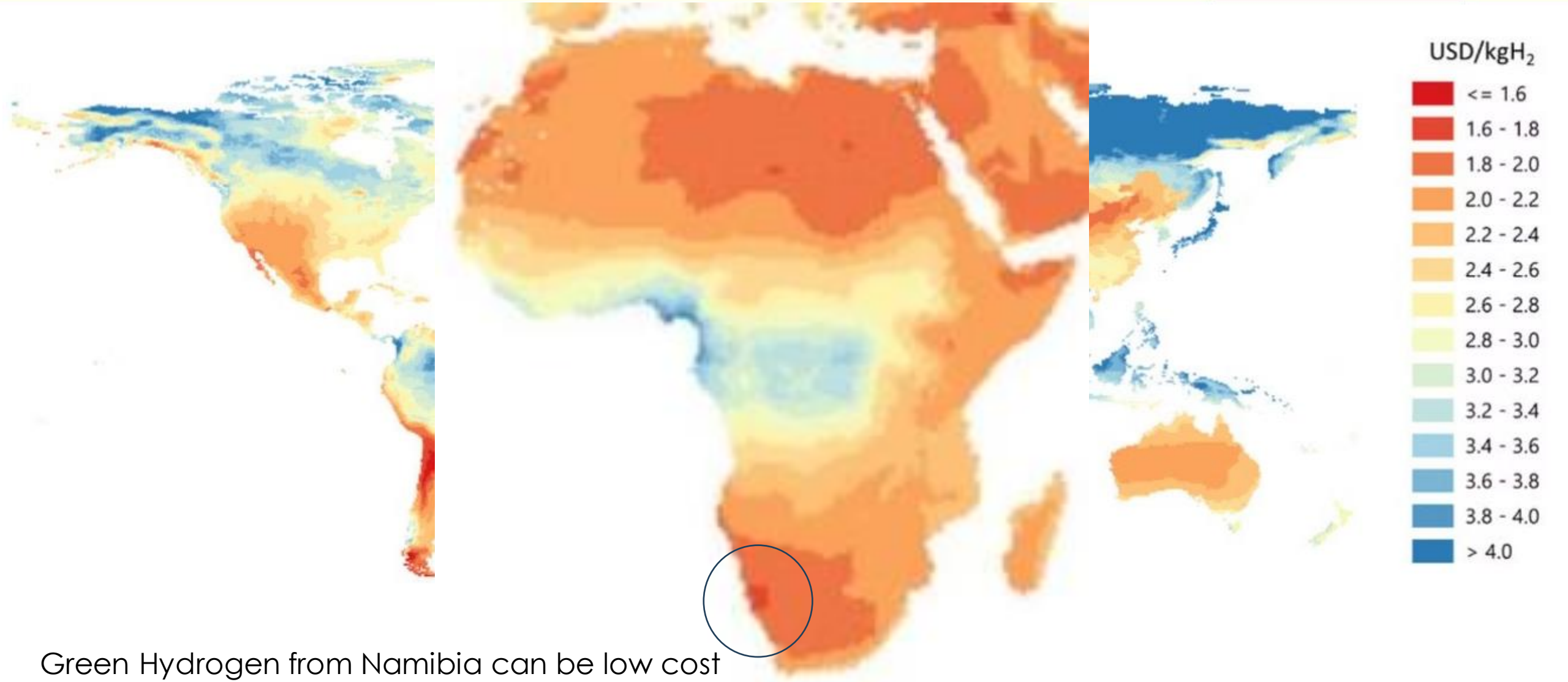


Green Hydrogen from Namibia can be low cost

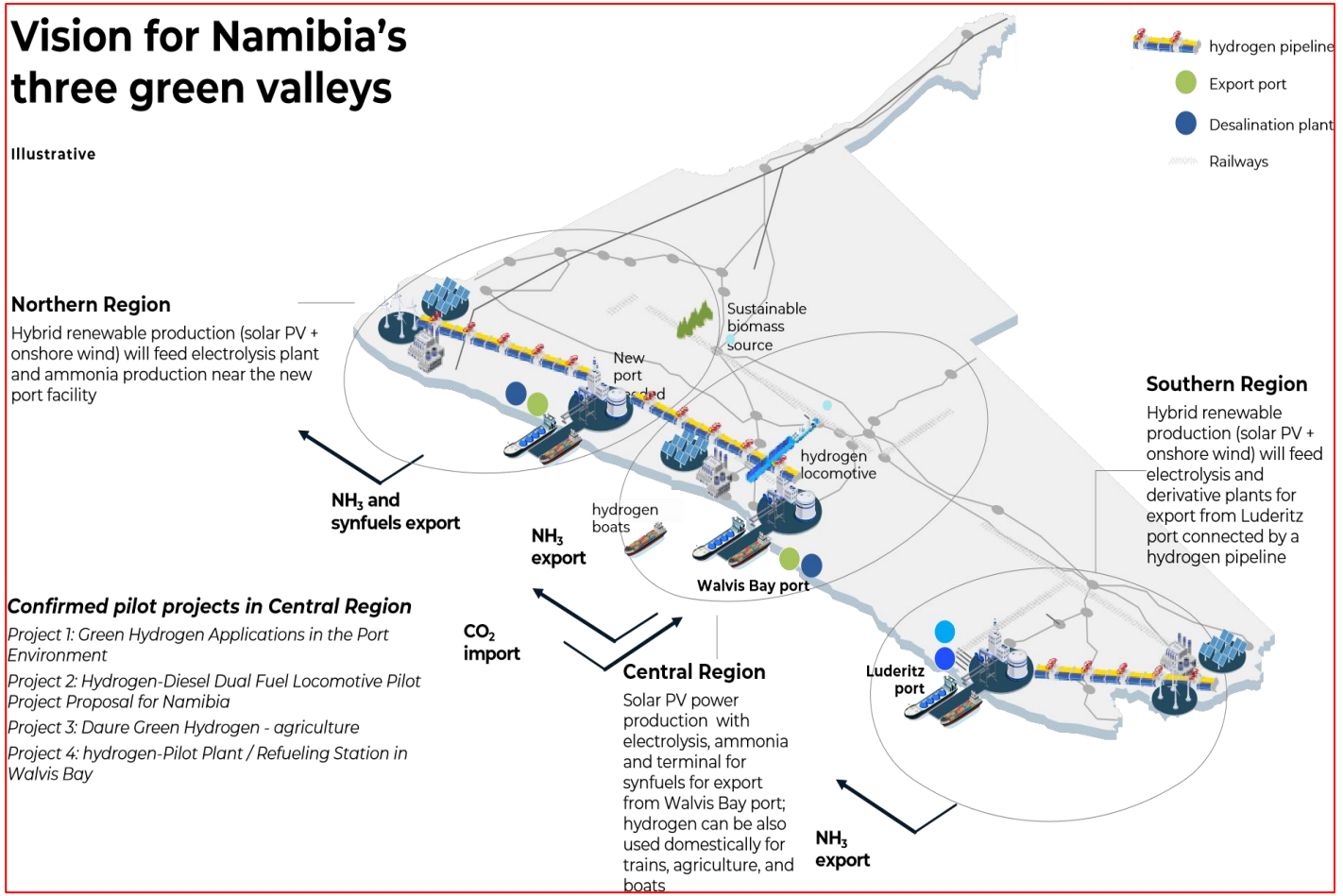
National Context: Green Hydrogen Strategy

Three hydrogen valleys will form a green fuel ecosystem based on its natural topography, domestic input factors (e.g., labour, land) and realistic achievable market share.

Namibia aspires to reach green hydrogen production volumes of 10-15 Mtpa by 2050 (corresponding to 5-8% of expected international hydrogen equivalent trade volume).

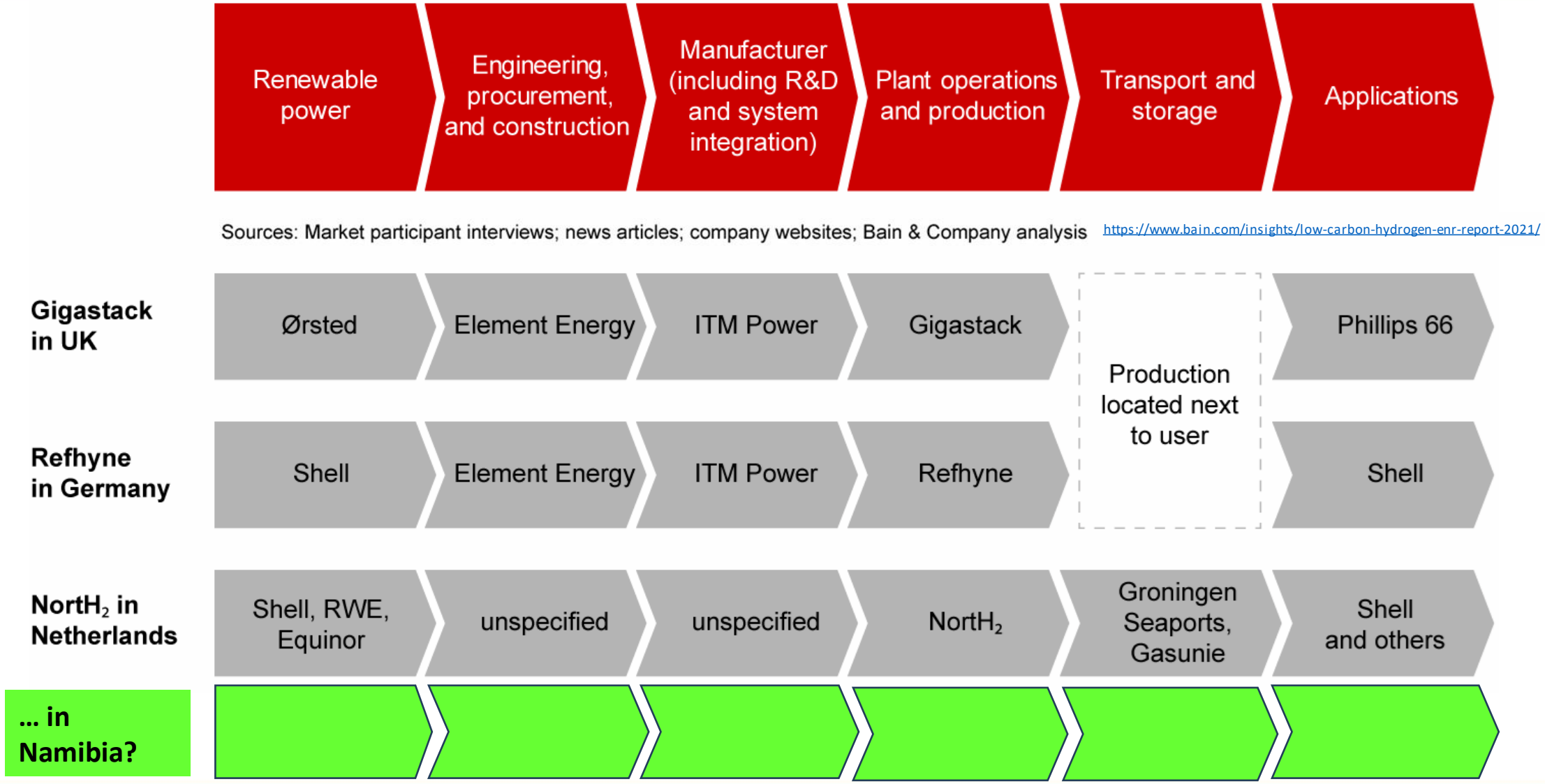
Namibia's ramp-up targets are:

- 2030: 1-2 Mtpa hydrogen equivalent
- 2040: 5-7 Mtpa hydrogen equivalent
- 2050: 10-15 Mtpa hydrogen equivalent



Three hydrogen valleys will produce ammonia, synthetic fuels and HBI in the southern region (Kharas), the central region (including Walvis Bay port and the capital Windhoek) and the northern region (Kunene)

Teaming Up to Meet Demands Along the Value Chain…



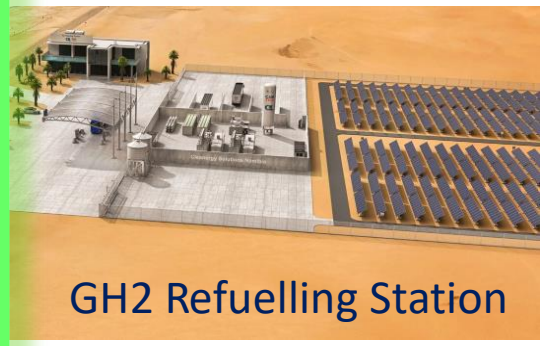
UNAM's Response to National Green Hydrogen Initiatives

- Established the Namibia Green Hydrogen Research Institute in 2021 (72 active researchers)
- Signed 30 MOU's with national and international institutions on GH2, and activities are underway
- Has hosted international visiting students and visiting Scientists
- Participated in various national and international fora on Green Hydrogen research and value chain
- Hosted an international conference on Hydrogen Energy Systems, in collaboration with NUST, in 2022
- UNAM is a Research Partner to Green Hydrogen Pilot Projects currently being established in Namibia:

Daures GH2 Village	***GH2 Refuelling Station***	***GH2- Diesel Locomotives***
○ Sustainable production and utilisation of green hydrogen and green ammonia from renewable energy sources	○ Development of a GH2 production plant comprising of hydrogen production, a refuelling station and a training centre.	○ Development of Africa's first dual-fuel hydrogen-diesel locomotive, with a unique hydrogen storage method

- BAM (Germany) – UNAM collaboration - 5 PhD scholarships awarded – started their studies in June 2023
- 24 of the 60+ candidates offered Masters' degree scholarships by BMBF/SASSCAL study at UNAM

Daures GH2 Village



GH2 Refuelling Station

GH2- Diesel Locomotives

Collaboration with government and private sector partners, International academic and research institutes, identified as key for success

NGHRI Structure

Namibia Green Hydrogen Research Institute (NGHRI)

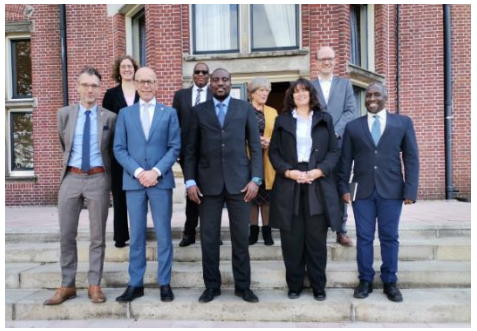
Centre for clean Hydrogen Production	Centre for Hydrogen Storage, New Materials, and Delivery	Centre for Hydrogen Fuel Cell Technology, and Mobility Applications	Centre for Hydrogen Energy Use, Economics, Law, Environment and Society	Centre for Hydrogen Capacity Building, Competence, and Standards	Centre for Hydrogen Digital and Emerging Technologies

Formulation of enabling policies, end use and environmental sustainability options for widespread hydrogen energy usage

Collaboration with government and private sector partners, International academic and research institutes, identified as key for success

Research and Stakeholder Engagements

- Studyvisits by UNAM delegation Engagements with German, the Netherlands and Belgium Institutions, and the discussions thereof, including participation in the EU H2 Week, where 4 meetings were held with various institutions (Oct 2022).
- UNAM and the NGHRI participation at COP-27.
- Dr. N. Shafudah – at Aachen for a one- week study on GH2 (23-27 Jan 2023).
- Dr A. Uusiku - at Aachen for 6 months research on GH2 starting August 2023
- Five PhD candidates at BAM since June 2023 (4 more expected – Cleanergy)



Research and Stakeholder Engagements

- 5 PhD scholarships awarded – BAM
- 60+ candidates offered Masters' degree scholarships
- 40 candidates offered TVET scholarships
- BMBF/SASSCAL
- Evaluation for 2024 awards - underway

Outlook

Stakeholder Engagements

- Ensure the operationalisation of the signed Memoranda of Understanding on collaboration in Green Hydrogen Research and Development.
- Identify and engage with new national and international partners.
- Receive, and host, international researchers including academics and postgraduate students.

Research Engagements

- Establish state of the art laboratories along the whole value chain
- Perform research in relation to the pilot projects already awarded
- Identify new research lines
- Publish research results in renowned journals

Outreach Activities

- Host International Conferences on Hydrogen-Based Energy Systems,
- Masterclasses on Green Hydrogen Value Chain for identified audiences (21-22 November 2023)
- Seek certification and / or accreditation for developed short courses and training programmes

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Outlook

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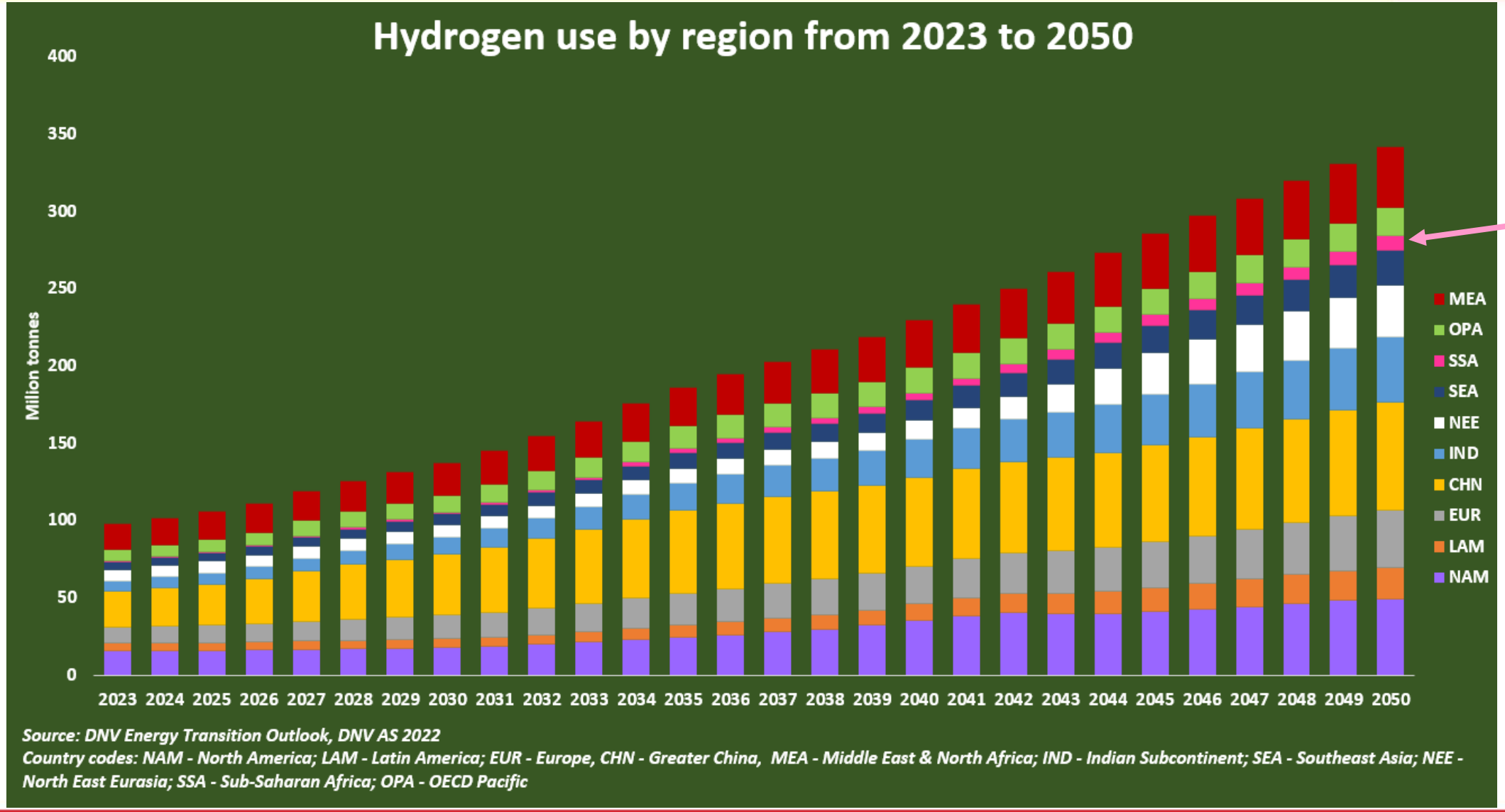

Sub Saharan Africa

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Outlook

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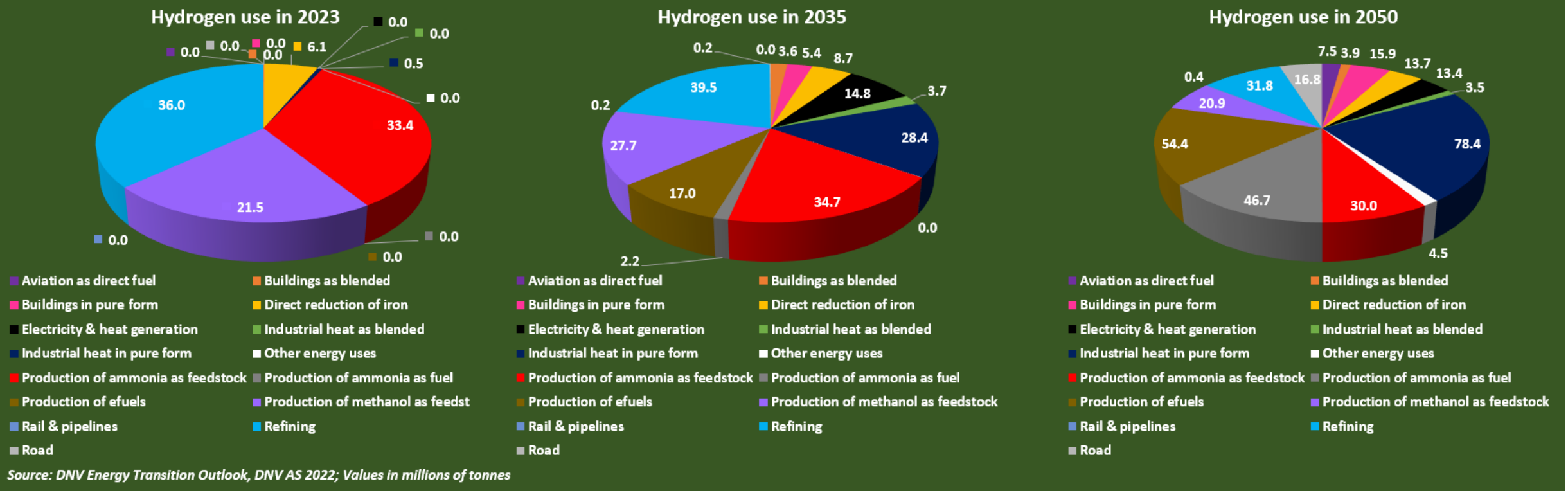
High hopes for hydrogen: Possible paths to greater industrial use by 2035 and 2050



Source: DNV Energy Transition Outlook, DNV AS 2022; Values in millions of tonnes

IEA's 7 key recommendations to scale up hydrogen

1. **Establish a role for hydrogen in long-term energy strategies.** Key sectors include refining, chemicals, iron and steel, freight and long-distance transport, buildings, and power generation and storage.

2. **Stimulate commercial demand for clean hydrogen.** Clean hydrogen technologies are available, but costs remain high. Scaling up supply chains can drive cost reductions.

3. **Address investment risks of first-movers.** Targeted and time-limited loans, guarantees and other tools can help the private sector to invest, learn and share risks and rewards.

4. **Support R&D to bring down costs.** Government actions, including use of public funds, are critical in setting the research agenda, taking risks and attracting private capital for innovation.

5. **Eliminate unnecessary regulatory barriers and harmonise standards.**

6. **Engage internationally and track progress.** On standards, sharing of good practices and cross-border infrastructure. Hydrogen production and use need to be monitored and reported on a regular basis.

7. **Focus on four key opportunities to further increase momentum over the next decade.**
   - Turn existing industrial ports into hubs for lower-cost, lower-carbon hydrogen.
   - Use existing gas infrastructure to spur new clean hydrogen supplies.
   - Support transport fleets, freight and corridors to make fuel-cell vehicles more competitive.
   - Establish the first shipping routes to kick-start the international hydrogen trade.

Outlook

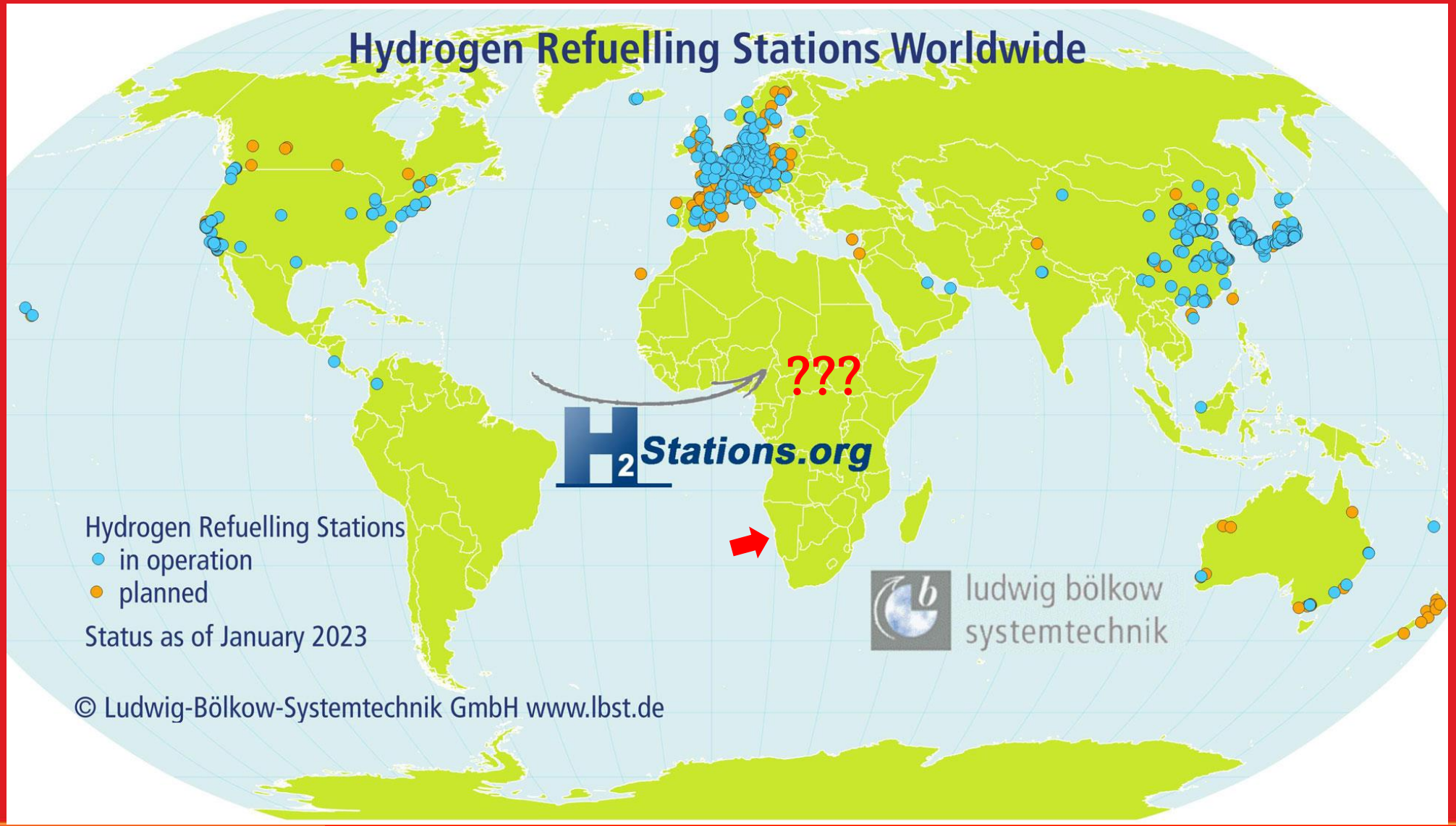
Hydrogen Technologies: **The Next Big Thing?**

- Facilitates Sector coupling across multiple market segments
- The PEM electrolyser increases stability of a renewables - heavy electrical grid
- Synchronised Grid development plan would be advantageous
- Hydrogen mobility (FCEV), increases the Electric Vehicle´s ability to replace traditional fossil fuelled motors, beyond the Battery Electric Vehicle
- Hydrogen is a raw product for many chemicals
- Synthetic Fuels from green hydrogen can be transitional products to reduce CO_2 during phase out of traditional fossil fuel motor vehicles
- **Namibia has kicked off … all players (national and international) be active, … GOAL!!!**

YES! – Hydrogen is the next big "thing"

NGHRI
Namibia Green Hydrogen Research Institute

THANK YOU



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How many Hydrogen Passenger Vehicles Have Been Sold So Far?

Over 56 Thousand

February 10, 2023

NGHRI
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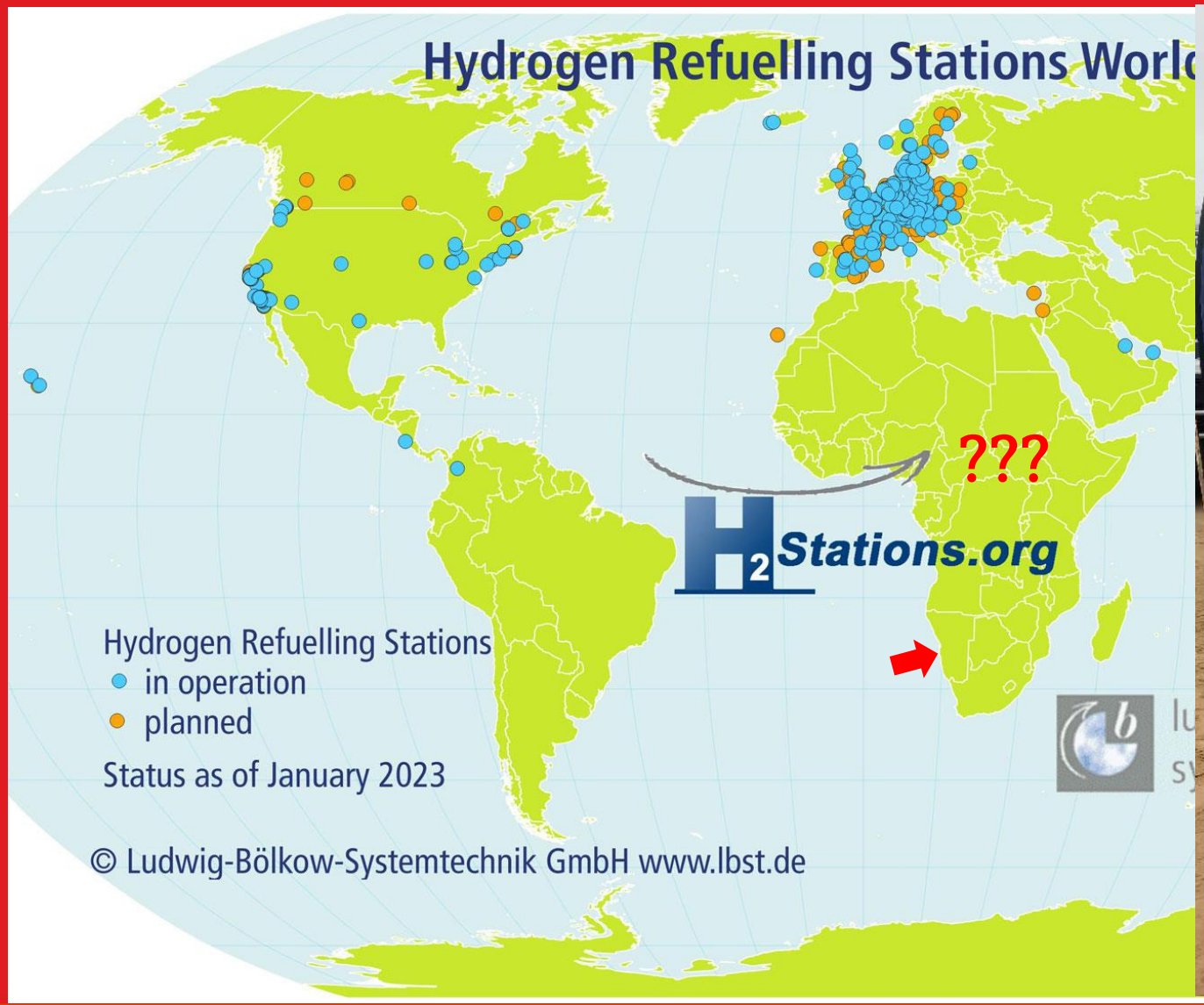
THANK YOU



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Namibia's and Africa's first Hydrogen Refuelling Station?

Currently being constructed in Walvis Bay.