

HYDROGEN & CARBON CAPTURE



FACILITATING GREEN HYDROGEN PRODUCTION AND IMPORT/EXPORT

FACILITATING HYDROGEN PRODUCTION AND EXPORT

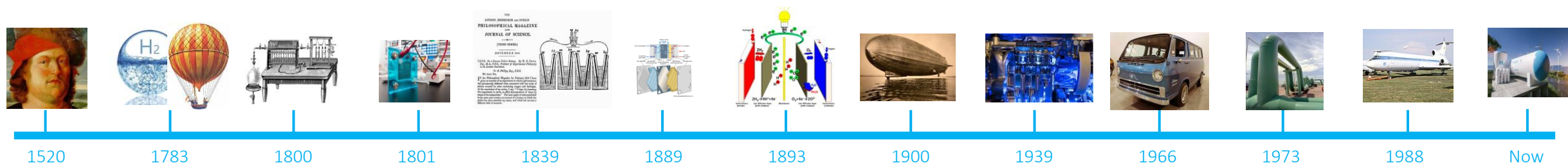
ANNEX

- Hydrogen development history
- Hydrogen potential VS other fuels
- Hydrogen transportation issues
- Hydrogen costs
- Hydrogen strategies
- Mapping global Hydrogen supply-demand
- Global Hydrogen import / export potential
- Discussion on facilitating Green Hydrogen production and export/import



FACILITATING HYDROGEN PRODUCTION AND EXPORT

Scientists have been interested in **Hydrogen** since 1520, and since the 1800 into as a source of energy.

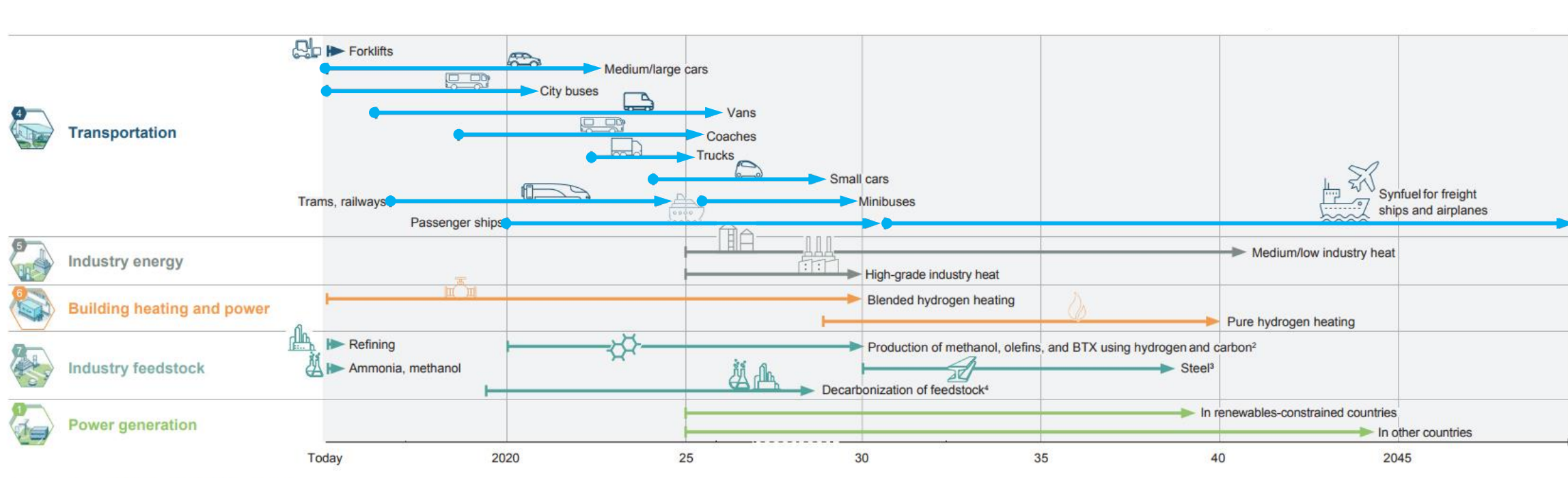


Timeline:

- 1520 – First recorded observation of Hydrogen by Paracelsus through dissolution of metals (iron, zinc, and tin) in sulfuric acid.
- 1783 – Antoine Lavoisier gave Hydrogen its name (Gk: hydro = water, genes = born of)
- 1783 – Jacques Charles made the first flight with his hydrogen balloon "La Charlière".
- 1800 – William Nicholson and Anthony Carlisle decomposed water into hydrogen and oxygen by electrolysis with a voltaic pile.
- 1801 – Humphry Davy discovers the concept of the Fuel Cell.
- 1839 – Christian Friedrich Schönbein published the principle of the fuel cell in the "Philosophical Magazine".
- 1889 – Ludwig Mond and Carl Langer coined the name fuel cell and tried to build one running on air and Mond gas.
- 1893 – Friedrich W. Ostwald experimentally determined the interconnected roles of the various components of the fuel cell.
- 1900 – Count Ferdinand von Zeppelin launched the first hydrogen-filled Zeppelin LZ1 airship.
- 1939 – Rudolf Erren – Erren engine – US patent 2,183,674 – Internal combustion engine using hydrogen as fuel.
- 1966 – General Motors presents Electrovan, the world's first fuel cell automobile.
- 1973 – The 30 km Hydrogen pipeline in Isbergues.
- 1988 – First flight of Tupolev Tu-155. This was a variant of the Tu-154 airliner designed to run on hydrogen.

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Timeline of future development of Hydrogen technologies:

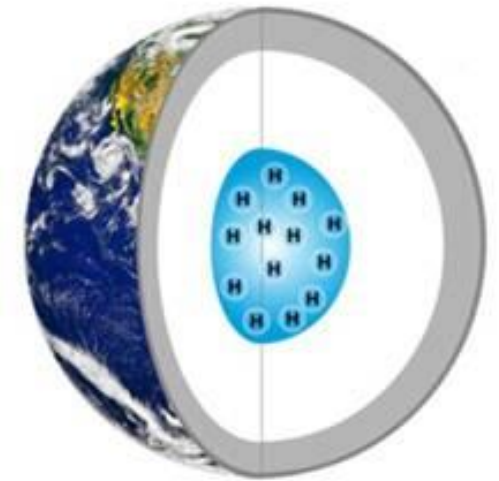


Start of Commercialization

Mass Market Acceptability

FACILITATING HYDROGEN PRODUCTION AND EXPORT

- **Hydrogen** H_2 is the most abundant element on the Earth. It is found naturally combined with other elements.
- Hydrogen is an **energy carrier** and **fuel** which can be used to **store**, **transport**, and **deliver** energy produced from other sources.
- **Hydrogen** can be **produced** without a carbon footprint from a variety of sources as coal, natural gas, biomass, waste materials as plastics, or by splitting water molecules.



FACILITATING HYDROGEN PRODUCTION AND EXPORT

- Hydrogen could account for **up to 12 %** of global energy use by 2050.
- Existing data shows that **hydrogen will play an important part** in energy transition and that all **sustainable hydrogen productions technologies** will play a role.
- Today is important to **define the right priorities** to kick-start a **hydrogen ecosystem** and start developing required **hydrogen infrastructure**.
- It is important to assess **national potential** to contribute to development of a hydrogen ecosystem and to explore what are the **opportunities for hydrogen export potential** as well as **domestic applications**.

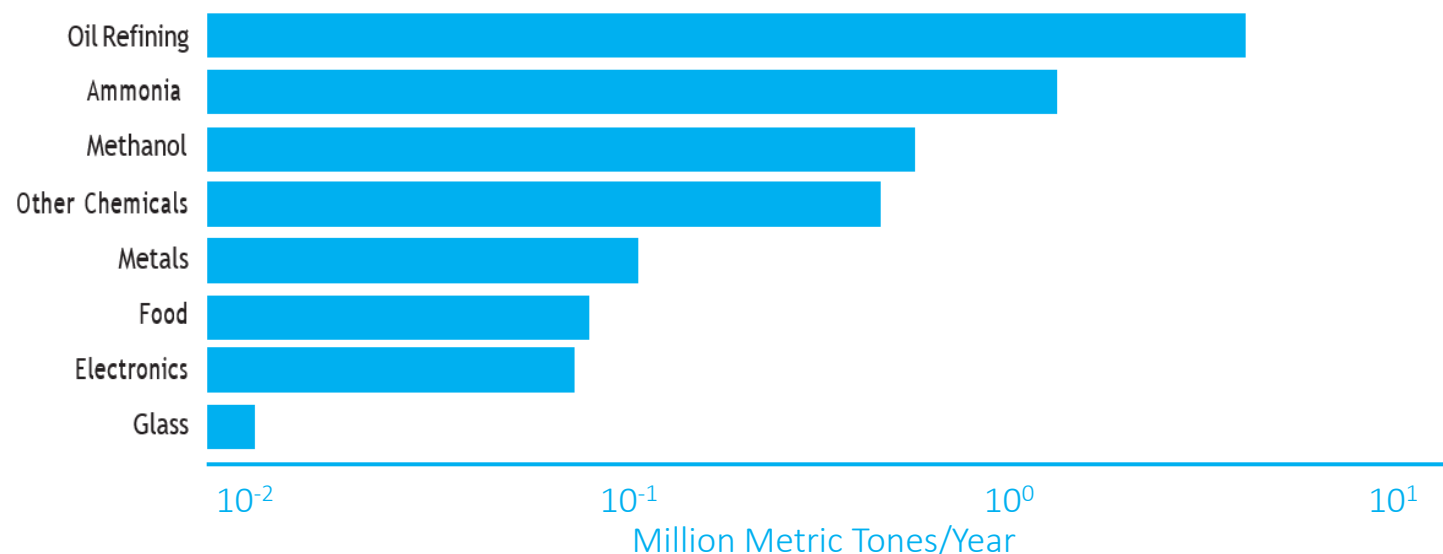


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Primary utilisation of Hydrogen includes the following **applications**:

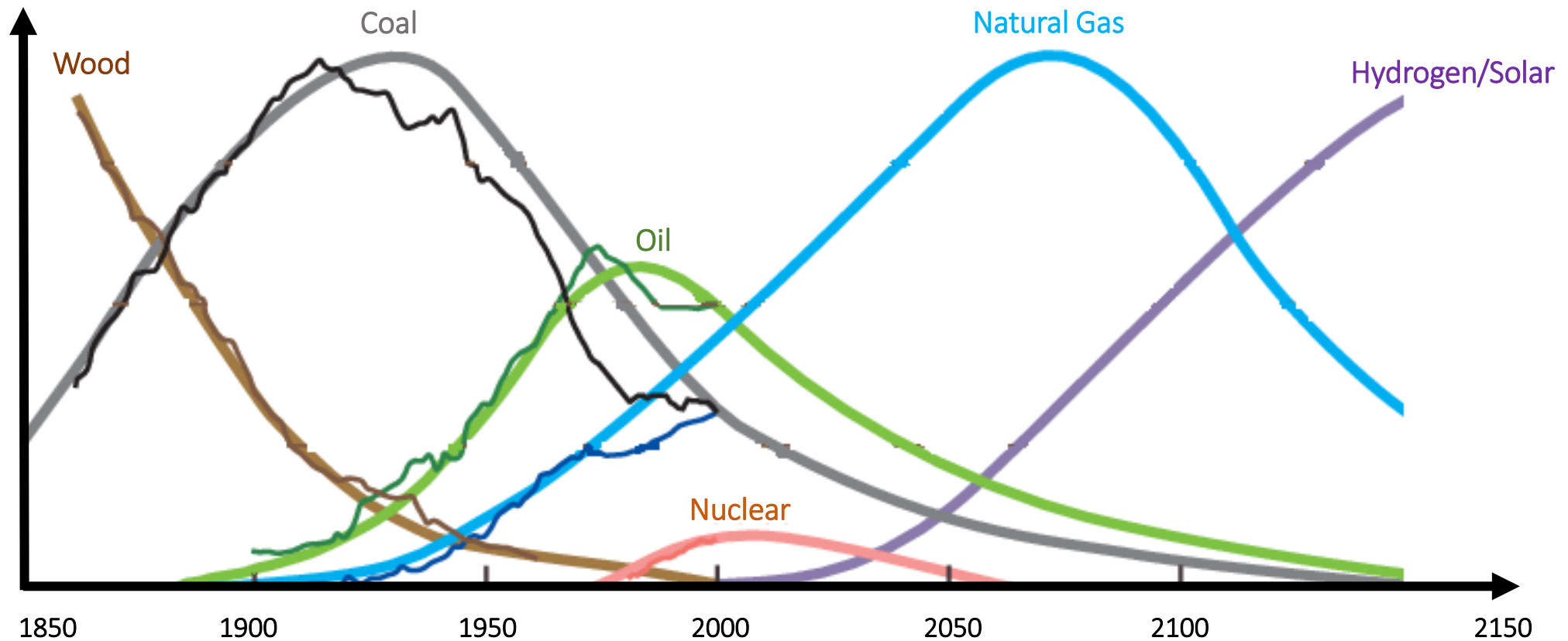
- As a chemical in **ammonia** (NH_3) production (mainly for fertilizers);
- As a chemical feedstock and **catalyst**;
- As a hydrogenating agent for **food** and **drug** production;
- In petrochemical and **refinery** processing

Hydrogen consumed by large volume consumer mostly is generated **onsite** (captive hydrogen), and for industries such as glass manufacture, food, and electronics, Hydrogen is **supplied by trailers** (merchant hydrogen).



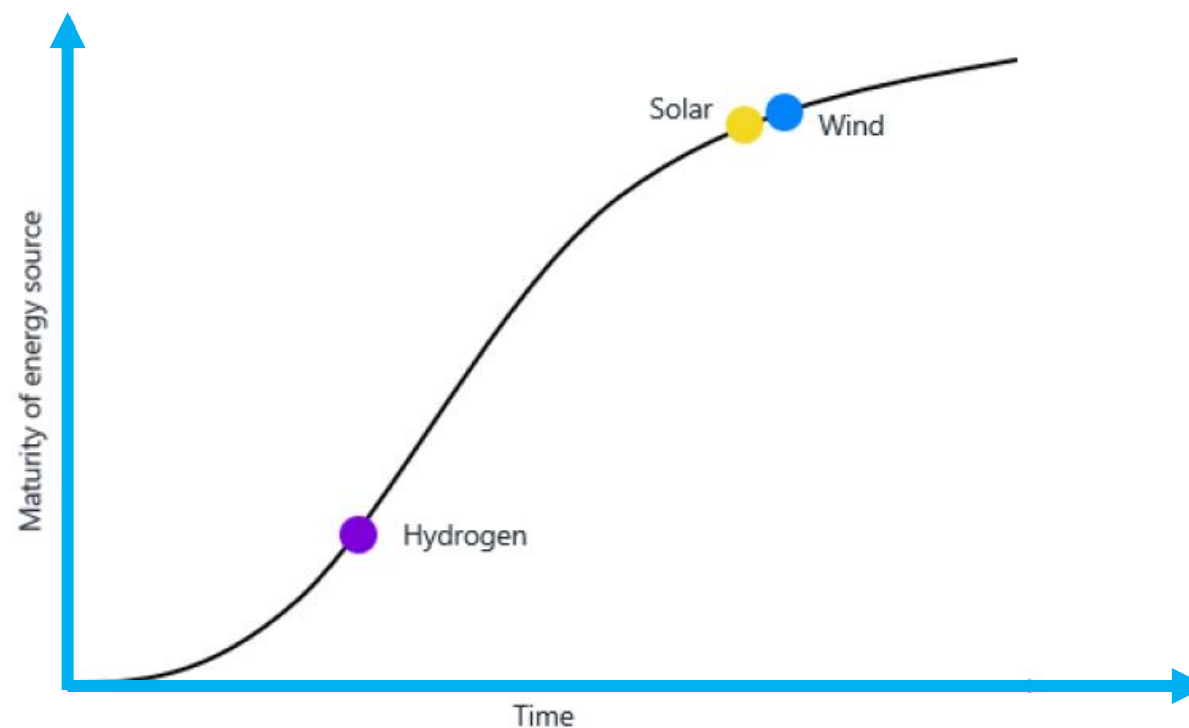
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Historical data of various Fuel types utilisation phase VS Hydrogen



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- Hydrogen technology is catching up on the **maturity curve** with solar and wind power



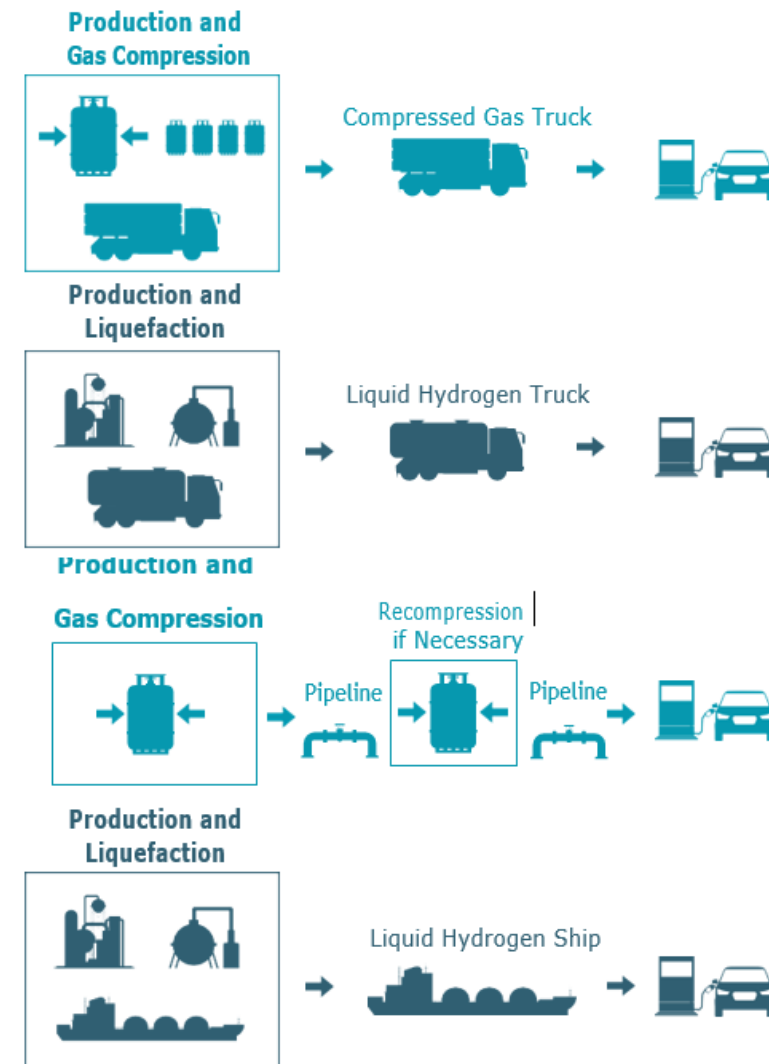
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- The **cost of hydrogen production** varies between **regions**, with **Europe** and **Japan** having relatively **high costs** and strong policy support for hydrogen.
- **Hydrogen importers** stand to benefit from cheaper, low-carbon energy—especially if their domestic renewable energy, nuclear, or CCUS resources are challenging or expensive to develop.
- According to the IEA, **in the future**, it may be **cheaper** in some instances for some countries to **import hydrogen** than to produce it domestically.



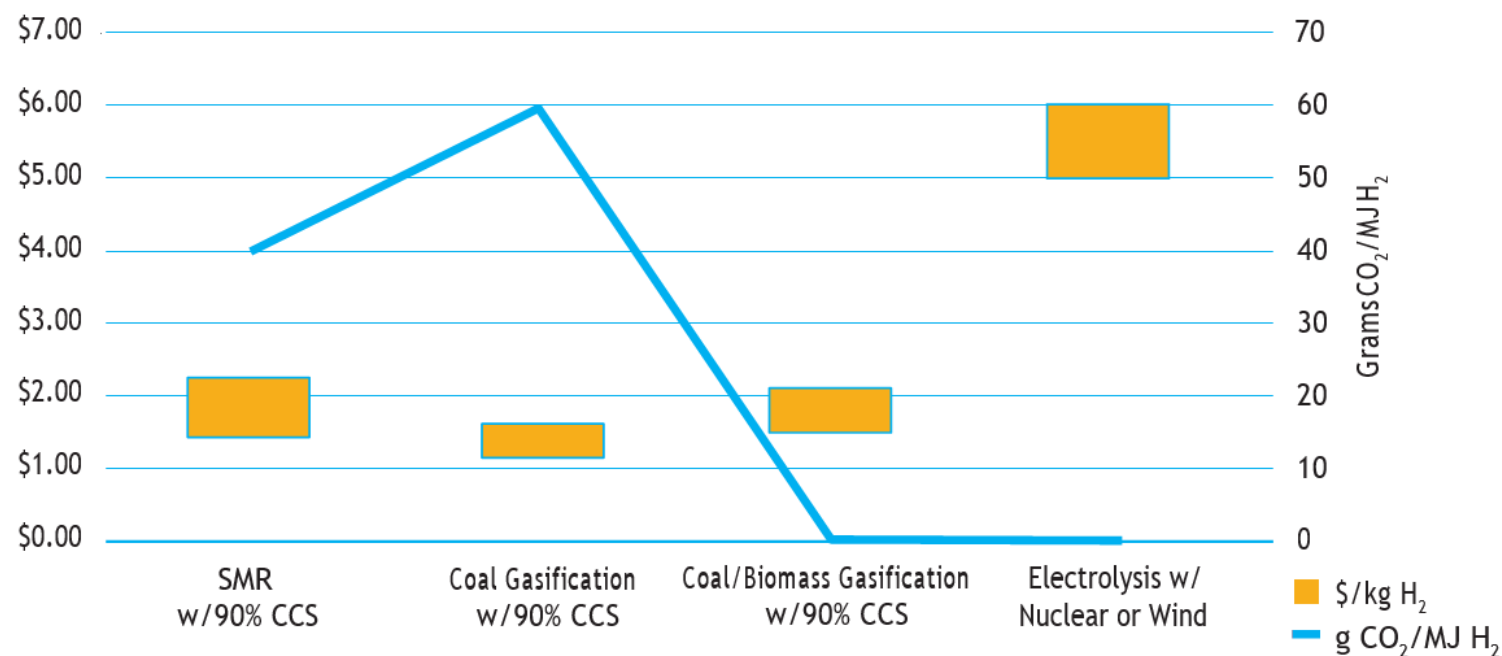
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- **Transportation** of Hydrogen is a **challenge**. Hydrogen has high energy density per unit mass, but a **low-volumetric energy density** (~30% of methane at 15°C/1bar) and an ability to permeate metal-based materials.
- Transportation requires **high pressures** / **low temperatures** / chemical processes to be stored compactly.
- **Gaseous** Hydrogen is transported by either **tube trailers** or **pipelines** (~300 km).
- **Liquid** Hydrogen for shorter distances/small volumes is transported by **road tankers** (~1.000 km) or longer distances/larger volumes by **ships** (between countries).



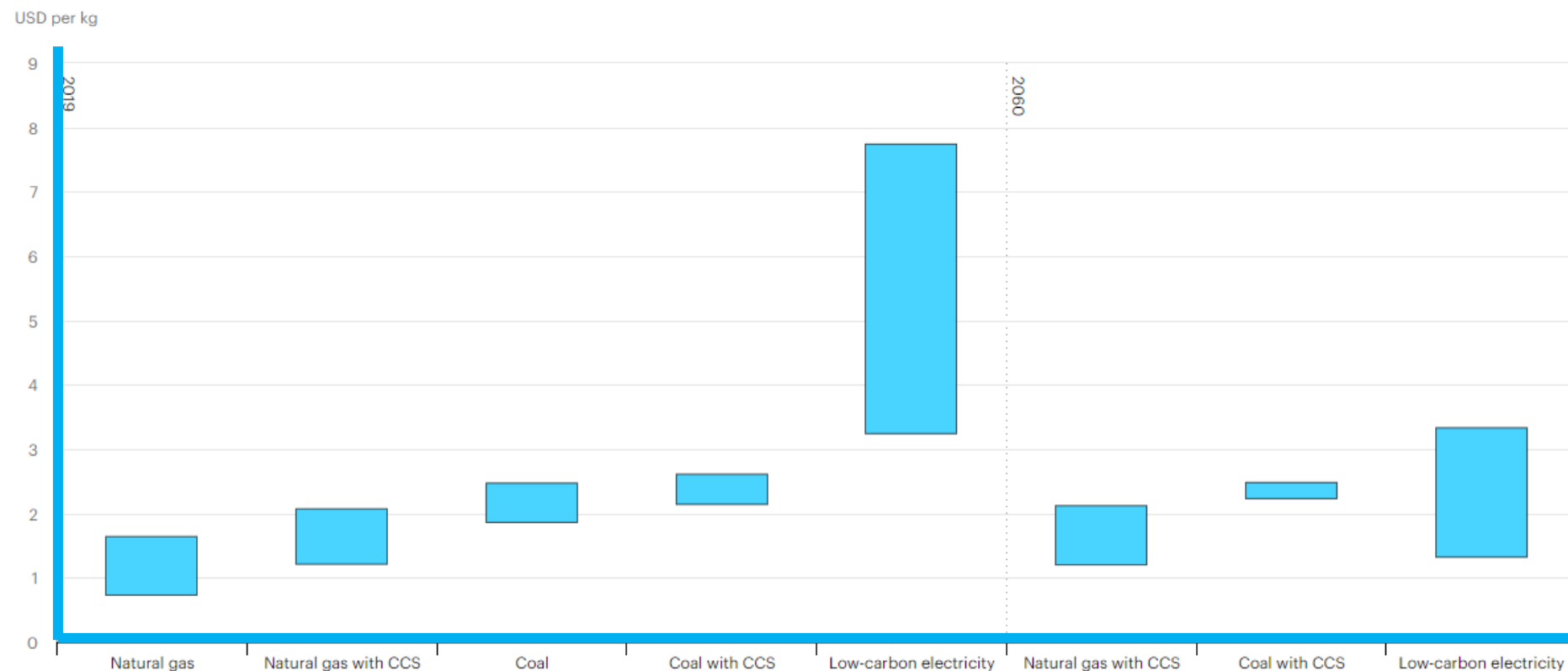
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- H₂ production from fossil fuels is the least expensive source of hydrogen.
- **Steam reforming** of natural gas for H₂ production costs vary from **\$1.43-2.27/kg** with CO₂ capture and storage (CCS) (highly dependent on natural gas price).
- H₂ from **gasification** to vary between **\$1.16-1.63/ kg** for coal and between **\$1.31-2.06/kg** for coal/biomass/waste plastic with CO₂ capture and storage (highly dependent on the feedstock price).
- H₂ production cost through **electrolysis** is estimated at **\$5-6/kg** with electricity from nuclear or wind resources.
- H₂ from **zero-carbon electricity** (nuclear/wind), is **2.5–4 times more costly** than H₂ from carbon-neutral or net-negative carbon fossil resources.



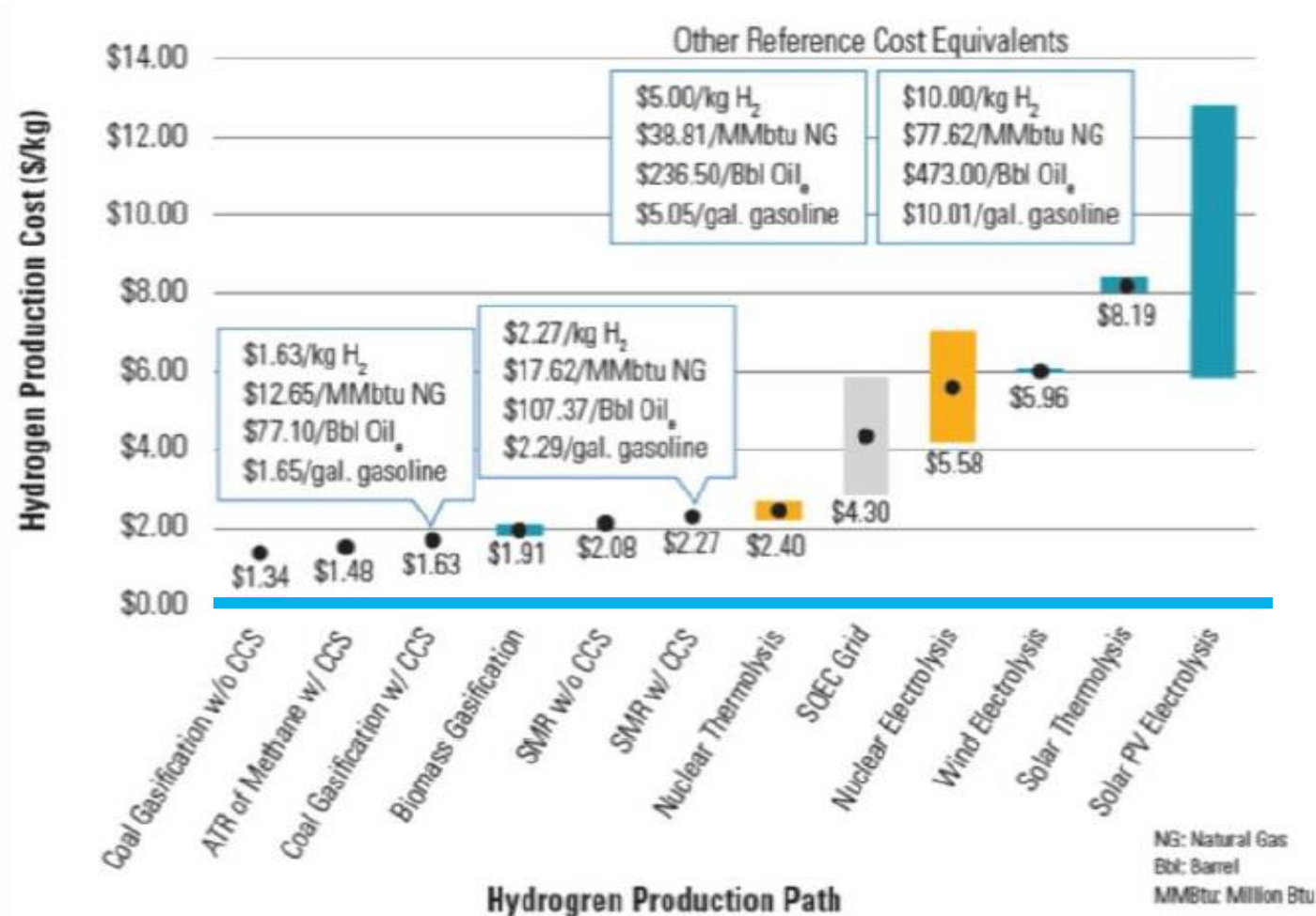
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Hydrogen costs (2019)



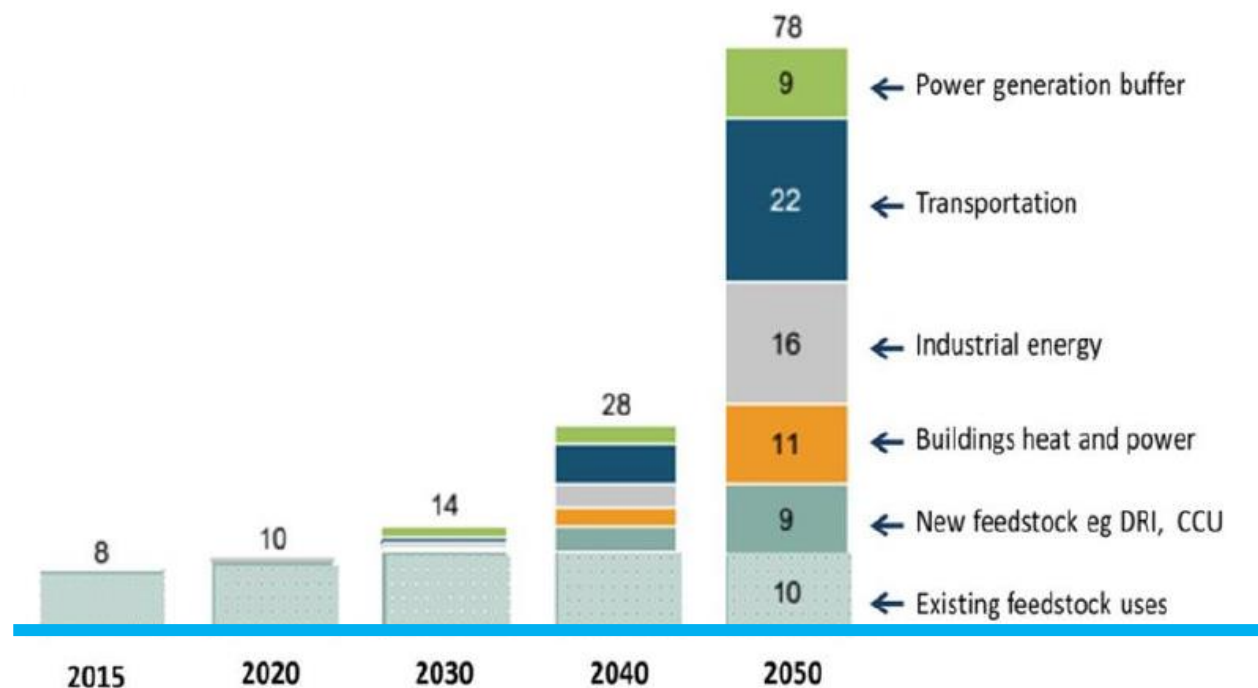
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Hydrogen costs (2020)



FACILITATING HYDROGEN PRODUCTION AND EXPORT

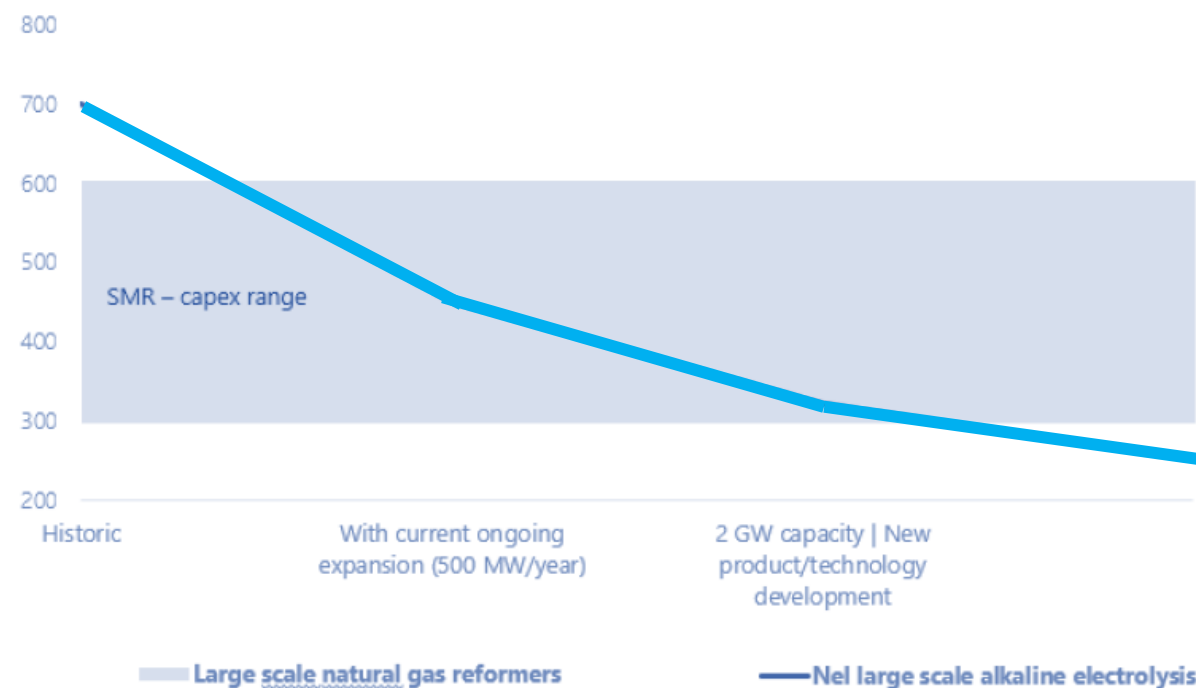
Future Hydrogen demand



Forecast increase in global hydrogen demand (EJ) through to 2050
(Hydrogen Council, 2017)

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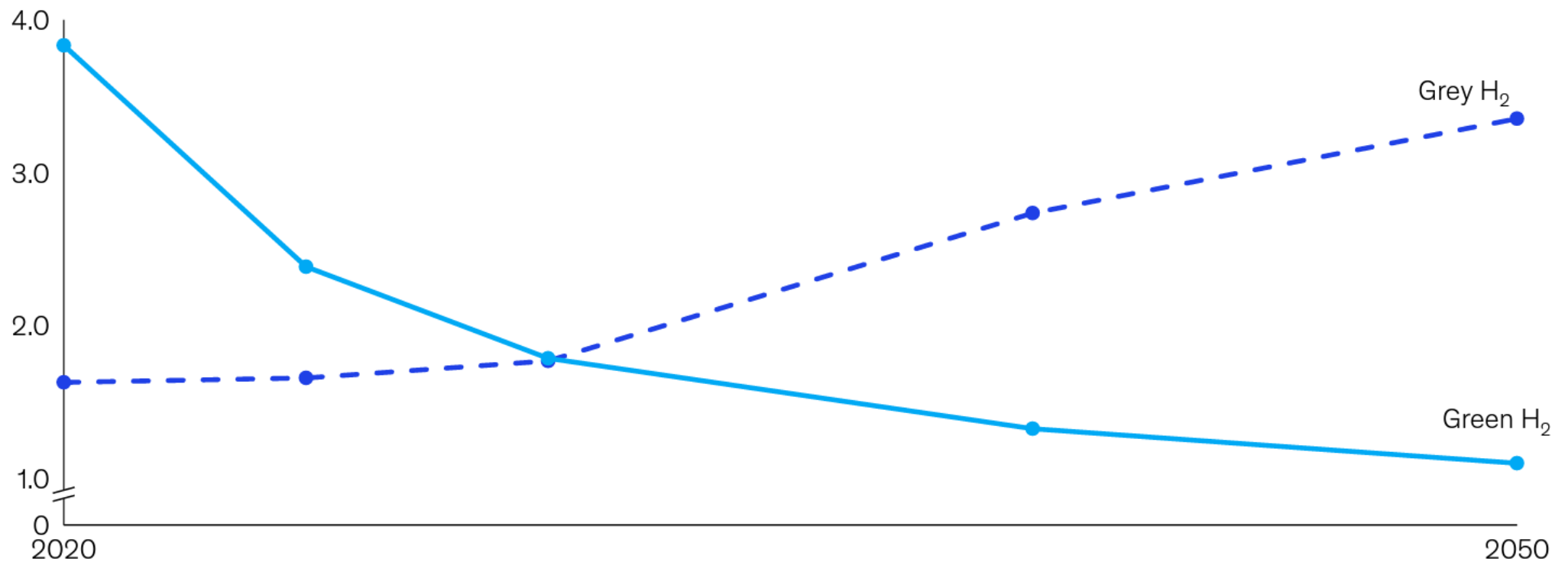
- **Growth** in renewable hydrogen is expected to accelerate **decrease** in CAPEX for electrolyzers and planned investments in the hydrogen sector by 2030.
- **Electrolysers market** by 2050 is expected to be \$50-60 bn.



Capex of steam methane reformers (SMR) vs. Nel's alkaline electrolyzers, \$/kW

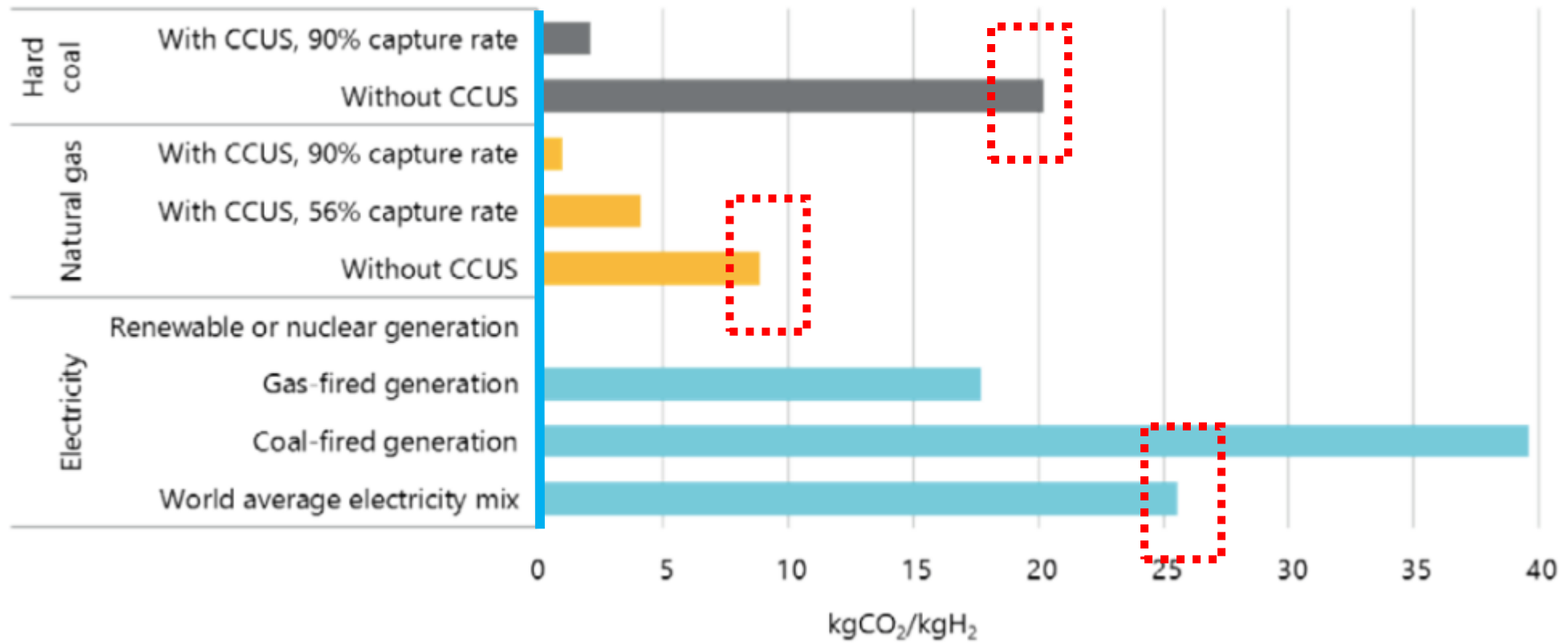
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Green hydrogen prices are expected to halve over the next ten years



FACILITATING HYDROGEN PRODUCTION AND EXPORT

Comparison of emissions



FACILITATING HYDROGEN PRODUCTION AND EXPORT

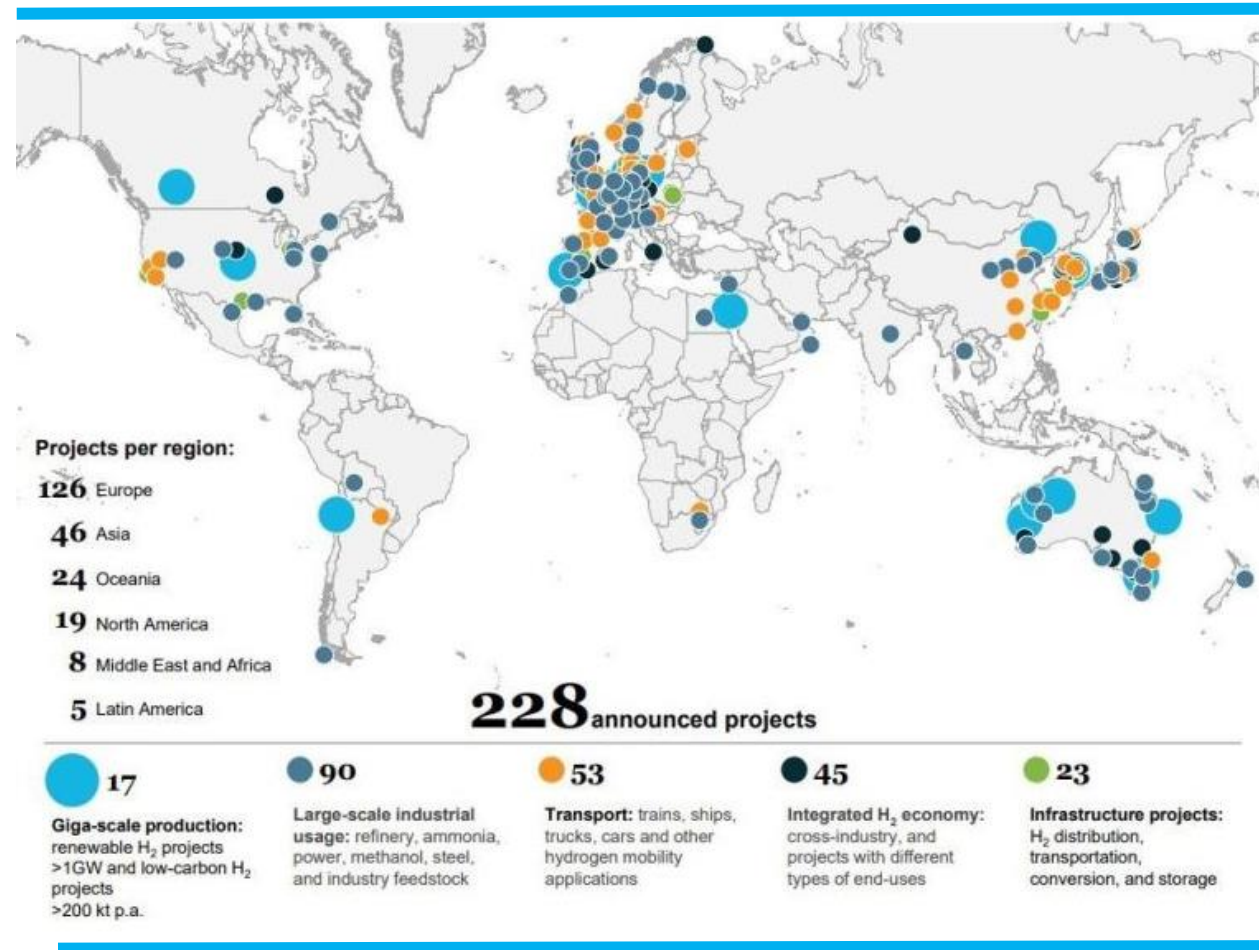
DRIVERS OF COST REDUCTION FOR RENEWABLE HYDROGEN INCLUDE:

- Electricity costs 70%,
- Capex costs 15%,
- Project financing costs 9%
- Operation & Maintenance costs 5%
- Two main issues remain an obstacle to its development: the manufacturing cost of electrolyzers and unclear regulatory framework.



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- A new Hydrogen Council report shows **over 30 countries with a national H₂ strategy** and budget, and **228 projects** in the pipeline.
- Governments worldwide **committed > USD 70 bln in public funding**. Momentum exists along the entire value chain and is accelerating **cost reductions** for hydrogen **production, transmission, distribution, retail, and end applications**.
- Underpinned by a global shift of regulators, investors, and consumers toward decarbonization, H₂ is receiving **unprecedented interest and investments**.



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- There is a **global commitment** to increase the electrolyzers capacity to achieve targeted production goals. The total commitments announced are equal to an increase of electrolyzers capacity to 38.5 GW by 2030 (EU target).



FACILITATING HYDROGEN PRODUCTION AND EXPORT

- Europe leads globally in the number of **announced hydrogen projects**, with Australia, Japan, Korea, China, and the USA following as additional hubs. There is a **gap** in Eastern Europe and Central Asia.
- European Union aims to increase the **production of hydrogen by 10 million tons by 2030** and imports 10 million more tons of hydrogen.
- This will lead to the **creation of 80 GW of electrolyzers capacity** (doubled the size of original 50 GW target).



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- 17 GW-scale H₂ production projects are planned, with the largest in Europe, including Netherlands, Australia, the Middle East, and Chile.
- Anticipating continued growth in scale, the data confirms that from a **total cost of ownership perspective** – hydrogen can become the most **competitive** low-carbon solution in **more than 20 applications** by 2030, including long haul trucking, shipping, and steel.



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WIDE PROVEN EXPERIENCE

Alkaline electrolyzers since 1927
and PEM electrolyzers since 1996

SCALABLE DESIGN

From <1 to > 8,000 kg/day
production able to deliver 100+
MW systems

DESIGNED FOR HIGH VOLUME MANUFACTURING

To achieve large scale plants with
fossil price quality

Wide proven experience

Alkaline electrolyzers since 1927 and
PEM electrolyzers since 1996



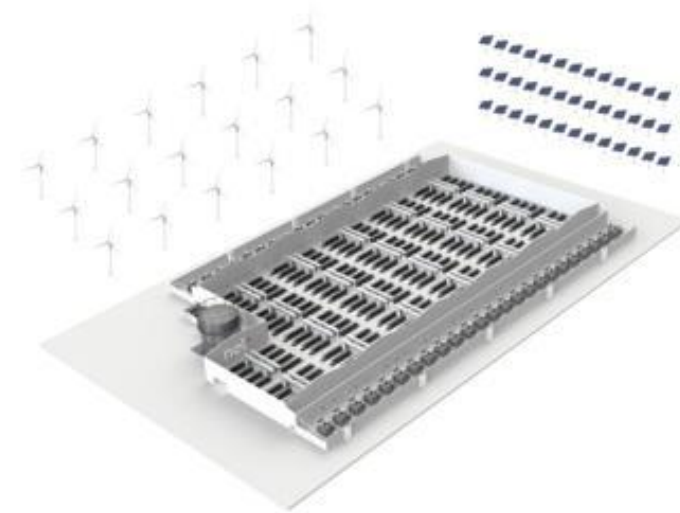
Scalable design

from <1 to >8,000 kg/day production
able to deliver 100+ MW systems



Designed for high volume manufacturing

to achieve large scale plants
with fossil price quality



FACILITATING HYDROGEN PRODUCTION AND EXPORT

BEST CASE PRACTICE - Heroya, Norway.

- Fully automated and designed according to lean manufacturing and **industry 4.0 principles**
- Industrial scale production of **most efficient electrolysers in the market**, at a **game-changing cost**
- Large scale production line, name plate **capacity of more than 500 MW**
- Room to expand to **~2 GW annually**
- CO₂ reduction potential in line 1 GW is 1,000,000 tonnes – with 2 GW is **4-5 million tonnes**



Dr. Romanas Savickas

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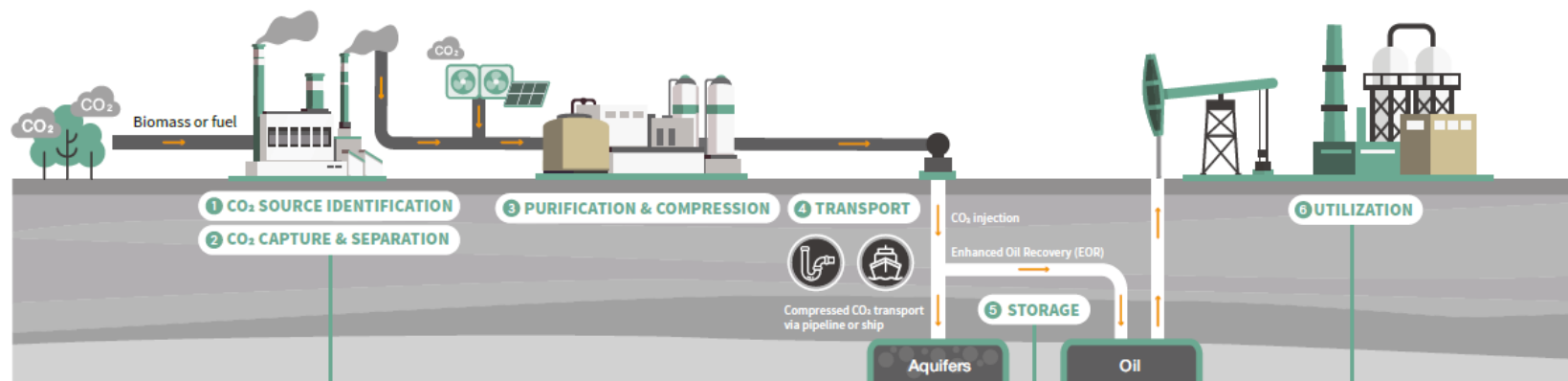
KEY DRIVERS FOR LARGE SCALE COMMERCIALIZATION AND DEPLOYMENT

- One standardized and universally applied **certification system** classifying the **different types of hydrogen** with common LCA methodology.
- Flexible and workable **rules for the sourcing of renewable electricity from the grid.**
- Clear demand signals promoted via **regulation** e.g.
- Targets for the use of **renewable hydrogen in industry / transport segments.**
- **No double grid fees** for renewable H₂ production.
- Distance targets for H₂ refueling stations.
- Contracts for difference.



FACILITATING HYDROGEN PRODUCTION AND EXPORT

CARBON CAPTURE, USAGE AND STORAGE



Point Sources of CO₂ in Industry

CO₂ from industries (cement, steel, hydrogen production from fossil fuels, or power generation) is captured before it reaches the atmosphere and is then compressed and injected into porous rock layers.



Biomass Energy with Carbon Capture and Storage (BECCS)



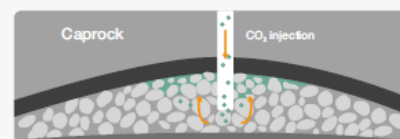
Direct Air Carbon Capture and Storage (DACCS)



Net negative emissions technologies are key to reach net-zero and then net negative emissions. In BECCS, CO₂ is taken out of the atmosphere by vegetation, then recovered from the combustion products when the biomass is burnt. In DACCS, CO₂ is captured directly from the air.

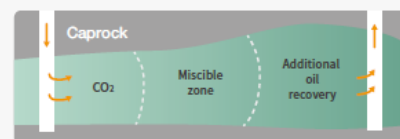
Aquifers for Sequestration of CO₂

Aquifers are geological formations containing brine in porous rock at depths over 1km. CO₂ can be pumped down into the rock for sequestration.



Enhanced Oil Recovery (EOR)

EOR is a family of techniques that increases the recovery of oil and gas while storing CO₂. Dependent on operational choices, the volume of CO₂ stored could exceed the CO₂ content of the produced hydrocarbons.



Solutions for Carbon Utilization



Carbon utilization can unlock the commerciality of CCUS projects for the industrial, steel, cement and chemical sectors. CO₂ captured can be used as a feedstock to produce a range of products, such as concrete, methanol, ethanol, carbonates, plastics etc.

Awareness

Recognise CCUS as a viable climate mitigation option and consider it when developing national plans.

Acceptance

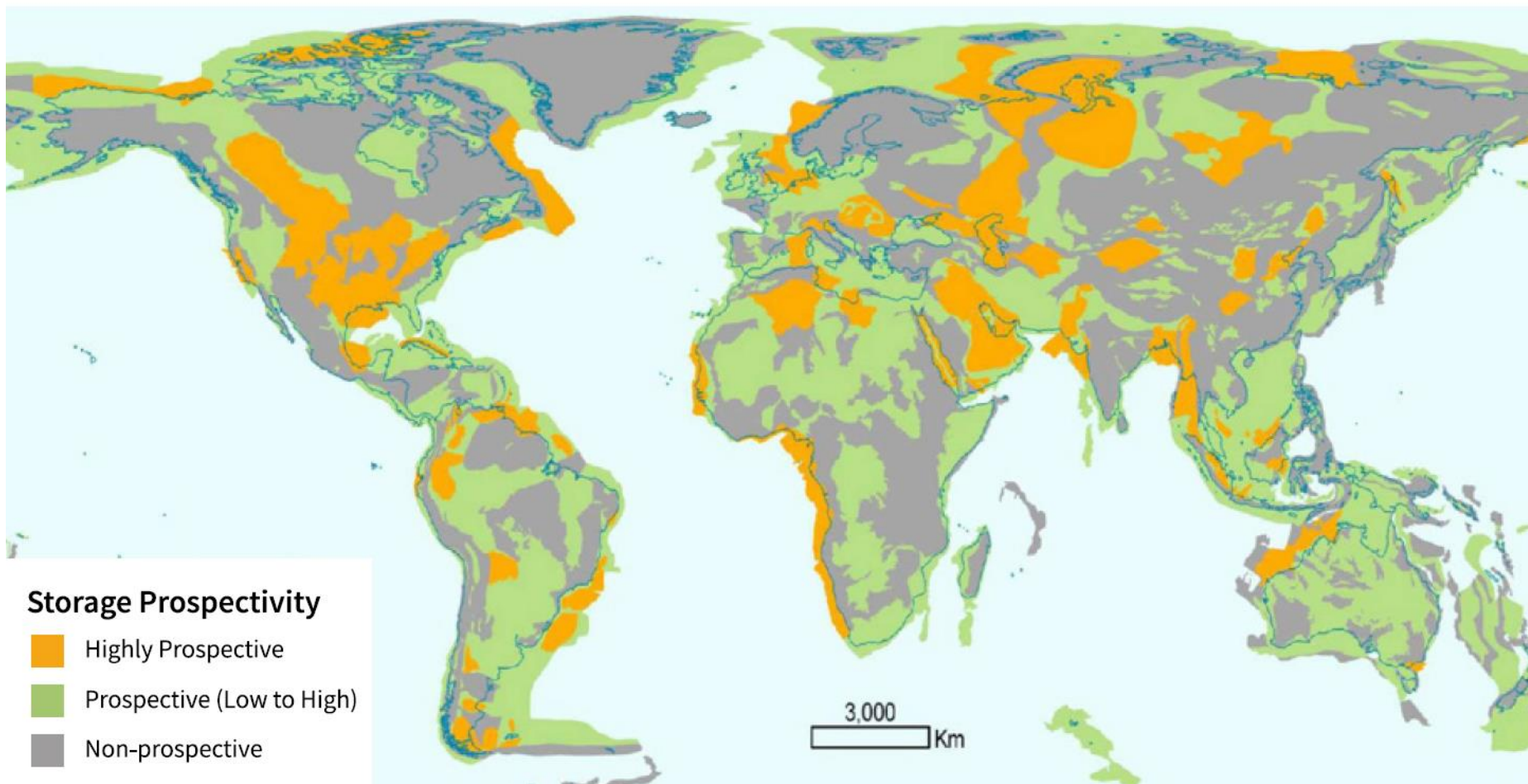
Develop and integrate policies to allow full commercialisation of CCUS technologies.

Finance

Create a funding mechanism for CCUS and direct investments towards modernization of energy infrastructure.

FACILITATING HYDROGEN PRODUCTION AND EXPORT

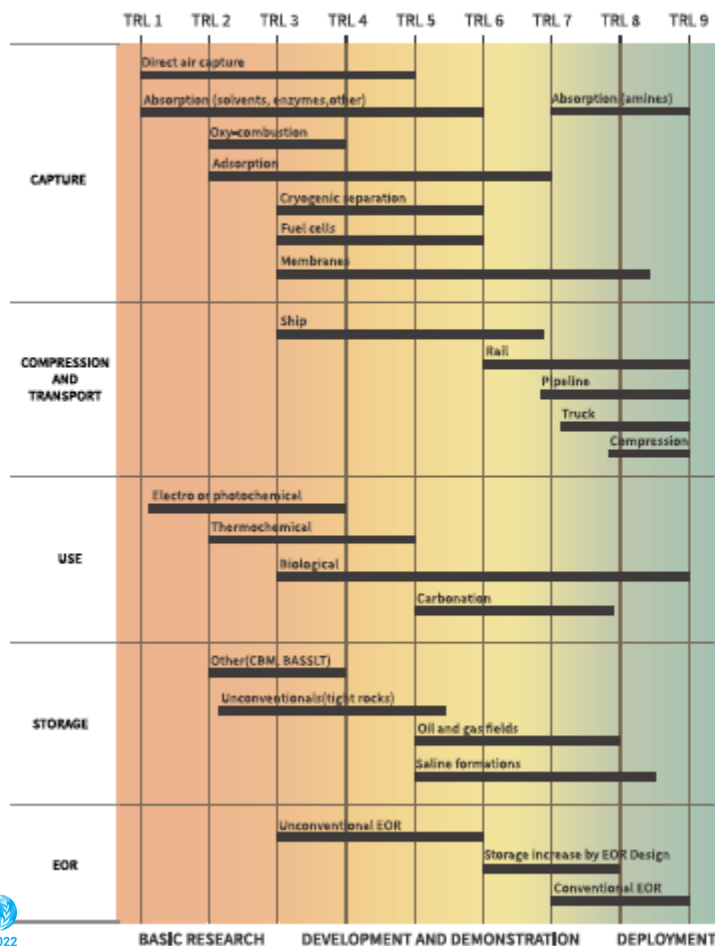
CARBON STORAGE POTENTIAL



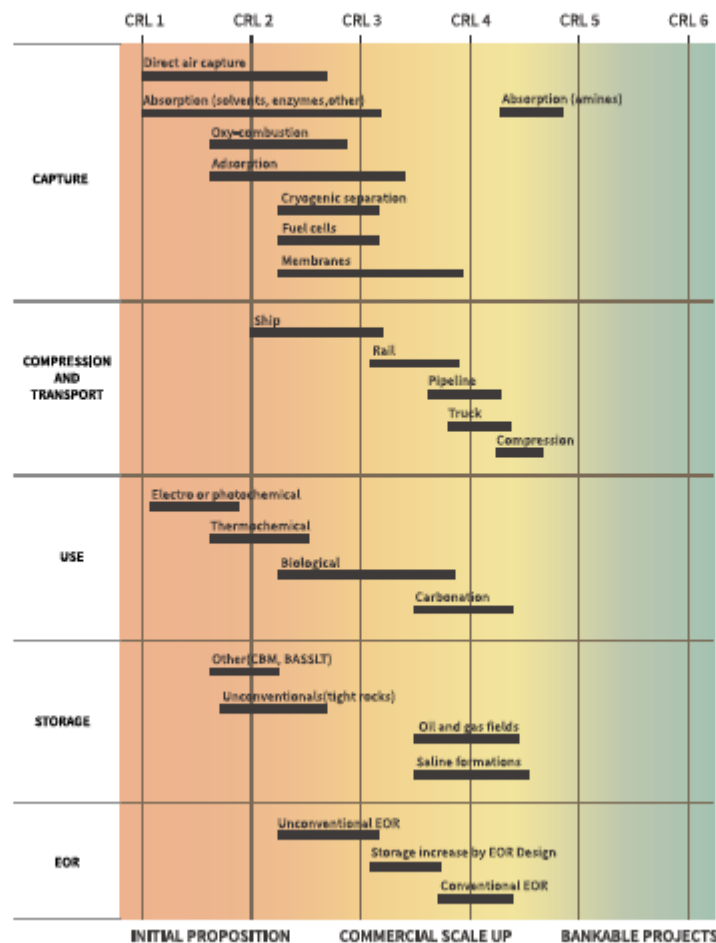
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CARBON CAPTURE, STORAGE AND USAGE READINESS LEVEL

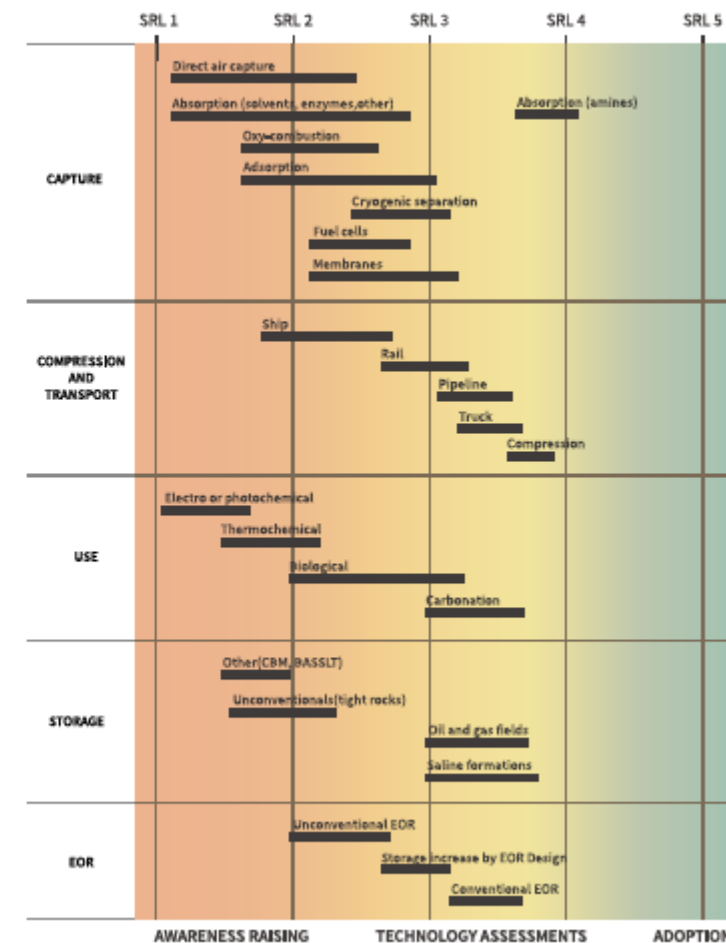
Technology Readiness Level



Commercial Readiness Level



Social Readiness Level



FACILITATING HYDROGEN PRODUCTION AND EXPORT

HYDROGEN FROM NUCLEAR POWER

- In some studies nuclear power is considered complementary to renewable energy technologies
- For countries that decided to deploy nuclear power there are wide properties of **nuclear power to produce hydrogen**
- Nuclear power can be used to produce **hydrogen through electrolysis**
- Nuclear power could be **used with steam electrolysis**; this production pathway could be ready in 2030 since the commercial technologies are in development and is expected to **improve efficiencies by 40 %**



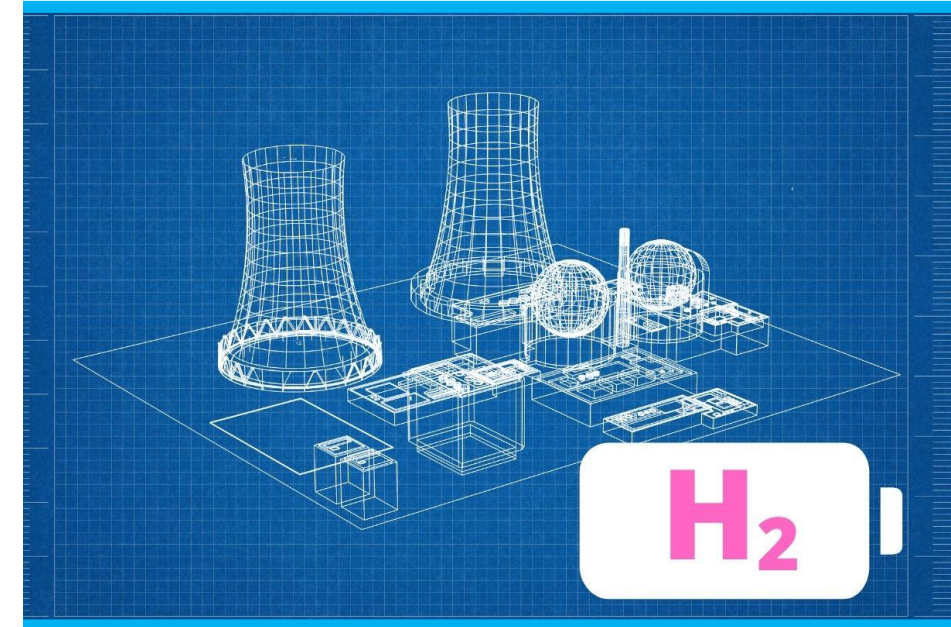
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- Heat and electricity produced by nuclear power can also be used in SMR (Steam Methane Reforming), this would significantly reduce carbon intensity compared to SMR pathway from fossil fuels
- The heat from nuclear power could be used to produce hydrogen through elevated temperature thermochemical reaction; this technology is still in R&D (Research & Development) and is planned for 2040



FACILITATING HYDROGEN PRODUCTION AND EXPORT

- Nuclear power produces **flexible electricity** to grid provided by electrolyser coupling.
- **Cost is highly dependent on financing arrangement**; it represents 60 % of nuclear power plants' cost
- A **project in Saudi Arabia** has been successful in achieving a **99% conversion efficiency** through solid oxide electrolysis.
- **Safety and waste remain a challenge** for a scaled nuclear power deployment



FACILITATING HYDROGEN PRODUCTION AND EXPORT

UK EXAMPLE

- Policies are being put in place now to deliver nuclear enabled hydrogen in the 2030's
- Long term thinking drives positive investments that deliver secure, low cost, low carbon energy
- Including nuclear in energy system strategies can unlock carbon neutrality in new ways
- International markets could enable cross border trade of nuclear enabled
- Hydrogen (similar to cross border electricity trades), potentially providing nuclear enabled hydrogen options for countries not seeking domestic nuclear deployment



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HYDROGEN FROM NATURAL GAS

- Steam methane reforming (SMR) from natural gas is currently the most commercially developed technology for large-scale hydrogen production, but it requires CCS to become zero-carbon
- Oxygen can be used as an input instead of air for combustion through Autothermal methane reforming which leads to more concentrated CO₂ emissions and an easier and more efficient CCUS deployment.



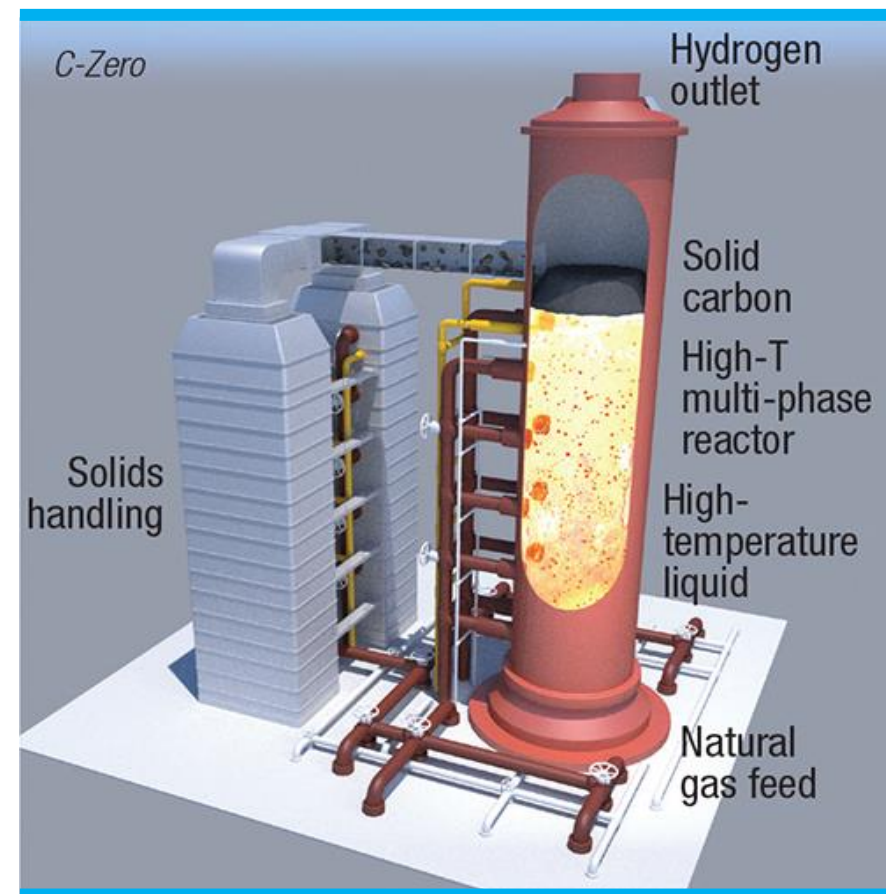
FACILITATING HYDROGEN PRODUCTION AND EXPORT

- Scaled hydrogen from natural gas with CCS will **require long-term storage of captured CO₂**; **20%** of the 40 million tons of CO₂ captured today is sent to long-term storage - the rest is used **for enhanced oil recovery (EOR)**
- One CCUS pathway is the **production of solid carbon through elevated temperatures**, but it does imply long term **storage issues**: the production of 5 million tons of hydrogen led to 60 million tons of solid carbon.



FACILITATING HYDROGEN PRODUCTION AND EXPORT

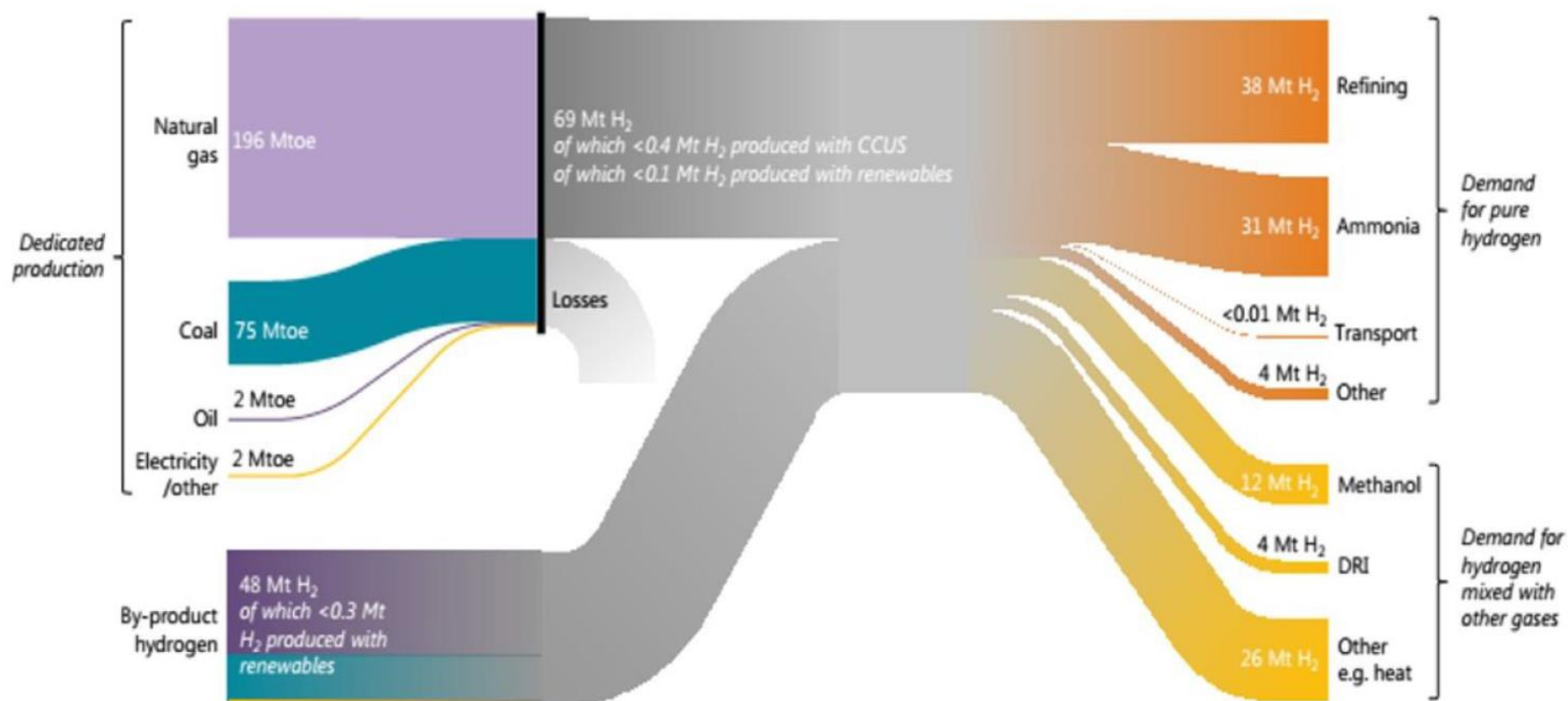
- **Pyrolysis** is a promising technology, but there are **issues with technological readiness**, scaling, cost and carbon utilization. The process **requires high temperatures** (more than 800 °C; the optimum level for a non-catalytic process is 1100-1300 °C)
- Hydrogen from natural gas **can be low-carbon** under certain conditions and its certification
- An LCA (lifecycle analysis) implies that **electrolysis should only be used if powered by low carbon energy sources** otherwise it produces more CO₂ emissions than SMR with CCUS.
- There is a consensus on the fact that **renewable hydrogen** will start to be as competitive as CCUS hydrogen cost wise in 10 to 40 years.



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HYDROGEN FROM COAL

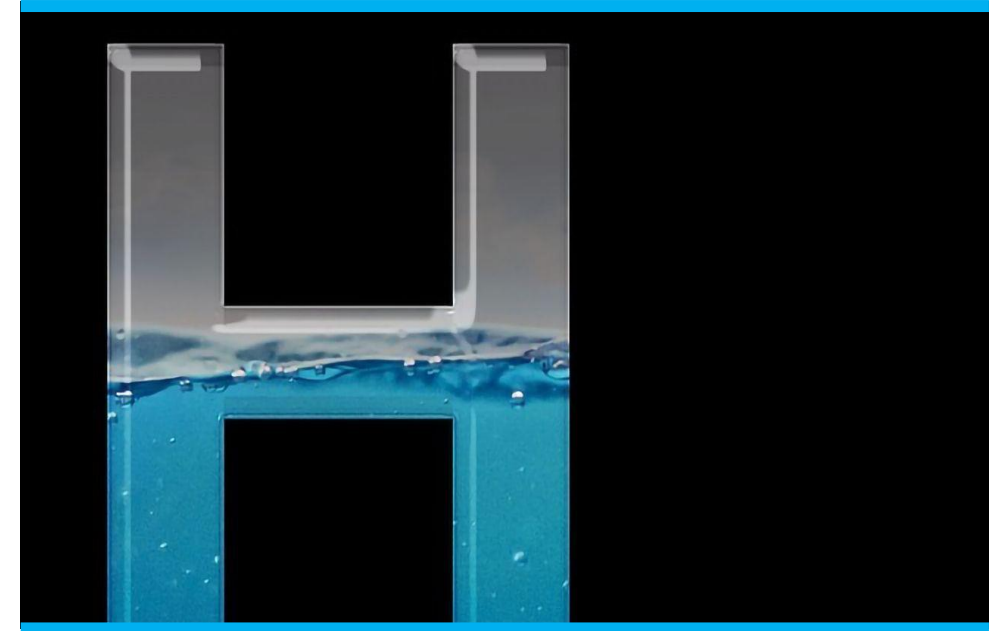
- Coal currently accounts for **27 %** of the hydrogen demand.



FACILITATING HYDROGEN PRODUCTION AND EXPORT

HYDROGEN FROM COAL

- According to IEA, the **demand for hydrogen**, including hydrogen from coal, will **follow an exponential curve by 2050**
- Hydrogen can be produced through **coal gasification** where coal is heated at high temperatures with **oxygen to produce syngas**, which is then upgraded through water gas shift reaction which allows to separate CO₂ from hydrogen.



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- **Costs vary due to local factors**, fuel price, renewable energy, load factor, learning rates and carbon taxes. Hydrogen from coal gasification with CCUS as low as US \$1.6/kg to US \$2.4/kg
- **Carbon intensity** of Hydrogen from coal with CCUS (90 % capture rate) can be **limited** to 3 kg CO₂/kg H₂
- Examples from Asia Pacific show that **there is no prejudice of hydrogen type** and all low-carbon hydrogen technologies are encouraged



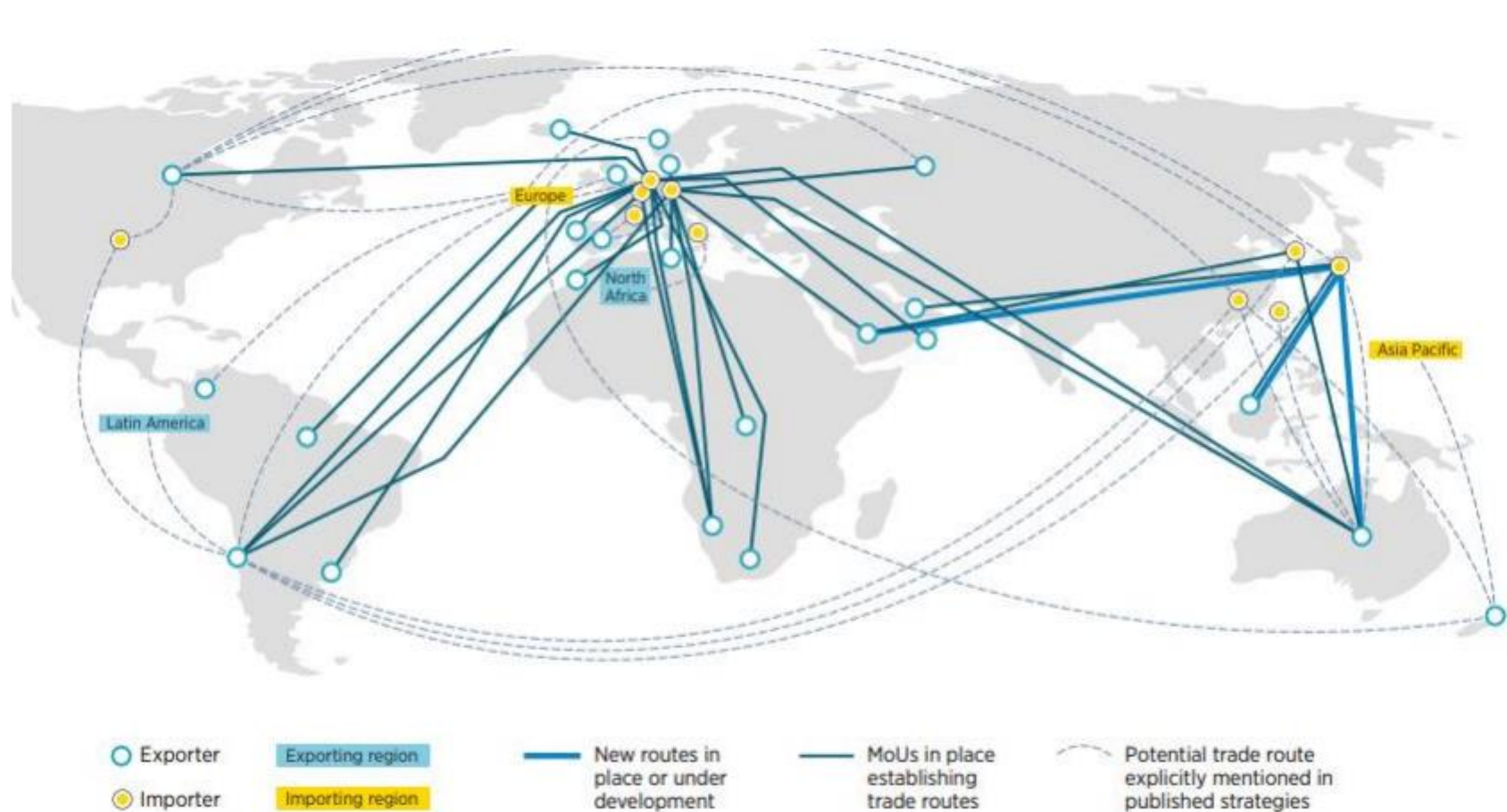
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- Examples from **North America** illustrate high technology readiness facilitate market creation in specific sectors (transport and industry)
- Near term actions are required to **overcome barriers and reduce costs**
- Role of hydrogen valleys and industrial clusters to establish longer term signals to promote investor confidence and stimulate commercial demand
- **Examples:** Humber project UK, Porthos NL, Northern Lights NO, NyNet UK



FACILITATING HYDROGEN PRODUCTION AND EXPORT

Hydrogen trade (import/export) routes 2022 (forecast)



FACILITATING HYDROGEN PRODUCTION AND EXPORT

UAE CAPABLE OF EXPORTING RENEWABLE HYDROGEN TO EUROPE IN FUTURE

- EU official pointed out that **hydrogen is an energy carrier**, which can help decarbonise sectors where it is not easy to do.
- **ABU DHABI** with its abundant solar power has the **potential to become an exporter of renewable hydrogen to Europe** in the future.
- In addition to scaling up renewable hydrogen in the EU, is important to **create a global hydrogen market** that would facilitate **production and trade**. For this, we need other pioneers across the globe who prioritise renewable hydrogen, and **UAE with its abundant solar power** and interest in hydrogen has much potential in this field.



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KAZAKHSTAN

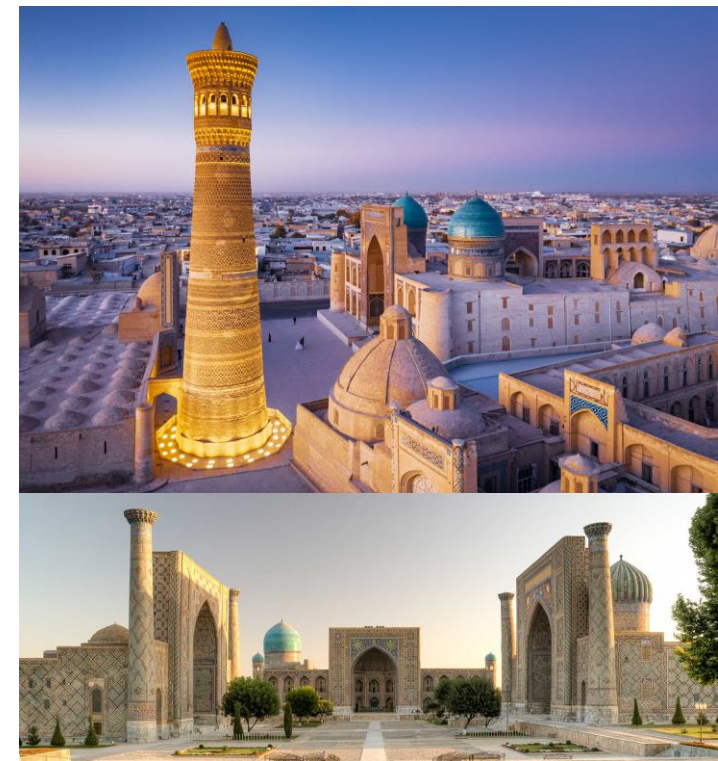
- In Kazakhstan, all types of hydrogen will play a role thank to its infrastructure and abundant natural resources.
- Kazakhstan is committed to achieve carbon neutrality by 2050 through its Roadmap Transition towards Green Economy by 2050. This also includes the development and the **deployment of a hydrogen development strategy**. The government aims to increase share of renewables from 3% in 2020 to 30% in 2030 and 50% in 2050
- Short-term: pilot projects focusing on mobility with the **deployment of hydrogen powered vehicles and hydrogen fueling stations**. (Cooperation with Airliquide) and creation of hydrogen competence centers and laboratories to support national R&D activities
- Mid- to long-term: **enhancing domestic hydrogen applications in heating and industry**
- These projects need a different policies framework than the one in the European Union due to different technology levels and needs as well as level of the institutional capacity.



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UZBEKISTAN

- Uzbekistan is at the stage of reforming its energy sector
- The country has **vast potential in solar and wind resources, gas, coal and nuclear**. As a major global uranium exporter, Uzbekistan started developing a nuclear power plant with 2.4GW capacity
- Natural gas is widely deployed in Uzbekistan. 15% of transportation in Uzbekistan is already using natural gas station. **This provides a solid base to launch hydrogen application in transport sector**
- Uzbekistan could become a hydrogen exporting country through the use of its already existing natural gas infrastructure.



FACILITATING HYDROGEN PRODUCTION AND EXPORT

TAJIKISTAN

- Mountainous country with **vast hydro potential** which currently accounts for about 98% of country's electricity generation.
- Still, the **power supply is vulnerable to supply shocks and seasonal shortages** that provide strong drivers for the development and deployment of alternatives
- The government is currently trying to exploit domestic coal reserves to diversify the national energy mix and is also **recognizing the potential of hydrogen** (incl synthetic fuels) from coal
- Development of **hydrogen in Tajikistan could be impacted by electricity costs variations**. There is a need for a more resilient energy system and energy connectivity and an integrated energy system could enable it.



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TURKMENISTAN

- In May 2021, the government published the presidential strategy for low carbon energy and **hydrogen on a global scale**, an **export-oriented strategy**.
- The first step toward this strategy is developing international cooperation in innovative technologies of which **hydrogen was identified as one of the key priorities**.
- Turkmenistan started drafting of a **national Roadmap** for the development of international cooperation in the field of hydrogen



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ARMENIA

- Armenia is currently vastly **dependent on imports of fossil fuels**, but country has a **vast hydropower and solar potential**; the basis of the Scaling up renewable energy program for Armenia
- Armenia reaffirms its **interest in hydrogen as a solution to decarbonize** its energy system as the government is currently developing the solar power infrastructure
- Need for a **clear policy framework** to allow full development of the renewable energy and hydrogen potential



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AZERBAIJAN

- Azerbaijan has played a historically important role as an oil producer. Most of its hydrocarbon production comes from offshore fields in the Caspian Sea. The country's largest hydrocarbon basins are located offshore in the Caspian Sea.
- Azerbaijan has been a net exporter of natural gas since 2007. Most of Azerbaijan's natural gas exports are shipped through Georgia to Turkey through the South Caucasus Pipeline (SCP)
- In October 2021, the Energy Ministry presented a green legislative package which includes the use of wind energy potential of the Caspian sea. The significant potential of offshore wind energy **can enable hydrogen production** in Azerbaijan. However, the country yet has to **develop its national strategy**.
- Azerbaijan can benefit from its large pipeline infrastructure **to export hydrogen**; via the Trans Adriatic Pipeline (TAP).



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MONGOLIA.

- The **first Mongolian-based green hydrogen project** Gobi H2 is moving forward. Mongolia Green Finance Corporate MGFC (joint-public-private sector body) is going to support the financing for the Elixir Energy. The MGFC was established to facilitate the financing of Mongolian projects that will assist the global energy transition to a net-zero carbon future.
- A detailed analysis of the legal issues surrounding a **potential green hydrogen project** in Mongolia states that no new major legislation is needed for the development of green hydrogen projects in the Mongolia country.



FACILITATING HYDROGEN PRODUCTION AND EXPORT

Next steps:

- **Identify** Mongolian carbon offset opportunities at the household level. The aim is to reduce its current exploration/appraisal stage scope 1 and 2 carbon emissions by such means;
- **Develop** larger-scale forestry/nature-related offsets in Mongolia. These are increasingly sought by international oil and gas companies to offset emissions in the production stage of operations;
- **Work with International Financial Institutions** (IFIs) over the project financing of proposed green hydrogen pilot production plant. A number of IFIs are present in Ulaanbaatar.
- Other than water, the other key input for a **green hydrogen project** is a high-quality renewable power source, which desktop analysis indicates are of globally very high quality in the Gobi region.

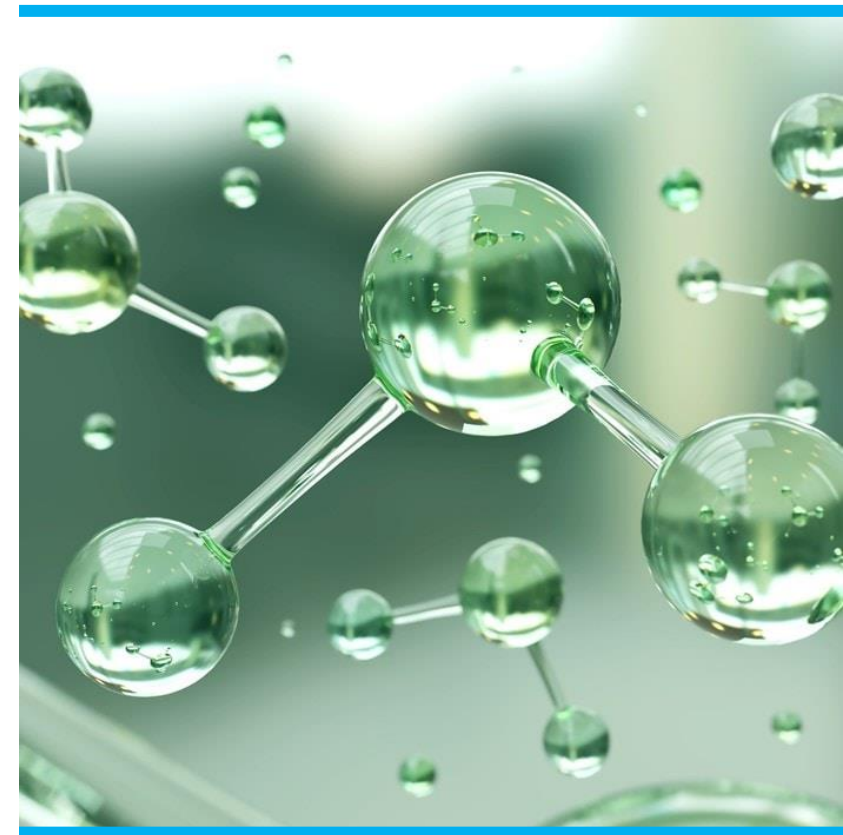


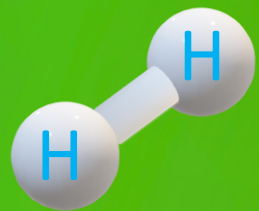
CONCLUSIONS

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CONCLUSIONS:

- Hydrogen could account for **up to 12 %** of global energy use by 2050.
- Existing data shows that **hydrogen** will play an important part in energy transition and that all **sustainable hydrogen productions technologies** will play a role.
- Most countries in their **Hydrogen strategies** give priority to a **Green Hydrogen**.
- Today is important to **define the right priorities** to kick-start a **Green Hydrogen ecosystem** and start developing required **Hydrogen infrastructure**.
- It is important to assess **global potential** to contribute to development of a hydrogen ecosystem and to explore what are the **opportunities for Hydrogen import/export potential** as well as **domestic applications**.





THANK YOU

Dr. Romanas Savickas
romanas.savickas@un.org



<https://www.linkedin.com/in/romanassavickas/>

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