NEEST

NEW ENERGY & ENVIRONMENTAL SOLUTIONS AND TECHNOLOGIES

TETHYS WEBINAR – GREEN HYDROGEN PRODUCTION

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HYDROGEN PRODUCTION

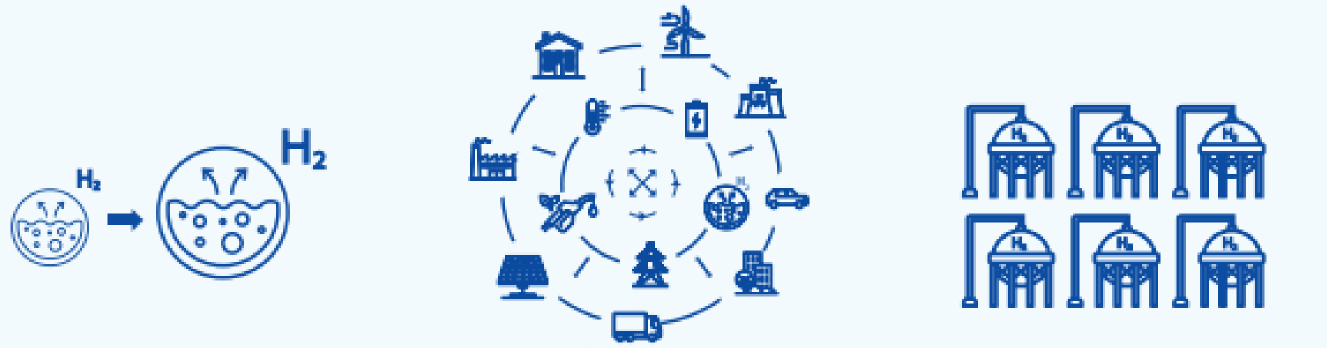
In 1874, in his famous novel The Mysterious Island, Jules Verne prophesied the advent of hydrogen in response to the exhaustion of coal: "*I believe that water will one day be used as a fuel, that hydrogen and oxygen, which constitute it, used alone or simultaneously, will provide an inexhaustible source of heat and light of an intensity that coal cannot have.*"

- Cyrus Harding, 1874
hero of Jules Verne's novel
"The Mysterious Island"

150 years later, at a time when the climate emergency has never been so urgent, this energy vector is at the heart of all attention and is enjoying unprecedented acceleration.

EU Position on Hydrogen

The path towards a European hydrogen eco-system step by step :



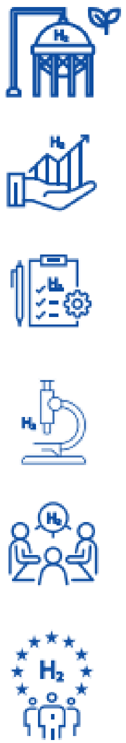
Today - 2024 → **2025 - 2030** → **2030 -**

Today - 2024: From now to 2024, we will support the **installation of at least 6GW of renewable hydrogen electrolysers in the EU**, and the production of **up to 1 million tonnes** of renewable hydrogen.

2025 - 2030: From 2025 to 2030, hydrogen needs to **become an intrinsic part of our integrated energy system**, with at least 40GW of renewable hydrogen electrolysers and the production of **up to 10 million tonnes** of renewable hydrogen in the EU.

2030 -: From 2030 onwards, **renewable hydrogen will be deployed at a large scale** across all hard-to-decarbonise sectors.

How can hydrogen be promoted in Europe?

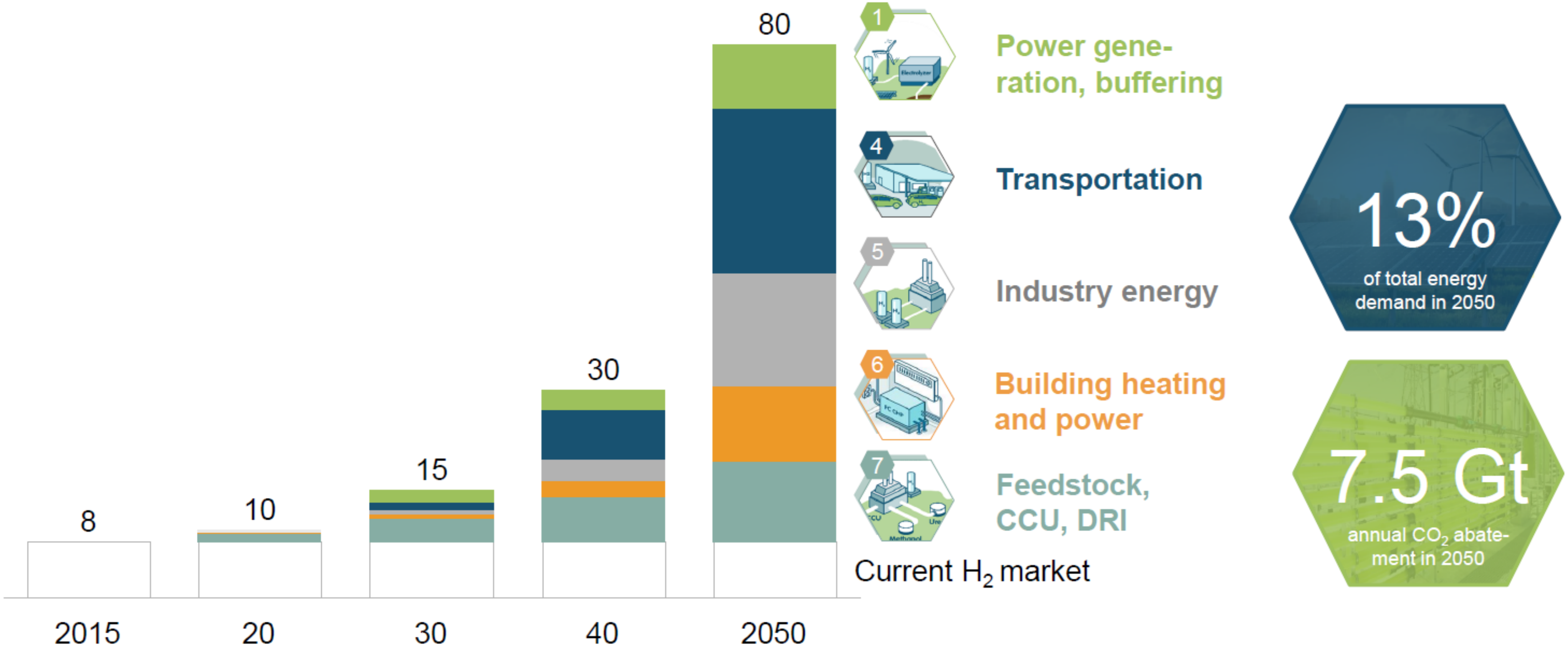


- The production of clean hydrogen needs to be increased **by creating a sustainable industrial value chain**.
- We should **boost the demand for clean hydrogen** coming from industrial applications and mobility technolgies.
- Clean hydrogen needs a **supportive framework**, **well-functioning markets** and **clear rules**, as well as dedicated infrastructure and a logistical network.
- **Promoting research** and **innovation** in clean hydrogen technologies is crucial.
- Europe we will secure **cooperation opportunities with neighboring countries and regions of the EU** and work to establish a global hydrogen market.
- The **European Clean Hydrogen Alliance** will help build up a robust pipeline of investments.

European Commission "A Hydrogen Strategy for a Climate-Neutral Europe", 2020. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

By 2050, hydrogen can enable major CO_2 emission reductions

Global Energy demand supplied with hydrogen, Exajoule (EJ)



1 Excluding feedstock

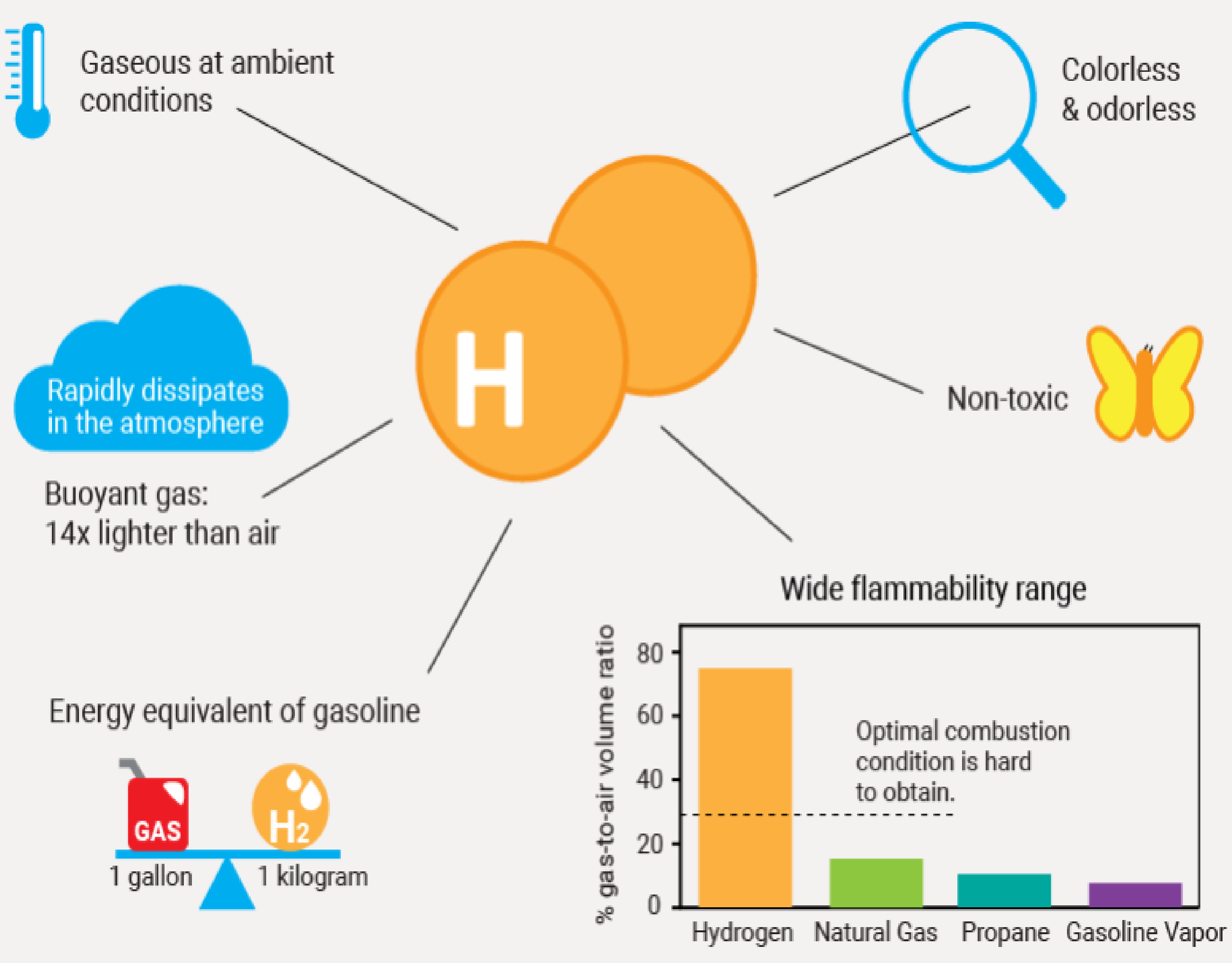
SOURCE: Hydrogen Council, IEA ETP Hydrogen and Fuel Cells CBS, National Energy Outlook 2016"

McKinsey & Company

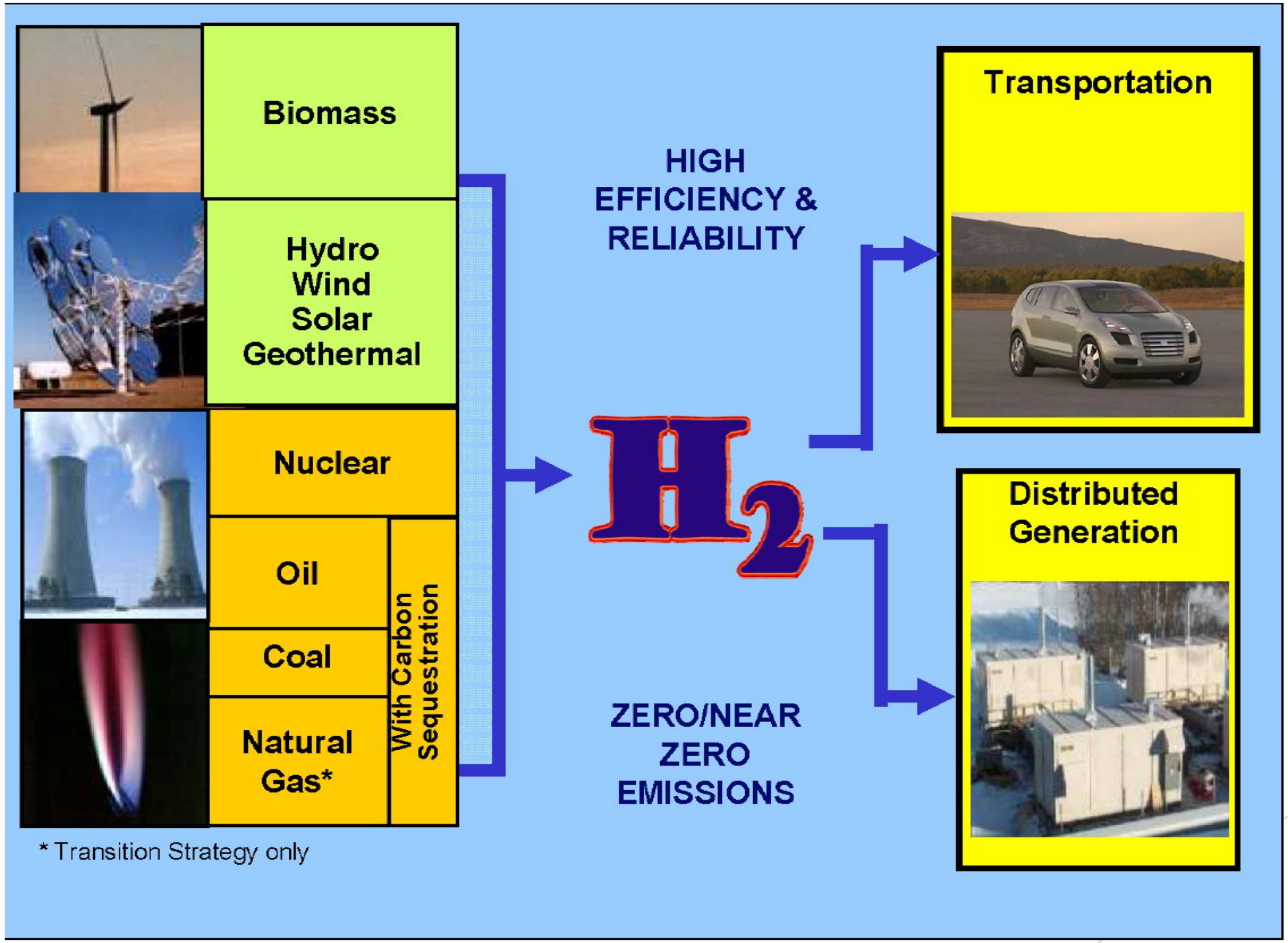
Basic properties and Initial Safety Concerns

Hydrogen (H_2) is :

- the simplest, lightest and most abundant element in the universe.
- the first element in the periodic table and is a fundamental building block for many of the chemicals, materials and processes we use every day.
- a very small, diffusive molecule that is 14 times lighter than air.
- a non-toxic element that has been safely used in manufacturing for more than 90 years.
- is flammable (like all fuels) and safety systems at the H_2 stations (HRS) and in the H_2 vehicles (FCEV) are designed specifically for hydrogen's properties.
- an energy carrier as it can be used to store and transport energy, offering the possibility of greater diversification and sustainability in energy supply



DIFFERENT ROUTES TO HYDROGEN



Production Methods

Hydrogen production methods can be categorized based on their energy sources and environmental impact. So, here are the most common methods from :

MATURE TECHNOLOGIES

1. Steam Methane Reforming (SMR) – Grey or Blue

Process: SMR is the most common method for producing hydrogen. It involves reacting natural gas (mostly methane) with steam at high temperatures to produce hydrogen and carbon monoxide. POX is a similar method but even less efficient than SMR.

2. Electrolysis – Green (if powered with RES)

Process: Electrolysis uses electricity to split water into hydrogen and oxygen.

3. Biomass Gasification – Brown

Process: Biomass (organic matter) is heated in the presence of a controlled amount of oxygen, producing a mixture of hydrogen, carbon monoxide, and CO_2.

4. Methane Pyrolysis - Turquoise (if powered with RES)

Process: Methane is split into hydrogen and solid carbon through high-temperature pyrolysis, without producing CO_2.

EXPERIMENTAL PHASE

1. Photolysis (Photo-electrochemical Water Splitting) - Green Hydrogen

Process: Uses sunlight to split water into hydrogen and oxygen using special photo-sensitive materials.
Efficiency is lower compared to electrolysis (PEM, AEL, SOEL, AEM).

2. Thermochemical Water Splitting – Green or Pink

Process: Uses high-temperature heat, often from nuclear reactors or solar concentrators, to drive chemical reactions that split water into hydrogen and oxygen.
Efficiency expected to be high if coupled with high-efficiency heat sources.

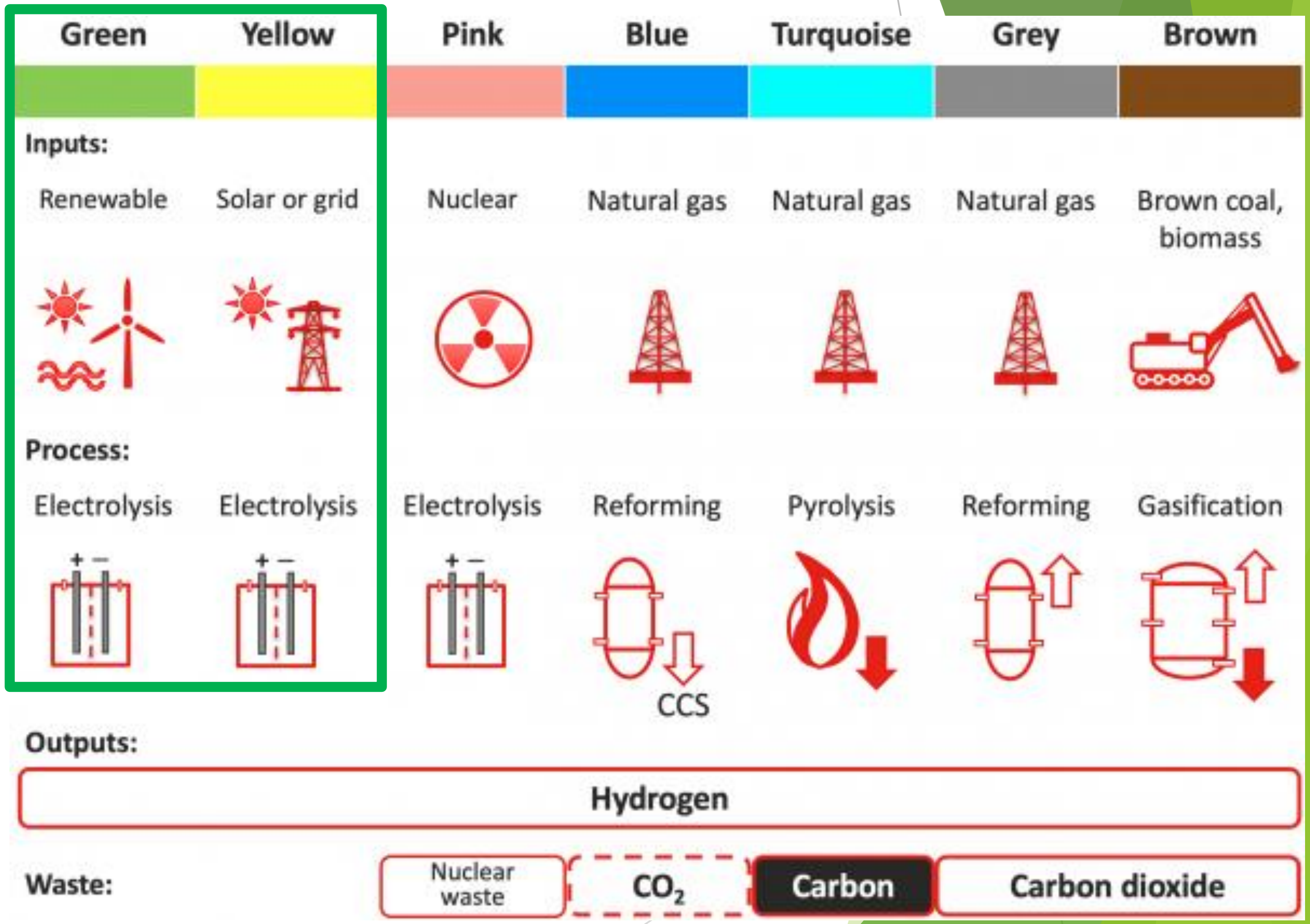
3. Microbial Electrolysis Cells (MEC) - Green

Process: Uses microbes and electricity to split water or wastewater into hydrogen.
Efficiency is low, but improving with research

Types (colors) of Hydrogen

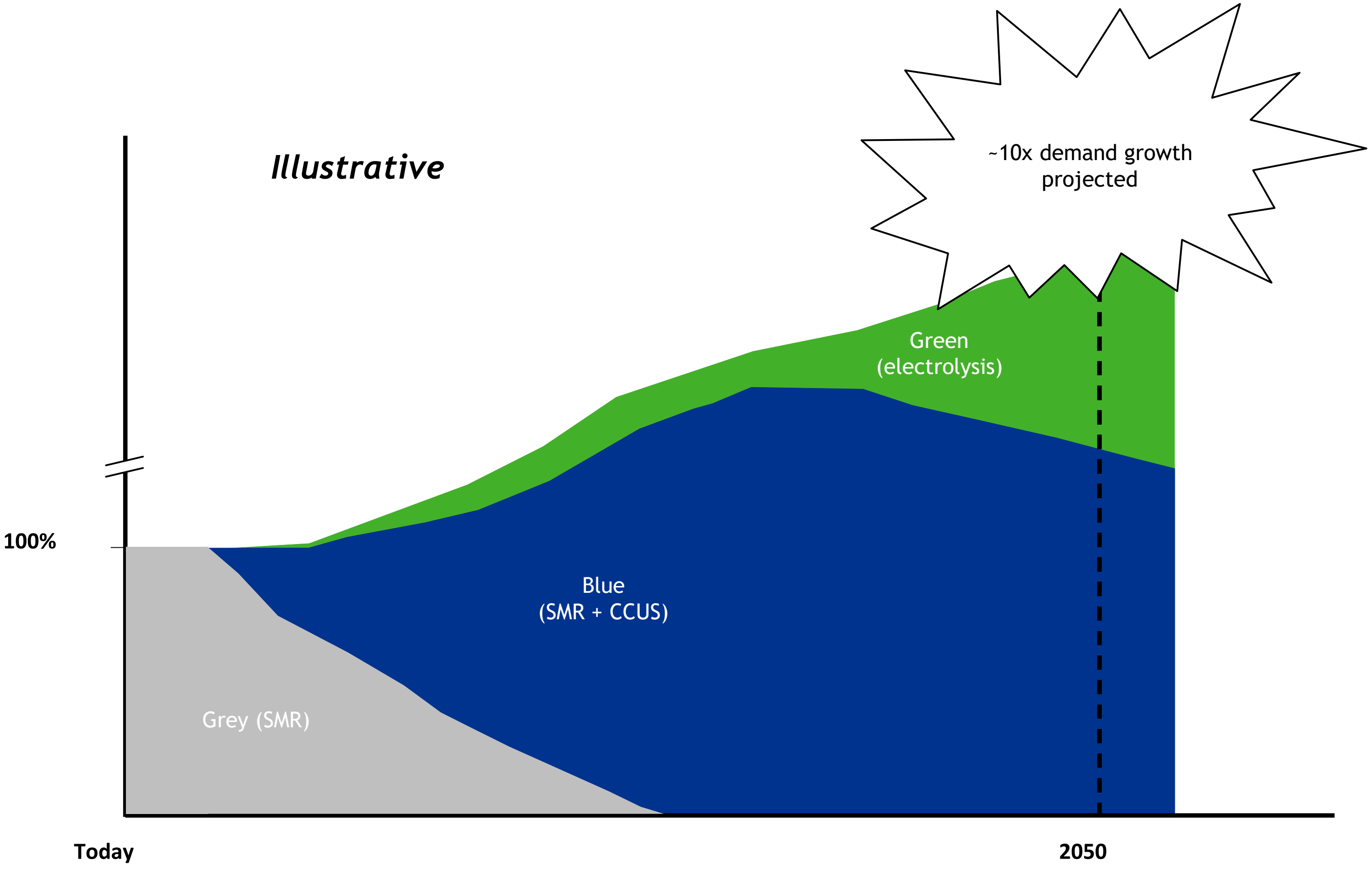
- Each method offers different trade-offs in terms of :
  - ✓ Efficiency
  - ✓ Scalability
  - ✓ Environmental impact

- **Green hydrogen,** though currently more expensive, is viewed as the future energy carrier, offering at the same time **zero-emission energy**.



Hydrogen market capture strategies are customized by region

Hydrogen demand and mix over time



Source: Barclays, HSBC, Hydrogen Council

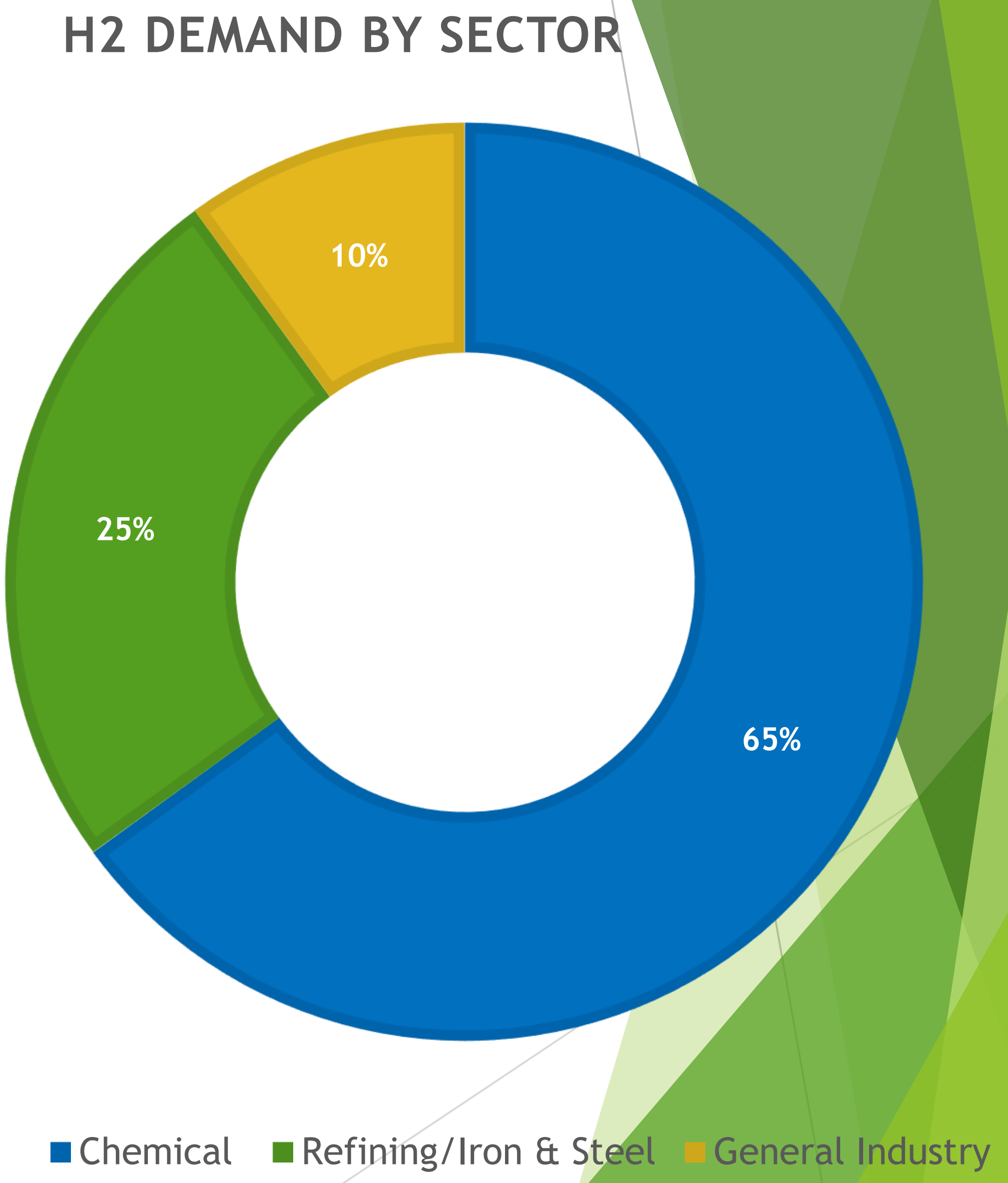
Regional Hydrogen Strategy Drivers

- Goals: 2050 net zero or similar
- Funding: Carbon fees or other
- Leverageable assets (blue)
  - H2 system
  - At-scale CCUS hub
- Leverageable assets (green)
  - Geologic storage
  - Low power prices

Global Hydrogen Market Enablers

- Cost and supply chain improvements; e.g.,
  - Electrolyzers
  - Renewables
- H2 and renewable synergies

INDUSTRY SECTOR	KEY APPLICATIONS
CHEMICAL	• Ammonia • Polymers • Resins
REFINING	• Hydrocracking • Hydrotreating
IRON & STEEL	• Annealing • Blanketing gas • Forming gas
GENERAL INDUSTRY	• Semiconductor • Propellant fuel • Glass production • Hydrogenation of fats • Cooling of generators

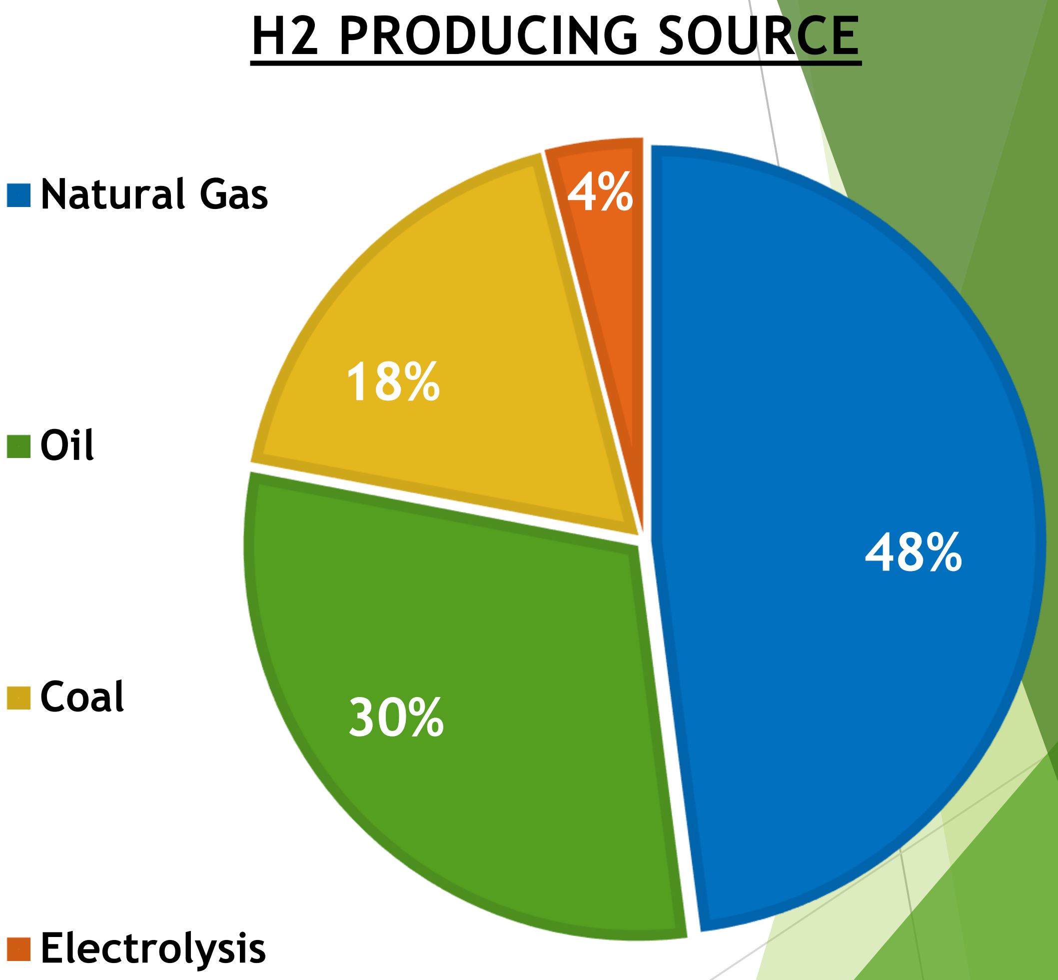


Main routes for H2 production

- Hydrocarbon based production
- Water Electrolysis
- Biogas, CCS & novel routes

Current situation

- 70 million metric tons of H2 produced in 2019, emitting in the process 830 million tons CO2
- About 95% of which is produced by fossil fuel based methods

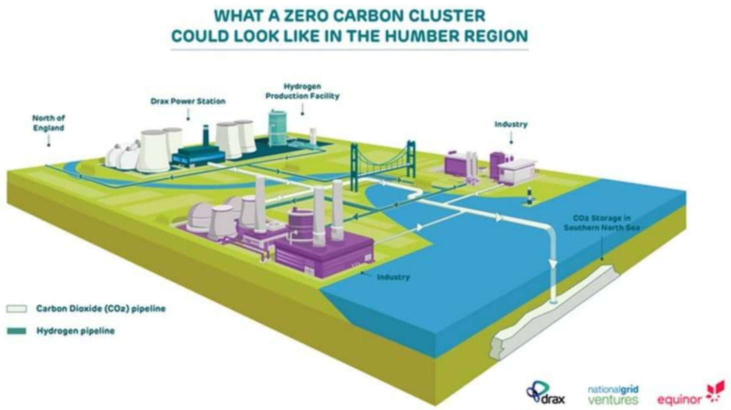


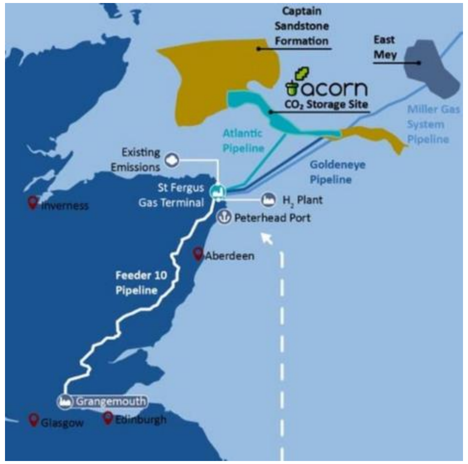
Steam Methane Reforming (SMR)

- SMR technology splits natural gas (NG) into mixture of hydrogen, CO and CO_2
- Industries use SMR technology to deliver large quantities of H_2 and CO with remaining CO_2 being released to atmosphere
- The process is mature with systems capable of producing up to 100s of metric tonnes per day of H_2/CO
- Currently over half the world's hydrogen is derived from NG feedstocks

SMR and Carbon Capture Utilisation and Storage (CCUS)

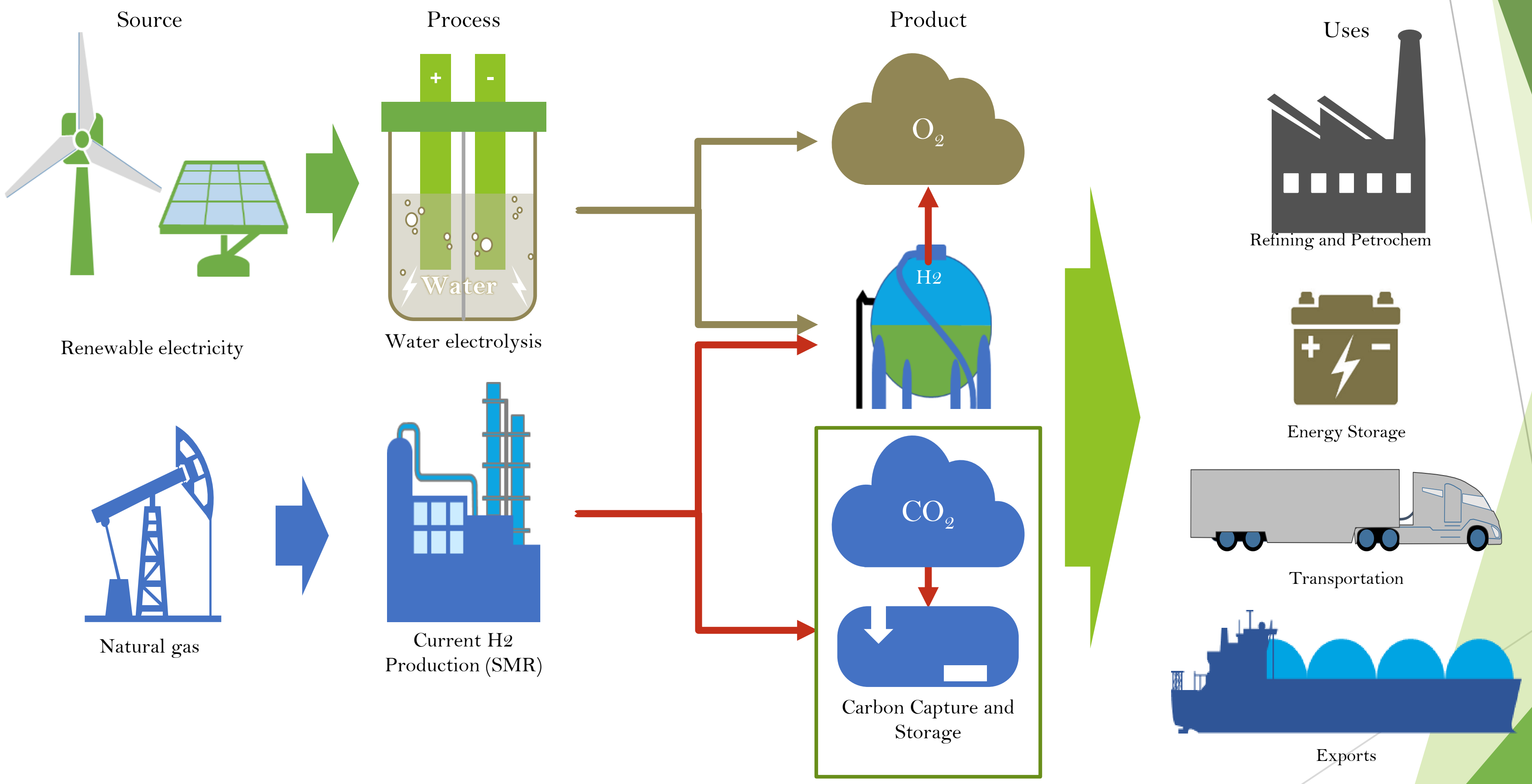
- Capturing the CO_2 produced by SMR can decarbonise the process
- Captured CO_2 can be stored in underground geological features or used
- **If CO_2 is captured/used, <u>HYDROGEN IS BLUE</u>**
- Many large scale CCUS projects are being developed internationally.





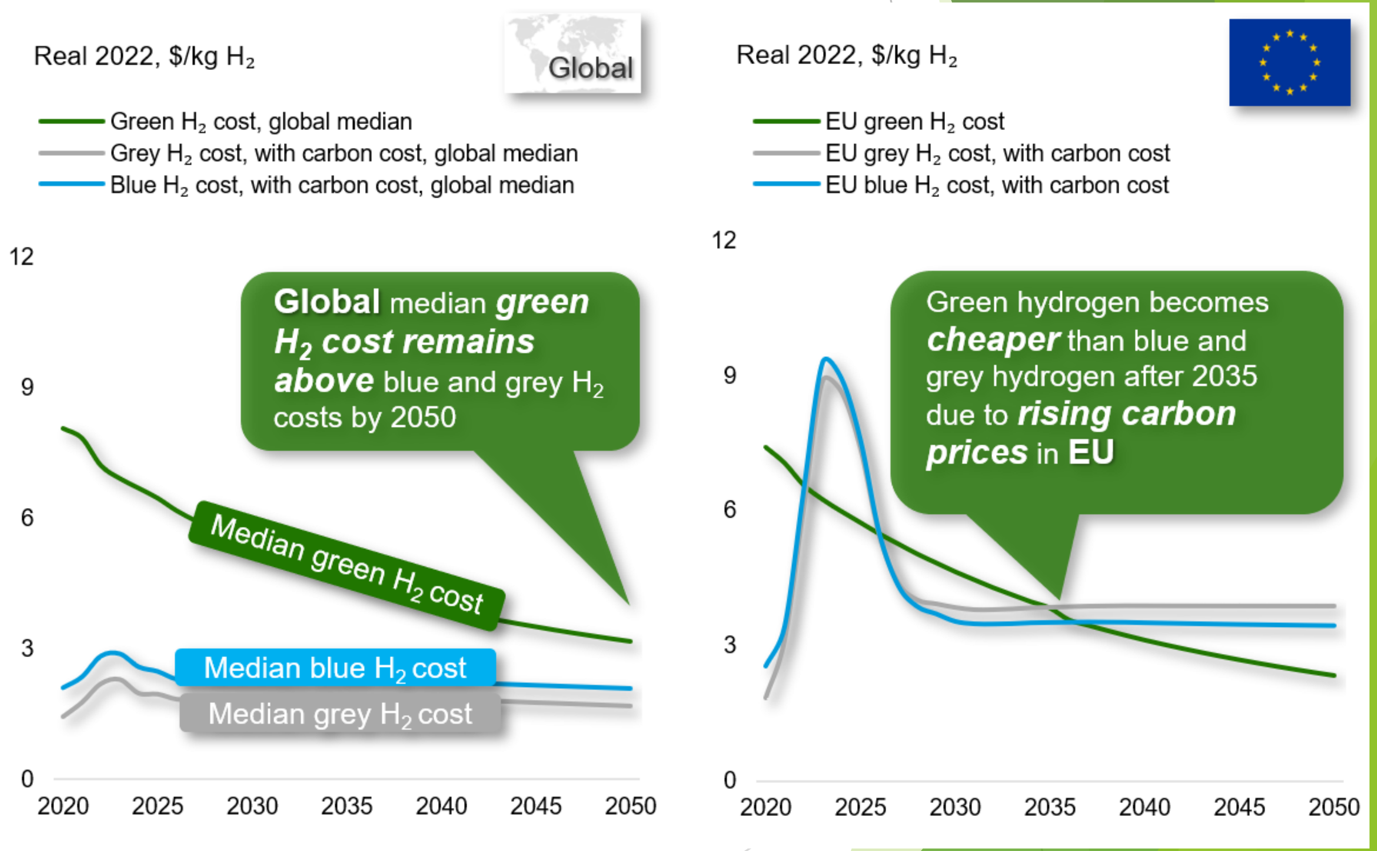
The Acorn Project will capture about 200,000 tonnes of CO_2 from the St Fergus Gas Terminal

Typical Clean Hydrogen Production Options



What is the cost of Green H2 ?

- ❖ The cost of hydrogen is heavily dependent on the way it is produced (Electrolysis or SMR).
- ❖ Blue/Grey hydrogen are a less costly option than Green Hydrogen but towards 2035 there is a break even point in EU
- ❖ **TODAY**, the cost of production for Green H_2 is approx. 5 – 7 € / kg H_2
- ❖ **2035 TARGET PRICE**, is that Green H_2 reaches a price between 2-3 €/kgH_2
- ❖ **TODAY it is sold** for 10 – 12 € / kg and looking for 2035 at a price of 5 - 6€ / kg H_2 and less reaching 2050.



<u>NOTE</u>

1 kg H_2 equals to approx. 4 lt of gasoline or petrol in terms of their calorific value.

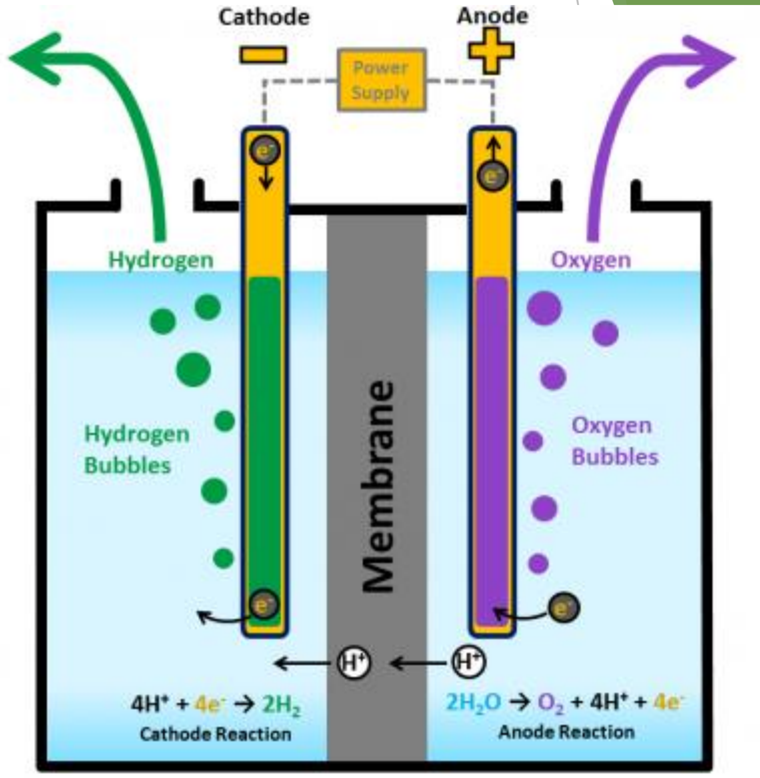
Water ELECTROLYSIS

- One of the most promising methods for hydrogen production

Reaction taking place:

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

- Requires a minimum energy of 39.4 kWh /kg of H_2
- Has the potential to be carbon free, if powered by renewable sources

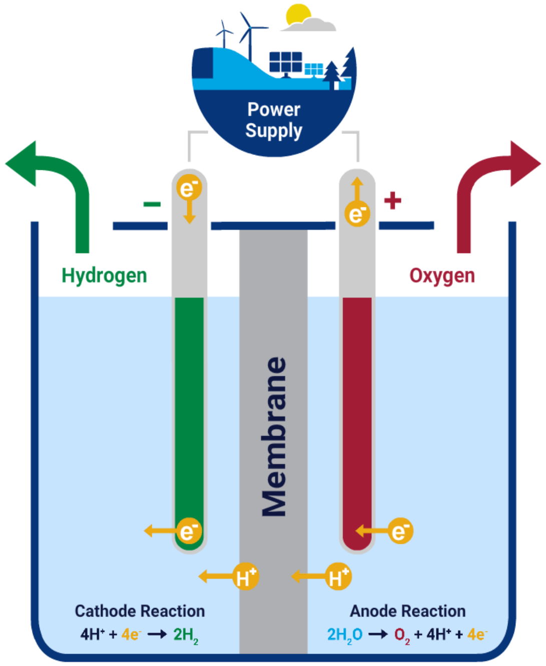


H2 Production by water electrolysis

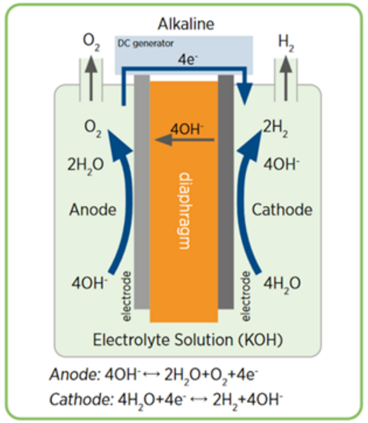
Electrolysis – Production of Green Hydrogen

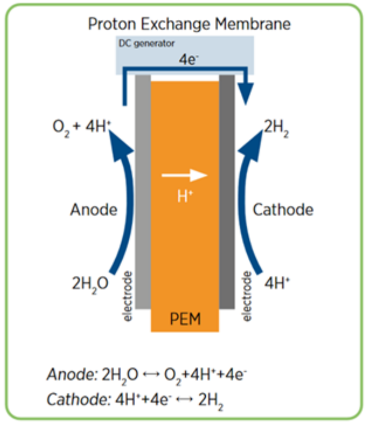
- First mentioned by Faraday, so not exactly modern technology.

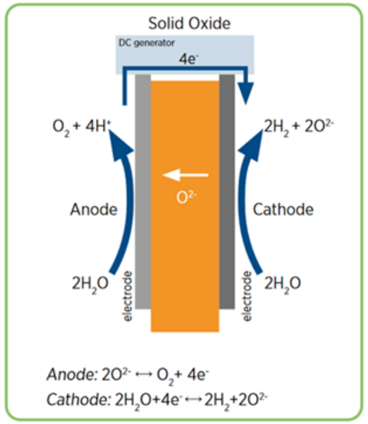
- Green hydrogen produced.
- Electric current is passed through water to separate it in hydrogen and oxygen.
- Membranes to separate the gases.
- Alkaline
- PEM (and HT-PEM at about 180 C)
- Solid Oxide (High temperature > 600 C)



Electrolyzer technologies



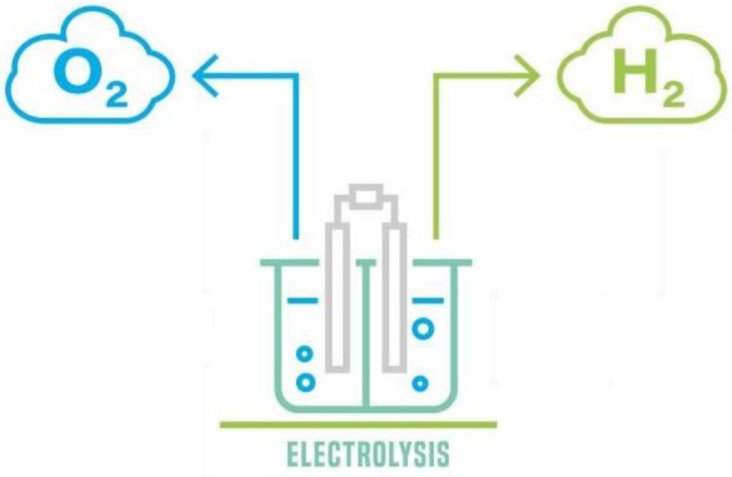




Alkaline
- ✔ Cheap
- ✘ Large equipment

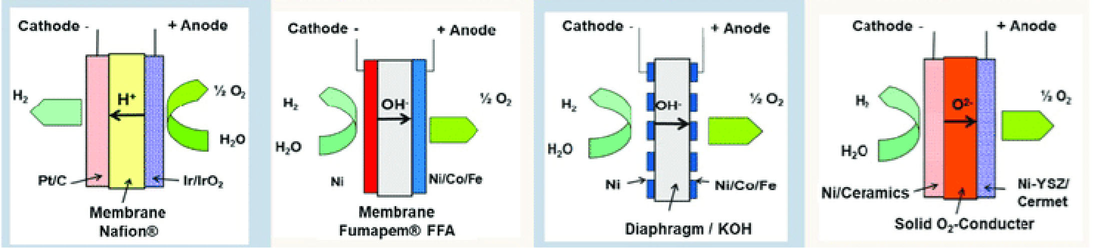
PEM
- ✔ Pure hydrogen
- ✘ Expensive catalysts

Solid oxide
- ✔ Reversible
- ✘ High temperature



	PEM	AEM	Alkaline	SOE
Electrolyte	PFSA membranes (e.g., Nafion)	Anion exchange ionomer	Aqueous potassium hydroxide	Yttria Stabilises Zirconia (YSZ)
Cathode	Platinum, Platinum - Palladium alloy	Nickel and Nickel alloys	Nickel, Nickel - Molybdenum alloy	Nickel/YSZ
Anode	Ruthenium oxide, Iridium oxide	Nickel, Ferrous, Cobalt oxides	Nickel, Nickel - Cobalt alloys	YSZ
Operating Temperature (℃)	50-80	50-60	60-80	500-850
Operating Pressure (Bar)	70	1-30	30	1-25
Stack Lifetime (h)	20-60k	-	60-100k	<10k
Technology Readiness	Commercialised	Large prototype	Matured	Demonstration
Cost	USD 1100-1800/kW		USD 500-1400/kW	USD 2800-5600/kW

	PEM-EL Polymer Electrolyte Membrane Electrolysis	AEM-EL Anion Exchange Membrane Electrolysis	A-EL Alkaline Electrolysis	HT-EL High-Temperature Electrolysis
Electrolyte	acidic	alkaline		O^{2-} - conducting
	solid (Polymer)		liquid	solid (ceramic)



E- FUELS as a short term solution

- E fuels are synthesized from hydrogen and CO_2 from unavoidable emissions, producing e-methane , e-methanol or e- gasoline
- A short to mid-term plan is required, so we can make use of the existing infrastructure and a suitable solution could be energy rich e-fuels
- Gradual infiltration of hydrogen and green energy to carbon based fuels

Examples of E-fuel production:

$CO_2 + 4 H_2 \rightarrow CH_4 + 2 H_2O$ (e-Methane Production)

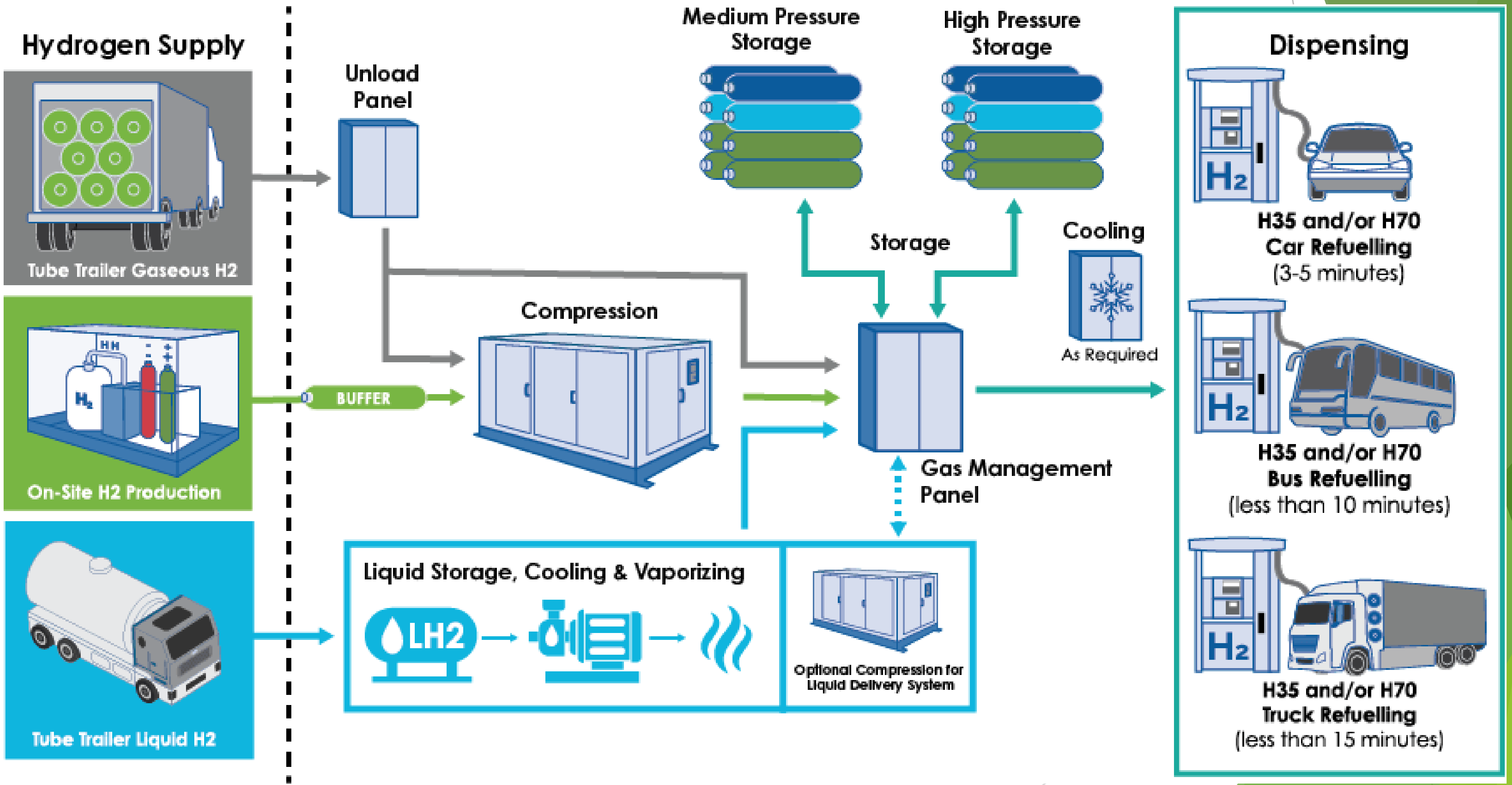
$CO_2+3H_2 \rightarrow CH_3OH + H_2O$ (e-Methanol Production)

Fischer- Tropsch process for producing e- fuels:

$(2n + 1) H_2 + n CO \rightarrow C_nH_{2n+2} + n H_2O$

<u>**Overall balance of these processes is largely carbon neutral**</u>

What is a HRS and how hydrogen is supplied?



Thanks for your interest!