



NEEST

NEW ENERGY & ENVIRONMENTAL  
SOLUTIONS AND TECHNOLOGIES

# TETHYS WEBINAR - GREEN HYDROGEN PRODUCTION

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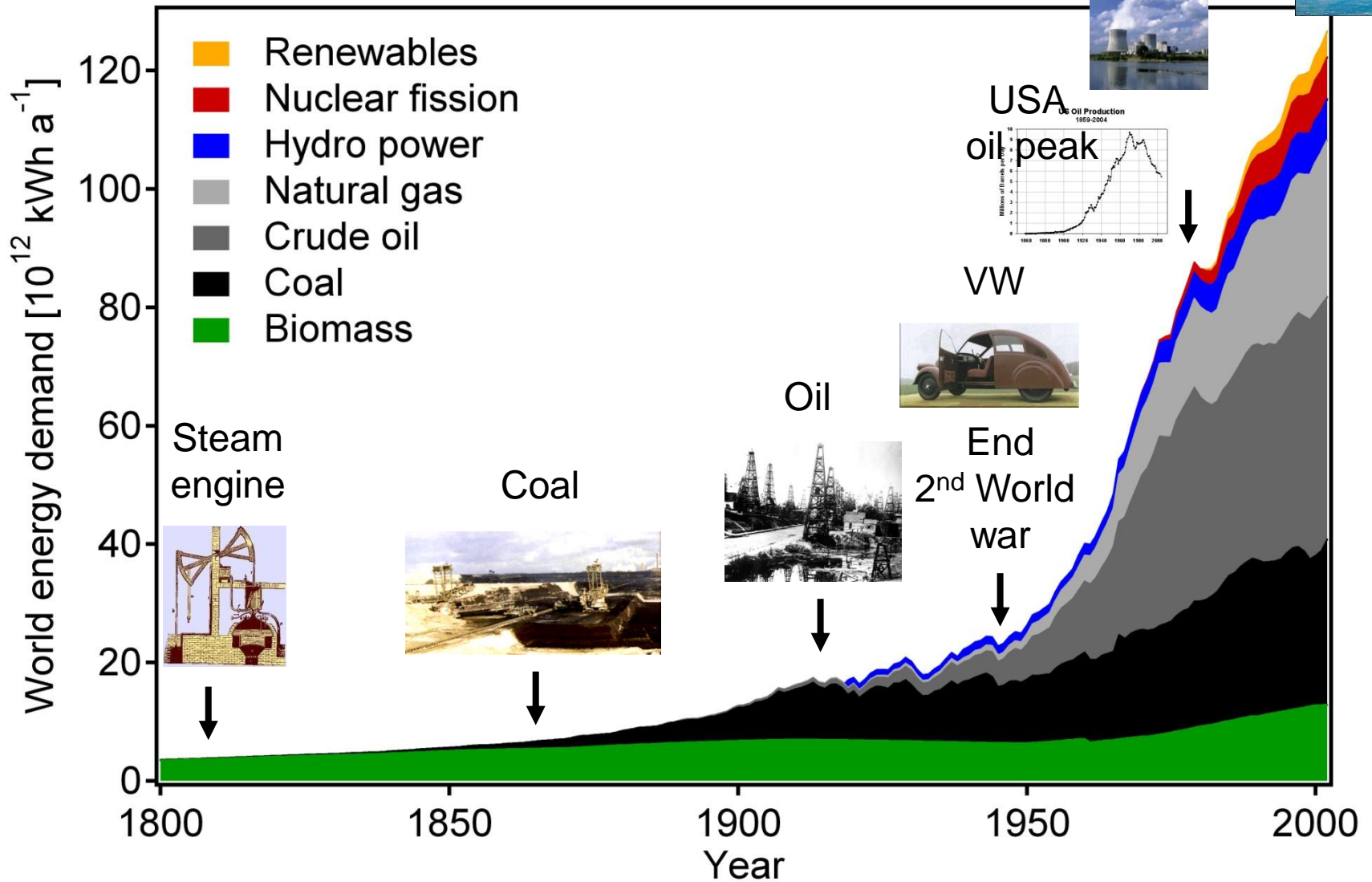
# INTRODUCTION

Why hydrogen? Climate change

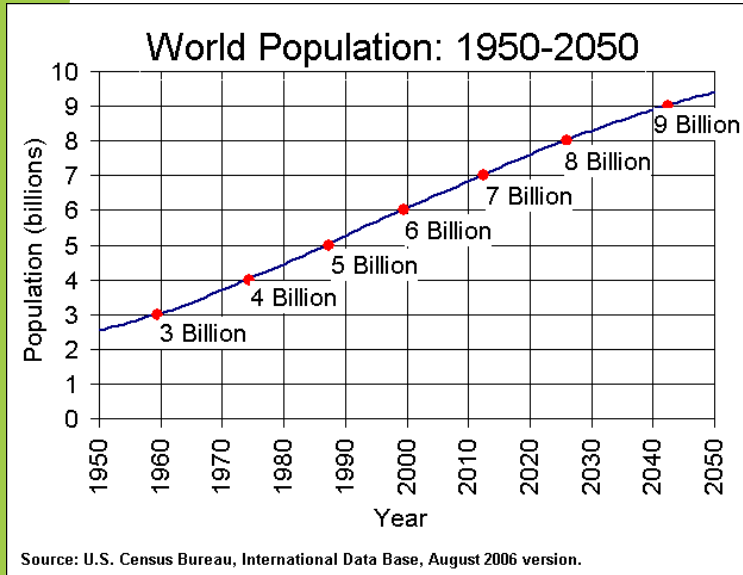
Hydrogen (H<sub>2</sub>) as energy carrier

Alternative fuels - European policies

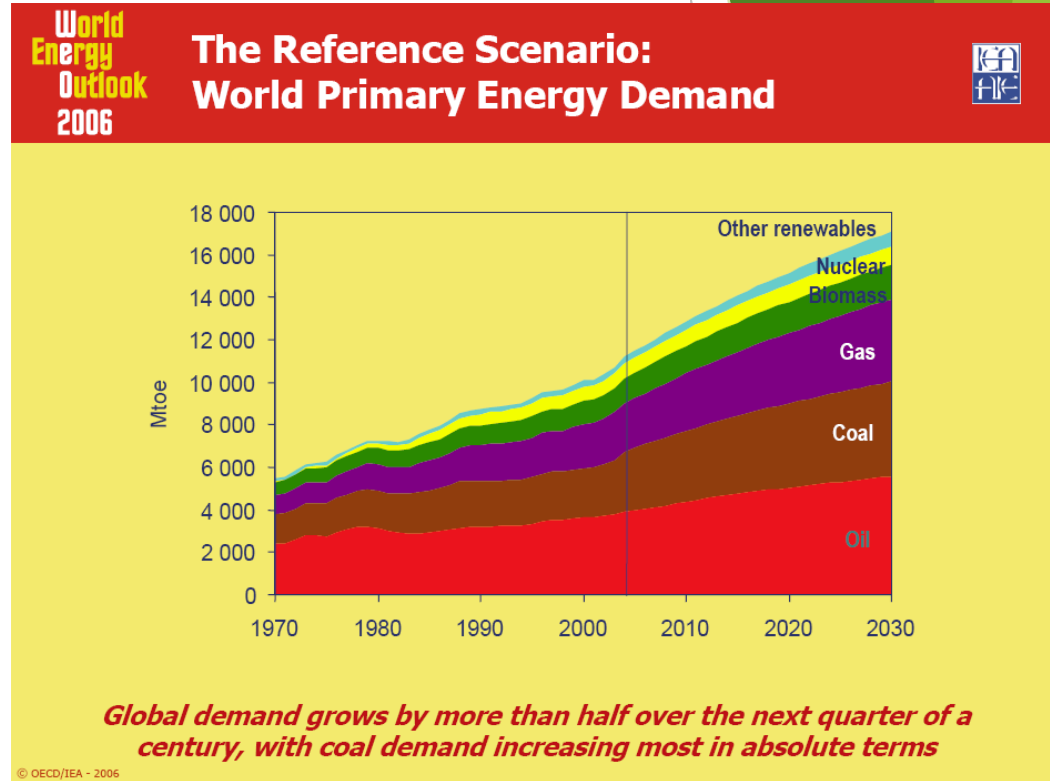
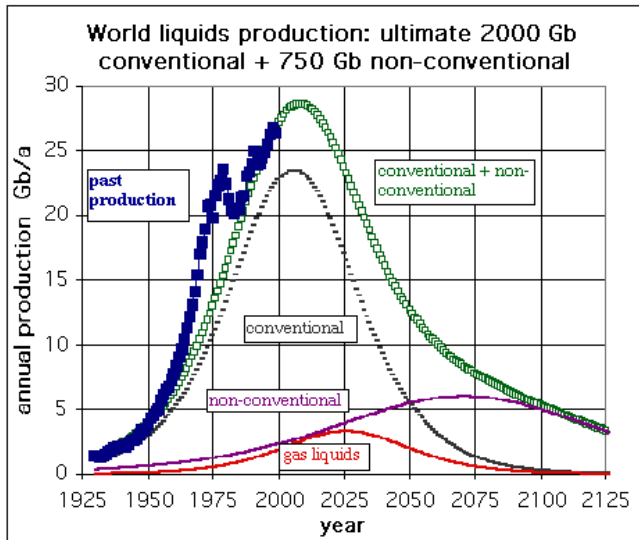
# WORLD ENERGY CONSUMPTION



# Energy Crisis?



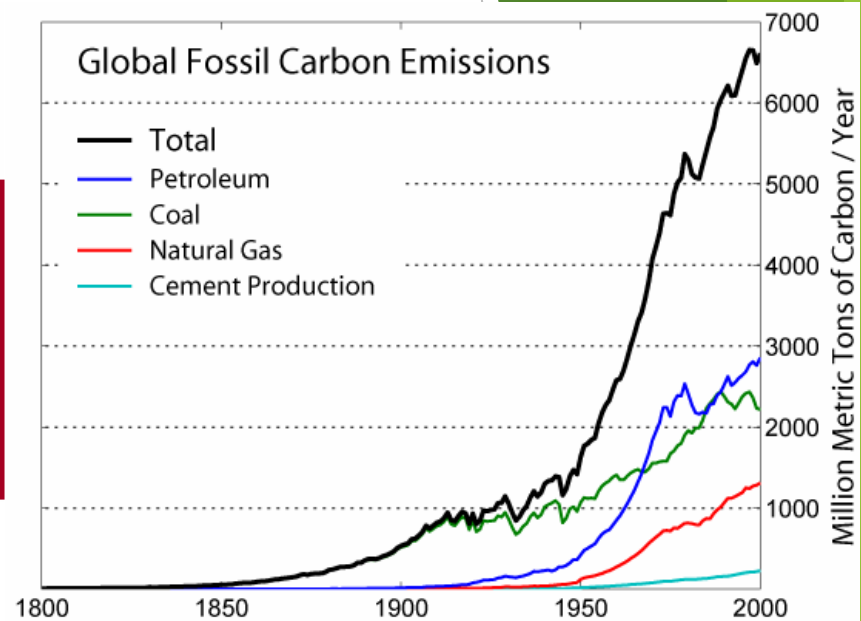
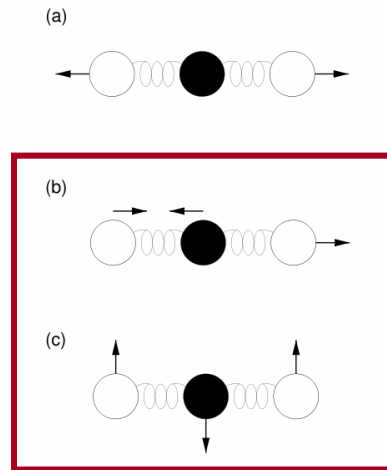
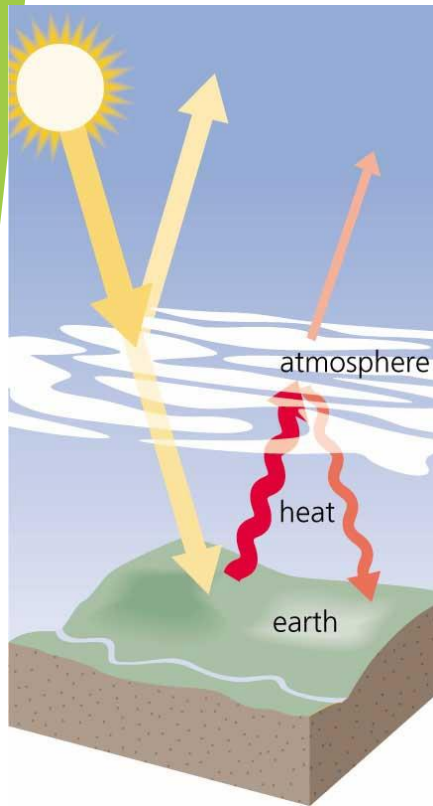
## THE HUBBERT CURVE



# Environmental Crisis ..... before!



Greenhouse Gas



Svante Arrhenius  
(1859-1927)

If the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression.

“On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground”, *Philosophical Magazine* 41 (1896) 237-276

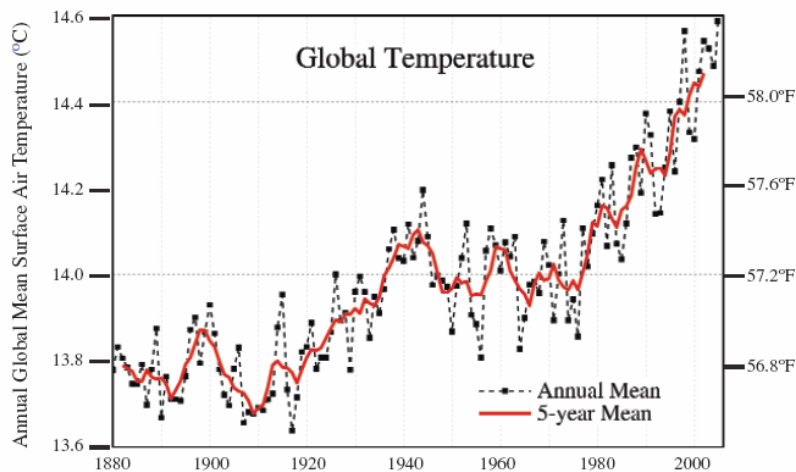
still valid in the simplified expression by Myhre et al. (1998).

# Environmental Crisis

The debate on global warming is over.

Intergovernmental Panel on Climate Change, 4th Assessment Report (IPCC - AR4), Paris, Feb. 2007

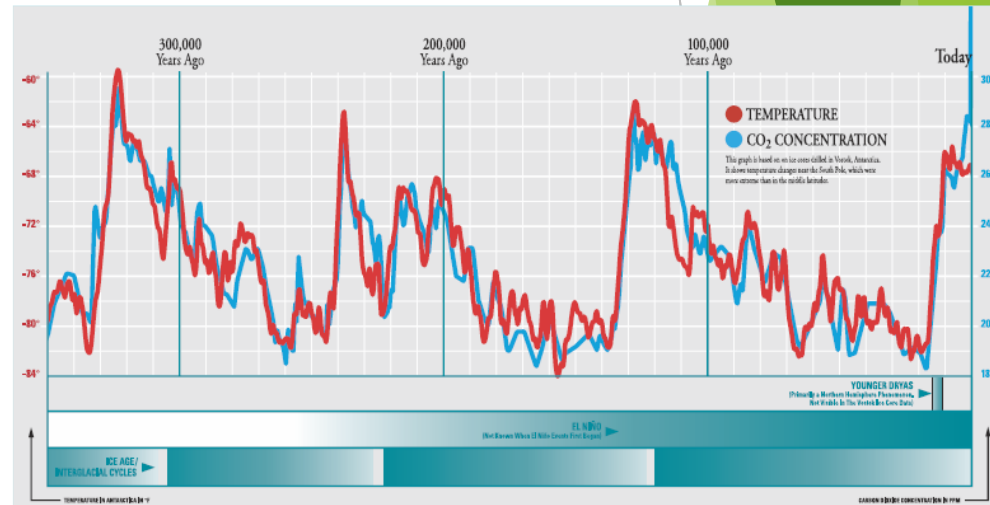
Present levels of carbon dioxide-nearing **400 ppm** in the earth's atmosphere-are higher than they have been at any time in the past 650,000 years and could easily surpass **500 ppm** by the year 2050 without radical intervention.



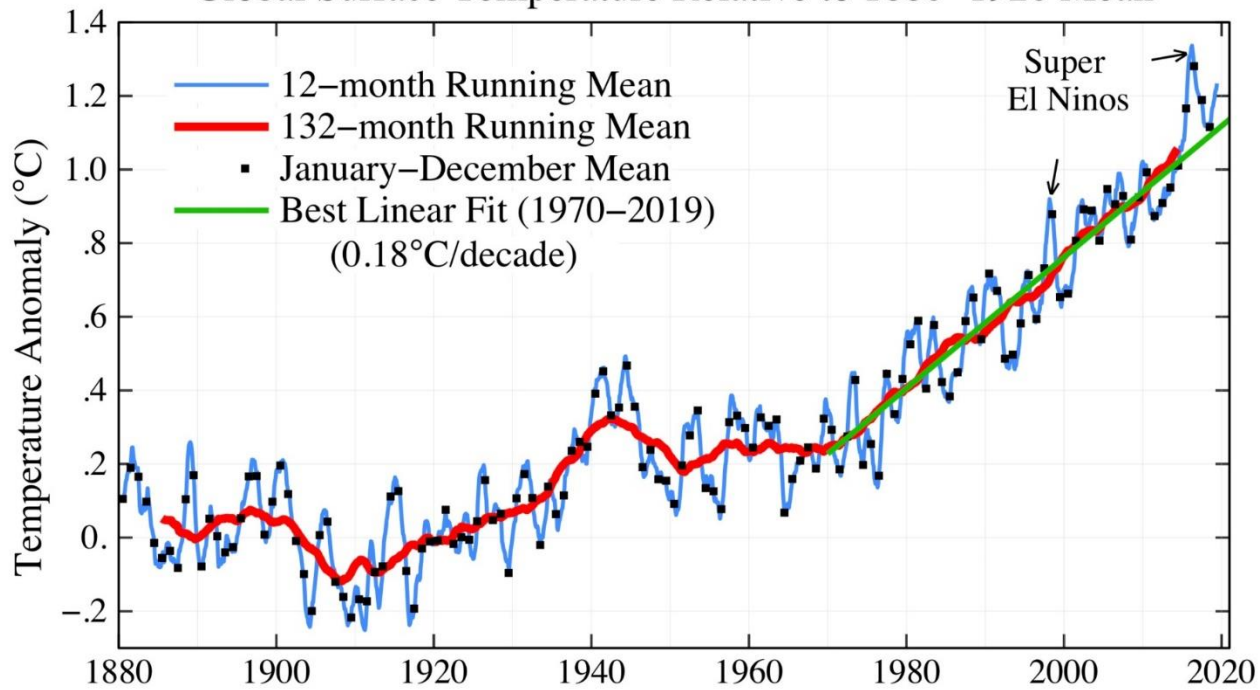
Measurements at meteorological stations  
Goddard Institute for Space Studies

Understanding and responding to climate change  
MARCH 2006 NATIONAL ACADEMY OF SCIENCES

Recorded in ice cores from Vostok, Antarctica  
Understanding and responding to climate change  
MARCH 2006 NATIONAL ACADEMY OF SCIENCES

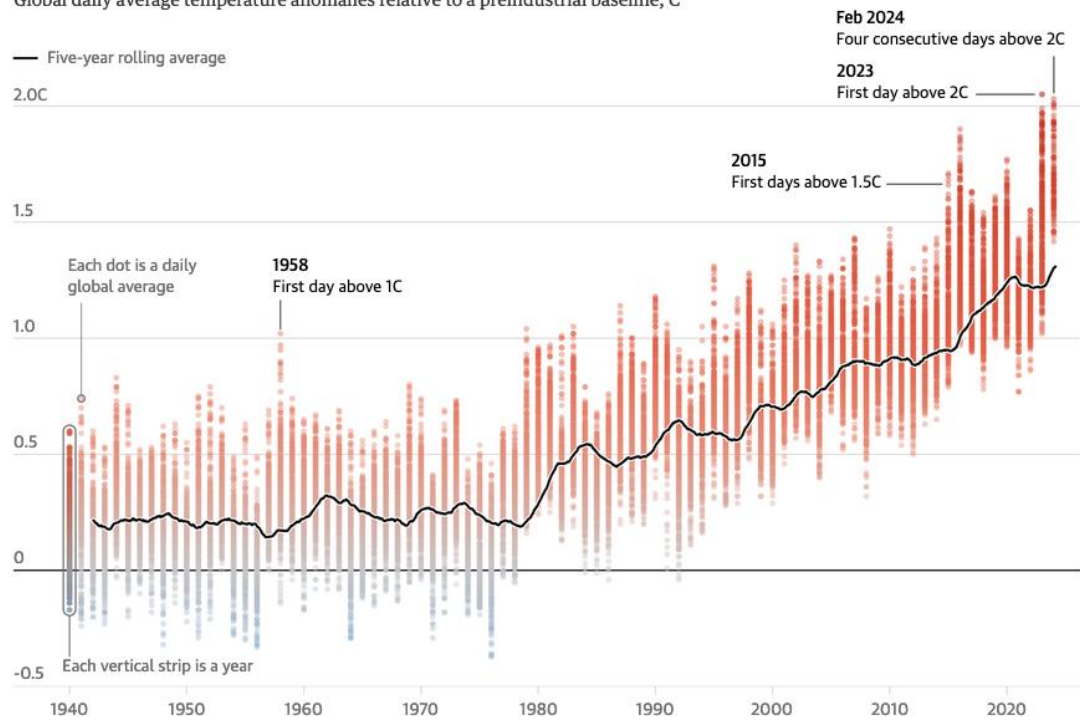


Global Surface Temperature Relative to 1880–1920 Mean



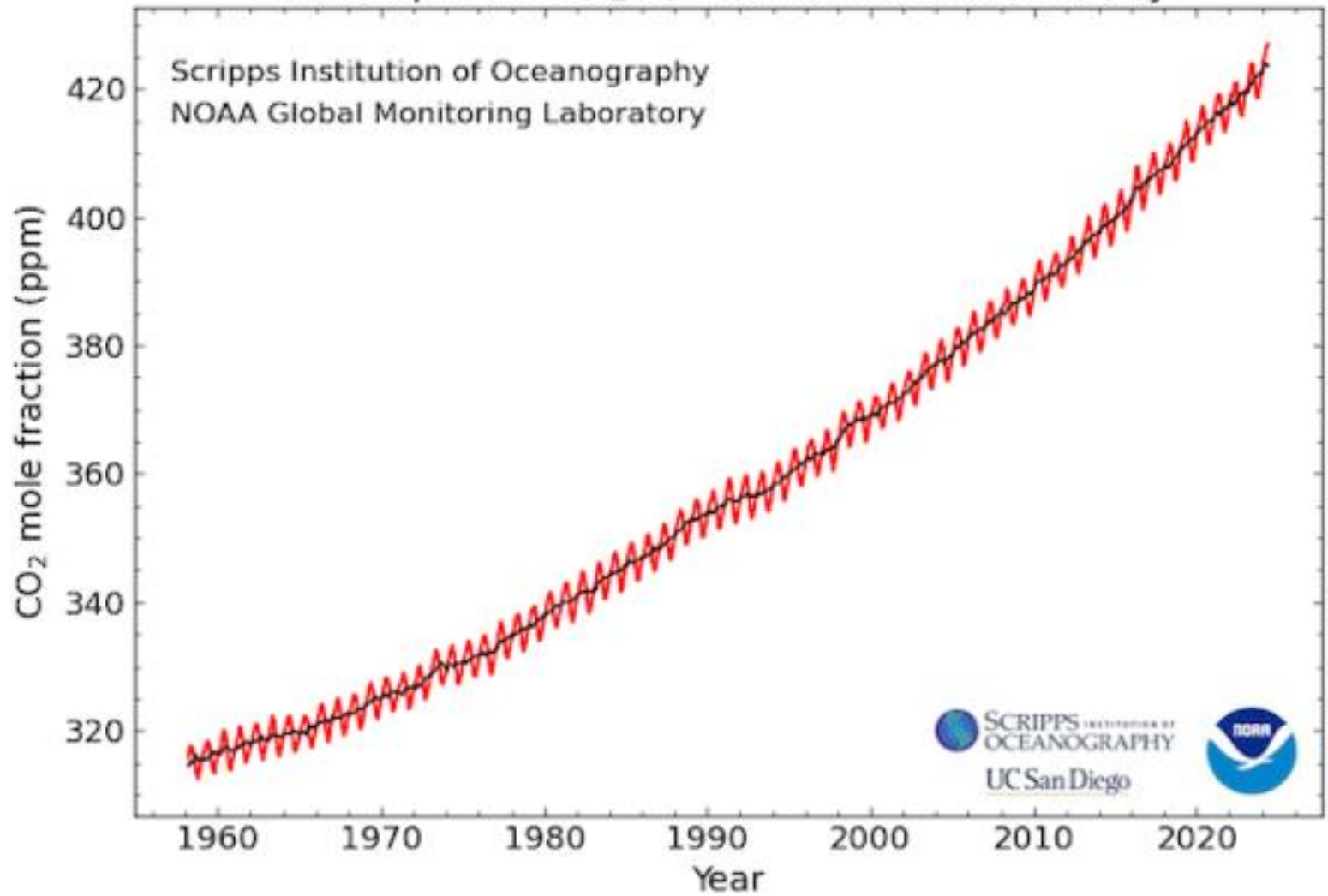
## Daily temperature anomalies

Global daily average temperature anomalies relative to a preindustrial baseline, C

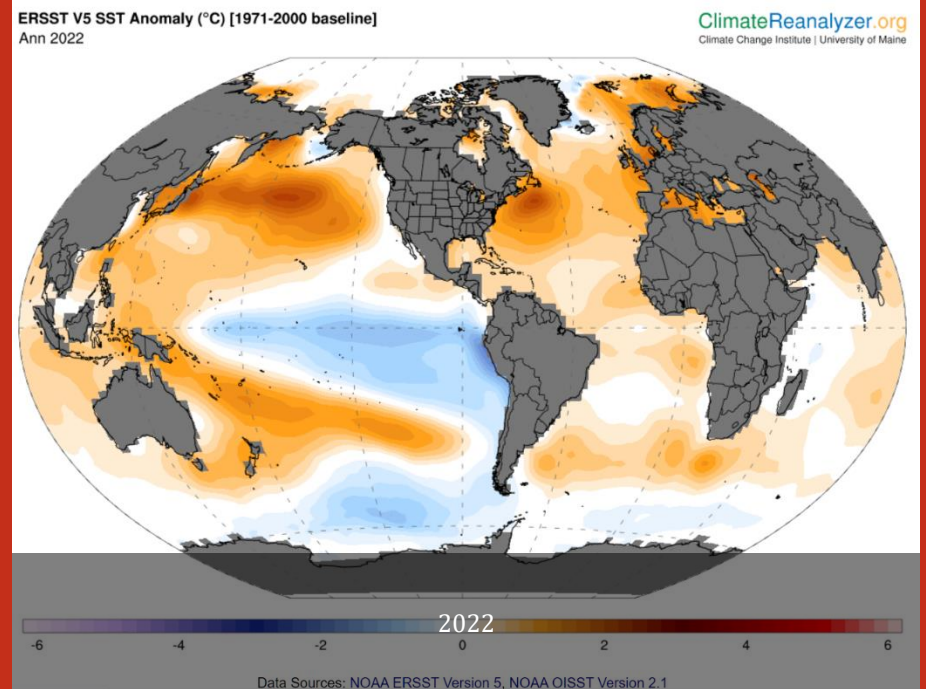
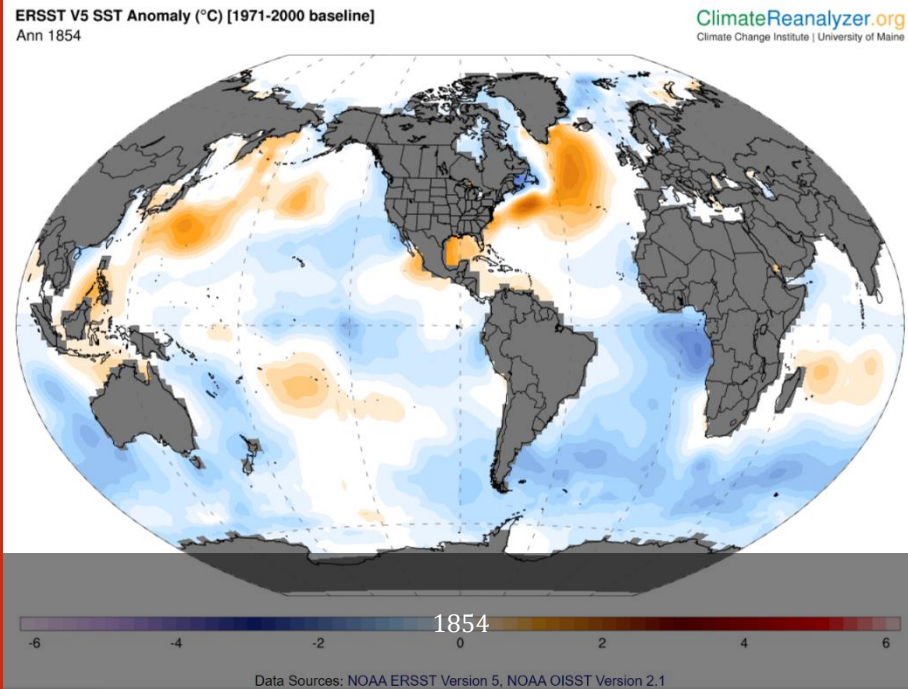


Guardian graphic. Source: Copernicus C3S/ECMWF Era5. Note: Preindustrial baseline = 1850-1900

## Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



# Sea Surface Temperature

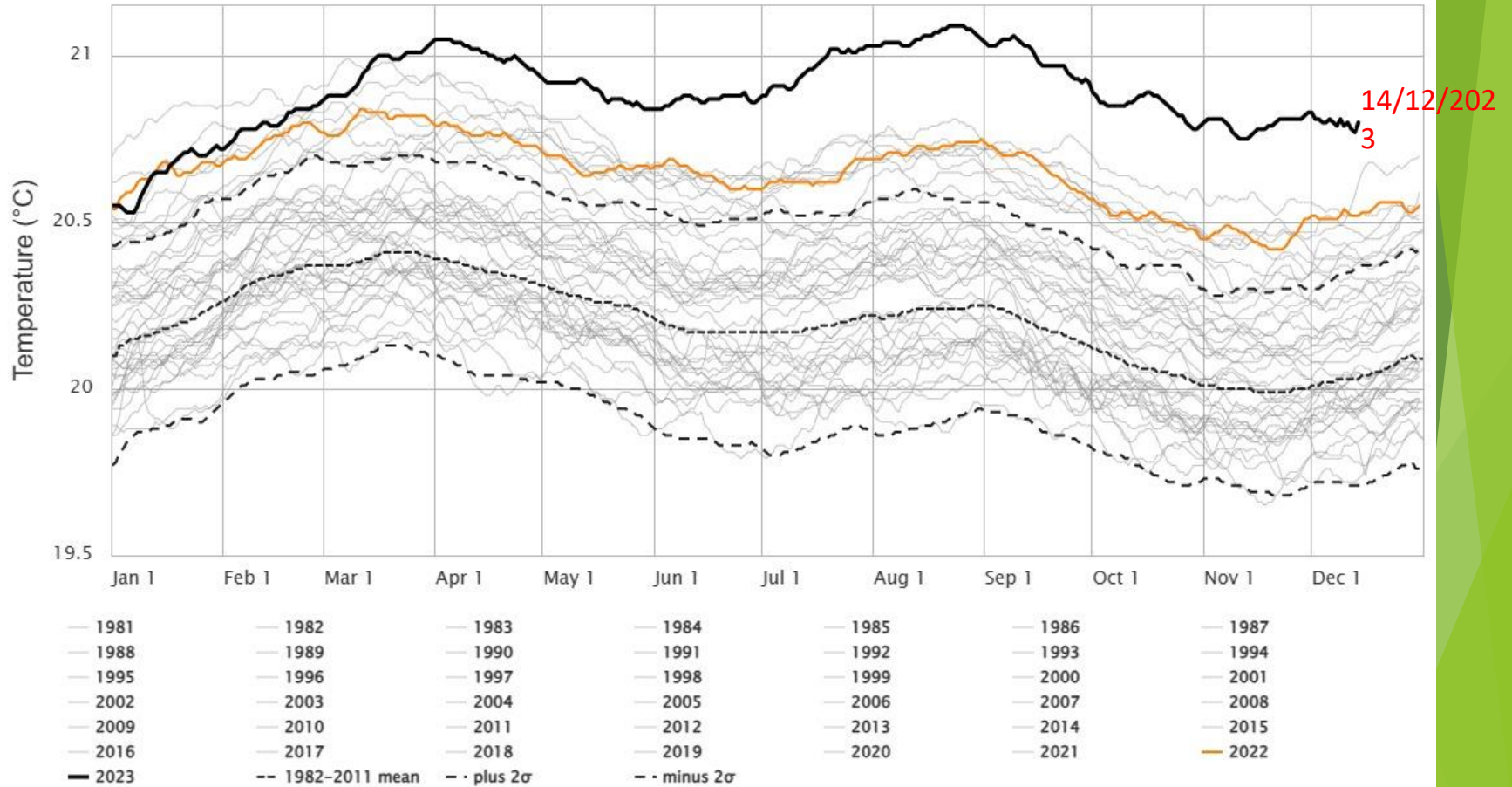


[https://climatoreanalyzer.org/clim/sst\\_monthly/](https://climatoreanalyzer.org/clim/sst_monthly/)

# Daily / annual sea surface temperature variation

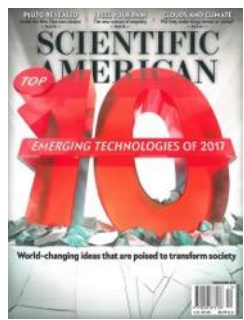
[https://climatereanalyzer.org/clim/sst\\_daily/](https://climatereanalyzer.org/clim/sst_daily/)

Data Source: NOAA OISST V2.1 | Image Credit: ClimateReanalyzer.org, Climate Change Institute, University of Maine



# Hydrogen as Energy Carrier





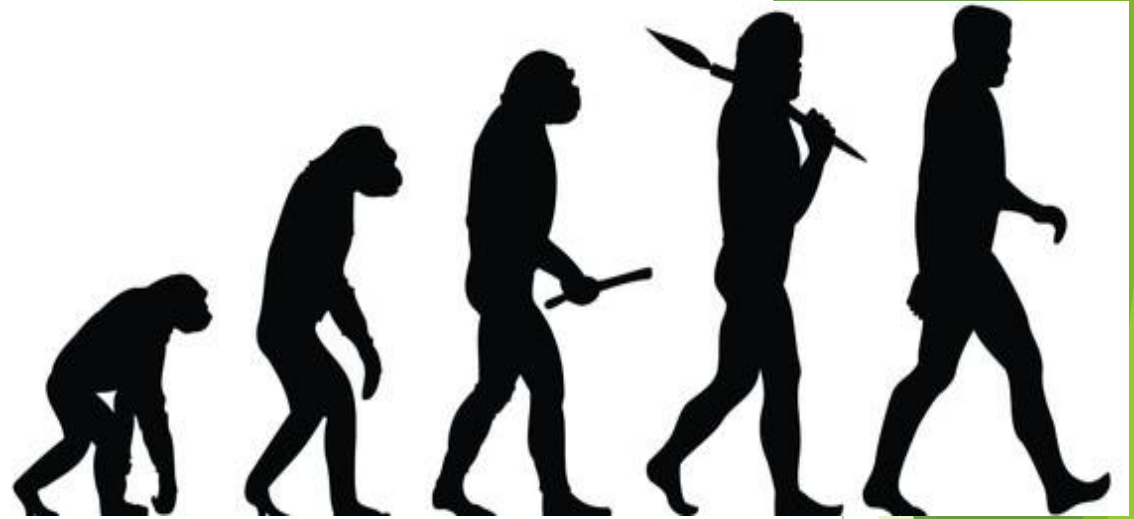
## TOP 10 EMERGING TECHNOLOGIES OF 2017

*a collaboration between Scientific American and  
the World Economic Forum*



1. Water Made by the Sun - Technologies that pull moisture from the air are now solar-powered
2. Fuel from an Artificial Leaf - Technology that mimics photosynthesis converts carbon dioxide to fuels in a sustainable way
3. AI that sees like humans - A deep-learning tool for visual tasks is changing medicine, security and more
4. Precision Farming - Sensors, imaging and real-time data analytics improve farm outputs and reduce waste
5. Mapping Every Cell - A global project aims to understand how all human cell types function
6. Liquid Biopsies – Ultrasensitive blood tests promise to improve cancer diagnosis and care
7. Hydrogen Cars for the Masses - Reducing precious metals makes fuel-cell catalysts affordable
8. Genomic Vaccines - Vaccines composed of DNA or RNA could enable rapid development of preventives for infectious diseases
9. Sustainable Communities – Instead of “Greening” individual houses, entire blocks of homes are retrofit into a single efficient unit
10. Quantum Computing - New algorithms and Techniques open the door to innovative applications

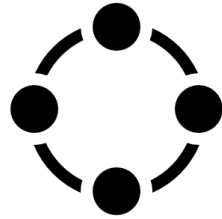
- Age of coal.
  - CCCCCC
- Age of oil.
  - CHCHCHCH
- Age of gas.
  - CH<sub>4</sub>
- Age of hydrogen ?



AS WE MOVE TO A 100% RENEWABLE ENERGY LANDSCAPE, A KEY CHALLENGE IS TO DECOUPLE SUPPLY FROM DEMAND IN RENEWABLE ENERGY IN ORDER TO ACHIEVE ENERGY BALANCE.

THIS BECOMES IMPOSSIBLE TO MANAGE WITHOUT SIGNIFICANT STORAGE CAPACITY.

# Universal Energy Vector



**Decouple  
Supply  
from  
Demand**

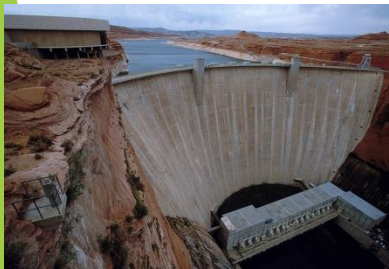




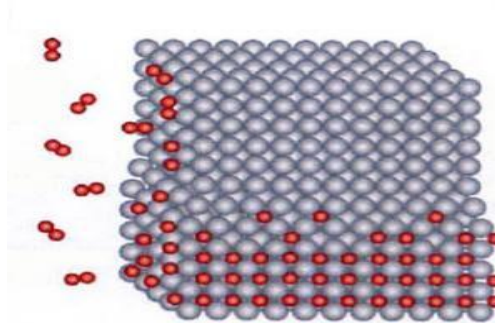
- ✓ By far the most abundant element in the universe (75%). However, on earth, it is not found practically free (but in compounds like water, hydrocarbons, etc.)
- ✓ The highest energy content per unit mass compared to any other known fuel (120.7 kJ/g, almost three times larger than gasoline).
- ✓ Clean combustion, produces water and electricity / heat.
- ✓ **Safety compared to gasoline**, diesel or natural gas.
- ✓ Decentralized energy production systems (can be produced in many ways anywhere).

# The Hydrogen Economy

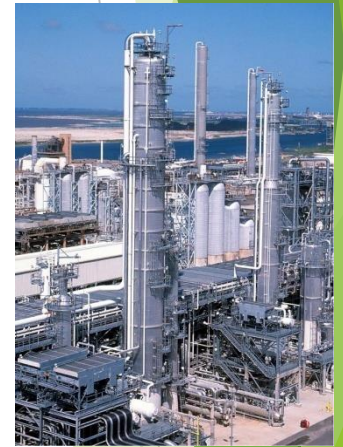
- PRODUCTION



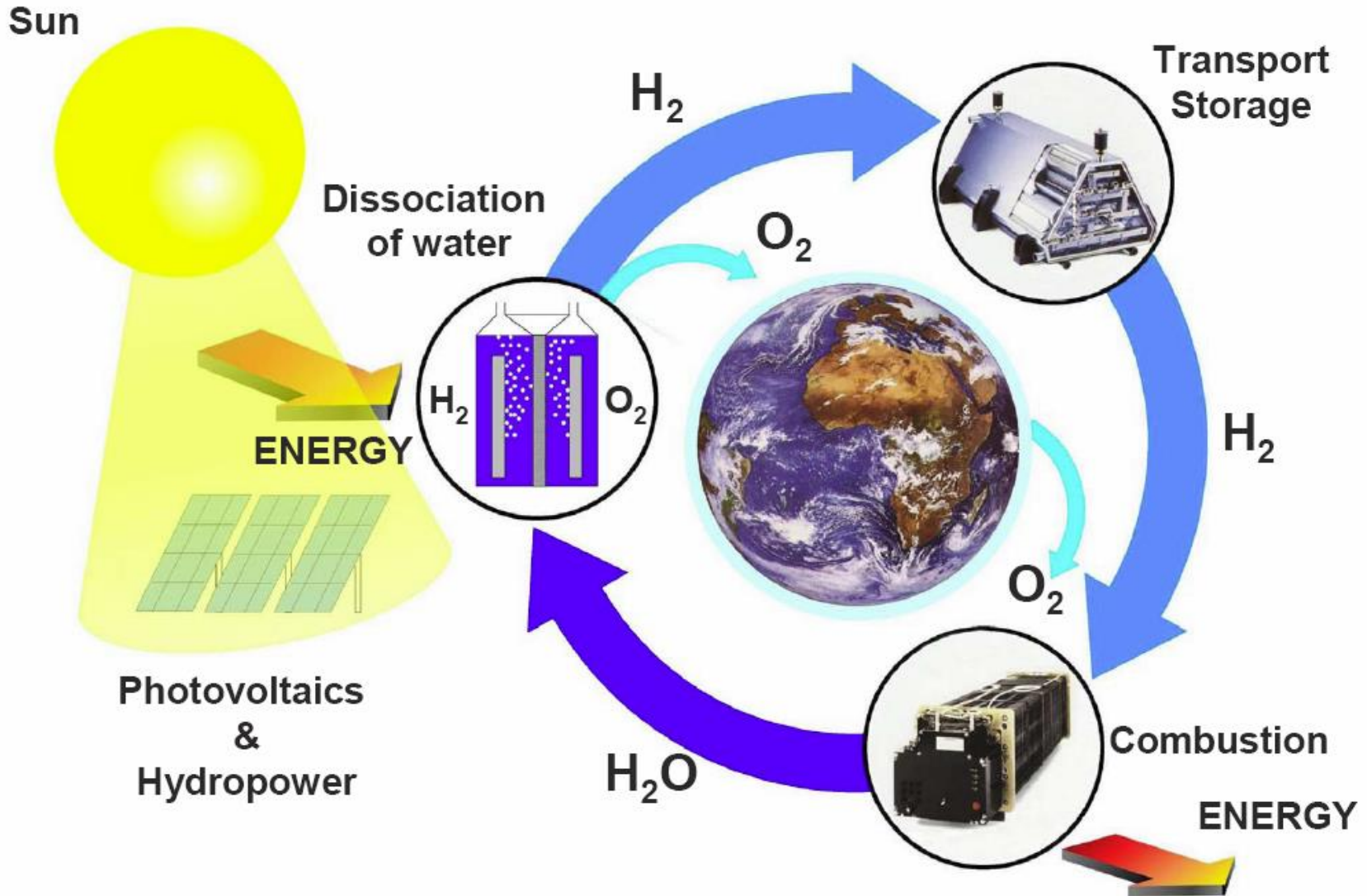
- STORAGE



- USE



# The Hydrogen Cycle



# EU Policies



# EU Regulatory Framework: Fit for 55

## **European climate law sets the reduction targets for net greenhouse gas emissions**

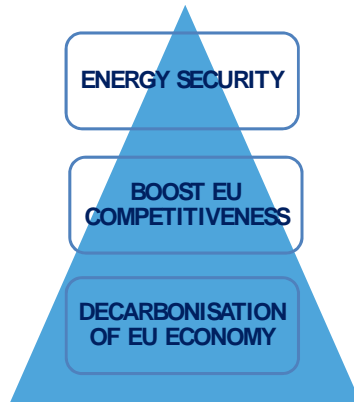
- > Ultimate goal: climate-neutrality by 2050
- > Intermediate goal: reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels

## **Fit for 55**

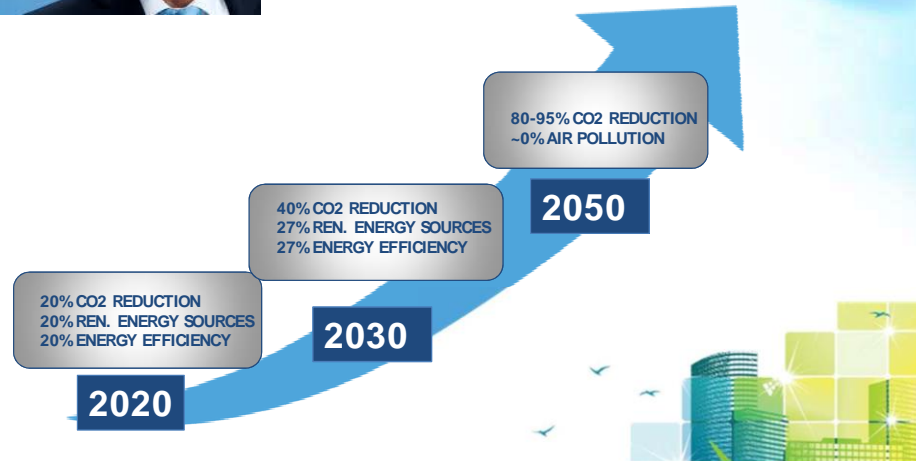
- > Proposals to revise and update EU legislation
- > Framework for achieving the climate targets
  - New cars and vans on the market as of 2035 should have zero-emissions. Creation of a new, separate emissions trading system for road transport and building sectors
  - Hydrogen filling stations on main roads at least every 200 km (end of 2030) – denser network expected in urban areas

# Decarbonisation - EU level

## EU CLIMATE AND ENERGY FRAMEWORK



*"I want to reform and reorganise Europe's energy policy in a new European Energy Union."*



# GLOBAL CO2 EMISSIONS BY SECTOR

## Key targets for 2030 in the E.U.:

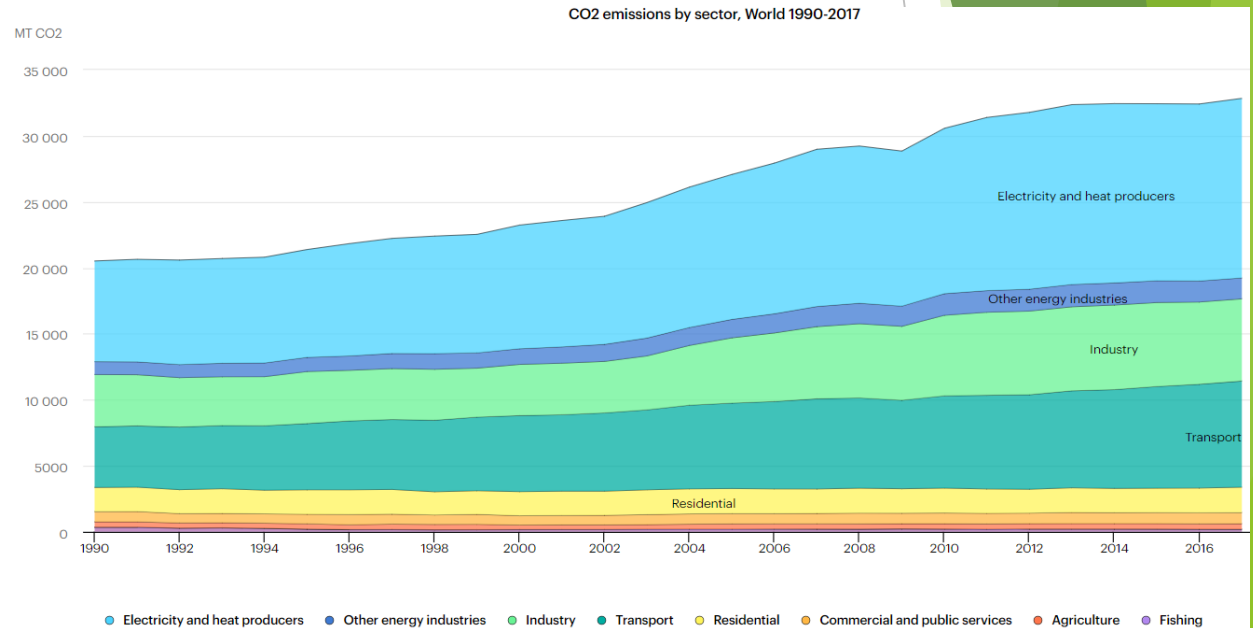
At least 40% cuts in **greenhouse gas emissions** (from 1990 levels)

At least 32% share for **renewable energy**

At least 32.5% improvement in **energy efficiency**

## E.U. targets for Transportation Sector

- **30%** decrease of CO2 emissions by 2030
- **60%** decrease of CO2 emissions by 2050



**“Water will be the coal of the future”** - Cyrus Harding, 1874 - *hero of Jules Verne’s novel*  
«*The Mysterious Island*»

**150 years later, hydrogen economy is about to become a reality...**



*“... In developing and deploying a clean hydrogen value chain, Europe will become a global frontrunner and retain its leadership in clean tech.”*

*Executive Vice-President for the Green Deal, Frans Timmermans*  
8 July 2020

## STATE OF THE UNION 2020

*“I want Next Generation EU to create new European hydrogen valleys, to modernise our industries, to power our vehicles, and to bring new life to our rural areas”*  
*EC President Ursula von der Leyen, 16 September 2020*

The President further announced that 30% of the €750 billion #NextGenerationEU budget will be raised through green bonds. And 37% funding will be invested in European Green Deal objectives, including ‘lighthouse’ European projects – hydrogen, green building and 1 million electric charging points.

# EU Position on Hydrogen

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



Today - 2024

From now to 2024, we will support the **installation of at least 6GW of renewable hydrogen electrolyzers 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 electrolyzers and the production of **up to 10 million tonnes** of renewable hydrogen in the EU.

2030

From 2030, **renewable hydrogen** deployed at **scale** as 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 technologies.



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 will secure **cooperation opportunities with neighboring countries and regions of the EU** and work to establish a global hydrogen market.

European Commission “A Hydrogen Strategy for a Climate-Neutral Europe”,

2020. [https://ec.europa.eu/energy/sites/ener/files/hydrogen\\_strategy.pdf](https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf)



The **European Clean Hydrogen Alliance** will help build up a robust pipeline of investments.

# Clean Hydrogen Joint Undertaking

EU Institutional Public-Private Partnership (IPPP)



**Industry**  
More than 350 members



**Research community**  
over 103 members

To facilitate the transition to a greener EU society through the development of hydrogen technologies



# Joint Undertaking on Hydrogen & Fuel Cells - Industry & Research



European Union represented by the European Commission




A portfolio of clean, efficient and competitive solutions based on fuel cells and hydrogen technologies in energy and transport




# Clean Hydrogen JU Objectives

Support a sustainable hydrogen economy, contributing to EU's climate goals




**Support the implementation of the Commission's Hydrogen Strategy**



**Stimulate research and innovation on clean hydrogen production, distribution, storage and end use applications**



**Strengthen the competitiveness of the EU clean hydrogen value chain**



**Contribute to the EU ambitious 2030 and 2050 climate ambition**

# EU Hydrogen Strategy launched on 8<sup>th</sup> July 2020

Objectives in 3 phases with the Hydrogen Alliance to support the investment agenda

## Phase 1: 2020-2024

- 6GW of renewable H<sub>2</sub> electrolyser
- 1 million tonnes renewable H<sub>2</sub>
- Replace existing H<sub>2</sub> production
- Regulation for liquid H<sub>2</sub> markets
- Planning H<sub>2</sub> infrastructure

## Phase 2: 2025-2030

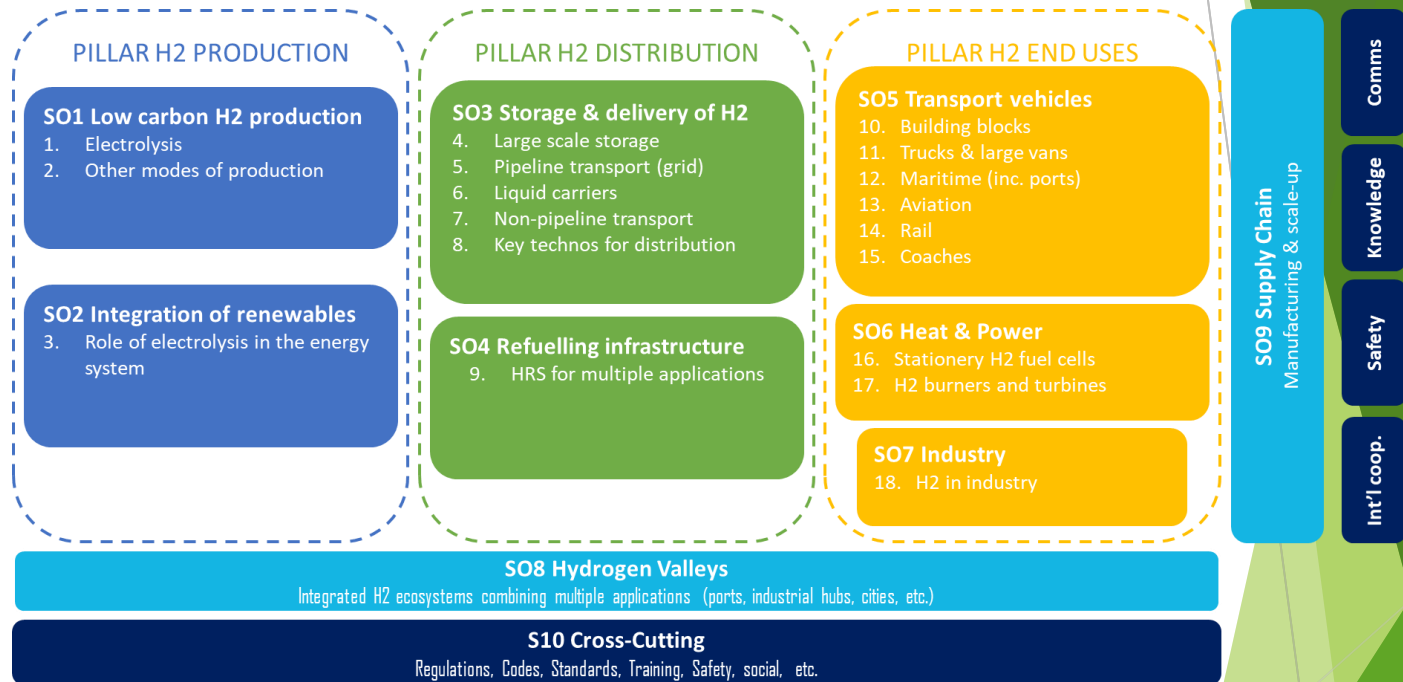
- 40GW renewable H<sub>2</sub> electrolyser
- 10 million tonnes renewable H<sub>2</sub>
- New applications in steel & transport
- H<sub>2</sub> for electricity balancing purposes
- Creation of "Hydrogen Valleys"
- Cross-border logistical infrastructure

## Phase 3: 2030-2050

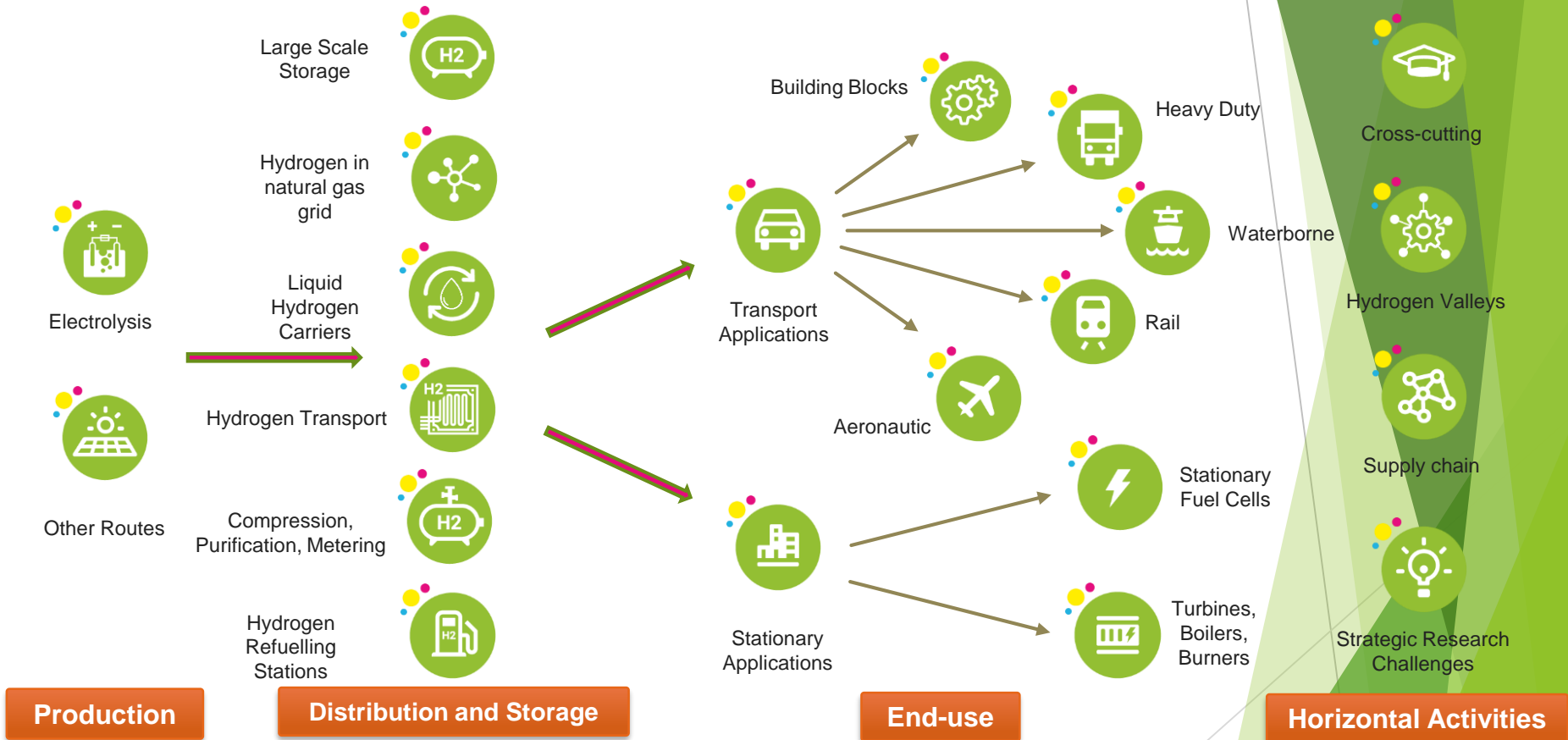
- H<sub>2</sub> technologies matured and deployed at large scale in hard to abate sectors.
- Expansion of hydrogen-derived synthetic fuels
- EU-wide infrastructure network
- An open international market

Clean Hydrogen Alliance to support the EU investment agenda

# Research and Innovation priorities in Clean Hydrogen JU



# Research & Innovation Activities





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# TETHYS WEBINAR - GREEN HYDROGEN PRODUCTION

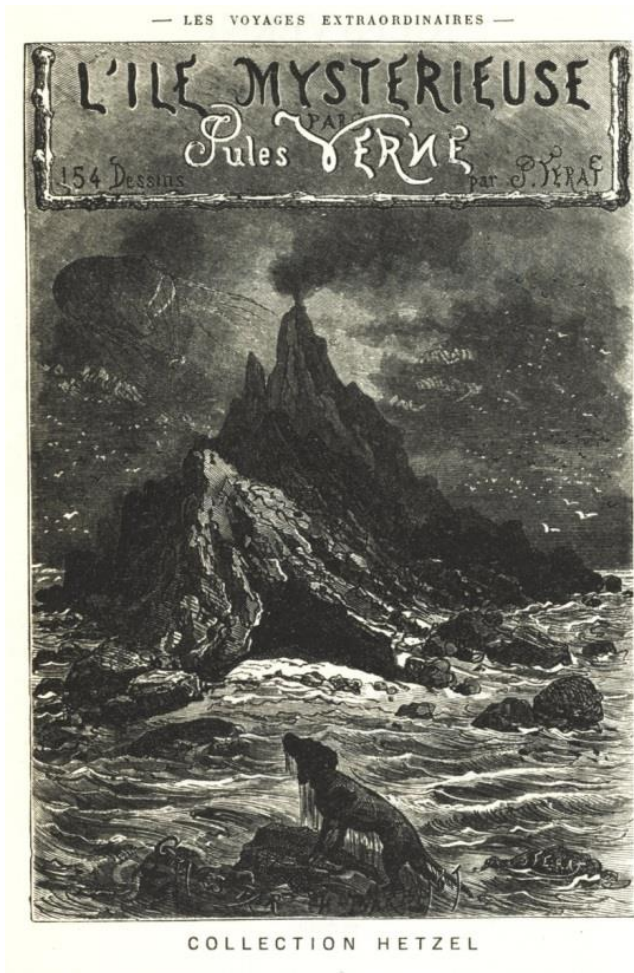
Dr. Manos Zoulias

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# **HYDROGEN PRODUCTION**

The background features abstract, overlapping geometric shapes in various shades of green, ranging from light lime to dark forest green. These shapes are primarily located on the right side of the page, creating a modern, dynamic feel. The text 'HYDROGEN PRODUCTION' is centered in the upper half of the page in a bold, dark red font.



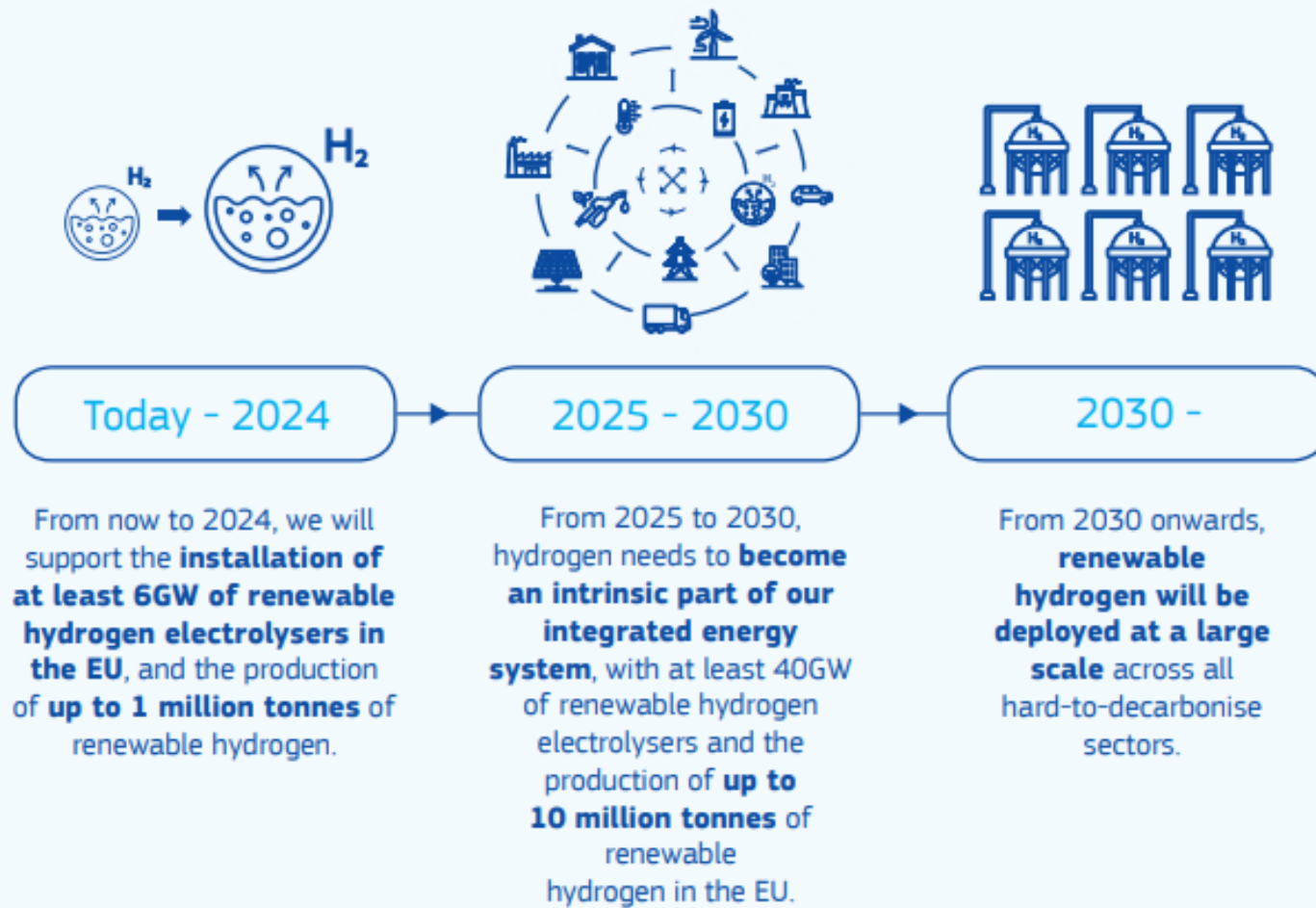
In 1874, in his famous novel *The Mysterious Island*, Jules Verne prophesied the advent of hydrogen in response to the exhaustion of coal: *"I believe that water will one day be used as a fuel, that hydrogen and oxygen, which constitute it, used alone or simultaneously, will provide an inexhaustible 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 :



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 technologies.



• 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.



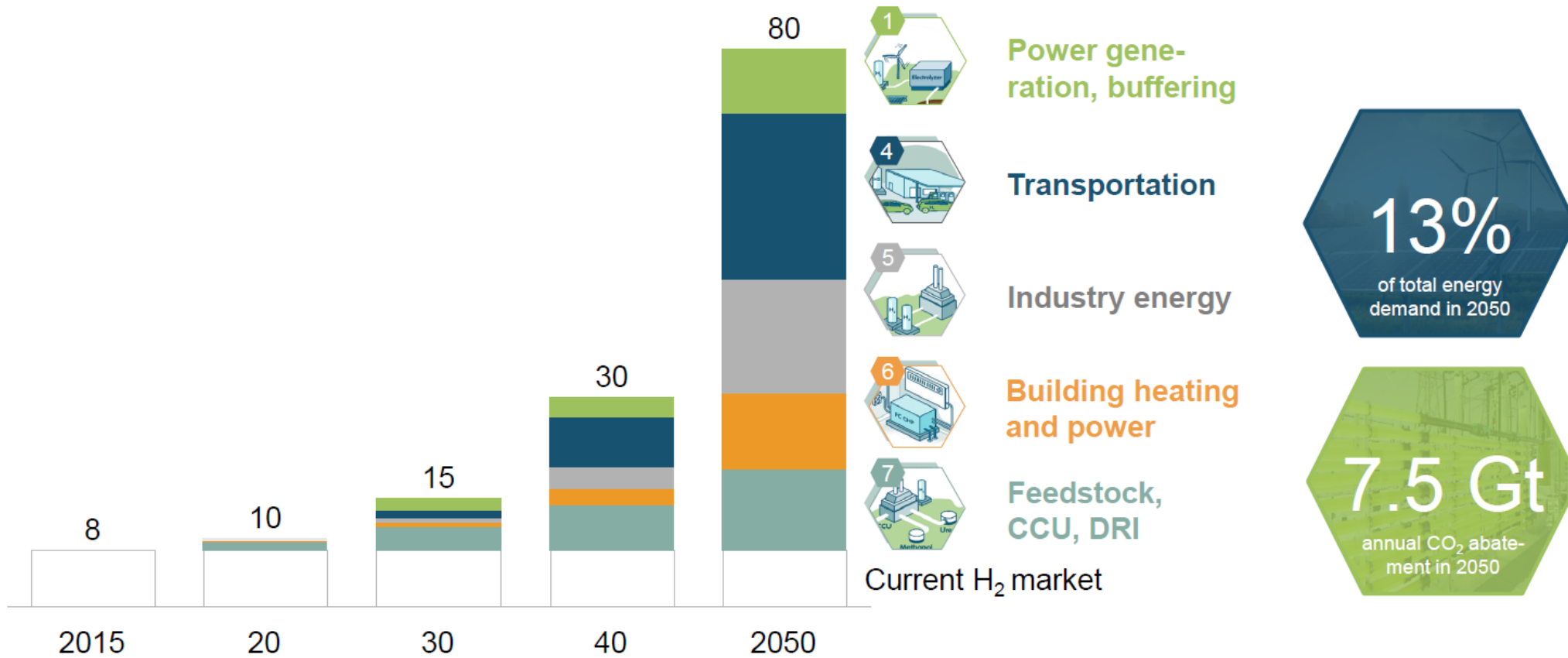
• Europe we will secure **cooperation opportunities with neighboring countries and regions of the EU** and work to establish a global hydrogen market.



• The **European Clean Hydrogen Alliance** will help build up a robust pipeline of investments.

# By 2050, hydrogen can enable major CO<sub>2</sub> emission reductions

Global Energy demand supplied with hydrogen, Exajoule (EJ)



1 Excluding feedstock

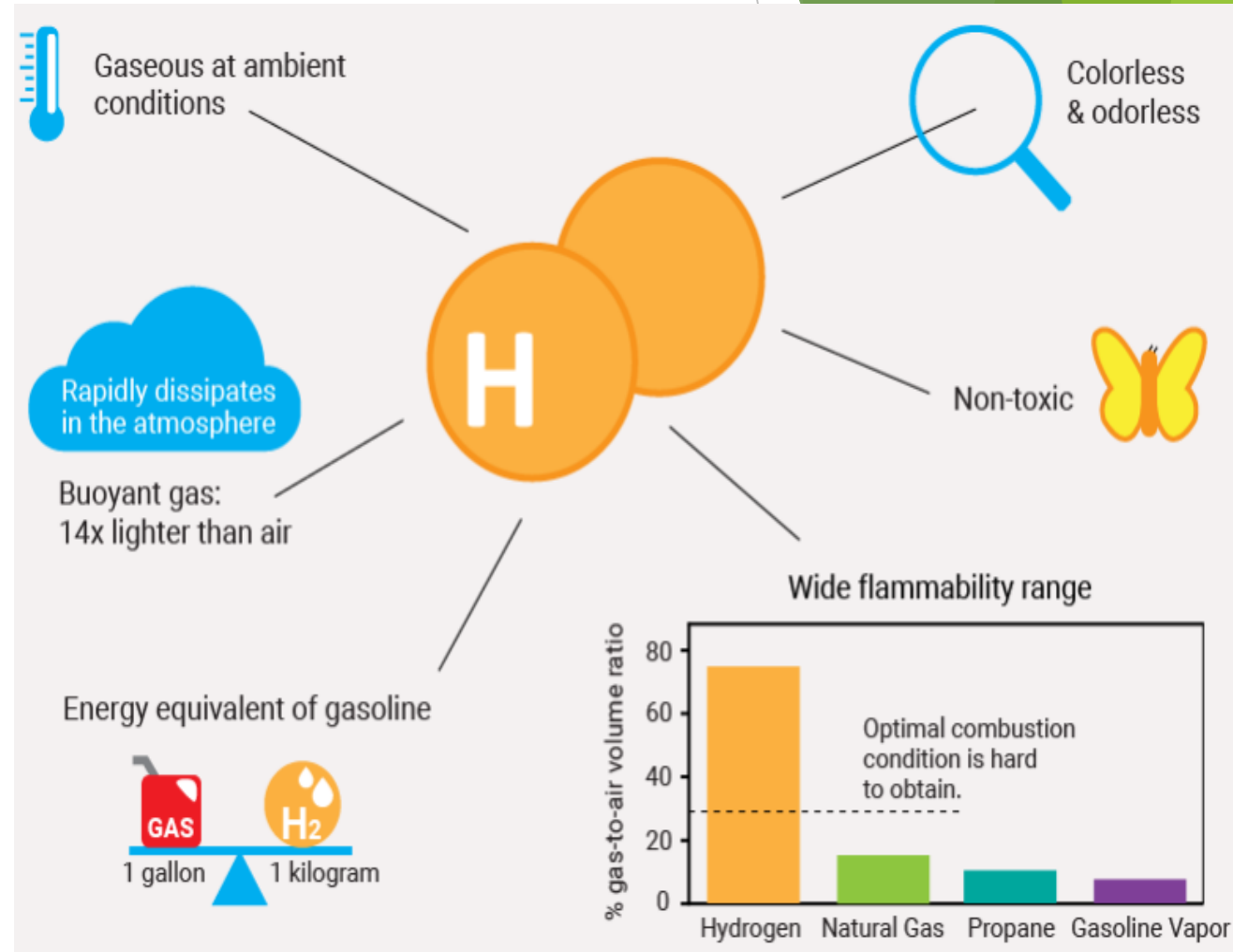
SOURCE: Hydrogen Council, IEA ETP Hydrogen and Fuel Cells CBS, National Energy Outlook 2016\*

McKinsey & Company

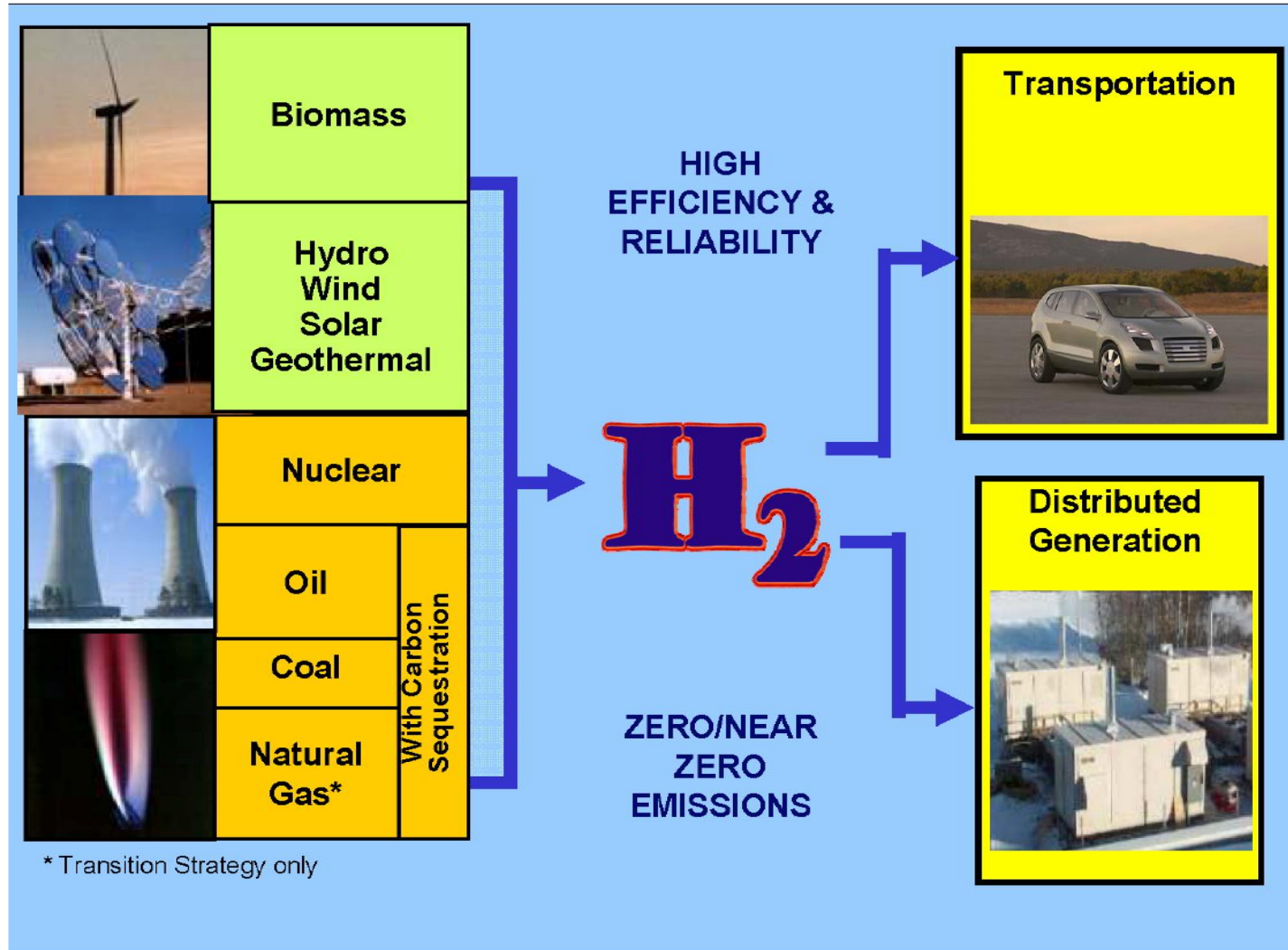
# Basic properties and Initial Safety Concerns

## Hydrogen (H<sub>2</sub>) 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<sub>2</sub> stations (HRS) and in the H<sub>2</sub> 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<sub>2</sub>.

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

**Process:** Methane is split into hydrogen and solid carbon through high-temperature pyrolysis, without producing CO<sub>2</sub>.

## 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

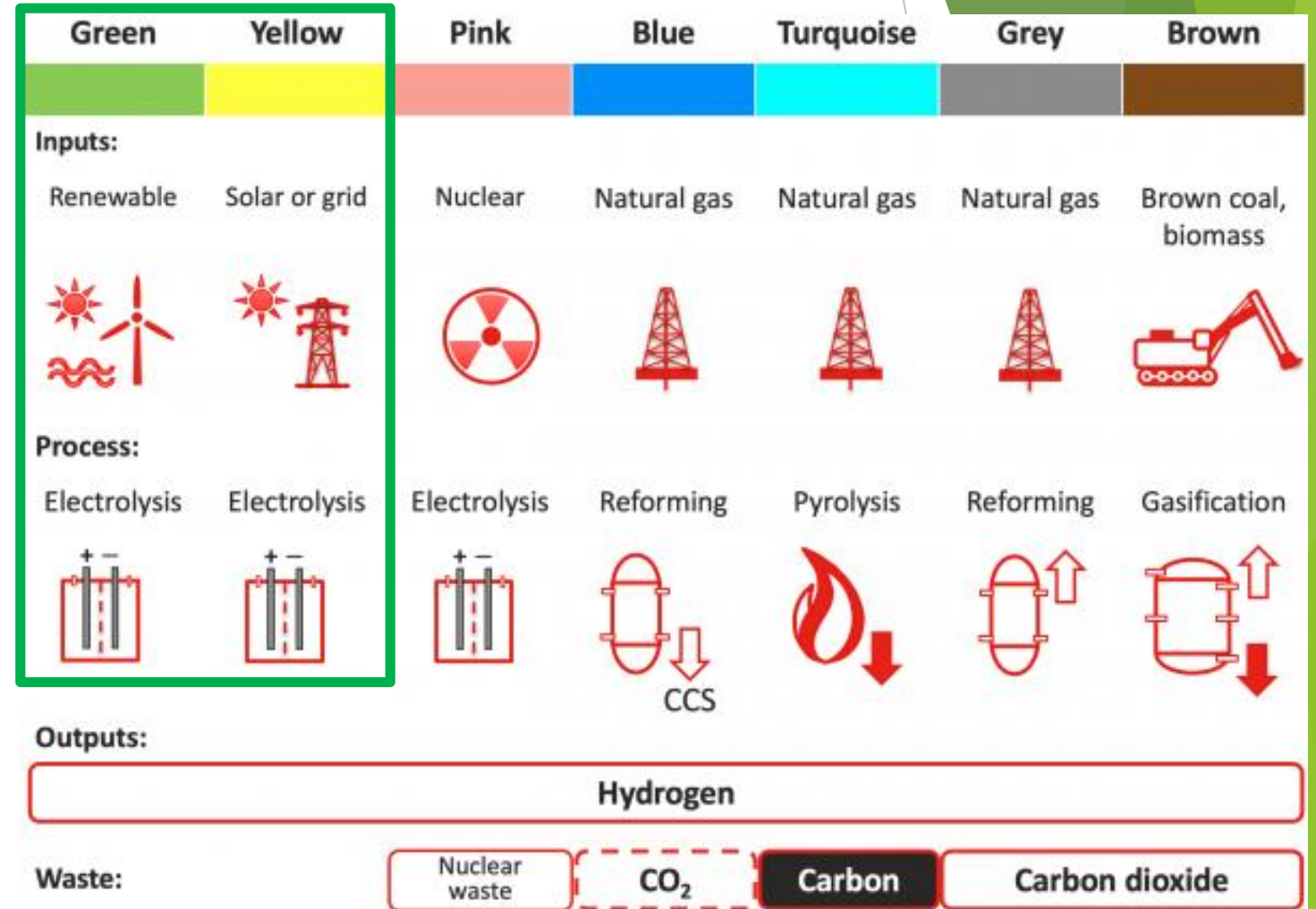
**Process:** Uses high-temperature heat, often from nuclear reactors or solar concentrators, to drive chemical reactions that split water into hydrogen and oxygen.  
Efficiency expected to be high if coupled with high-efficiency heat sources.

### 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

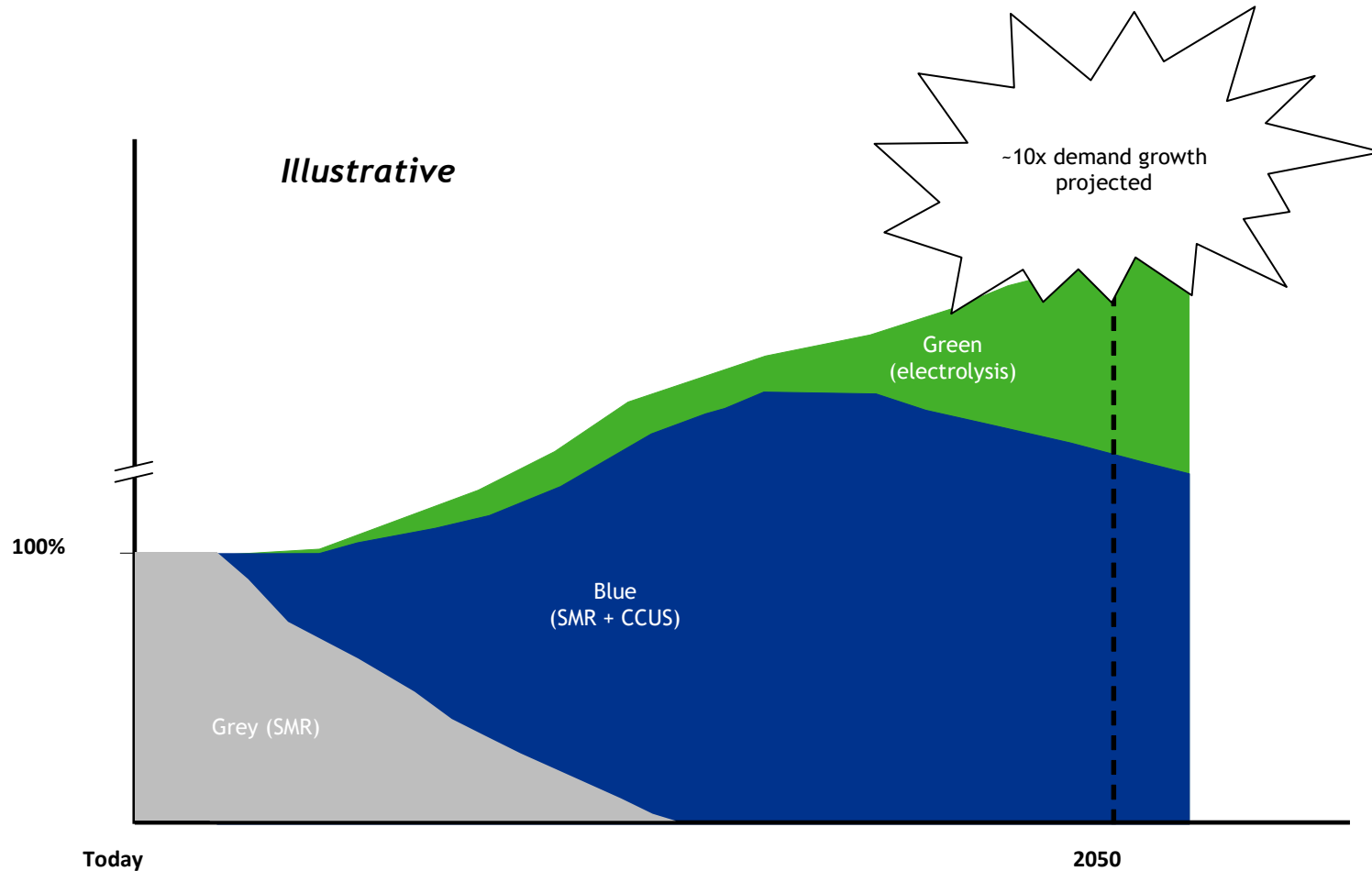
# Types (colors) of Hydrogen

- 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



## Regional Hydrogen Strategy Drivers

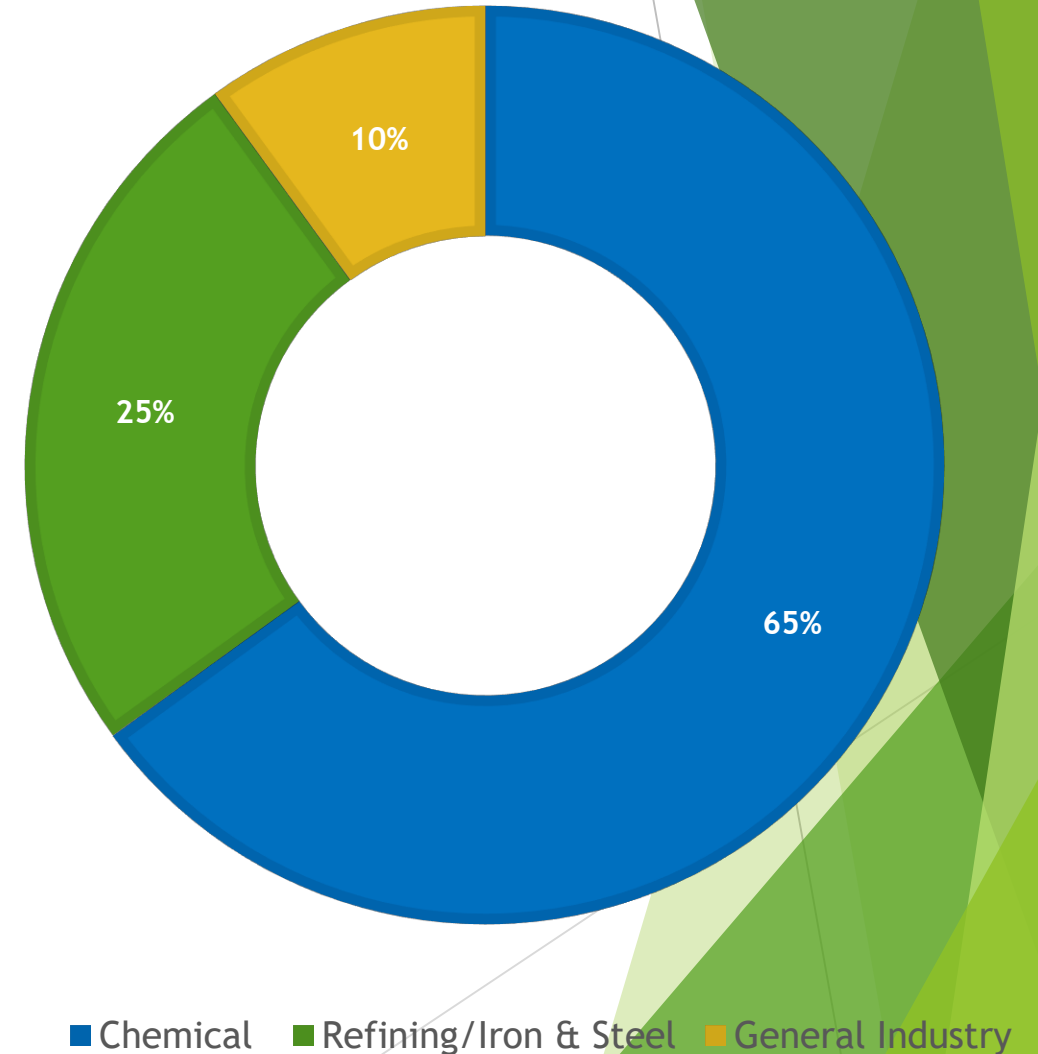
- Goals: 2050 net zero or similar
- Funding: Carbon fees or other
- Leverageable assets (blue)
  - H2 system
  - At-scale CCUS hub
- Leverageable assets (green)
  - Geologic storage
  - Low power prices

## Global Hydrogen Market Enablers

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

INDUSTRY SECTOR	KEY APPLICATIONS
CHEMICAL	<ul style="list-style-type: none"> <li>• Ammonia</li> <li>• Polymers</li> <li>• Resins</li> </ul>
REFINING	<ul style="list-style-type: none"> <li>• Hydrocracking</li> <li>• Hydrotreating</li> </ul>
IRON & STEEL	<ul style="list-style-type: none"> <li>• Annealing</li> <li>• Blanketing gas</li> <li>• Forming gas</li> </ul>
GENERAL INDUSTRY	<ul style="list-style-type: none"> <li>• Semiconductor</li> <li>• Propellant fuel</li> <li>• Glass production</li> <li>• Hydrogenation of fats</li> <li>• Cooling of generators</li> </ul>

H2 DEMAND BY SECTOR



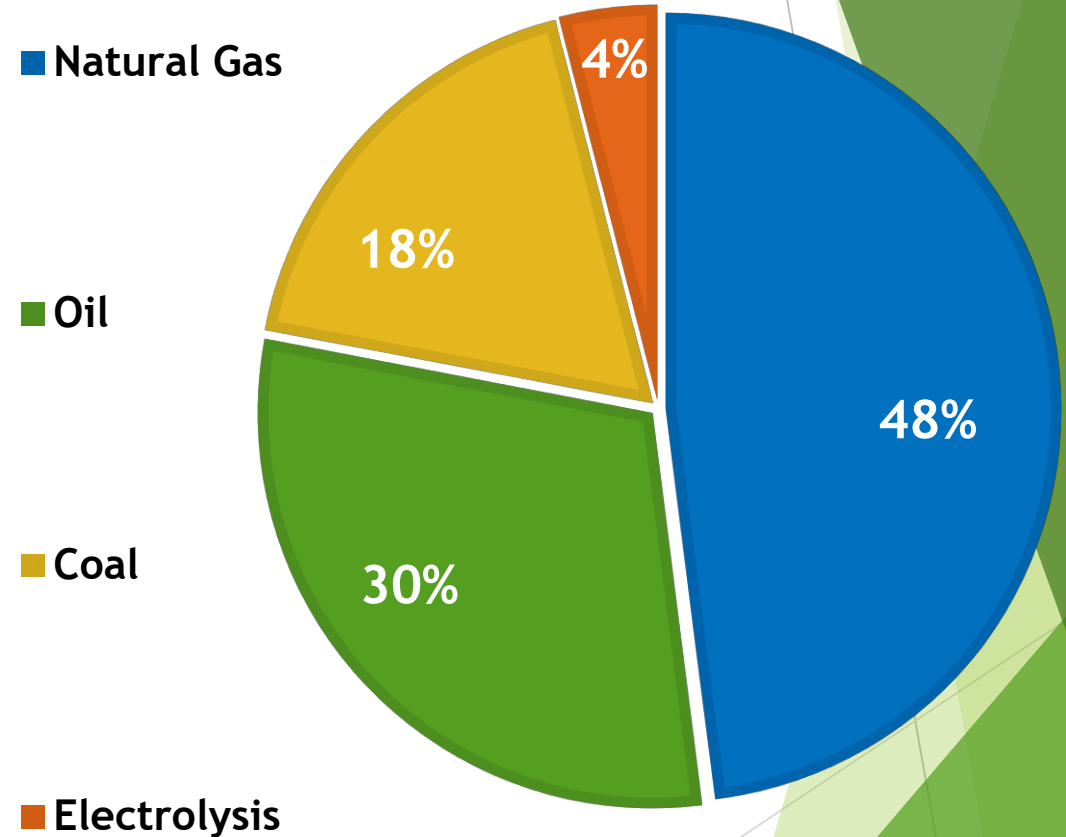
## Main routes for H2 production

- ▶ 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

## H2 PRODUCING SOURCE



# Steam Methane Reforming (SMR)

- ▶ SMR technology splits natural gas (NG) into mixture of hydrogen, CO and CO<sub>2</sub>
- ▶ Industries use SMR technology to deliver large quantities of H<sub>2</sub> and CO with remaining CO<sub>2</sub> being released to atmosphere
- ▶ The process is mature with systems capable of producing up to 100s of metric tonnes per day of H<sub>2</sub>/CO
- ▶ Currently over half the world's hydrogen is derived from NG feedstocks



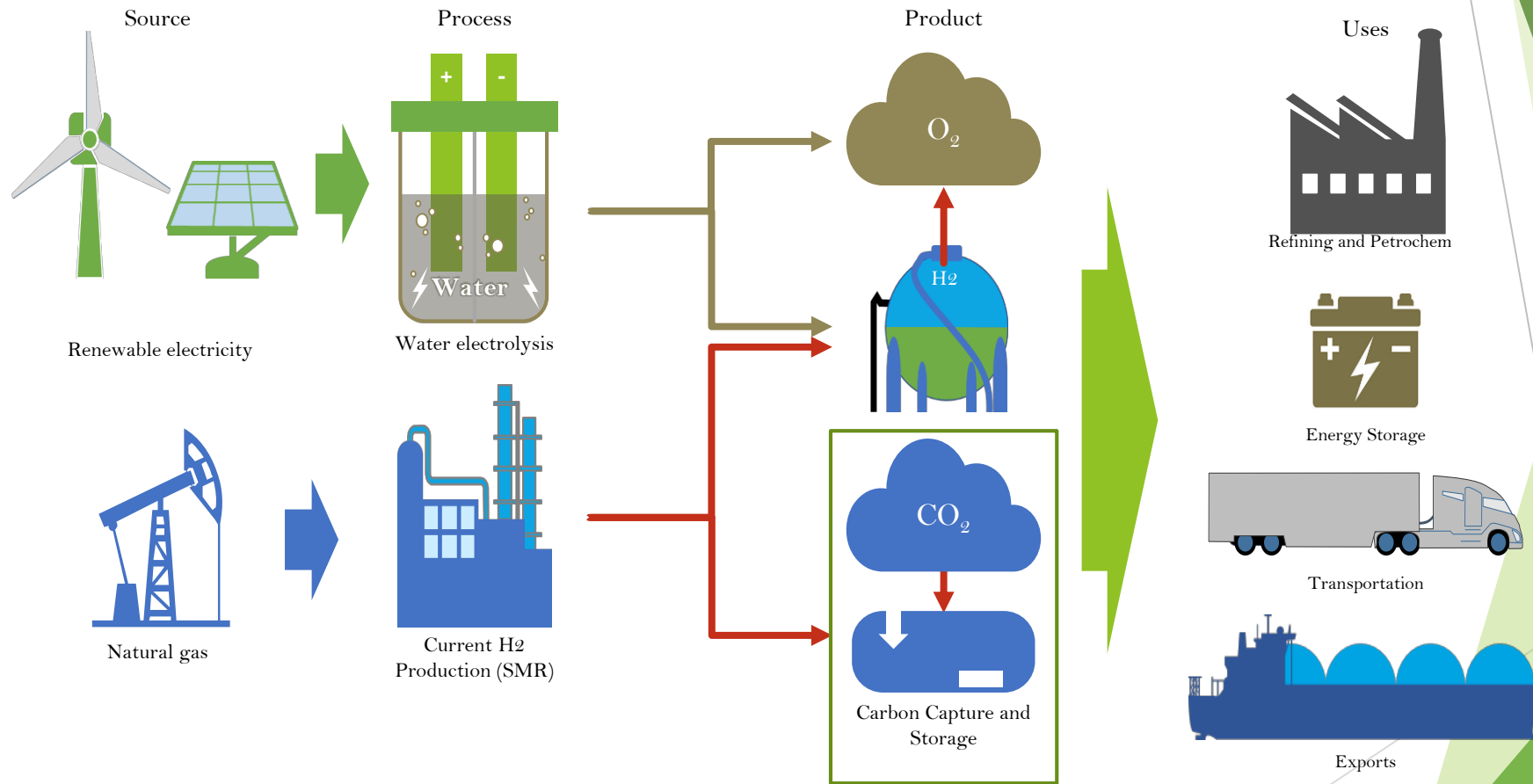
# SMR and Carbon Capture Utilisation and Storage (CCUS)

- ▶ Capturing the CO<sub>2</sub> produced by SMR can decarbonise the process
- ▶ Captured CO<sub>2</sub> can be stored in underground geological features or used
- ▶ **If CO<sub>2</sub> is captured/used, HYDROGEN IS BLUE**
- ▶ Many large scale CCUS projects are being developed internationally.



The **Acorn Project** will capture about 200,000 tonnes of CO<sub>2</sub> from the St Fergus Gas Terminal

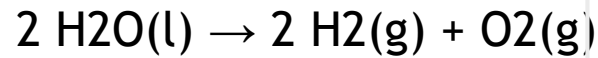
# Typical Clean Hydrogen Production Options



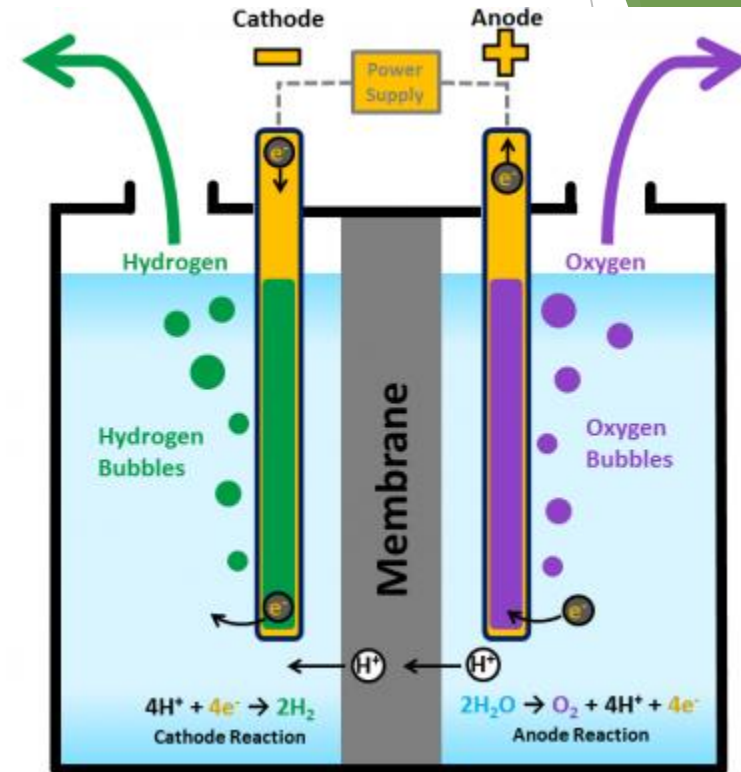
# Water ELECTROLYSIS

- One of the most promising methods for hydrogen production

## Reaction taking place:



- Requires a minimum energy of 39.4 kWh /kg of H<sub>2</sub>
- Has the potential to be carbon free, if powered by renewable sources

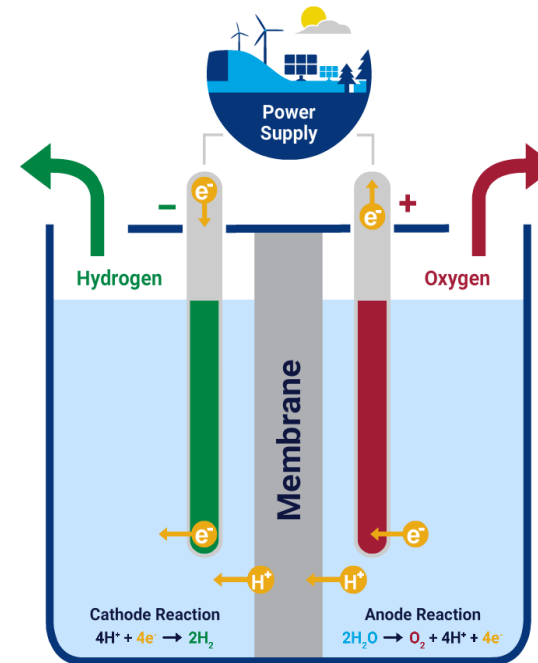


H<sub>2</sub> Production by water electrolysis

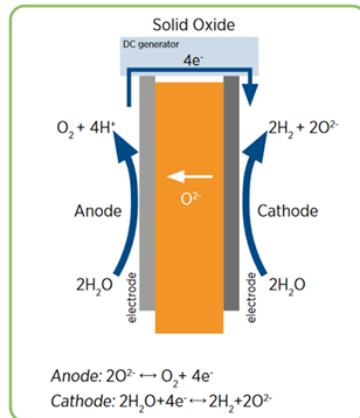
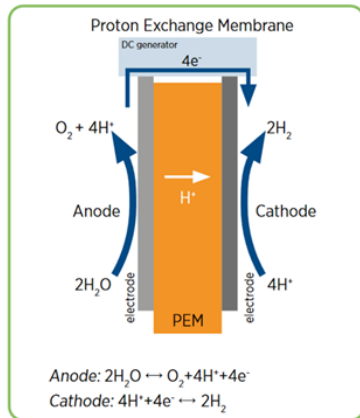
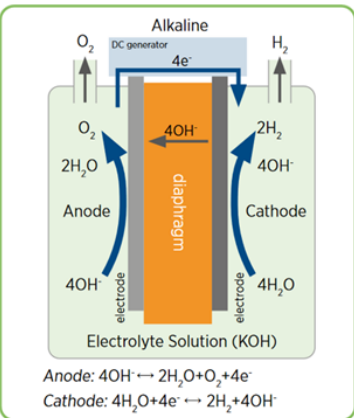
# Electrolysis - Production of Green Hydrogen

- 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



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

**Alkaline**

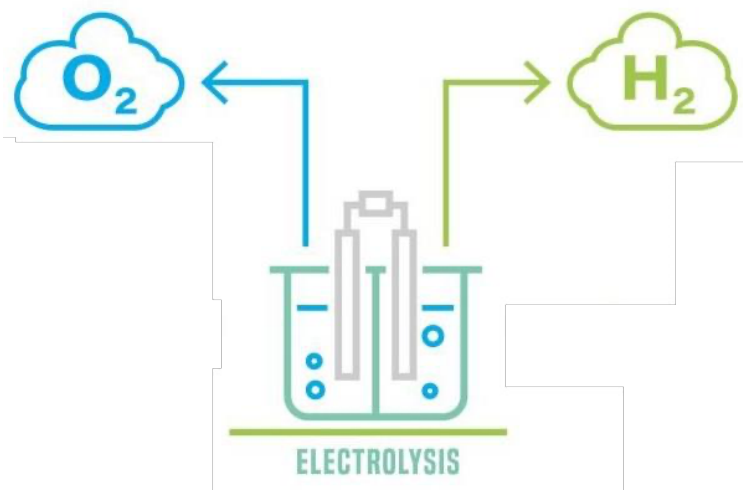
- ✓ Cheap
- ✗ Large equipment

**PEM**

- ✓ Pure hydrogen
- ✗ Expensive catalysts

**Solid oxide**

- ✓ Reversible
- ✗ High temperature



	PEM-EL Polymer Electrolyte Membrane Electrolysis	AEM-EL Anion Exchange Membrane Electrolysis	A-EL Alkaline Electrolysis	HT-EL High-Temperature Electrolysis
<b>Electrolyte</b>	acidic	alkaline	liquid	O <sup>2-</sup> - conducting solid (ceramic)
	solid (Polymer)			
	<p>Cathode - Pt/C + Anode - Ir/IrO<sub>2</sub> Membrane Nafion®</p>	<p>Cathode - Ni + Anode - Ni/Co/Fe Membrane Fumapem® FFA</p>	<p>Cathode - Ni + Anode - Ni/Co/Fe Diaphragm / KOH</p>	<p>Cathode - Ni/Ceramics + Anode - Ni-YSZ/Cermet Solid O<sub>2</sub>-Conductor</p>

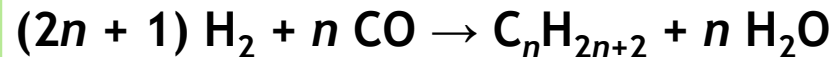
# E- FUELS as a short term solution

- ▶ E fuels are synthesized from hydrogen and CO<sub>2</sub> 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:

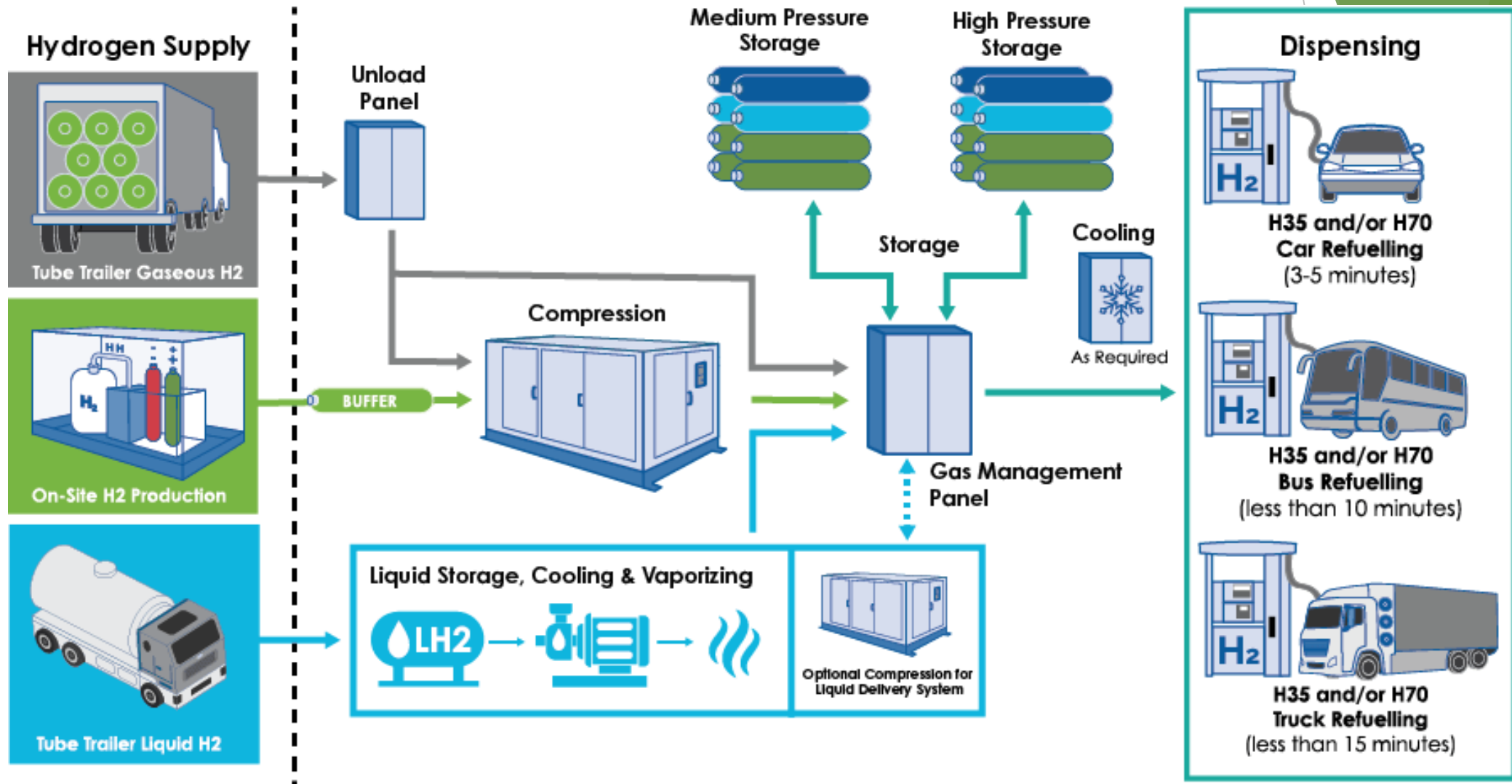


Fischer- Tropsch process for producing e- fuels:



Overall balance of these processes is largely carbon neutral

# What is a HRS and how hydrogen is supplied?



Thanks for your interest!



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Dr. Emmanuel Stamatakis

# STORAGE / DISTRIBUTION OF HYDROGEN

Compressed Gas

Liquefaction - Cryocompression

Solid Materials

Underground Storage

# Hydrogen - Storage issues

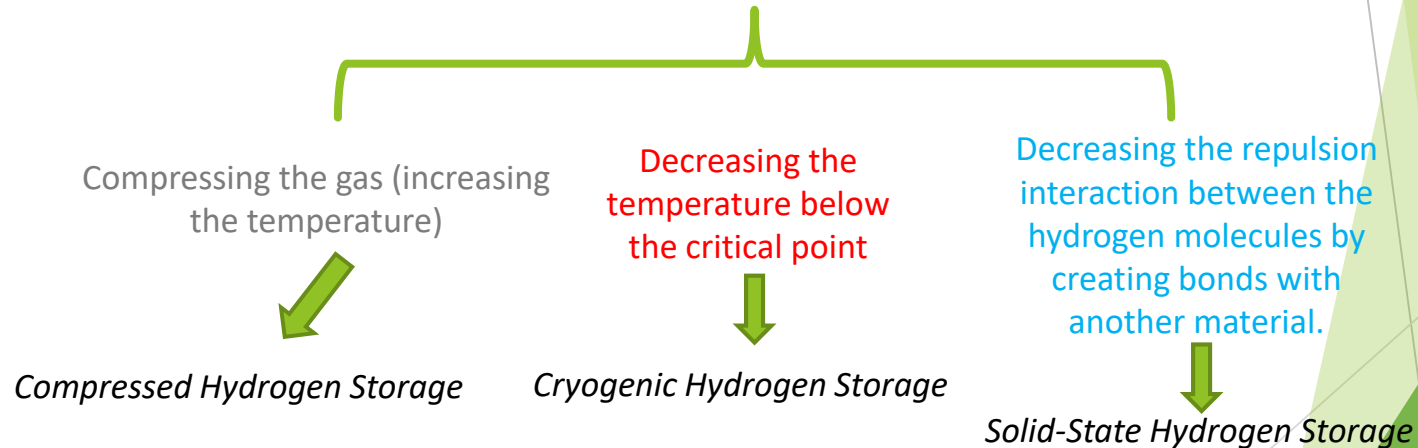
- ✓ Gas under normal conditions
- ✓ Density (0 °C) 0.0899 kg/m<sup>3</sup> (12 times less than air)
  - ✓ Low Boiling Point (20K)
- ✓ Safety (under specific conditions)

# Hydrogen Storage



Under normal temperature and pressure conditions, 1 kg of hydrogen will occupy a volume of  $12.15 \text{ m}^3$  and an energy content of 33.5 kWh. Hydrogen presents HIGH energy per unit mass 140MJ/kg but LOW energy density per volume:  $12.7\text{MJ}/\text{m}^3$

For hydrogen to become a competitive energy carrier, its volume density must be increased  reducing the volume that hydrogen occupies under normal conditions

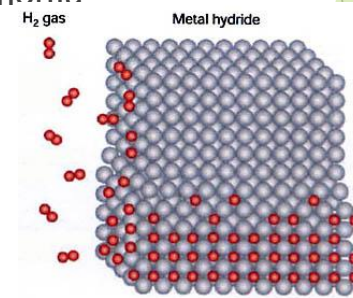


# HYDROGEN STORAGE

- ▶ One of the major issues regarding hydrogen is its storage
- ▶ High energy density per weight / Low energy density per volume

## 3 main ways to store hydrogen:

- ▶ Storage as a compressed gas: By compressing  $H_2$ , the volume it occupies is reduced thus resulting in higher energy density per volume
- ▶ Storage as a liquid: Liquid hydrogen is cryogenic and boils around  $-252.882$  °C.
- ▶ Chemical Storage:  $H_2$  can be chemically stored in substances like ammonia or various hydrides



gen in  
des

# Applications

## Stationary Systems



## Mobile Systems

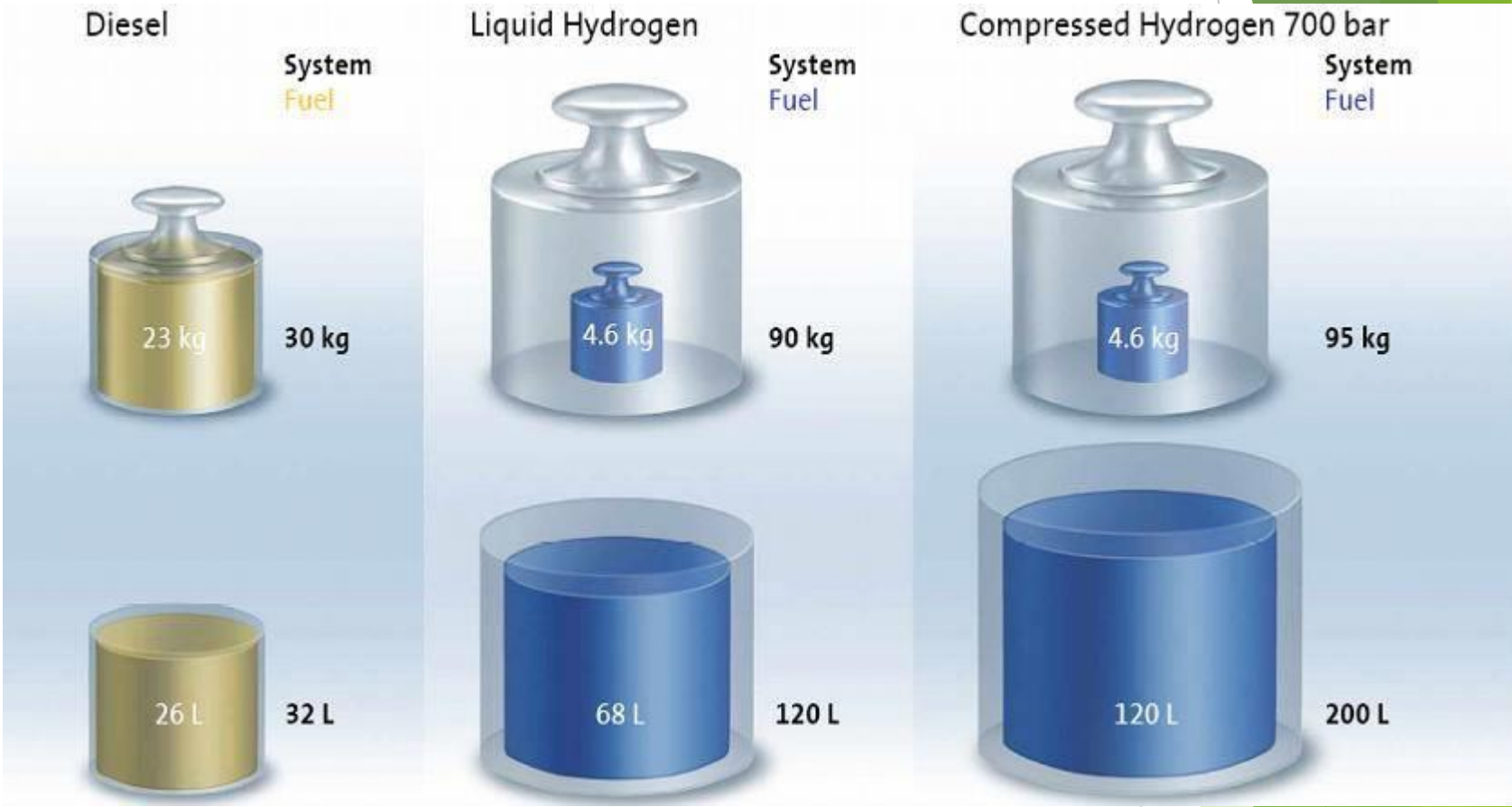
*Volume of 4 kg of hydrogen compacted in different ways, with size relative to the size of a car.*



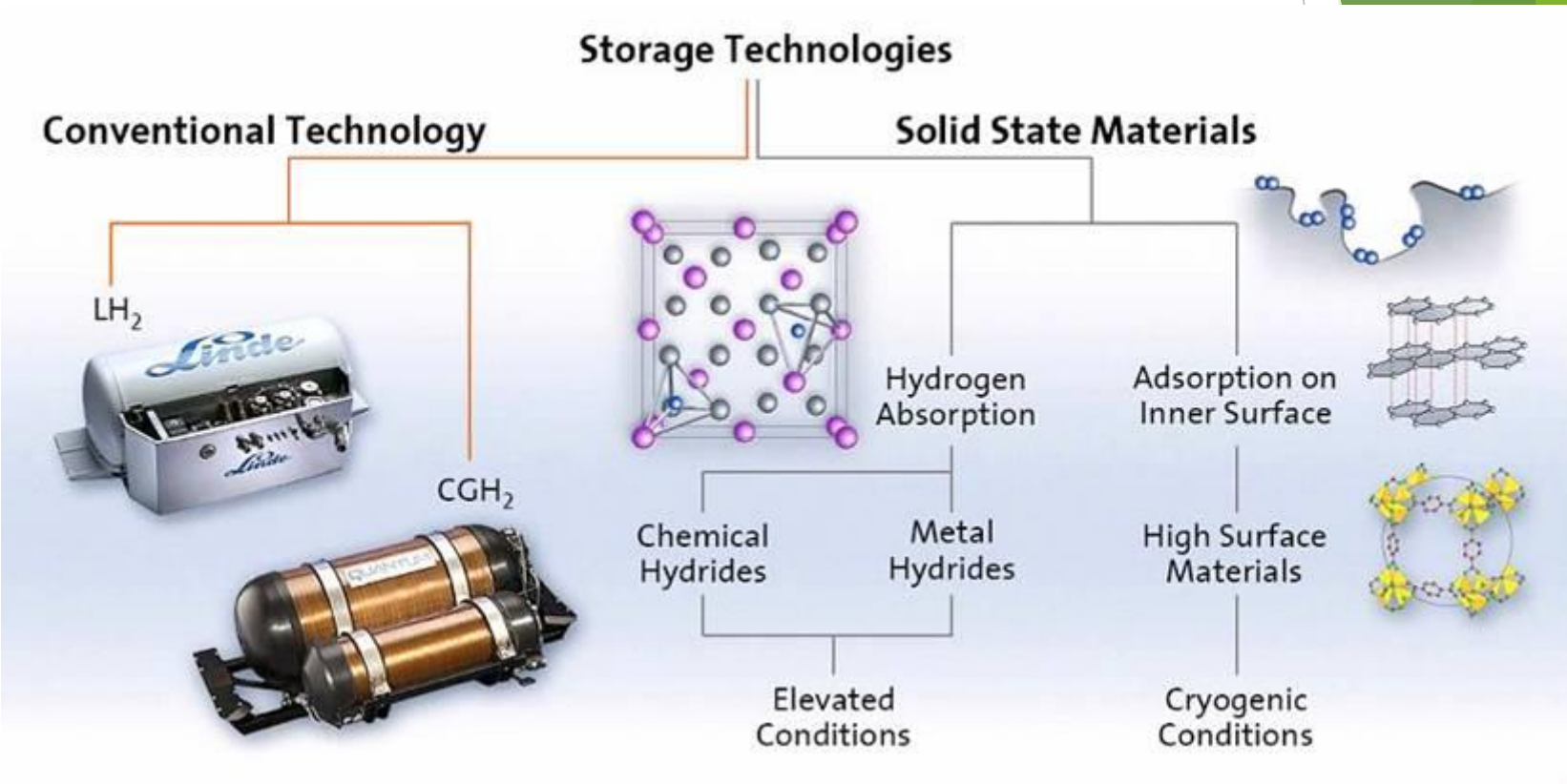
## Portable Systems



# H2 Tank Mass & Volume (autonomy ~600 km)



# H2 Storage Technologies



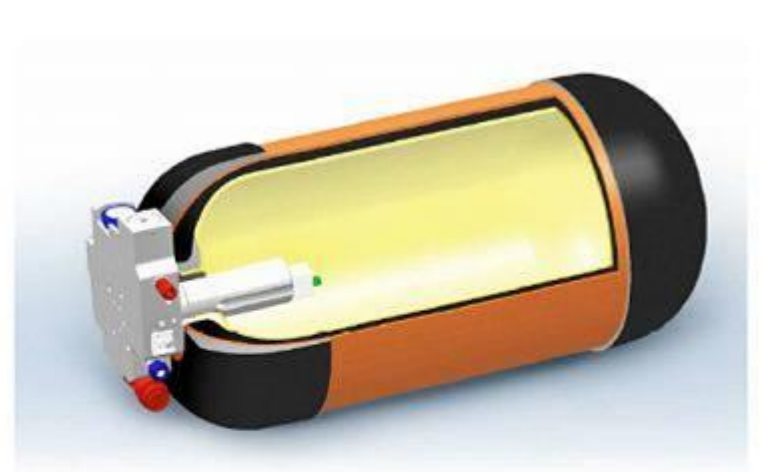
# “Conventional” Technologies



Minimize Heat Inflow (300 K  $\rightarrow$  20 K)



Optimize Volume / Surface Ratio

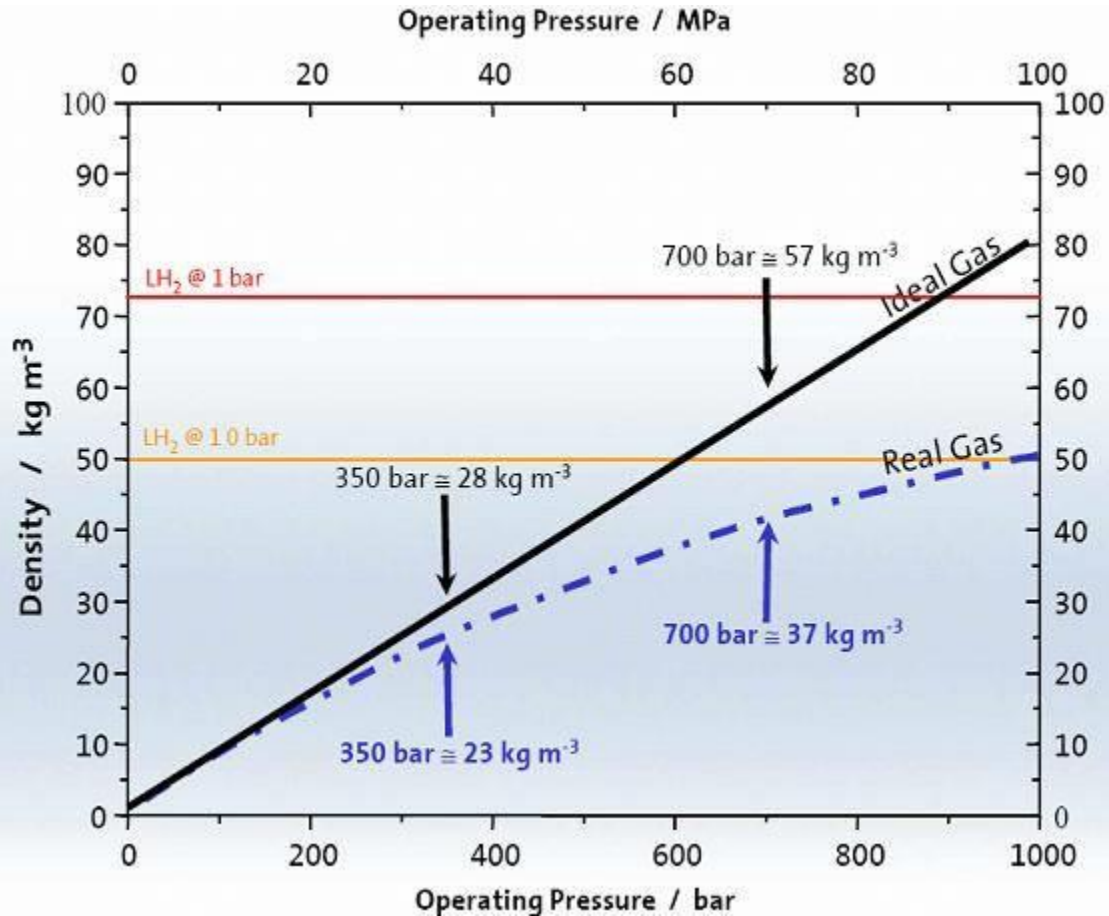


Pressure Vessel Equation (700 bar)



Optimize Geometry

# H2 density



## General Challenge

Low Volumetric Density



Low Heating Value

LH<sub>2</sub> 8.5 MJ / liter

Gasoline 31.7 MJ / liter

Diesel 36 MJ / liter

# Storage in solid materials: an interesting option

## Mean distance between hydrogen molecules

**CGH<sub>2</sub>**

1 bar  
300 K

3.3 nm

$5.6 \times 10^{19}$   
atoms cm<sup>-3</sup>



**CGH<sub>2</sub>**

350 bars  
300 K

0.54 nm

$1.3 \times 10^{22}$   
atoms cm<sup>-3</sup>

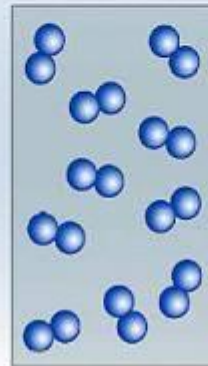


**CGH<sub>2</sub>**

700 bars  
300 K

0.45 nm

$2.3 \times 10^{22}$   
atoms cm<sup>-3</sup>

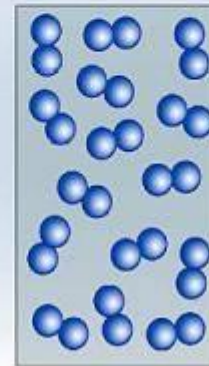


**LH<sub>2</sub>**

1 bar  
20 K

0.36 nm

$4.2 \times 10^{22}$   
atoms cm<sup>-3</sup>

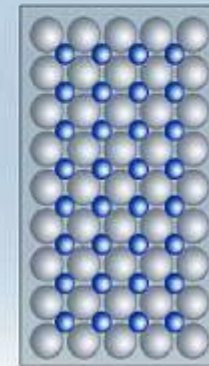


## Mean distance between hydrogen atoms

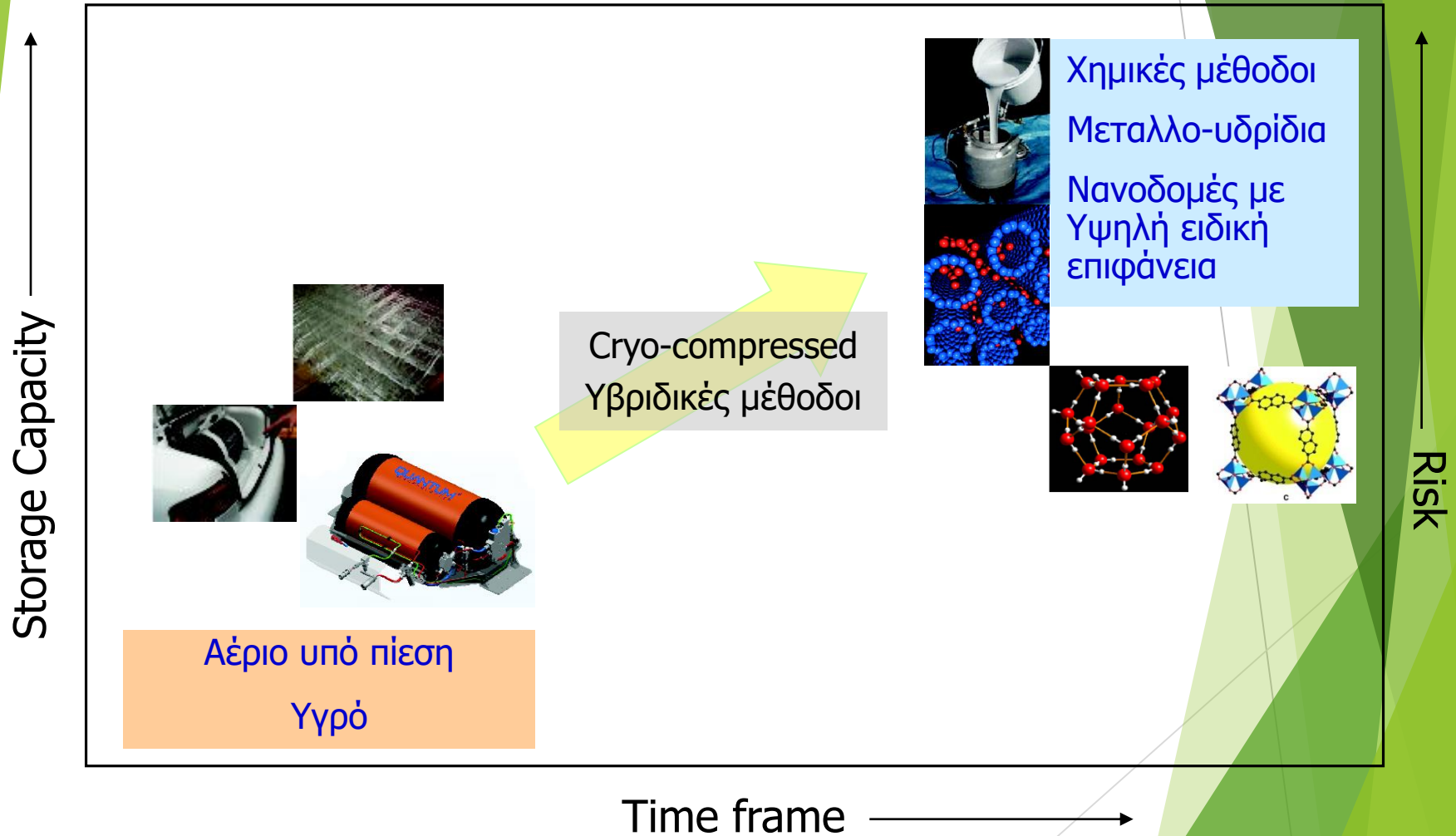
**Conventional  
metal hydrides**

0.21 nm Westlake Criterion

$10.7 \times 10^{22}$   
atoms cm<sup>-3</sup>



# Research Trends



# **HYDROGEN STORAGE IN ROAD VEHICLES**

- Pressures of 200, 350, 700 bar
- Made of composite materials in steel casings
- Material specifications
  - Mechanical durability (Piercing, crashing durability etc)
  - Low weight
  - Zero H<sub>2</sub> permability
  - Efficient thermal behaviour
  - Use of parallel tank configuration
- Pilot application on public transportation vehicles



*Hydrogen tanks used for on- board applications*

## Pros

- Big storage capacity
- Relatively low cost

## Cons

- Safety, especially in transportation applications
- Incapable of working under changing pressure

# H2 TRANSPORT & DISTRIBUTION



eous

# H<sub>2</sub> Large scale underground storage



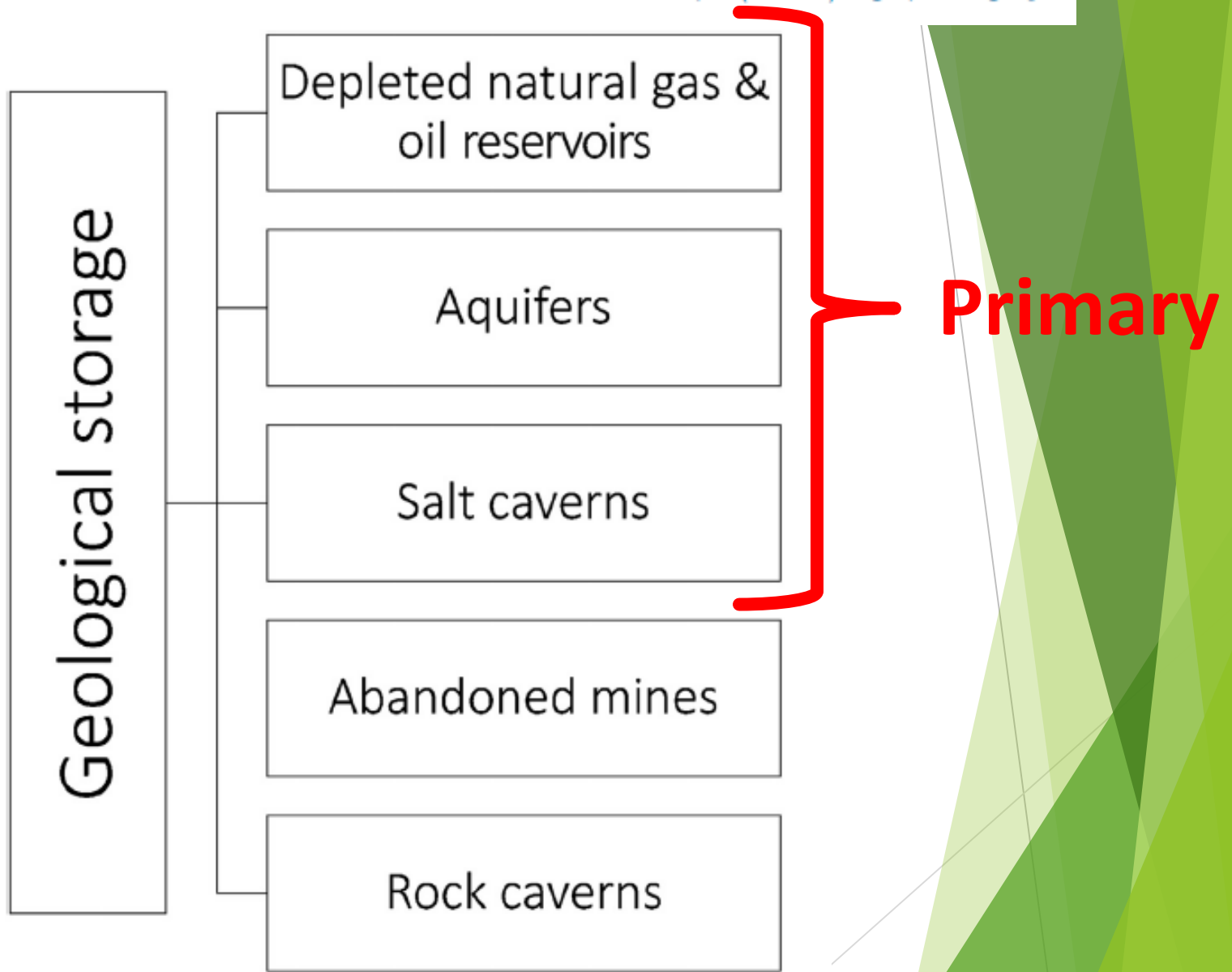


Fig. 9 – A scheme for types of geological storage.

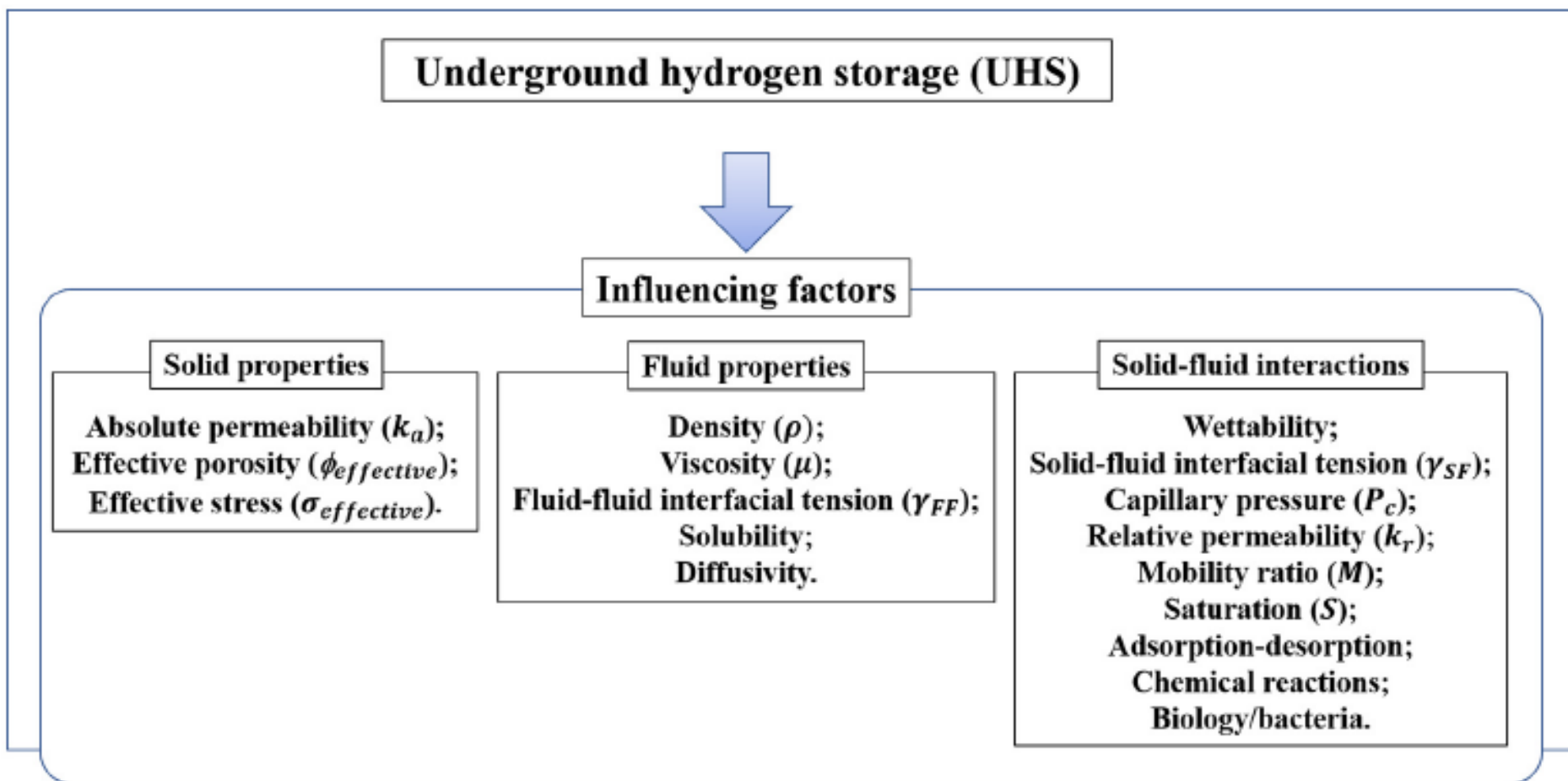


Fig. 1. Multi-scale parameters relevant in underground hydrogen storage.

Injection & production well

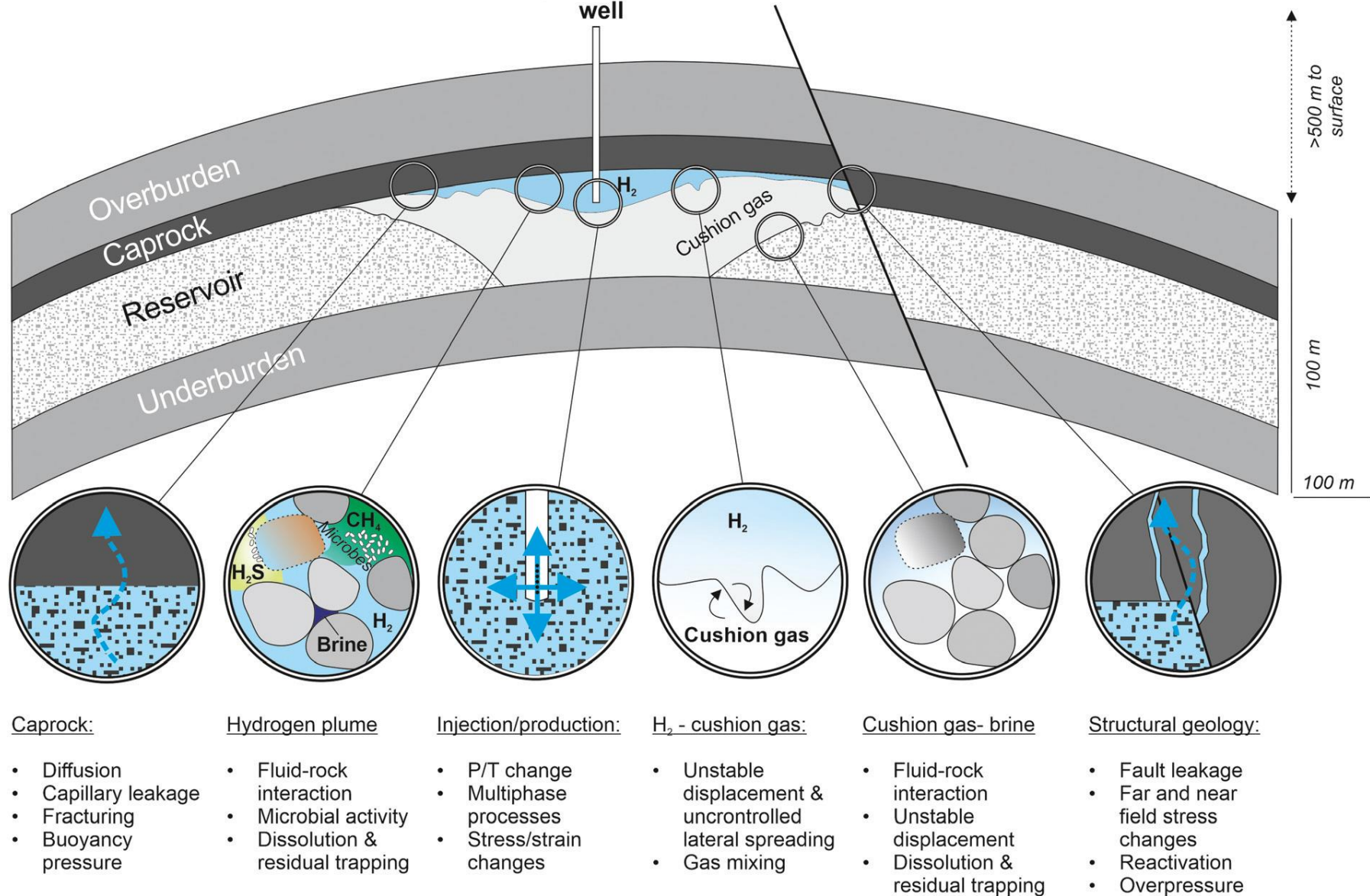
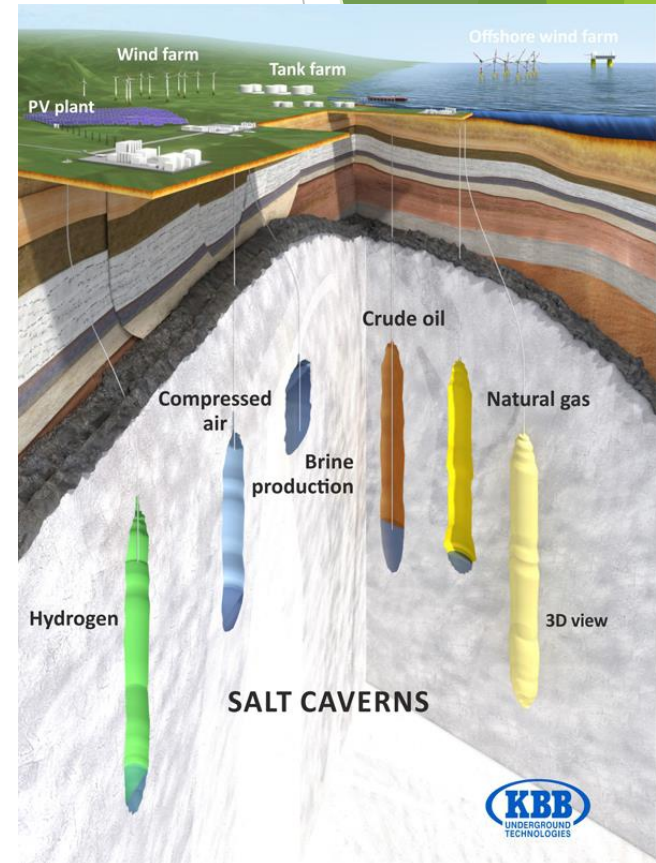


Fig. 2 Hydrogen storage in porous media highlighting all geological uncertainties considered in this paper. Note that both depth, formation thickness and horizontal do not represent scientifically justified ranges but are included to provide an idea of the magnitude of the operations.

# Salt Caverns for Gas Storage

- Used to store gases including hydrogen since the 1950s
- Sites have traditionally been developed after salt extraction by the chlorine industry
- Over 30 caverns in use in the UK today
  - mainly used for NG
  - 1 in use for hydrogen
  - internal wall properties prevent leakage and contamination of the hydrogen
- Lowest cost direct storage mechanism for large hydrogen volumes
- Possibility to use Larne salt caverns for hydrogen storage





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# H2 APPLICATIONS: SAFETY

Typical examples - cases

## Hydrogen safety

- › All fuels (or energy carriers) (like Gasoline, Coal, CNG, LNG, H<sub>2</sub>) have „safety“ issues (otherwise they wouldn't be used as fuels)
- › According to the specific characteristics of each energy carrier, appropriate safety measures are developed
- › Hydrogen is a (light) gas and shares similarities with natural gas
- › The utilization and safety measures for natural gas are well known and may be considered as a good first approximation for the use of hydrogen

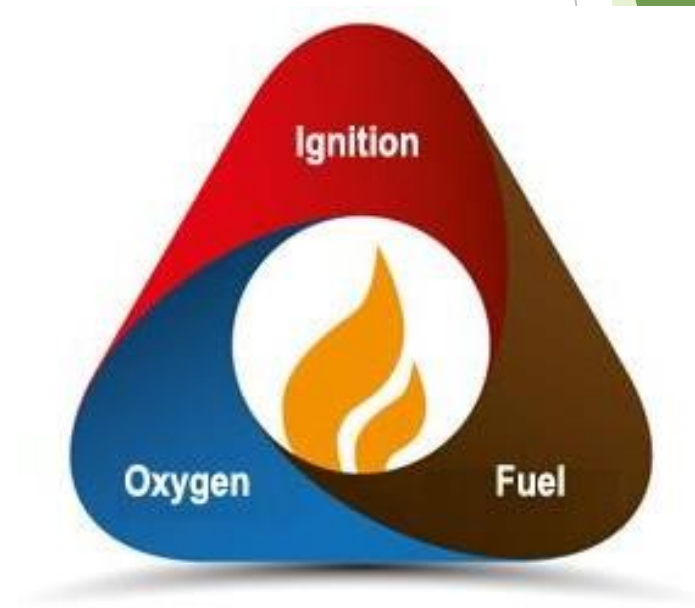
## Hydrogen safety: Basic principle (as in all fuels)

### Explosion conditions

- > Fuel
- > Oxygen
- > Ignition source

All three factors must be present in sufficient quantity for a fire to occur

**Always avoid ignitable mixtures and ignition sources**



Grafik: [www.sentronic.com](http://www.sentronic.com)

# Hydrogen safety: Relevant material data

## Basic principles - hydrogen data

(and for natural gas)

- > Lower and upper concentration limit for the ignition
  - 4 %... 74% (4.1% ... 16.5%)
- > Lower and upper concentration limit for the detonation
  - 13 %... 65%
- > Ignition temperature
  - 560°C (575 ... 640°C)
- > Minimum ignition energy
  - 0.02 mJ (0.28 mJ)
- > Density
  - 0.089 kg/m<sup>3</sup> (air density: 1.225 Kg/m<sup>3</sup>) (0.83 kg/m<sup>3</sup>)

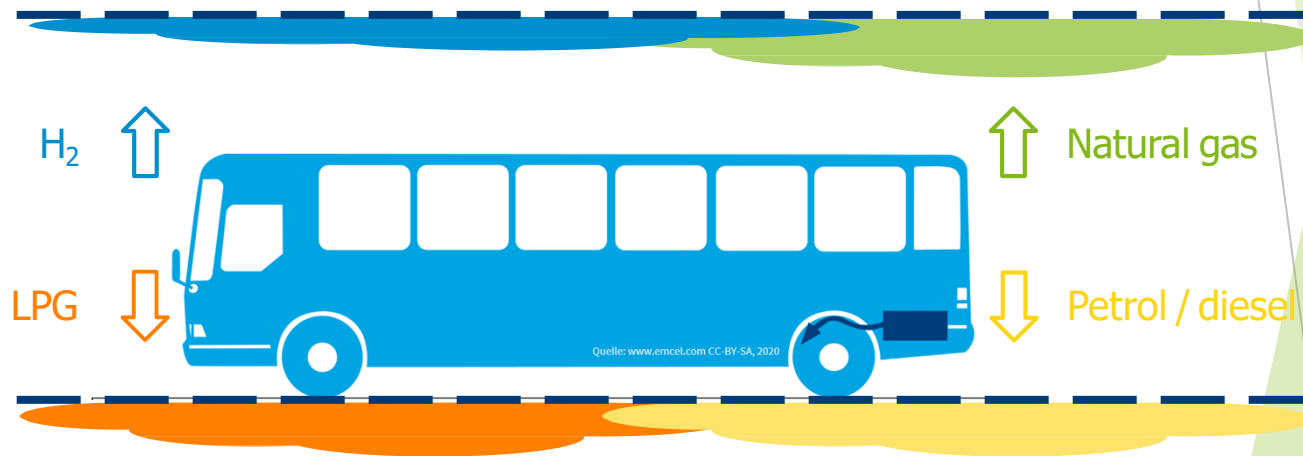


(EC) No. 1272/2008 [CLP]



# Hydrogen Safety

## Fuel density & distribution in the surroundings



# H2 safety compared to other fuels

## A comparison



Fire in petrol engine (15,000 vehicle fires in GER/year) and the hydrogen vehicle (left) with leaking tank.



Tesla after a short circuit while charging at a supercharger.

# Hydrogen safety



# Thought experiment on Hydrogen Safety\*

In your mind, go to your gas cooker, turn the knob and leave the room. What happens?

## LPG

Gas out of the hob.  
Denser than air so drops on top of the floor.  
Builds up a mixture of gas and air on the floor till about 2 feet deep.  
Spark in the back of the fridge.  
Boom - Bye Bye kitchen.

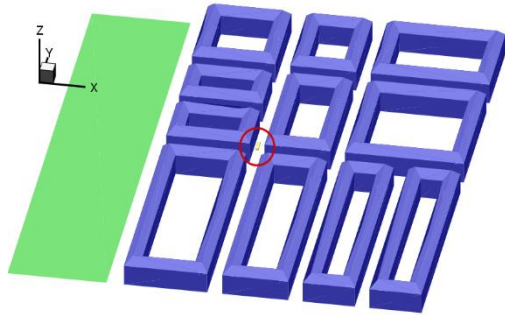
## Hydrogen

Gas out of the hob.  
Rises at a speed of about 67 km/h.  
Hits ceiling finds a crack and escapes through the roof.  
Does not build up a mixture of H<sub>2</sub> and air.  
Without hermetically sealing the room you cannot build this explosive mixture.  
Generally, H<sub>2</sub> is not very suitable to create explosive mixture which will then ignite.

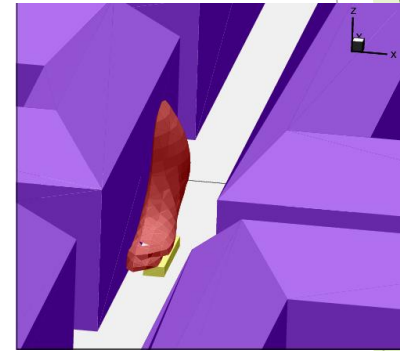
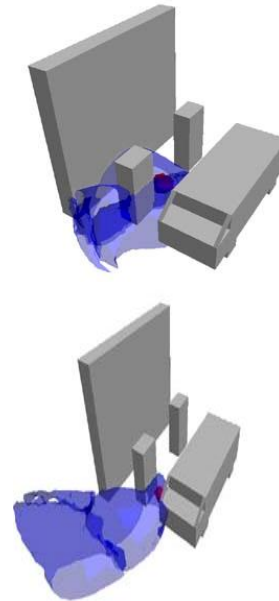
\*adapted from Dr. Ch. Dunnill, Swansea Univ., UK

# Simulation Tools: Storage Systems & Safety Studies

## Safety analysis of hydrogen used as a fuel for vehicles



The 1983 Stockholm H<sub>2</sub> accident.  
Modeled site and truck carrying 4 kg  
of H<sub>2</sub> in 18x200 lt, 200 bar bottles



The 1983 Stockholm H<sub>2</sub> accident  
predicted lower flammability H<sub>2</sub>-air  
cloud for 10 seconds after start of  
accident.



HyApproval

# Hydrogen Safety: Summary

## Summary

- > Safe operation (as for other fuels) with hydrogen is possible
- > Synergies / similarities between natural gas and H<sub>2</sub>
- > Set-up / installation of components in rooms is technically possible and can be safe
- > Adapt safety concept according to the application – cost-effective solutions are possible



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# HYDROGEN REFUELLING STATIONS (HRS)

Hydrogen Refueling Stations (HRS) - EU

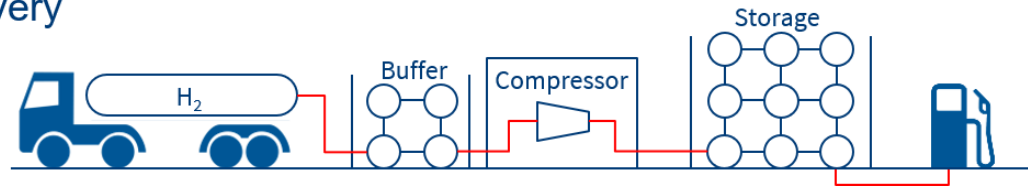
Typical Sub-systems HRS

Pilot Integrated Station H2 - NCSR

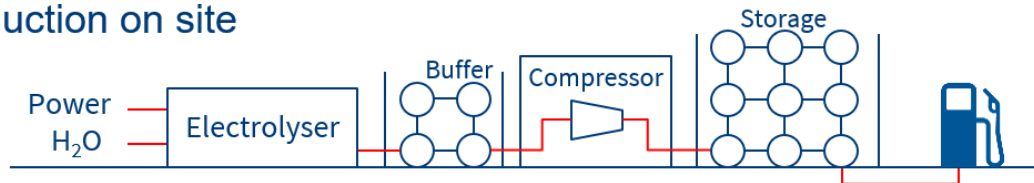
# Hydrogen Refueling Stations

## Hydrogen supply for refueling stations

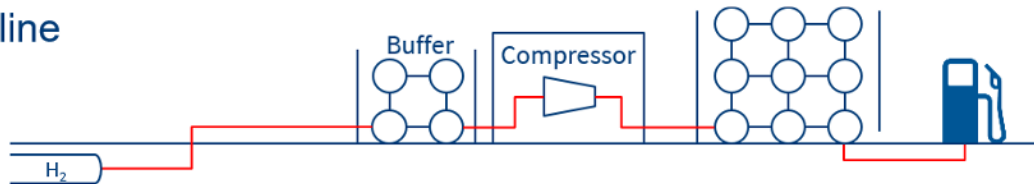
Delivery



Production on site



Pipeline



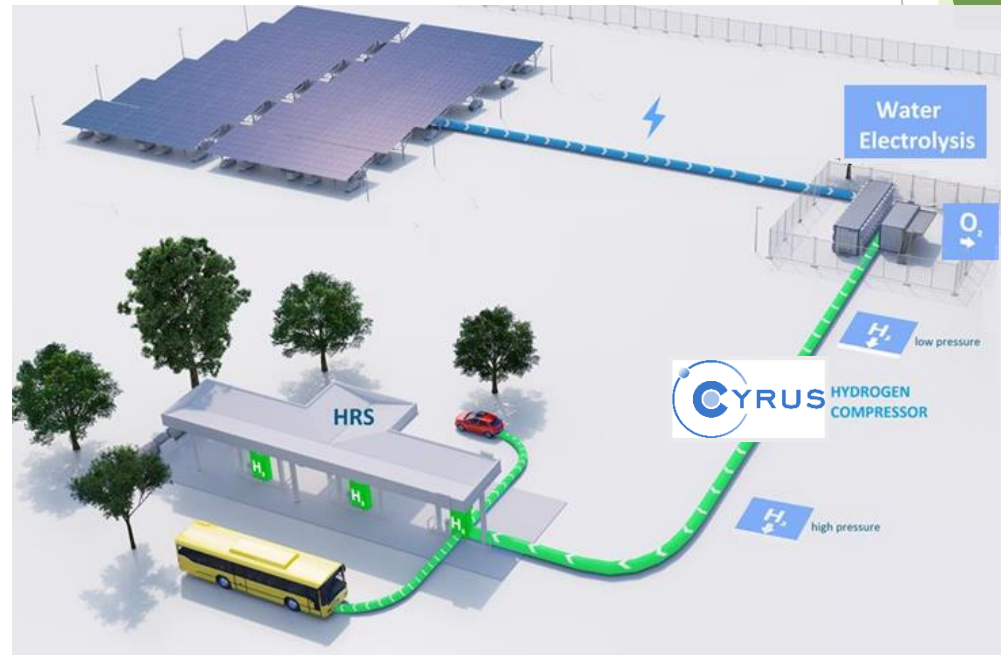
# THE H2TRANS PROJECT

## H2TRANS main goal

Developing the first hydrogen refueling station in Greece and demonstrating hydrogen-powered vehicles

## Parties involved:

- NSCR Demokritos
- NEEST
- ELFON
- XANTHIS
- CITIPOST



This work is co-financed by the European Regional Development Fund of the EU and Greek national funds under the call RESEARCH – CREATE – INNOVATE (project H2TRANS T1EDK-05294).

## H2 stations in operation



*H2 stations in operation in Europe*

- **432 stations in operation worldwide and another 226 are being planned.**
- **177 stations in Europe with the majority in Germany, and the rest distributed throughout central Europe.**
- **Most notable manufacturers include Shell, Total and Air Liquide**
- **Different layouts are being tried**

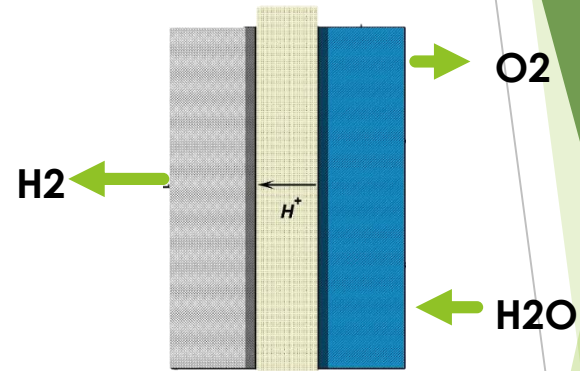
# The 4 subsystems



PV System



H2 Vehicles



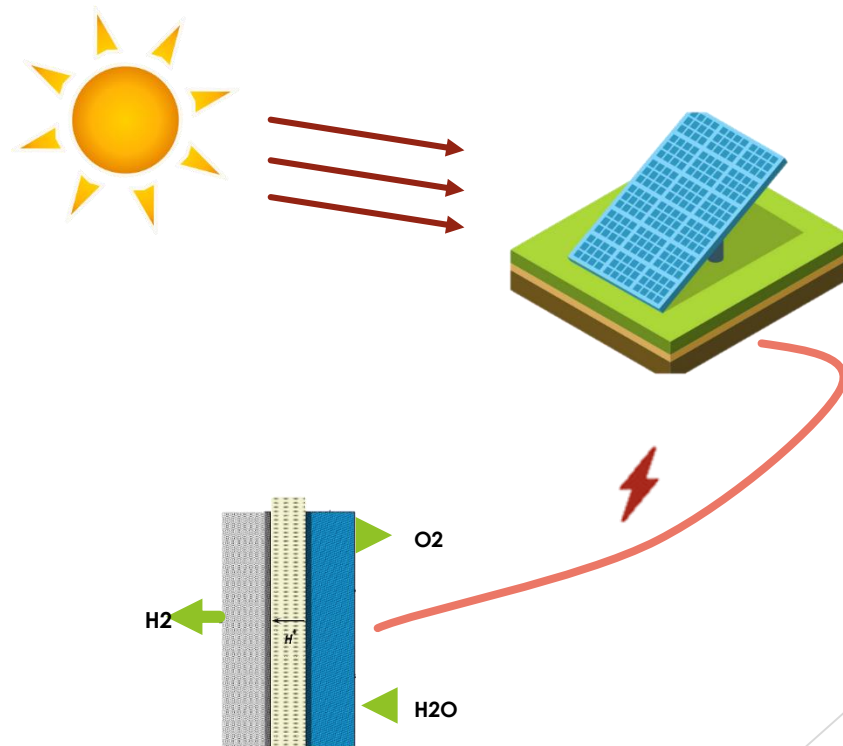
PEM Electrolysis Unit



H2 Storage and compression

## Photovoltaic System

- In order to improve the sustainability of the installation, the use of renewable energy sources is inevitable
- This ensures the minimization of CO<sub>2</sub> emissions of the system
- For the purposes of the project the installed power will be 20kWp

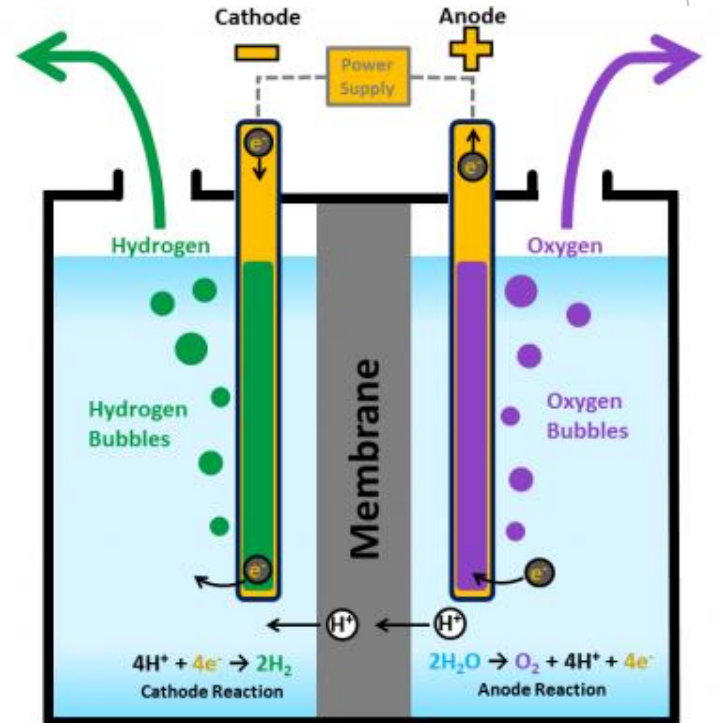


# Hydrogen production system

- **Electrolysis unit is powered by DC current produced by solar panels**
- **PEM Electrolyzers use a solid polymer electrolyte for conducting protons from the anode to the cathode**

## Working Principle of PEM Electrolysis:

1. Water at the anode reacts to form oxygen and positively charged H<sup>+</sup> ions which can pass through the membrane
2. Electrons flow via an external circuit
3. H<sup>+</sup> ions combine with electrons of the external circuit to form H<sub>2</sub> gas.



*Working of PEM electrolysis*

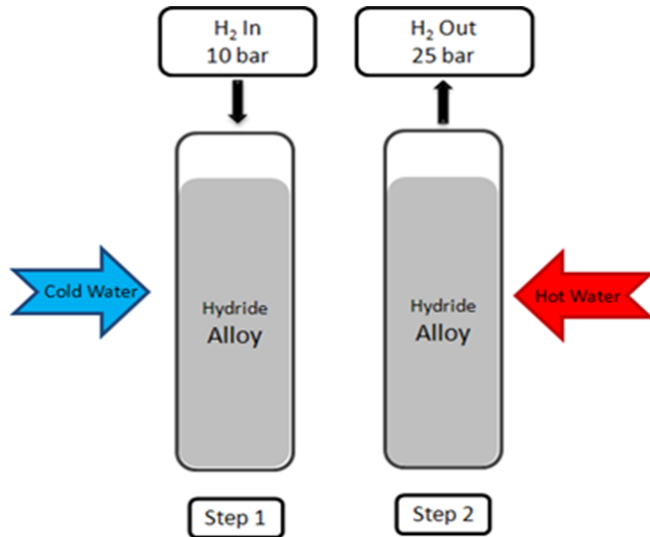
## H2 storage system

- Different approaches: Gaseous, Liquid, Chemical storage
- H2TRANS utilizes storage in gaseous form
- Need for compression in order to store larger quantity in given volume
- By compressing H2 :
  - **increased density**
  - **minimized volume**
- Storage at 200 bar in stainless steel tanks
- Total station capacity: 120 Nm<sup>3</sup> (12 tanks of 10 Nm<sup>3</sup>)



*Hydrogen in gaseous form storage tanks*

# Compression system

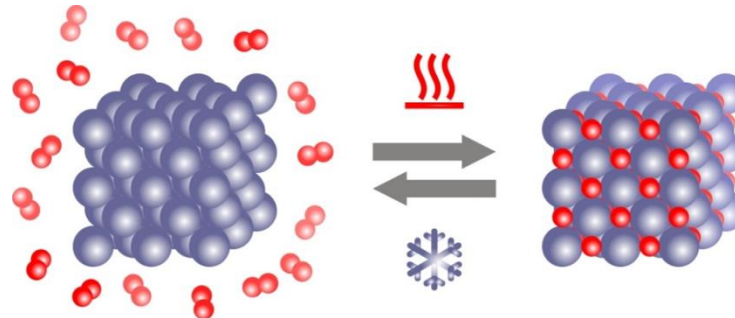


## Thermal Compression

- Utilizing metal hydrides (MH) which store hydrogen chemically
- MH store hydrogen at low temperature & pressure
- MH release stored hydrogen when heated
- Energy needs minimized when there is external flux of heat such as waste heat
- Outlet pressure: 200 bar

## Metal Hydride Compressor

- No moving parts (low OPEX)
- Low noise
- Ideal for residential areas



*Metal Hydride principle of operation*

## Hydrogen powered Vehicles

- The FCEVs will be implemented by transforming electrical vehicles in a way that they can use fc for powering their electrical motor.
- Transformed vehicles include a scooter and a golf cart
- Compatibility of the fuel cell which will replace the battery, with the electric motor must be ensured
- Vehicles will have on board light weight 200 bar tank
- An ultra capacitor will be installed on board as well ensuring better response of the system
- Vehicles will also have a register and visualization system for monitoring the key performance indicators



*Electrical vehicles suitable for fuel cell transformation*

# Hydrogen Refueling Station



The Hydrogen Refueling Station (HRS) for small vehicles has already been developed at the premises of NCSR DEMOKRITOS (containerized solution)



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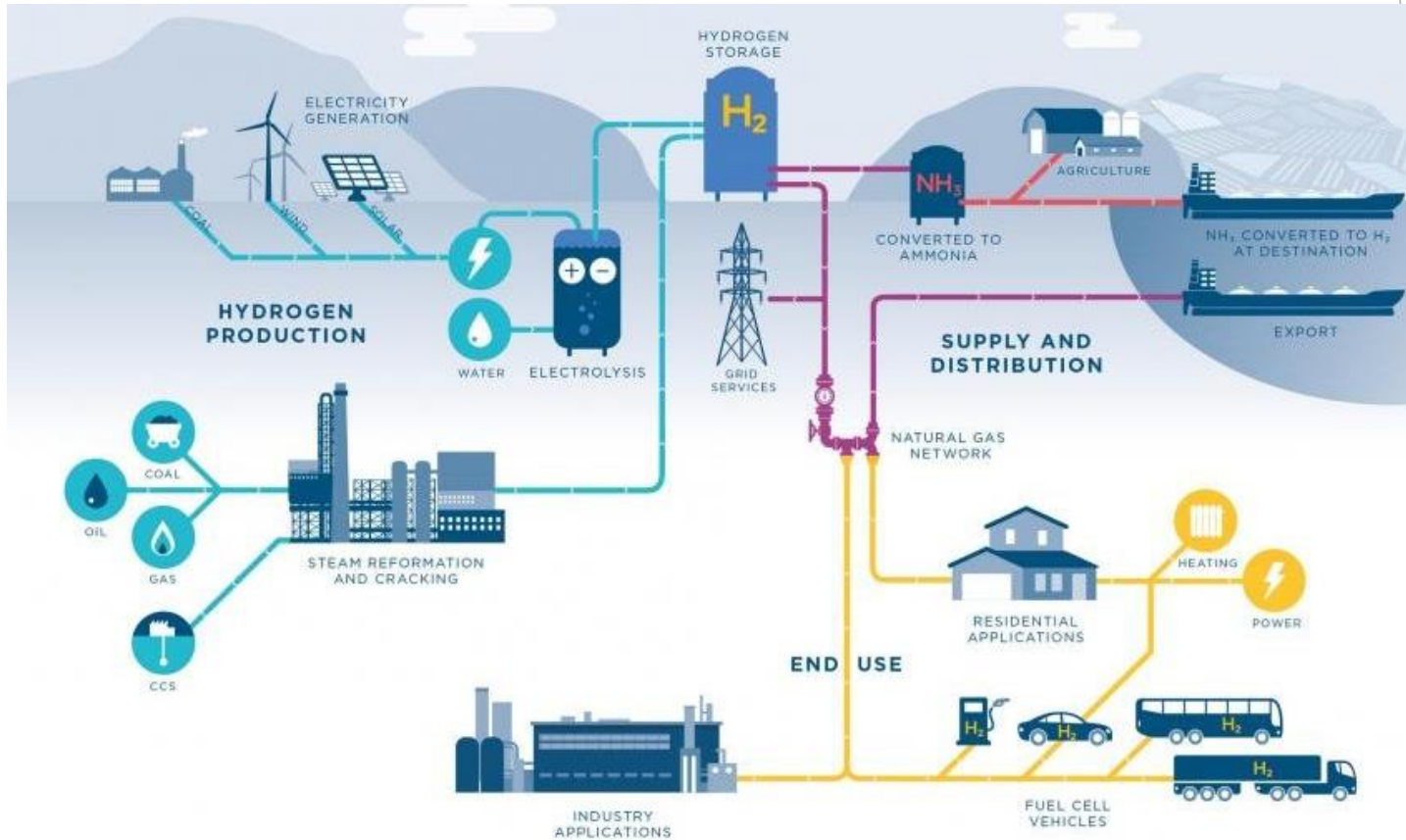
# H2 APPLICATIONS & USE IN VARIOUS SECTORS

Transport (Light & Heavy Duty Vehicles, Ships,  
Trains...)

Industry (Hard to Abate Sectors)

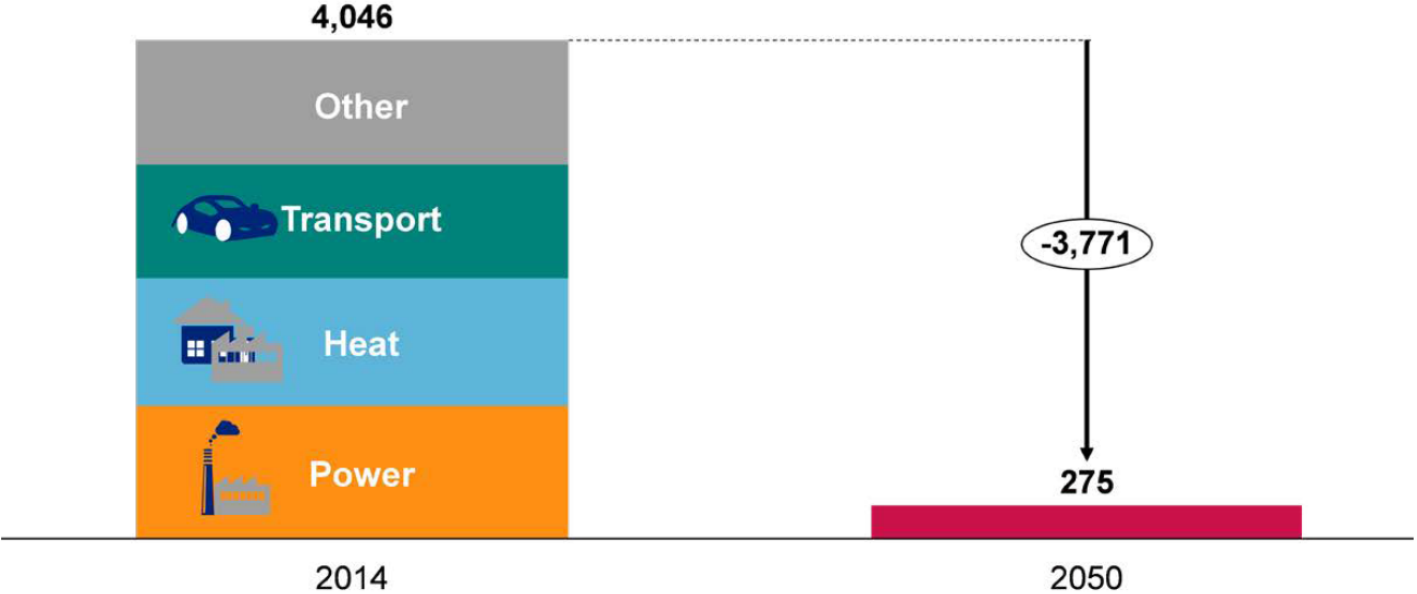
Fuel Cells - Use in ICEs

# From H2 Production towards an H2 Ecosystem



# Intensification of effort is needed

FIGURE 1 – THE SCALE OF EUROPE’S DECARBONISATION PROBLEM (MtCO<sub>2</sub>e)



Source: 2016 National Inventory Submissions (Common Reporting Format) for EU, Norway and Switzerland.

Source: Poyry point of view, fully decarbonising europe's energy system by 2050, May 2018

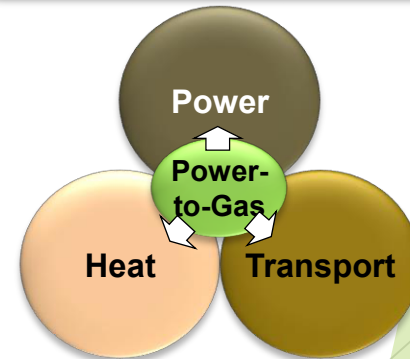
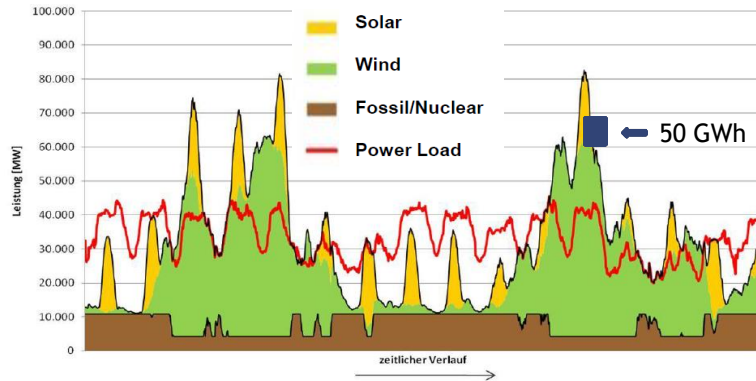
# Power-to-Gas

## From electric energy to gaseous fuels

Integration of  
renewables

Storage

Power-to-X:  
Sector Coupling



Source: BTU Cottbus, innogy

# Hydrogen is key for the unification of the energy sector

Enable the renewable energy system → Decarbonize end uses

Enable **large-scale renewables integration** and **power generation**



**Distribute** energy across sectors and regions



Act as a **buffer** to increase system resilience



Help decarbonize **transportation**



Help decarbonize **industrial energy use**

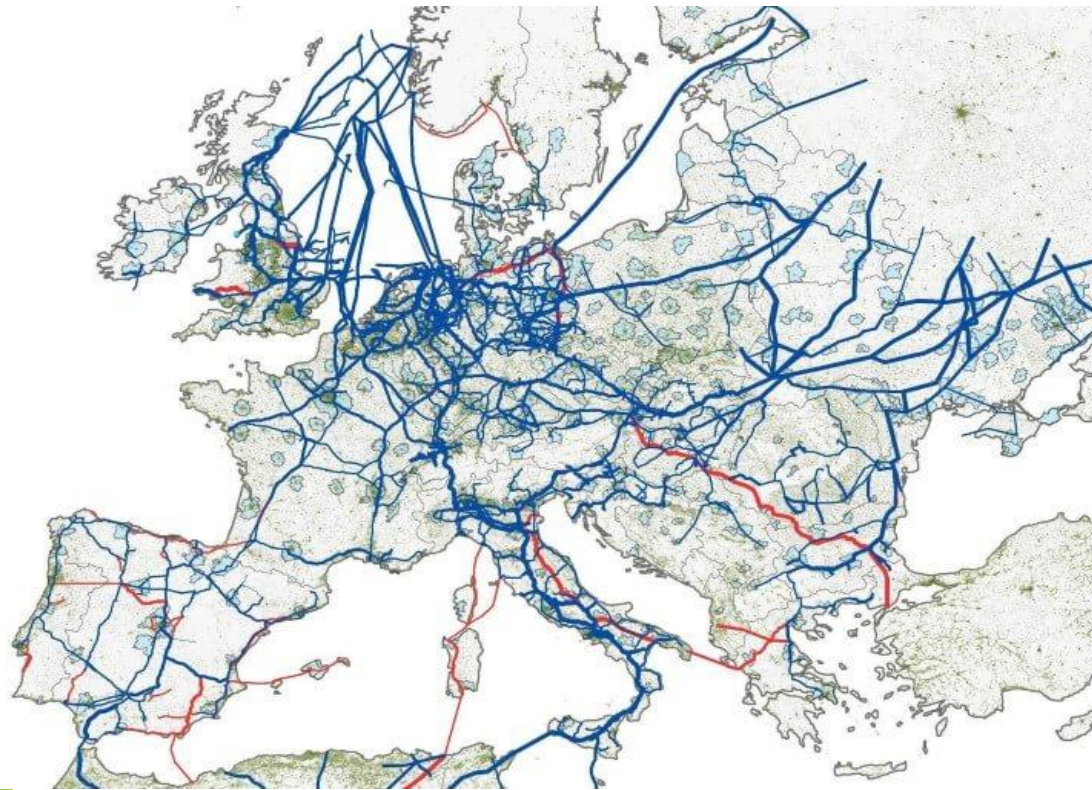


Help decarbonize **building heat and power**



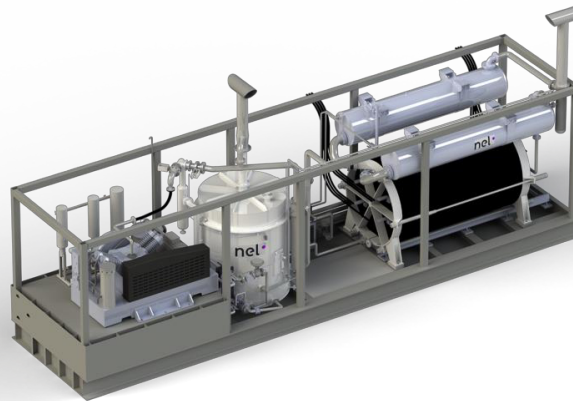
Serve as renewable **feedstock**

# Gas network / pipelines: A basis for carbon independence processes in energy



Opening the market via a series of appropriate initiatives

## A “coalition” needed for 40 GW Electrolysers!



Europe is among the world leaders in this technology!

# EU Regulatory Framework: Fit for 55

## **European climate law sets the reduction targets for net greenhouse gas emissions**

- > Ultimate goal: climate-neutrality by 2050
- > Intermediate goal: reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels

## **Fit for 55**

- > Proposals to revise and update EU legislation
- > Framework for achieving the climate targets
- New cars and vans on the market as of 2035 should have zero-emissions. Creation of a new, separate emissions trading system for road transport and building sectors
- Hydrogen filling stations on main roads at least every 200 km (end of 2030) – denser network expected in urban areas

## EU Regulatory Framework: AFID - Alternative Fuels Infrastructure Directive

- › Adopted in 2014, on the development of alternative fuels' infrastructure in Europe for transport networks
- › Implementation of AFID at the federal level (poor results)

### AFIR<sup>1</sup> (Regulation) proposed in July 2021

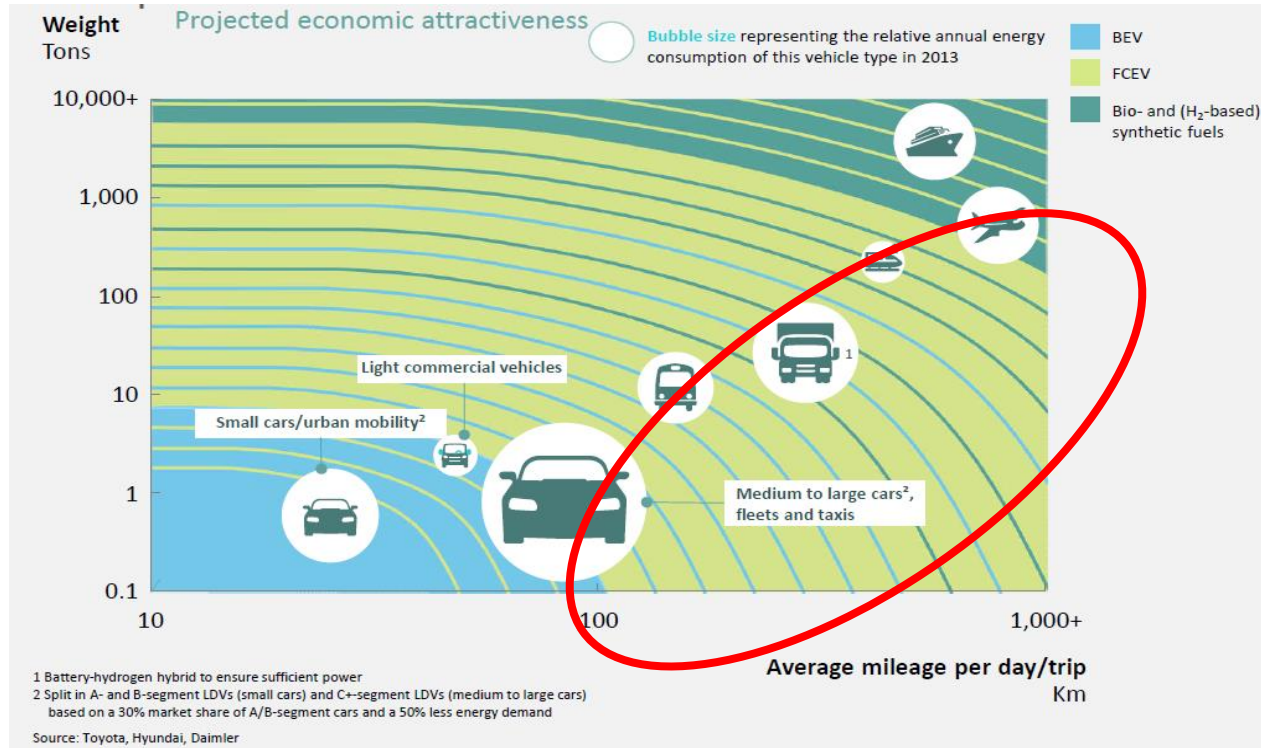
TEN-T-comprehensive network & TEN-T-core network until 2030:

- › Hydrogen dispensers (700 bar): max. 150 km distance in both driving directions
- › Hydrogen dispensers for liquid hydrogen: max. 450 km distance in both driving directions







<sup>1</sup> On 19 October, the European Parliament adopted in plenary session its position on the Alternative Fuels Infrastructure regulation (AFIR) proposal

# Hydrogen for transportation / car industry



Source: H2 Council

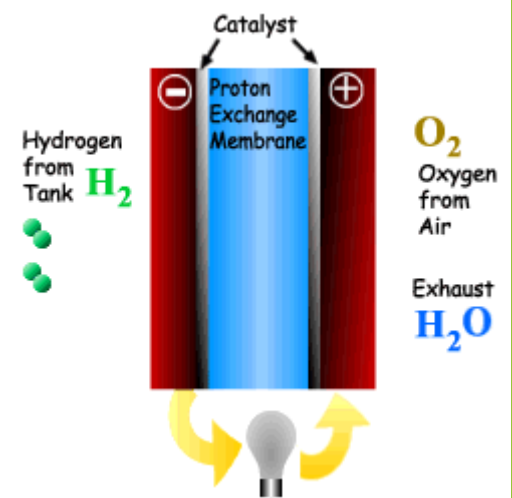
# The FC-Vehicle market: Overview

Type	Passenger car	Bus	LD-Truck	HD-Truck	Garbage truck	Forklift
Range [km]	400 – 650	Ca. 400	Ca. 400	Ca. 400 (– 1200)	Ca. 500	Ca. 6 h
Pressure [bar]	700	350	700	350/700 (liquid)	350 / 700	350
Fuel capacity [kg]	4 – 6	35 – 40	4 - 5	> 35	10-20	1,5 - 2
Fueling time [min]	3 – 5	Ca. 10	3 – 5	Ca. 10	Ca. 10	< 3
Fuel consumption [kg/100km]	Ca. 1	6 – 10	1 – 1,5	7 – 10	7 - 10	0,3 kg/h
						

source: [www.faun.com](http://www.faun.com), 2020; [www.still.de](http://www.still.de), 2020; Hyundai, 2020; Toyota, 2020; [www.auto-motor-und-sport.de](http://www.auto-motor-und-sport.de)

# Fuel Cells

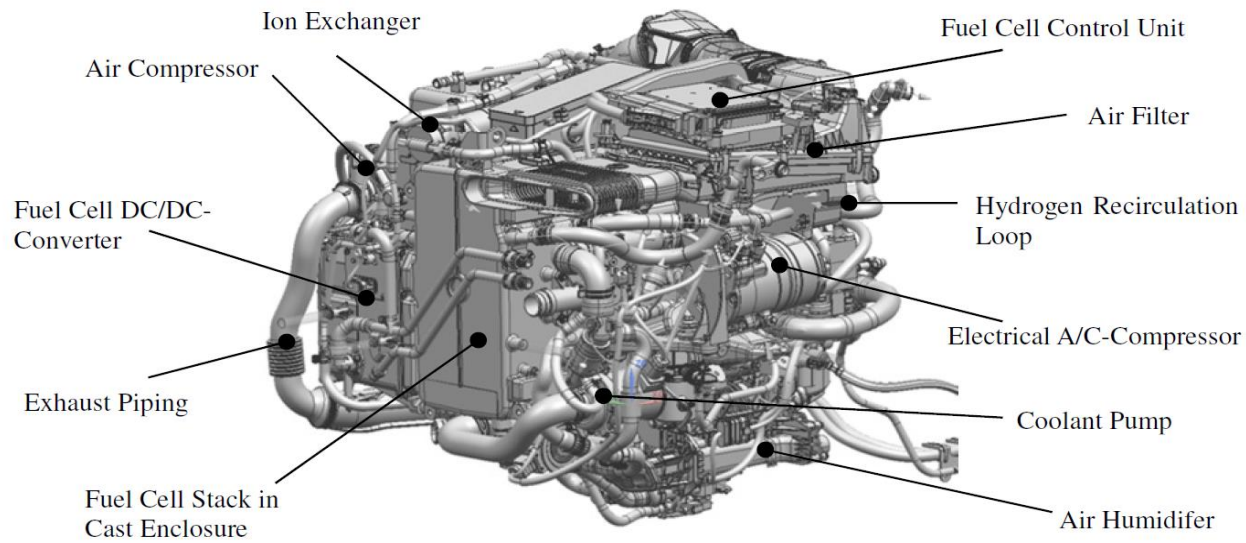
- Electrochemical Equipment operating similar to Batteries
- Consume Hydrogen and Oxygen to produce:
  - Electrical Energy
  - Heat
  - Water
- They are not RES, but a conversion equipment for power which has been stored in the form of a fuel (Hydrogen, Methane, Natural Gas, Methanol)
- Capital Cost between € 2,000 – € 5,000 / kW
- When the fuel is “green” hydrogen, the only emission is water
- When hydrocarbons are used FCs emit CO<sub>2</sub> but in significantly lower quantities compared to ICEs (ca. 1kg CO<sub>2</sub> per m<sup>3</sup> H<sub>2</sub>)



The electrolyte: special polymer or similar material, allowing ions to pass through it, but is not permeable from electrons

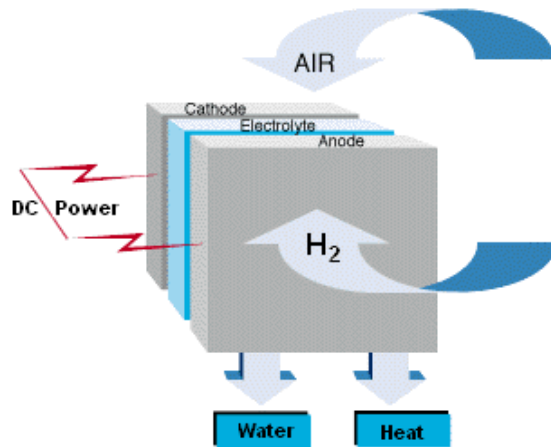


# Fuel cells may keep the value chain in Europe!



Source: Daimler

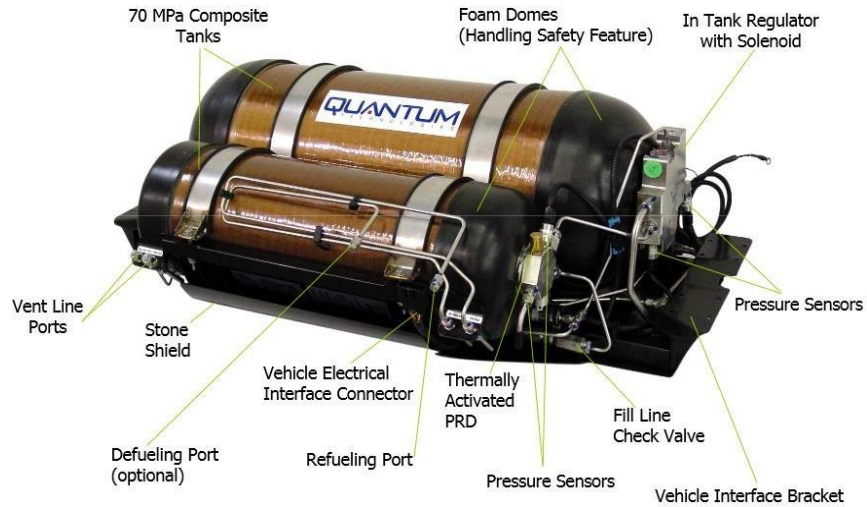
# Fuel cells in vehicles



- Reversed process of electrolysis. Here hydrogen reacts with oxygen to produce electricity and water
- Electricity is then used to power an electric motor
- FCEVs\* are essentially electric vehicles
- FCEVs and BEVs\*\* are not always competing technologies
- FCEVs can be considered complementary to BEVs

# Fuel Cell Vehicles: Types of hydrogen tanks

## Compressed hydrogen gas container assembly



Source: Quantum

## Type 3 tank



# WHAT IS A FUEL CELL VEHICLE (FCEV)?

An EV drive train that's refuelled rather than recharged

- Refuel in 3 mins
- Range >300 miles



**POWER CONTROL UNIT**  
Manages the fuel cell stack and battery.



**MOTOR**  
Runs on electricity from the fuel stack and the battery.

**FUEL CELL STACK**  
Generates electricity from hydrogen fuel.

**HYDROGEN TANK**  
Stores hydrogen fuel under high pressure.

**BATTERY**  
Stores energy from deceleration.

Image by Toyota

FUEL CELL VEHICLES  
ENERGY STORAGE | CLEAN FUEL



# TOYOTA MIRAI



First mass produced  
FCEV



ΜΗΔΕΝΙΚΕΣ ΕΚΠΟΜΠΕΣ ΡΥΠΩΝ



ΣΥΝΟΛΙΚΟΣ ΧΡΟΝΟΣ ΓΕΜΙΣΜΑΤΟΣ

3 ΛΕΠΤΑ



ΑΠΟΣΤΑΣΗ ΑΝΑ ΓΕΜΙΣΜΑ

500 ΧΙΛΙΟΜΕΤΡΑ

# EARLY MARKETS- SPECIAL TRANSPORTATION APPLICATIONS



*Fuel cell powered forklift*

- An early market for hydrogen vehicles is the forklift market
- Already entered the market by being used in warehouses, ports and industrial zones
- Value proposition of productivity gains
- In order for hydrogen to get traction in different segments there are several alternative routes

# The case of Fuel Cell Buses

## Advantages

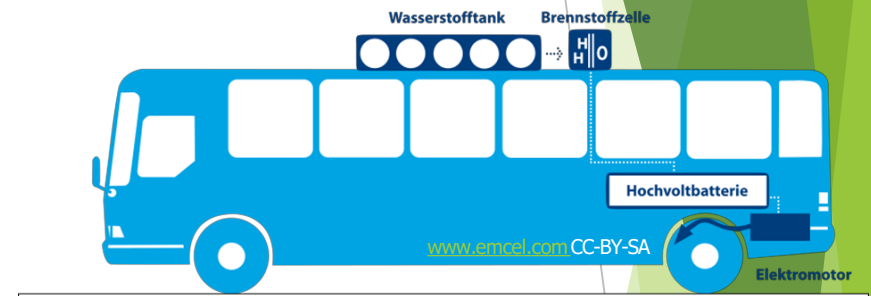
- + Approx. 400 km range and short refueling times
- + Route planning as for diesel buses
- + Flexible to use
- + No local emissions, low global emissions

## Disadvantages

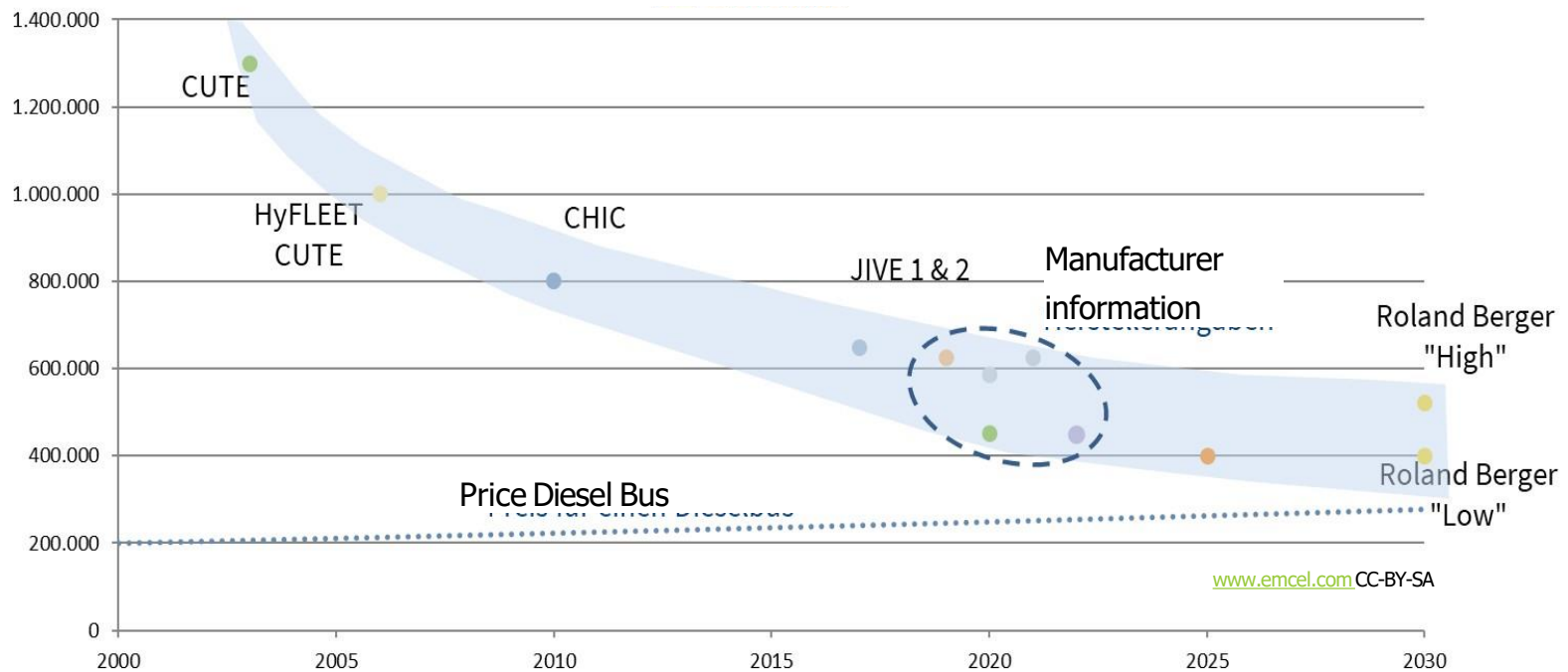
- Acquisition costs (as of today)
- Establishment of own hydrogen infrastructure (start-up costs)

## Consequence / possible solution

- > Shared use of hydrogen refueling stations, also public
- > Hydrogen filling station in operator mode



# The FC-Bus market: 20 years of proven technology



# Buses: A flexible competitive clean solution

Europe is world leader



## Achieved

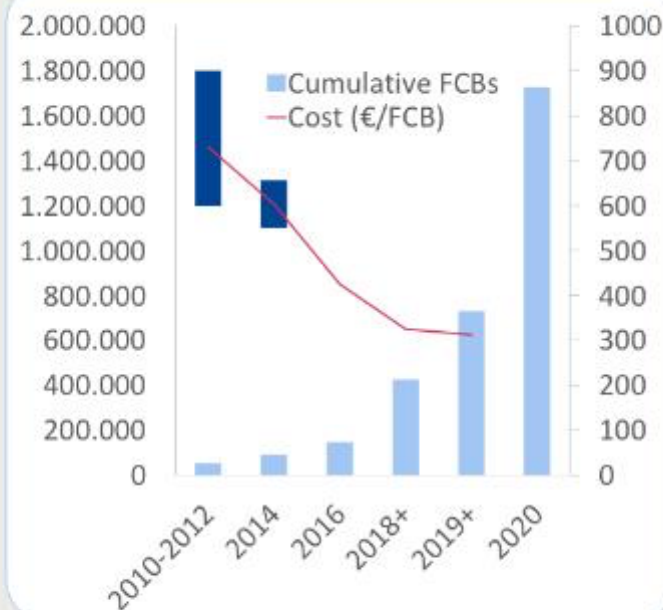
- >5,000,000 km driven since projects started
- > 300,000 h of operation
- >159 tn of H<sub>2</sub> consumed only in 2016

## Pre-commercialisation phase

- 25,000 h lifetime reached
- Availability proven but with teething problems
- 650,000 €/bus offered
- Average 9.86 kg/100km (very dependent on city)

## Challenges

- Mature supply chain to ensure availability
- Continue reducing the price of the bus
- European fuel cell supplier



# The case of Fuel Cell Trucks

## Advantages

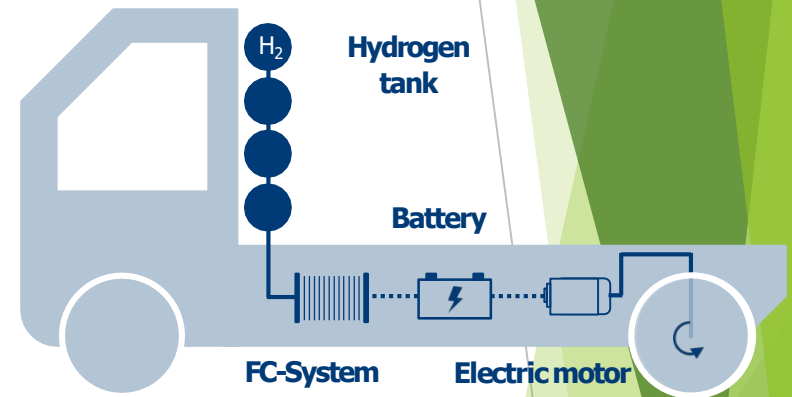
- + Approx. 600 km range and short refuelling times
- + Flexible use
- + No local emissions, low global emissions

## Disadvantages

- Acquisition costs (as of today)
- Establishment of hydrogen infrastructure necessary (start-up costs)

## Consequence / possible solution

- > Shared use of hydrogen refueling stations, also public
- > Hydrogen filling station in operator mode



# Fuel Cell Vehicles: H<sub>2</sub> ICE

## Advantages

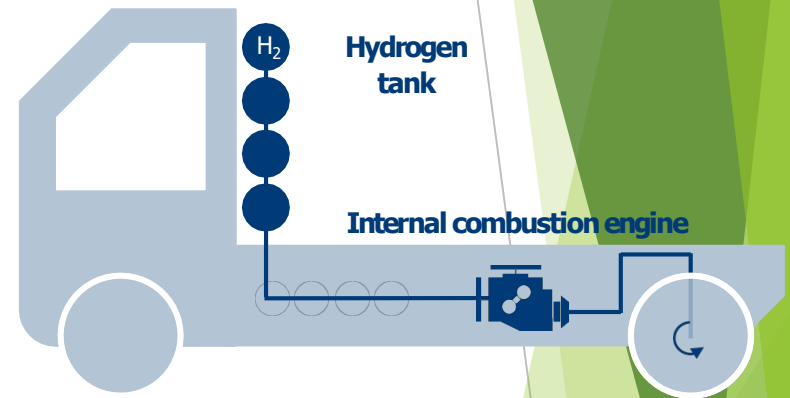
- + Approx. 450 km range and short refuelling times
- + Known engine technology
- + Vehicle investment costs could be lower than FC truck (short term)

## Disadvantages

- Higher operating costs than fuel cell
- Noise (possibly louder than trucks with electric drive)
- Possible NO<sub>x</sub> emissions (however lower than diesel engines)

## Consequence / possible solution

- > Adaptation in workshop necessary
- > Vehicles still in development / testing phase



# Hydrogen Trains

World premiere: Alstom's hydrogen trains enter passenger service in Lower Saxony



"This is a revolution for [@Alstom](#) and for the [#FutureOfMobility](#).

The world's first [#hydrogen #fuelcell](#) train is entering passenger service and is ready for serial production" emphasises Henri Poupart-Lafarge, Chairman & CEO of Alstom

16 September 2018

Switzerland: 1000 hydrogen trucks ordered for the 5 coming years



## Hydrogen vehicles available in the market



Renault HyKangoo: 300 km range, plug-in-battery with 5 kW range extender, ca. 200 pcs



Toyota Mirai: 650 km range, market introduction in Japan in 2015, > 4,000 pcs by now



Hyundai NEXO, 800 km range  
Hyundai ix 35: 600 km range, 300 pcs in Europe



Mercedes GLC: starting 2019, fuel cell with plug-in-battery, 500 km range (50 km by battery)

# Hydrogen buses / trains



## FC bus hotspot at RVK Cologne

- Today: 16 FC buses in Germany in operation, 80 in Europe
- Additional 140 FC via EU project JIVE and 150 via JIVE 2 by 2020/21
- “JIVE hotspot” NRW: Cologne (45) and Wuppertal (20)

Source: RVK



## Prototype of Alstom FC train

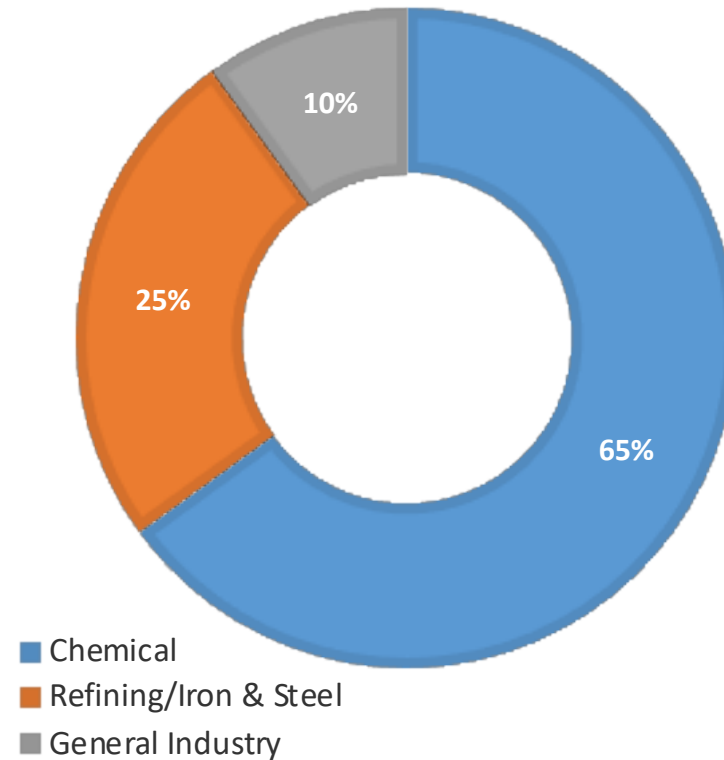
- About 100 FC trains in Germany by 2021 on non-electrified railway tracks
- CO<sub>2</sub> mitigation: 40 % (H<sub>2</sub> from natural gas compared with diesel)
- Suppliers from NRW
- Application of FC trains in NRW under preparation

Source: Alstom

# HYDROGEN DEMAND BY INDUSTRY

INDUSTRY SECTOR	KEY APPLICATIONS
CHEMICAL	<ul style="list-style-type: none"><li>• Ammonia</li><li>• Polymers</li><li>• Resins</li></ul>
REFINING	<ul style="list-style-type: none"><li>• Hydrocracking</li><li>• Hydrotreating</li></ul>
IRON & STEEL	<ul style="list-style-type: none"><li>• Annealing</li><li>• Blanketing gas</li><li>• Forming gas</li></ul>
GENERAL INDUSTRY	<ul style="list-style-type: none"><li>• Semiconductor</li><li>• Propellant fuel</li><li>• Glass production</li><li>• Hydrogenation of fats</li><li>• Cooling of generators</li></ul>

H2 Demand By Sector



# Green Steel - role of EU

The EU evolved starting with coal and steel

European Coal and Steel Community	Treaty of Rome	Treaty of Maastricht	„Green Steel“ redefines Europe’s global role
-----------------------------------	----------------	----------------------	--

1951



1957



1992



2020?





NEEST

NEW ENERGY & ENVIRONMENTAL  
SOLUTIONS AND TECHNOLOGIES

# TETHYS WEBINAR - GREEN HYDROGEN PRODUCTION

Dr. Manos Zoulias

Dr. Athanasios Stubos

Dr. Emmanuel Stamatakis

# MAJOR ISSUES FOR A WIDE MARKET DEPLOYMENT OF H2

## The Infrastructures Issue

Intl. Cooperation - Legal Framework

Regulations, Codes & Standards (RCS)

# UNDERSTANDING RISKS AND OVERCOMING BARRIERS

## Main issues to be addressed

- Fuel and refuelling infrastructure: Location and accessibility of site and fuel supply. Security of fuel source.
  - Vehicle supply: Currently few commercial models exist and slightly more variants of buses and trucks
  - Cost competitiveness: Driven by the limited number of suppliers currently manufacturing FCEVs. Costs are expected to be lowered as more manufacturers enter the market
- In transport, the competitiveness of hydrogen fuel cell cars depends on fuel cell costs and refuelling stations while for trucks the priority is to reduce the delivered price of hydrogen. Shipping and aviation have limited low-carbon fuel options available and represent an opportunity for hydrogen-based fuels.

# Hydrogen as Energy Carrier

- All components of the technology (Hydrogen & Fuel Cells) exist.
- Further R&D priorities related to H2 include issues in production, storage and distribution, compression...
- The issue of infrastructures remains open...



# Hydrogen Fueling and Electric Charging of Vehicles in Germany

2018, JULY, 12<sup>TH</sup> | JOCHEN LINSSEN, MARTIN ROBINIUS, THOMAS GRUBE,  
MARKUS REUSS, PETER STENZEL, KONSTANTINOS  
SYRNANIDIS, DETLEF STOLTEN

6<sup>th</sup> Hellenic Forum for Science Technology and Innovation, Athens Greece

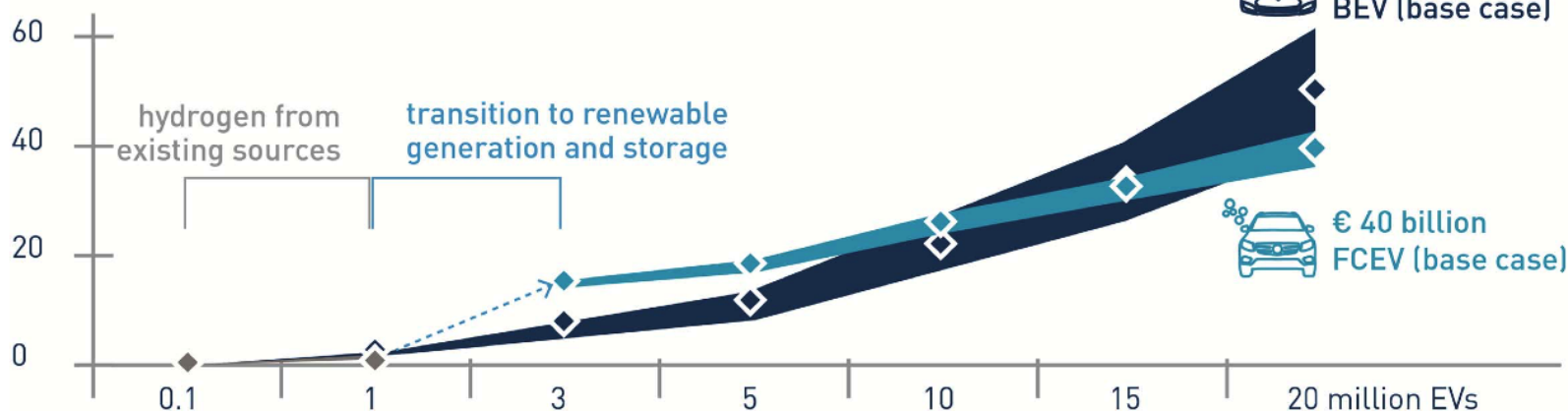
[j.linsSEN@fz-juelich.de](mailto:j.linsSEN@fz-juelich.de)

Institute of Electrochemical Process Engineering (IEK-3)

# Cumulative Investment

## Infrastructure Roll-Out

cumulative investment [€ billion]



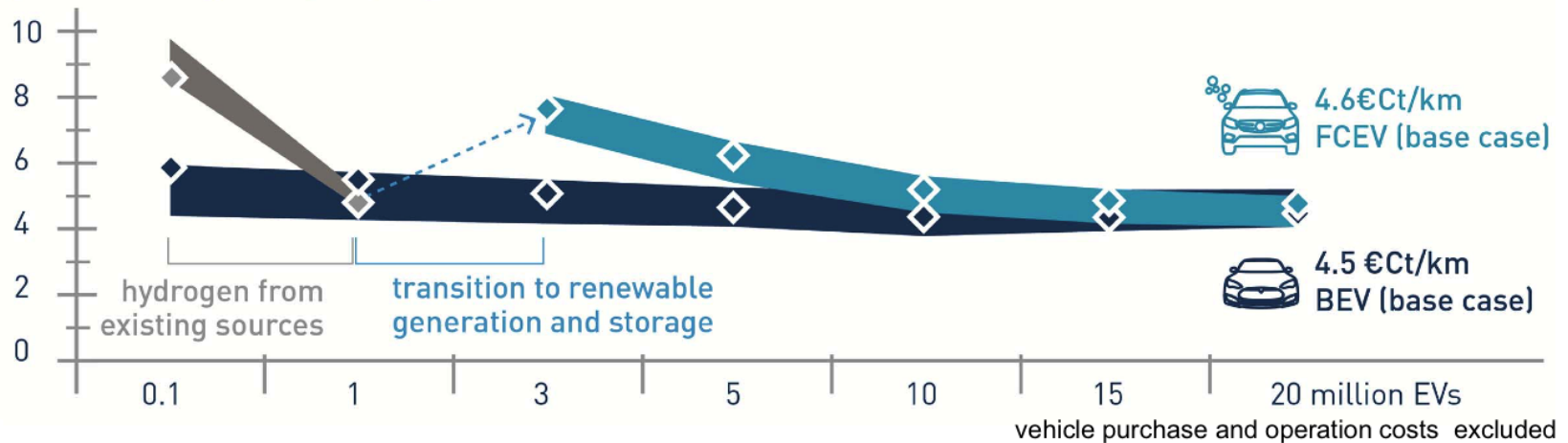
- Hydrogen more expensive during the transition period to renewable electricity-based generation
- High market penetration: battery charging needs more investment than hydrogen fueling
- For both infrastructures investment low compared to other infrastructures



	Investment [€ billion]
Renewable electricity generation scenario	374
Electric grid enhancement plan 2030	34
Federal transport infrastructure plan 2030	265
Hydrogen fueling infrastructure	40
Electric charging infrastructure	51

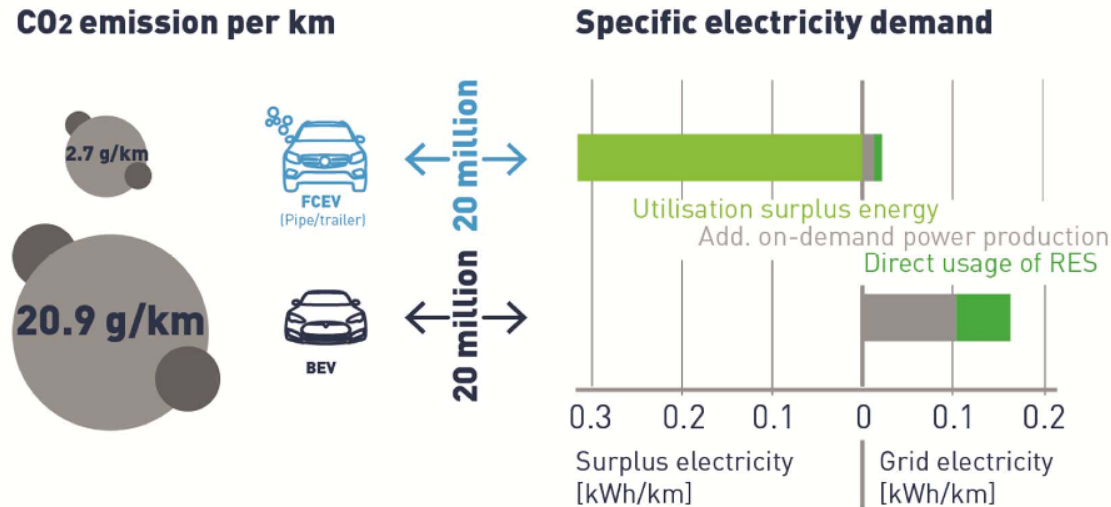
## Comparison of Mobility Costs

specific mobility costs [€Ct/km]



- For small vehicle fleets, i.e. 0.1 million cars, BEV fuel costs are significantly lower compared to FCEVs.
- Increase for hydrogen between 1 and 3 million cars results of switching to exclusive utilization of renewable energy for hydrogen production via electrolysis
- Mobility costs per kilometer are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km → the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs.

## CO<sub>2</sub> Emissions & Electricity Demand



- Efficiency of charging infrastructure is higher, but limited in flexibility and use of surplus electricity
- Fueling infrastructure for hydrogen with inherent seasonal storage option
- Low specific CO<sub>2</sub> emissions for both options in high penetration scenarios with advantage for hydrogen, well below the EU emission target after 2020: 95 g<sub>CO<sub>2</sub></sub>/km

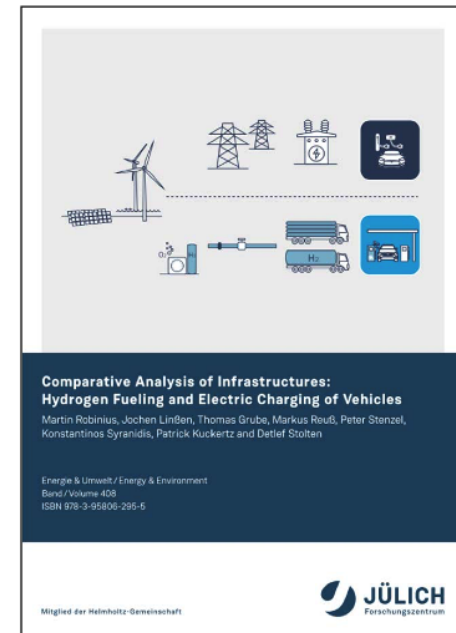
Full Report Available



<http://hdl.handle.net/2128/16709>

### Project team:

Martin Robinius, Jochen Linßen, Thomas Grube, Markus Reuß, Peter Stenzel, Konstantinos Syranidis, Patrick Kuckertz and Detlef Stolten



Funded by



# EU Regulatory Framework: Fit for 55

## **European climate law sets the reduction targets for net greenhouse gas emissions**

- > Ultimate goal: climate-neutrality by 2050
- > Intermediate goal: reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels

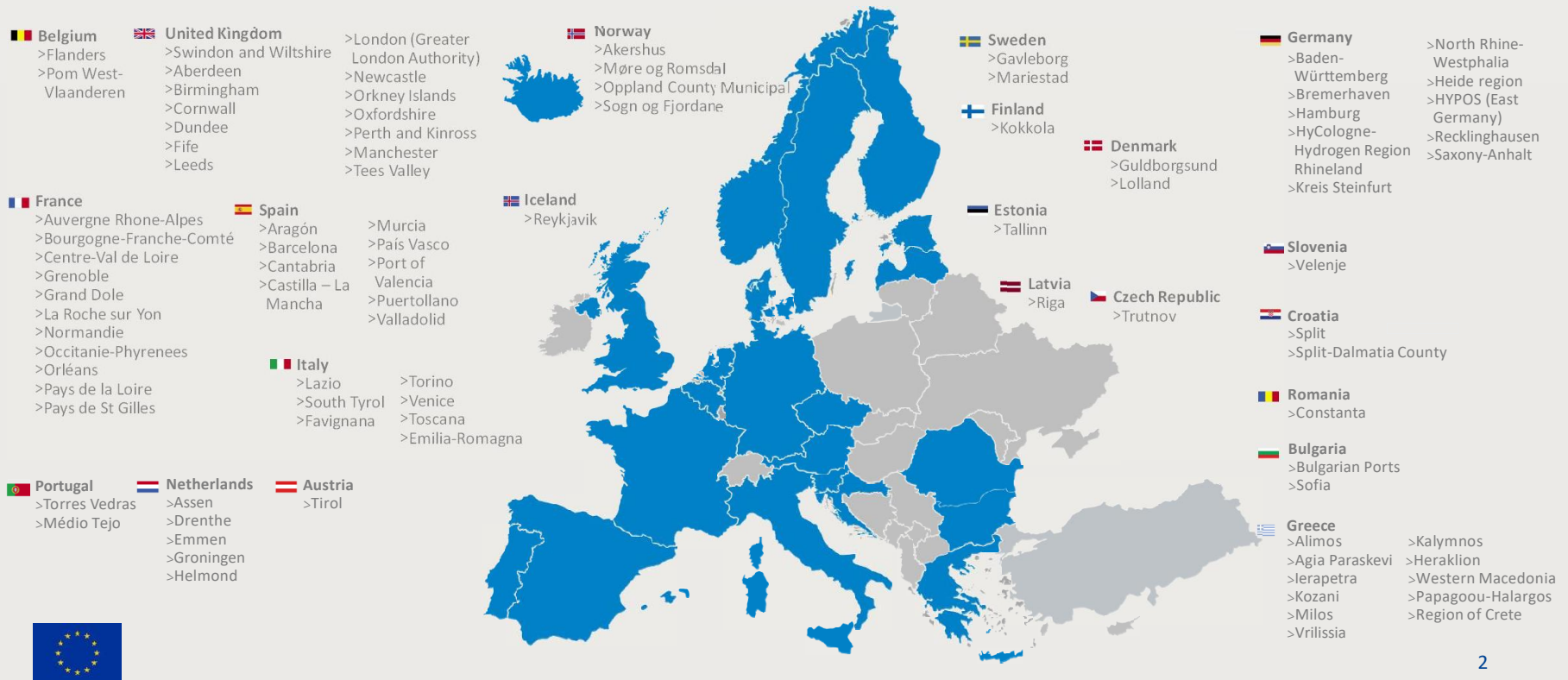
## **Fit for 55**

- > Proposals to revise and update EU legislation
  - > Framework for achieving the climate targets
- New cars and vans on the market as of 2035 should have zero-emissions. Creation of a new, separate emissions trading system for road transport and building sectors
- Hydrogen filling stations on main roads at least every 200 km (end of 2030) – denser network expected in urban areas

# Fuel cells and hydrogen for green energy in European Cities and Regions



# 91 Regions/Cities from 22 countries representing ca. one quarter of Europe participate





# Study Conclusions: Proposed Specific Actions for Coalition Members

Scope and workstreams of a continued FCH project support framework

## 1 H<sub>2</sub> Valley Support

- >Prepare and bring to financing stage fully integrated valley projects to start implementation from 2019 onwards
- >Provide individual support for each valley

## 2 FCH Project Implementation Support

- >Prepare demo projects (for 1-2 appl.)
- >Support detailed business cases, project organisation, joint procurement etc.
- >Potentially, help to launch large-scale pan-European projects on selected applications

## 3 Joint Platform Work

- >Networking, exchange, information sharing (e.g. in regular meetings)
- >Outreach, communication and visibility (e.g. through communication campaign, letter of intent)
- >Development of general concepts and tools (e.g. business cases, cost assessment, funding/financing)
- >Technology discussions and dialogue with industry

# Coordinated action needed to deploy infrastructure and vehicles

Conclusions of meeting of 6 November 2018 at FCH JU with MS



## CHALLENGES:

- ✓ Recognise both FCEV & BEV as ZEV
- ✓ Address the Chicken-egg dilemma – HRS vs. Vehicles
- ✓ Coordination of deployment of HRS across the EU (TEN-T corridors)
- ✓ Find right Funding instruments
- ✓ Aggregate demand to faster achieve cost drop of deployment

PROPOSAL is to discuss with EC/FCH JU and coordinate efforts to finance deployment:

- ✓ Agree on standard topic applicable to all (local, regional or national)
  - ✓ Eligibility rules – for HRS (density of the network?), Electrolyser (?), Vehicles (car, bus/coach, van, truck ?), H2 distribution (?)
  - ✓ Co-funding rules – fixed or % grant on CAPEX?; on the basis of the funding/financial viability gap (e.g. 40%EC/FCHJU + 10%National + 50%Private)
- ✓ Explore possibility of adding National funding programs to help co-fund
- ✓ Check availability and ensure commitment beforehand



# **EC - FCH JU Regions & Cities Initiative**

## **Application Packages for:**

**Buses, Heavy Duty Trucks, Trains**

**Bikes, Scooters, Garbage Trucks, Sweepers**

**Boats, Ferries, Ships, Port Operations**

**Equipment**

**Commercial Buildings, Residential mCHP,**

**Off-grid Power, Industrial Use Cases**

**P2H: Green H2, Electric Grid Services, H2 in**

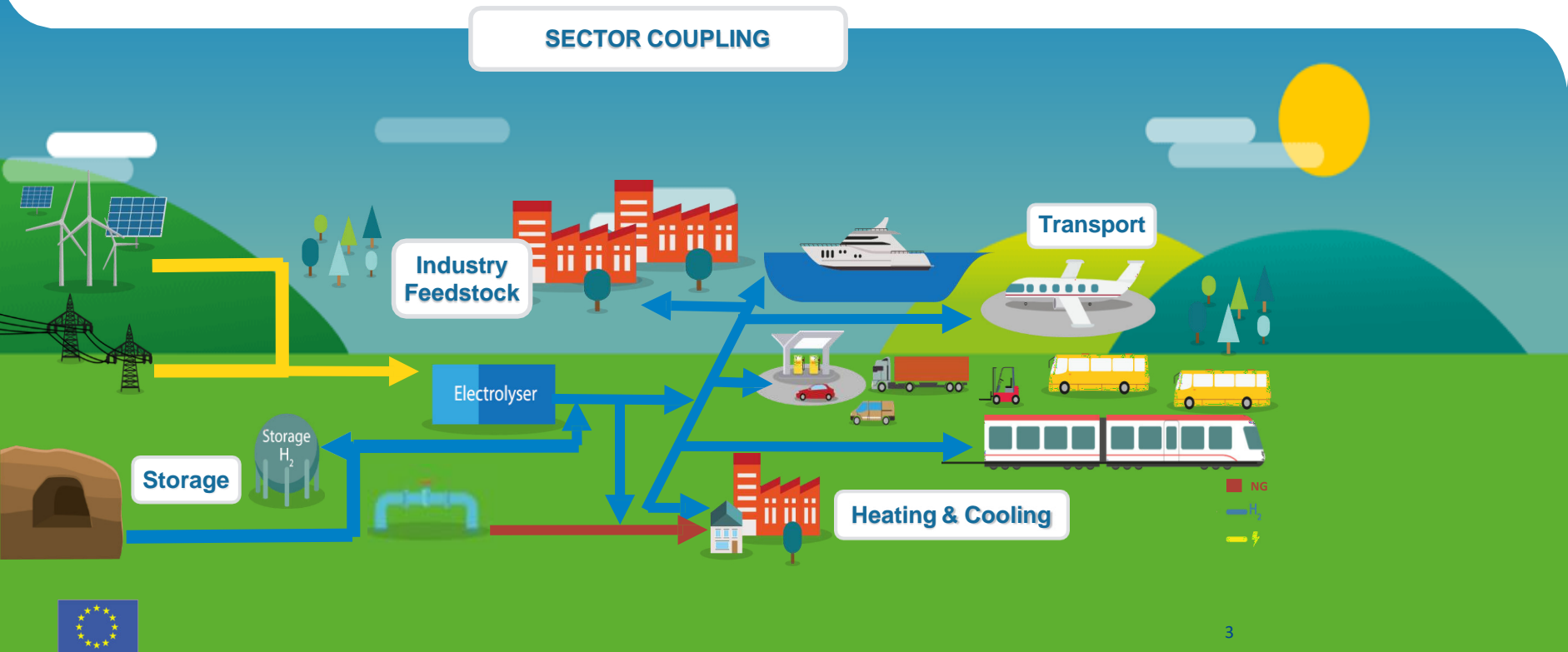
**NG Grid**

# Alternative Fuels Based on H<sub>2</sub>: Ammonia, Methanol, Synthetic Fuels...



# The hydrogen economy

Hydrogen allows more renewables in the energy system and enables sector-coupling



## Speed of change



- > New York 1900
- > First car in 1885, petrol from the pharmacy



- > New York 1913

## And safety is important, but so is fear of change...

“A new source of power... called gasoline has been produced by a Boston engineer. Instead of burning the fuel under a boiler, it is exploded inside the cylinder of an engine...

The dangers are obvious. Stores of gasoline in the hands of people interested primarily in profit would constitute a fire and explosive hazard of the first rank. Horseless carriages propelled by gasoline might attain speeds of 14, or even 20 miles per hour. The menace to our people of [vehicles of] this type hurtling through our streets and along our roads and poisoning the atmosphere would call for prompt legislative action even if the military and economic implications were not so overwhelming... the cost of producing [gasoline] is far beyond the financial capacity of private industry... In addition the development of this new power may displace the use of horses, which would wreck our agriculture.”

US Congressional Record, 1875

THANK YOU

The background features abstract, overlapping geometric shapes in various shades of green, ranging from light lime to dark forest green. These shapes are primarily located on the right side of the frame, creating a modern, layered effect against the white background.

# Some numbers / case studies

Electrolyzer: needs approx. 50 kWh to produce 1 kgH<sub>2</sub>

Energy content of Hydrogen: 33 kWh per kgH<sub>2</sub>

Fuel Cell: 60% efficiency i.e. provides approx. 20 kWh per kgH<sub>2</sub>

# Green Hydrogen – basic considerations

- Costs for producing green hydrogen have fallen 50% since 2015 and could be reduced by an additional 30% by 2025
- Producing green hydrogen by electrolysis needs a huge amount of electricity, which means a mind-blowing increase in the amount of RES (mainly wind and solar power) to meet global targets
- On March 16, 2023, the EC set out new plans to stimulate and support investment in sustainable hydrogen production through a European Hydrogen Bank (EHB) in order to bridge the investment gap for the EU to reach its ambitious REPowerEU targets of producing 10 million tonnes of green hydrogen by 2030

# Case Study 50MW

## A. Green Energy From Stand Alone PV

### ASSUMPTIONS

- About 150 MW PV station is required
- 180 hect. for PV station
- 1 hect. for Hydrogen production
- 10 hours daily operation
- 10 tn/day production H<sub>2</sub>

# Case Study 50MW

## B. Green Energy From AC Grid

### ASSUMPTIONS

- Green certificates or PPAs are required (energy from e.g. 250 MW PV stations)
- AC grid connection is required
- 1 hect. for Hydrogen production
- Up to 24 hours daily operation
- 24 tn/day production H<sub>2</sub>

# Case Study 50MW

## C. AC Grid Balancing

### ASSUMPTIONS

- AC grid connection is required
- Fuel cells (FC) are required
- Up to 24 hours daily operation
- 60% efficiency for FC