How Hydrogen empowers the Energy Transition

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Outline

Basic principles of hydrogen

How hydrogen empowers the energy transition

World and Europe market visions at 2030 – 2050

I. Industry
II. Public authorities
III. Public-Private partnership – FCH 2 JU
IV. 2030 European technological roadmaps

Conclusions

Key messages

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- **Hydrogen**, as a **clean, safe and versatile energy carrier**, is part of the energy transition and is key to enable the renewable energy system and to decarbonize end uses. Hydrogen is **the only zero-emission energy carrier with electrons**.
- Hydrogen technologies are mature and have significant potential across all applications, in particular **when looking for high payload, high autonomy and flexibility.**
- **Hydrogen is fully part of the European strategy** for a climate neutral Europe by 2050
  - **Horizon Europe** mentions research on Hydrogen and Fuel Cells
  - Hydrogen energy is one of the **European strategic value chain**
- **Hydrogen & Fuel Cells are today**!
  An international momentum worlwide with a strong position in Asia (Japan, South Korea **and now China**) but a **strong European Public-Private Partnership** with close collaboration between **Industry** (Hydrogen Europe Industry) and **Research** (Hydrogen Europe Research) has a fundamental role to develop technological research, to maintain European competitiveness and to bring products to market readiness. The close collaboration between research and industry is the basis of the European strength in the Hydrogen and Fuel Cell sector.
- A **global collaborative approach** of policy makers, investors and industry is needed today to enable the full potential of hydrogen in the energy transition.
- **Industry/Chemical sector** can be an important costumer of the **hydrogen sector** for decarbonizing its industry owing to “clean” hydrogen.

Basic principles of hydrogen

Key figures of Hydrogen

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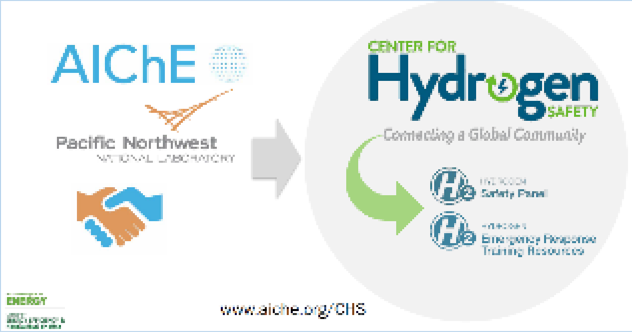
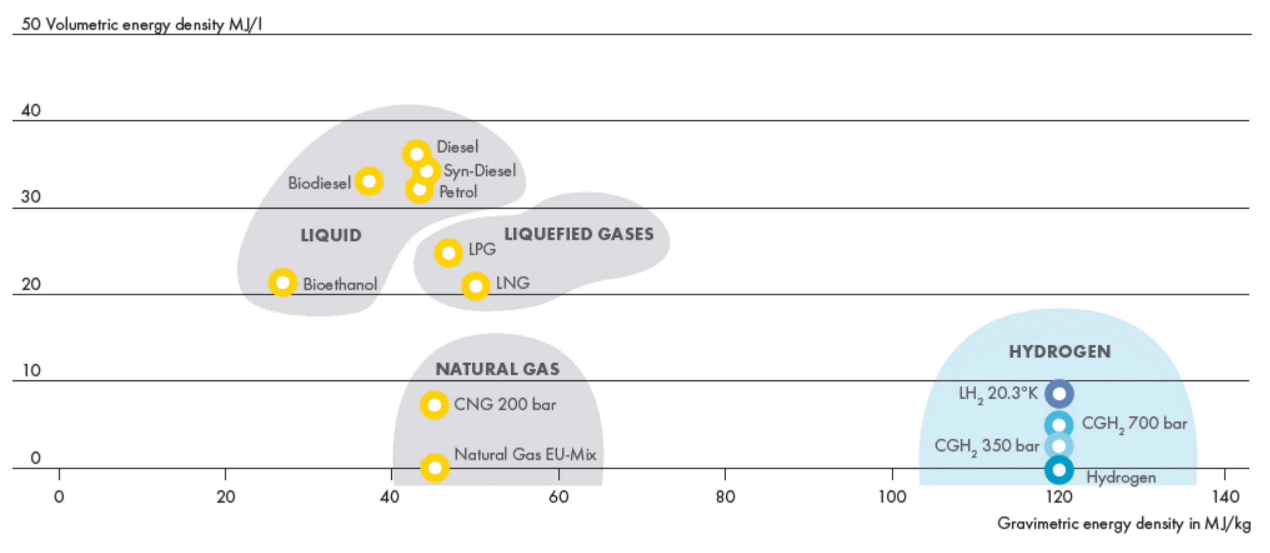
- One of the most abundant element on Earth
- Non polluting, non toxic

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m^3 (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m^3 (-253°C, 1 bar)	1/6 of natural gas
Boiling point	-252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG
Flame velocity	346 cm/s	8x methane
Ignition range	4–77% in air by volume	6x wider than methane
Auto ignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 MJ	1/10 of methane
Explosion energy (kg TNT/m3)	2,02	7,3 for NG
Blast overpressure (bar)	14,7	16,8 for NG
Diffusion Coefficient (cm^2/s)	0,61	0,16 for NG
Blast speed (m/s)	2000	1800 for NG

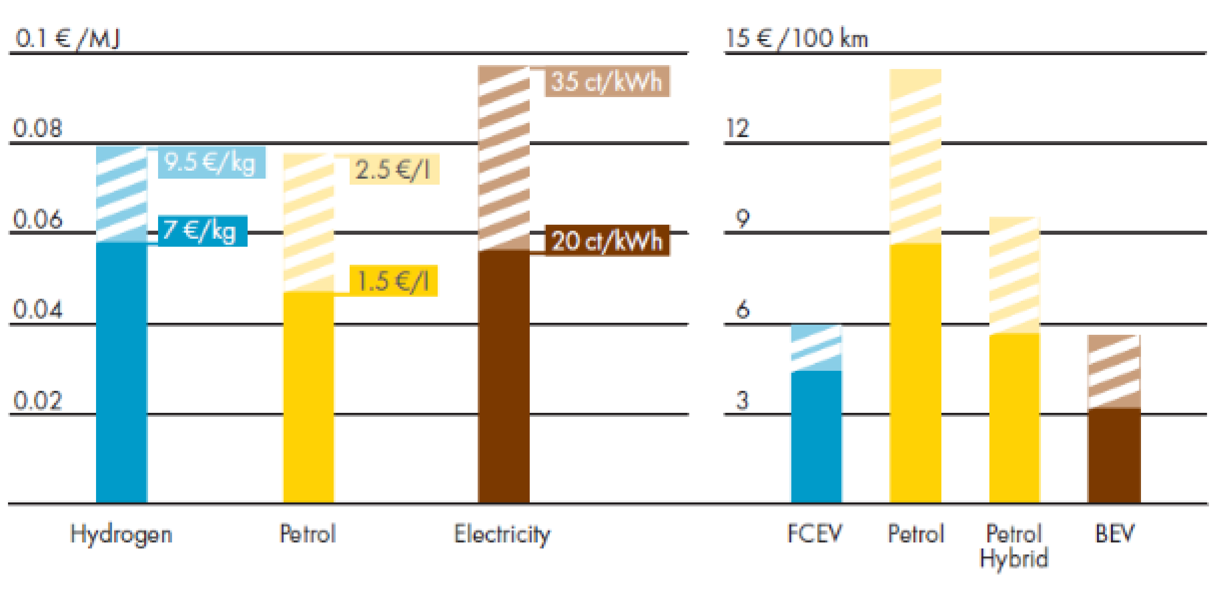
(Saint Lo, France)



Key figures of Hydrogen



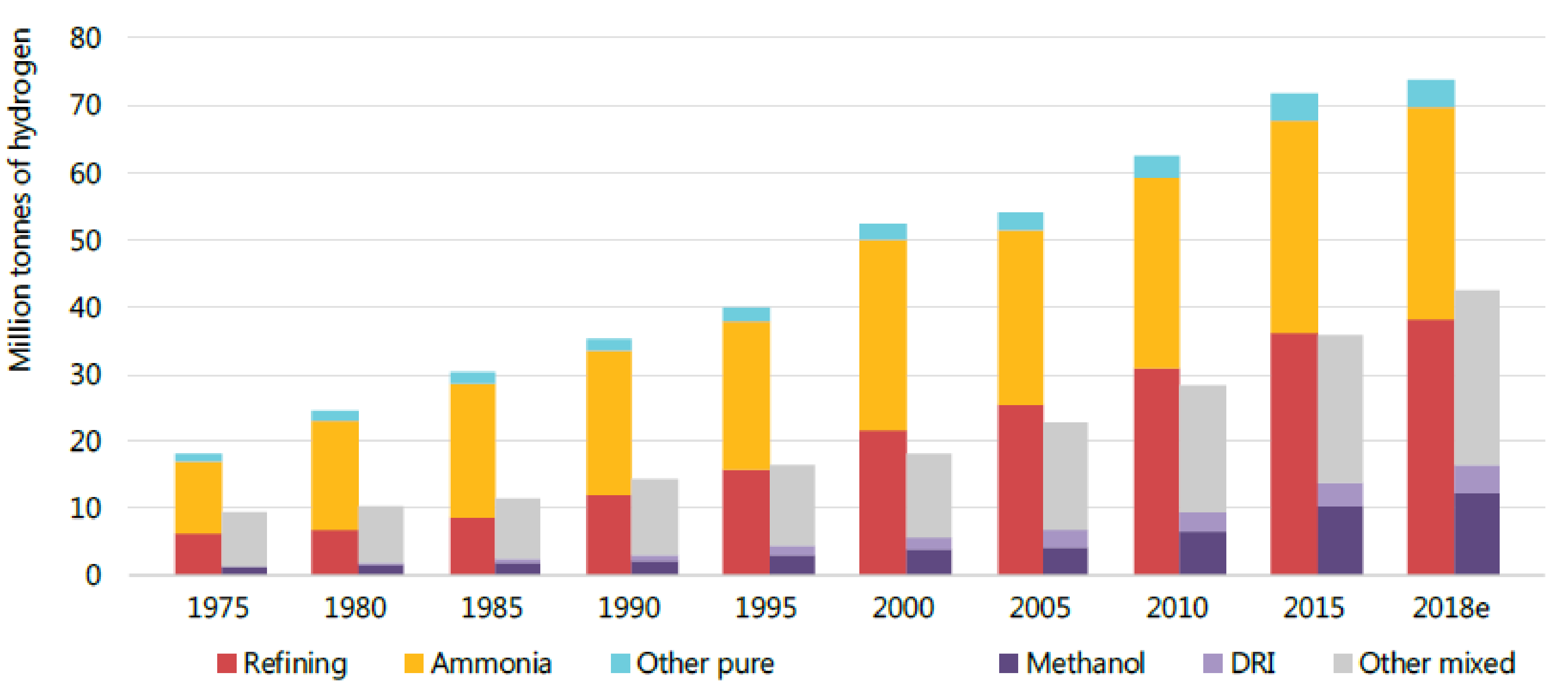
Source: Shell 2017



- 1 kg of hydrogen (33 kWh)
  - 100 km drive for a medium passenger car
  - 1 to 2 days of energy for a house (without heating)

Current usage of hydrogen

Around **70 MtH_2/yr** is used today in pure form, mostly for oil refining and ammonia manufacture for fertilisers
A further **45 MtH_2** is used in industry without prior separation from other gases.



Source: IEA 2019

Not new!

Former urban gas contained almost 50% H2

- H_2 : 48 %
- CH_4 : 36 %
- CO : 8 %
- CO_2 : 5 %

Processes for producing hydrogen

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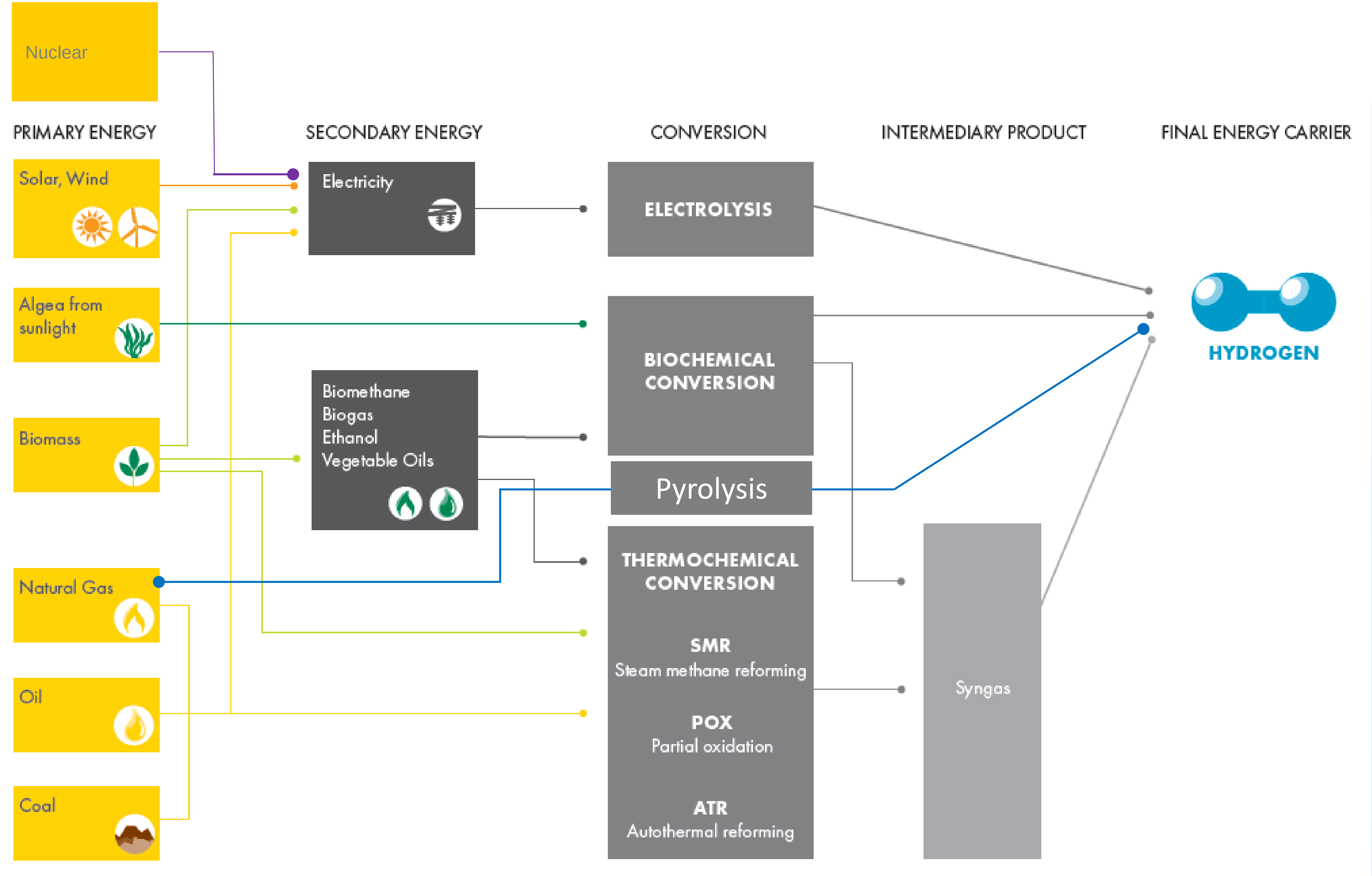
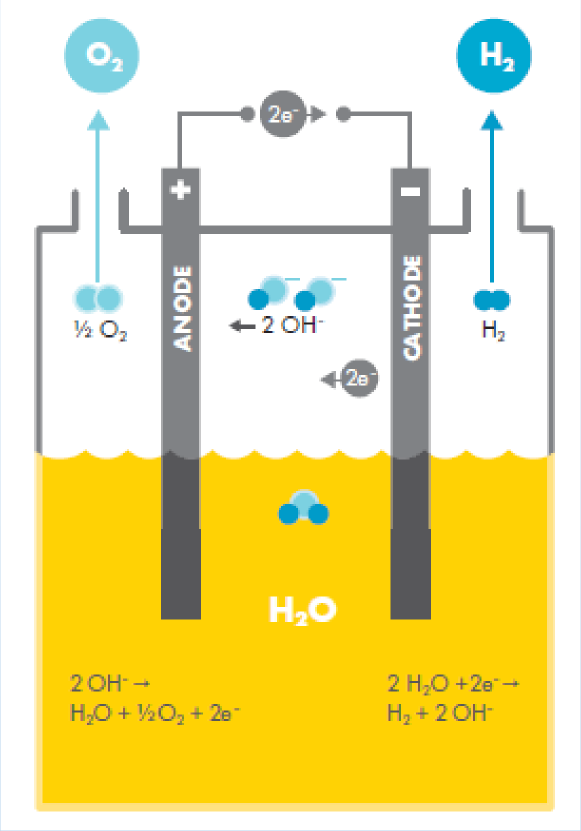
- **Renewable hydrogen** is produced from renewable energy sources as per REDII
- **Low-carbon and/or decarbonised hydrogen** is produced from non-renewable energy sources with an ambitious minimum emission reduction threshold with a degressive factor



Water Electrolysis

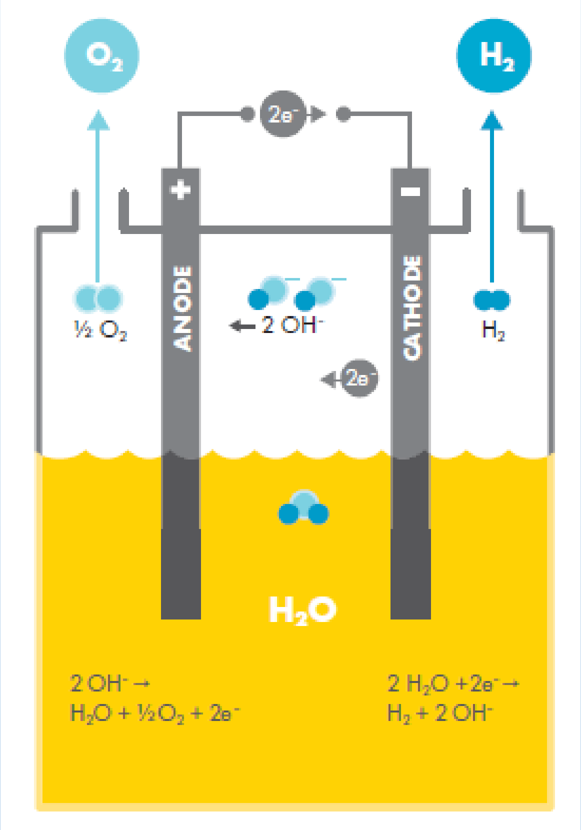
Hydrogen Europe Research



	Alkaline electrolyser			PEM electrolyser			SOEC electrolyser		
	Today	2030	Long term	Today	2030	Long-term	Today	2030	Long term
Electrical efficiency (%,LHV) (kWhe/kg, LHV)	63–70 48-53	65–71 47-51	70–80 42-48	56–60 56-60	63–68 49-53	67–74 45-50	74–81 41-45	77–84 40-42	77–90 37-43
Operating pressure (bar)	1–30			30–80			1		
Operating temperature (°C)	60–80			50–80			650 – 1 000		
Stack lifetime (operating khours)	60 – 90	90 – 100	100 – 150	30 – 90	60 – 90	100 – 150	10 – 30	40 – 60	75 – 100
Load range (%, relative to nominal load)	10–110			0–160			20–100		
Plant footprint (m^2/kWe)	0.095			0.048					
CAPEX (USD/kWe)	500 – 1400	400 – 850	200 – 700	1 100 – 1 800	650 – 1 500	200 – 900	2 800 – 5 600	800 – 2 800	500 – 1 000

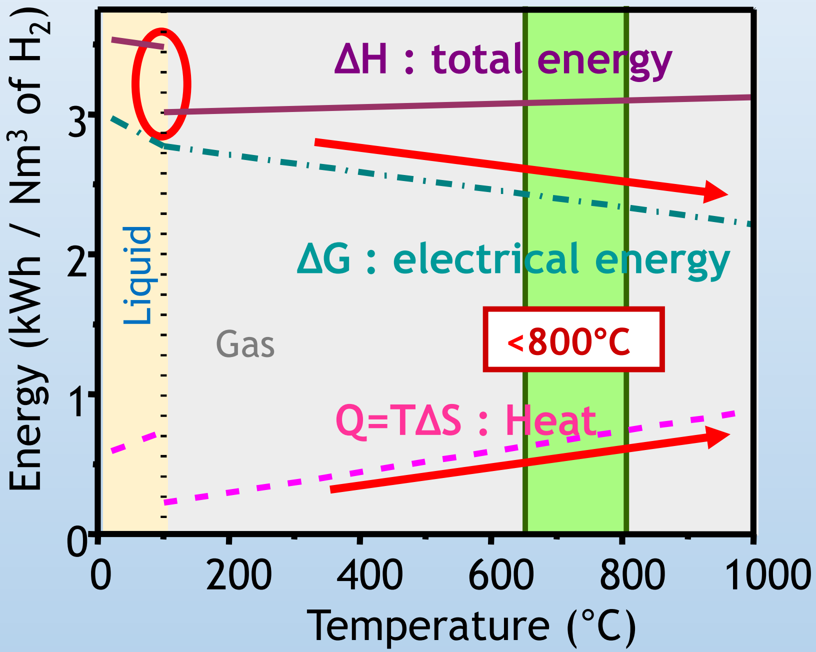
Source: IEA 2019

Water Electrolysis

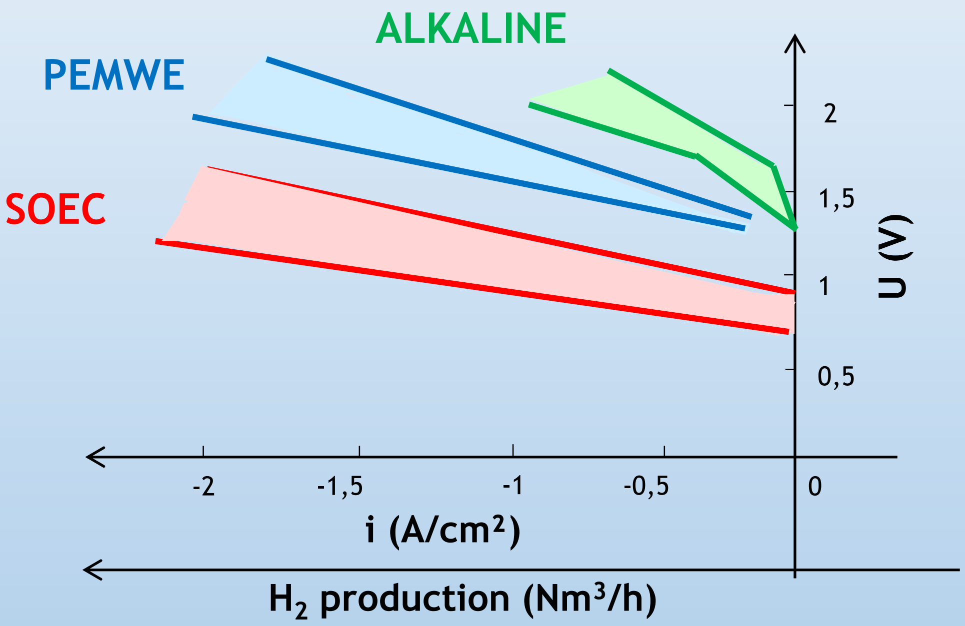


$H_2O \rightarrow H_2 + ½ O_2$

$\Delta H = \Delta G + T\Delta S$



Source: Chase *NIST-JANAF Thermochemical Tables* (1998) Monograph 9, 1325



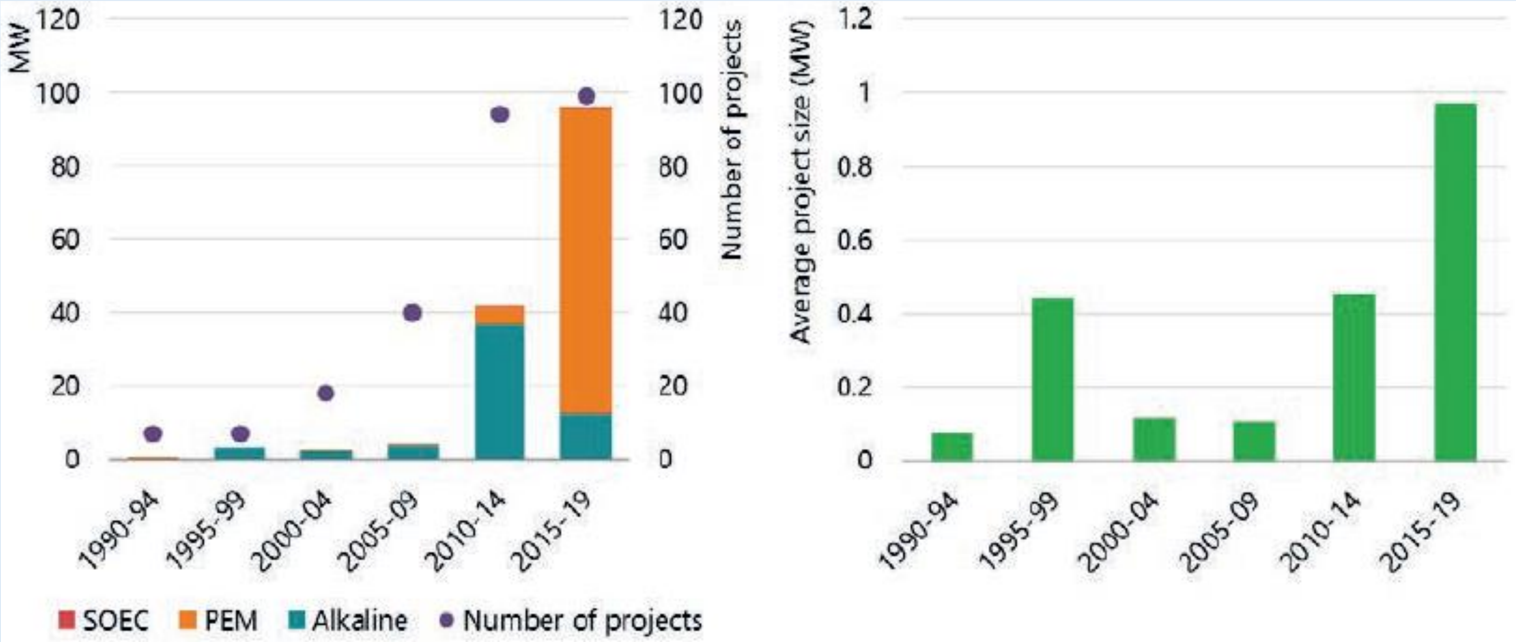
SOEC interesting:

- Better efficiency
- Less sensitive to the price of electricity (but higher cost for initial investment)

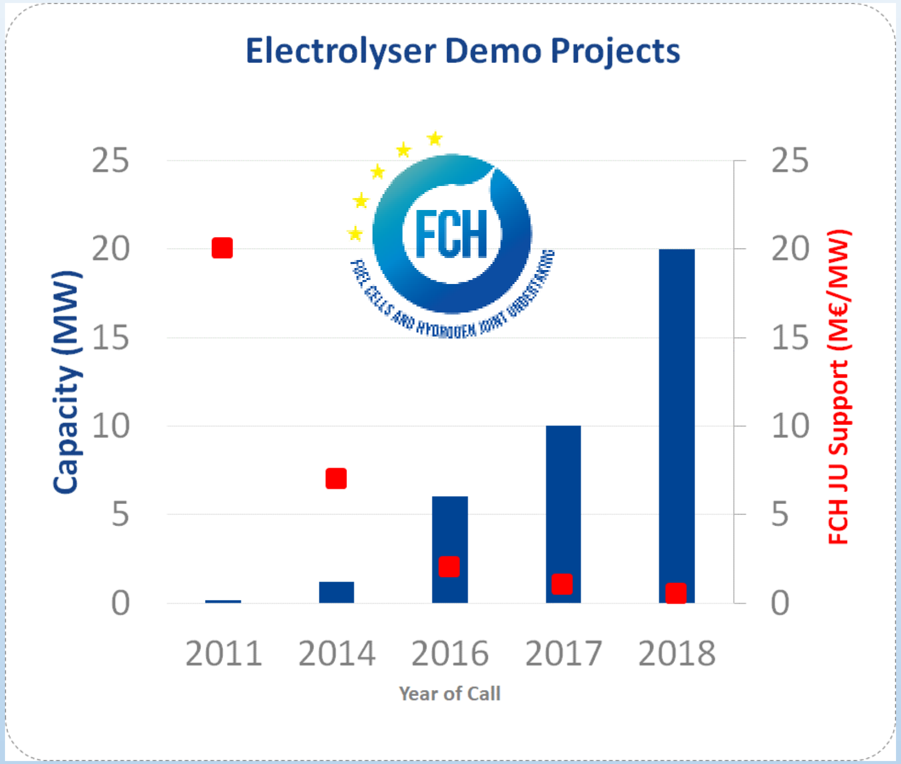
Water Electrolysis

Hydrogen Europe
Research

Development of electrolyser capacity additions for energy purposes and their average unit size, 1990–2019



Source: IEA 2019



H_2 production cost in the range 1.4 and 2 €/kg is achievable

How Hydrogen empowers the energy transition

Societal demand

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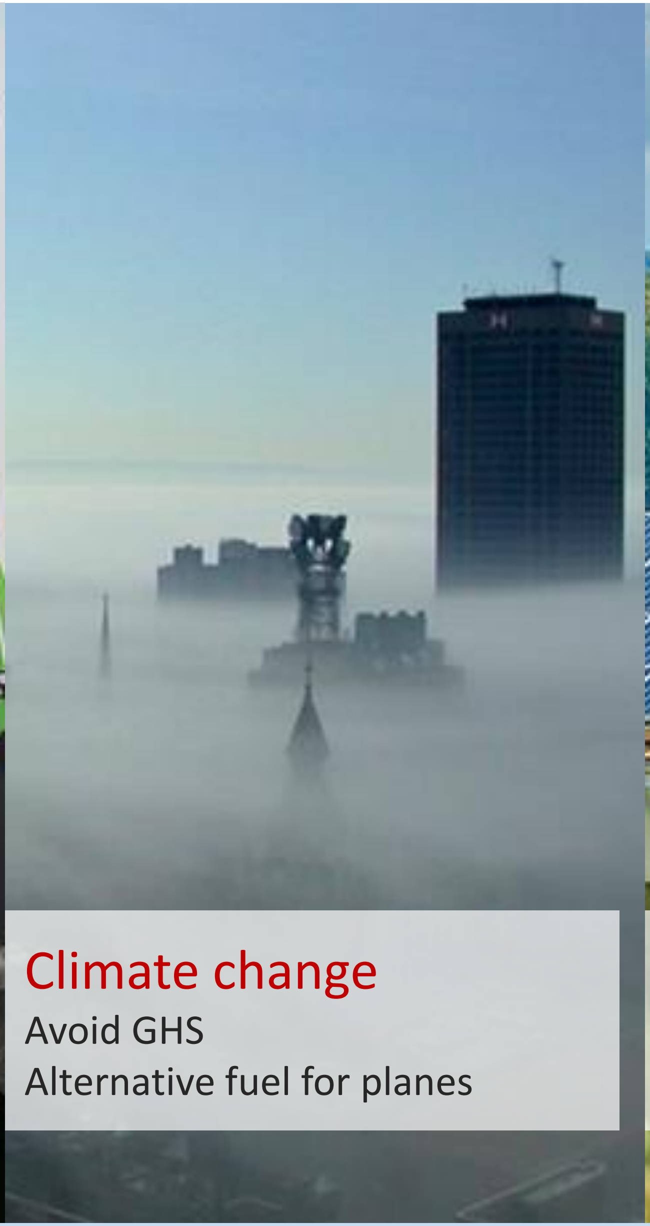
Health
zero-emission mobility



Climate change
Avoid GHS
Alternative fuel for planes

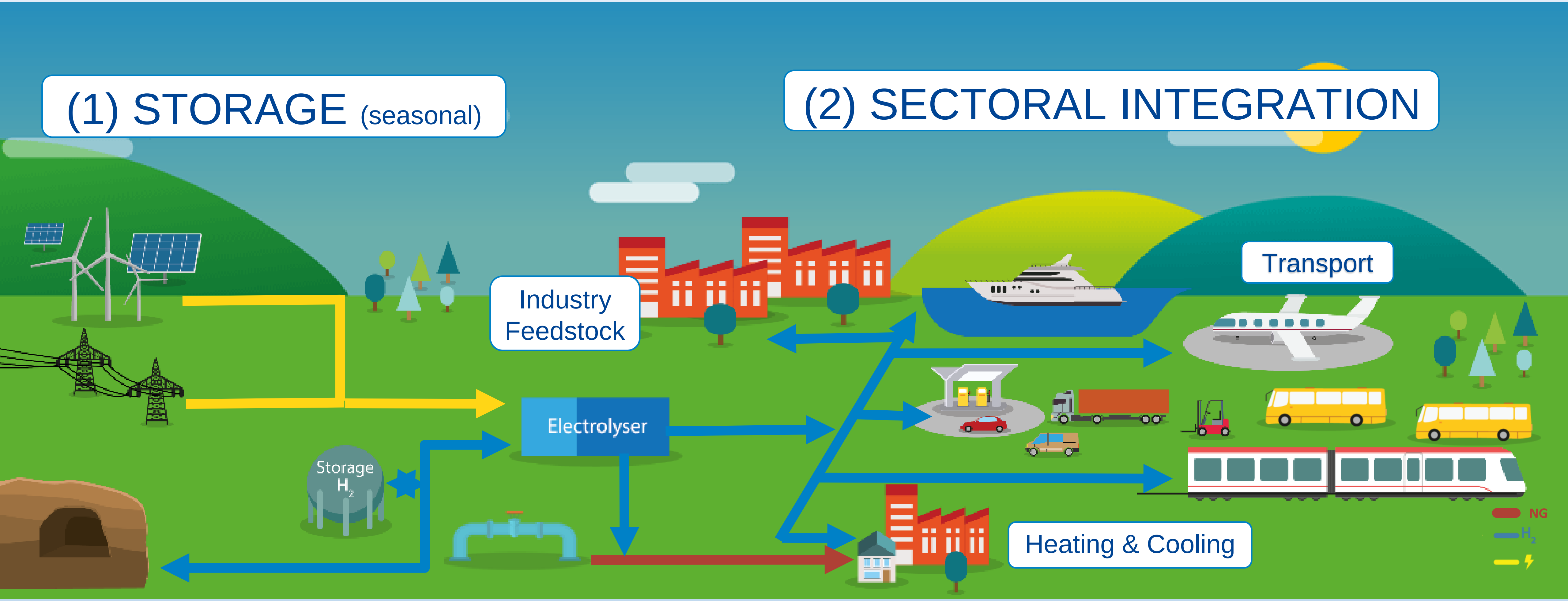
Energy availability
Grids stability
Massive energy production

Jobs
Technology leadership

The role of hydrogen in our society & economy

Hydrogen Europe Research

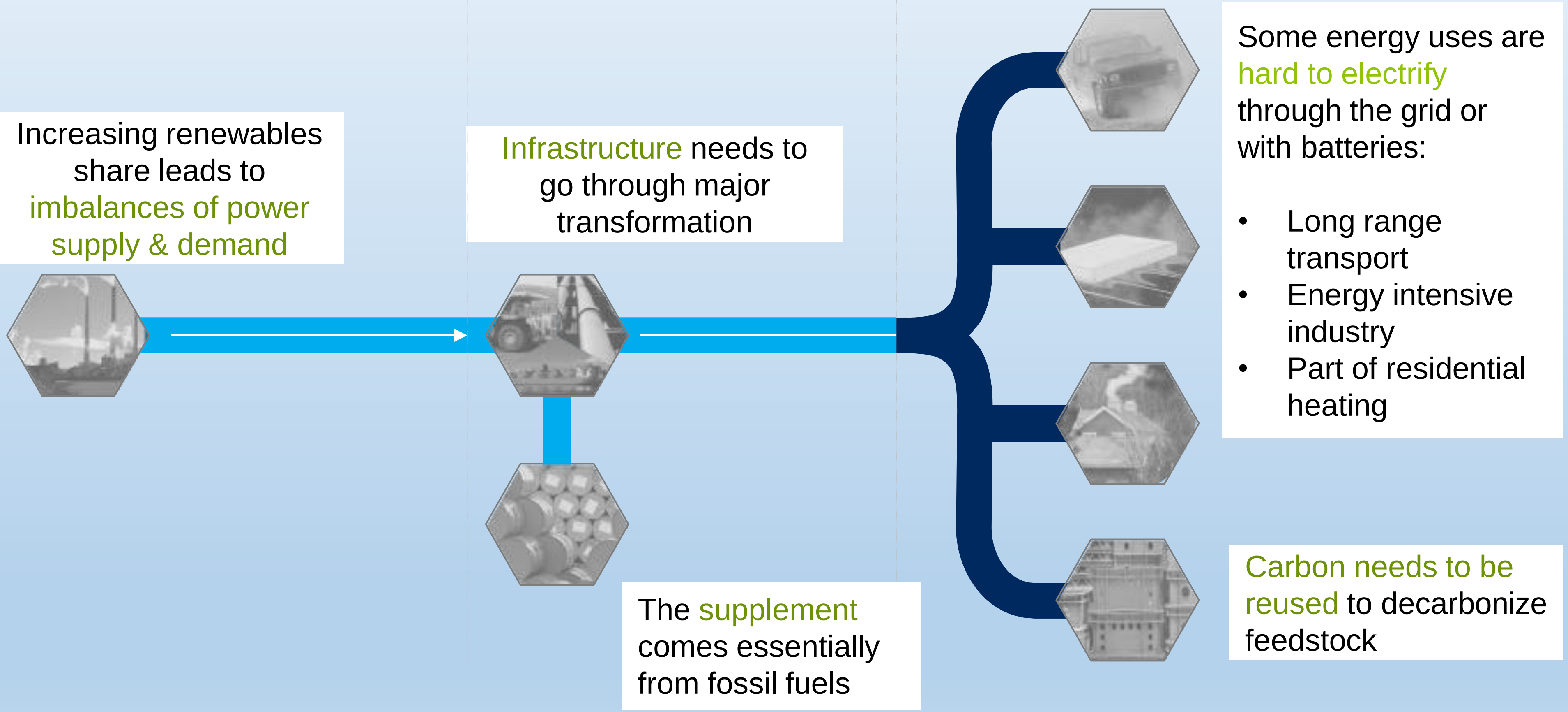
Hydrogen allows more renewables in the energy system through storage and enables sectoral integration



The energy transition creates multiple challenges

Hydrogen Europe Research

Enable the renewable energy system → **« Decarbonise » end uses**



Hydrogen Council, 2017

The energy transition creates multiple challenges

Enable the renewable energy system → **Decarbonise end uses**

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

2 **Distribute** energy across sectors and regions

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

4 Decarbonize **transportation**

5 Decarbonize **industry energy** use

6 Help decarbonize **building heating and power**

7 Serve as renewable **feedstock**

Hydrogen Council, 2017

1st guarantees of origin for green hydrogen about to hit the market

Hydrogen Europe Research

Important for member states to implement these Guarantees of Origin in their national legislation

CertifHy

http://www.certifhy.eu/

Main objectives:

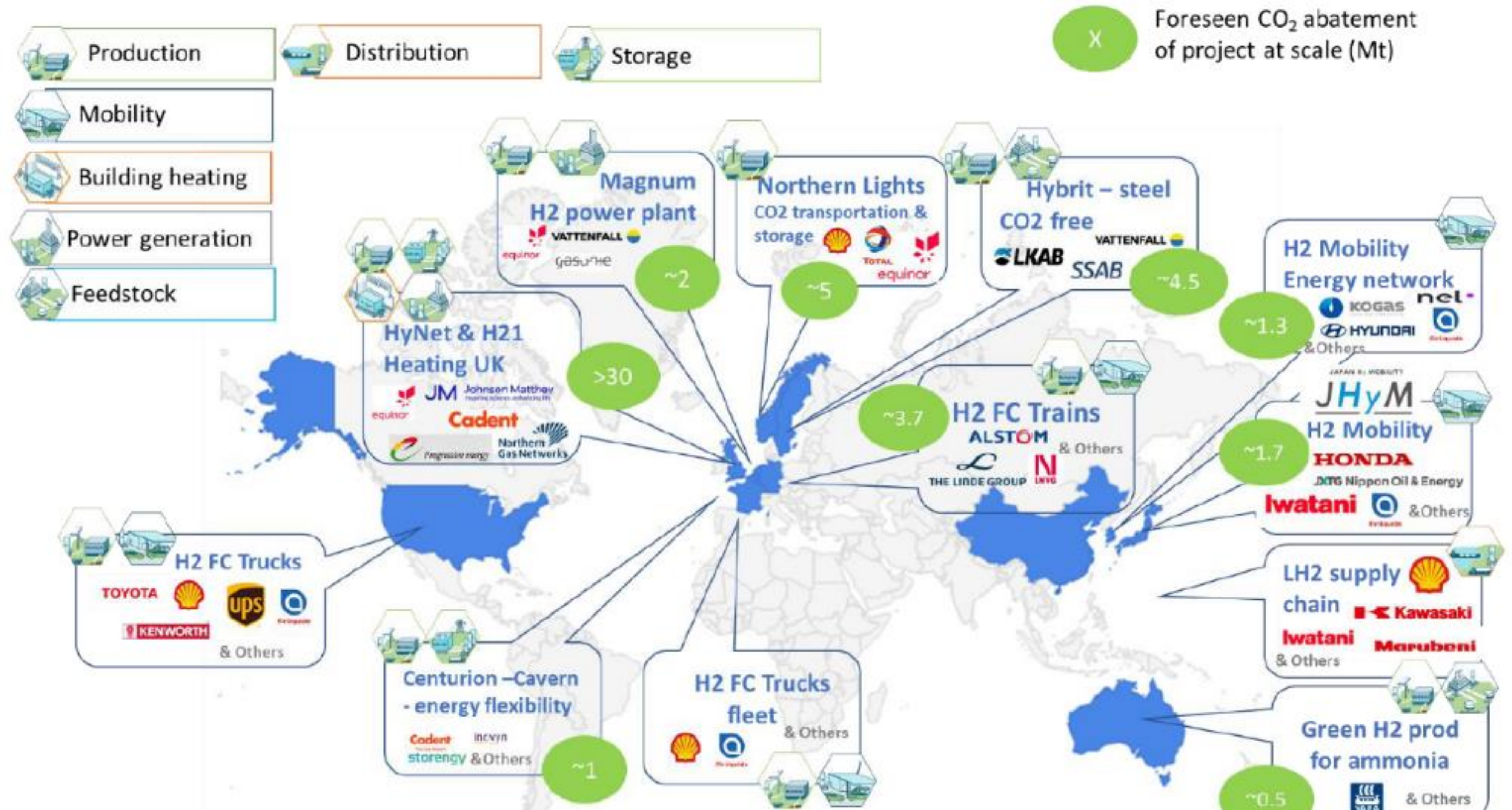
- To define a widely acceptable definition of green H_2
- Design a robust GoO scheme for green hydrogen
- Propose roadmap to implement the initiative in EU
- Establish a stakeholder platform
- Real trial in 4 pilot operations for a guarantee of origin scheme for green and low carbon H_2

NEXT: **FAST IMPLEMENTATION IN NATIONAL LEGISLATION**

- **Renewable hydrogen** is produced from renewable energy sources as per REDII
- **Low-carbon and/or decarbonised hydrogen** is produced from non-renewable energy sources with an ambitious minimum emission reduction threshold with a degressive factor
- **Synthetic methane** is a methane gas produced from renewable hydrogen and CO_2.

Representative sample of projects per geography (selected from a broader list of existing hydrogen flagship projects)

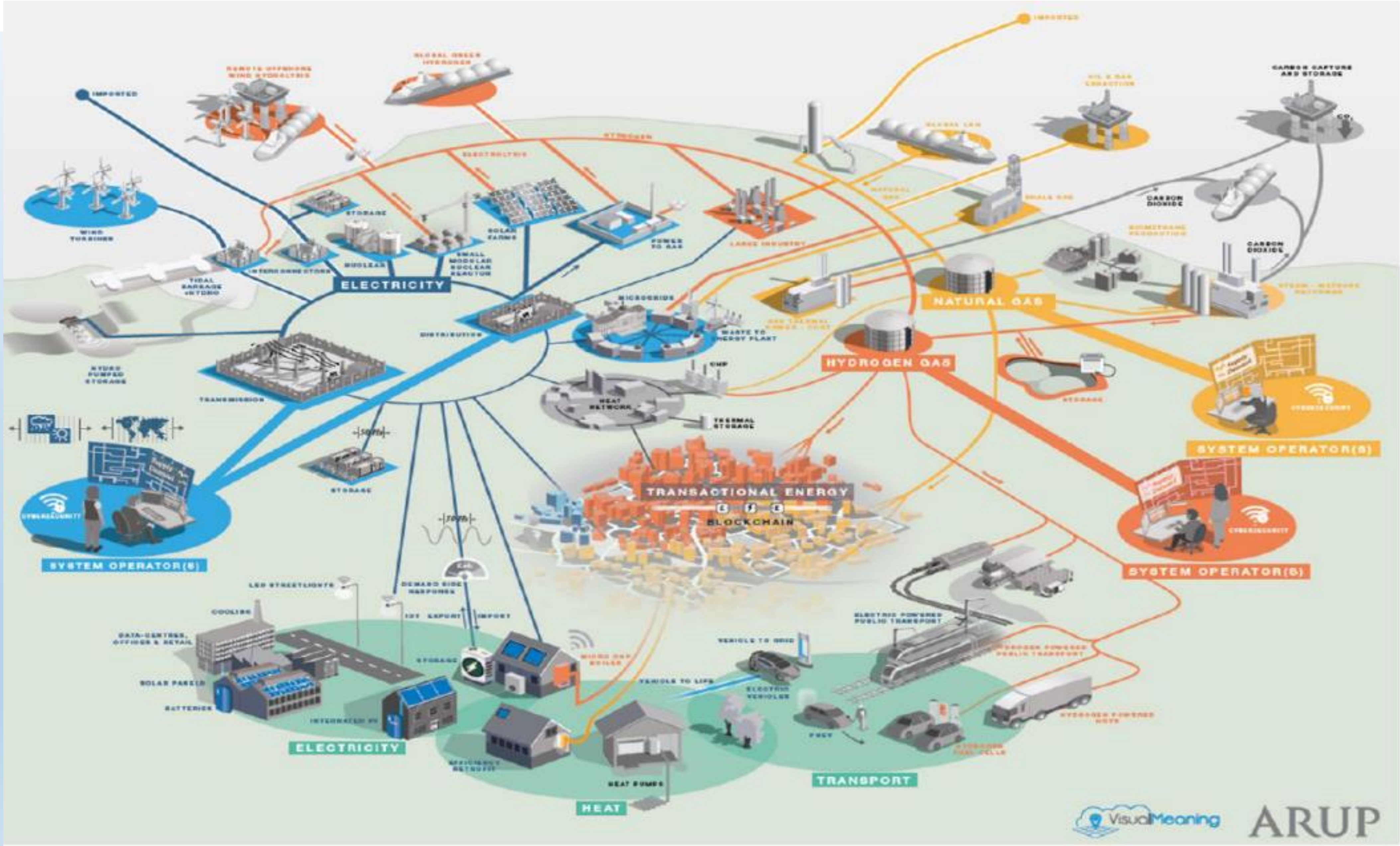
Hydrogen Europe Research



Hydrogen Council, 2018

Hydrogen: Sector coupling & sectoral integration

Hydrogen Europe Research



Energy intensive industries are discovering the potential of Hydrogen (1/5)

Hydrogen Europe Research

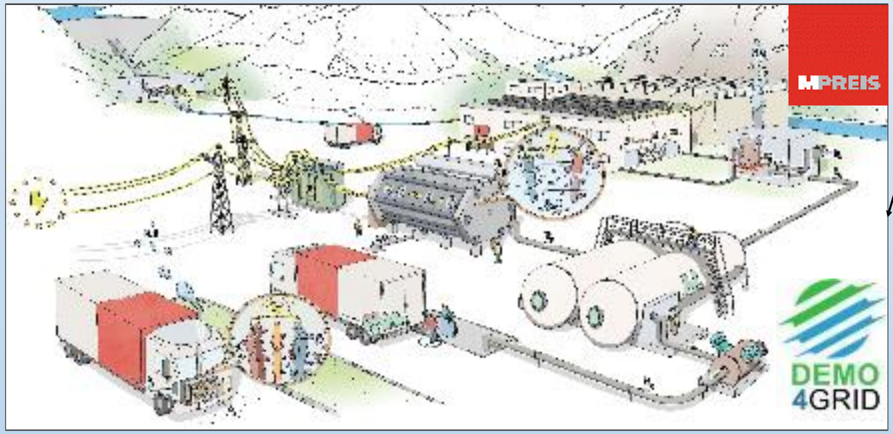
Overview of low-CO2 technology potential for the sub-value chains

	Electrification (heat/ mechanical)	Electrification (processes)	Hydrogen (heat / process)	CCU	Biomass (heat/feed-stock/biofuels)	CCS	Other alternatives (only with high potential)
Steel	**applied**	medium	high	high	possible	high	Avoidance of internmediate process steps & recycling process gases, recycling high quality steel
Chemicals fertilizers	High	high	high	high	high	High *	use of waste streams (chemical recycling)
Cement	medium	-	possible	high	**applied**	high	Alternative binders, efficient use of cement, use of waste streams

Source: Wyns T, Khandekar G, Robson I.(VUB) Industrial Value Chain. A Bridge Towards a Carbon Neutral Europe.; 2018

Energy intensive industries are discovering the potential of Hydrogen (2/5)

Thanks to FCH-JU research projects the costs of electrolysers decreased and became interesting for energy intensive industries to invest



3.4 MW electrolyser at MPREIS (bakery plant) in Völs

- The green H_2 is produced from hydro-electricity (from Alps)
- 1st phase: it is used to heat the ovens to bake the bread
- 2nd phase: distribution by using H_2 trucks

DURATION: 2017-2022; project 7.74 M€ (2.93 M€ by FCH-JU)

https://www.demo4grid.eu/

6 MW electrolyser at VOESTALPINE (steel plant) in Linz

- The green H_2 is produced from hydro-electricity (from Alps)
- It is used to produce steel in this way the industry can make a first step towards CLEAN STEEL

DURATION: 2017-2021; project 18 M€ (12 M€ by FCH-JU)

https://www.h2future-project.eu/

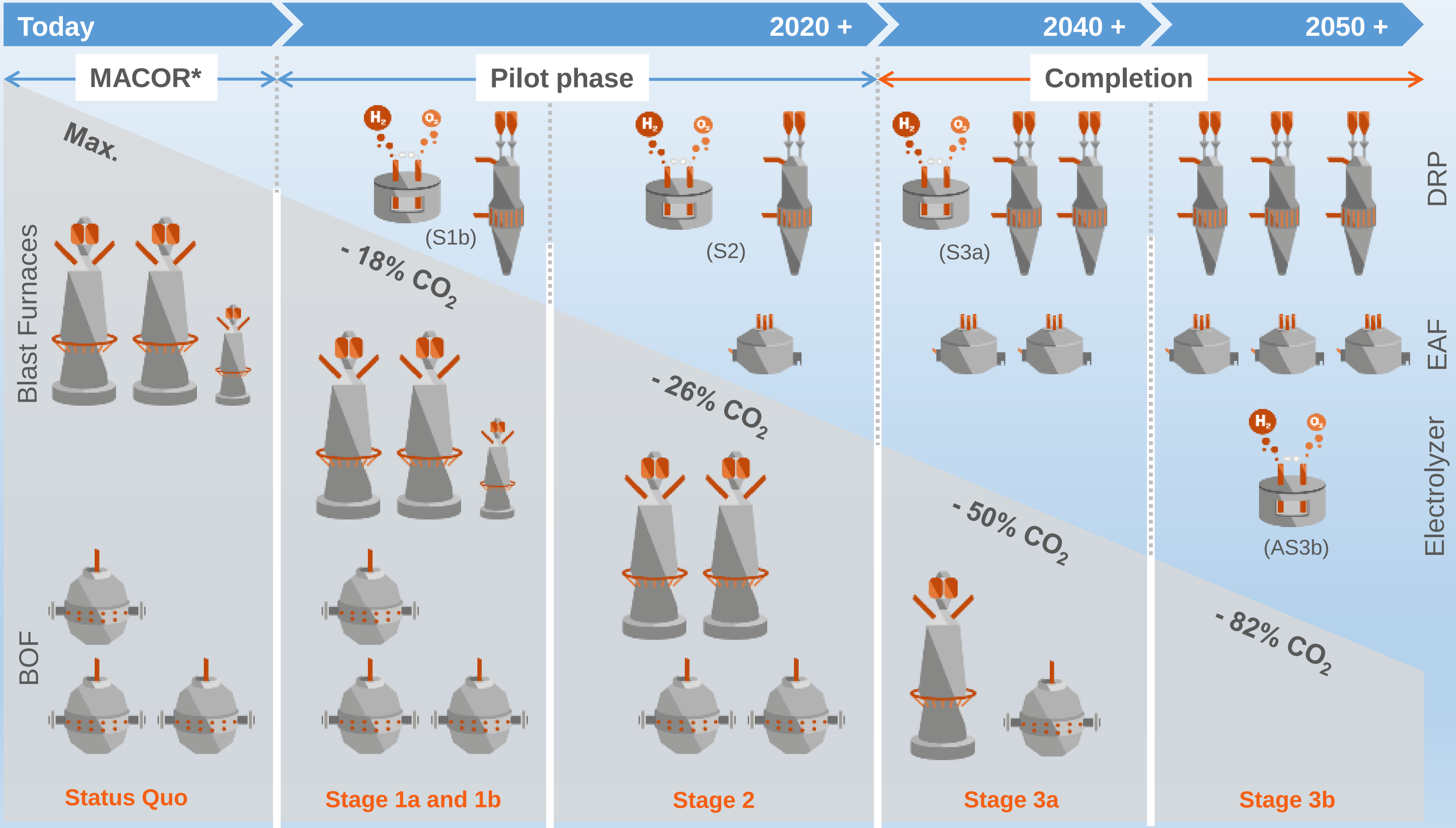
Energy intensive industries are discovering the potential of Hydrogen (3/5)

Hydrogen Europe Research

SALCOS –
SAlzgitter Low
CO_2 Steelmaking

Fraunhofer

SALZGITTER AG Stahl und Technologie



***MACOR:** Feasibility study for SALCOS

Energy intensive industries are discovering the potential of Hydrogen (4/5)

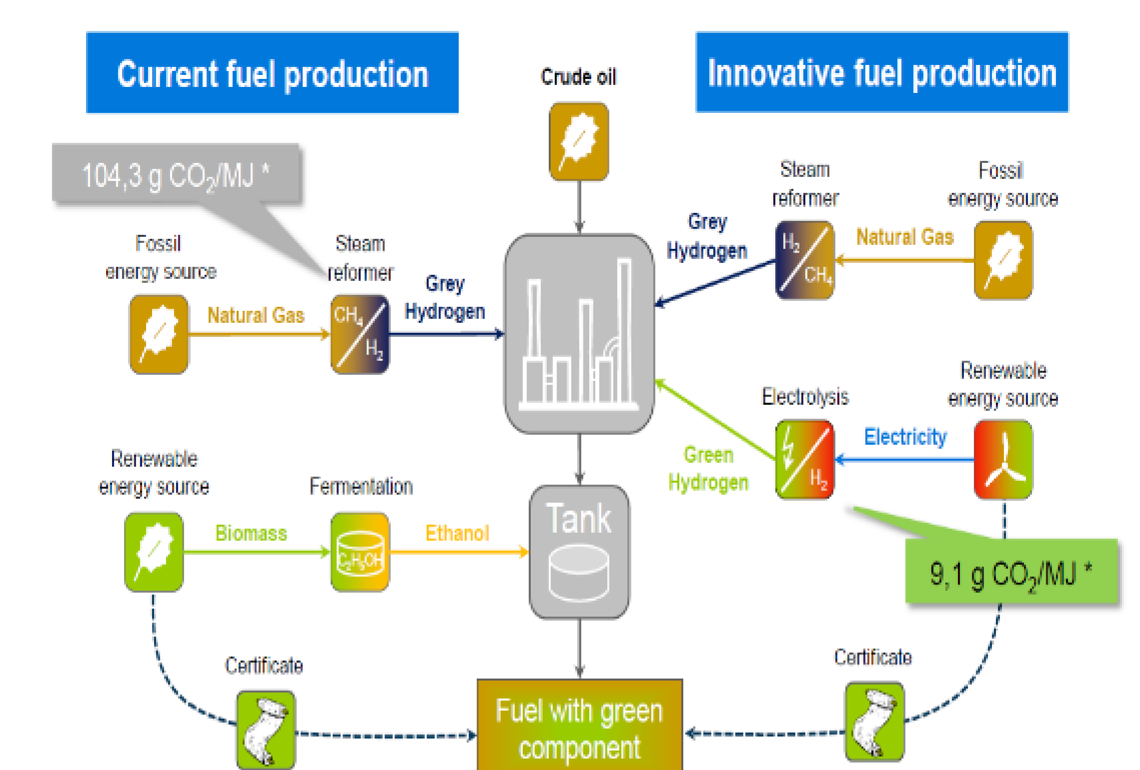
Hydrogen Europe Research

Thanks to FCH-JU research projects, the costs of electrolysers decreased and became interesting for energy intensive industries to invest

<u>10 MW electrolyser at SHELL in Köln</u>

- The green H_2 is produced from curtailed wind energy due to a full electricity grid.
- The produced H_2 will be injected in the natural gas grid (part of it can be used for Shell internal processes)

DURATION: 2018-2022; project 16 M€ (10 M€ by FCH-JU)



Source: Uniper

(Website under preparation)

Energy intensive industries are discovering the potential of Hydrogen (5/5)

Hydrogen Europe Research

Thanks to FCH-JU research projects, the costs of electrolysers decreased and became interesting for energy intensive industries to invest

GERMANY

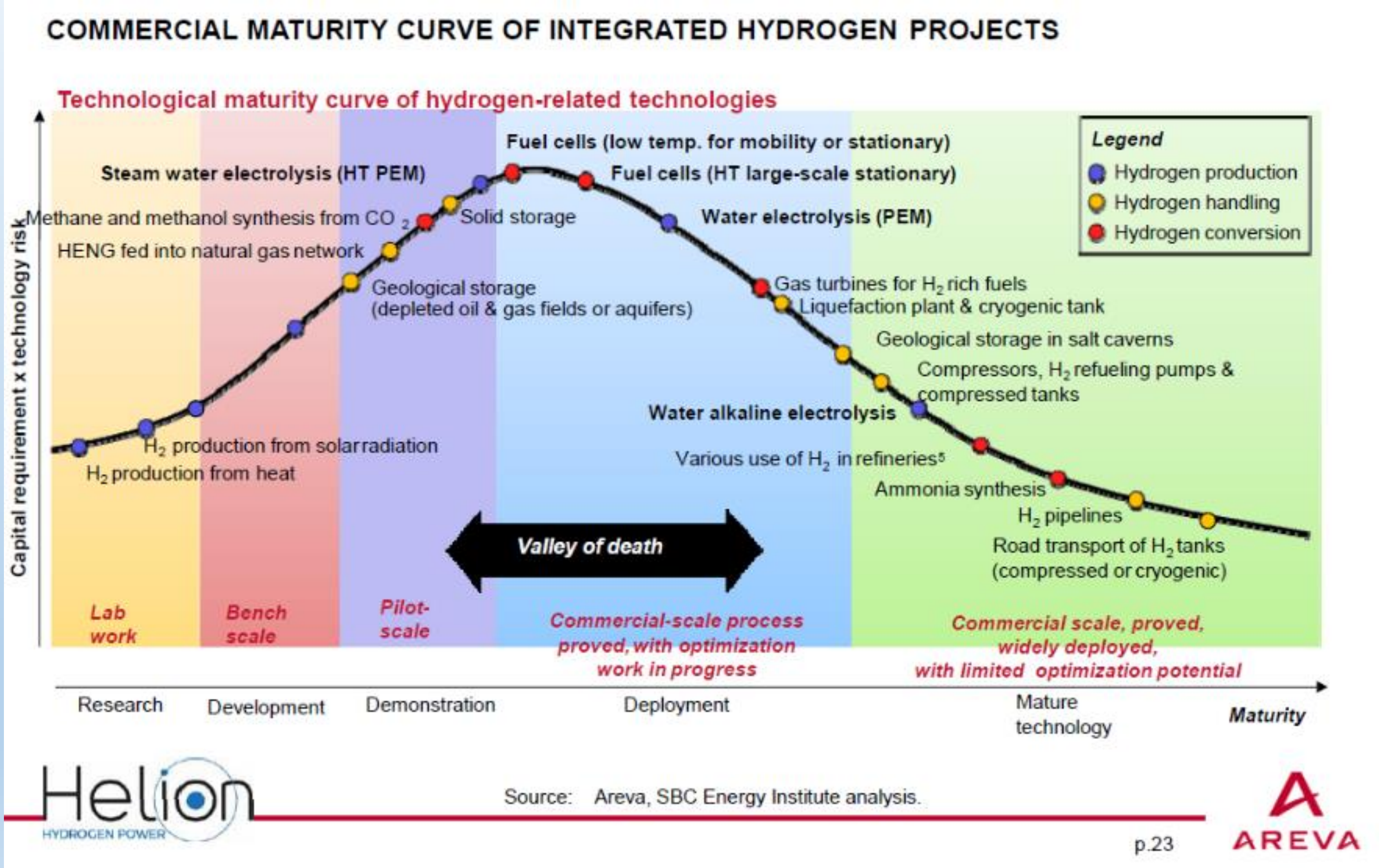
150/30kW Reversible electrolyser, Salzgitter

- To operate a high-temperature Electrolyser as reversible generator (rSOC, reversible Solid Oxide Cell) in the industrial environment of an integrated iron and steel work.
- The system is flexible to produce either H_2 or electricity.

DURATION: 2016-2019; project 4.5 M€ (100% by FCH-JU)

(http://www.green-industrial-hydrogen.com/home/)

FCH technologies are technologically mature for different applications, but most of them are in the “death valley”



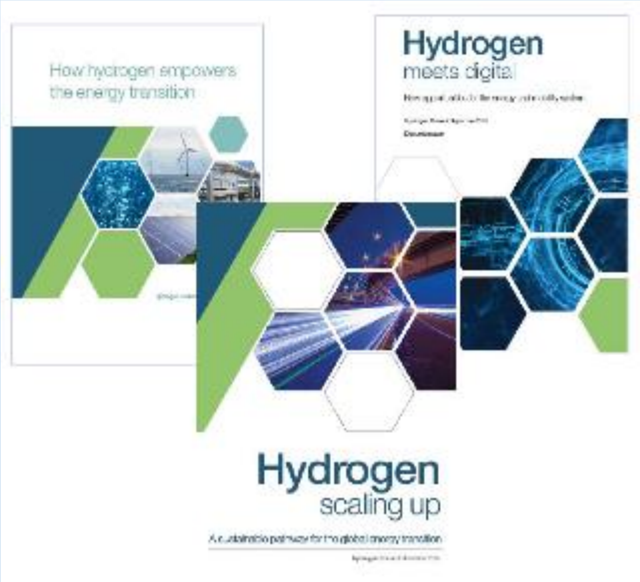
World and Europe
Market vision by 2030 - 2050

Hydrogen: a central pillar of the required energy transition

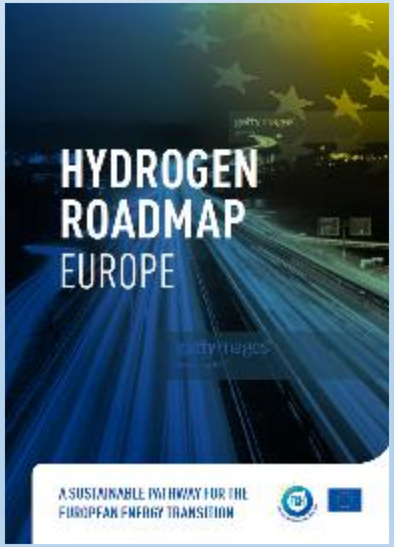
Hydrogen Europe Research

Objectives of the studies

- **Comprehensive quantified vision** and **roadmap** for deployment
- Not a forecast, but an **ambitious yet realistic** scenario
- Answers the question “How could hydrogen contribute to **achieving the two degree scenario**?”



World
November 2017

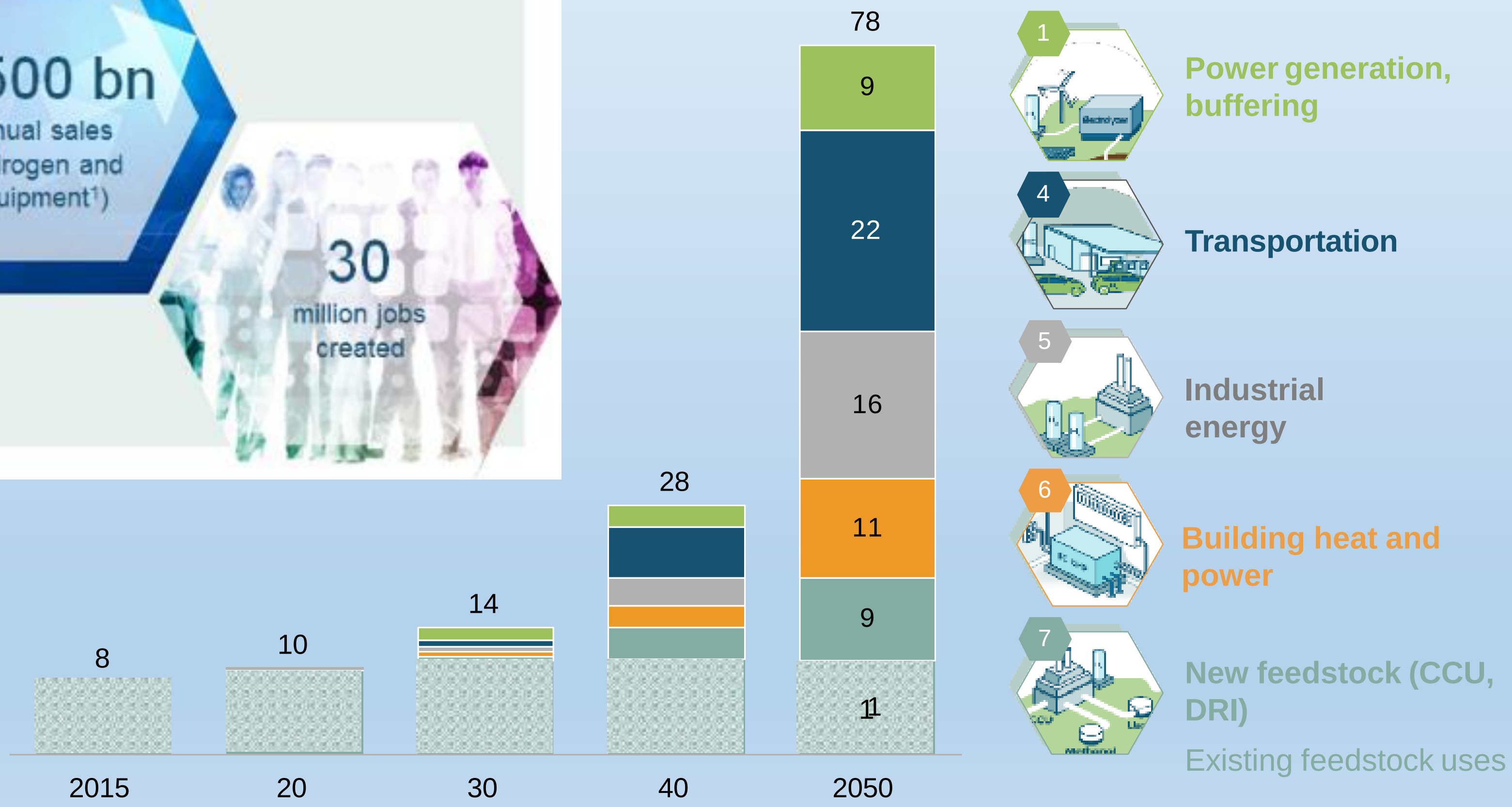


Europe
March 2019

Hydrogen: a central pillar of the required energy transition

Estimated impact in 2050

Potential global energy demand supplied with hydrogen, Exajoule (EJ)

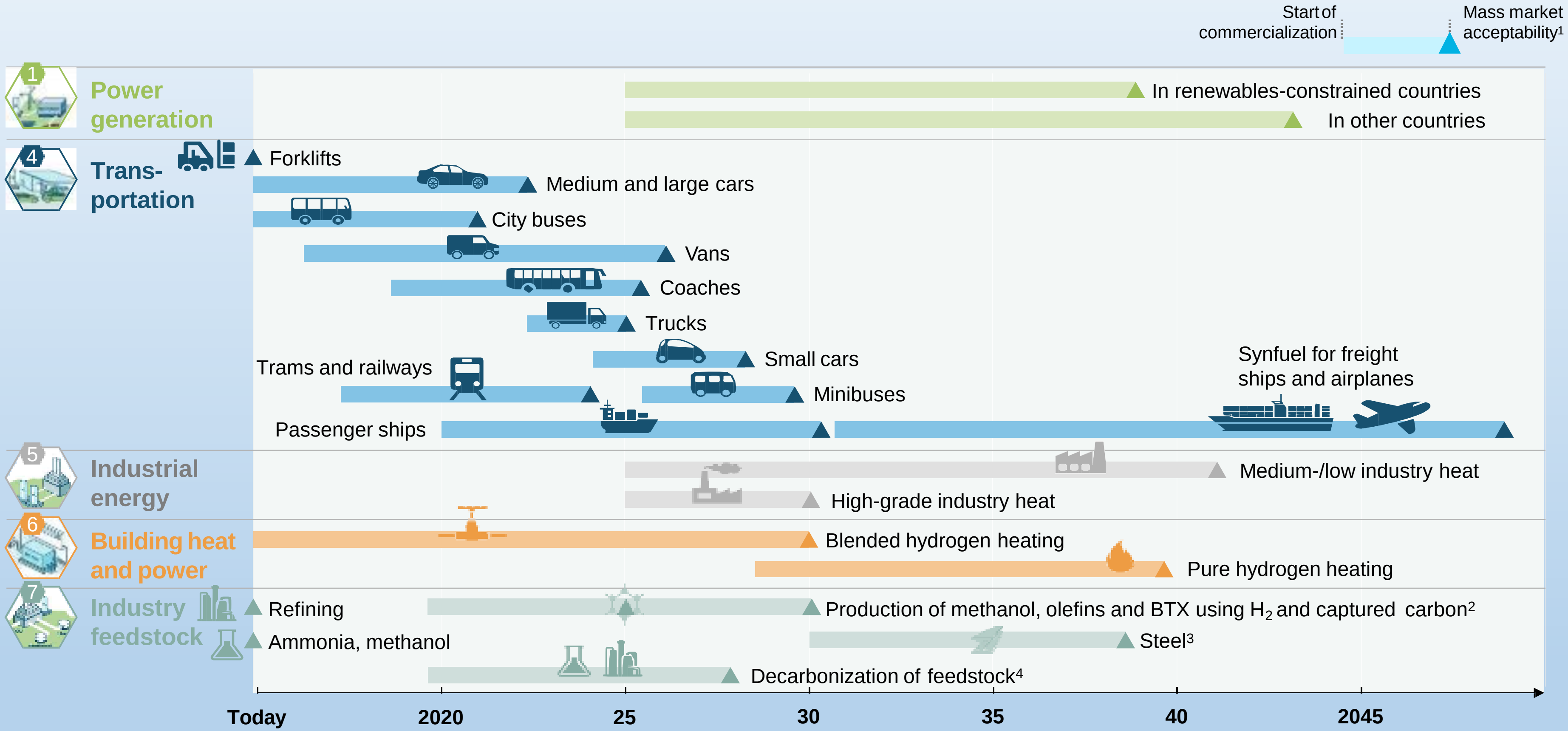


SOURCE: Hydrogen Council

Hydrogen: a central pillar of the required energy transition

Estimated impact in 2050

The technologies exist and are ready to be deployed



1 Mass market acceptability defined as sales >1% within segment in priority markets

2 Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock

3 DRI with green H_2, iron reduction in blast furnaces and other low-carbon steel making processes using H2

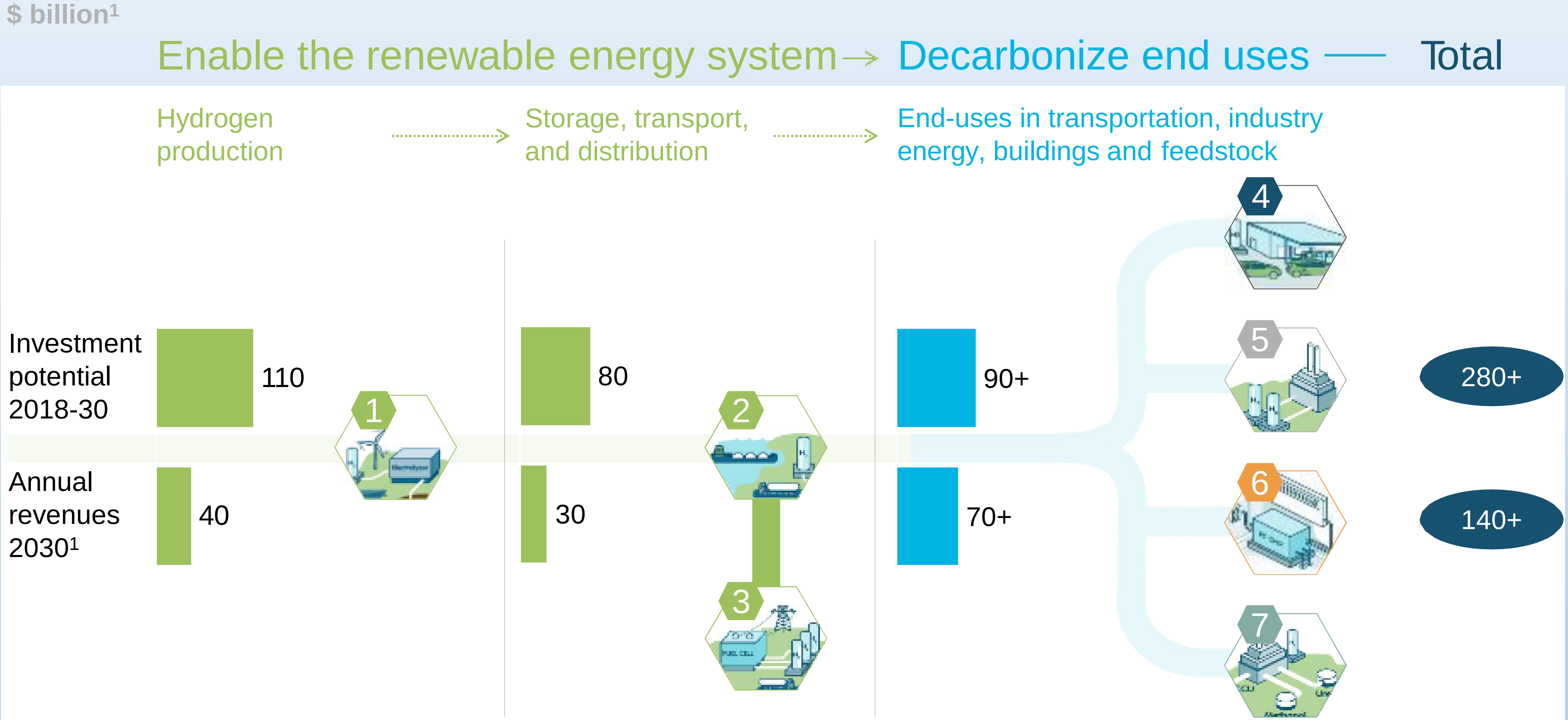
4 Market share refers to the amount of feedstock that is produced from low-carbon sources

SOURCE: Hydrogen Council

Hydrogen: a central pillar of the required energy transition

Hydrogen Europe Research

Investments of $280bn until 2030 build $140bn+ annual market



1 Excluding existing feedstock uses, considering only hydrogen value-added

The world already invests more than US$1.7 trillion in energy each year, including US$650 billion in oil and gas, US$300 billion in renewable electricity, and more than US$300 billion in the automotive industry

Hydrogen: a central pillar of the required energy transition

Hydrogen Europe Research

The case for acting now: Large-scale deployment initiatives underpinned by long-term policy frameworks to attract investors

Urgency to initiate scale-up to meet **climate change targets**

Hydrogen technology proven in a wide range of applications

Momentum in the industry – Hydrogen Council is established

Industry

Accelerate development and commercialization of products and build-out infrastructure to support large-scale deployment

Investors

Finance infrastructure and value chain development for large-scale deployment

Policymakers

Collaborate with industry to build national strategies and roadmaps and put in place long- term policy frameworks

Besides CO_2 abatement, deployment of the hydrogen roadmap also cuts local emissions, creates new markets and secures sustainable employment in EU

Hydrogen Europe
Research

2050 hydrogen vision

~24%	~560 Mt	~EUR 820bn	~15%	~5.4m
of final energy demand[1]	annual CO_2 abatement[2]	annual revenue (hydrogen and equipment)	reduction of local emissions (NO_x) relative to road transport	jobs (hydrogen, equipment, supplier industries)[3]

1 Including feedstock 2 Compared to the reference technology scenario 3 Excluding indirect effects

SOURCE: Hydrogen Roadmap Europe team

https://fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

World and Europe
Market vision by 2030 – 2050
State of Play

I. Industry

Hydrogen Council members have started investing and deploying

Hydrogen Europe Research

MEMBERSHIP QUADRUPLED IN 18 MONTHS – CLEAR MOMENTUM

Hydrogen Council Steering members

Supporting members

Hydrogen EUROPE Industry and research (200+ members)

Hydrogen Europe Research

Hydrogen Europe Industry

About 120+ members
~ 50% SME

Hydrogen Europe National Associations

16 members

Hydrogen Europe Research

73 members

World and Europe
Market vision by 2030 – 2050
State of Play

II. Public authorities

Hydrogen is on the international political agendas

G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth
June 15-16, 2019, Karuizawa, Japan
The importance of hydrogen will be referred in the Communique and Action Plan.
* It will be the first time to be mentioned on hydrogen in G20 Ministerial Communique.
* Hydrogen Report released at G20 by IEA

CEM -New Hydrogen Initiative
May 27-29, 2019, Vancouver, Canada
Objective: Advance policies, programs and projects to accelerate commercial scale deployment of hydrogen and fuel cell technologies across all sectors of the economy

MISSION - INNOVATION – Innovative Challenges 8 « Renewable and Clean Hydrogen Challenge"
May 27-29, 2019, Vancouver, Canada
Objective: To accelerate the development of a global hydrogen market by identifying and overcoming key technology barriers to the production, distribution, storage, and use of hydrogen at gigawatt scale

HEM - Hydrogen Energy Ministerial Meeting 2019
September 25, 2019, Tokyo, Japan
Objective: Follow up "Tokyo Statement" to realize it and set "Global Hydrogen Target" to share global goal.

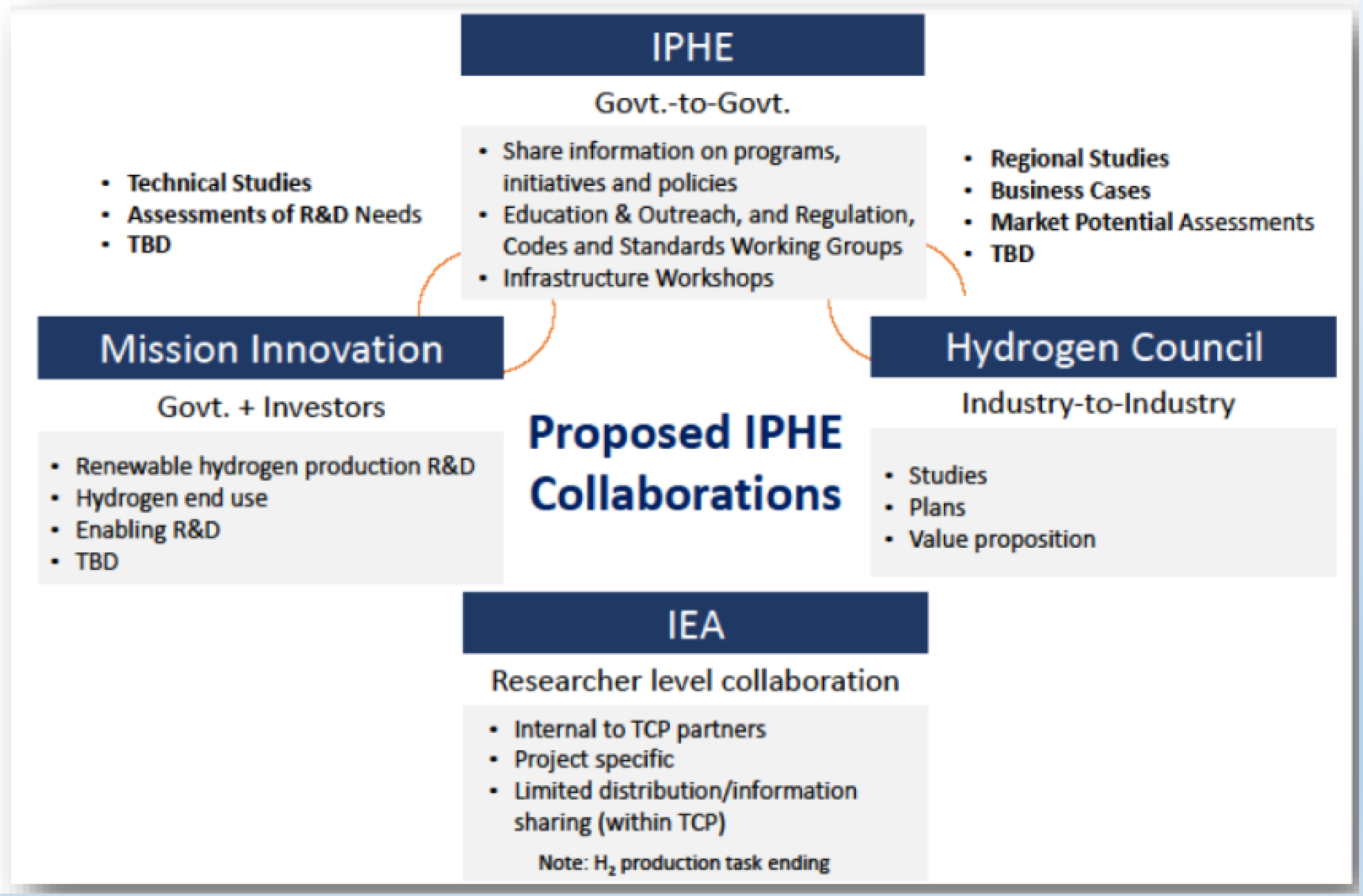
Hydrogen is on the international political agendas

The time is right to tap into hydrogen's potential to play a key role in a clean, secure and affordable energy future.

The IEA's 7 key recommendations to scale up hydrogen

1. **Establish a role for hydrogen in long-term energy strategies.**
2. **Stimulate commercial demand for clean hydrogen.**
3. **Address investment risks of first-movers.**
4. **Support R&D to bring down costs.** Alongside cost reductions from economies of scale, R&D is crucial to lower costs and improve performance, including for fuel cells, hydrogen based fuels and electrolysers. Government actions, including use of public funds, are critical in setting the research agenda, taking risks and attracting private capital for innovation.
5. **Eliminate unnecessary regulatory barriers and harmonise standards.**
6. **Engage internationally and track progress.**
7. **Focus on four key opportunities to further increase momentum over the next decade.**
   - Make the most of existing industrial ports to turn them into hubs for lower-cost, lower-carbon hydrogen.
   - Use existing gas infrastructure to spur new clean hydrogen supplies.
   - Support transport fleets, freight and corridors to make fuel-cell vehicles more competitive.
   - Establish the first shipping routes to kick-start the international hydrogen trade.

Hydrogen: International organizations

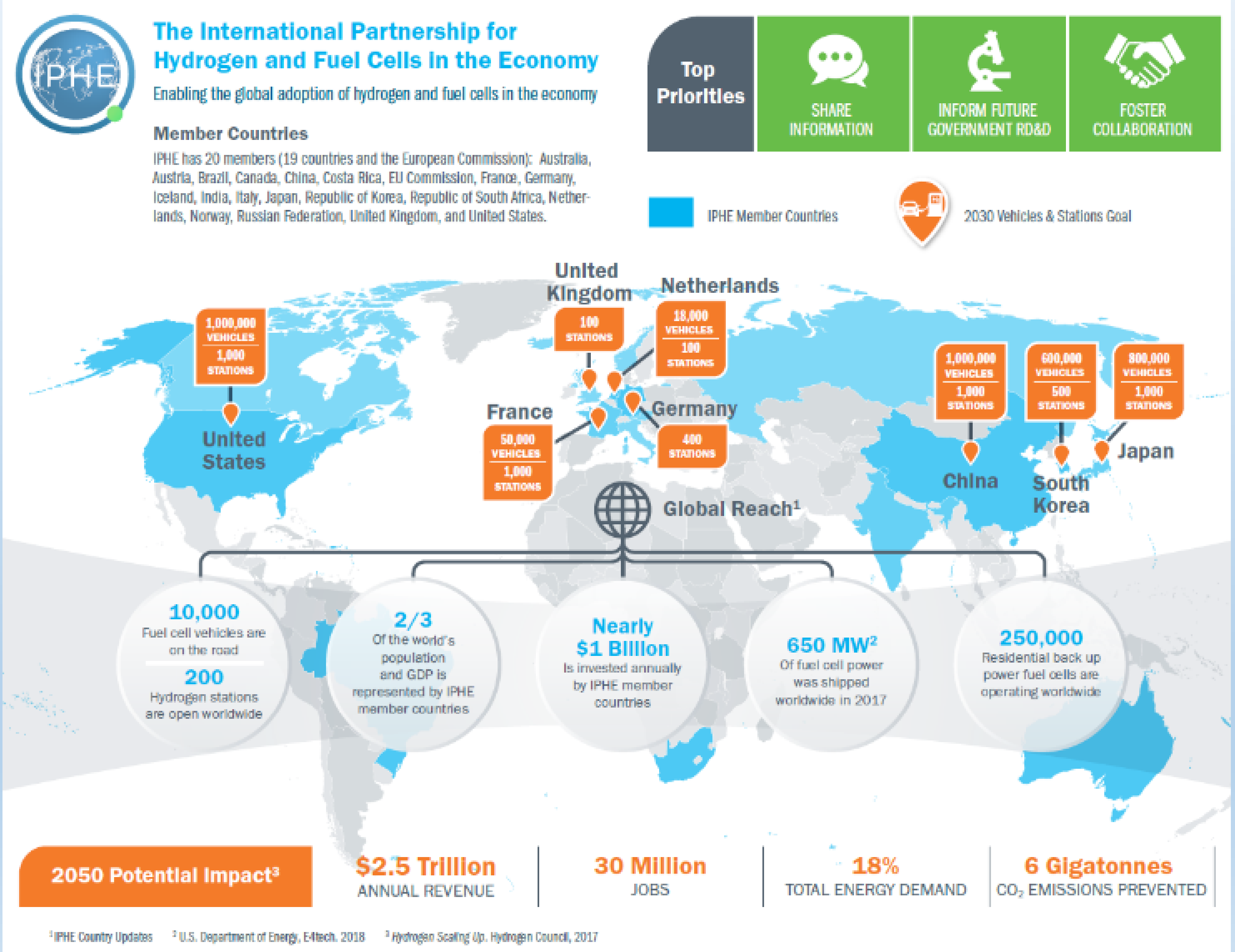


Hydrogen: many national hydrogen plans

Hydrogen Europe
Research

International Partnership for Hydrogen and Fuel Cells in the Economy

International governmental partnership with of 19 member countries and the European Commission



European Union’s targets for climate & energy

Hydrogen Europe Research

European Commission

2020	**-20 %** GHG Emissions	**20%** Renewable Energy	**20 %** Energy Efficiency
2030	**≥-40 %** GHG Emissions	**≥ 32 %** Renewable* Energy	**≥32,5 %** Energy Efficiency*
2050	**-80 to 95%** GHG Emissions (-100%?)		

COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

**targets revised upwards in 2018*

EU strategy for a climate neutral Europe by 2050

Hydrogen Europe Research

November 2018

Detailed assessment supported by scenario analysis

	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (EE)	Circular Economy (CIRC)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable Lifestyles (1.5LIFE)
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency	Cost-efficient combination of options from 2°C scenarios	Based on COMBO with more BECCS, CCS	Based on COMBO and CIRC with lifestyle changes
GHG target in 2050	-80% GHG (excluding sinks) [“well below 2°C” ambition]					-90% GHG (incl. sinks)	-100% GHG (incl. sinks) [“1.5°C” ambition]	
Major Common Assumptions	• Higher energy efficiency post 2030 • Deployment of sustainable, advanced biofuels • Moderate circular economy measures • Digitilisation					• Market coordination for infrastructure deployment • BECCS present only post-2050 in 2°C scenarios • Significant learning by doing for low carbon technologies • Significant improvements in the efficiency of the transport system.		
Power sector	Power is nearly decarbonised by 2050. Strong penetration of RES facilitated by system optimization (demand-side response, storage, interconnections, role of prosumers). Nuclear still plays a role in the power sector and CCS deployment faces limitations.							
Industry	Electrification of processes	Use of H2 in targeted applications	Use of e-gas in targeted applications	Reducing energy demand via Energy Efficiency	Higher recycling rates, material substitution, circular measures	Combination of most Cost-efficient options from “well below 2°C” scenarios with targeted application (excluding CIRC)	COMBO but stronger	CIRC+COMBO but stronger
Buildings	Increased deployment of heat pumps	Deployment of H2 for heating	Deployment of e-gas for heating	Increased renovation rates and depth	Sustainable buildings			CIRC+COMBO but stronger
Transport sector	Faster electrification for all transport modes	H2 deployment for HDVs and some for LDVs	E-fuels deployment for all modes	Increased modal shift	Mobility as a service			• CIRC+COMBO but stronger • Alternatives to air travel
Other Drivers		H2 in gas distribution grid	E-gas in gas distribution grid				Limited enhancement natural sink	• Dietary changes • Enhancement natural sink

- The Commission favours “climate neutrality” by 2050.
- *“[..]The role of **hydrogen is likely to become more prominent** in a fully decarbonised energy system […]”.*
- *“[…] **EU research** should focus on transformational carbon-neutral solutions in areas such as electrification (renewables, smart networks and batteries), **hydrogen and fuel cells**, **energy storage, carbon-neutral transformation of energy intensive industries**, the circular economy, the bio-economy and sustainable intensification of agriculture and forestry […]”.*

The European "Hydrogen Initiative"

Hydrogen Europe
Research

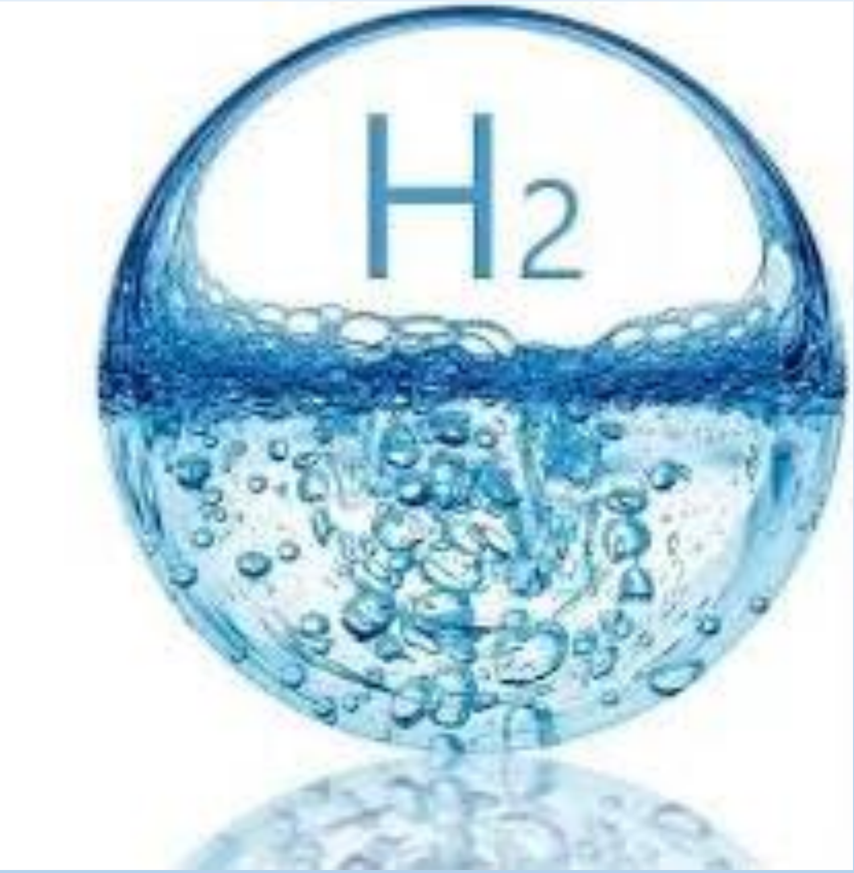
European Commission

UK and Sweden have not signed as EU M/S

"[…] *We, the signatories of this initiative, gathered in Linz, Austria, on the 17th and 18th of September 2018,* ***collectively aim to maximise the great potentials of sustainable hydrogen technology*** *for the decarbonisation of multiple sectors, the energy system and for the long-term energy security of the EU*.

[…] *Furthermore, we encourage third countries and industry to join our efforts set out in this declaration to promote worldwide supporting framework for sustainable hydrogen technology* […]."

Research has still a major role to play



- Decrease products, systems and services costs
- Improve durability & performances
- Scale up manufacturing at industrial level
- Prepare the next generation through technological breakthroughs
- Provide case studies for safety and regulations
- Educate and train to ensure a highly qualified workforce

a European R&D community in FCH technologies

73 members from 20 members states

Virtual Competence Centres in European FCH R&D

In **close collaboration with the industry association** and establishing together with the European Commission common objectives leading to a competitive Europe in Fuel Cells and Hydrogen technologies.

Draft Council conclusions on the Future of Energy Systems in the Energy Union

Hydrogen Europe
Research

European Council
Council of the European Union

Council of the EU | Press release | 25/06/2019 | 13:25

Council outlines principles and priorities for the future of energy systems in the Energy Union

The Council today adopted a set of conclusions on the future of energy systems in the Energy Union. They identify priorities and principles for future policy-making aimed at ensuring the energy transition towards an **affordable, safe, competitive, secure and sustainable energy system**.

⇒ CALLS on the European Commission to:

⇒ Promote sector coupling and sector integration

⇒ Analyse sector coupling and sector integration technologies, **including the production of hydrogen,** in particular with regards to regulatory and market barriers and based on this analysis explore possible initiatives to **improve the functioning and integration of electricity and gas markets regarding the deployment of such technologies and energy carriers.**

⇒ Reflect the efforts required to reach the **EU energy and climate targets for 2030 in the context of any revision of the EU State aid rules** which may be carried out as a result of the fitness check.

- Hydrogen energy has been selected as one of the **European critical value chain** → IPCEI

Hydrogen Europe Research

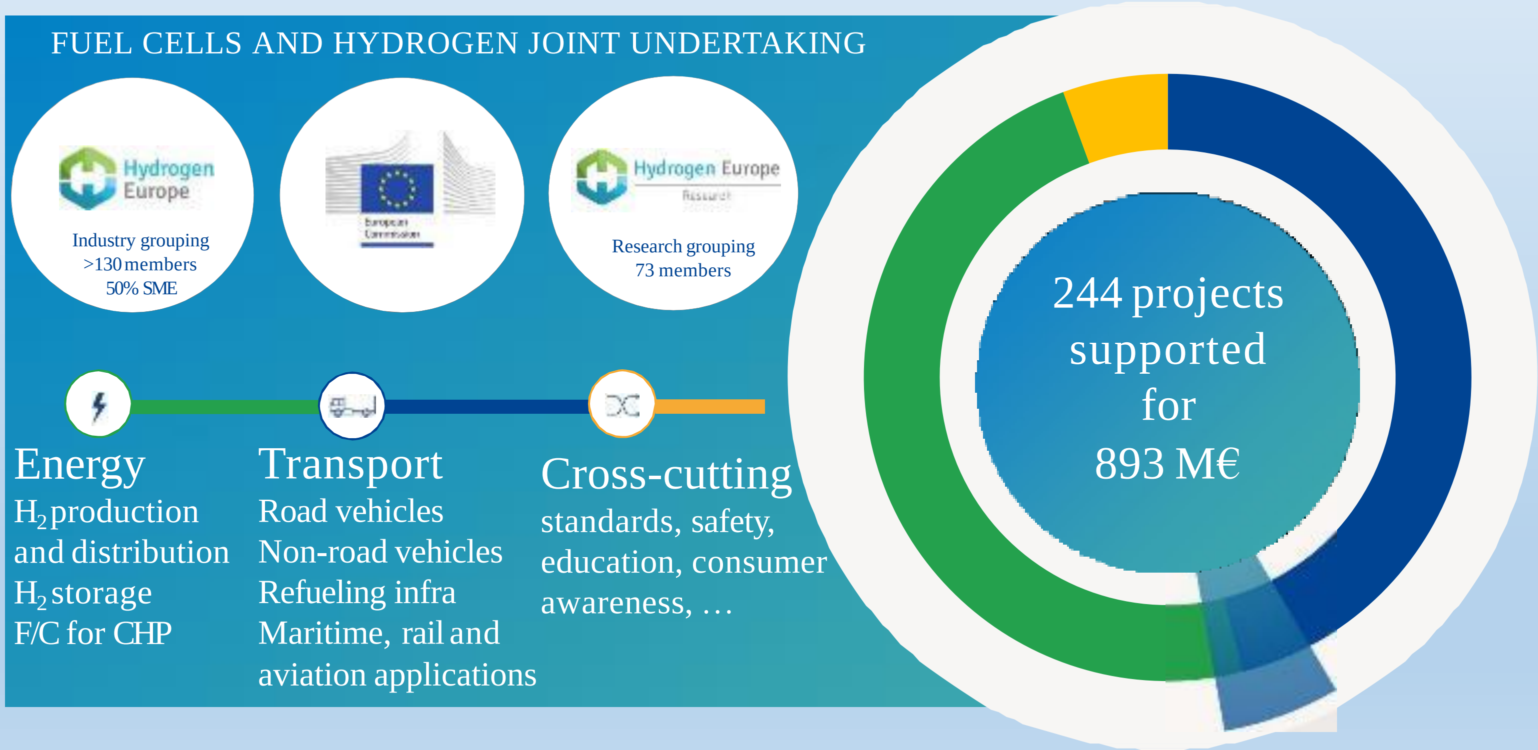
World and Europe
Market vision by 2030 – 2050
State of Play

III. European Public – Private Partnership

Strong public-private partnership with a focused objective

Hydrogen Europe Research

A combined private-public of 1.73 billion Euros has been invested to bring
- research to validation and field demonstration
- products to market readiness by 2020



47 %
418 million euros
135 projects

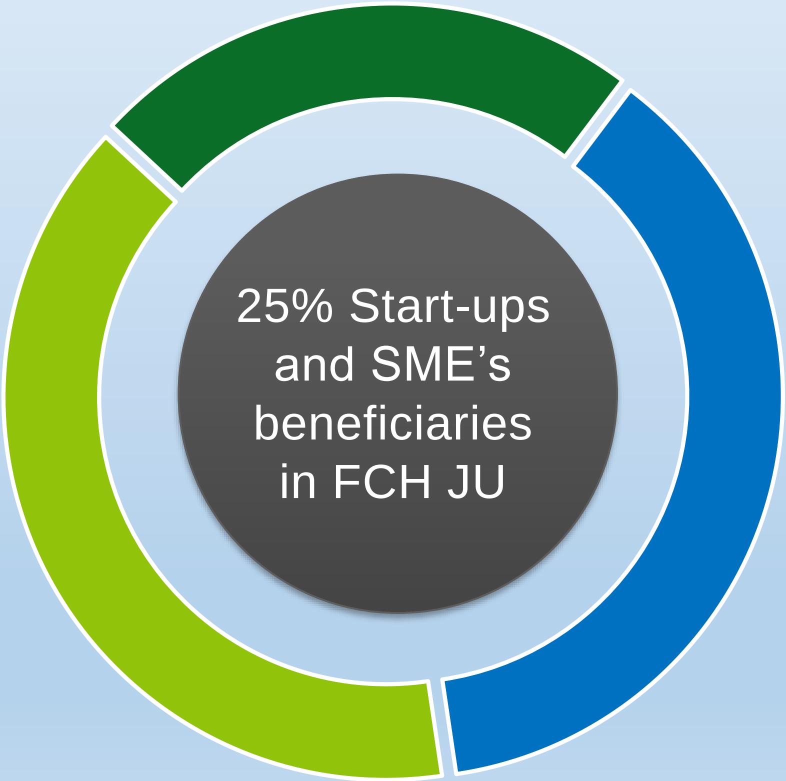
42 %
376 million euros
65 projects

6 %
53 million euros
40 projects

5 %
46 million euros
4 projects

Similar leverage of other sources of funding: 892 M€

Start-ups and SMEs benefit from FCH-JU research projects



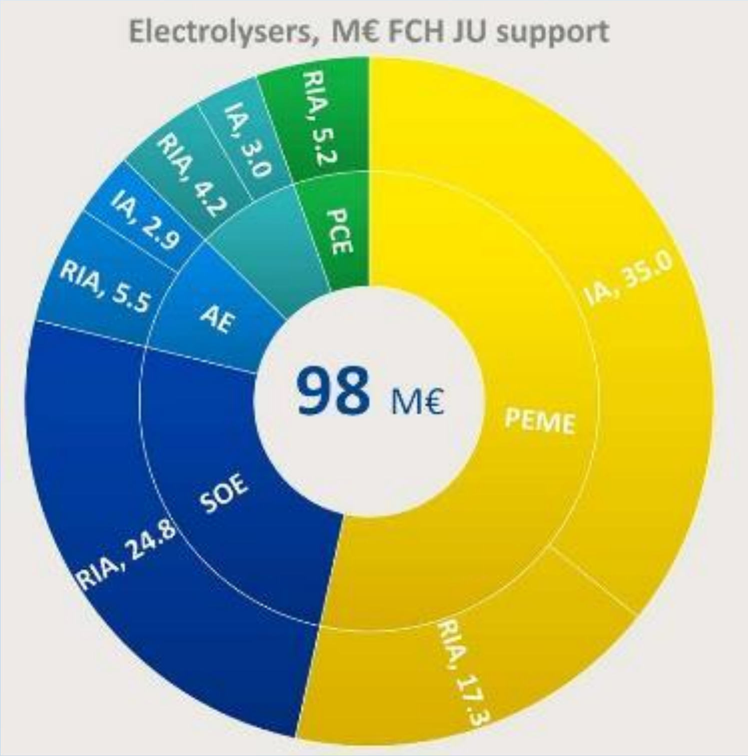
MAHYTEC
borit
elcogen
Fuel cell technology
OPTIMUM CPV
COMPOSITE PRESSURE VESSEL
H2 LOGIC
Hydrogen fueling solutions
Sylfen
ITM POWER
Energy Storage | Clean Fuel
sunfire
POWERCELL
SOLID POWER
HYGEAR
ENGINEERING FOR SUSTAINABLE GROWTH
SYMBIO
convion
FUEL CELL SYSTEMS
Intelligent Energy

Renewable H_2 production and industry

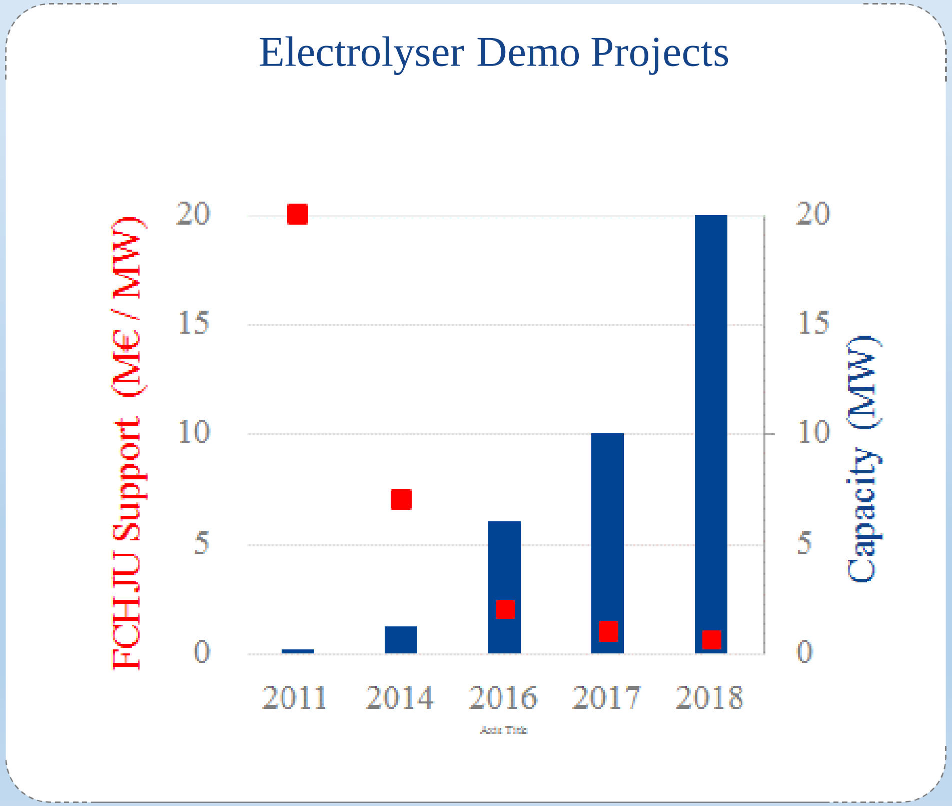
Electrolysis for energy storage and greening of industry

The potential of hydrogen for the greening of energy intensive industries (EII) has led to fast capacity increase and cost reduction.

HRS Steel industry Refineries Food industry



31 Projects



Research for electrolysis

Active community of OEMs and R&D institutions safeguarding Europe's leading position in electrolysis

Low temperature electrolysis

- Capex targets for AE and PEME < 1.2 k€/kW
- Current density > 3 A/cm^2
- Efficiency at system level < 55 kWh/kg
- Dynamic op / Testing Harmo / Degradation / Diagnostics

High temperature electrolysis

- Electricity consumption < 40 kWh/kg
- Production loss rate < 1.9%/1000h
- Availability >95%, reversible efficiency 54%
- Co-electrolysis / Integrated methanation

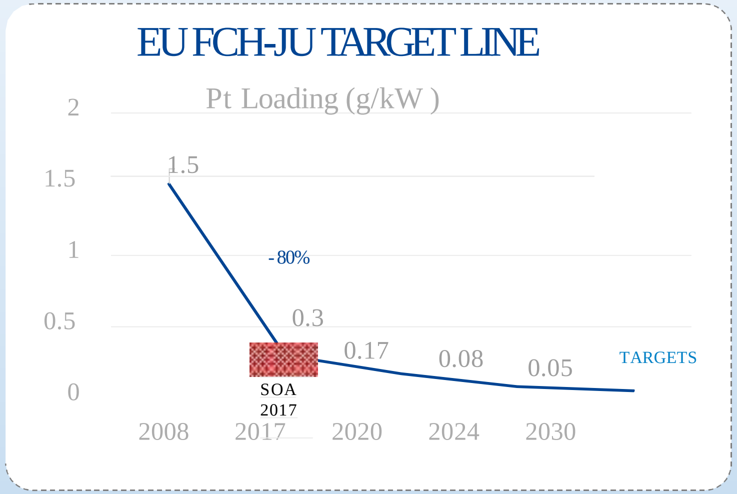
TRANSPORT

Development of new generation of stacks and tanks

Hydrogen Europe Research

Materials key to MEA to

- Reduce costs
- Improve durability and performance
- Improve Scalability of catalyst production



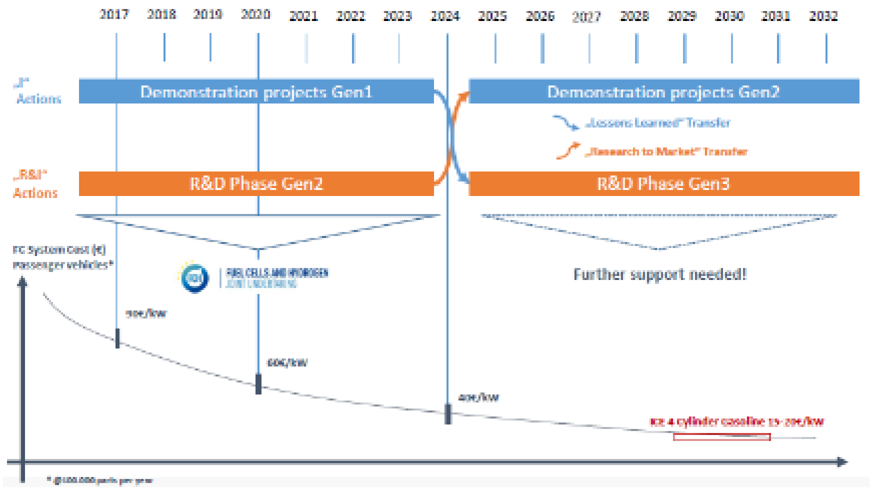
- Since 2011 efforts to reduce/replace PGM
- 9 projects/ € 41.5 Million funding
- \- 80 % Pt loading between 2008 and 2017

a) 4 projects ongoing/ € 17 Million funding

b) Next milestone -43% Pt by 2020

c) Projects working on replacement of PGM

European automotive stack



Establish a EU supply chain for a fuel cell stack

Automotive tanks

- Reduced cost by 5 to 3,000 €
- 20% reduced mass by design
- Use of robots to produce

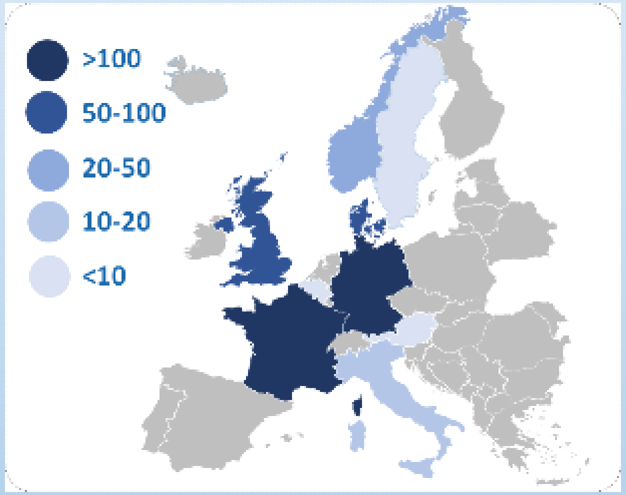
Simultaneously roll-out of vehicles and infrastructure in Europe

Hydrogen Europe Research

Europe supports FC vehicles and Hydrogen Refuelling Stations thanks to EU programs (FCH-JU & CEF) & national programs.

Fuel cell vehicles (2018)

625 cars deployed, 1900 planned



Rated consumption < 0.90 kg/100km

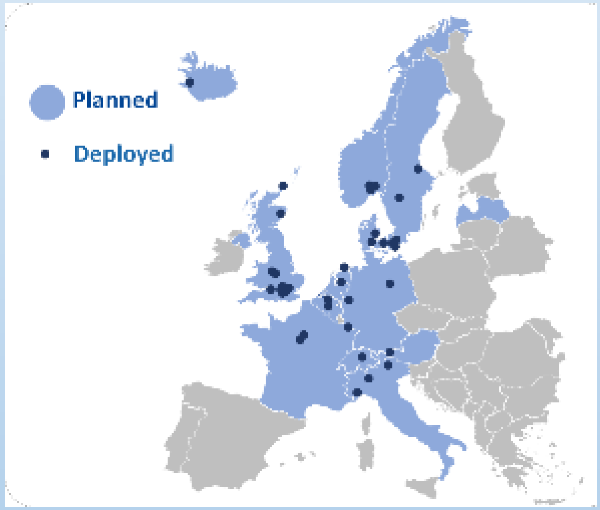
Availability close to 100%

- EU OEM's: small demo's ~2025, mass production 2025~
- European Tier 1 strongly engaged
- FIA: In 2024 a H_2 class @ Le Mans

Hydrogen Refuelling stations (2018)

41 HRS deployed, 100 planned

85% ***green hydrogen***



Permitting down from 24 to 18 months

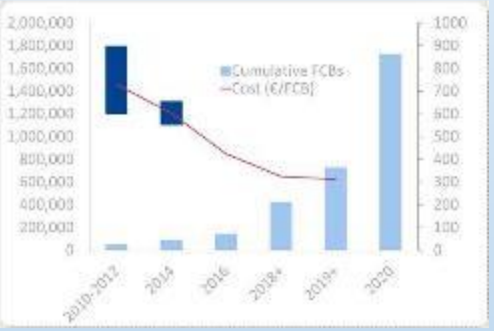
Availability >99% (buses), >97% (cars)

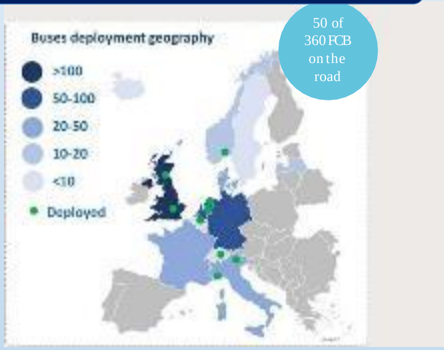
Roll-out of FC buses accelerates & FC Trucks are starting to appear

Hydrogen Europe Research

Europe is supporting **360 Hydrogen buses** deployment that lead to a **price reduction of 66% vs 2010** while worldwide there is a clear traction towards Hydrogen for trucks due to the limited range of batteries.

Buses

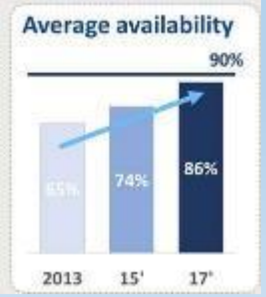




10 European OEM's are developing H_2 buses: www.fuelcellbuses.eu

88% green hydrogen

Achieved
- > 6,000,000 km driven since projects started
- > 92 t of H_2 consumed only in 2017
- > 25,000 h lifetime reached
- 625,000 €/bus offered
- From order to operation, 18m delivery time



Trucks

REVIVE: H2 Garbage trucks in 8 EU cities

VDL – COLRUYT

ASKO-SCANIA

Hyundai signs deal to sell 1,000 hydrogen-powered trucks in Switzerland

Norway aims for 1000 hydrogen trucks by 2023

Nicola Truck

Toyota Truck @LA port

Toyota & 7-eleven partnering

FCH-JU started with Fuel Cells in trucks for APU's but was found to expensive, therefore focus shifted to developing and testing trucks with range-extenders or fuel cell only e.g.: garbage trucks in cities.

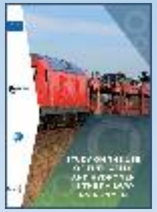
Rail, Aviation and Maritime are discovering Hydrogen and Fuel Cells

The first business models are appearing in hard to abate sectors

- 42% of EU railway not electrified
- H_2 train requires half the investment vs full electric train (catenary 1 M€ / km)
- Sept. '18 commercial operation starts in Germany. Other EU countries are on the way

- In 2016 first 4-seater plane propelled by H_2 took off from Bonn airport
- Development of H_2 powered small business jets ongoing ~2030
- Auxiliary power (infotainment / galleys) produced by H_2 for big airplanes (maiden flight in 2019)

- First demo projects appear
- H_2 needed to reach IMO target of 50% $C0_2$ reduction by 2050
- URGENT need for regulation to homologate a H_2 powered ship
- R&D needed e.g. LH_2 storage, MW scale Fuel Cells



Study on the use of fuel cells and hydrogen in the railway environment has just been released: https://fch.europa.eu/publications/study-use-fuel-cells-and-hydrogen-railway-environment

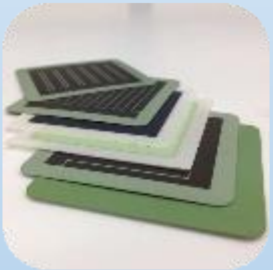
Heating and Cooling

Material Research as a cornerstone for highly efficient SOFCs

Hydrogen Europe Research

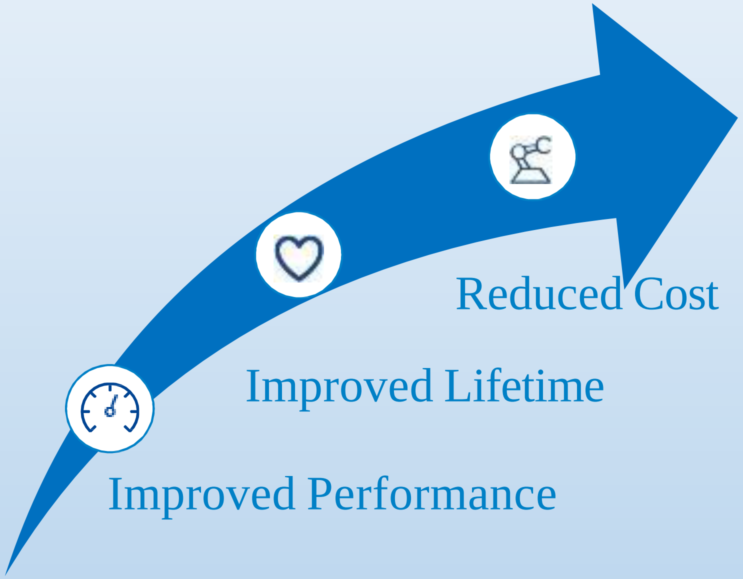
First products in the market – Material Research necessary to further reduce cost

- €40 Million Funding
- 18 Research Projects



Material Research on:

- Electrolytes
- Electrodes
- Interconnects
- Sealants
- Protective coatings



Electrical Efficiencies exceeding targets

Efficiency @Stack level	Voltage degradation @stack level	Efficiency @system level
η_{el} = 74%	0.2%/1000h	η_{el} = 60%

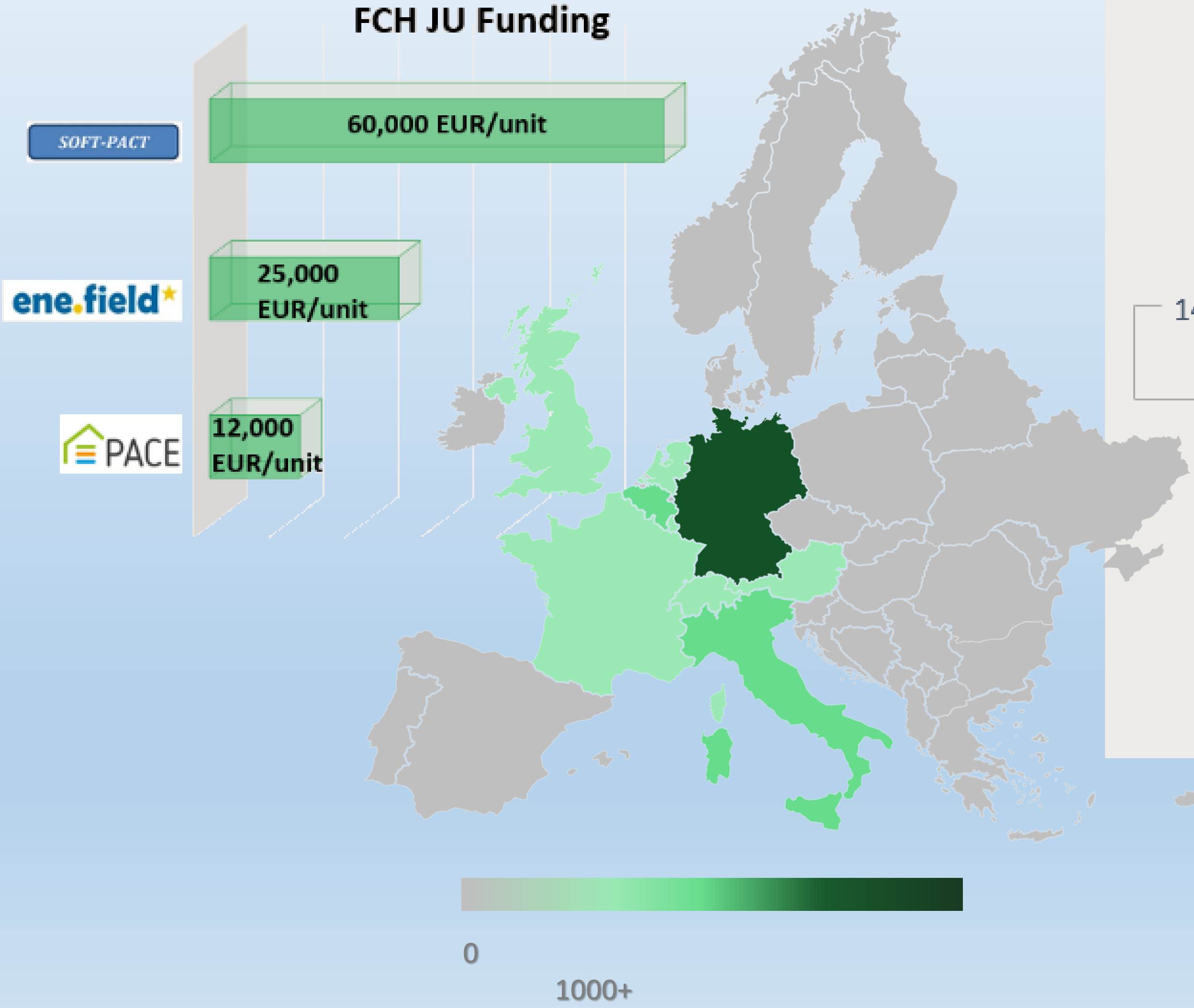
Next steps - Evolution

- Next generation materials for novel cells
- Decreasing the use of high cost and critical raw materials
- €5 Million Funding Available in 2019

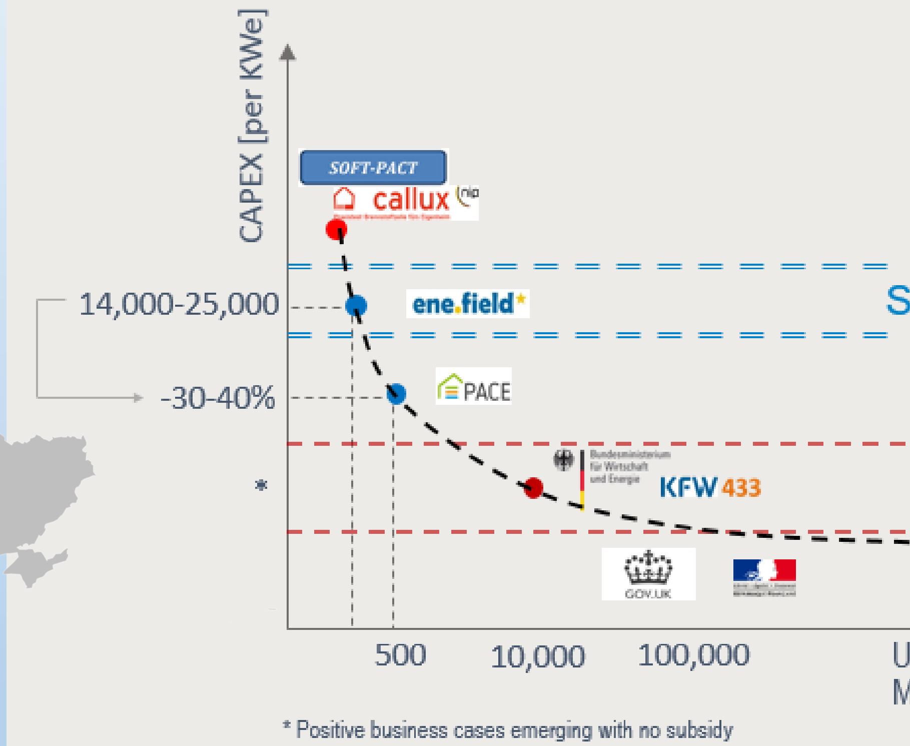
Over 1000 fuel cell µCHP systems installed across EU

Hydrogen Europe Research

Track record of domestic heat and power systems created



0.5~1.5 kW



1046 units deployed under ene.field project
Over 1 MWe capacity installed
>5 million operating hours
Additional >1,000 units deployed under German scheme

Over 1000 fuel cell µCHP systems installed across EU

Hydrogen Europe Research

Track record of domestic heat and power systems created

50~200 kW

1 ~2 MW

175kW SOFC in waste water treatment plant, Turin Italy Area will guarantee the supply of around 30% of the site electrical consumption, and almost 100% of the thermal requirement.

DURATION: 2015-2020 with FCH JU Funding: ~4.5M€

2MW plant at Ynnovate, Yingkou (province Liaoning), China Design, build and operate a 2 MW power generator, with full integration of heat and power with an existing chlorine production plant. Fully automated way of operation + remote control

DURATION: 2015-2018 with FCH JU Funding: ~5.5M€

Overarching

Towards a hydrogen society

Integration of renewable energies

BIG HIT

1.5 MW of PEM electrolysis for ~50 t pa of hydrogen

transported by sea to Kirkwall in 5 hydrogen trailers

to heat two local schools, to fuel a 75kW fuel cell which will provide heat and power to the harbour buildings, a marina and 3 ferries when docked and a HRS for a fleet of 10 fuel cell vehicles

Improve Local Knowledge & Public Acceptance of Hydrogen

SAFETY, STANDARDS,

EDUCATION…

Towards a hydrogen society

Cross-cutting activities comprise projects and complementary actions

Projects

- Legal, administrative and regulatory framework
- Education and training
- Safety
- Social awareness & public acceptance
- Sustainability
- Databases & Monitoring

Complementary Actions

- Regulations, Codes and Standards Strategy Coordination Group (RCS SCG)

- European Hydrogen Safety Panel

- Collaboration with JRC
- Additional initiatives, studies …

Codes and standards

Hydrogen Europe Research

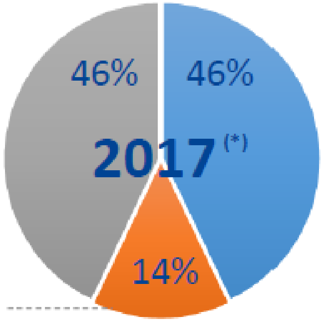
Providing science-based information to improve and develop standards

H_2 Production	H_2 storage	H_2 Distribution	H_2 Consumption
HyCoRA	HyCOMP, FireCOMP, HyPACTOR	HyTransfer, MATHRYCE, HyCoRA, Hy-AC	STACK-TEST, SOCTESQA

Targeting standards at European and International level

International Electrotechnical Commission — IEC

CEN CENELEC
European Committee for Standardization
European Committee for Electrotechnical Standardization



ISO
International Standardization Organization

* 5 projects on-going over 2017

Preparing the European workforce

Projects running include training packs in different languages, formats, means, etc.

HyResponse

Training for first responders

KnowHy

Courses for professionals/ general public

TeacHy

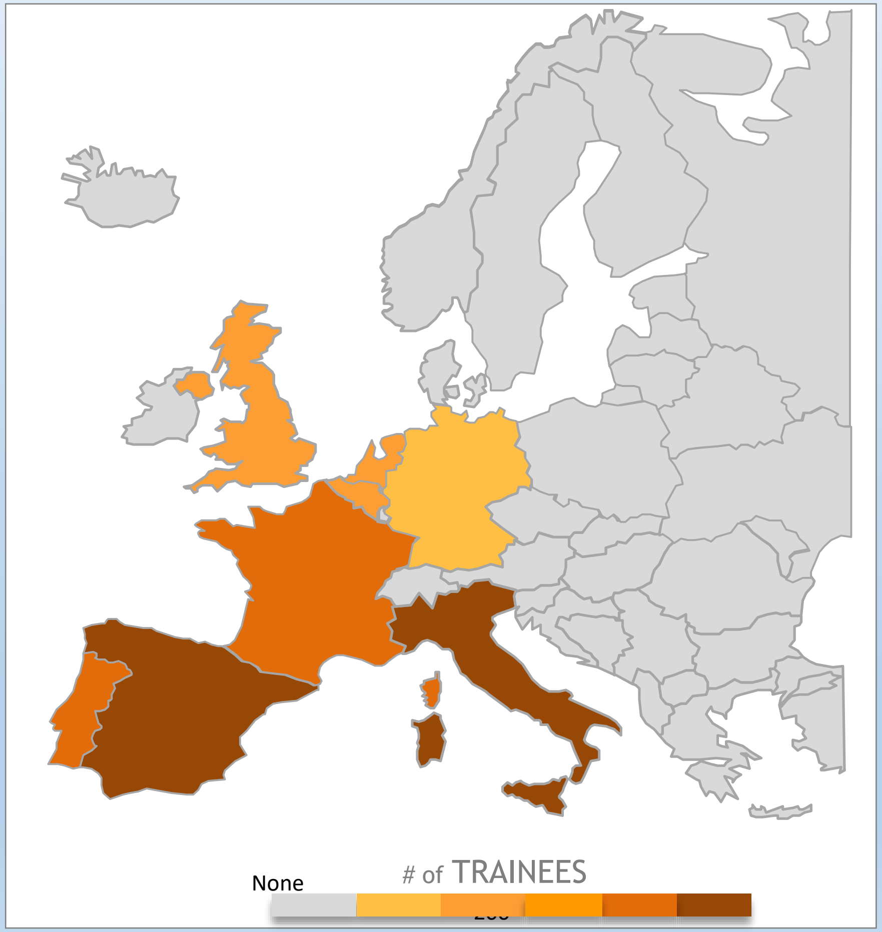
undergraduate & graduate education PhD BEng/BSc MEng/MSc

Country	Total
BE	33
DE	8
ES	170
FR	71
IT	188
NL	35
PT	80
UK	21

2016

>600 trainees
8 countries
7 languages

in person training, e-learning, blended learning…virtual reality, serious games… …mock-up installations…



Outreach

FCH-JU initiative: 92 Regions/Cities from 22 countries (about 25% of EU) study to:

(1) assess FCH applications,
(2) identifying financing/funding options
(3) develop roadmaps,
(4) engage their stakeholders

Belgium
>Flanders
>Pom West-Vlaanderen

United Kingdom
>Swindon and Wiltshire
>Aberdeen
>Birmingham
>Cornwall
>Dundee
>Fife
>Leeds
>London (Greater London Authority)
>Newcastle
>Orkney Islands
>Oxfordshire
>Perth and Kinross
>Manchester
>Tees Valley

Norway
>Akershus
>Møre og Romsdal
>Oppland County Municipal
>Sogn og Fjordane

Iceland
>Reykjavik

Sweden
>Gavleborg
>Mariestad

Finland
>Kokkola

Germany
>Baden-Württemberg
>Bremerhaven
>Hamburg
>HyCologne-Hydrogen Region Rhineland
>Kreis Steinfurt
>North Rhine-Westphalia
>Heide region
>HYPOS (East Germany)
>Recklinghausen
>Saxony-Anhalt

France
>Auvergne Rhone-Alpes
>Bourgogne-Franche-Comté
>Centre-Val de Loire
>Grenoble
>Grand Dole
>La Roche sur Yon
>Normandie
>Occitanie-Phyrenees
>Orléans
>Pays de la Loire
>Pays de St Gilles

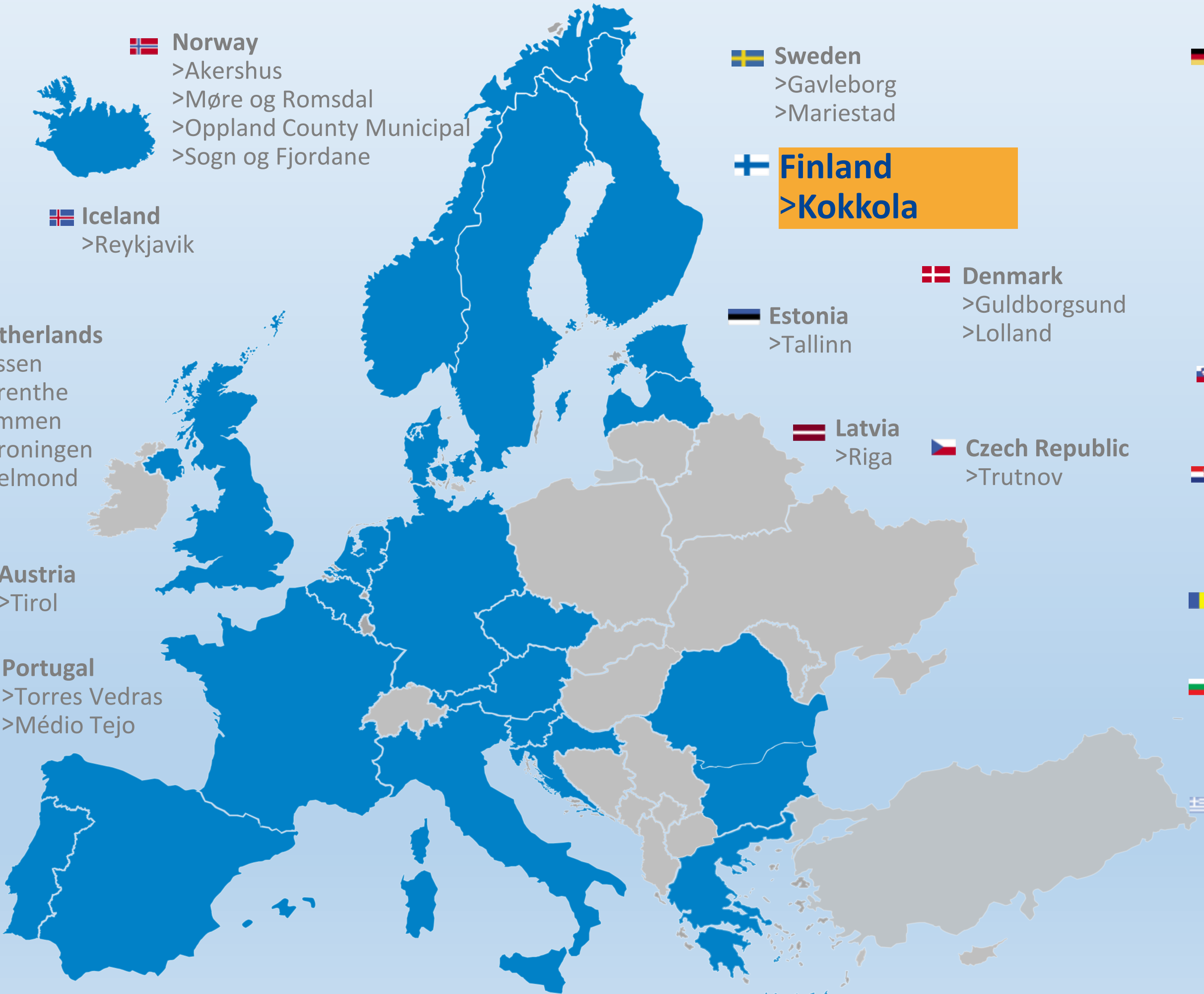
Spain
>Aragon
>Barcelona
>Cantabria
>Castilla – La Mancha
>Murcia
>Port of Valencia
>Puertollano
>Valladolid

Netherlands
>Assen
>Drenthe
>Emmen
>Groningen
>Helmond

Italy
>Lazio
>South Tyrol
>Favignana
>Torino
>Venice
>Toscana

Austria
>Tirol

Portugal
>Torres Vedras
>Médio Tejo



Estonia
>Tallinn

Denmark
>Guldborgsund
>Lolland

Latvia
>Riga

Czech Republic
>Trutnov

Slovenia
>Velenje

Croatia
>Split
>Split-Dalmatia County

Romania
> Constanța

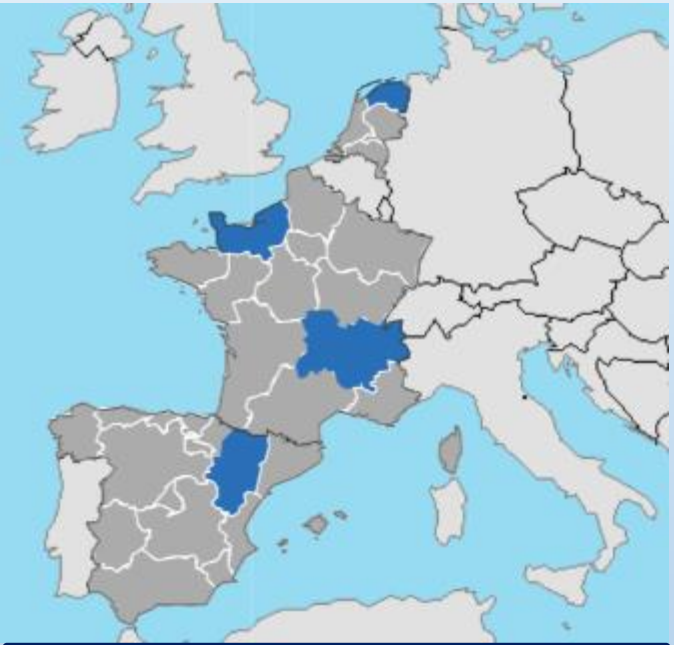
Bulgaria
>Bulgarian Ports
>Sofia

Greece
>Alimos
>Agia Paraskevi
>Ierapetra
>Kozani
>Milos
>Vrilissia
>Kalymnos
>Heraklion
>Western Macedonia
>Papagou-Halargos
>Region of Crete

Signing ceremony 23 Nov. 2016 with CoR President Markku Markkula + FCH-JU and 40 regions

European Hydrogen Valleys Partnership

Established under the EC smart specialization platform for Industrial Modernization



Partnership led by:
- North of Netherlands (NL)
- Auvergne-Rhône Alpes (FR)
- Le Normandy (FR)
- Aragon (ES)

Above 40 regions plan to join

Launched on 22nd May 2019 at EVS 32 in Lyon

http://s3platform.jrc.ec.europa.eu/hydrogen-valleys

World and Europe
Market vision by 2030 – 2050
State of Play

IV. 2030 European Technology Roadmaps

HE/HER strategic plan 2020-2030 for FCH technologies

Hydrogen Europe
Research

1 Low carbon hydrogen production	Electrolysis Other modes of hydrogen production
2 Hydrogen production enables increased renewables	Role of electrolysis in energy system Large scale hydrogen storage
3 Hydrogen is delivered at low cost	Key technologies for distribution Transport of hydrogen by road, ship etc Transport and storage in liquid carriers
4 Affordable hydrogen is dispensed to transport applications	Hydrogen refuelling stations
5 Fuel cell vehicles (road, rail, ship) are competitively priced	Technology Building Blocks Cars, 2-3 wheelers, vans Buses & coaches Trucks Material handling Rail Maritime Aviation
6 Hydrogen meets demands for heat and power	Hydrogen in the gas grid Stationary fuel cells Domestic and Commercial Burners
7 Hydrogen decarbonises industry	Hydrogen in industry
8 Horizontal activities support the development of hydrogen	Supply chains & other cross cutting issues

To achieve this vision, the sector needs to achieve a range of 2030 targets

Hydrogen Europe Research

1. A diversity of clean hydrogen production routes have matured, *producing hydrogen at a cost of €1.5-3/kg, allowing penetration into mass markets .*

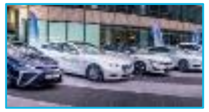
2. Hydrogen production enables increased penetration of 100's of MWs of renewable electricity.

3. Hydrogen can be moved to target markets at low cost.

Transport costs <€1/kg at scale.

4. An affordable zero carbon fuel can be delivered to fuel cell transport applications, *with total fuel cost below diesel, taking into account taxation.*

5. Fuel cell vehicles (road, rail, ships) are produced at a price equivalent to other vehicle types, *with a compelling user case.*



6. Hydrogen meets demands for heat and power at a meaningful scale, with:

- 25 TWh of hydrogen blended into the natural gas grid
- Fuel cell CHP efficiency contributes to reducing energy usage, with 0.5 million FC CHP units deployed in the EU.

7. Hydrogen is actively displacing fossil fuels as a clean energy input into a wide range of industrial processes:

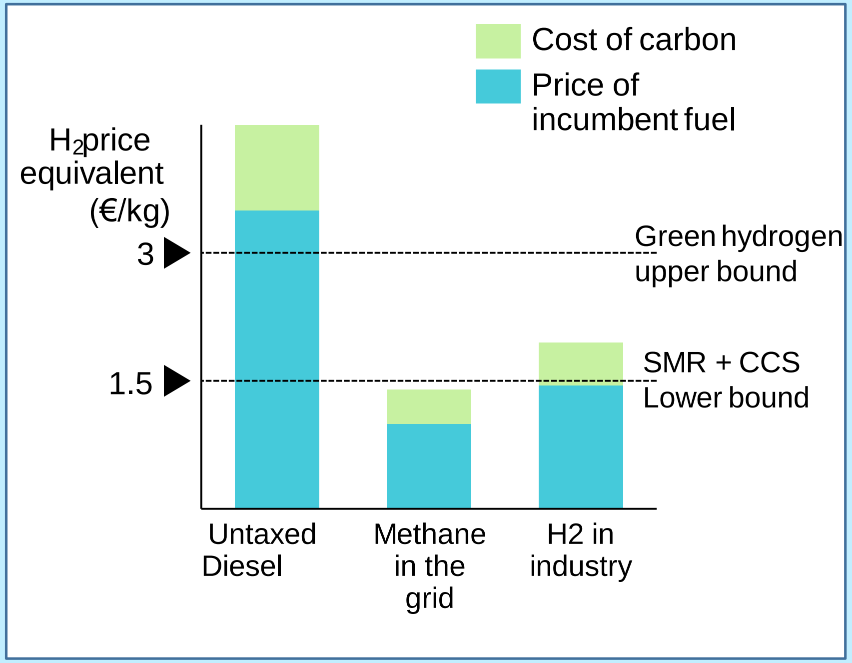
- 8 TWh of hydrogen used for industrial heat.
- Clean hydrogen replaces conventional fossil-fuel derived hydrogen.
- Replacing other fossil fuels e.g. coke in the steel making process, methanol production etc.

8. Regulations, standards and training/education programmes are supporting the transition to a hydrogen economy.

By achieving these targets, clean hydrogen can be produced and distributed to markets at competitive prices…

Production costs for clean H_2 compete with conventional fuels

Hydrogen produced at a cost between €1.5-3/kg is competitive with conventional fuels for transport applications amongst others once a 2030 carbon price is taken into account[1]. These prices are viable for SMR with CCS[2] and for electrolysis (assumptions as per roadmap targets).



Distribution costs for centralised H_2 production are lower at scale

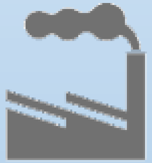
Some hydrogen will be produced in large centralised production plants for access to low-cost renewable energy. The distribution costs need to be minimised to ensure the fuel remains competitive.

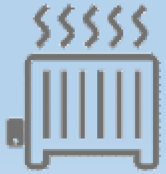
Transport of hydrogen at scale is expected to cost at most €1/kg

On-site hydrogen production offers an alternative

In some locations, decentralised hydrogen production may offer a lower cost route. Distribution costs are avoided, but production costs may be higher at smaller scales. The best solution will be location-specific.

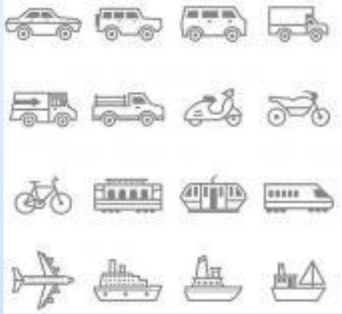
A commercially competitive energy vector



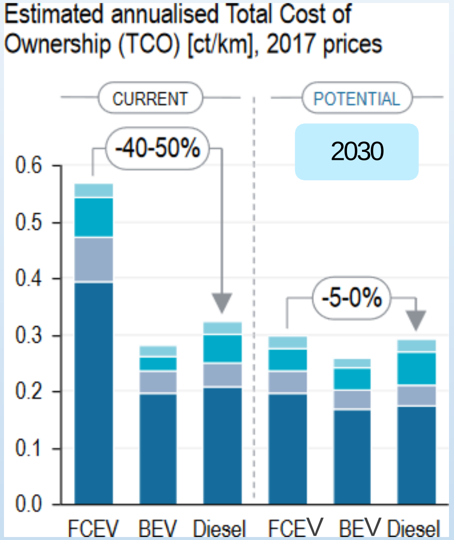


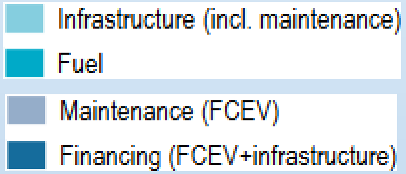
1 2030 CO2 price of €55/tonne based on "Closing the gap to a Paris compliant EU-ETS" by Carbon Tracker, 2018
2 - Assuming €40/tonne transport and storage cost for the CO2

…. prices that are competitive in a range of applications that are key to decarbonising Europe’s economy

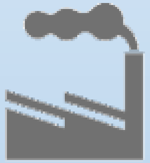


Transport – for example, FC cars are projected to achieve cost parity with diesel at commercial production volumes at a H_2 cost of €5/kg.



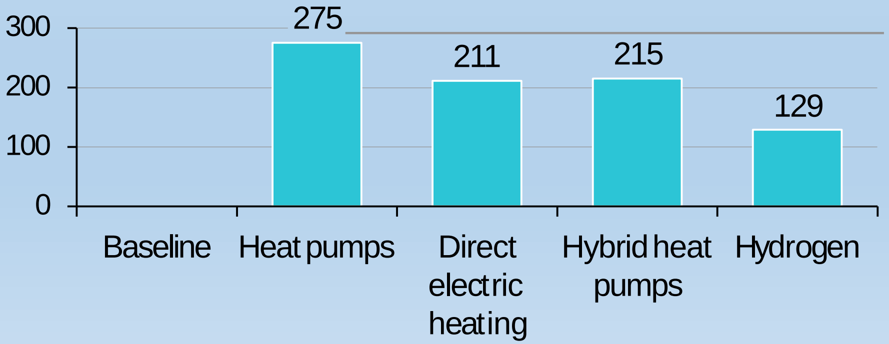


Adapted from “Development of business cases for Fuel Cell and Hydrogen applications for Regions and Cities”, 2017, Roland Berger for the FCH-JU

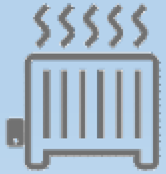


Industry and gas – clean H_2 as a feedstock can reach parity with fossil-based inputs once the cost of carbon is included.

Net cost of CO_2 abatement for different options for decarbonising heat
€/tonne CO_2



Adapted from data in “Cost analysis of future heat infrastructure options” Report for the UK National Infrastructure Commission, 2018.
Data = whole system costs for 4 options & cumulative carbon emissions from heat,
€/£ = 1.14



Buildings – fuel cell CHPs are high efficiency and can reduce energy use and associated CO_2 emissions even in advance of grid decarbonisation. Hydrogen may be the lowest cost way to decarbonise the gas grid.

Conclusions

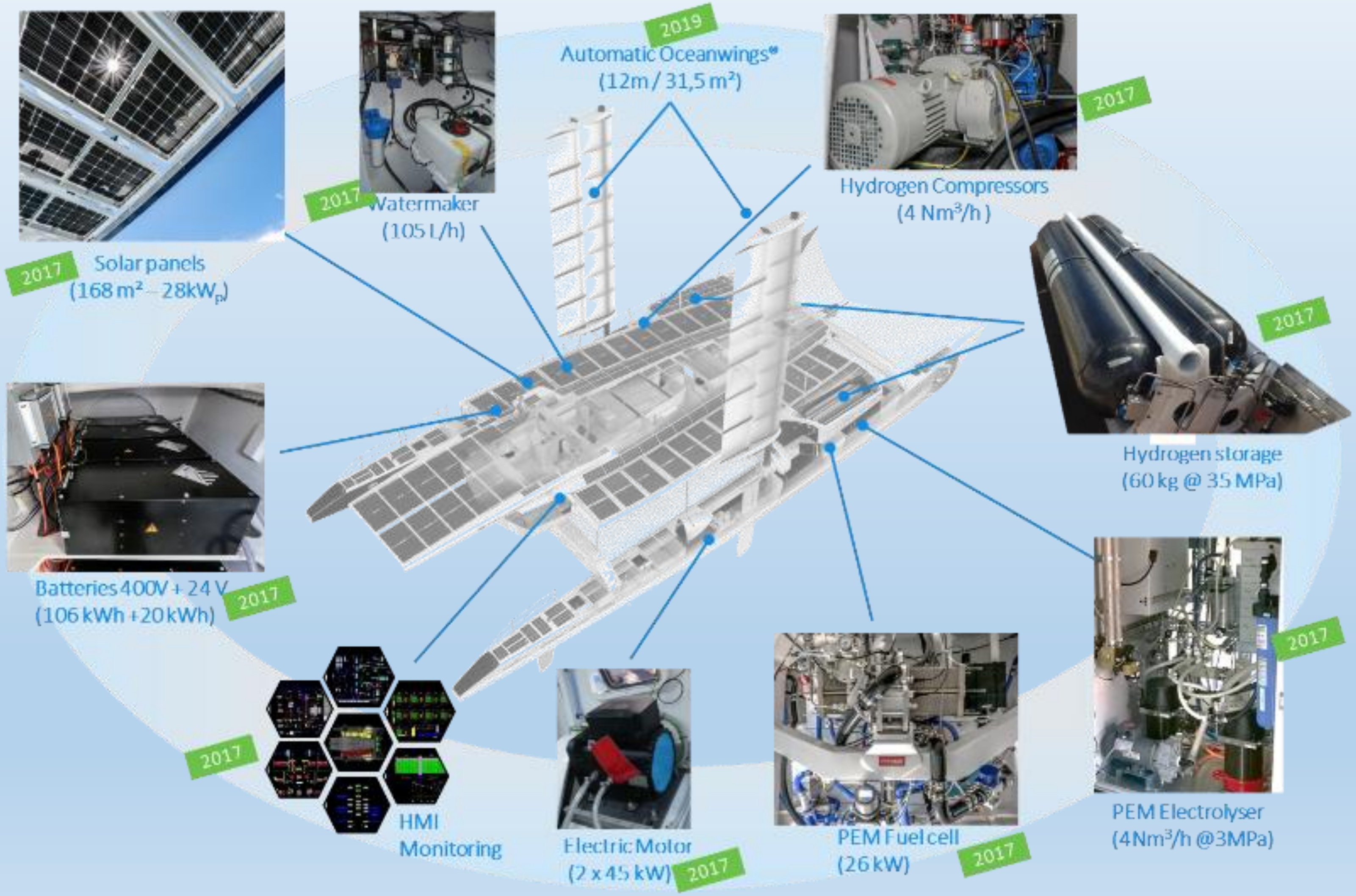
Conclusions

- **Hydrogen**, as a **clean, safe and versatile energy carrier**, is part of the energy transition and is key to enable the renewable energy system and to decarbonize end uses. Hydrogen is **the only zero-emission energy carrier with electrons**.
- Hydrogen technologies are mature and have significant potential across all applications, in particular **when looking for high payload, high autonomy and flexibility.**
- Hydrogen is fully part of the European strategy for a climate neutral Europe by 2050
  - **Horizon Europe** mentions research on Hydrogen and Fuel Cells
  - Hydrogen energy is one of the **European strategic value chain**
- **Hydrogen & Fuel Cells are today**!
  An international momentum worlwide with a strong position in Asia (Japan, South Korea **and now China**) but a **strong European Public-Private Partnership** with close collaboration between **Industry** (Hydrogen Europe Industry) and **Research** (Hydrogen Europe Research) has a fundamental role to develop technological research, to maintain European competitiveness and to bring products to market readiness. The close collaboration between research and industry is the basis of the European strength in the Hydrogen and Fuel Cell sector.
- A global collaborative approach of policy makers, investors and industry is needed today to enable the full potential of hydrogen in the energy transition.
- **Industry/Chemical sector** can be an important costumer of the **hydrogen sector** for decarbonizing its industry owing to “clean” hydrogen.

The first hydrogen vessel which aimed at energy autonomy and that emits no greenhouse gases or fine particles

A systemic approach

Didier Bouix, One of the world
Champions of Mission
Innovation, May 2019



Thank you for your attention!

More info

- European Commission: https://ec.europa.eu/
- FCH 2 JU: www.fch.europa.eu
- Hydrogen Europe: www.hydrogeneurope.eu
- Hydrogen Europe Research: www.hydrogeneurope.eu