FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

HYDROGEN ROADMAP EUROPE

+

NECP POTENCIAL

Roadmap para o Hidrogénio: a visão da AP2H2 para Portugal

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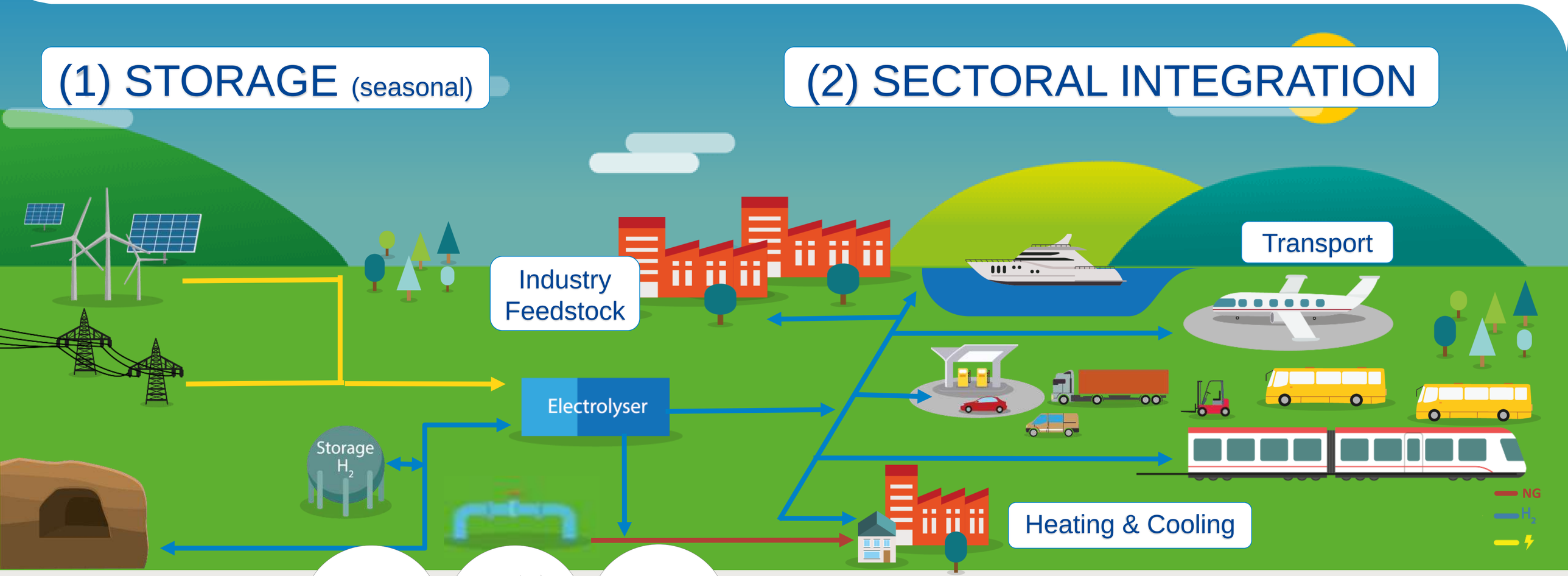
GUEDES DE CAMPOS

2nd December 2019
Ordem dos Engenheiros (Portugal)

The role of hydrogen in our society & economy

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



AGENDA

Hydrogen Roadmap for Europe + NECP potential for H2

1) Hydrogen Roadmap for Europe

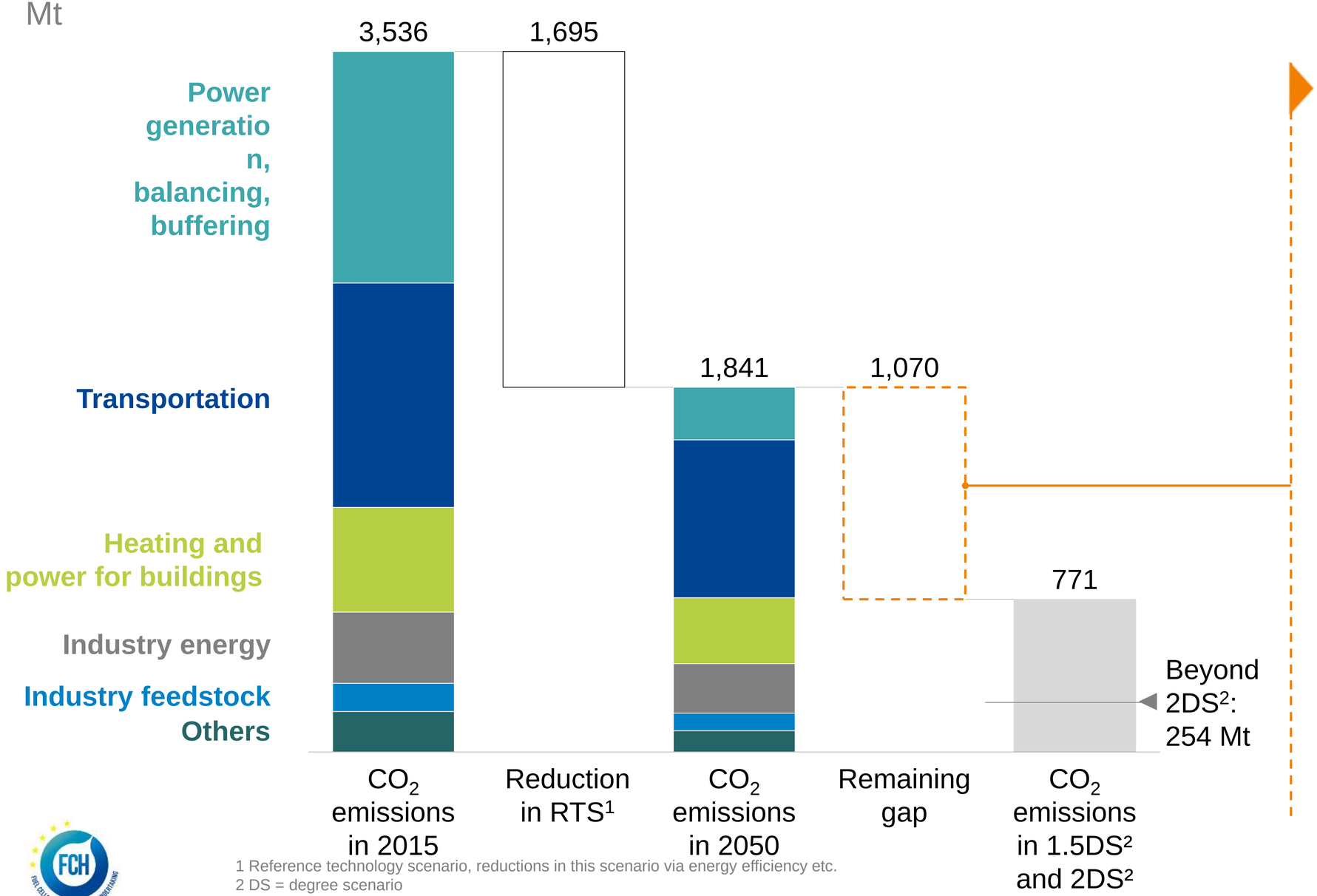
2) Opportunities for inclusion of H2 in the Portuguese NECP

3) IPCEI - Important Project(s) of Common European Interest

TOGETHER WITH AN INDUSTRY COALITION, A HYDROGEN ROADMAP FOR EUROPE HAS BEEN DEVELOPED

- Study by the FCH JU, supported by Hydrogen Europe and **17 companies and organizations** along the whole value chain of hydrogen
- First **comprehensive quantified European perspective** for deployment of hydrogen and fuel cells in two scenarios
  - Ambitious, yet realistic **two-degree scenario** and **business-as-usual scenario**
  - Long-term **potential**
  - **Roadmap** with intermediate milestones
  - **Recommendations** to kickstart

WHY HYDROGEN: TO REALIZE THE AMBITIOUS TRANSITION OF THE EU'S ENERGY SYSTEM, A NUMBER OF CHALLENGES NEED TO BE RESOLVED



Challenges

Achieving deep decarbo-nisation

Managing variable renewables

Meeting customer preferences

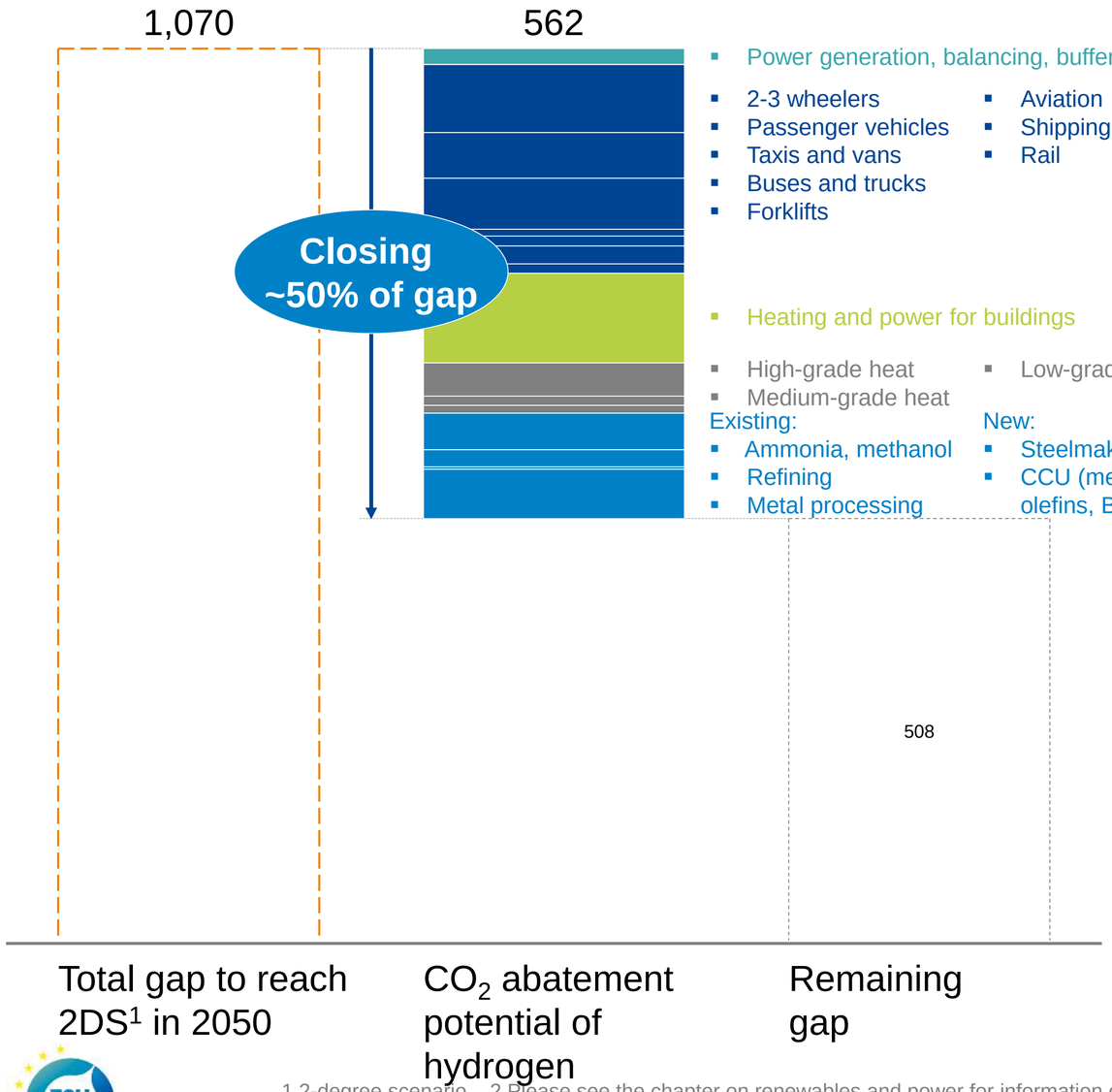
Retaining EU technology leadership to create jobs and wealth

1 Reference technology scenario, reductions in this scenario via energy efficiency etc.
2 DS = degree scenario

SOURCE: IEA Energy Technology Perspectives 2017; Hydrogen Roadmap Europe team

ACROSS APPLICATIONS HYDROGEN CAN CLOSE HALF OF THE GAP TOWARDS THE 2DS

Carbon emissions gap to reach 2DS[1] in 2050, Mt



Segments

- Power generation, balancing, buffering
- 2-3 wheelers
- Passenger vehicles
- Taxis and vans
- Buses and trucks
- Forklifts
- Aviation
- Shipping
- Rail
- Heating and power for buildings
- High-grade heat
- Medium-grade heat
- Low-grade heat

Existing:
- Ammonia, methanol
- Refining
- Metal processing

New:
- Steelmaking (DRI)
- CCU (methanol, olefins, BTX)

Hydrogen decarbonization levers

Power generation	Integration of renewables into the power sector[2] Power generation from renewable resources
Transportation	Replacement of combustion engines with FCEVs, in particular in buses and trucks, taxis and vans as well as larger passenger vehicles Decarbonization of aviation fuel through synthetic fuels based on hydrogen Replacement of diesel-powered trains and oil-powered ships with hydrogen fuel-cell-powered units
Heating and power for buildings	Decarbonization of natural gas grid through blending Upgrade of natural gas to pure hydrogen grid
Industry heat	Replacement of natural gas for process heat
Industry feedstock	Switch from blast furnace to DRI steel Replacement of natural gas as feedstock in combination with CCU

1 2-degree scenario 2 Please see the chapter on renewables and power for information on the role of hydrogen as enabler of a renewable power system. The "enabled" carbon abatement from renewables is not included here and is an additional benefit of hydrogen for decarbonization

SOURCE: IEA Energy Technology Perspectives 2017; Hydrogen Roadmap Europe team

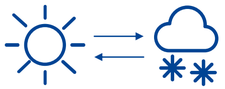
MANAGING VARIABLE RENEWABLES REQUIRES HYDROGEN

Challenge

Hydrogen is the only option to enable the transition of the energy system – managing quadrupling renewables requires...

Managing variable renewables

AT-SCALE SECTOR COUPLING MECHANISM



LOW-COST SEASONAL ENERGY STORAGE

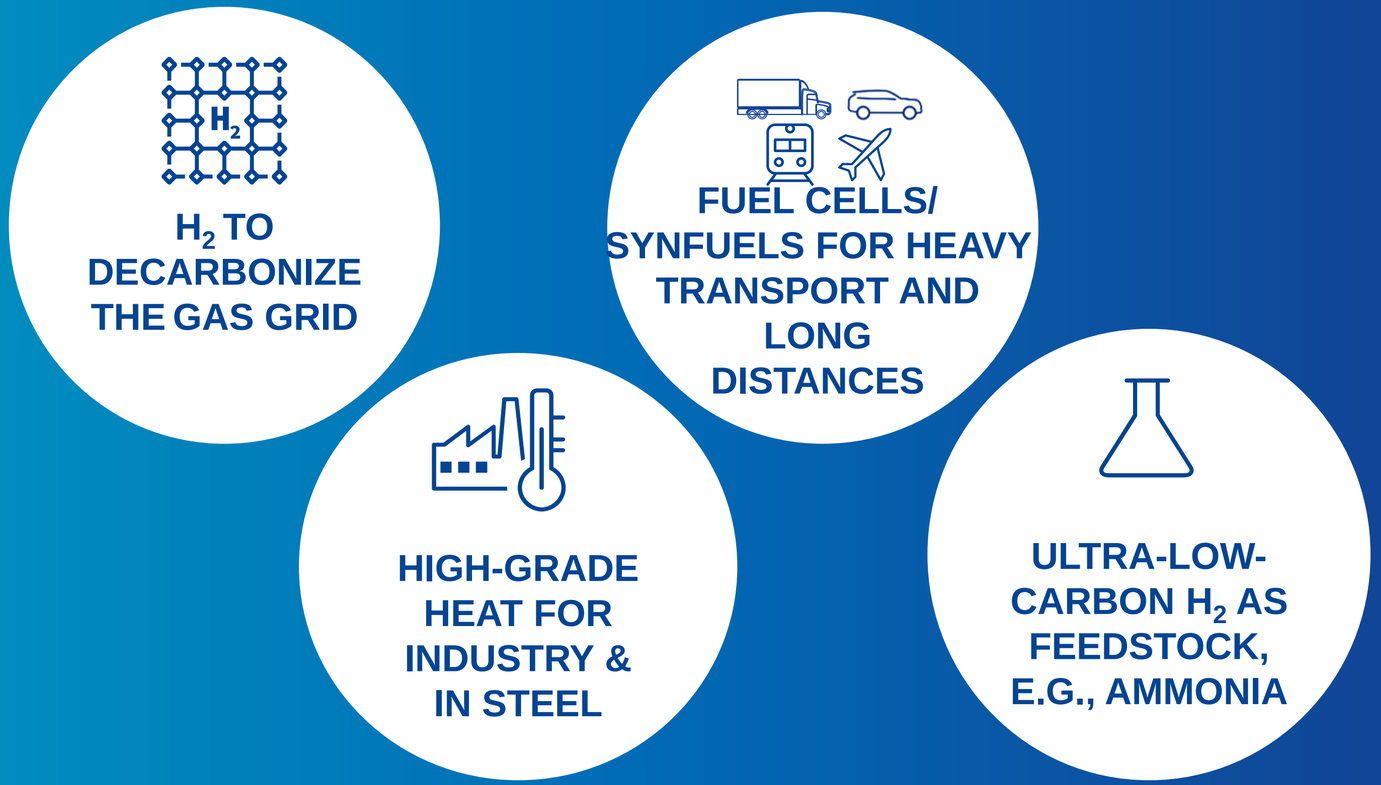
LINK BETWEEN PRODUCTION AND DEMAND REGIONS

ACHIEVING DEEP DECARBONIZATION OF >80% OF CO_2 EMISSIONS REQUIRES HYDROGEN

Challenge

Achieving deep decarboni-sation

Hydrogen is the best or only choice for at-scale decarbonization of key segments, for example:



HYDROGEN AND FUEL CELL SOLUTIONS MEET CUSTOMER PREFERENCES AND ARE CONVENIENT

Challenge

Hydrogen and fuel cells are compatible with current usage patterns and convenience due to...

Meeting customer preferences

- SUPERIOR RANGE AND REFUELING TIME OF FCEVs
- NO OR FEW CONSTRUCTION CHANGES REQUIRED FOR HEATING WITH H_2
- POTENTIAL FOR LOWER ENERGY COSTS IN THE LONG TERM

HYDROGEN AND FUEL CELL TECHNOLOGIES ARE AN OPPORTUNITY FOR EUROPE'S INDUSTRY

Challenge

Securing EU technology leadership to create jobs and wealth

Hydrogen and fuel cell technologies are an opportunity for Europe's industry as to...

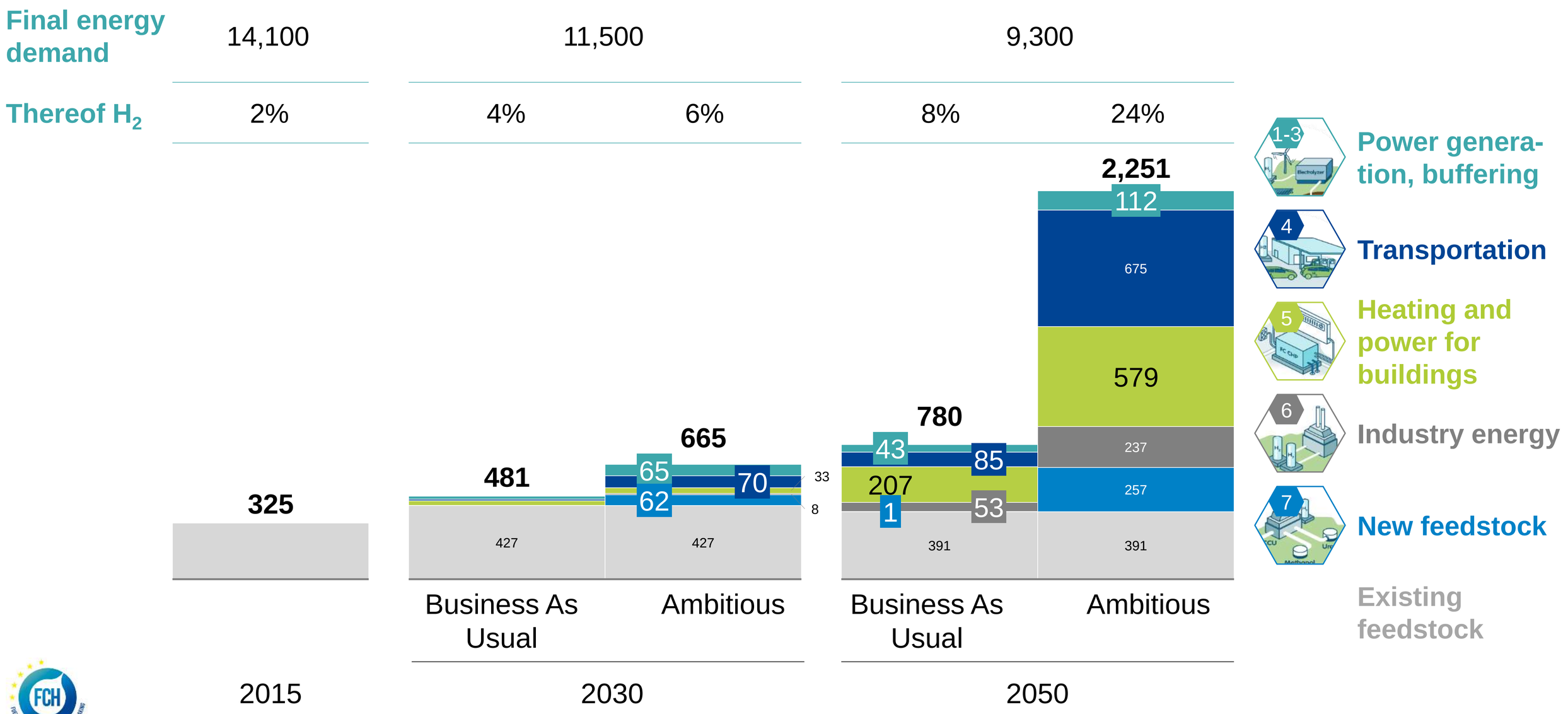
BUILD ON CURRENT SKILLS AND MANUFACTURING CAPACITY

REDUCE DEPENDENCY ON FOSSIL FUEL IMPORTS

LEVERAGE EXISTING INFRASTRUCTURE

HYDROGEN COULD PROVIDE UP TO 24% OF TOTAL ENERGY DEMAND, OR UP TO ~2,250 TWH OF ENERGY IN THE EU BY 2050

TWh



SOURCE: Hydrogen Roadmap Europe team

BESIDES CO_2 ABATEMENT, DEPLOYMENT OF THE HYDROGEN ROADMAP ALSO CUTS LOCAL EMISSIONS, CREATES NEW MARKETS AND SECURES SUSTAINABLE EMPLOYMENT IN EUROPE

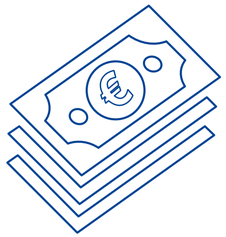
2050 hydrogen vision

~24%

of final energy demand[1]

~560 Mt

annual CO_2 abatement[2]

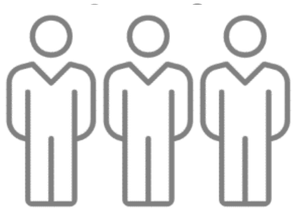


~EUR 820bn

annual revenue (hydrogen and equipment)

~15%

reduction of local emissions (NO_x) relative to road transport



~5.4m

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

IN TOTAL, A MARKET OF EUR ~150 BN AND ~1 M JOBS COULD BE UNLOCKED BY 2030

2030 hydrogen vision

Estimation of industry size

EU and global market potential taken from hydrogen vision

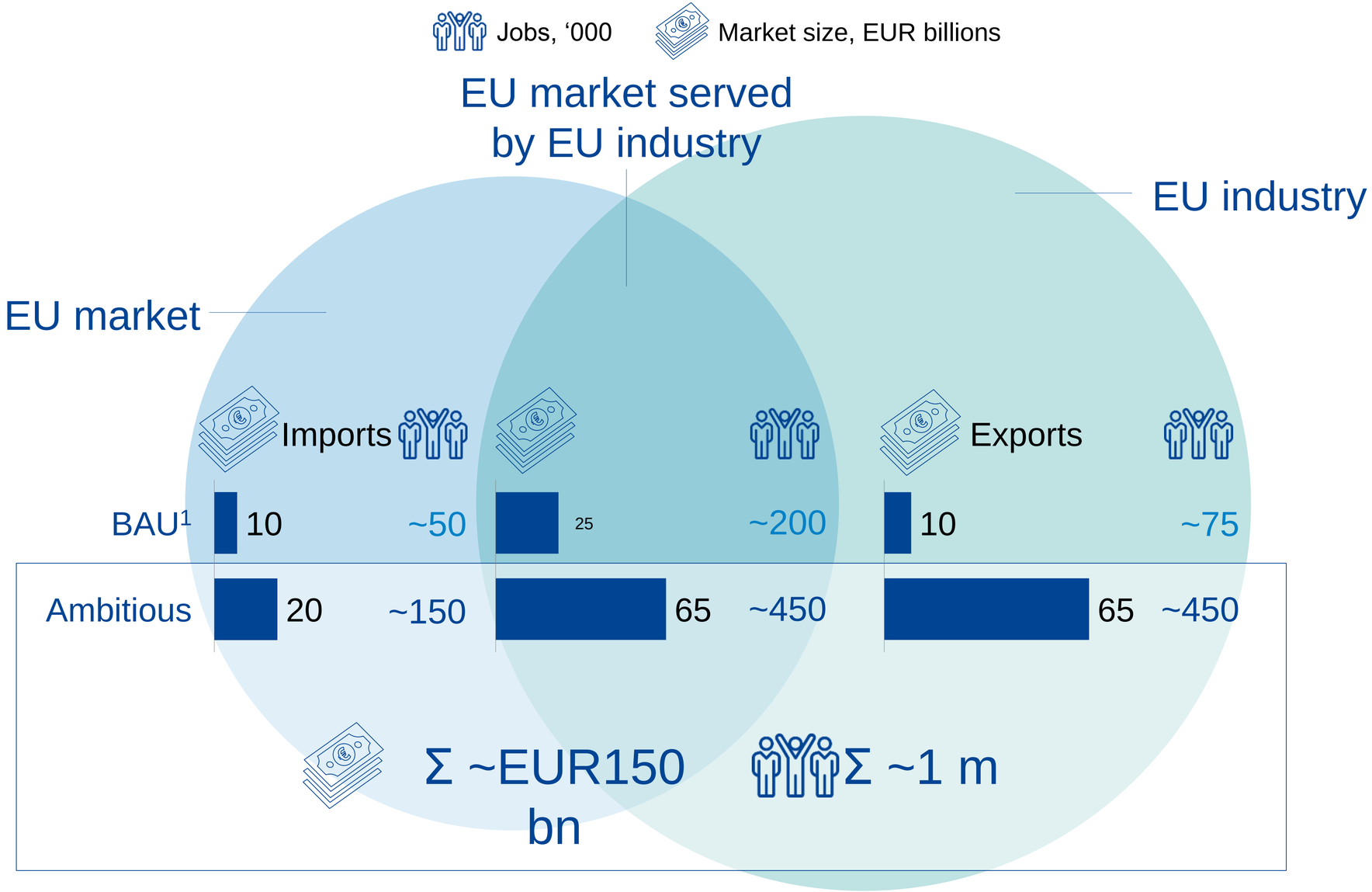
“Fair share” of EU industry on domestic and worldwide market derived from industry statistics and industry interviews

Revenue and jobs multipliers estimated from EU input-output models

Ambitious scenario

Fair domestic market share for EU players (between 60% and 90% depending on the step in the value chain)

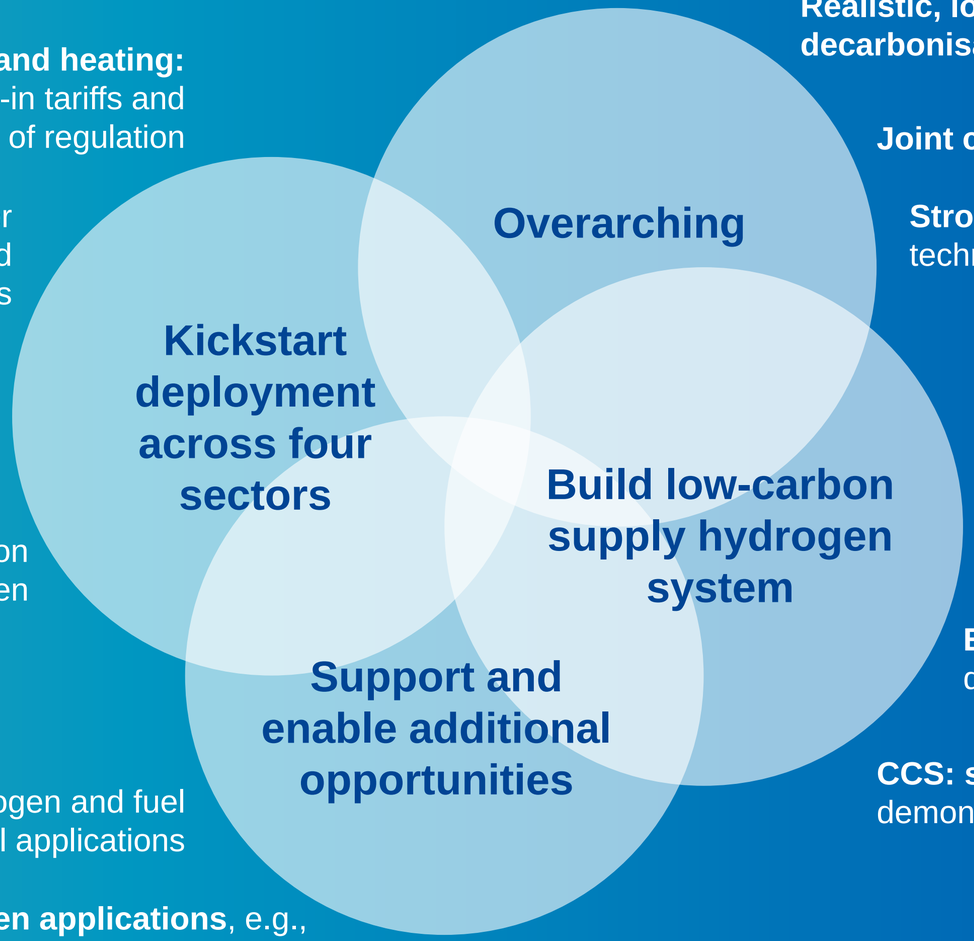
Fair market share for EU players in RoW (between 10% and 25% depending on the step in the value chain)



1 Business as usual scenario

SOURCE: Hydrogen Roadmap Europe team

INDUSTRY, REGULATORY AND INVESTORS NEED TO ACT TOGETHER



Realistic, long-term and holistic decarbonisation pathways for all sectors

Joint commitment from regulators and industry

Strong investment in hydrogen and fuel cell technology by the European industry

Gas grid for building power and heating: binding targets or feed-in tariffs and modernisation of regulation

Power system: decarbonisation of power balancing markets using electrolyzers and regulatory mechanisms

Transport: credible funding mechanism for infrastructure and clear industry investments in product development

Industry: regulatory targets for transition from grey to low-carbon hydrogen

Scale-up of electrolysis and CCS

Electrolysis: incentives from gas grid decarbonisation

CCS: support for industry-scale demonstration projects

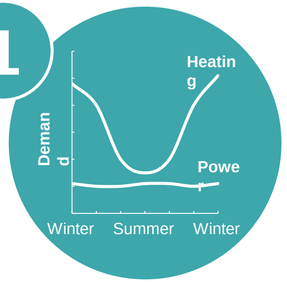
Development of additional hydrogen and fuel cell applications

Plans to **scale-up proven applications**, e.g., hydrogen trains, ships and mCHPs

USING HYDROGEN IN THE GAS GRID OFFERS THREE MAJOR ADVANTAGES OVER OTHER DECARBONISATION SOLUTIONS FOR BUILDING HEATING

H_2 TO DECARBONIZE THE GAS GRID

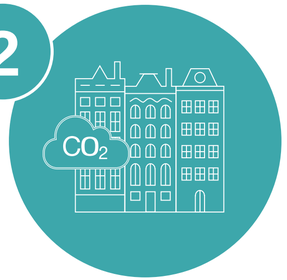
1



Full direct electrification of heating not feasible

Would require significant increase in power generation that is used only in the winter

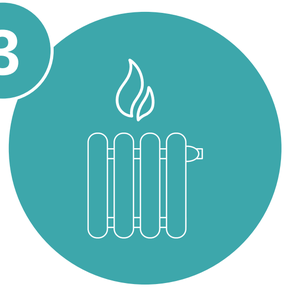
2



Compatible with existing building stock compared to use of heat pumps

90% of all buildings emissions result from buildings older than 25 years

3



Infrastructure, skills and regulations already available and ready to be leveraged

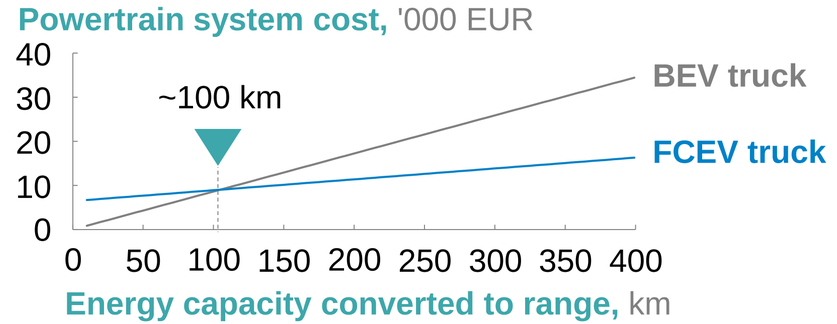
40% of all European households have gas heating as of today making fast and convenient implementation possible

EXAMPLE FOR TRUCKS: HYDROGEN FUEL CELL POWERTRAINS ARE A TECHNICALLY ADVANCED ZERO EMISSION TECHNOLOGY AND COST COMPETITIVE FOR HEAVY TRANSPORT

FUEL CELLS FOR HEAVY TRANSPORT

1

FCEV powertrains for trucks are cost competitive with BEV from 100 km range



2

Hydrogen refueling is 15 times faster than fast charging

After 10 minutes refueling/recharging time

90% FCEV truck vs. **10%** BEV truck of ~1000 km range

3

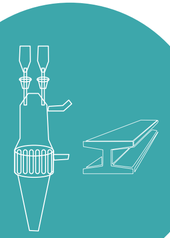
Recharging infrastructure…

requires **10-15X** less space and creates **flexible** instead of peak load

IN THE INDUSTRY, HYDROGEN PROVIDES LARGE-SCALE OPPORTUNITIES TO DECARBONISE HIGH-GRADE HEAT OR REPLACE CARBON-INTENSIVE INPUTS AS A FEEDSTOCK

HIGH-GRADE HEAT FOR INDUSTRY AND AS FEEDSTOCK

1



Only feasible route for decarbonisation of steel

Replacement of blast furnace with direct reduction process using hydrogen

2

At-scale decarbonisation of high-grade heat industrial processes

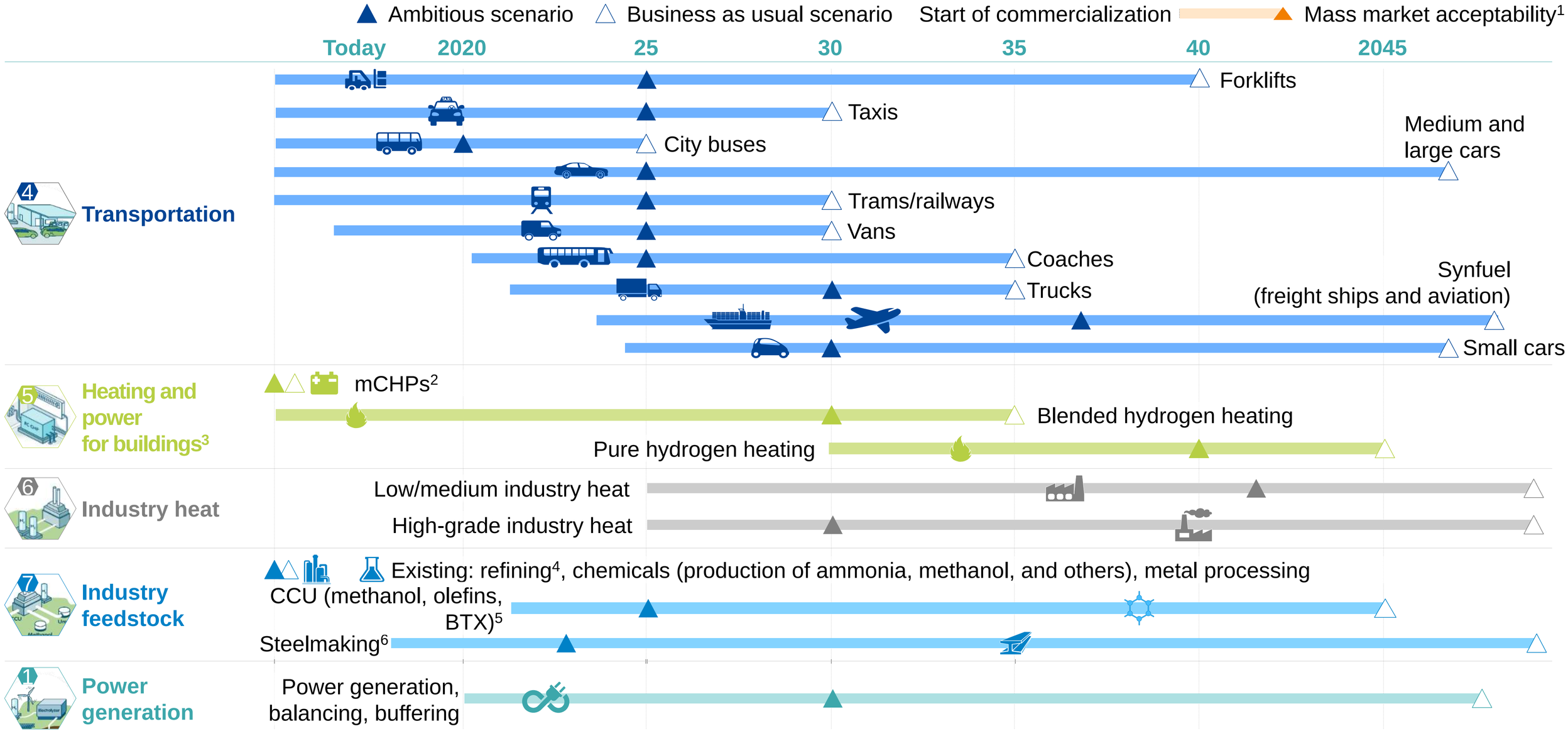
Decarbonization route compatible with current processes

3

Conversion of hydrogen production to ultra-low-carbon hydrogen

Decarbonization of hydrogen production where currently used – e.g., in Ammonia production, refining and petrochemical industries

HYDROGEN TECHNOLOGY EXISTS AND IS READY TO BE DEPLOYED



1 Defined as sales >1% within segment; 2 mCHPs sales in EU independent of fuel type (NG or H_2); 3 Pure and blended H_2 refer to shares in total heating demand; 4 Refining includes hydro-cracking, hydro-treating, bio-refinery; 5 Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock; 6 CDA process and DRI with green H_2, iron reduction in blast furnaces, and other low-carbon steel making processes using H_2

SOURCE: Hydrogen Roadmap Europe team

HYDROGEN PLAYS AN IMPORTANT, COMPLEMENTARY ROLE IN THE 2050 ENERGY SYSTEM

Segments	Key subsegments	Relative importance by 2050[1]	Complementary decarbonisation solutions
Transportation	▪ Large cars (fleets) and taxis ▪ Trucks and buses ▪ Light commercial vehicles ▪ Trains ▪ Ships and aviation	39% 22% 30% 9% 4%	▪ Battery-electric vehicles ▪ Plug-in hybrid electric vehicles ▪ Electrified trains ▪ Biofuels and CNG/LNG
Heating and power for buildings	▪ Hydrogen blending for heating ▪ Pure hydrogen grids for heating	2% 16%	▪ Electrification of heating via heat pumps ▪ Energy efficiency measures ▪ Biogas/biomass
Industry energy	▪ High-grade heat	23%	▪ Demand side and energy efficiency measures ▪ Electrification ▪ Biogas/biomass ▪ Carbon capture
Industry feedstock	▪ Ultra-low-carbon hydrogen as feedstock for – Ammonia, methanol – Refining ▪ Feedstock in steelmaking (DRI) ▪ Combined with CCU in production of olefins and BTX	100% 80% 20% 30%	*For steel:* ▪ Coke from biomass ▪ CCS on blast furnace *For CCU:* ▪ Carbon storage
Power generation	▪ Power generation from hydrogen ▪ Flexible power generation from hydrogen	2% 55%	▪ Biogas ▪ Post-combustion CCS ▪ Batteries

1 In transportation: percent of total fleet; in heating and power for buildings: percent of total heating demand; in industry energy: percent of final energy demand; in industry feedstock: percent of total feedstock for production; in power generation: percent of total power generation and percent of power generated from natural gas

SOURCE: Hydrogen Roadmap Europe team

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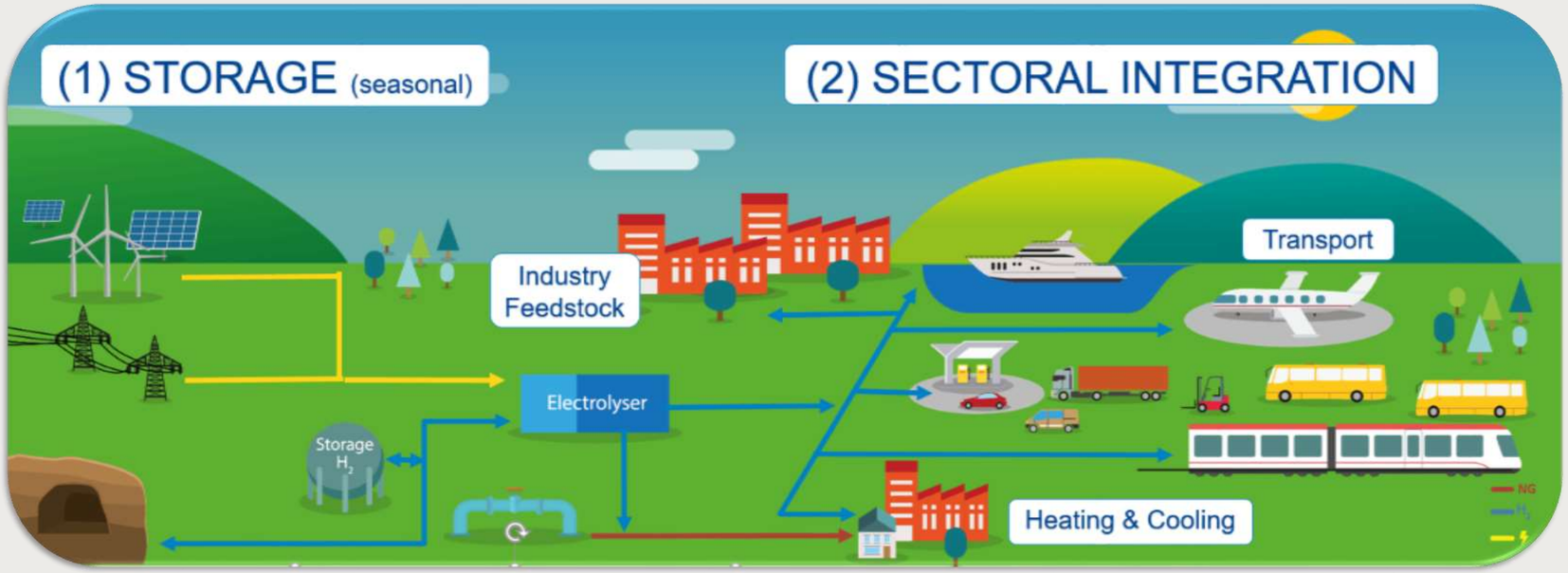
Hydrogen Roadmap for Europe + NECP potential for H2

1) Hydrogen Roadmap for Europe

2) Opportunities for inclusion of H2 in the Portuguese NECP

3) IPCEI - Important Project(s) of Common European Interest



Opportunities from the inclusion of Hydrogen in NECPs (DRAFT)

Project Objective and Scope

Objective of the study commissioned by FCH JU:

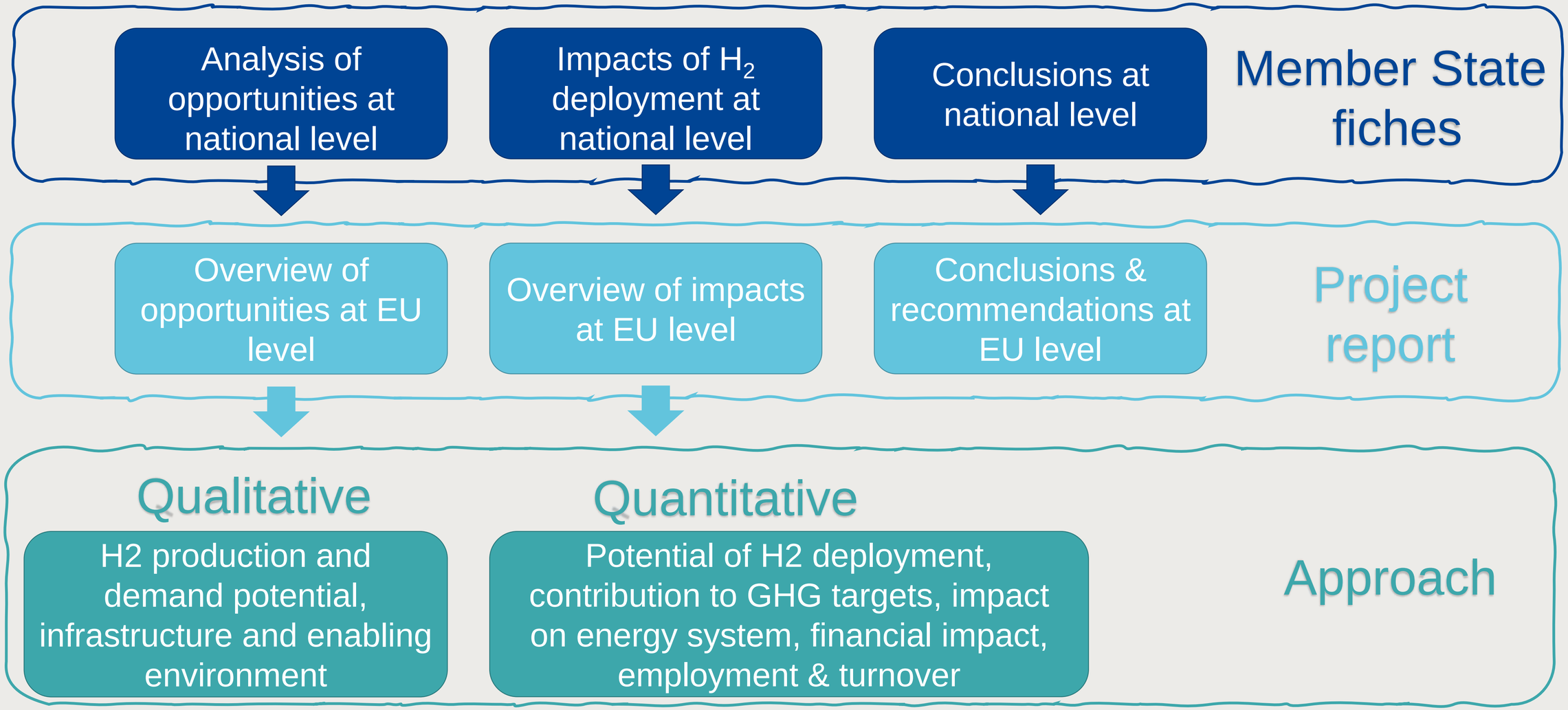
Identify opportunities for hydrogen energy technologies to contribute **to achieving** the climate and energy **targets** of the EU and its Member States **effectively and efficiently**

Scope:

- EU28, with Member State focus
- Up to 2030
- Renewable & low-carbon hydrogen

Methodology & Deliverables

What will be the outcome of this project?

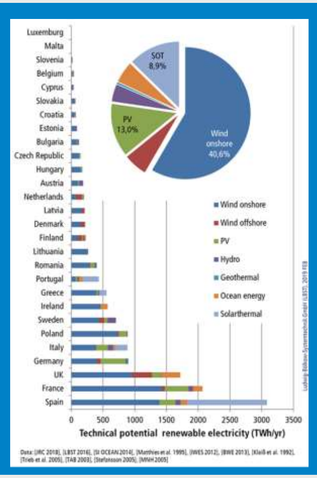


Approach towards opportunity analysis

Assessment of opportunities for hydrogen development across four aspects using indicators

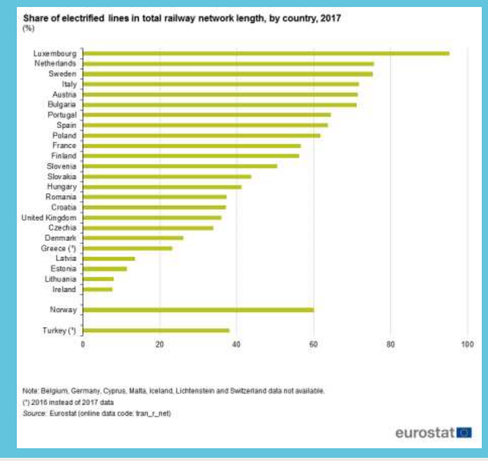
Hydrogen Production Potential

Potential for intermittent renewable electricity



Potential Hydrogen Demand

Non-electrified rail transport

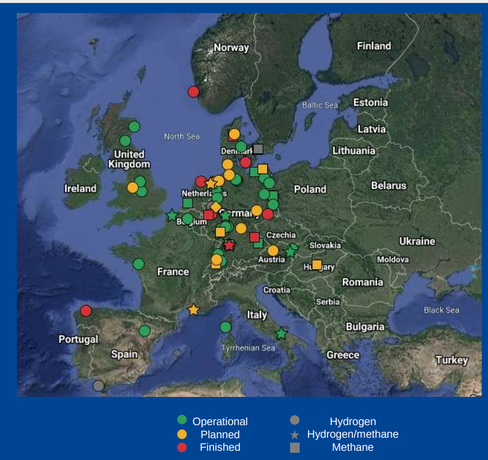


Energy infrastructure

Suitable geological formations for H2 storage

Enabling Environment

Power-to-gas projects



Sources: Trinomics & LBST (2019) & http://europeanpowertogas.vps1.clean-fresh.nl/projects-in-europe/

Sources: Eurostat & http://europeanpowertogas.vps1.clean-fresh.nl/projects-in-europe/

Preliminary opportunity analysis

DRAFT: Hydrogen production potential & its role in energy system flexibility

Portugal with opportunity to produce H_2 based on green electricity 'surpluses'

- Substantially higher domestic intermittent renewable electricity **potential** than demand (> x10)
- "Suitable" gas infrastructure for **H_2 transport** and **storage** (92% polyethilene pipelines)

Portugal with opportunity to produce H_2 for energy system balancing

PtP and grid balancing electrolysers

- Substantially higher installed intermittent renewable electricity **capacity** than load
- Limited other low-carbon flexibility options

Portugal with opportunity to decarbonise heavy-duty transportation through green H_2

bus, truck, train, shipping, aviation

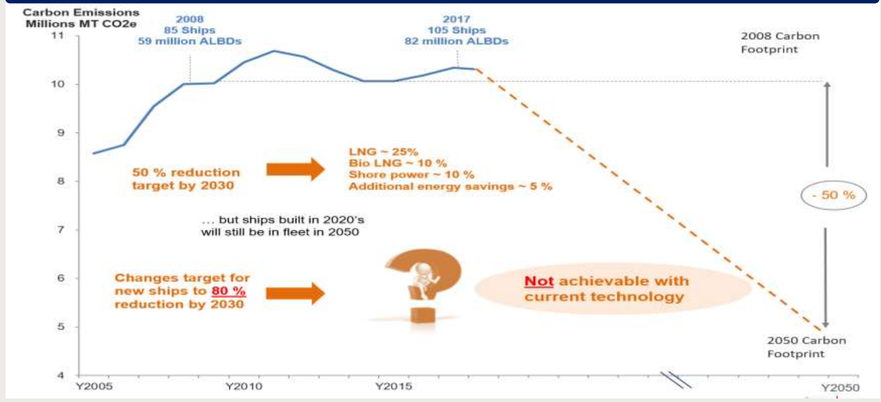
- 18% weight of heavy-duty road in total transport energy demand
- 1/5 railway still dependent on fossil fuels (10 kTOE)

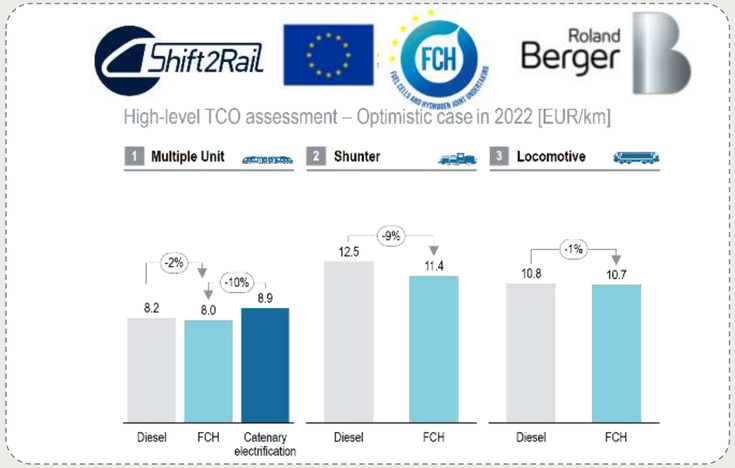
Green H2 to green Heavy Duty Applications

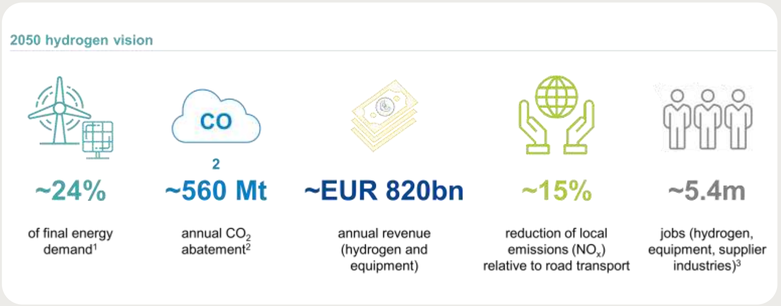
Heavy Industry, Heavy Transportation (maritime, railway, bus and freight trucks) and decarbonisation of NG assets:

The first business models are appearing

- IMO April 2018: "at least 50% of CO_2 reduction by 2050"







Reduction in emissions by fuel conversion (Petroleum oils → Natural gases)

NOx	SOx, PM	GHG
80%~90% reduction	Zero emission	20%~25% reduction

- FCH-JU + S2R JU cooperating in a joined study to look at business cases beyond Regional trains - 20% by 2030*

https://www.fch.europa.eu/publications/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition

Base scenario market share in EU by 2030 achieved by H2 powered trains (28% for frontrunners, 11% for newcomers and 9% for later adopters)
https://fch.europa.eu/news/new-study-shows-good-potential-hydrogen-powered-trains-europe

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STRATEGIC VALUE CHAINS AND IPCEI: opportunities and limits

THE HYDROGEN VALLEYS SMART SPECIALISATION PLATFORM: regional profiles

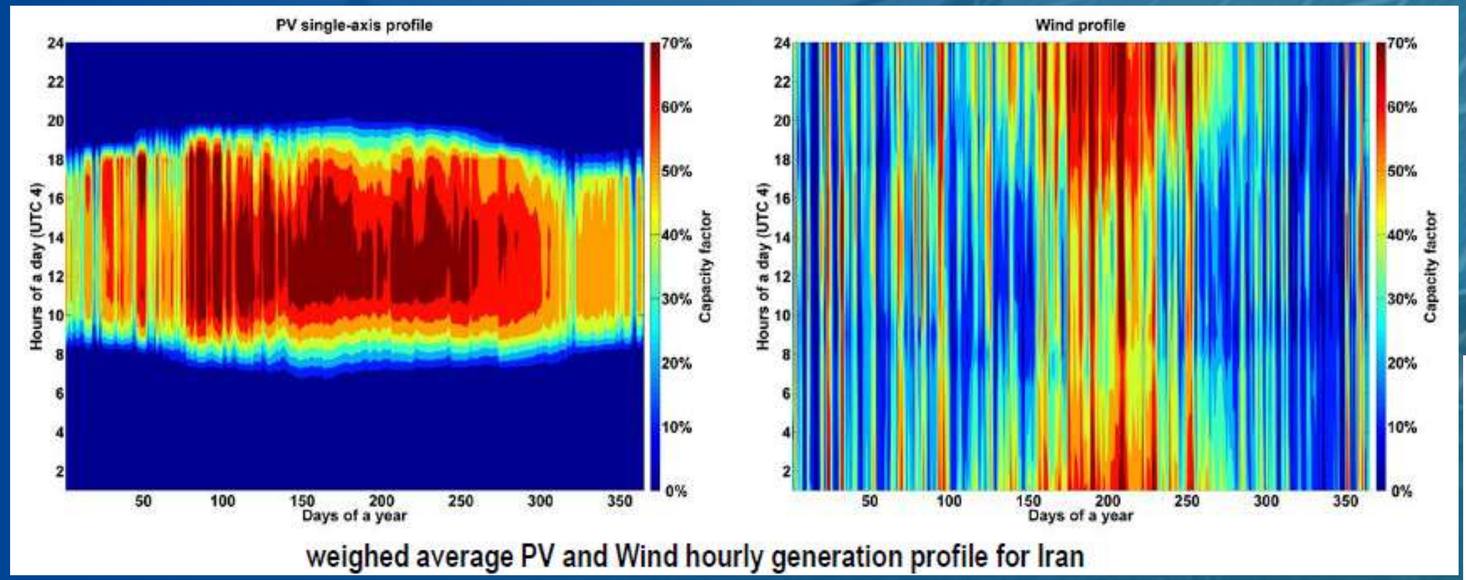
https://www.hydrogen4climateaction.eu/

- **Green Flamingo:** 1 GW solar-based hydrogen production, transportation by tube trailers and ships using LOHC technology, distribution to HRSs and industrial users. ES, DE, NO, DK
- **Orange Camel:** 5000 hydrogen trucks for retail distribution, HRSs at retail stores. BE, IT, DE, FR, DK, NL
- **Golden Eagle**: 3 GW wind-based hydrogen production, transportation by pipelines, supply to steel plants, HRS, 500 public transport buses. AT, RO, PL, DE, DK, IT
- **Yellow Turtle:** Island decarbonisation via the use of hydrogen pipeline to and from mainland. For the use in public transport buses, HRSs, fleets (taxis, shuttles, etc.), heating. ES, BE, PL, NL, DE
- **Black Horse:** Heavy duty vehicles for long haul, tractors, HRSs, hydrogen infrastructure. SK, PL, CZ, HU, SE, DK
- **White Dragon:** 1 GW solar field covering previous lignite site, buses/public transport, LOHC based distribution system, HRSs, CHP for house heating. GR, DE, DK, FR, IT
- **Pink Snake:** 2 GW wind-based hydrogen plant, injecting and transporting hydrogen across borders using 800 km of existing/retrofitted/new gas pipelines thus creating a backbone for the hydrogen economy vie the connection of mayor ports and industrial sites, steel plants, HRSs, regional public transport. NL, BE, DE, DK, NO, LU
- **Blue Dolphin:** 6 liquid hydrogen cargo ships, 3 terminals and related storage facilities. IT, FR, NL, ES

The projects' list is tentative and based on indicative submissions received so far. Final selection to be done in early October

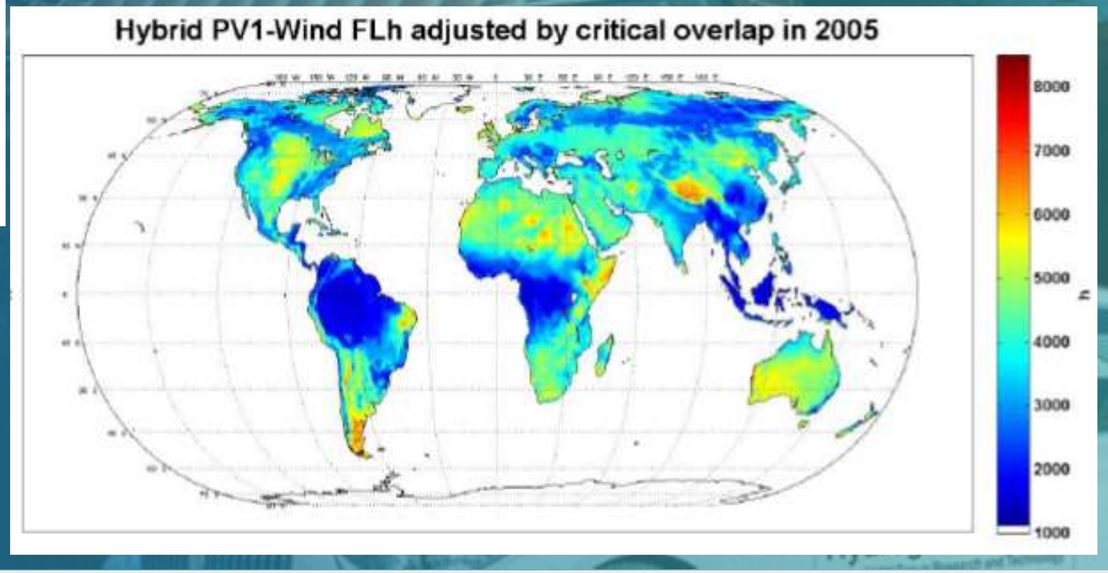
H2 at scale to effectively integrate Volatile and Intermittent RES

H2 plays a key role converting RES fluctuating flows into a steady commodity (“steady flows”) to use as energy or a chemical raw material for decarbonizing the power, gas (heat and industry) and mobility sectors



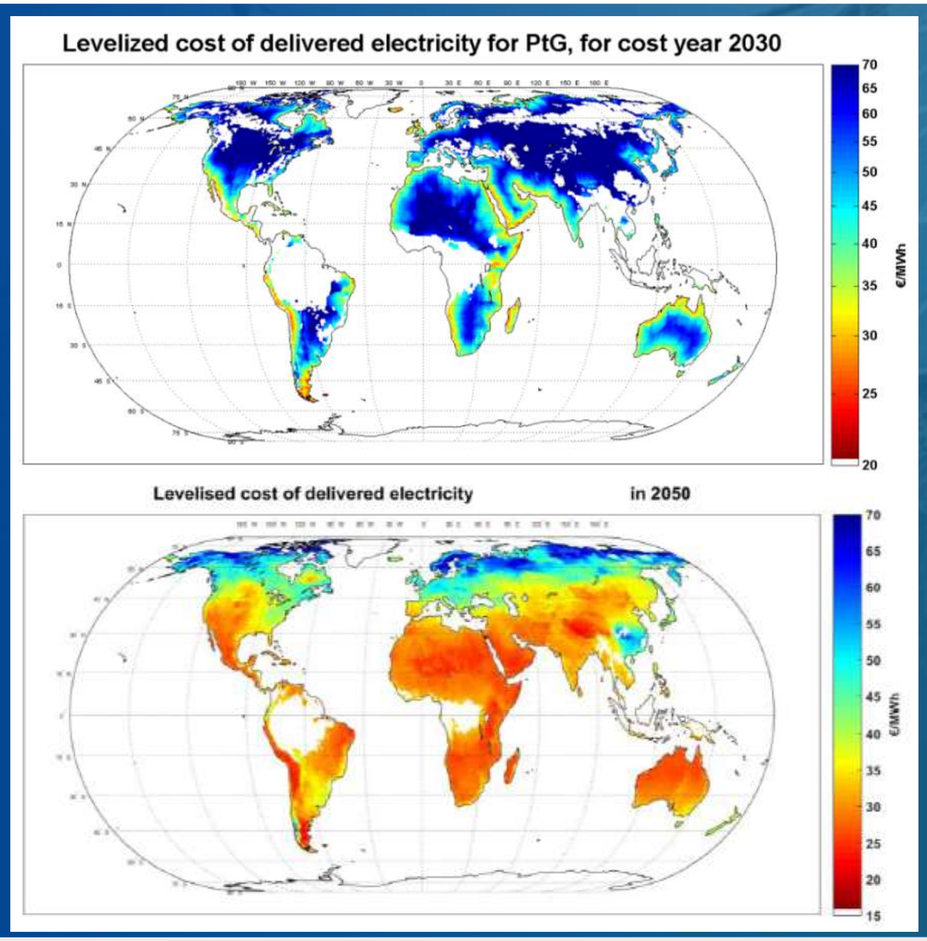
(Example of) Daily profile of PV and Wind

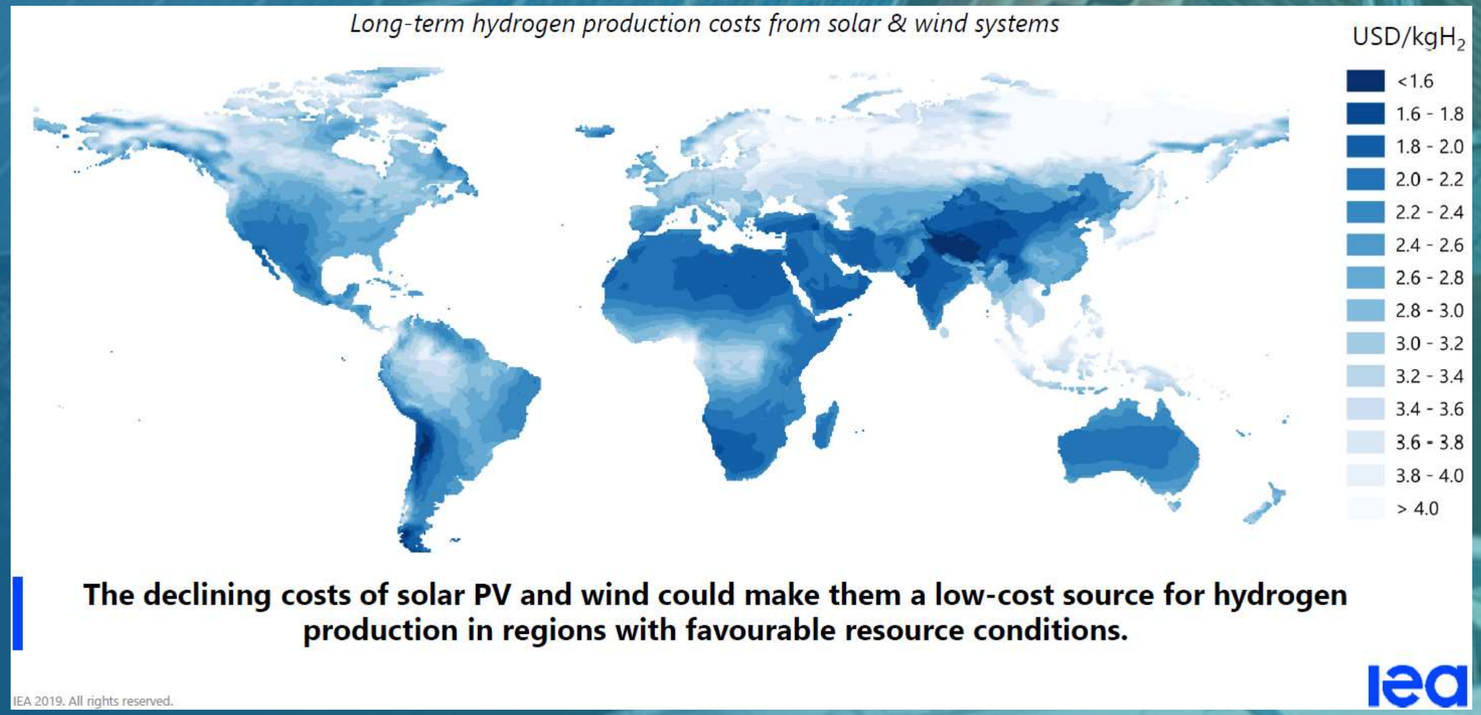
Yearly **F**ull **L**oad **h**ours of PV+Wind (e.g. 2005)



Mahdi Fasihi and Christian Breyer, Strommarkttreffen.org, *Synthetic fuels and chemicals: options and systemic impact*, 29 June 2018
https://www.strommarkttreffen.org/2018-06-29_Fasihi_Synthetic_fuels&chemicals_options_and_systemic_impact.pdf
Data source: NASA’s databases

Tech development and climate goals push further cheaper RES uptake which in turn requires and boosts cheap green H2 offtake World wide





Strommarkttreffen.org, *Synthetic fuels and chemicals: options and systemic impact*, 2018

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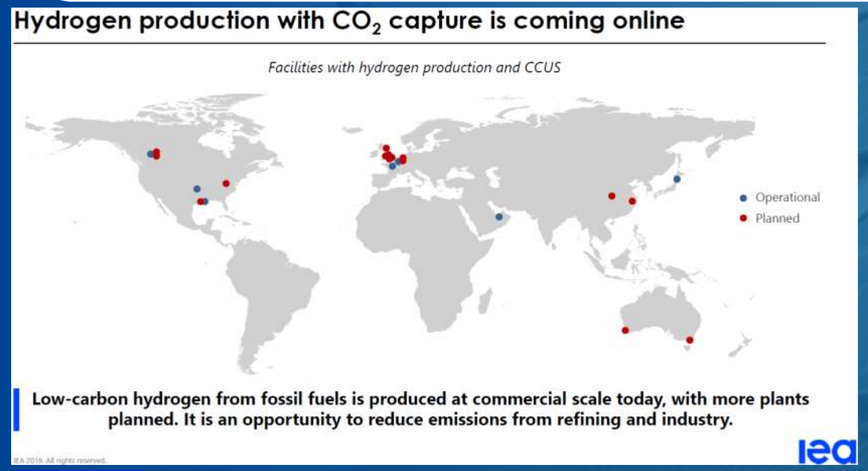

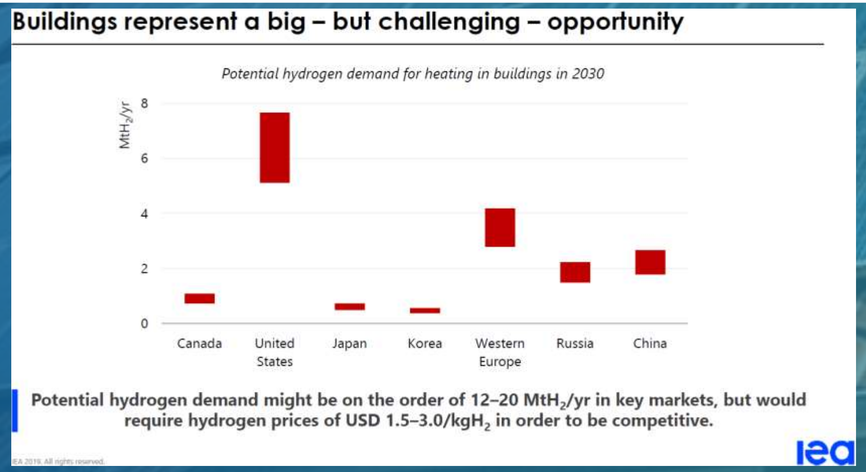

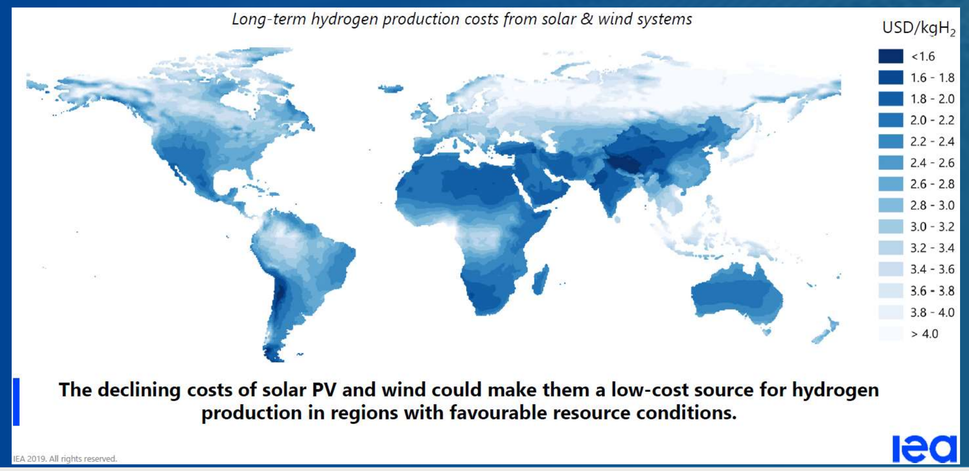

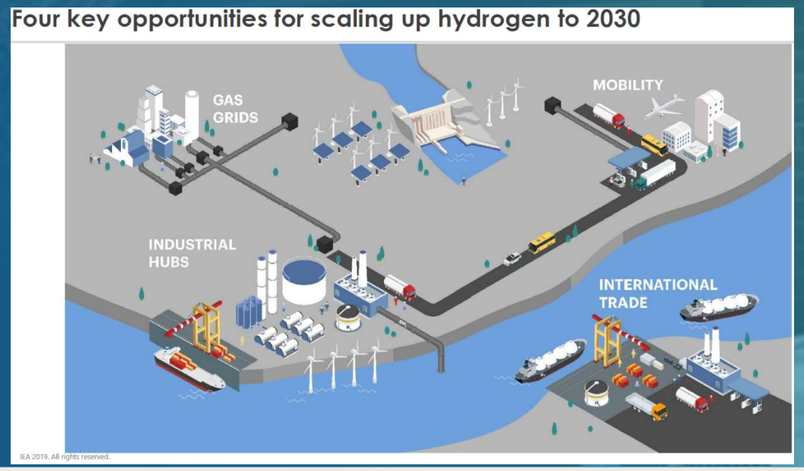

Study on “Early Business Cases for Power-to-Hydrogen (PtH) in Europe”

https://www.fch.europa.eu/publications/study-early-business-cases-h2-energy-storage-and-more-broadly-power-h2-applications (June 2017)

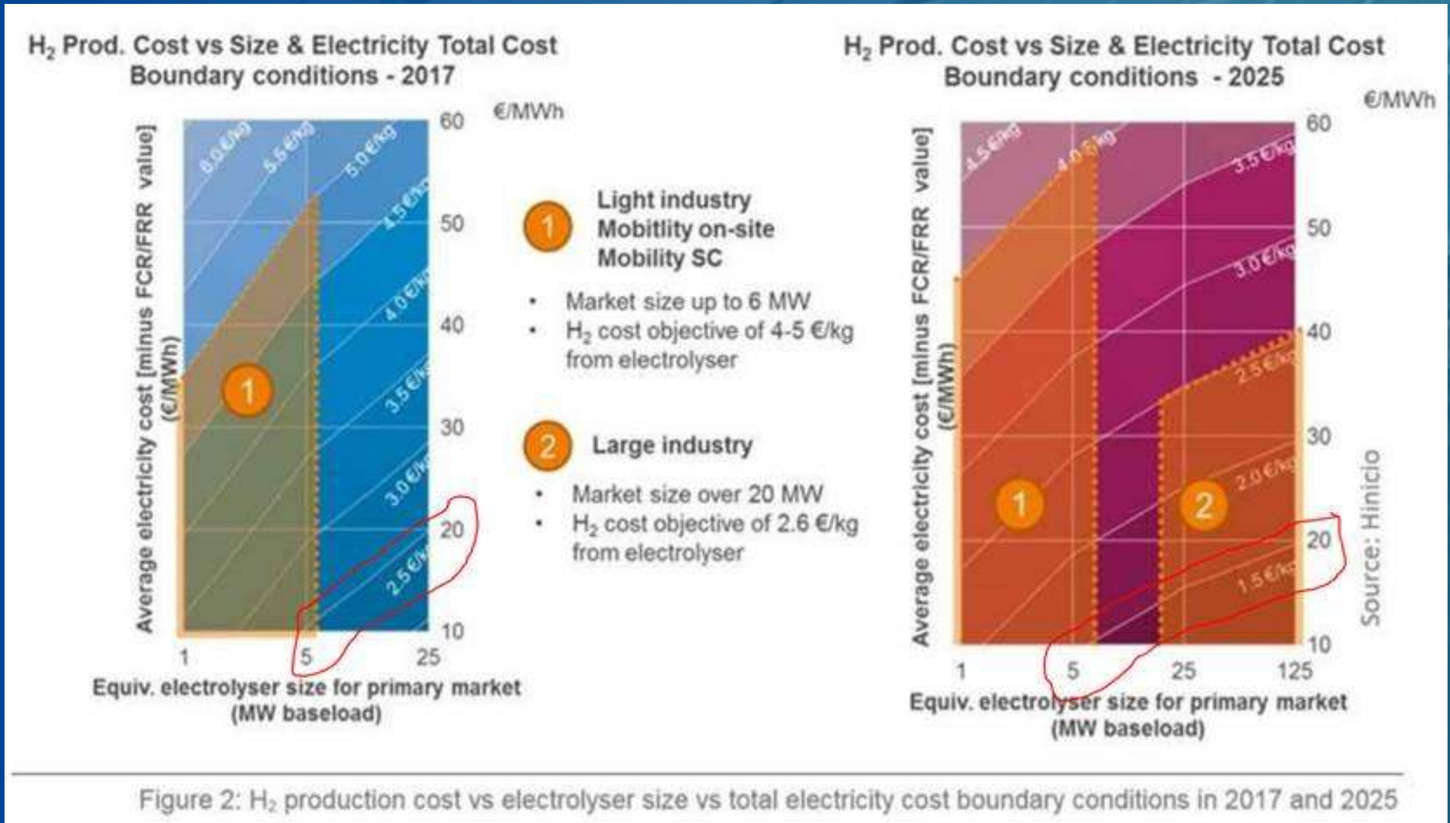

Figure 2: H_2 production cost vs electrolyser size vs total electricity cost boundary conditions in 2017 and 2025

Opens new pathways for PtH and enables new business models that can be highly complementary and symbiotic with RES projects (cPPA).

- Key variables for the profitability of PtH:
  - Size of the electrolyser - scale effect
  - Time of deployment - maturity of the technology is still increasing and so are sizes which, together with higher deployment rates will bring further down its CAPEX
  - Value of the hydrogen produced - and the grid services the electrolyser can deliver
  - Electricity cost for running the electrolyser

FCHJU web: Initiatives/ funding & finance/ advice on complex business models/ coupling wind with PtH2

AGENDA

Hydrogen Roadmap for Europe + NECP potential for H2

1) Hydrogen Roadmap for Europe

2) Opportunities for inclusion of H2 in the Portuguese NECP

3) IPCEI - Important Project(s) of Common European Interest

√ EU industry fully aligned with EU Climate policies!

√ Green H2 potential in PT

- enabler of cheap intermittent RES
- decarbonize NG grid
- seasonal energy storage
- Heavy-duty transport potential – bus, truck, rail, shipping, aviation
- FCH's value chain creating jobs and improving PT competitiveness!

√ Potential for green H2 exports to the North of Europe

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

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