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HYDROGEN TECHNOLOGIES

Hydrogen Knowledge Exchange Program ready, set, go.

H2 value chain in Piedmont

SMART4ENERGY WEBINAR

SMARTENERGY

Overview of H2 technology trends

17/02/2021

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EUROPE'S TRANSITION TO A DECARBONIZED ENERGY SYSTEM

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COP21: agreement to keep global warming "well below 2 degrees Celsius above preindustrial levels, and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius."

2020

- 20% CO2 reduction
- 20% Renewables
- 20% Energy efficiency

2030

- 40% CO2 reduction
- 27% Renewables
- 27% Energy efficiency

2050

- 80-95% CO2 reduction

✓ H2 is a clean energy carrier

- Transport and Energy applications, generate electricity and heat with very high efficiency
- Possibility for storage of renewable energy sources
- Reduction of CO2 emissions

✓ H2 can help ensure the current rapid growth of renewable electricity continues

✓ H2 Increase independence from unstable outside regions

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EUROPE'S TRANSITION TO A DECARBONIZED ENERGY SYSTEM

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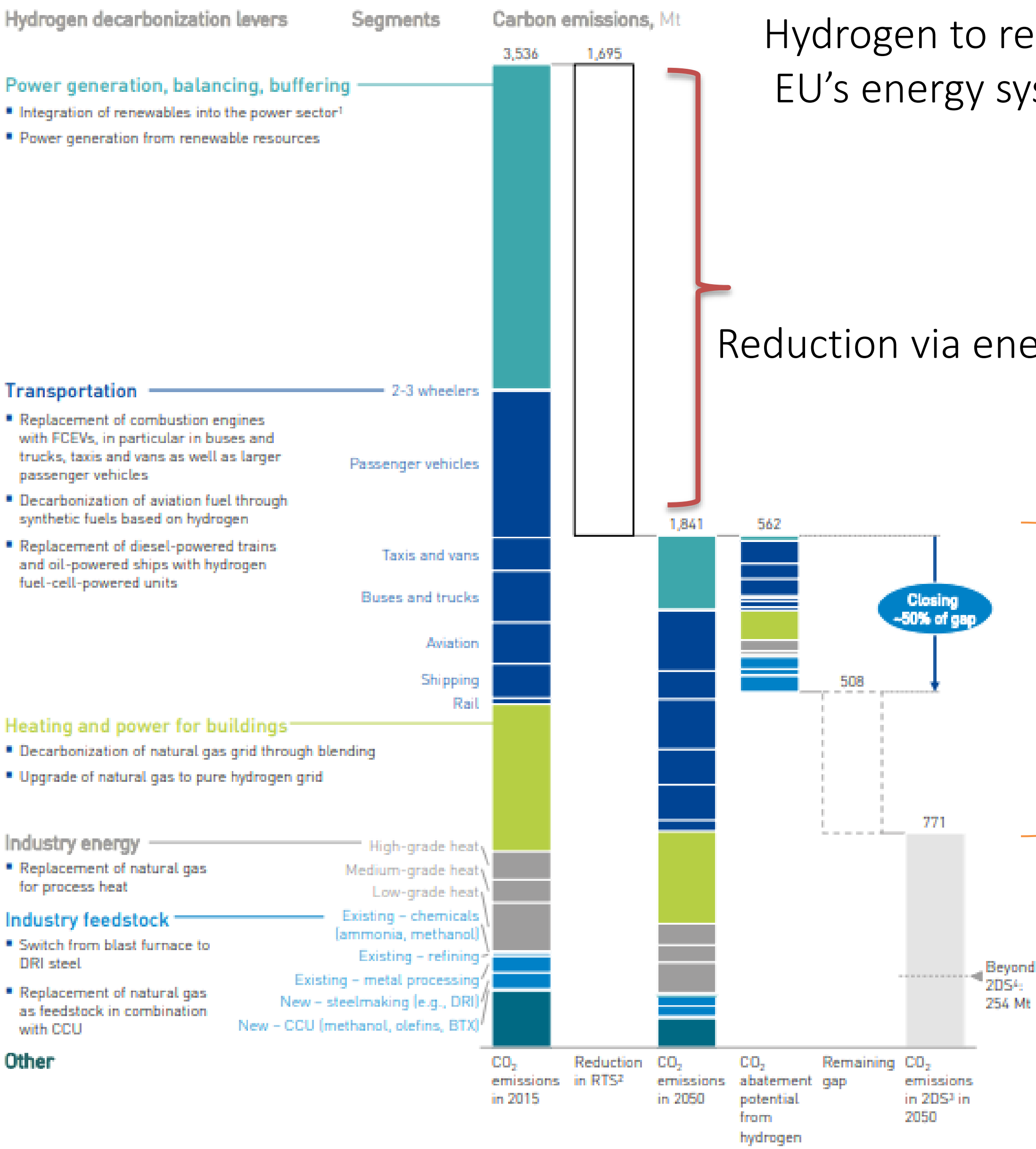

Hydrogen to realize the ambitious transition of the EU's energy system, a number of challenges need to be solved

Challenges:

- Achieving deep decarbonisation
- Management of variable renewable sources
- Meeting customer preferences

Source: Hydrogen roadmap europe

EUROPE'S TRANSITION TO A DECARBONIZED ENERGY SYSTEM

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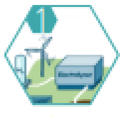


Power generation

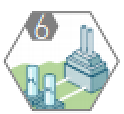
- Integration of renewables into the power sector.
- Power generation from renewable resources

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

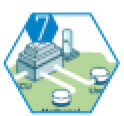
Heating and power for buildings

- 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 (direct reduced iron) steel
- Replacement of natural gas as feedstock in combination with CCU

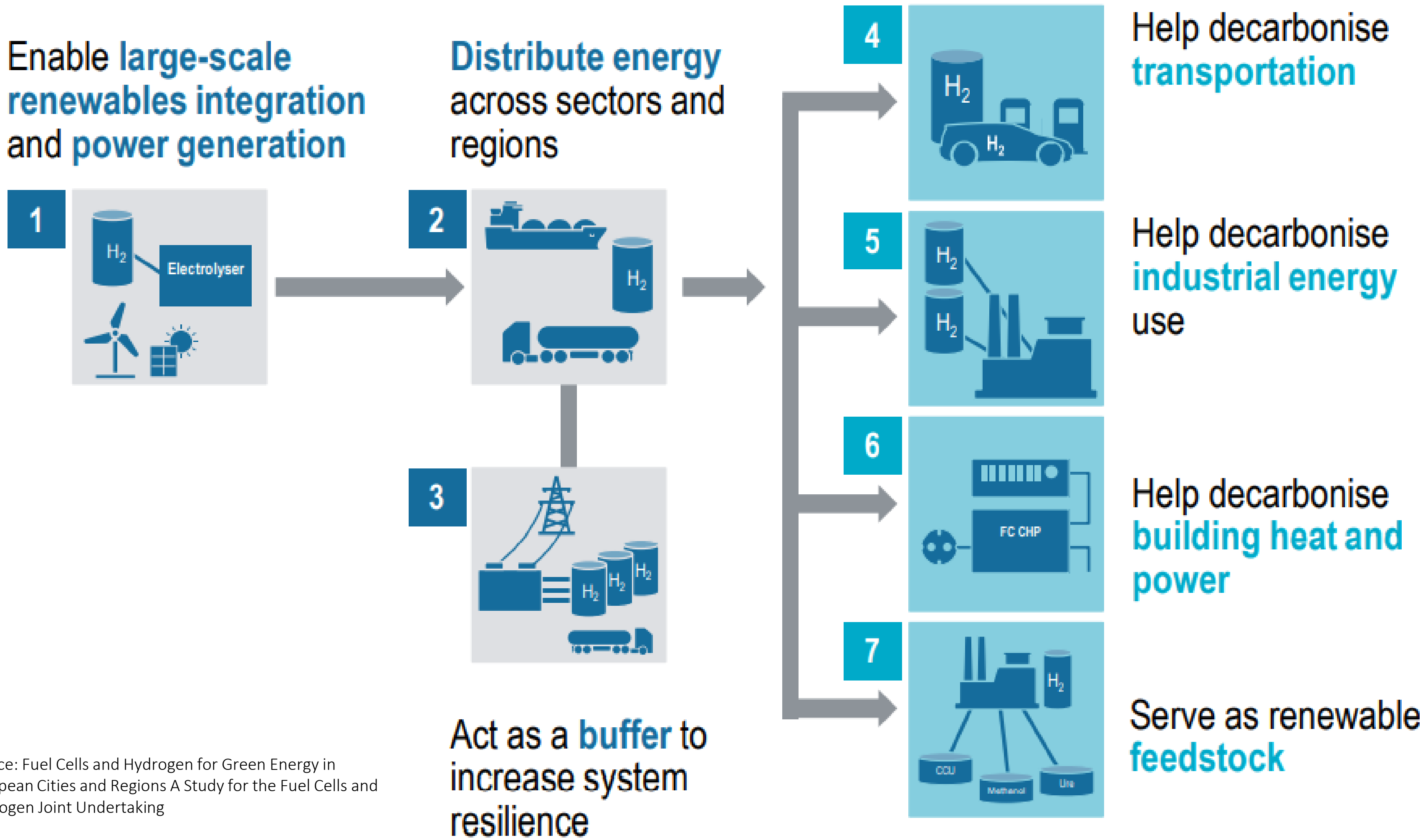
SOURCE: IEA Energy Technology Perspectives 2017; Hydrogen Roadmap Europe team

EUROPE'S TRANSITION TO A DECARBONIZED ENERGY SYSTEM

By analyzing its potential segment by segment, hydrogen is the key to achieve the energy transition in an efficient and economically attractive manner in the EU.

Enable the renewable energy system

Decarbonise end uses



Source: Fuel Cells and Hydrogen for Green Energy in European Cities and Regions A Study for the Fuel Cells and Hydrogen Joint Undertaking

ACHIEVING THE 2050 TARGETS:

Hydrogen is the best choice to decarbonize key sectors:

FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Achieving deep decarboni-zation

- H_2 TO DECARBONIZE THE GAS GRID
- FUEL CELLS/ SYNFUELS FOR HEAVY TRANSPORT AND LONG DISTANCES
- HIGH-GRADE HEAT FOR INDUSTRY & IN STEEL
- ULTRA-LOW-CARBON H_2 AS FEEDSTOCK, E.G., AMMONIA

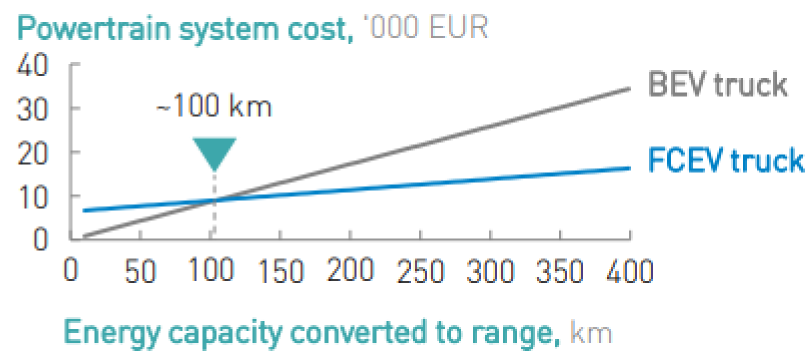
The decarbonization of the gas grid that connects Europe’s industry and delivers more than 40% of heating in EU households and 15% of EU power generation requires hydrogen.

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

- Full direct electrification of heating not feasible. Would require significant increase in power generation and grid capacity that is used only in the winter
- Compatible with existing building stock compared to use of heat pumps. <u>90% of all buildings emissions result from buildings older than 25 years</u>
- Infrastructure, skills and regulations already available and ready to be leveraged. <u>40% of all European households have gas heating as of today making fast and convenient implementation possible</u>

In transport, hydrogen is the most promising decarbonization option for trucks, buses, ships, trains, large cars, and commercial vehicles, where the lower energy density (hence lower range), high initial costs, and slow recharging performance of batteries are major disadvantages.

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



- Hydrogen refueling is 15 times faster than fast charging: after 10 minutes of refueling/recharging time the FCEV truck is 90% charged, BEV truck only 10%
- The Hydrogen recharging infrastructure requires 10-15x less space and creates flexibles instead of peak load
- Fuel cells also require significantly less raw materials compared to batteries and combustion engines.

Industry can burn hydrogen to produce **high-grade heat and use the fuel in several processes as feedstock**, either directly or together with CO2 as synfuel/electrofuel. In steelmaking, e.g., hydrogen can work as a reductant, substituting for coal-based blast furnaces.

- Only feasible route for decarbonization of steel

Replacement of blast furnace with direct reduction process using hydrogen

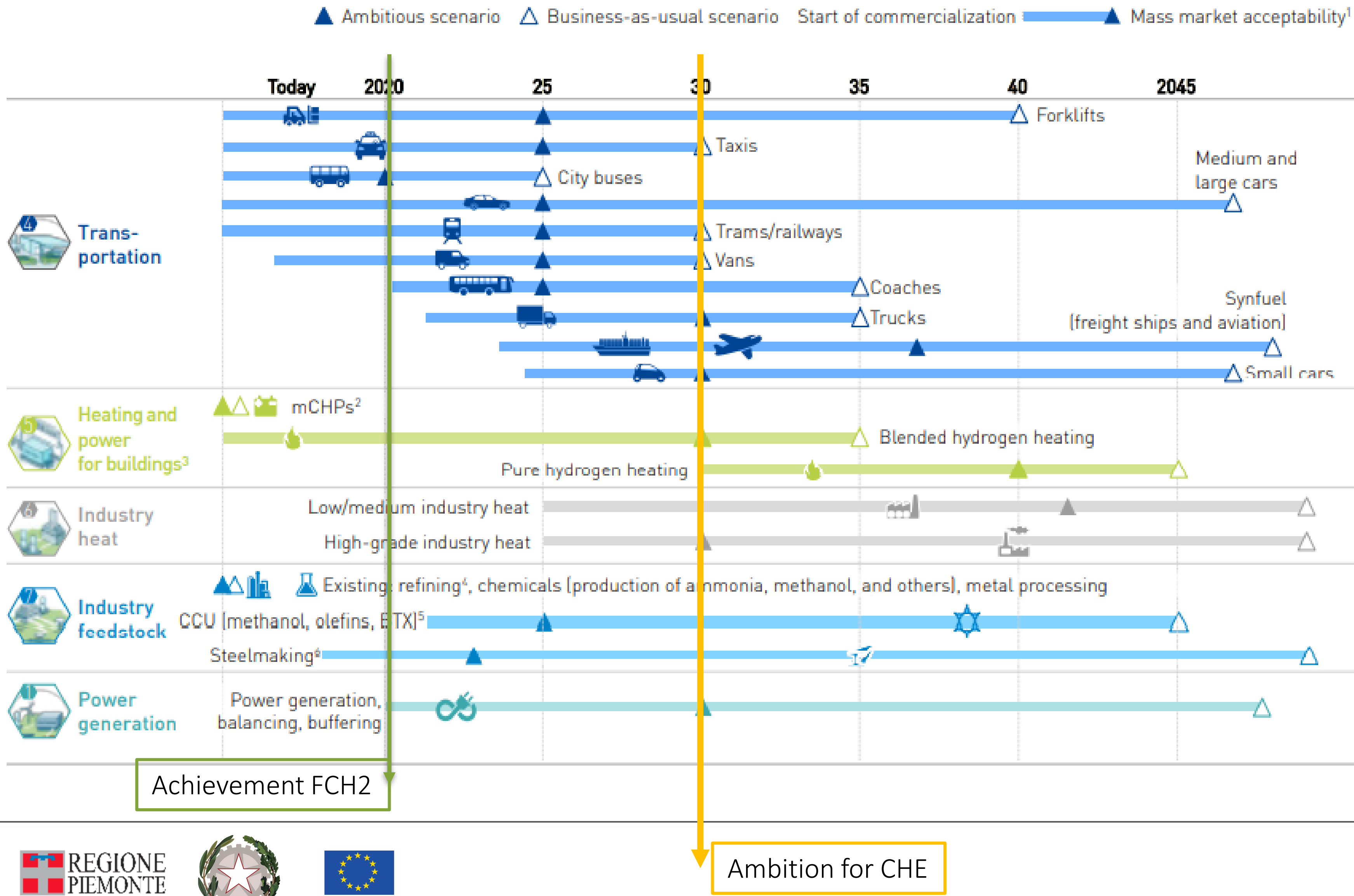
- At-scale decarbonization of high-grade heat industrial processes

Decarbonization route compatible with current processes

- 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 PRODUCTS EXISTS AND READY TO DEPLOYMENT



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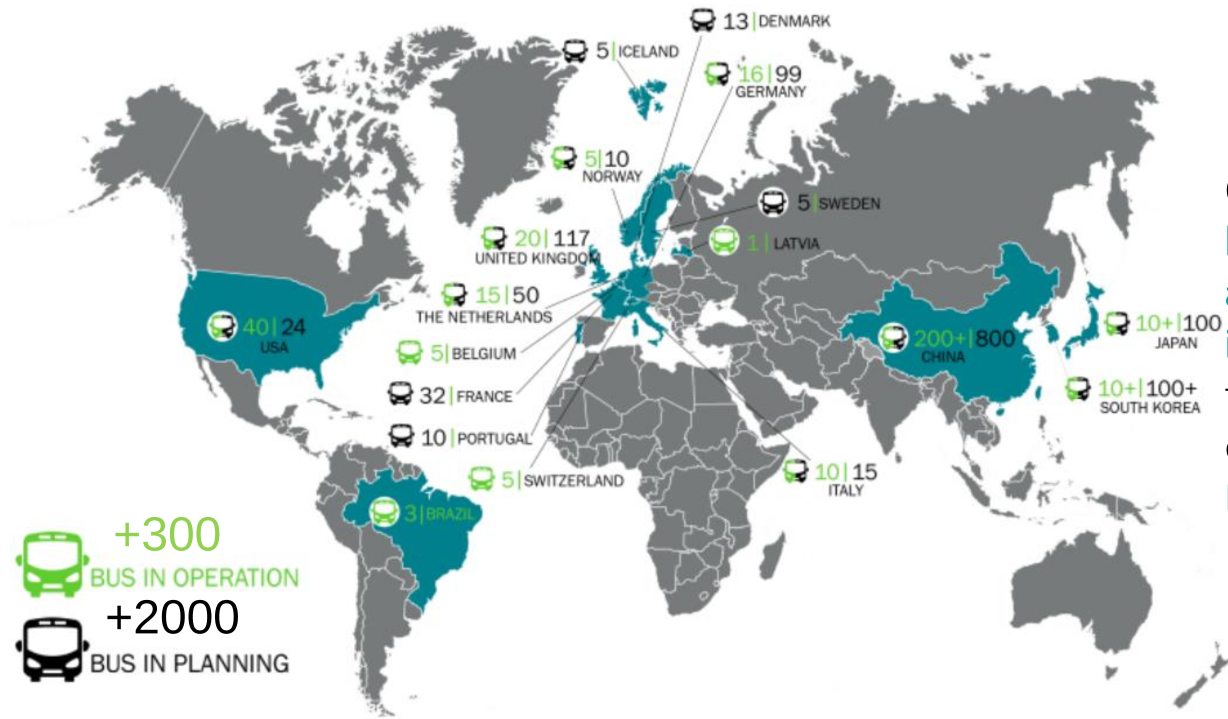
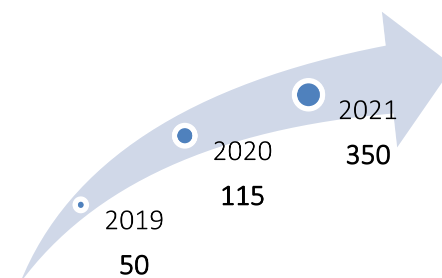
Fuel cell buses worldwide:



Over the past 15 years, FCEV buses have been operating across more than 8 million km in Europe, proving that the technology works, is flexible, operational and safe.

EVOLUTION IN EU-OPERATION



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FUEL CELL BUSES

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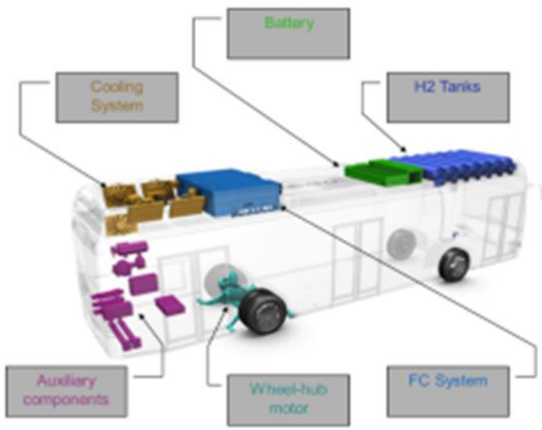
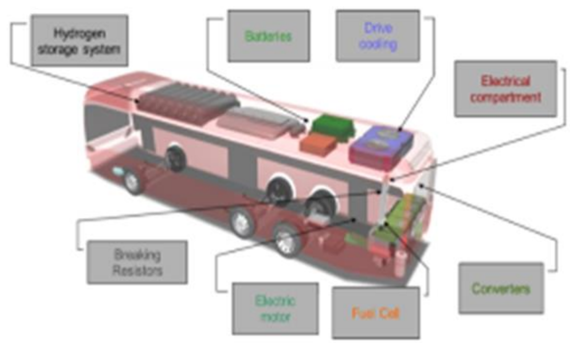
EVOBUS (Daimler) – FC bus 12 m



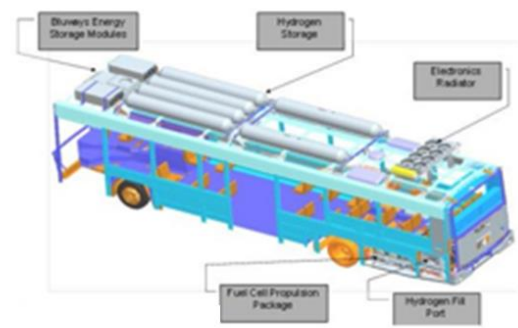
Fuel cell system: 120 kW
Battery system: 250 kW
Hydrogen storage system: 7 tanks, 350 bar
Full tank capacity: 35 kg



VAN HOOL – FC bus 12 m

(Oslo)

Fuel cell system: 150 kW
Battery system: 100 kW
Hydrogen storage system: 7 tanks, 350 bar
Full tank capacity: 35 kg

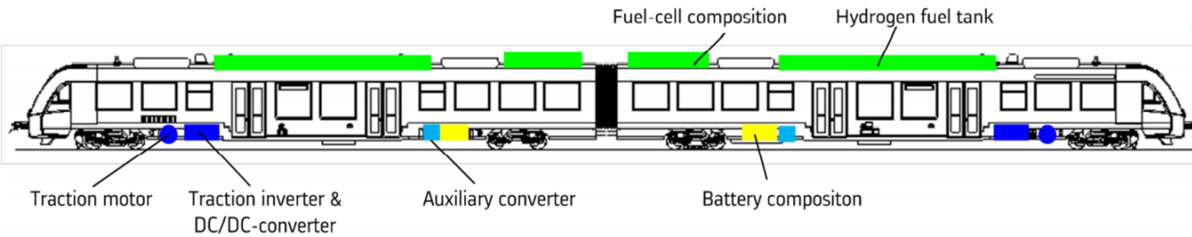


Fuel Cell System: 75 kW
Supercapacitor system: 240 kW
Hydrogen storage system: 4 tanks, 350 bar
Full tank capacity: 33 kg

WRIGHT – FC bus 12 m

Fuel cell buses now have a range of 300 to 450 km and so offer almost the same flexibility as diesel buses in day-to-day operation. While some older municipal buses still consume well over 20 kg of hydrogen (rather than 40 liters of diesel) per 100 km, newer fuel cell buses now use only 9 to 10 kg per 100 km, giving FCEBs an energy efficiency advantage of around 40 % as compared with diesel buses. Refueling time below 10 minutes. In order to develop the market, demonstration projects with large fleets in long-term use are planned.

FUEL CELL TRAINS



	Characteristics	Value
Dynamics & capacity	> Maximum speed > Passenger capacity	> 140 km/h > 300/150[1)] seats
Consumption & range	> Fuel consumption > Average range per tank	> 0.25 kg/km > 1,000[2)] km
On board hydrogen system	> Storage pressure > Storage capacity > Fuel cell system > Fuel cell power	> 350 bar > 260 kg (1 tank[2)] of ~130 kg per car) > Hydrogenics HyPM™ Power Modules > 400 kW (200 kW module per car)
Powertrain	> Traction motors > Hybridization system > Energy storage capacity	> Alstom-power-management-system > Li-Ion batteries > 110 kWh
Costs	> Rolling stock costs > Infrastructure costs > Hydrogen fuel	> tbc > Included in hydrogen fuel cost > EUR 4-7 per kg

1) Seated seats 2) Latest modification of Coradia iLint – Each tank contains several pressurized bottles

STUDY ON THE USE OF FUEL CELLS & HYDROGEN IN THE RAILWAY ENVIRONMENT –State of the art & business case and market potential - © Shift2Rail Joint Undertaking and Fuel Cells and Hydrogen Joint Undertaking, 201910

The Coradia iLint is the world's first passenger train powered by a hydrogen fuel cell, which produces electrical power for traction. This zero-emission train emits low levels of noise, with exhaust being only steam and condensed water. The iLint is special for its combination of different innovative elements: clean energy conversion, flexible energy storage in batteries, and smart management of traction power and available energy. Specifically designed for operation on non-electrified lines, it enables clean, sustainable train operation while ensuring high levels of performance.

H2 storage@350 bar

Fuel cells

FUEL CELL TRAINS

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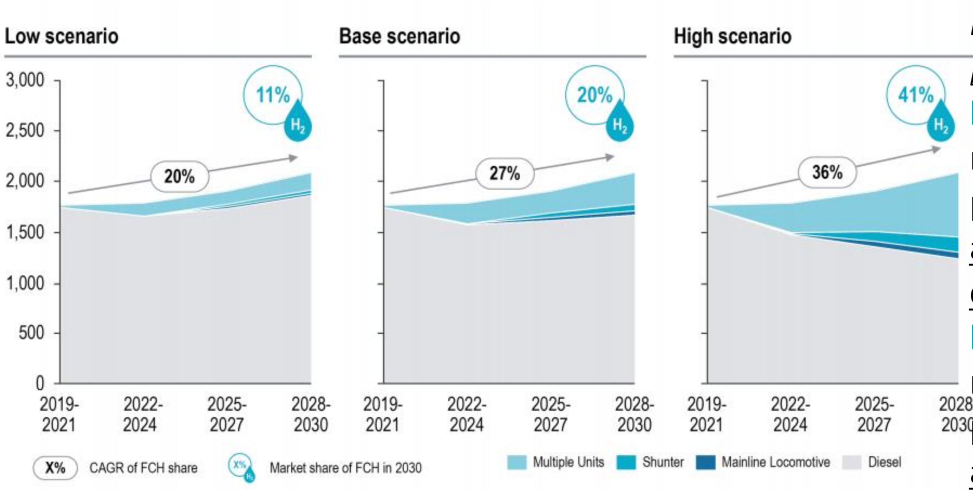


EU market potential for FCH trains – scenario comparison [standard units]:

Low scenario: The estimation of the market potential for FCH rail application in the low scenario indicates a market potential of 127 SU 2022 – 2024 which grows by approximately 20% to 546 SU until 2028 – 2030. This comprises a share of 11% of the overall market potential.

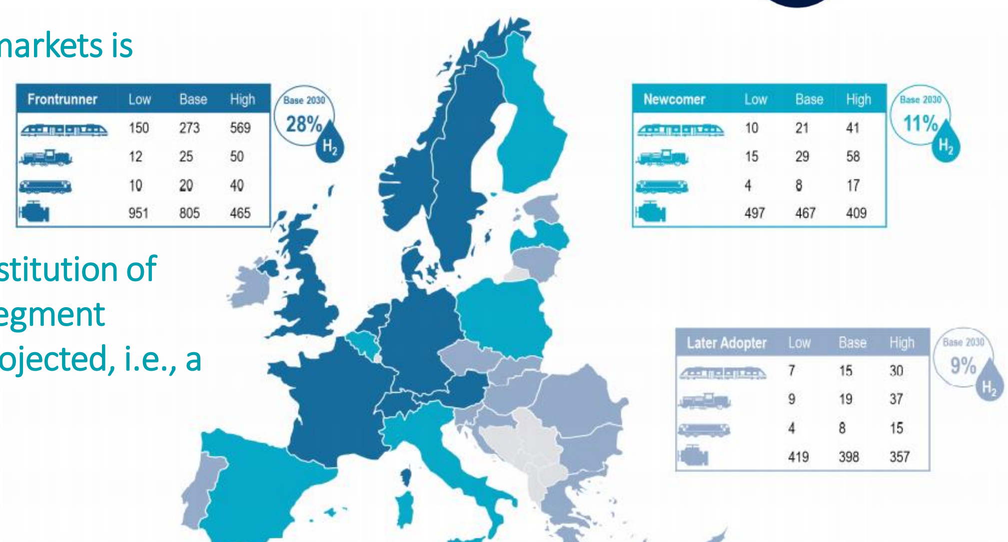
High scenario: The estimation of the market potential for FCH rail application in the base scenario indicates a market potential of 313 SU in 2022 – 2024 which grows by approximately 36% to 1,753 SU until 2028 – 2030. This comprises a share of 41% of the overall market potential.

Market potential by geography.

FCH train market categories including base scenario estimations for 2028 – 2030 [standard units]

The market potential for FCH trains in Frontrunner markets is highest (2022-2024: 193 SU, 2028-2030: 318 SU), followed by Newcomer markets (2022-2024: 11 SU, 2028-2030: 58 SU) and Later Adopter markets (2022-2024: 5 SU, 2028-2030: 41 SU). In Frontrunner markets the substitution of diesel trains is mainly driven by the Multiple Units segment where, firstly, high diesel purchasing volumes are projected, i.e., a high substation potential exists.

Shift2Rail



Frontrunner	Low	Base	High
	150	273	569
	12	25	50
	10	20	40
	951	805	465

Newcomer	Low	Base	High
	10	21	41
	15	29	58
	4	8	17
	497	467	409

Later Adopter	Low	Base	High
	7	15	30
	9	19	37
	4	8	15
	419	398	357

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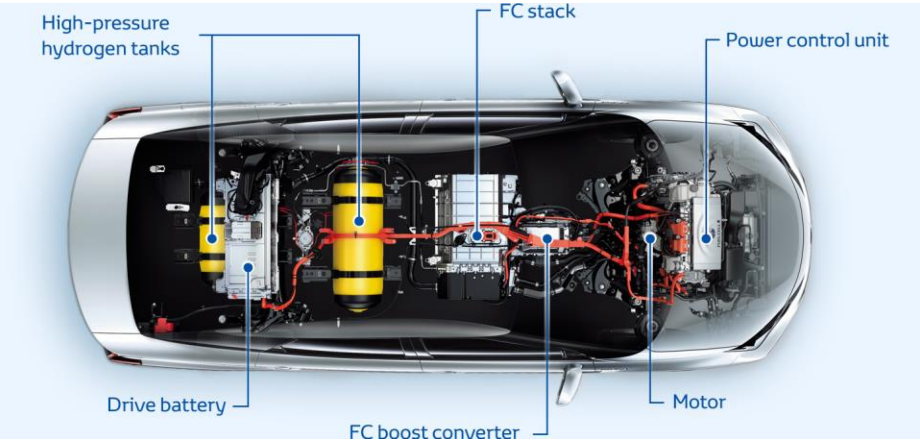
TOYOTA — **2016 Mirai Product Information**

MECHANICAL	
FUEL CELL SYSTEM	
Name	Toyota Fuel Cell System (TFCS)
FUEL CELL STACK	
Name	Toyota FC Stack
Fuel Cell Stack Type	Solid polymer electrolyte fuel cell
Humidification System	Internal circulation system (humidifier-less)
Power Output	153 HP (114 kW) MAX
Output Density	By Volume: 3.1 kW/L By Weight: 2.0 kW/kg
Cell	Number of cells in one stack: 370 (single-line stacking) Thickness: 1.34 mm Weight: 102 g Flow Channel: 3D fine-mesh flow field (cathode)
Emission Rating	Zero Emissions Vehicle (ZEV)
ELECTRIC MOTOR	
Motor Type	AC synchronous electric generator
Power Output	151 HP (113 kW) MAX
Peak Torque	247 lb-ft (335 N-m)
HYDROGEN TANKS	
Storage Method	Carbon fiber high-pressure tanks
Number of Tanks	2
Type	Type-4
Material	Three layer structure: Inner layer: plastic liner (prevents hydrogen leakage) Middle layer: carbon fiber reinforced plastic (structural element) Surface layer: glass fiber reinforced plastic (protects outer surface from abrasion)
Fuel	Compressed hydrogen gas
Maximum Filling Pressure	87.5 MPa
Normal Operating Pressure	70 MPa (approx. 10,000 psi)
Storage Density (Capacity)	5.7 weight %
Internal Volume	122.4 L Front: 60.0 L Rear: 62.4 L
Hydrogen Storage Mass	Approx. 5.0 kg
Refueling Time	About 5 minutes

The number of fuel cell cars manufactured over the coming years is projected to range from several hundred up to thousands of units. Fuel cell passenger cars today are equipped with PEM fuel cells, in both series and parallel configurations. The prices for medium-sized vehicles fitted with fuel cells are still well above those for passenger cars with internal combustion engines – at around 60,000 EUR/USD. With the launch of FCEV series production, vehicle cost and prices are expected to fall substantially.

The fuel cell stacks in the latest fuel cell models have an output of 100 kW or more. As compared with battery electric cars they have a greater range – of around 400 to 500 kilometers today – with a lower vehicle weight and much shorter refueling times of three to five minutes. They usually carry 4 to 7 kg of hydrogen on board, stored in pressure tanks at 700 bar.



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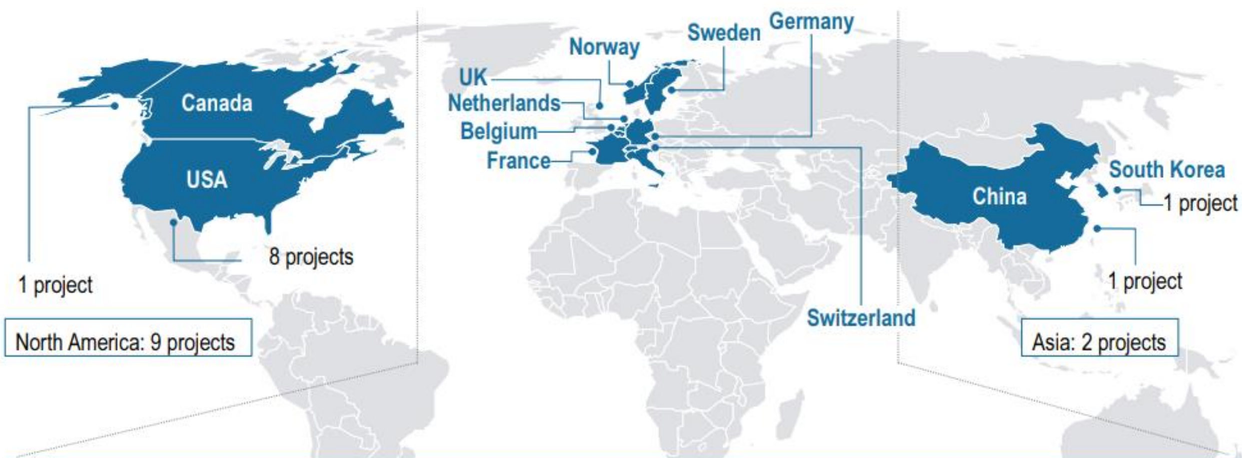
Europe shows a specific focus on FCH heavy-duty trucks trial and demonstration projects, levelling up with US efforts

Geography of key fuel cell hydrogen HDT (Heavy-duty-truck) trial and demonstration projects

Geography of key fuel cell hydrogen HDT trial and demonstration projects[1]



Europe: Overall, 12 relevant projects have been identified – many projects are conducted cross-nationally[2]

Belgium	France	Germany	Netherlands	Norway	Sweden	Switzerland	UK
5 projects (5)	5 projects (3)	5 projects (3)	6 projects (5)	1 project	1 project	4 projects (1)	1 project (1)

1) Finalised, ongoing and planned HDT trial and demonstration projects since 2015 until today 2) The number in ( ) signals the number of cross-national projects

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Roland Berger

H2 TRUCKS

European projects often include multi-national stakeholders with a strong participation of wholesale and retail companies…

Project	Country	Duration	Operator / logistics user	Application	OEM/ System integrator	FC provider
1 H2-Share		2017 – 2021	BREYTNER, Colruyt Group		VDL (DAF)	Ballard
2 H2Haul		2019 – 2024	BMW Group logistics, Coop, Colruyt Group, Carrefour (Chabas, Perrenot), Air Liquide	Rigid and tractor	IVECO, FPT Industrial, VDL	ElringKlinger, PowerCell
3 Waterstofregio 2.0		2016 – n/a	Colruyt Group		VDL (DAF)	Ballard
4 ASKO distribution logistics trucks		2017 - 2024	ASKO		Scania / Hydrogenics	Hydrogenics
5 Hyundai Hydrogen Mobility[1] Business venture		Start in 2020	Hyundai Hydrogen Mobility		Hyund	

Rigid 4x2 truck · Tractor 4x2 truck · Rigid 6x4 truck · Tractor 6x4 truck

1) The Hyundai Hydrogen Mobility project refers to a commercial roll-out of trucks. It is not a trial and demonstration in a strict sense.

Source: Desk research; Roland Berger

Note: Information in the trial and demonstration dossier relies on company information and publicly available sources. Some information is missing as indicated.

H2 TRUCKS

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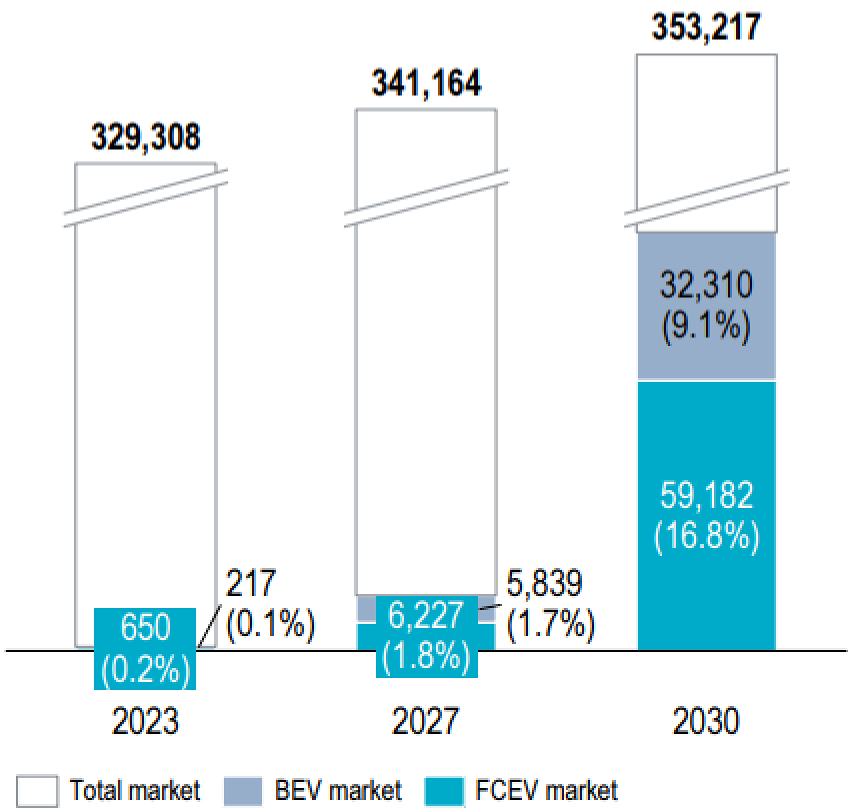
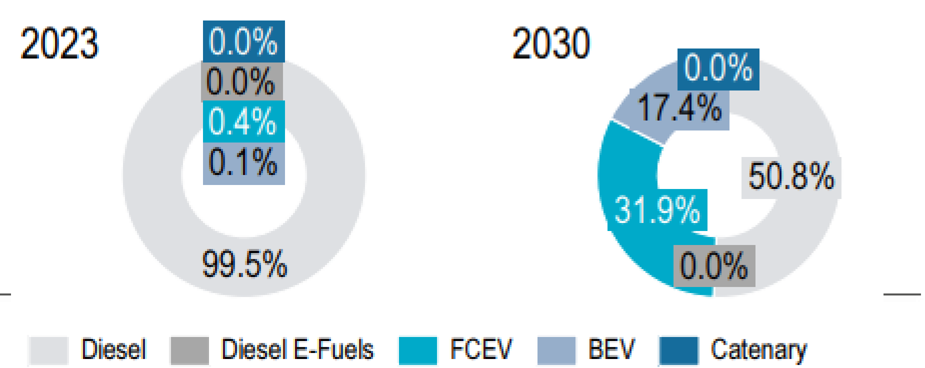
European market potential of FCEV [# of truck sales][1]



- The market potential analysis focuses on selected market segments (international logistics, national logistics, manufacturing industry, wholesale, retail and regional logistics) with a sales share of ~53%
- Overall, FCEV have a high potential within the whole truck market – steep increase in sales share from 0.2% in 2023 to 16.8% in 2030
- Within the specific market segments, the technology split shows clear changes between 2023 and 2030: FCEV technology represents ~32% in 2030

Market segment technology split [%]



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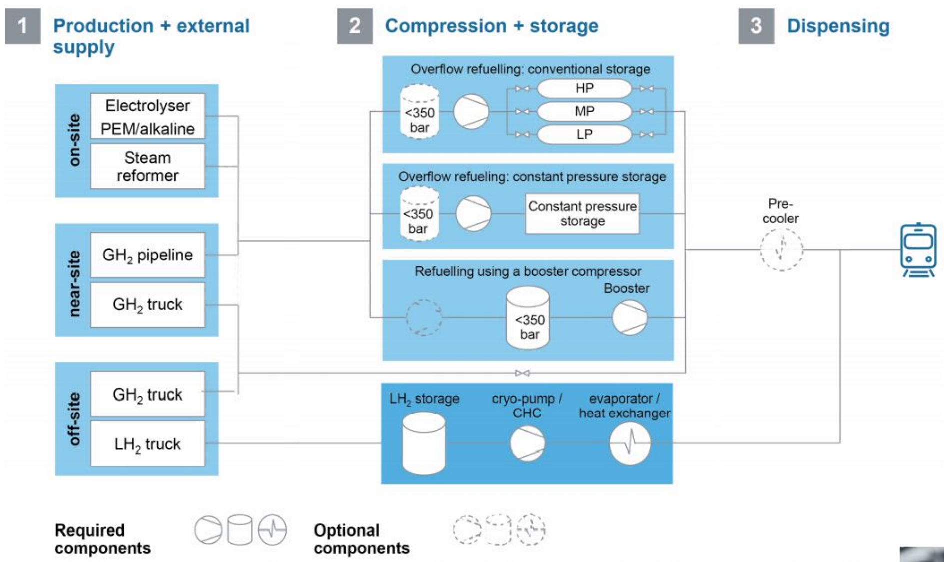
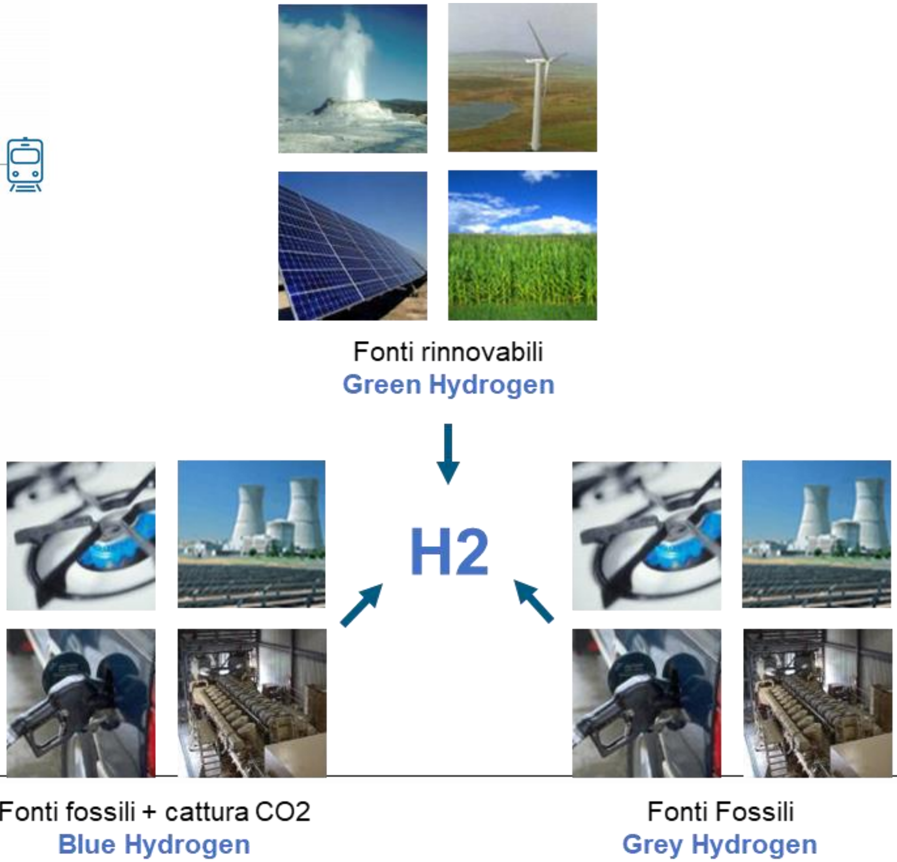
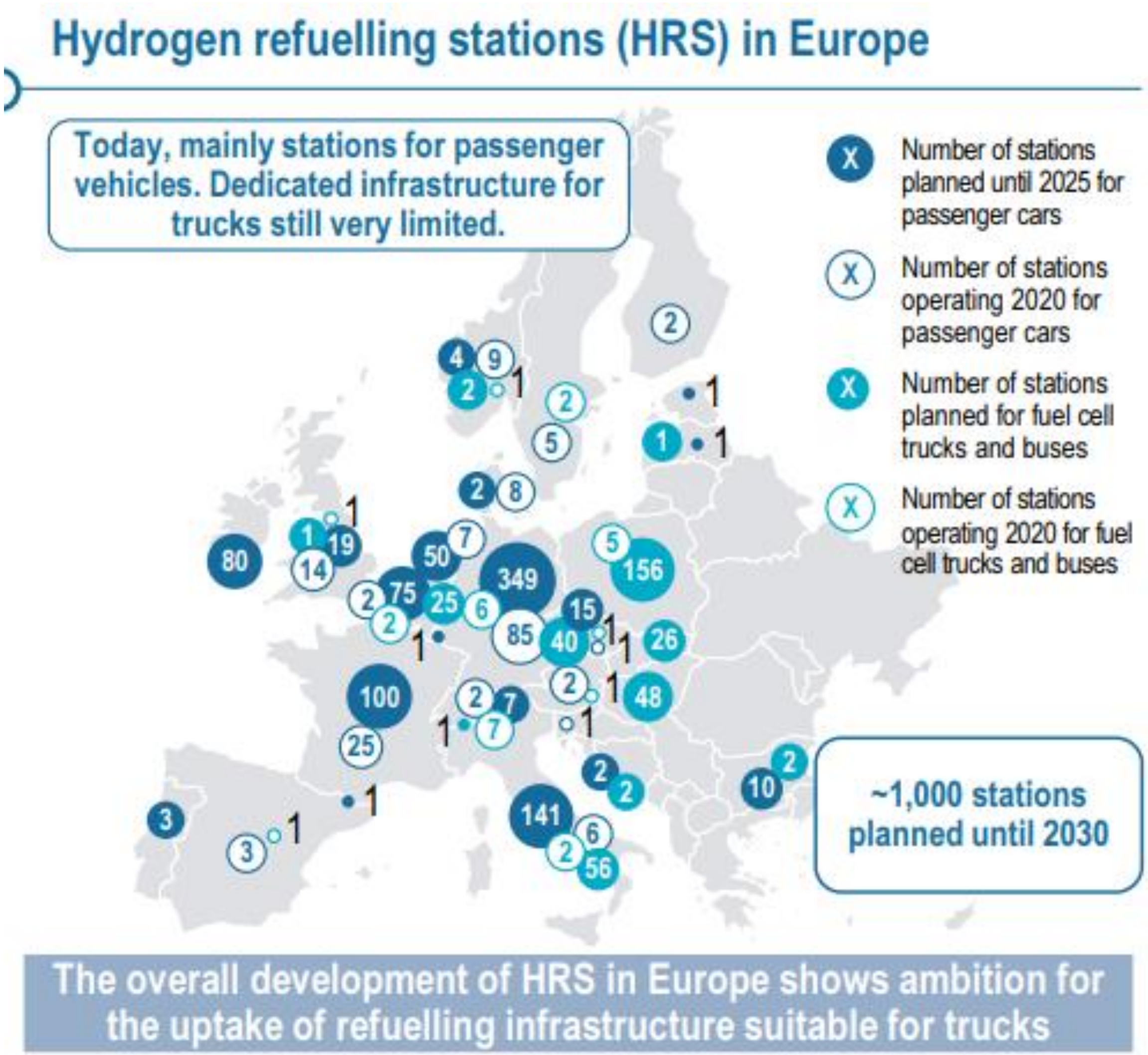
HRS Refueling stations





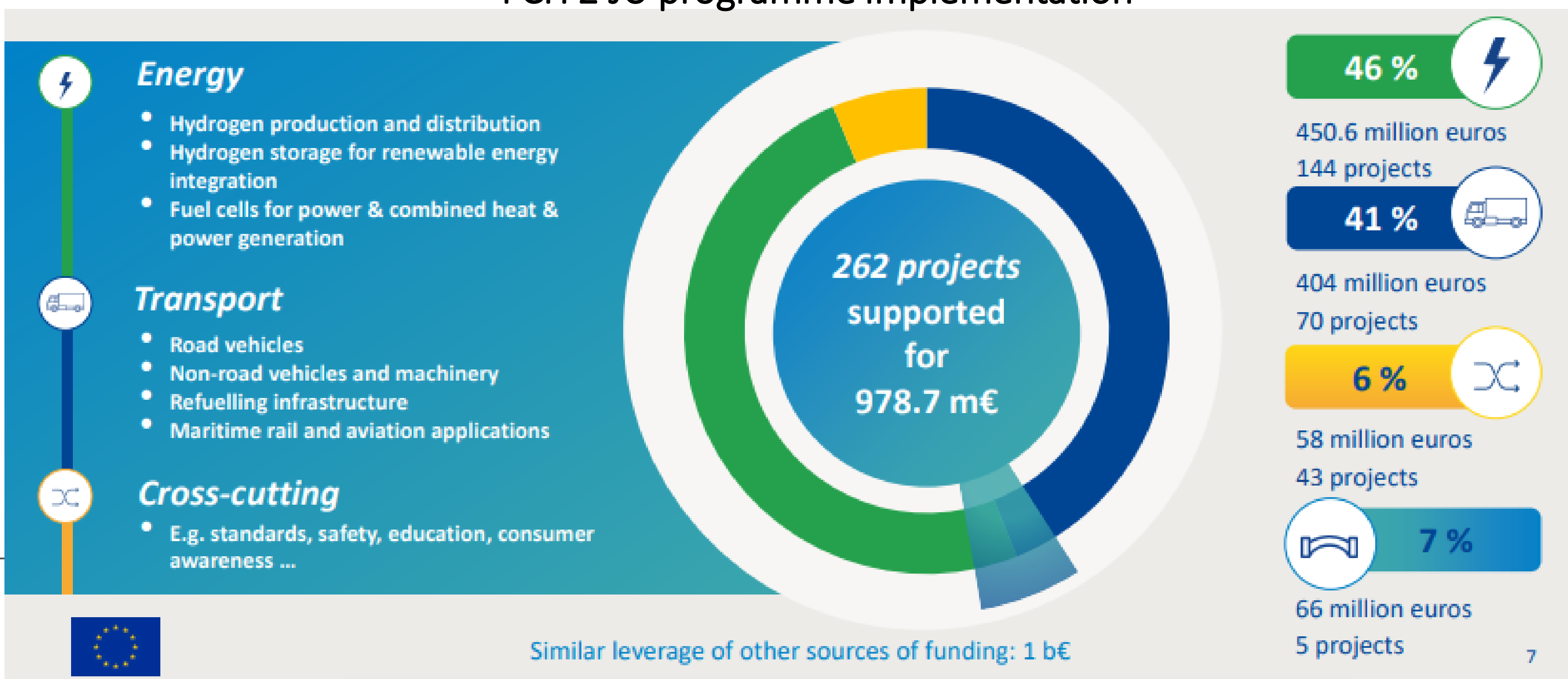
June 2020

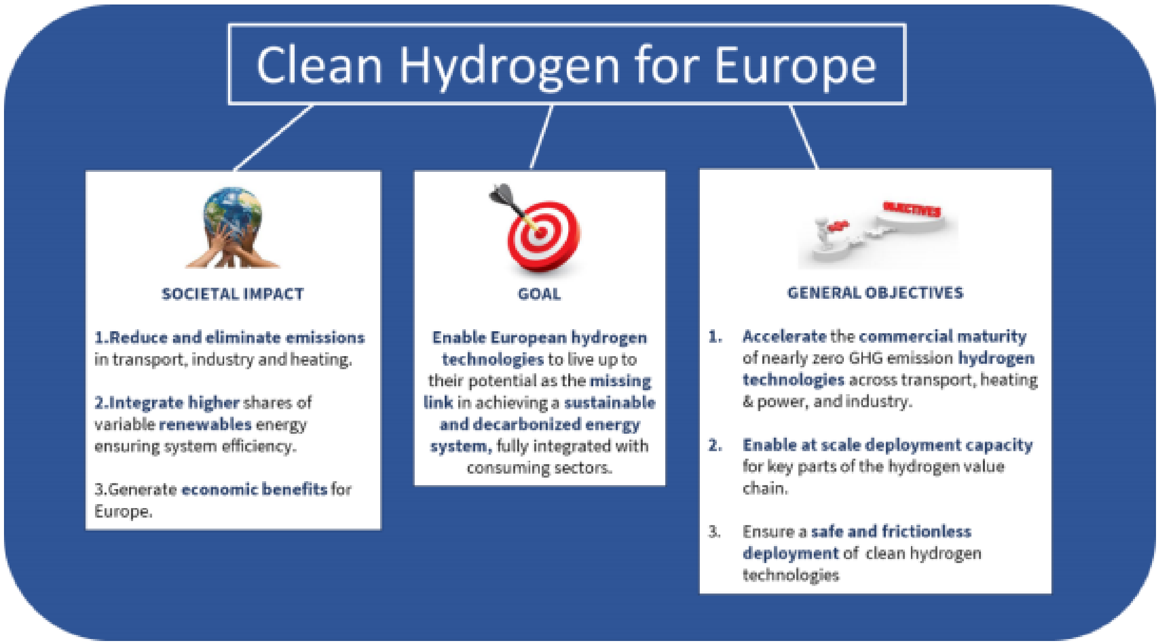

Hydrogen refuelling stations (HRS) in Europe
Today, mainly stations for passenger vehicles. Dedicated infrastructure for trucks still very limited.
Number of stations planned until 2025 for passenger cars
Number of stations operating 2020 for passenger cars
Number of stations planned for fuel cell trucks and buses
Number of stations operating 2020 for fuel cell trucks and buses
~1,000 stations planned until 2030
The overall development of HRS in Europe shows ambition for the uptake of refuelling infrastructure suitable for trucks

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

The FCH1JU and FCH2JU have proven effective in developing hydrogen technologies to a high Technology Readiness Level (TRL), allowing for large-scale deployment. Yet, there is still an important work to be performed in terms of Research and Innovation in order to develop the next generation of products as well as technologies that did not reach a sufficiently high TRL to envisage a large-scale deployment.

FCH 2 JU programme implementation





Within the framework of the preparation of the foreseen Clean Hydrogen for Europe (the third public-private partnership, continuation of the FCH2JU), Hydrogen Europe and Hydrogen Europe Research have prepared their Strategic Research and Innovation Agenda (SRIA) which is made of a set of approximately 20 roadmaps. This SRIA represents the view of the private partner and will be used as a basis to develop the Multi Annual Work Plan (MAWP) of the Clean Hydrogen for Europe partnership. The current version (July 2020) is the final draft that has been submitted to the European Commission.

OPPORTUNITIES AT EU LEVEL

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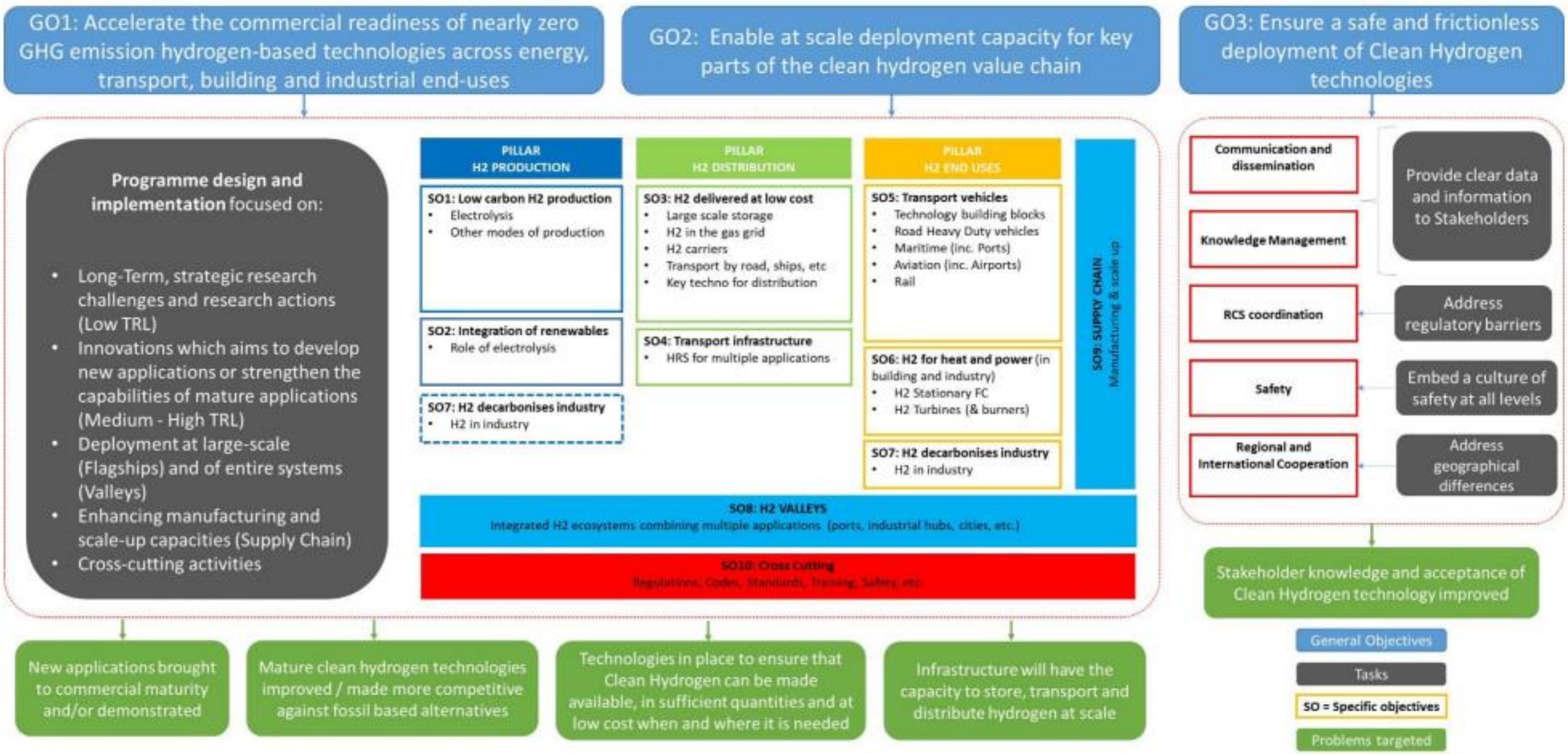
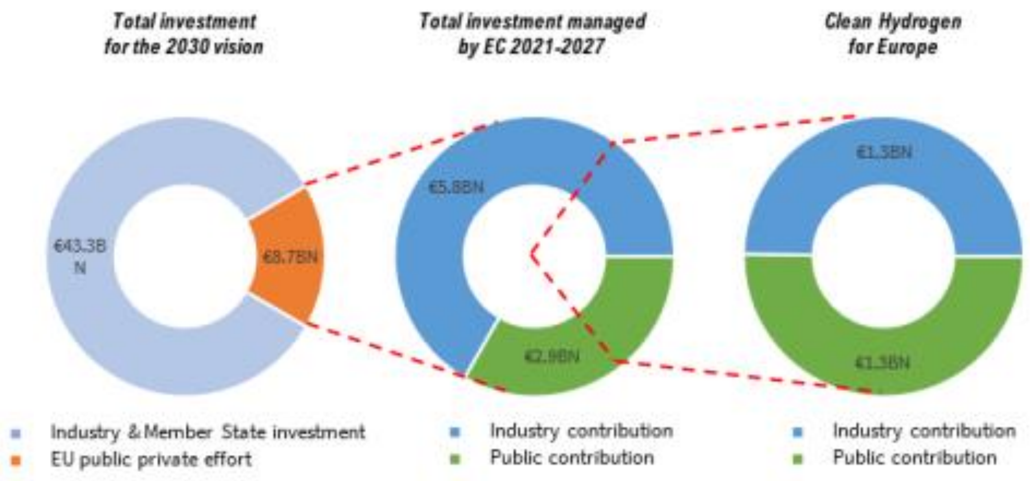
The objectives of the Clean Hydrogen for Europe are fully aligned with the goals of the European Green Deal:

- Sustainable transport
- Achieving climate neutrality
- Clean, reliable and affordable energy
- Zero pollution in Europe



OPPORTUNITIES AT EU LEVEL



Overall, €52 billion of investment will be needed to realize this vision in the decade 2020-2030. While the bulk of this investment will come from private investors and must be triggered by proper regulation and Member States support.

It is necessary to trigger 8.7 billion investment by EU funding and financing action, with roughly 1/3 third coming from EU public contribution and 2/3 from private investment. 70 % of the €8.7 billion programme could be provided through existing or planned EU support funds like CEF Transport and Energy or the ETS Innovation Fund (mostly market deployment actions). It is estimated that €2.6 BN (30%) would be needed for the partnership on Clean Hydrogen to deliver its targets. It is expected that contributions will be shared equally by the partners (industry and research) and the European Commission

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