GREEN HYDROGEN

FACTBOOK

The role of green hydrogen in the energy transition

The electrification of final consumption, using energy from renewable sources, already represents the cheapest and most efficient way to decarbonize sectors such as transport, domestic heating, various industrial uses, and manufacturing processes. However, there are sectors where direct electrification struggles to penetrate due to physical or technological reasons, the so-called "hard to abate" sectors such as steel mills, worldwide shipping and aviation. In these cases, hydrogen represents the best complement to electrification as a decarbonization solution since it does not produce carbon dioxide emissions during its use and is the basic feedstock to produce renewable synfuels.

Nonetheless, hydrogen production processes are not all the same in terms of their effects on the environment. Currently, more than 99% of the hydrogen produced is derived from fossil fuels (Grey and Brown Hydrogen), with significant carbon dioxide emissions along the entire supply chain. In the production of hydrogen from renewable sources, however, there is no generation of greenhouse gas emissions: this is why it is considered the only hydrogen that is truly sustainable.

Substituting Grey and Brown Hydrogen with Green Hydrogen will in itself be the first and best use of the Green Hydrogen technology.

We believe that the best complement to electrification to achieve full decarbonization is green hydrogen, strictly produced from 100% renewable sources. Its production requires rather simple systems, it supports a decentralized and more flexible energy model, and it has no critical impacts on health, safety, and the environment. However, we need to start working now to make green hydrogen economically competitive with respect to hydrogen produced from fossil fuels.

As one of the largest and fastest growing renewable energy producers we are committed to testing at an international level, from Chile to Italy, new models and innovative solutions capable of reducing the costs of the electrolyzers used to produce green hydrogen and promote the development of an economy of scale. We want to do this by working together with our partners, our technology suppliers, startups, and anyone who develops ideas and technologies that point in our same direction, according to an open and collaborative model.

Many countries are publishing ambitious hydrogen strategies with their visions for the future. These will establish regulatory frameworks which, we hope, will allow the development of green hydrogen in the "hard to abate" sectors through a distributed production model. This would have a double benefit: on the one hand, hydrogen is produced where its decarbonization potential can be fully exploited, on the other hand it relies on the electricity grid to directly feed electrolyzers on-site with renewable energy. This would minimize the risk of investing massively in assets, such as new gas pipelines or retrofitting existing infrastructures, even before a demand and a market are well defined.

We also think that regulatory frameworks under developments around the world should identify a rigorous taxonomy of the various production methods signaling to final users the real value of green hydrogen and guiding governments in their policy choices.

Francesco Starace
CEO & General Manager Enel Group

Green hydrogen and electrification: what is the most efficient solution to decarbonize final energy uses

	INDUSTRY	TRANSPORT				BUILDINGS		
GREEN HYDROGEN	✓ HARD TO ABATE SECTORS	✗	✓ LONG HAUL SHIP POWERTRAIN	✓ IF ELECTRIFICATION IS NOT POSSIBLE	✓	✗	✗	✗
ELECTRIFICATION	✓	✓	✓ COLD IRONING[1]	✓	✗	✓	✓	✓

Electrification, if possible, represents the most efficient solution to decarbonize all three sectors of energy consumption.

INDUSTRIAL PROCESSES:
electrification is key to decarbonize the industrial sector, with green hydrogen representing a viable option for the so-called "hard to abate" sectors.

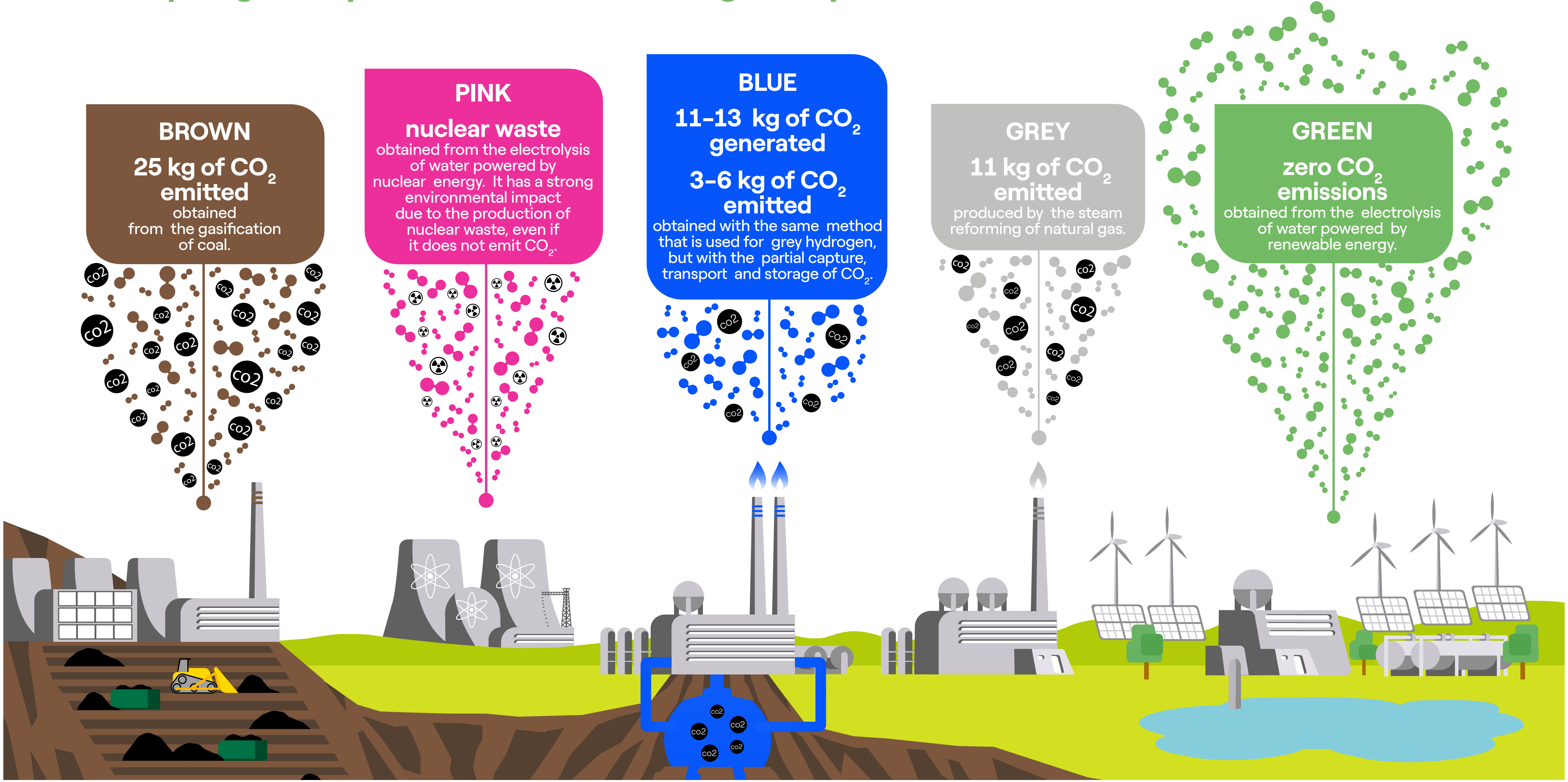
TRANSPORT
- **Road transport:** electric powertrains are more efficient, have a better environmental performance and are more convenient than their hydrogen counterparts.
- **Shipping:** cold ironing represents a ready and proven solution for electrification of energy needs of moored ships. In upcoming years, green hydrogen might become an effective solution for long haul shipping.
- **Railways:** electrification represents the ideal solution unless it is not achievable due to the line's physical logistics or expense factors with green hydrogen representing a viable option.
- **Aviation:** electrification is a long-term opportunity so the decarbonization of this sector can occur through the use of green hydrogen.

BUILDINGS:
electric heat pumps represent the most cost-effective path towards the decarbonization of both residential and commercial heating since they are a more mature market solution compared to hydrogen boilers.

1) Cold ironing is the process of providing shoreside electrical power to a ship at berth while its main and auxiliary engines are turned off.

GREEN HYDROGEN: THE DECARBONIZATION SOLUTION FOR INDUSTRY, AVIATION AND SHIPPING

How can hydrogen be produced without having an impact on the environment?



CO_2 emissions figures source: IEA and BNEF

Hydrogen today derives from fossil fuels **but it is turning green to meet tomorrow's decarbonization goals**

75 Mt

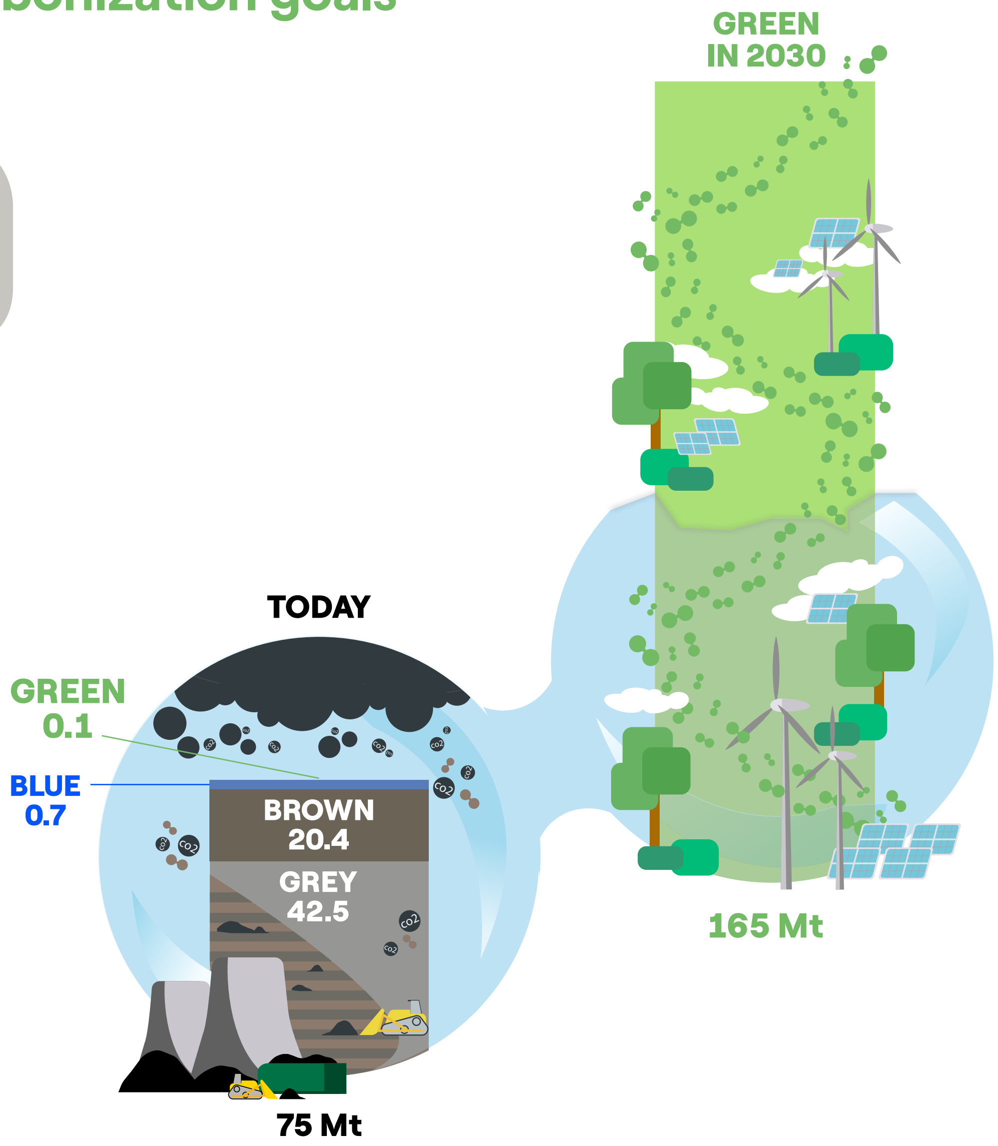
Dedicated production of hydrogen in 2020.

900 Mt CO_2

The dominance of fossil fuels has made H2 production responsible for 2.5% of global CO_2 emissions in energy and industry.

FEEDSTOCK FOR SOME INDUSTRIAL PROCESSES

Today it is mainly used for refining and producing ammonia and fertilisers.



165 Mt

>2x possible growth in hydrogen production to reach net-zero emissions.

0 Mt CO_2

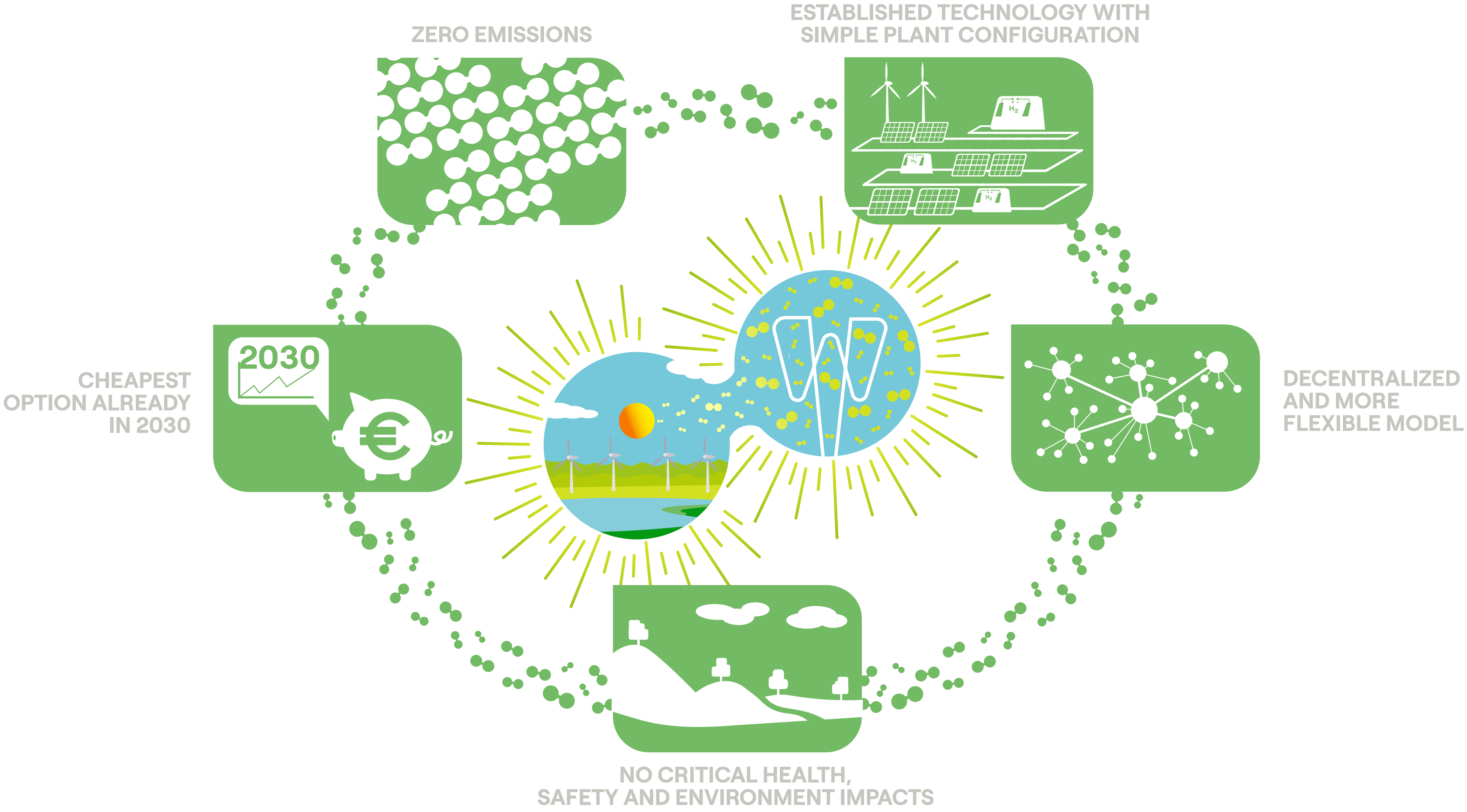
Only Green Hydrogen is fully zero-impact, without polluting emissions and without consuming fossil natural resources.

HARD-TO-ABATE SECTORS

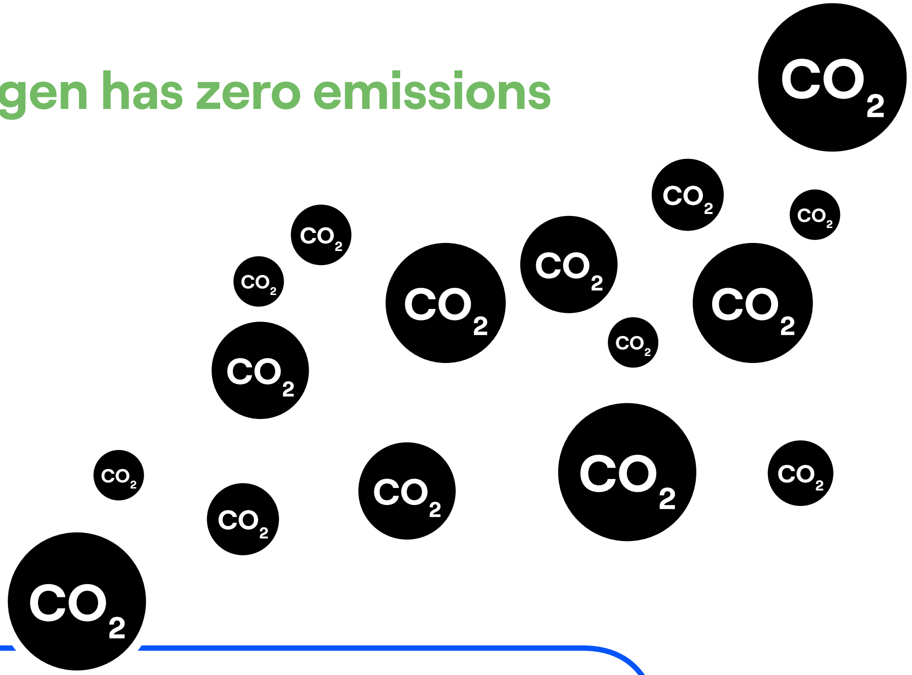
Decarbonization goals and technological improvements will enhance the crucial role of hydrogen as a complement to electrification.

Source: IEA - Global Hydrogen Review 2021
BNEF - New Energy Outlook 2021; Green Scenario

Why Green Hydrogen is better than Blue?



Green Hydrogen has zero emissions



3-6 kg CO_2

PER KG OF BLUE H_2

BLUE HYDROGEN EMISSIONS RANGE

- As a matter of fact, blue hydrogen generates CO_2 and manages it downstream but is able to capture only up to 90% of the CO_2 generated.
- The remainder is emitted into the atmosphere.
- In addition, methane, a gas with a much larger greenhouse gas potential, is also leaked into the atmosphere in the upstream process of production and transport.

VS

kg CO_2

PER KG OF GREEN H_2

GREEN HYDROGEN DOES NOT GENERATE ANY CO_2 NOR EMIT IT INTO ATMOSPHERE

Green Hydrogen plants support a distributed model

DECENTRALIZED MODEL

Green Hydrogen production takes place where it is consumed.

LOW COMPLEXITY

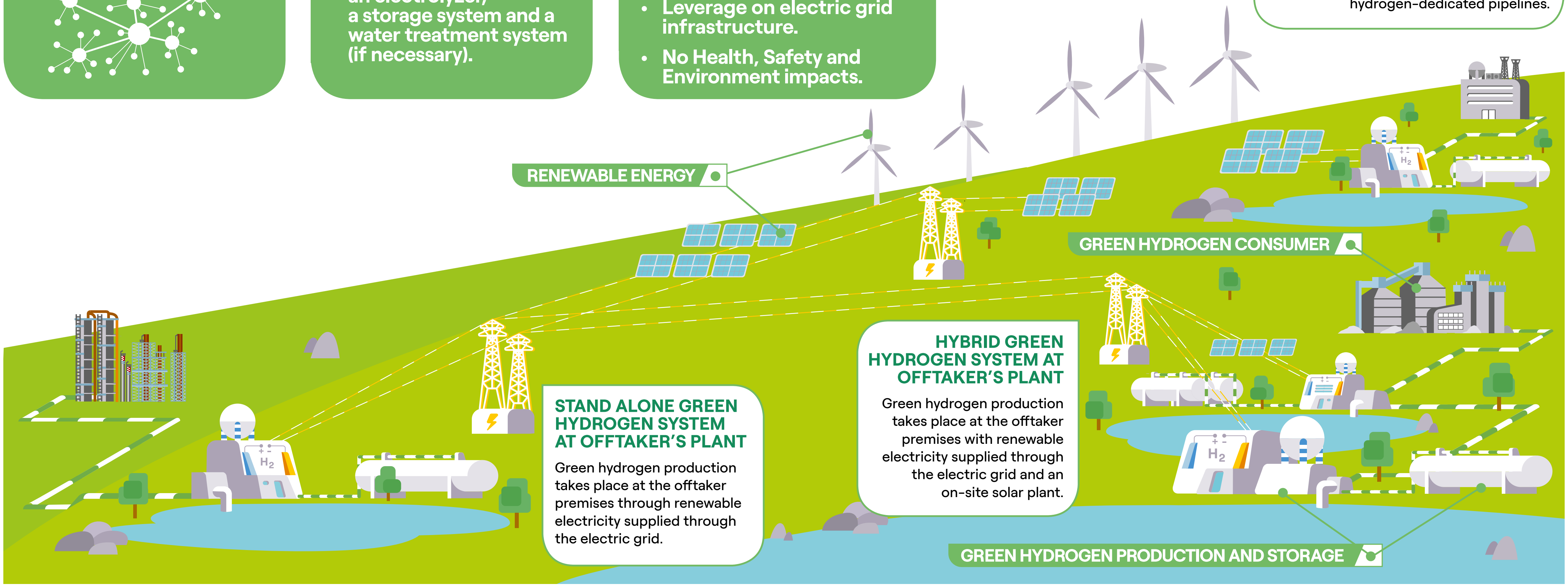
- Lower design complexity vs Carbon Capture and Storage plants.
- Easy to use: it just requires an electrolyzer, a storage system and a water treatment system (if necessary).

ADDITIONAL BENEFITS

- CO_2-free → no Co_2 handling nor storage needs.
- High flexibility in the plant size and location.
- Leverage on electric grid infrastructure.
- No Health, Safety and Environment impacts.

CO-LOCATED GREEN HYDROGEN SYSTEM AT RENEWABLE PLANT

Green hydrogen production takes place at the renewable power plant premises and green hydrogen is transported to the final offtaker through dedicated bottled trucks or through local 100% hydrogen-dedicated pipelines.



STAND ALONE GREEN HYDROGEN SYSTEM AT OFFTAKER'S PLANT

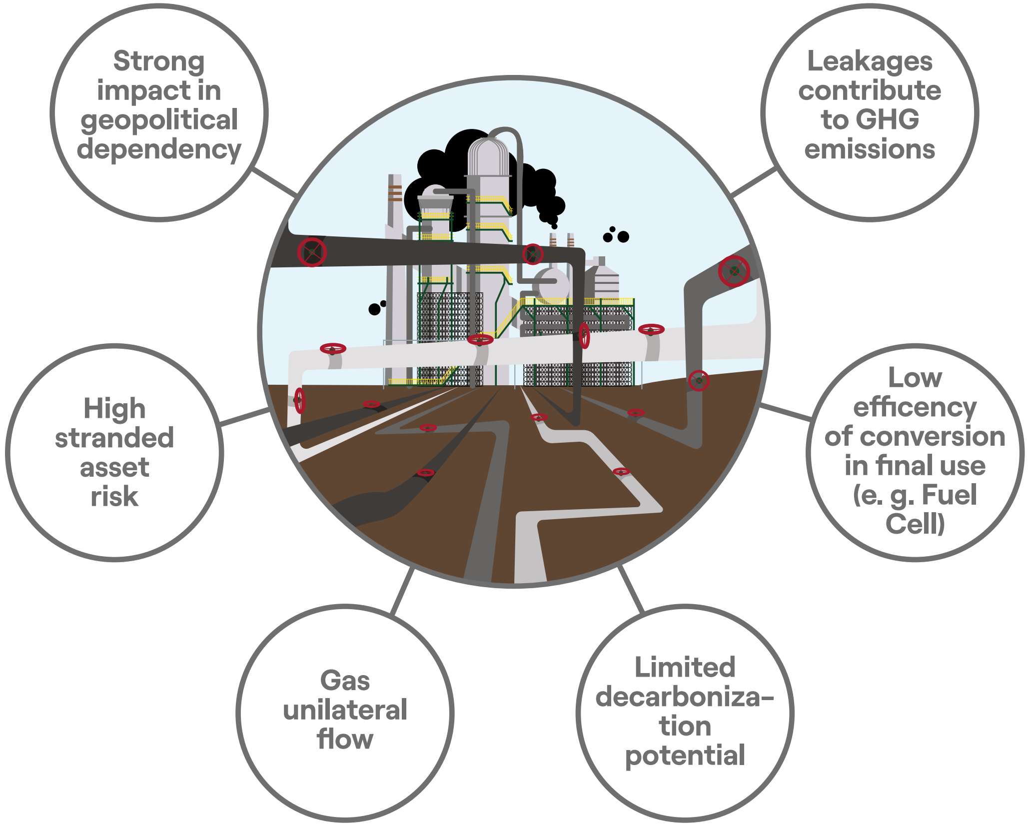
Green hydrogen production takes place at the offtaker premises through renewable electricity supplied through the electric grid.

HYBRID GREEN HYDROGEN SYSTEM AT OFFTAKER'S PLANT

Green hydrogen production takes place at the offtaker premises with renewable electricity supplied through the electric grid and an on-site solar plant.

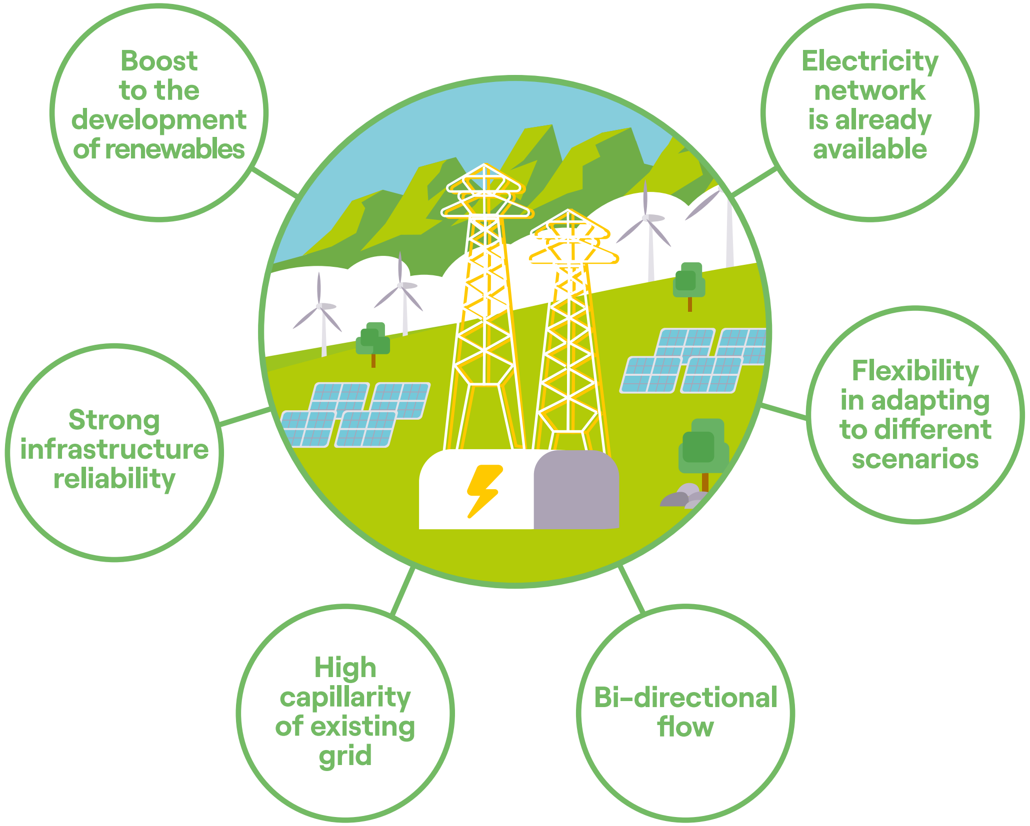
Transporting hydrogen vs. transporting electricity: the grid transporting renewable electricity fears no comparison with the gas network

Why hydrogen transport should be avoided



Large dedicated H2 network or blending in the existing gas network

Why electricity transport is the best choice

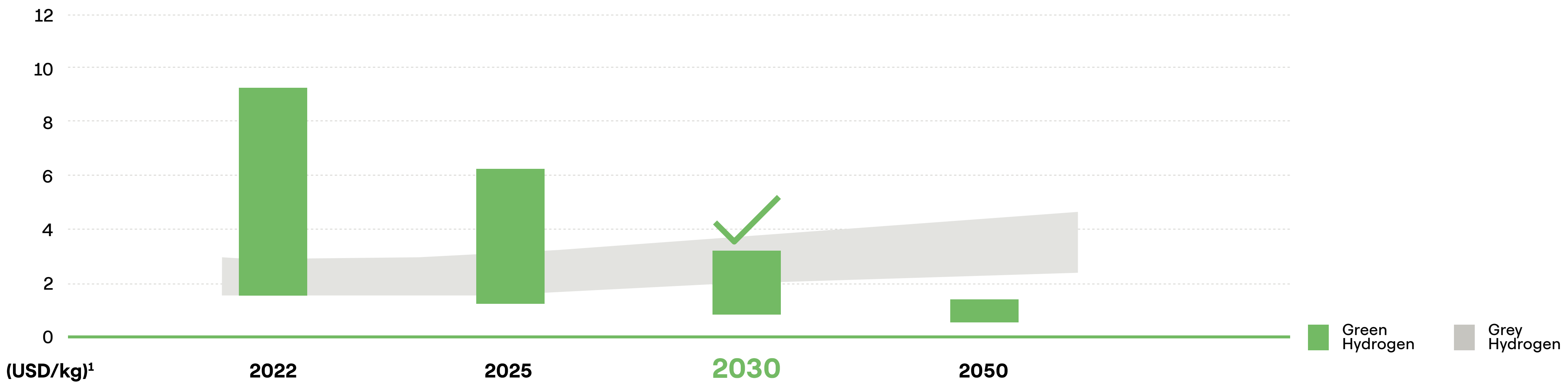


Extended Electricity network

Transport Green Electricity extensively. Produce Green Hydrogen locally.

Green Hydrogen is the only sustainable hydrogen and is expected to be competitive already by 2030

GREEN HYDROGEN PRODUCTION COST ACCORDING TO BloombergNEF



Focus on cost reduction of green hydrogen technology through

- Industry scale-up
- Innovation (capex reduction and efficiency increase)

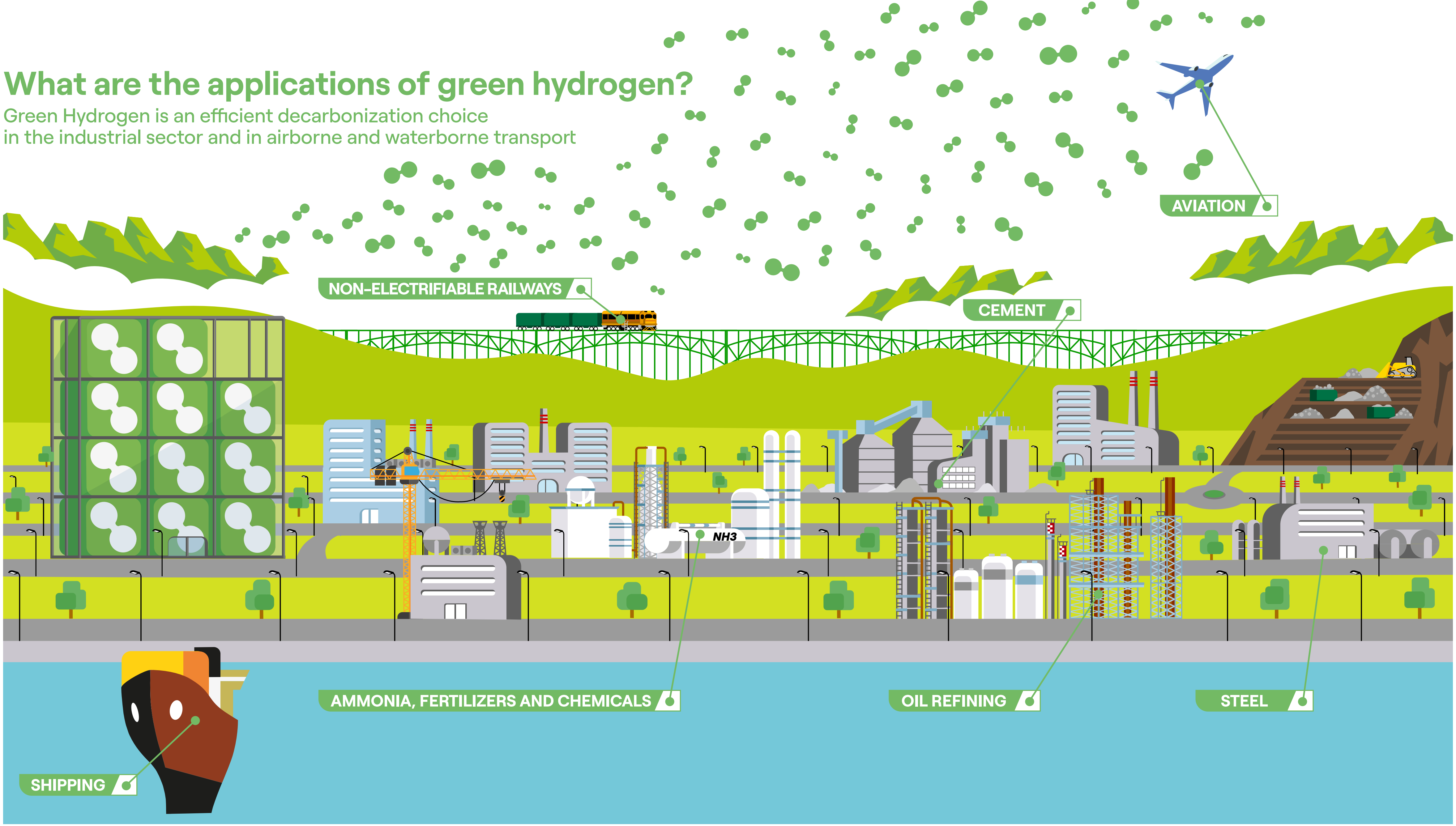
MARKET – Green Hydrogen is expected to be competitive already by 2030 thanks to:

- Sharp capex reduction >80%
- Efficiency improvements of electrolyser
- No CO_2 emission cost vs. grey hydrogen
- No exposure to gas price fluctuations

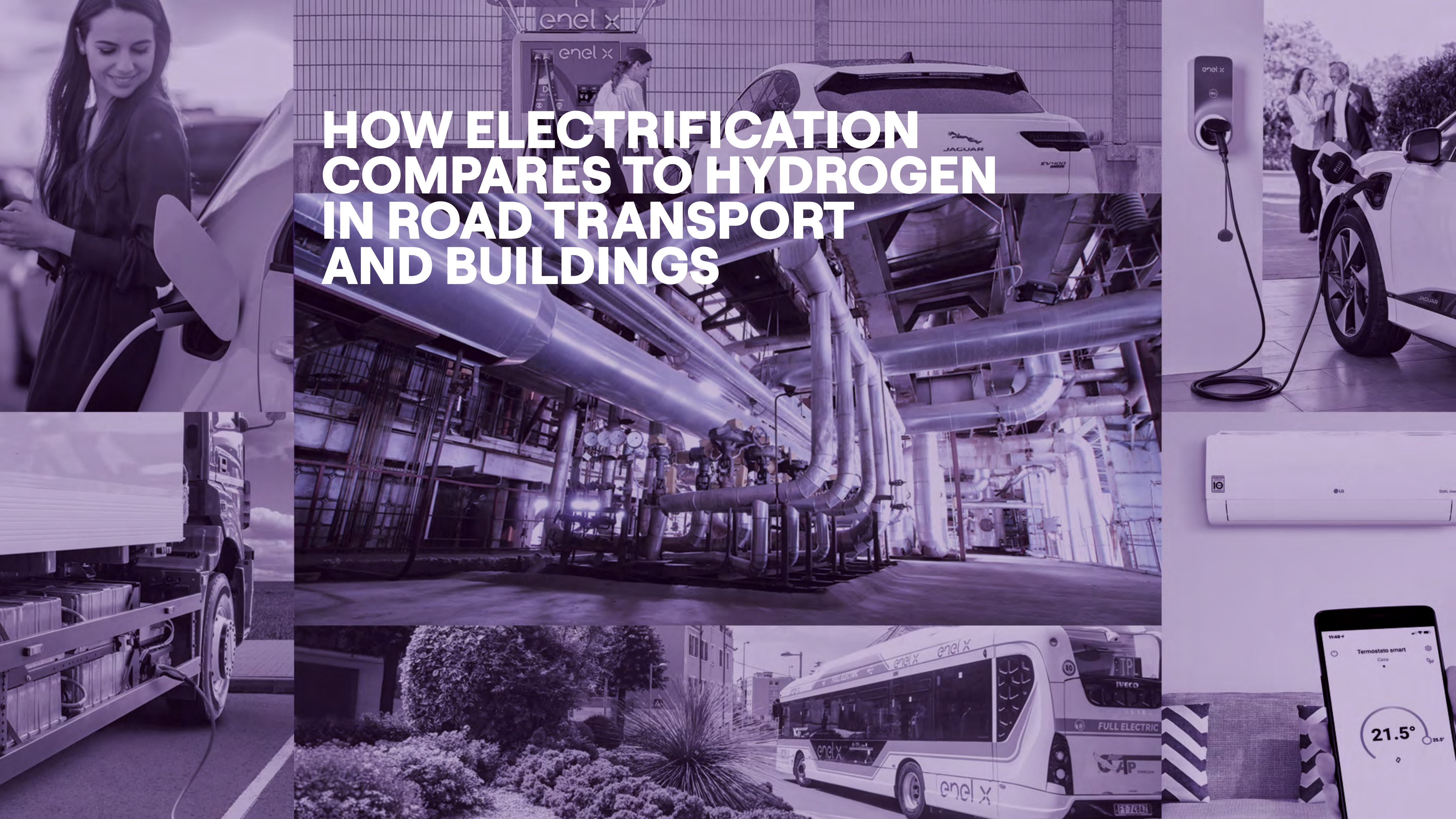
1) BNEF – "1H 2022 Hydrogen Levelized Cost Update"; June 2022. CO_2 price [USD/kg] 2025: 80-112; 2030: 100-170; 2050: 120-220; Natural Gas [USD/MMBtu]: 2-10.

What are the applications of green hydrogen?

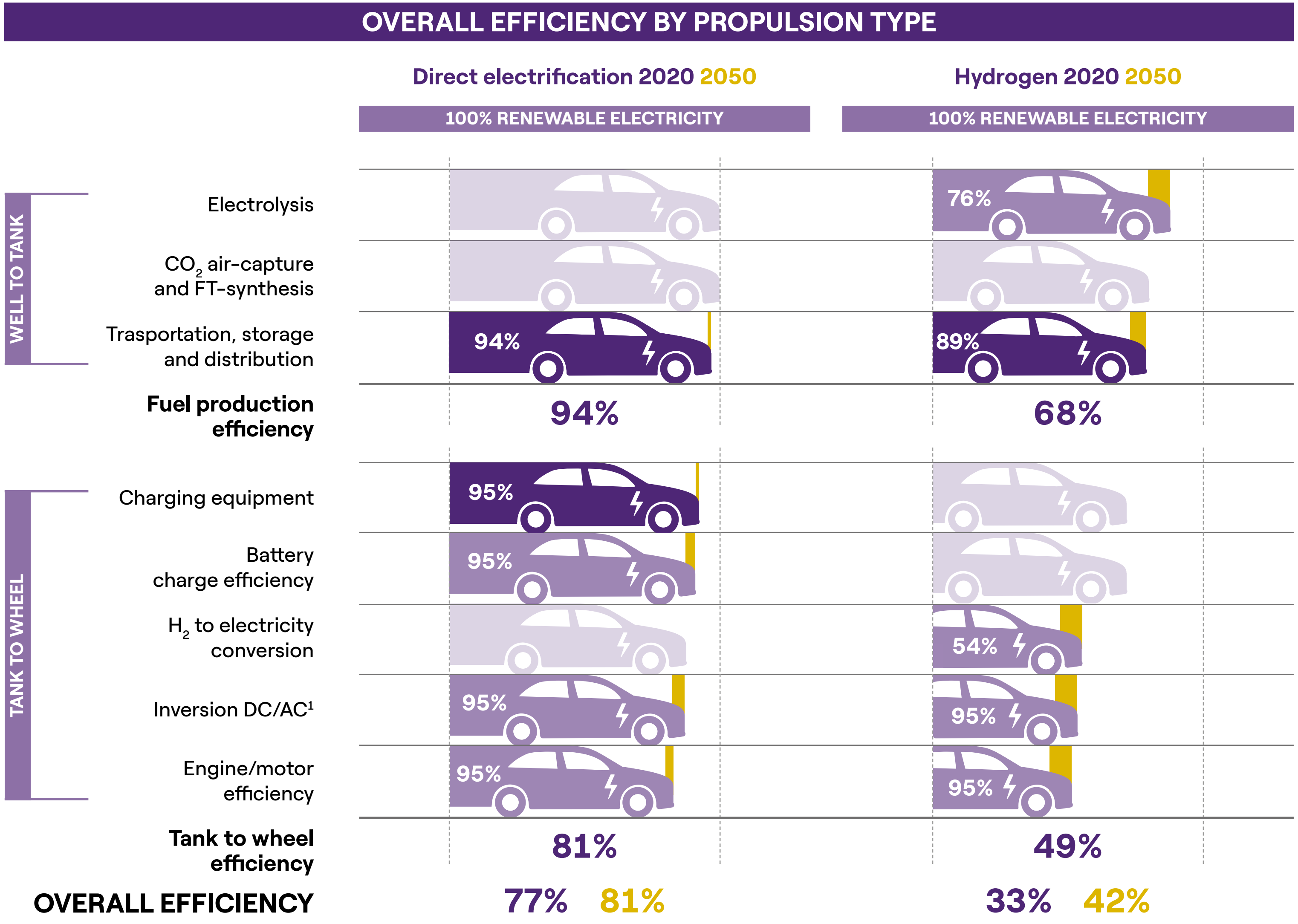
Green Hydrogen is an efficient decarbonization choice
in the industrial sector and in airborne and waterborne transport



HOW ELECTRIFICATION COMPARES TO HYDROGEN IN ROAD TRANSPORT AND BUILDINGS



Electric powertrains are more efficient



Source: T&E 2020 "Electrofuels: yes we can...if we are efficient", 2020.

EFFICIENCY BY POWERTRAIN

In 2020 BEV[2] powertrains were more efficient than FCEVs[3] >2x on a Well to Wheel basis

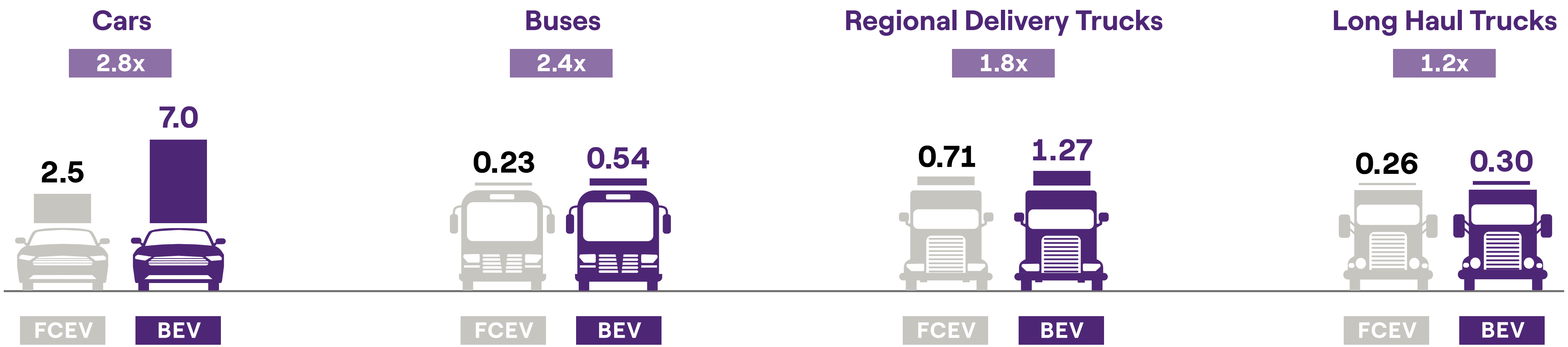
Well-to-Wheel = BEV efficiency is 2.3x FCEV efficiency (77% vs. 33%)[4]

- Well-to-Tank = electricity production efficiency is 1.4x hydrogen (94% vs. 68%)[5]
- Tank-to-Wheel = BEV efficiency is 1.7x FCEV efficiency (81% vs. 49%)[6]

Note:
1) Direct current/alternate current.
2) Battery Electric Vehicles.
3) Fuel Cell Electric Vehicles.
4) Well-to-wheel emissions include all emissions related to fuel production, processing, distribution, and use.
5) Well-to-tank describes the transition of the supply of fuel, from the production of the energy source (gasoline, diesel, electricity, natural gas) to the supply of fuel in the tank.
6) Tank-to-wheel refers to the transition in the energy chain of a vehicle that extends from the point in which the energy is absorbed (charging point) to the discharge.

Battery Electric Vehicles run much longer than Fuel Cell Electric Vehicles per kWh

VEHICLE AUTONOMY (KM) PER kWh OF RENEWABLE ELECTRICITY - WELL TO WHEELS



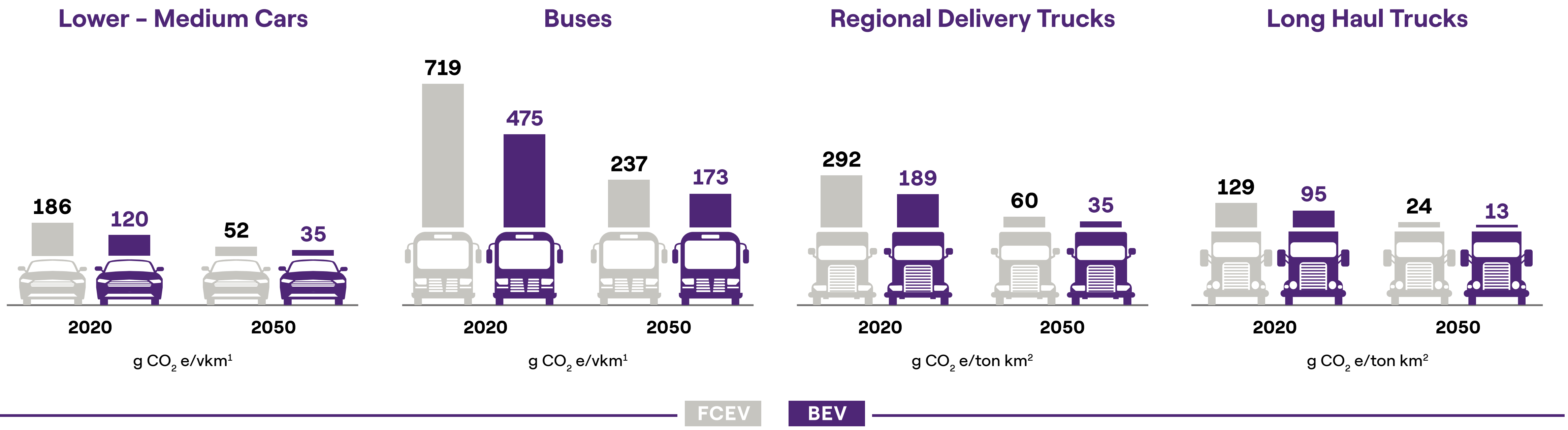
For every kWh of electricity produced, BEVs[1] may run more km than their FCEV[2] counterparts in every vehicle category

Source: Internal elaboration on Terna "L'Italia, con l'Europa, alla sfida della decarbonizzazione", Webinar 2020 and T&E 2020 "Electrofuels: yes we can...if we are efficient", 2020 (well to tank). "BNEF Hydrogen: the economics of production from renewables" 2019; "Hydrogen: fuel cell vehicle outlook", 2020 (tank to wheel).

Notes: Regional Delivery Trucks refer to medium duty commercial trucks, Long Haul trucks refer to Heavy duty transport trucks.
1) Battery Electric Vehicles. 2) Fuel Cell Electric Vehicles

Battery Electric Vehicles
have a better environmental performance

OVERALL LIFE CYCLE GLOBAL WARMING POTENTIAL IMPACTS BY POWERTRAIN FOR 2020 AND 2050 – EU PERIMETER

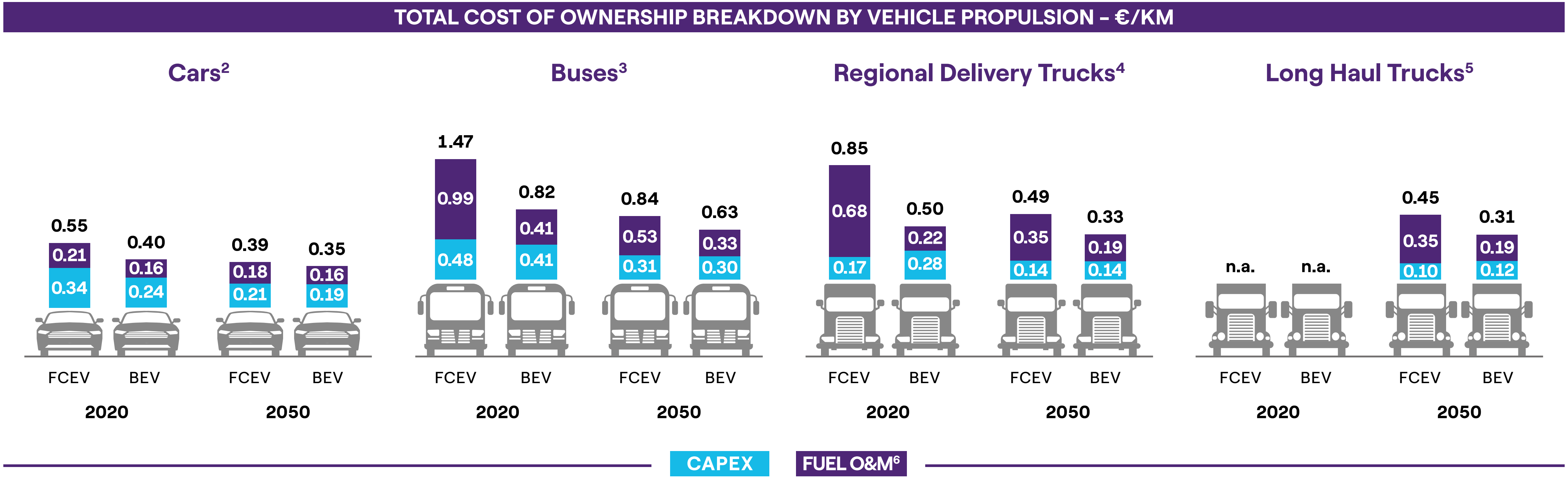


Battery Electric Vehicle have a better environmental performance than other powertrains including Fuel Cell Electric Vehicle, especially considering their impact towards Global Warming Potential

Source: European Commission. DG Climate Action, "Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA", 2020.

Note: Buses refer to urban buses, Regional Delivery Trucks refer to rigid lorries, Long Haul trucks refer to articulated lorries.
1) g CO_2e/vkm stands for g CO_2 equivalent per vehicle km.
2) g CO_2 e/ton km stands for g CO_2 equivalent per ton-km.

Battery Electric Vehicles are more convenient in terms of Total Cost of Ownership[1]

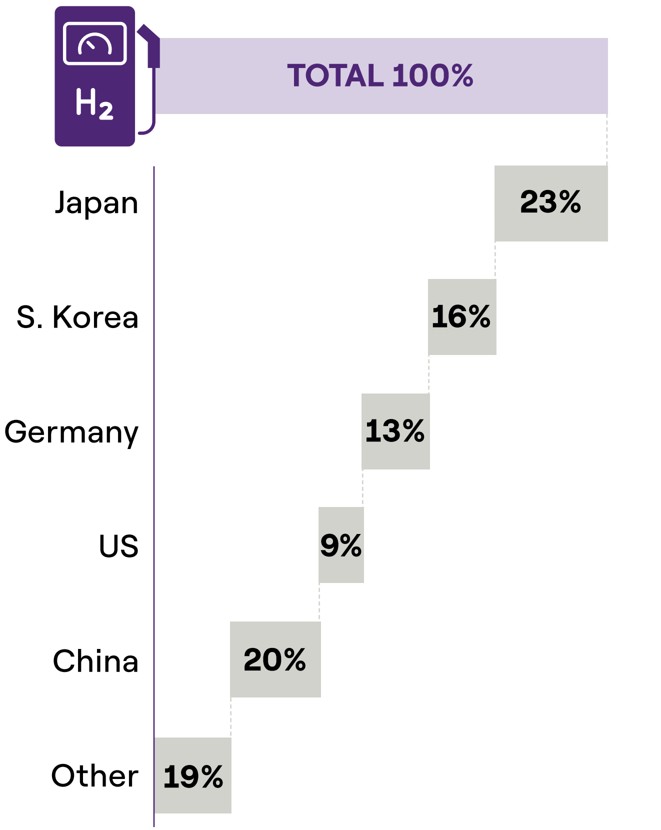


Source: Deloitte elaboration - TCO estimates.

Notes: Regional Delivery Trucks refer to medium duty commercial trucks, Long Haul trucks refer to Heavy duty transport trucks.
1) Total Cost of Ownership refers to the purchase price of an asset plus the costs of operation over the asset's lifespan; 2) Assuming 650 Km range passenger car, 11.5 years life-time, 12,000 km by year (BEV and FCEV); 3) Assuming 200 Km range passenger bus, 12 years life-time, 65,000 km per year (BEV and FCEV); 4) Assuming 400 Km range heavy-duty truck, 13 years life-time, 80,000 km by year 400 Km range car (BEV and FCEV); 5) Assuming 1,000 Km range long-haul truck, 13 years life-time, 120,000 km by year; 6) Operation & Maintenance.

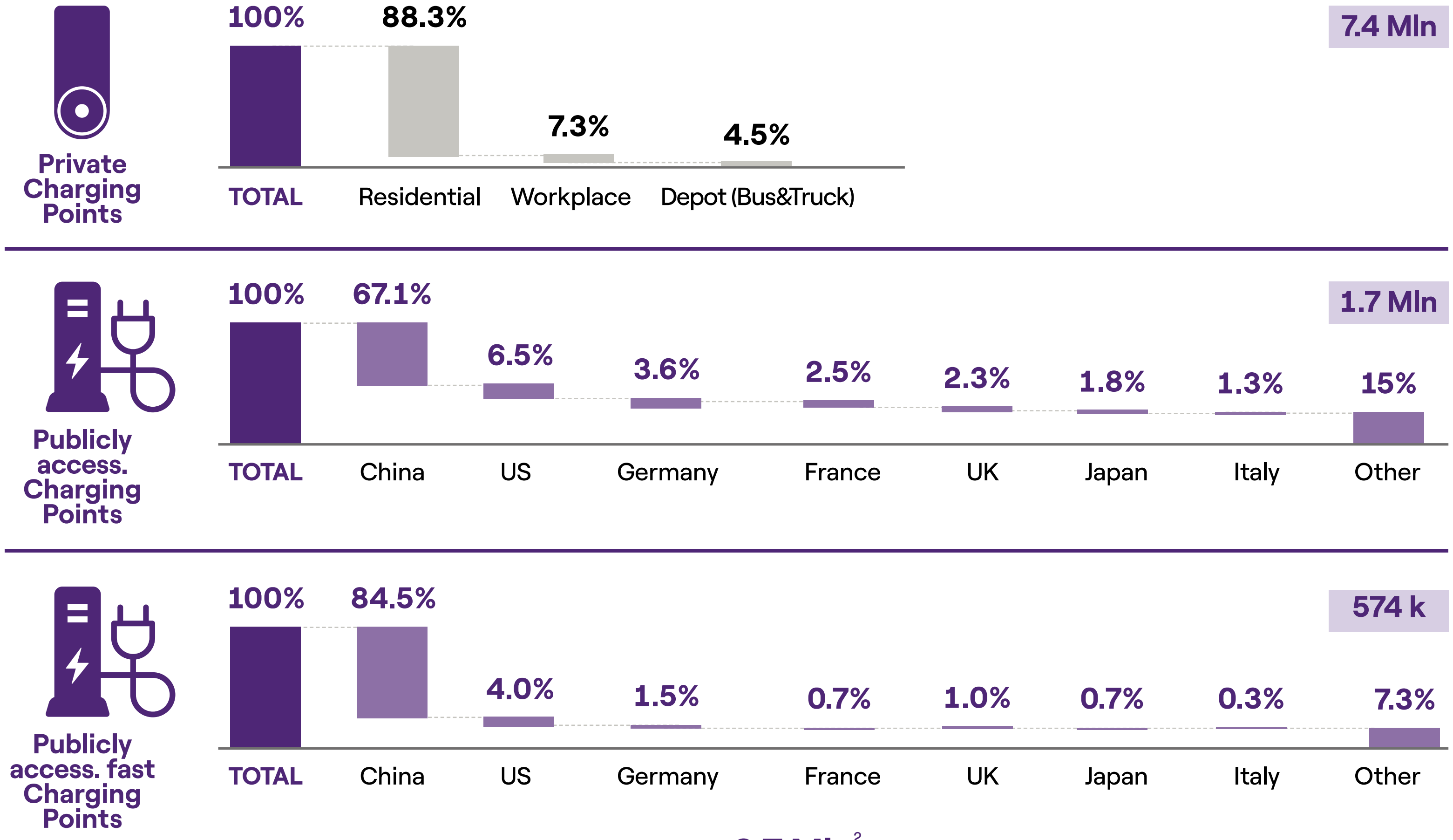
EV charging infrastructures are more developed than Hydrogen refueling stations

H2 REFUELING STATIONS



TOTAL 2021: 730 [1]

EV CHARGING POINTS

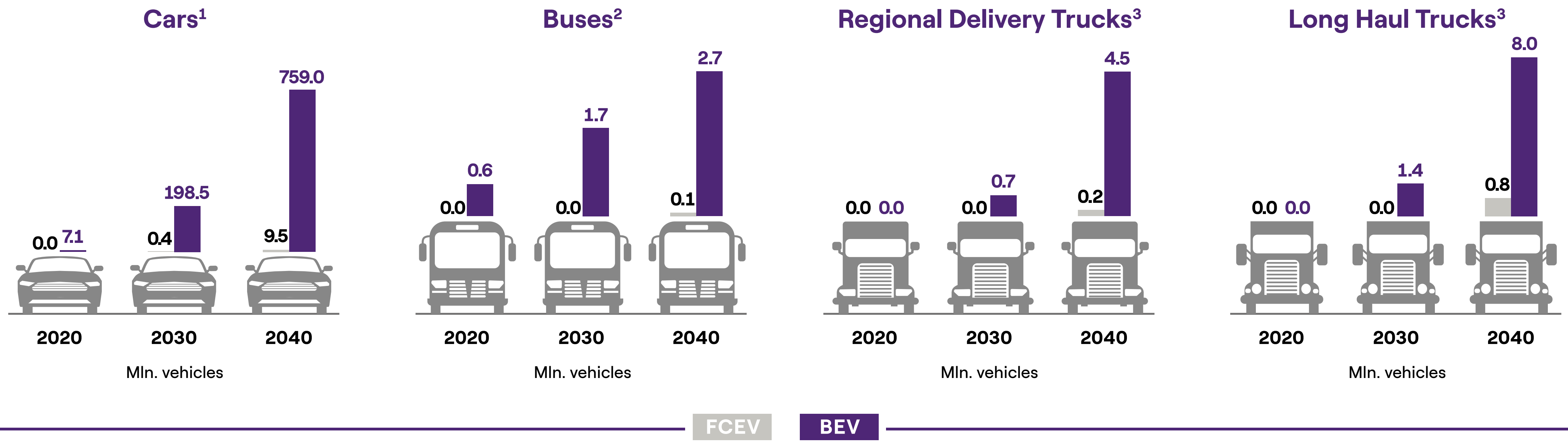


TOTAL 2021: 9.7 Mln [2]

[1] *Source: IEA Global EV Outlook 2022.* [2] *Source: BNEF 2022*

Battery Electric Vehicles are expected to lead the decarbonization of the transport sector

FUEL CELL ELECTRIC VEHICLES VS. GLOBAL BATTERY ELECTRIC VEHICLES



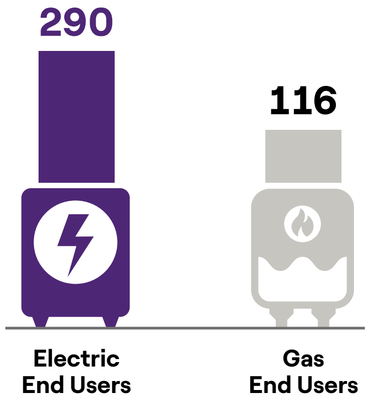
In the next 20 years, BEV technology is expected to become the leading alternative powertrain

Source: BNEF Long Term EV Outlook 2022 – last update June 2022.

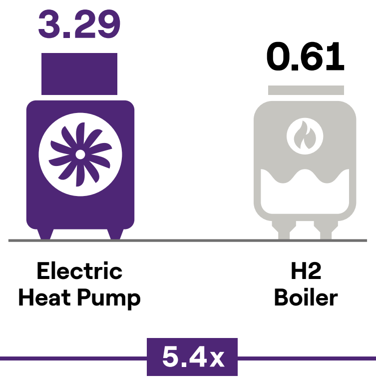
Notes: 1) Includes Light Commercial Vehicles 2) BNEF's Bus estimates also include PHEVs Regional Delivery 3) Trucks refer to medium duty commercial trucks, Long Haul trucks refer to Heavy duty transport trucks

Heat pumps are more efficient than Hydrogen boilers in the decarbonization of buildings and rely on the electricity grid which is extremely widespread

GAS GRIDS VS. ELECTRICITY IN EU (MLN USERS)[1]



kWh OF HEAT PRODUCED PER kWh OF RENEWABLE ELECTRICITY



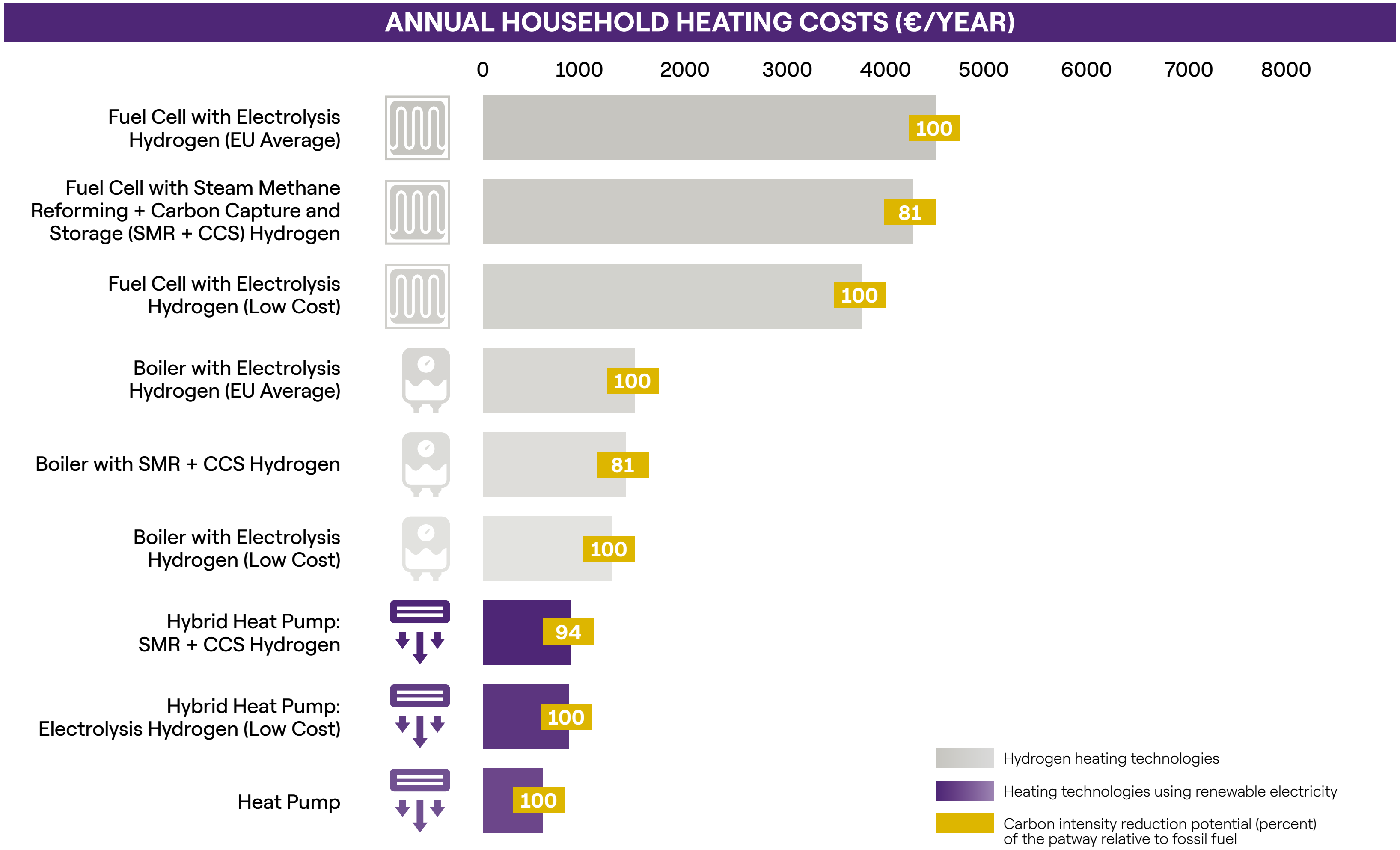
For every kWh of electricity, Heat pumps produce x5.4 more heat than a hydrogen boiler

This also means that decarbonizing heating with hydrogen requires x5.4 more generation in renewables than with heat pumps (and therefore more investment for the same degree of decarbonization).

Source: EU – Hydrogen for Heating February 2021
1 European Commission – Benchmarking smart metering deployment in the EU-28.

Notes: Internal analysis based assuming: Heat pump COP 3.5 (air – air), hydrogen boiler performance of 90%, electricity network efficiency of 94%, hydrogen production efficiency of 68% with 53 kWh of RES needed to produce 1 kg of H2 (36kWh/kg). Does not include losses in hydrogen network.

Heat pumps are more cost efficient than other alternatives



ES1. Cost comparison and greenhouse gas intensity reduction potential of different technology options for heating a household for one year in the EU in 2050.

Source: International Council on Clean Transportation: Hydrogen for Heating? Decarbonization options for household in the European Union in 2050 – Published in 2021.

Heat pumps represent the most cost-effective path towards the decarbonization of residential heating technology. In 2050 they are expected to imply at least 50% lower costs than hydrogen-only based technologies.

Even if natural gas costs were 50% lower or renewable electricity prices were 50% higher in 2050, heat pumps would still be more cost-effective than hydrogen boilers or fuel cells.

It could be argued that Heat Pumps are already a more cost efficient solution than H_2, since there is no value chain as of today to deliver H_2 to residential customers out of pilot projects, whereas heat pumps are already a mature market solution.

Note: These costs include annuitized capital expenses, operating expenses and fuel costs.