SHELL HYDROGEN STUDY

ENERGY OF THE FUTURE?

Sustainable Mobility through Fuel Cells and H_2

In cooperation with Wuppertal Institut

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The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this presentation "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this presentation refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to "joint ventures" and "joint operations" respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as "associates". The term "Shell interest" is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

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SHELL HYDROGEN STUDY

- Shell scenario studies (since 1958)
- Shell → H_2 R&D, production and use
- Own business Unit Shell Hydrogen
- Shell hydrogen study → objectives:
  - Future potentials of hydrogen
  - Analyse business opportunities
  - Focus on (auto)mobility applications
  - Inform business partners, customers, stakeholders
- Collaboration with think-tank Wuppertal Institut

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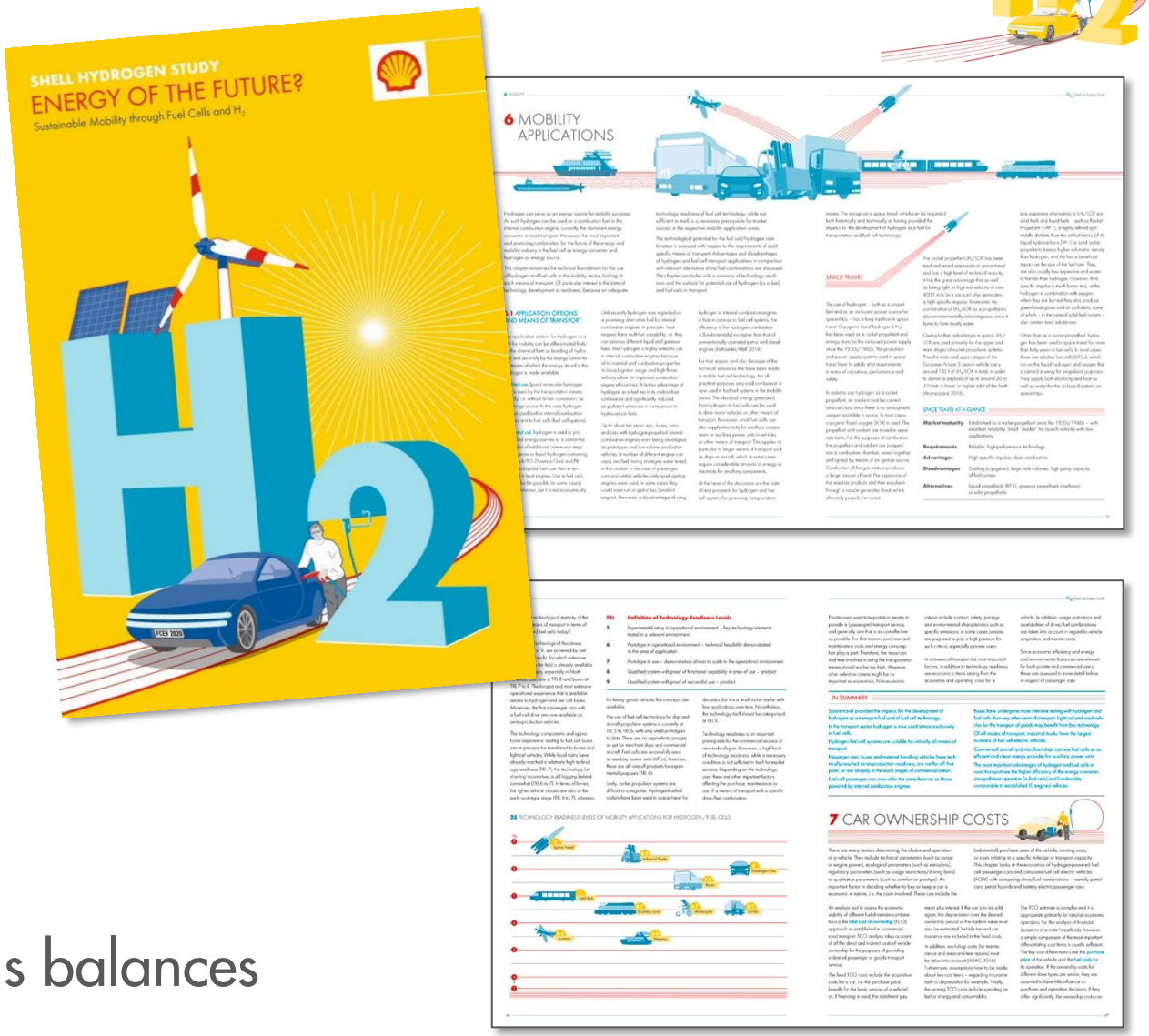


THE ELEMENT HYDROGEN

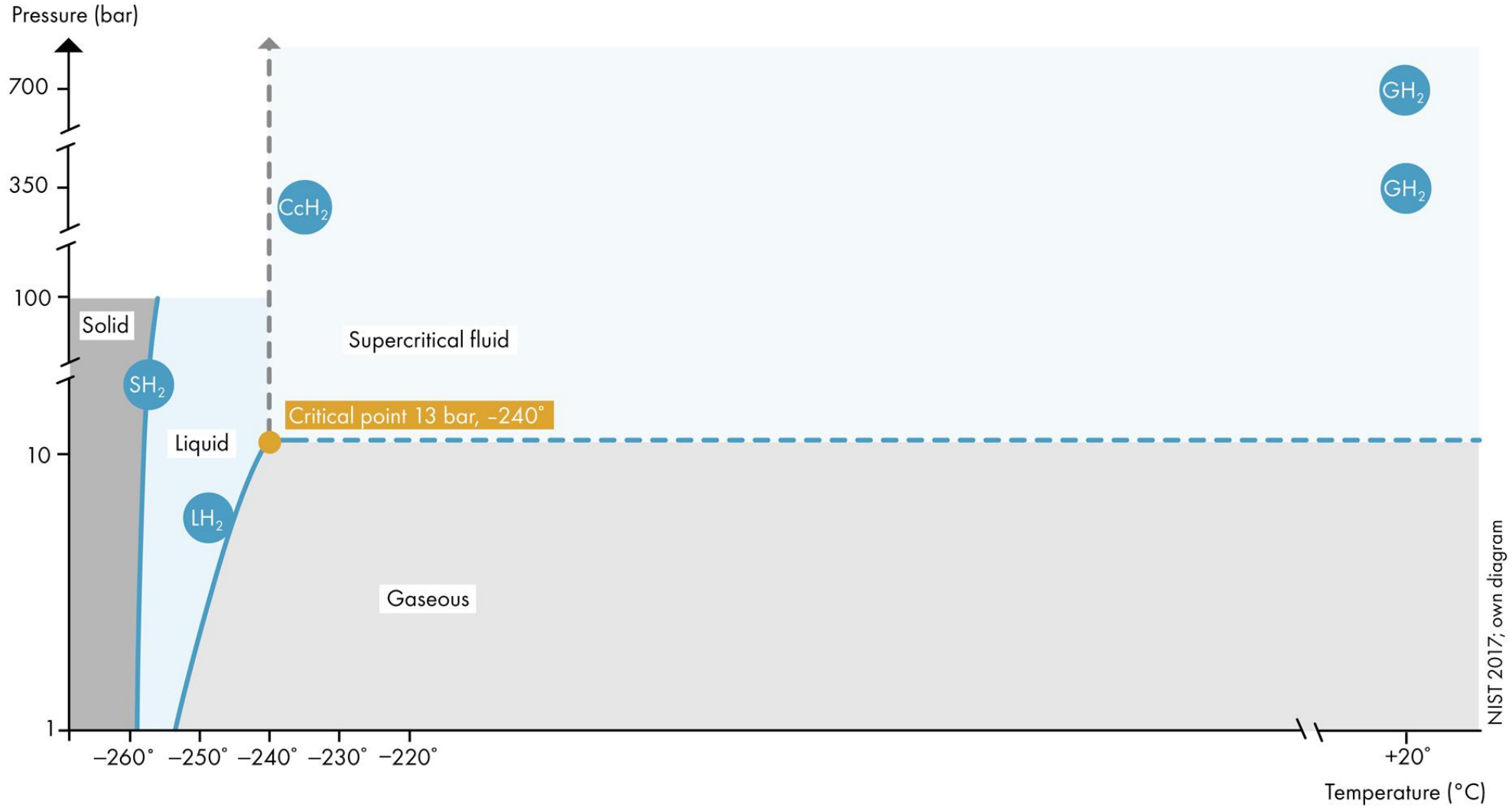
Jules Verne
„The Mysterious Island"
1874

Jules Verne: water – the new coal?

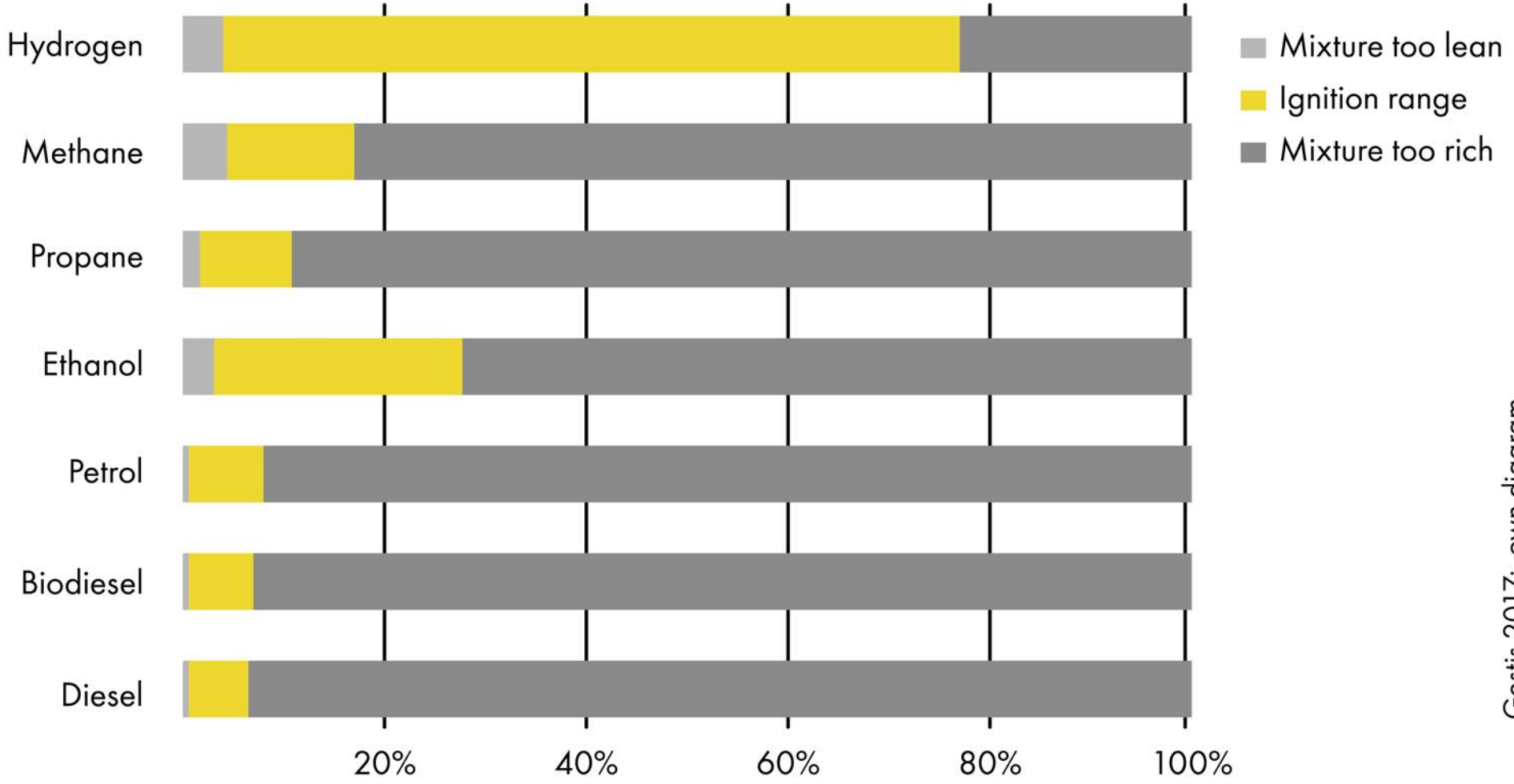
Dieter Zetsche: hydrogen – the better oil?

Which future role for hydrogen as an energy carrier?

PHASE DIAGRAM HYDROGEN

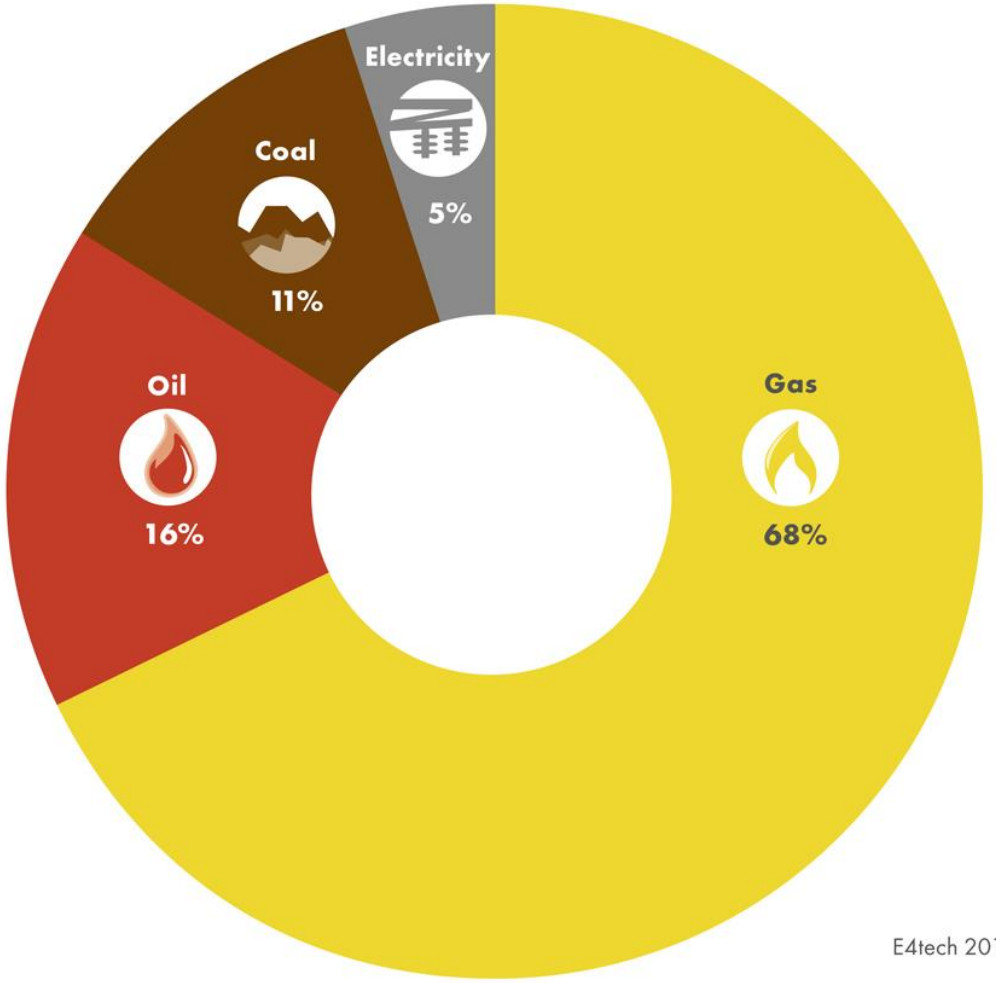


IGNITION RANGE OF FUELS



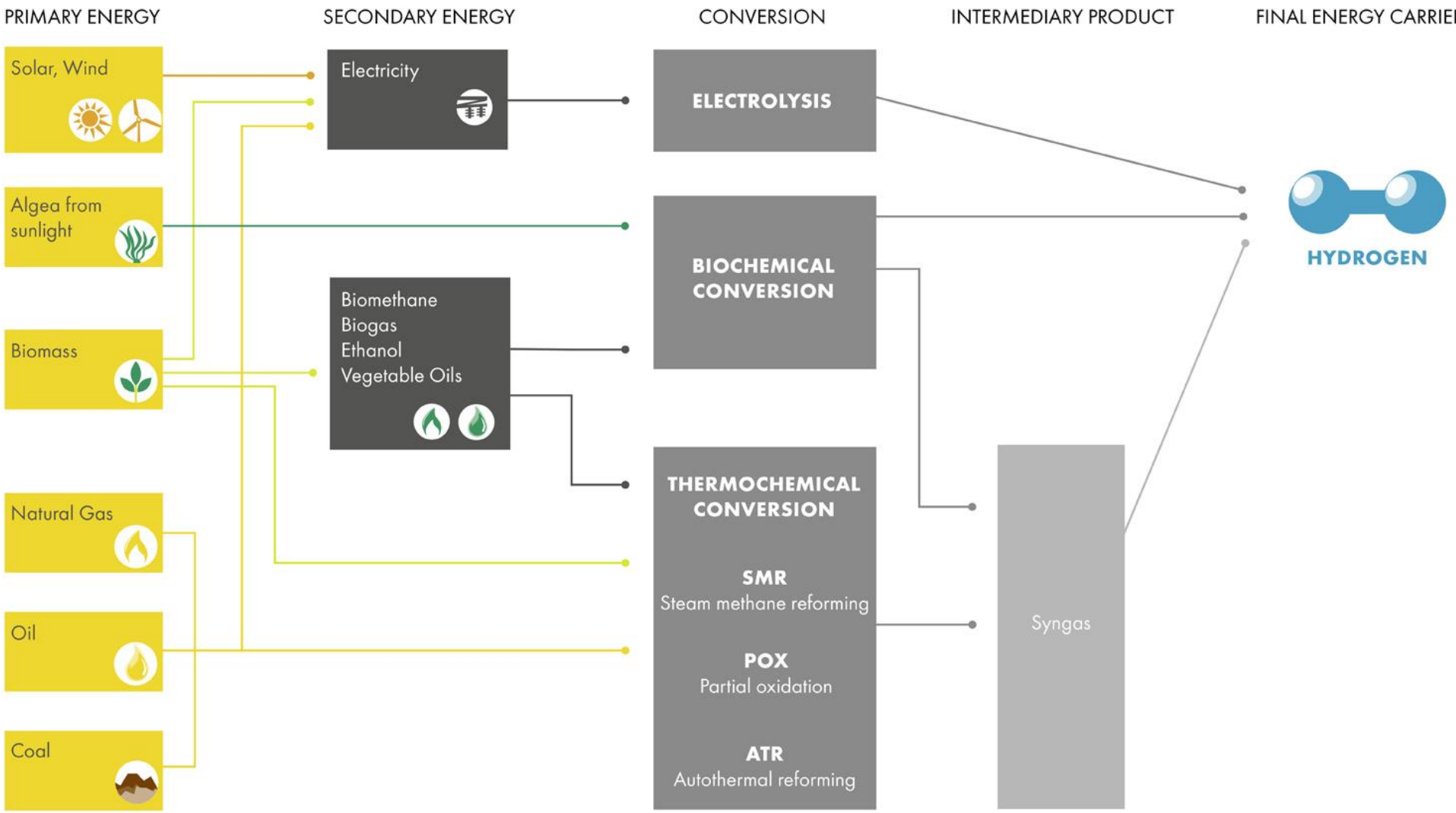
Gestis 2017; own diagram

SHARE OF PRIMARY ENERGY CARRIERS IN GLOBAL HYDROGEN PRODUCTION

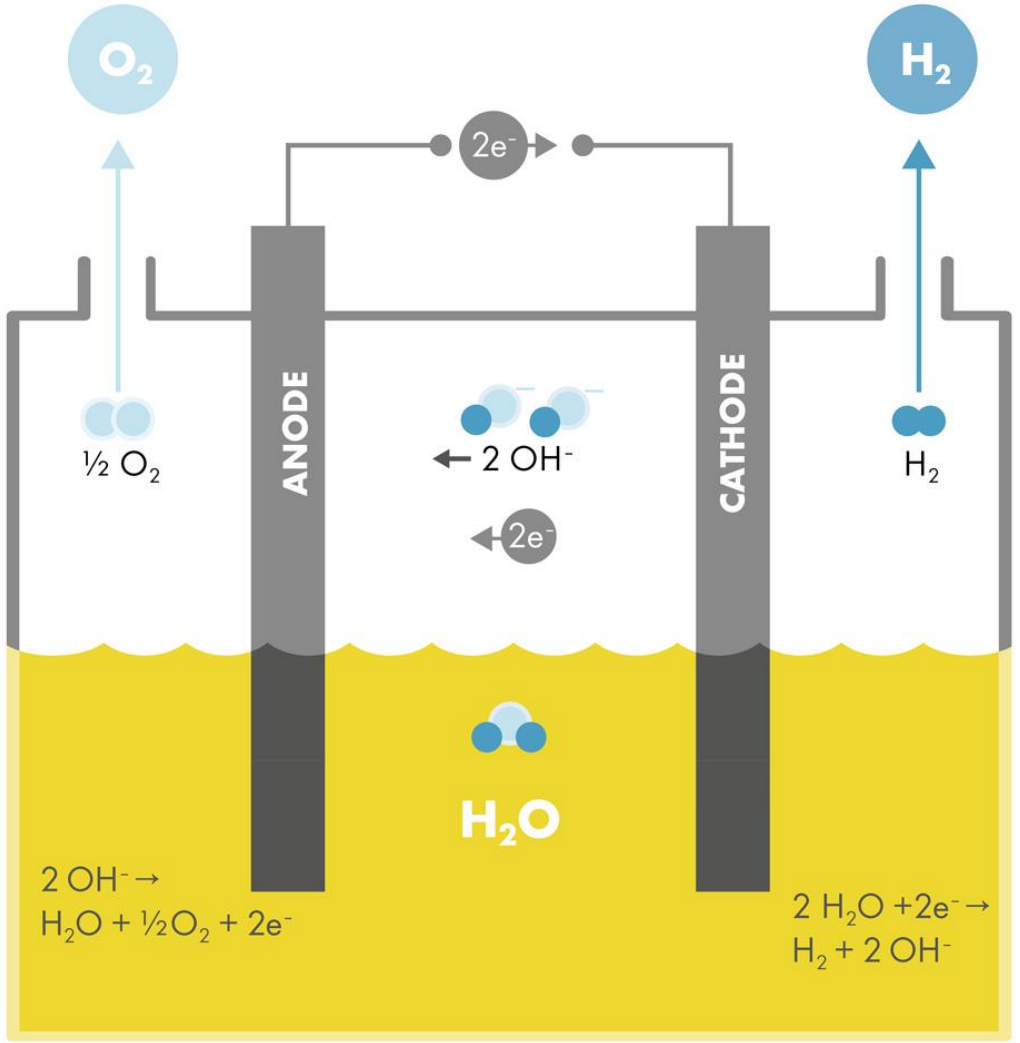


E4tech 2014; own diagram

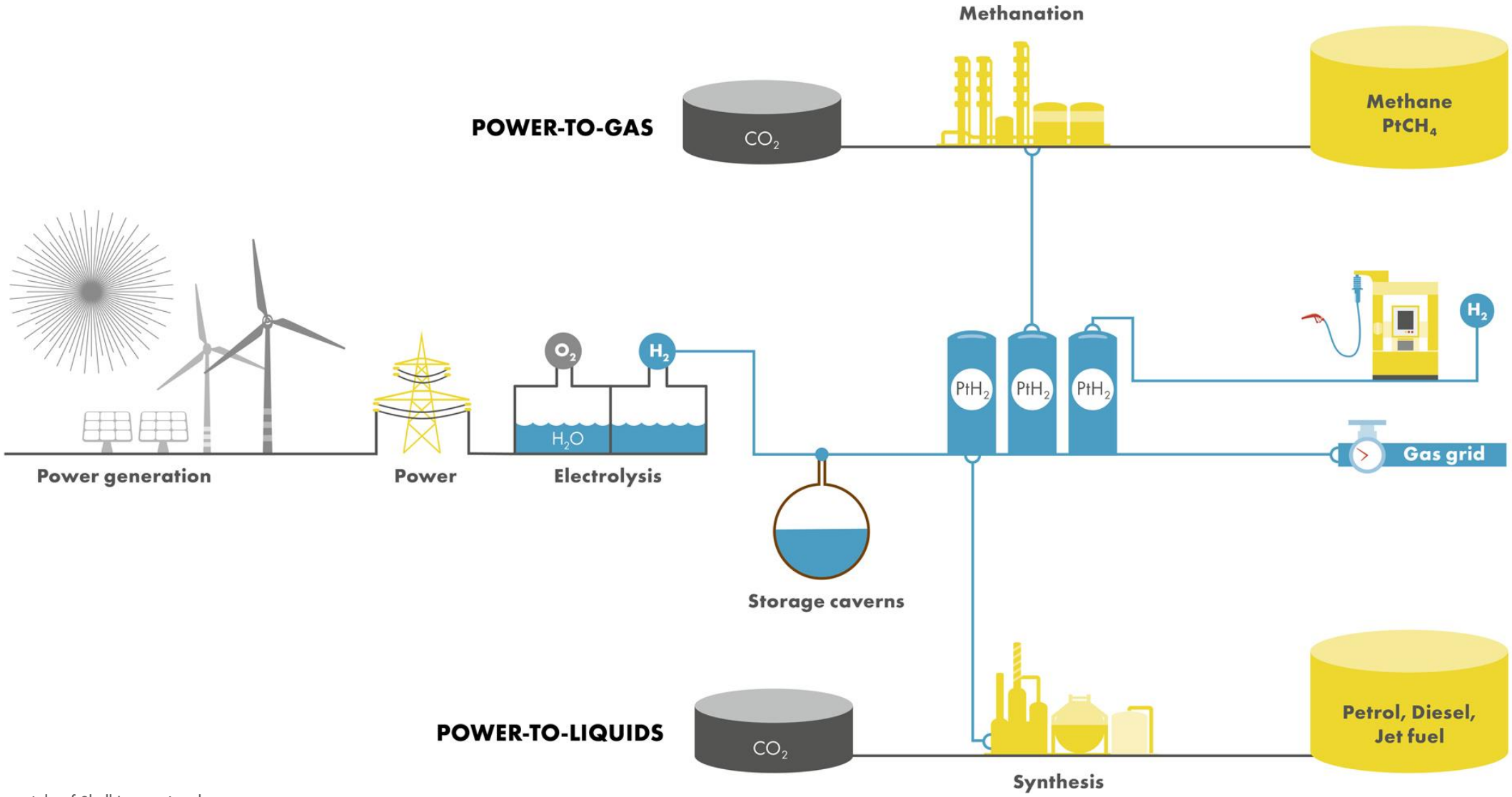
PROCESSES FOR PRODUCING HYDROGEN



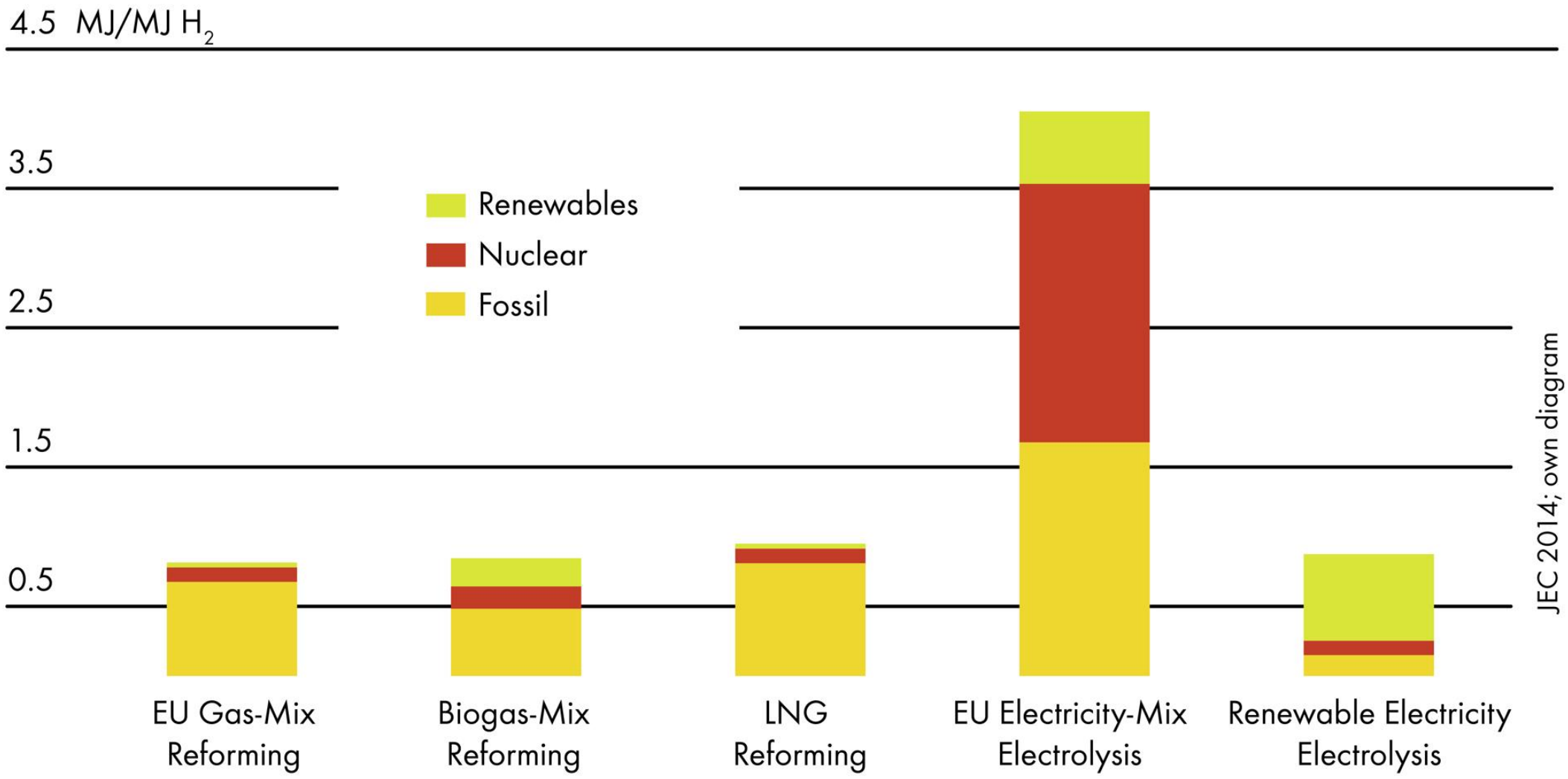
THE PRINCIPLE OF AN ALKALINE ELECTROLYSER



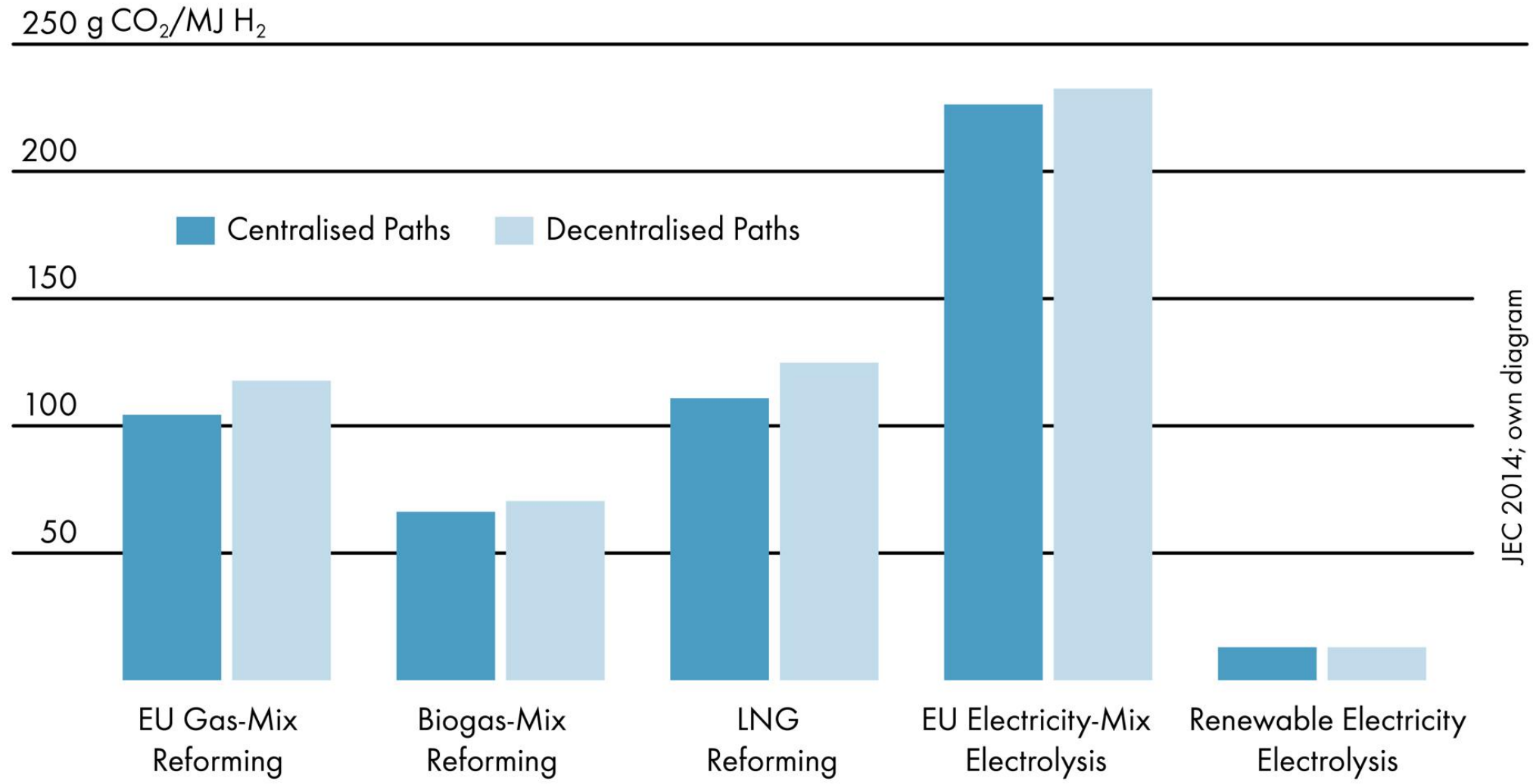
SECTOR COUPLING: POWER-TO-X PATHWAYS



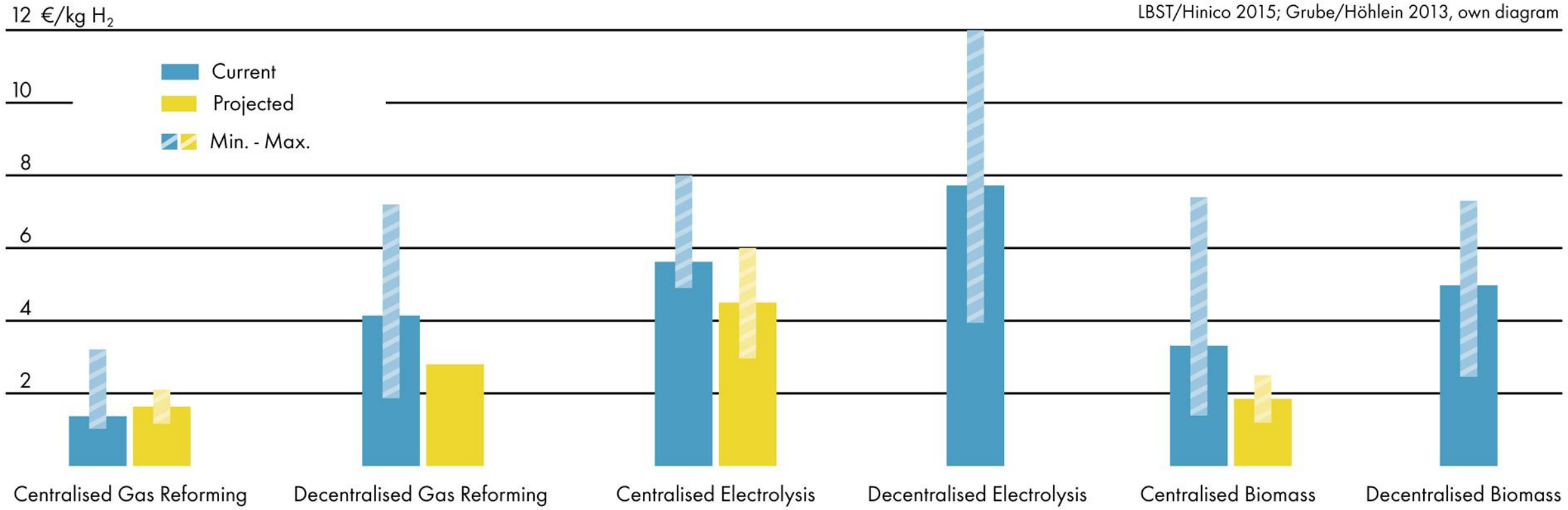
ENERGY INPUT FOR HYDROGEN SUPPLY



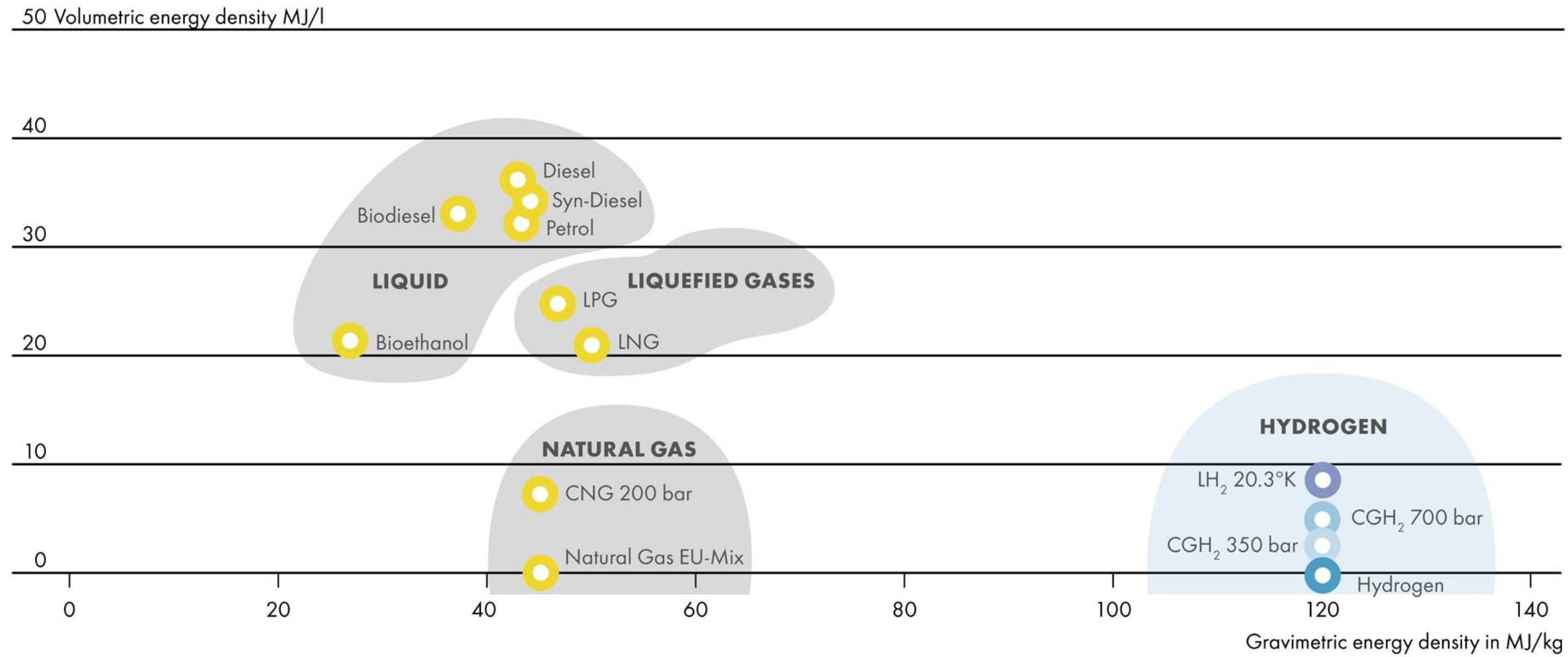
GREENHOUSE GAS EMISSIONS OF HYDROGEN SUPPLY



HYDROGEN PRODUCTION COSTS



ENERGY DENSITY OF FUELS



HYDROGEN STORAGE METHODS

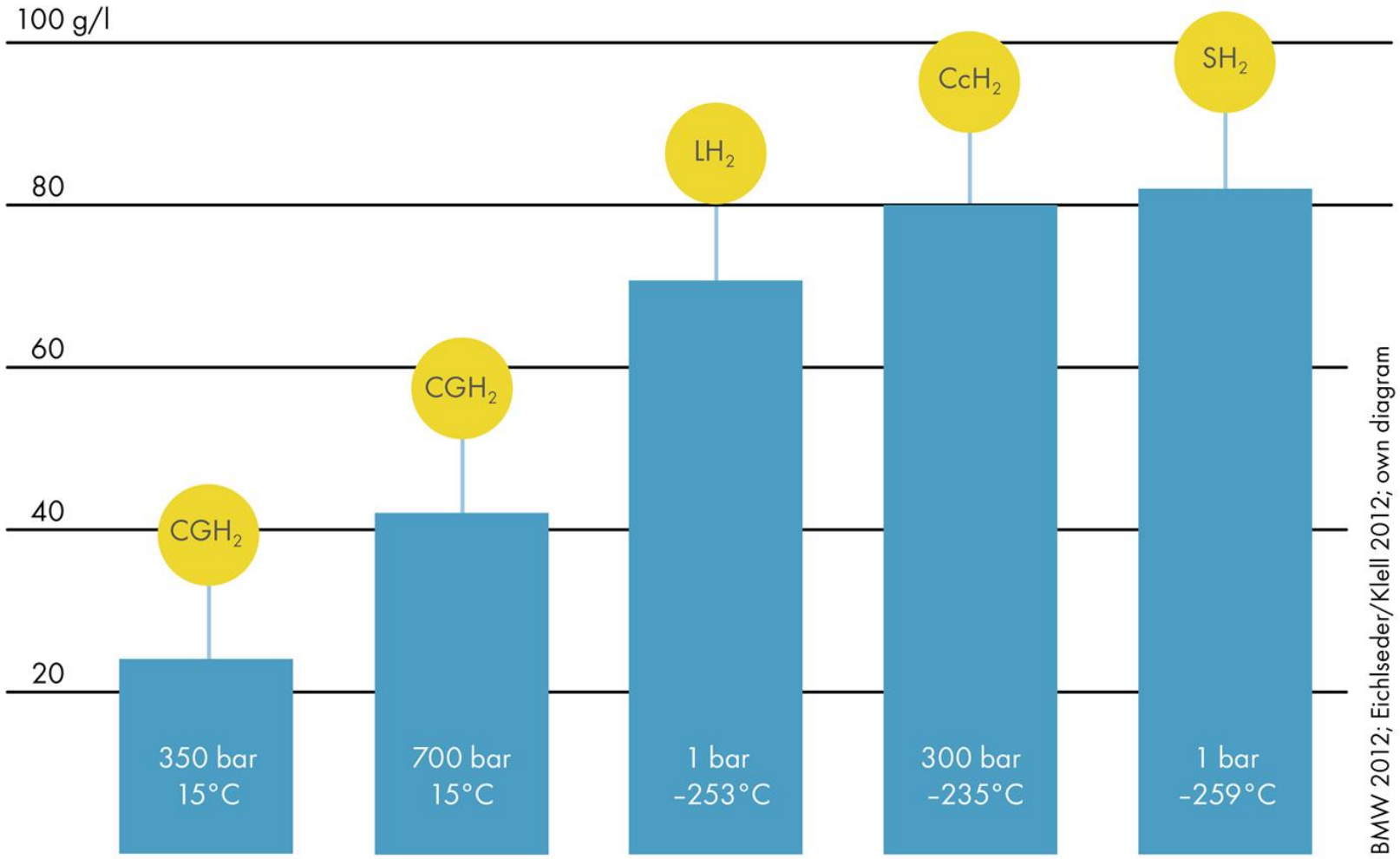
PHYSICAL

- Compressed Gaseous Hydrogen CGH_2 (350, 700 bar)
- Liquefied Hydrogen LH_2
- Cryo-compressed Hydrogen CcH_2
- Slush Hydrogen SH_2

MATERIALS-BASED

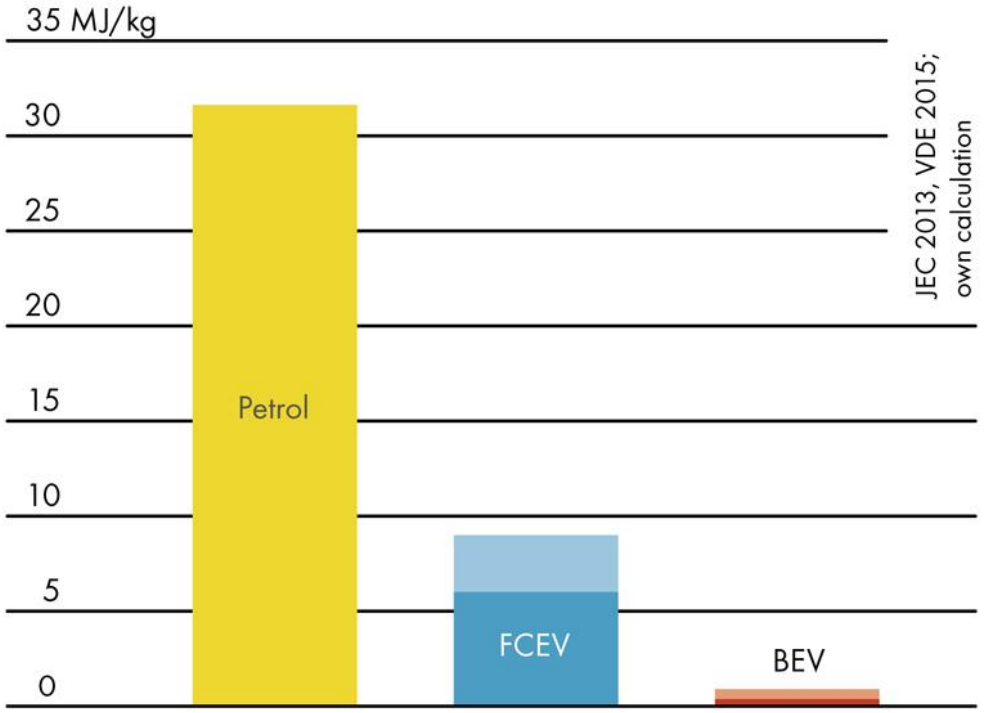
- Metal Hydrides
- Liquid Organic Hydrogen Carriers LOHCs
- Sorbents (MOFs, Zeolites, Nanotubes)

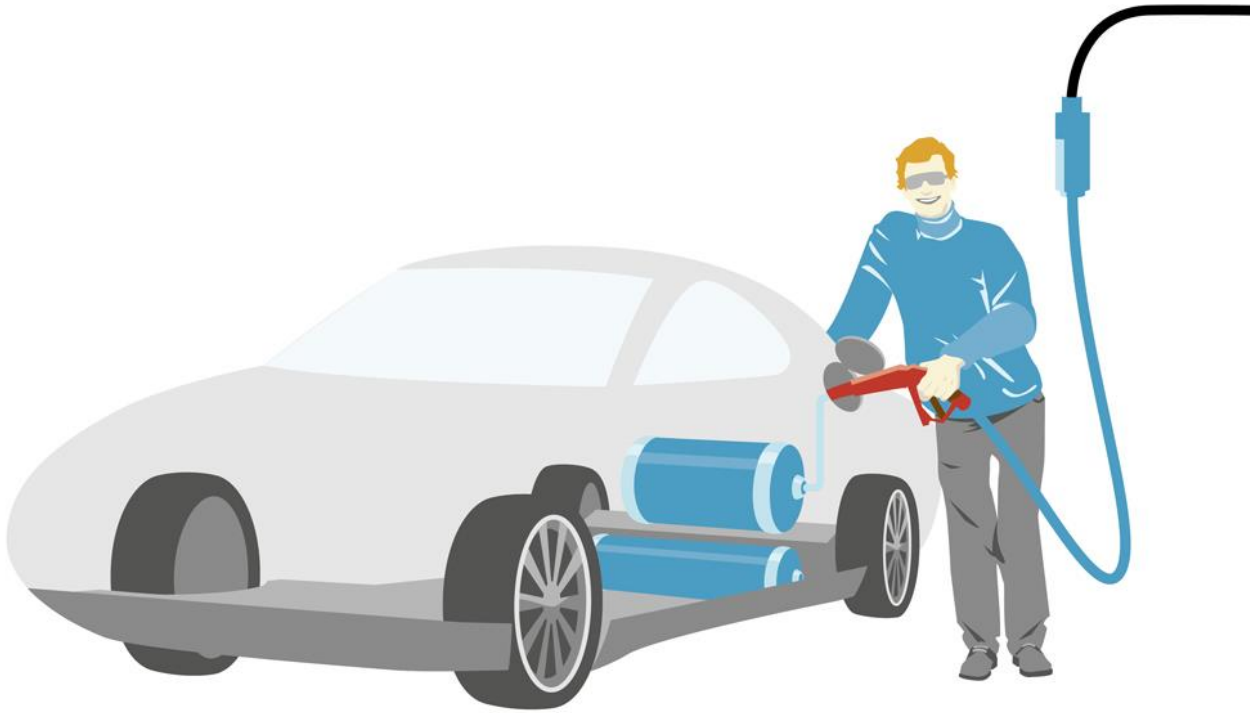
HYDROGEN STORAGE DENSITY



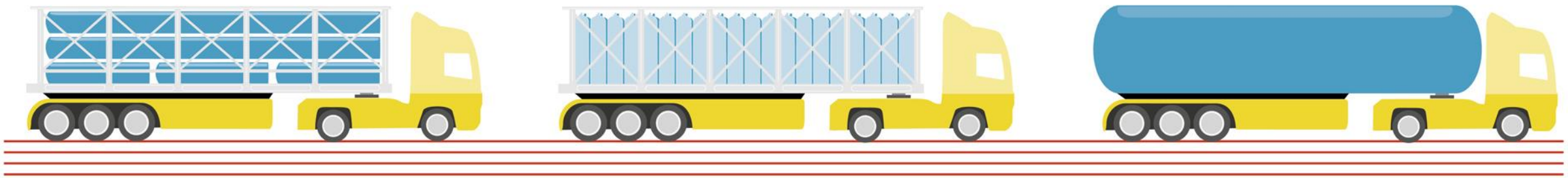
BMW 2012; Eichlseder/Klell 2012; own diagram

STORAGE DENSITY OF TANK SYSTEMS





HYDROGEN ROAD TRANSPORT



TUBE TRAILER

200 – 250 bar, ≈ 500 kg, ambient temperature

CONTAINER TRAILER

500 bar, ≈ 1,000 kg, ambient temperature

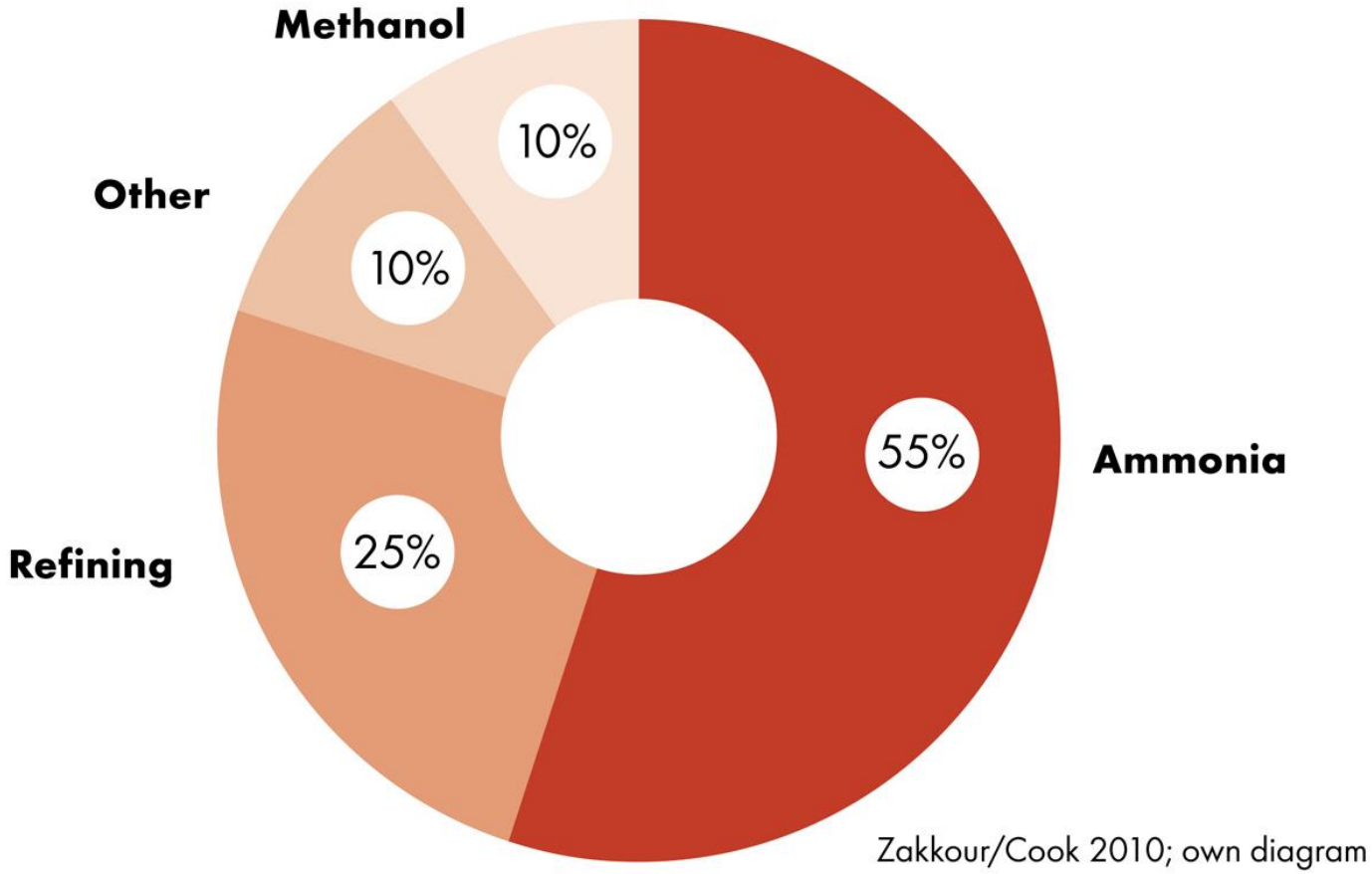
LIQUID TRAILER

1 – 4 bar, ≈ 4,000 kg, cryogenic temperature

HYDROGEN PIPELINES PER COUNTRY

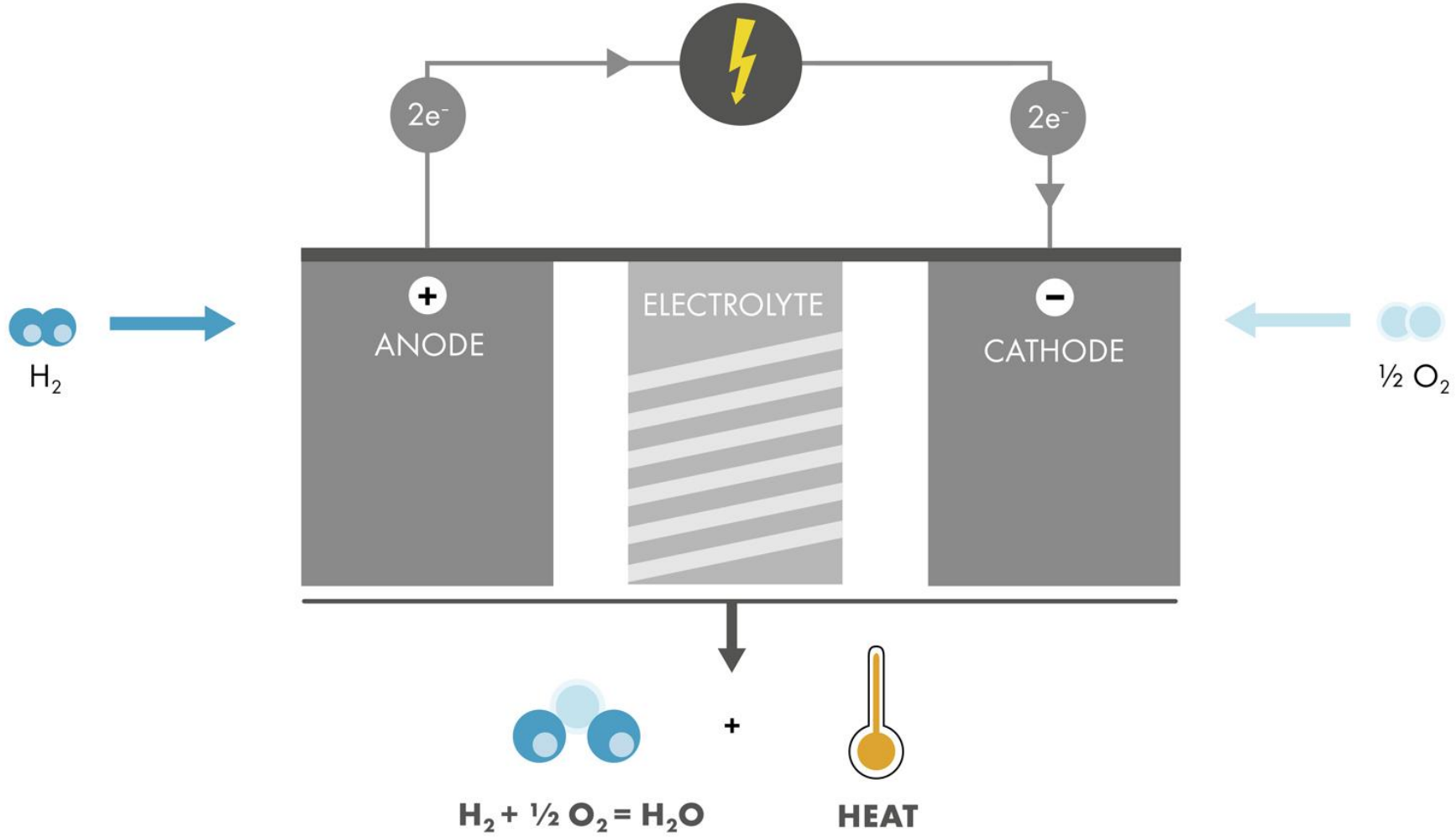
HyARC 2017; own diagram

GLOBAL USAGE OF HYDROGEN

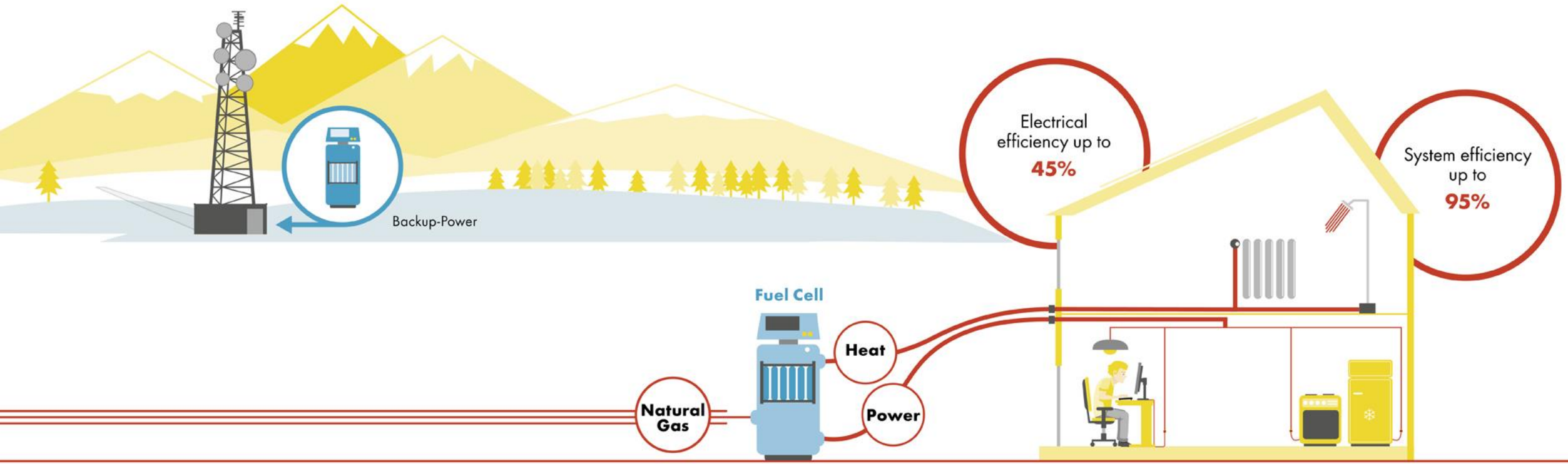


Zakkour/Cook 2010; own diagram

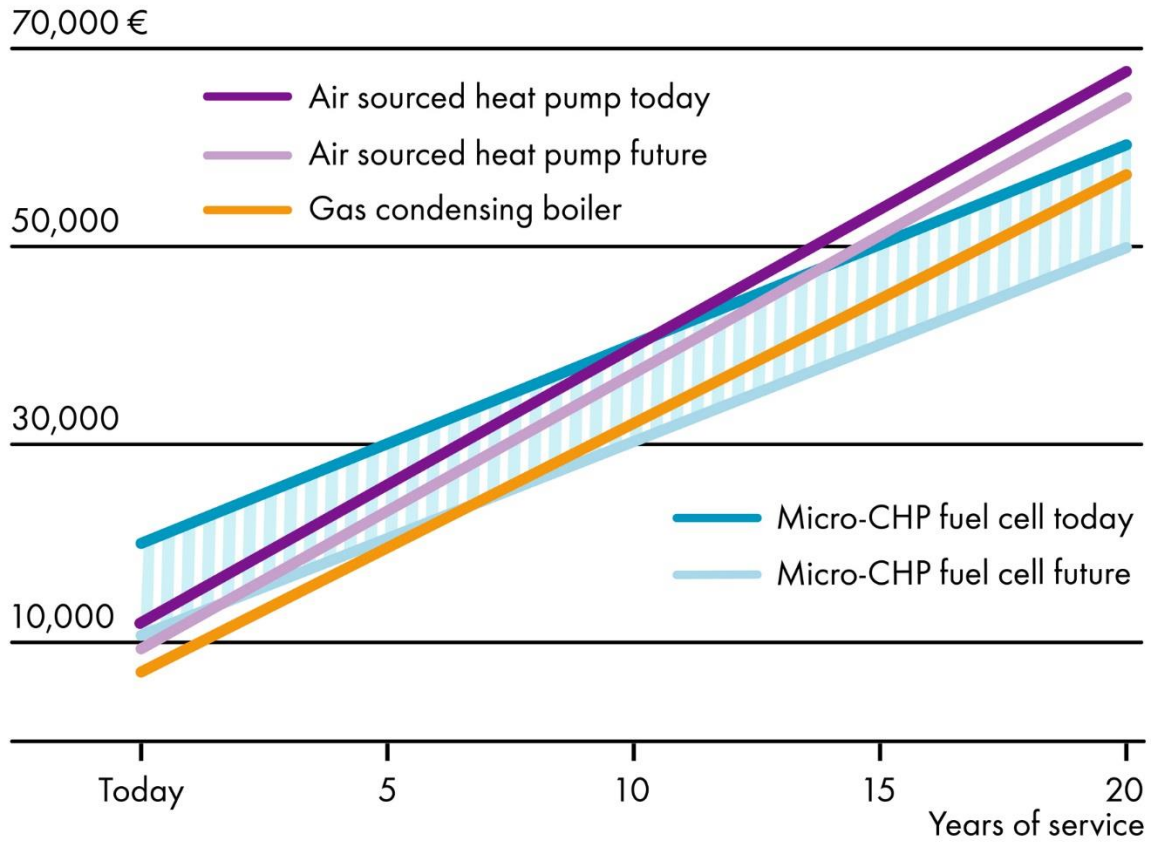
PRINCIPLE OF THE FUEL CELL



STATIONARY APPLICATIONS

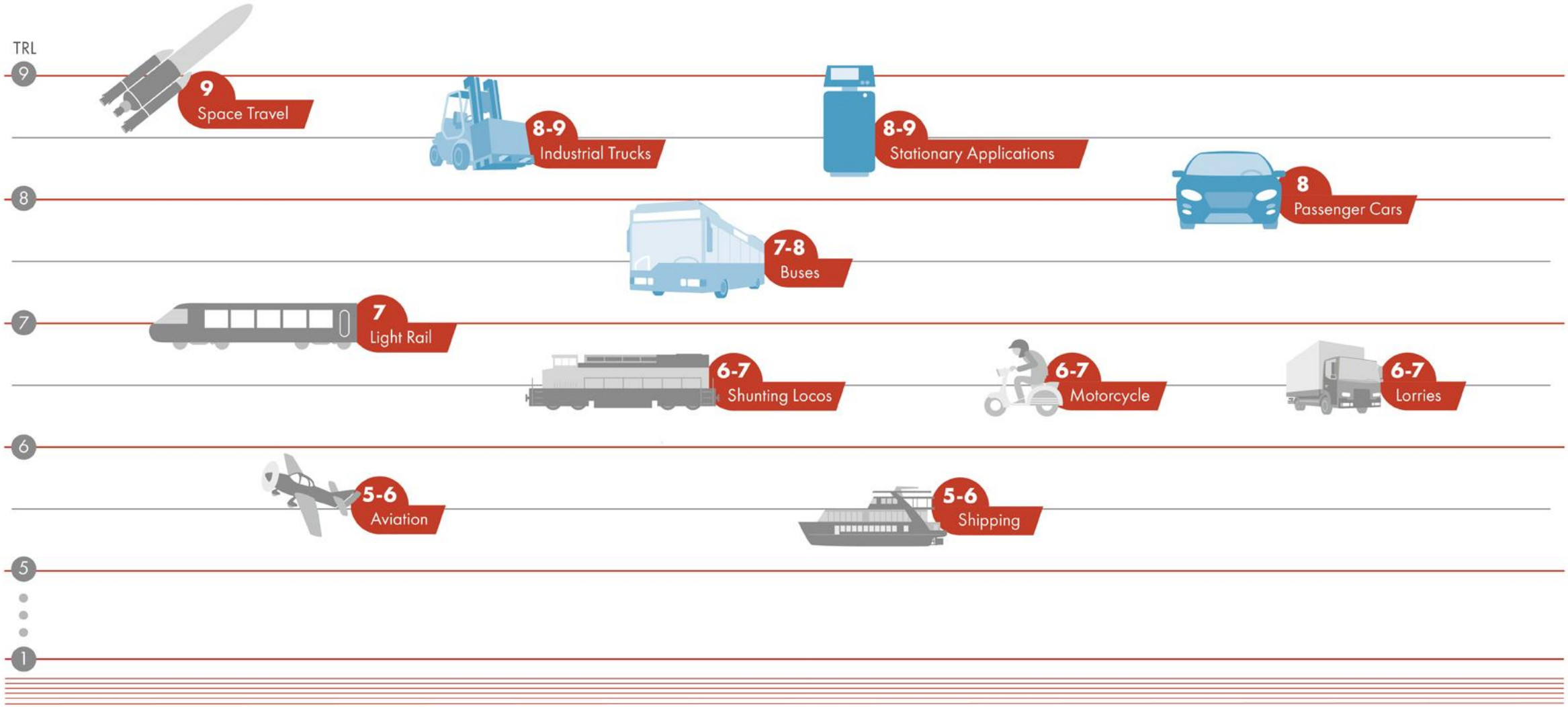


OWNERSHIP COST OF DOMESTIC ENERGY



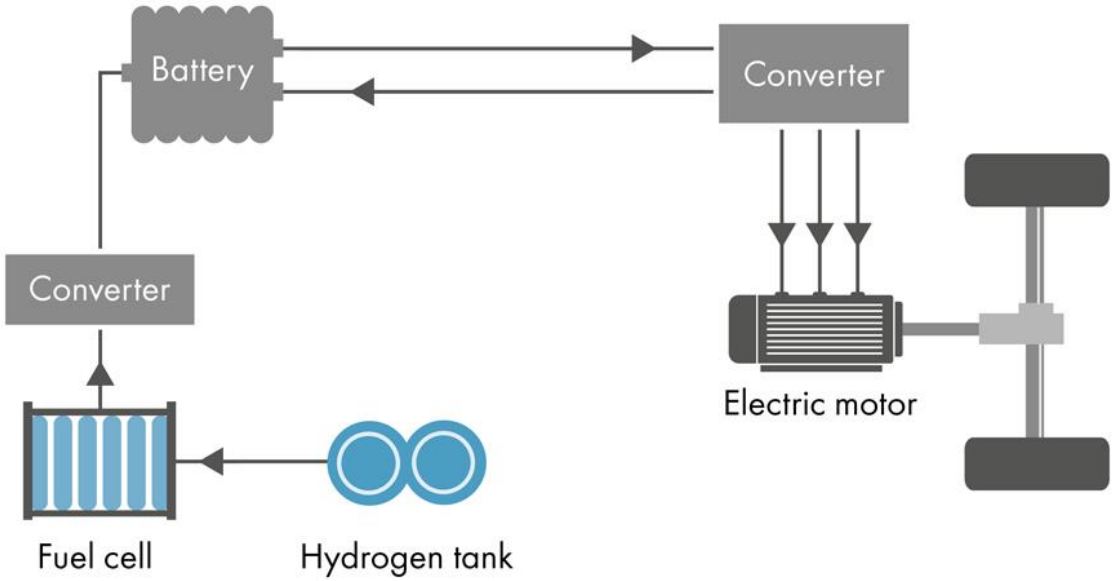
- Assumptions of TCO calculation:
  - Reference building 150 m^2
  - Heat: low-temperature gas boiler with consumption of 22,500 kWh/a,
  - Electricity consumption 4,000 kWh/a
  - Installation + energy cost, 20 years lifetime
- Three modernisation options:
  - Condensing gas boiler (€ 7,000)
  - Air sourced heat pump (€ 12,000)
  - Micro-CHP fuel cell (€20,000)

TECHNOLOGY READINESS LEVELS OF HYDROGEN APPLICATIONS

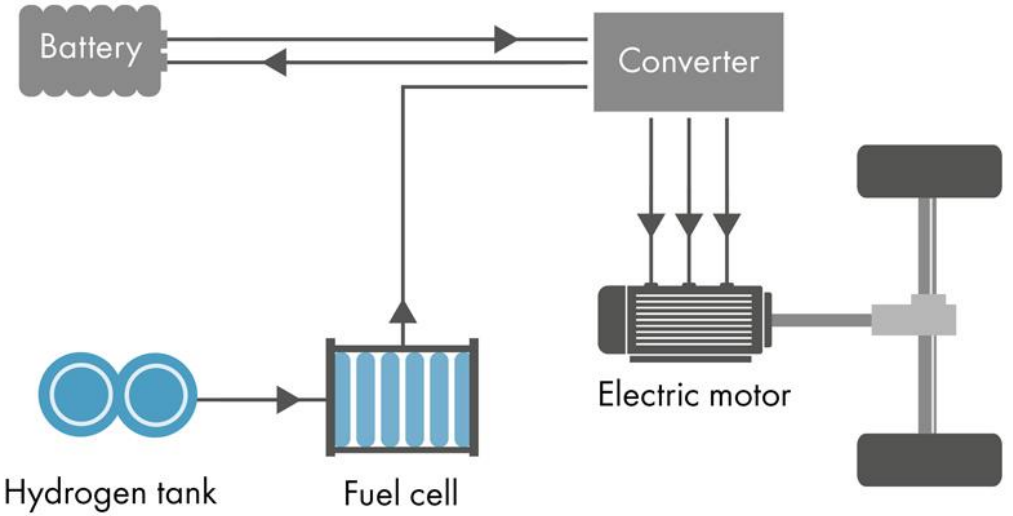


FUEL CELL CONCEPTS FOR PASSENGER CARS

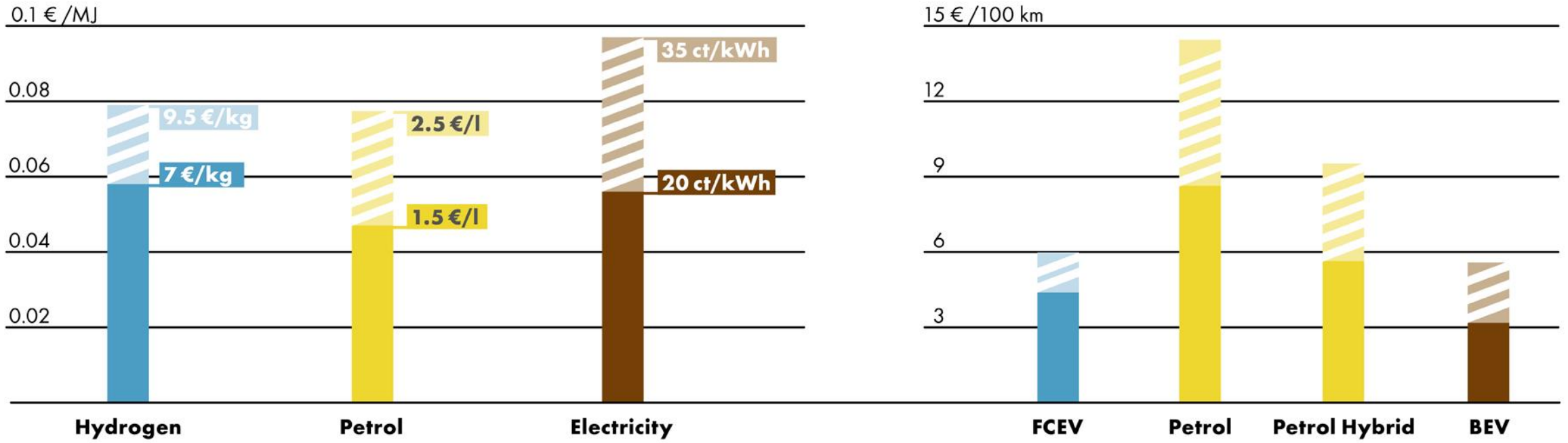
BEV WITH RANGE EXTENDER



FUEL CELL-DOMINANT SYSTEM

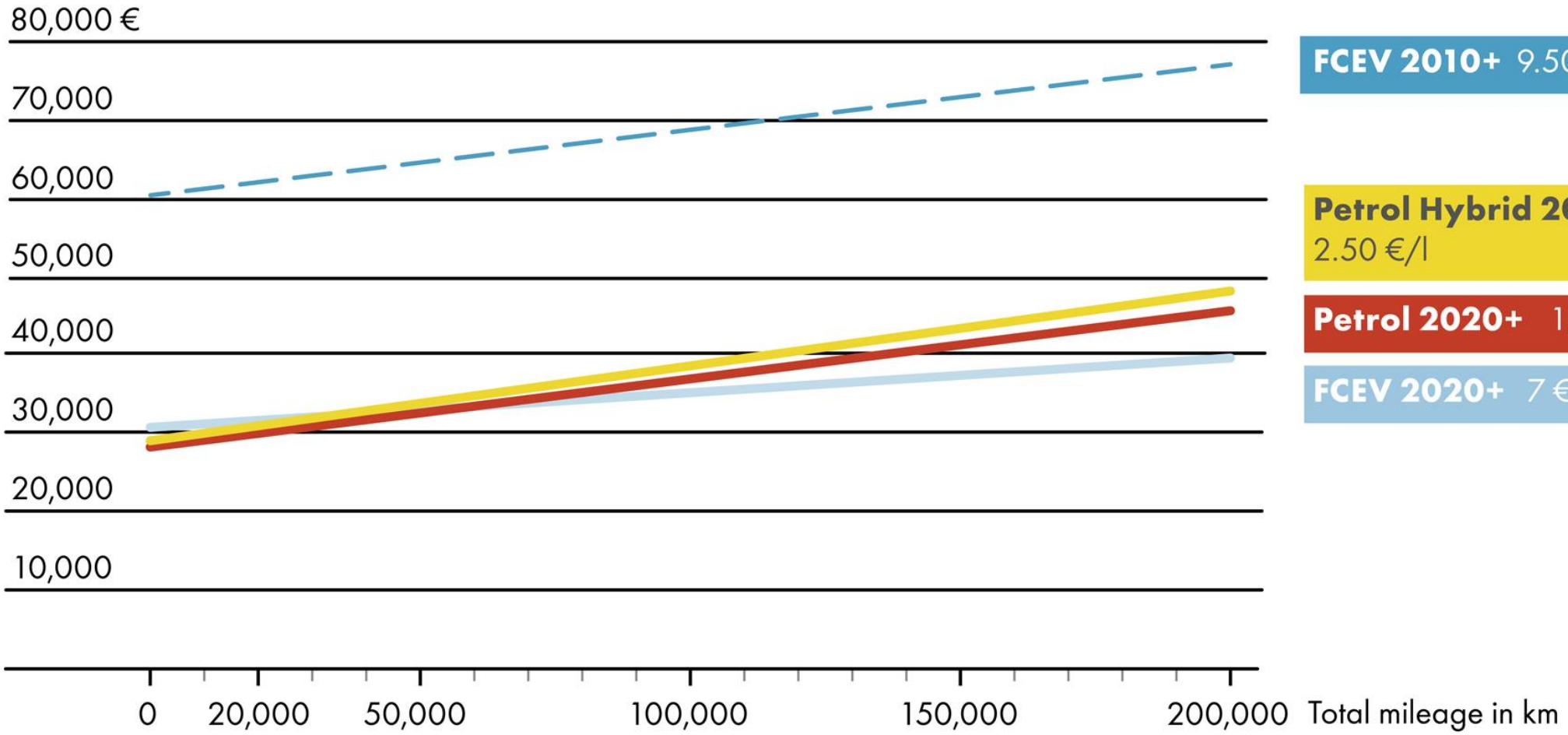


FUEL COSTS COMPARED*

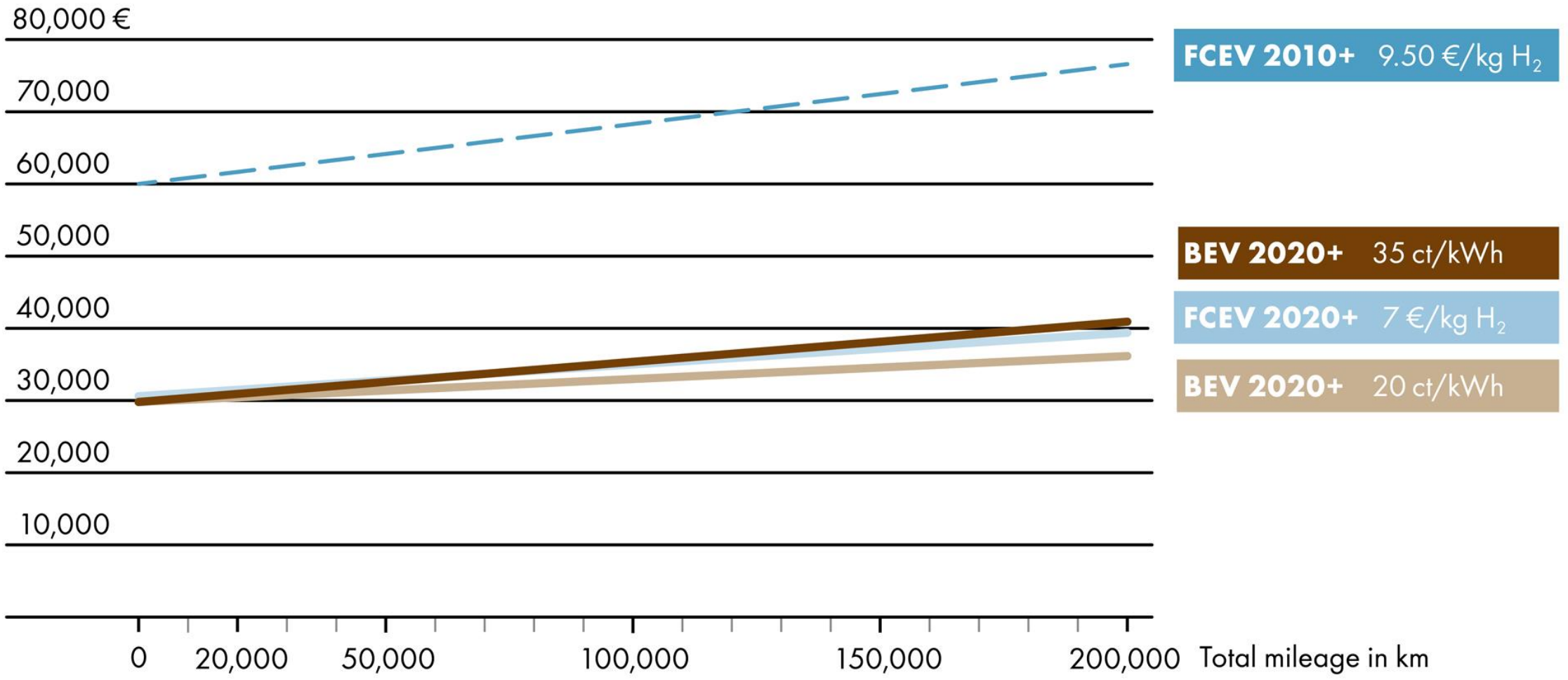


* European fuel prices, passenger cars 2020+ (JEC 2014)

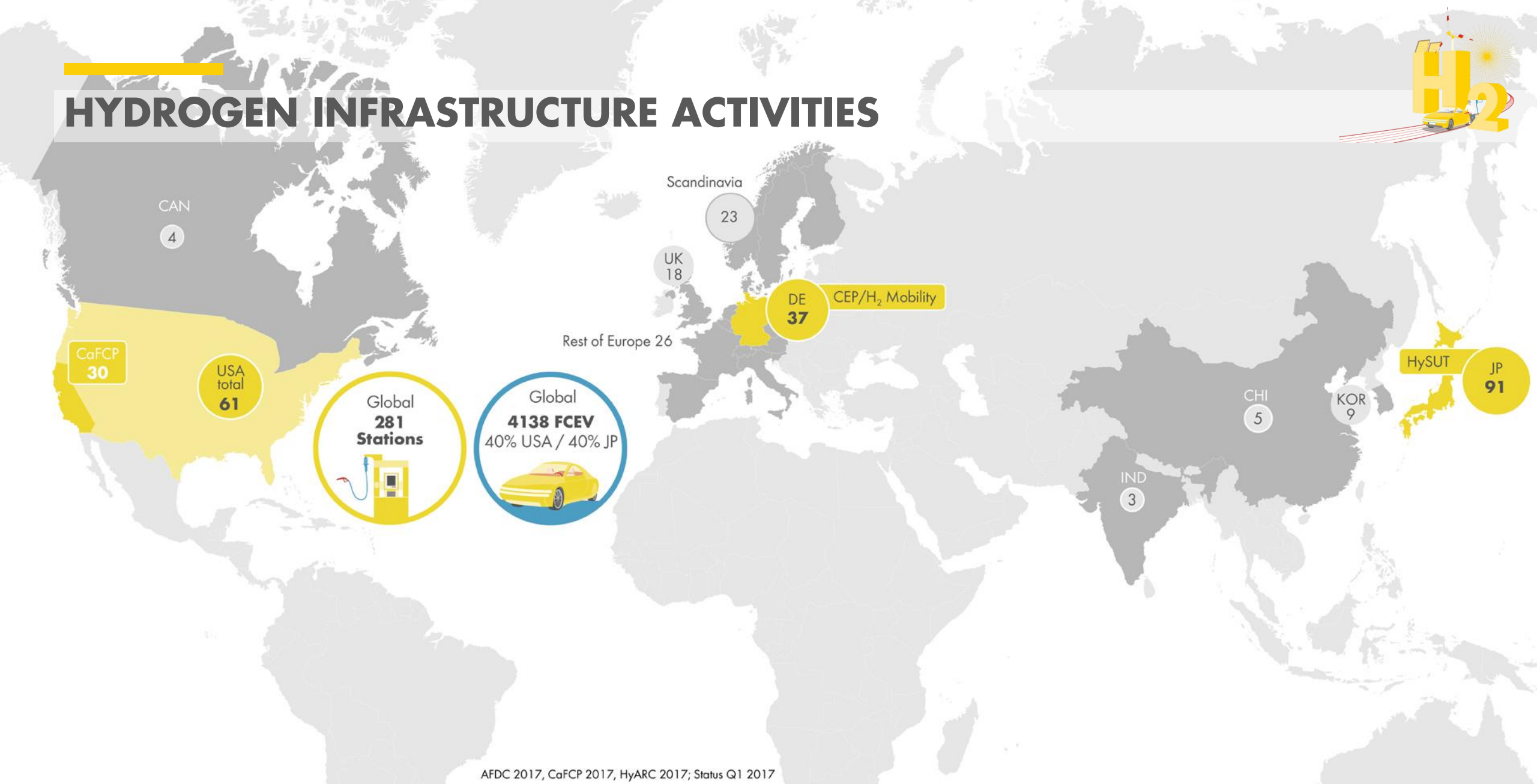
OWNERSHIP COSTS: FCEV AND PETROL VEHICLES



OWNERSHIP COSTS: FCEV AND BEV



HYDROGEN INFRASTRUCTURE ACTIVITIES

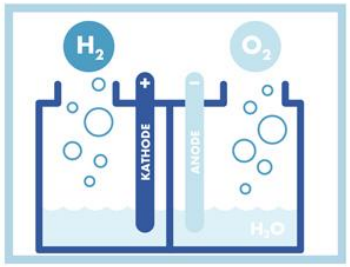


AFDC 2017, CaFCP 2017, HyARC 2017; Status Q1 2017

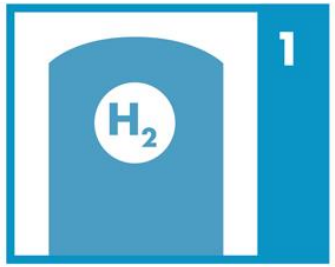
COMPONENTS OF A HYDROGEN REFUELLING STATION

UPSTREAM

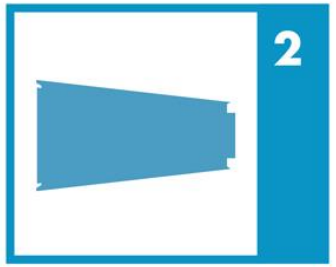
REFUELLING STATION



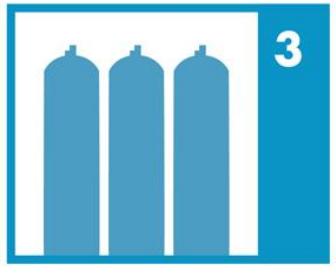
Electrolyser



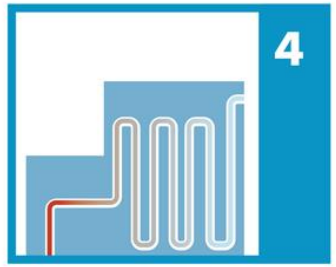
Low-Pressure Storage



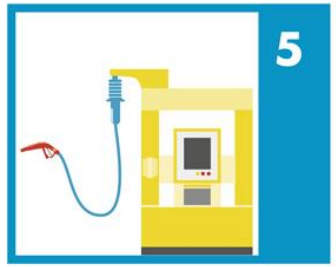
Compressor



High-Pressure Storage

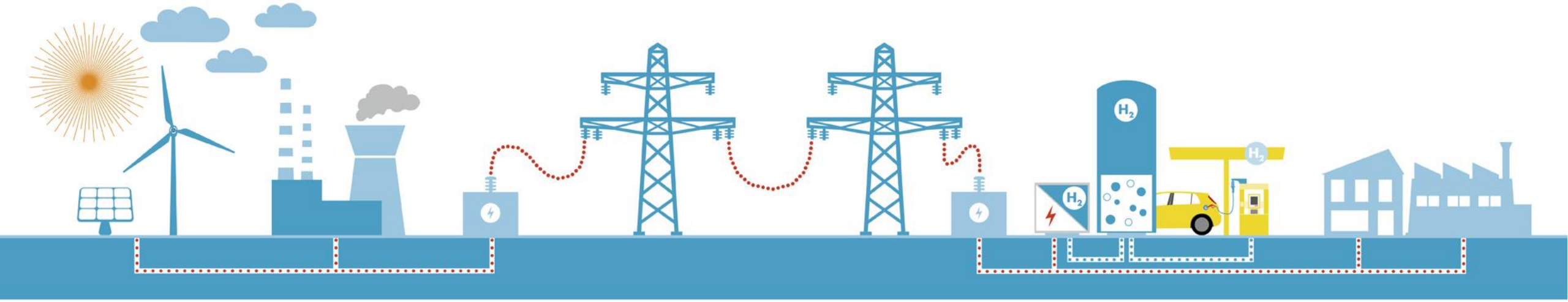


Precooling



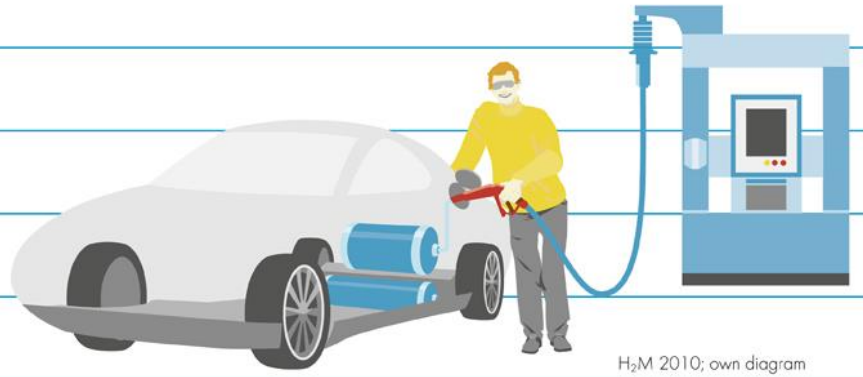
Dispenser

SUPPLY PATHWAYS:
DECENTRALISED HYDROGEN PRODUCTION ON A RETAIL SITE



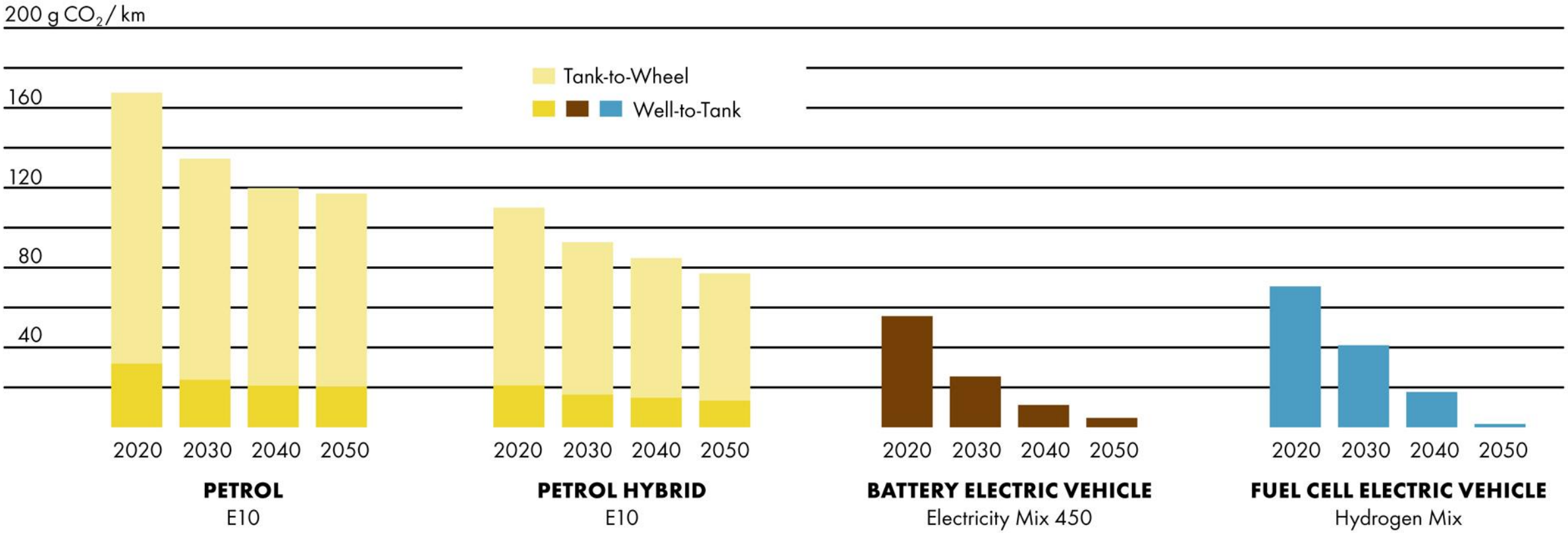
CLASSES OF HYDROGEN REFUELLING STATIONS BY SIZE

	Very small XS	Small S	Medium M	Large L
Dispenser	1	1	2	4
Max throughput per day	80 kg	212 kg	420 kg	1,000 kg
Max no. of refuellings per day	20	38	75	180
Max no. of FCEVs supplied per station	100	400	800	1600

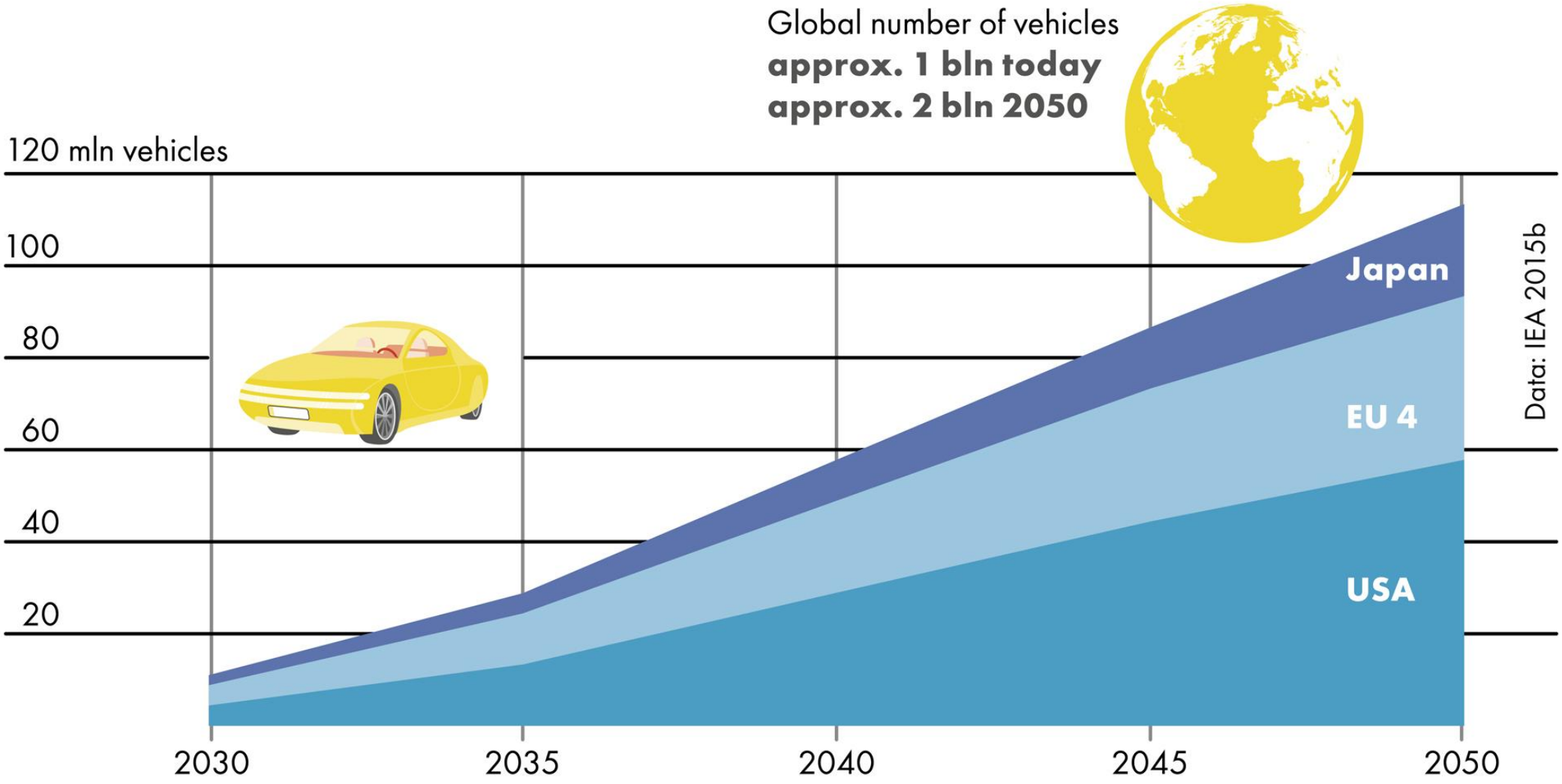


H_2M 2010; own diagram

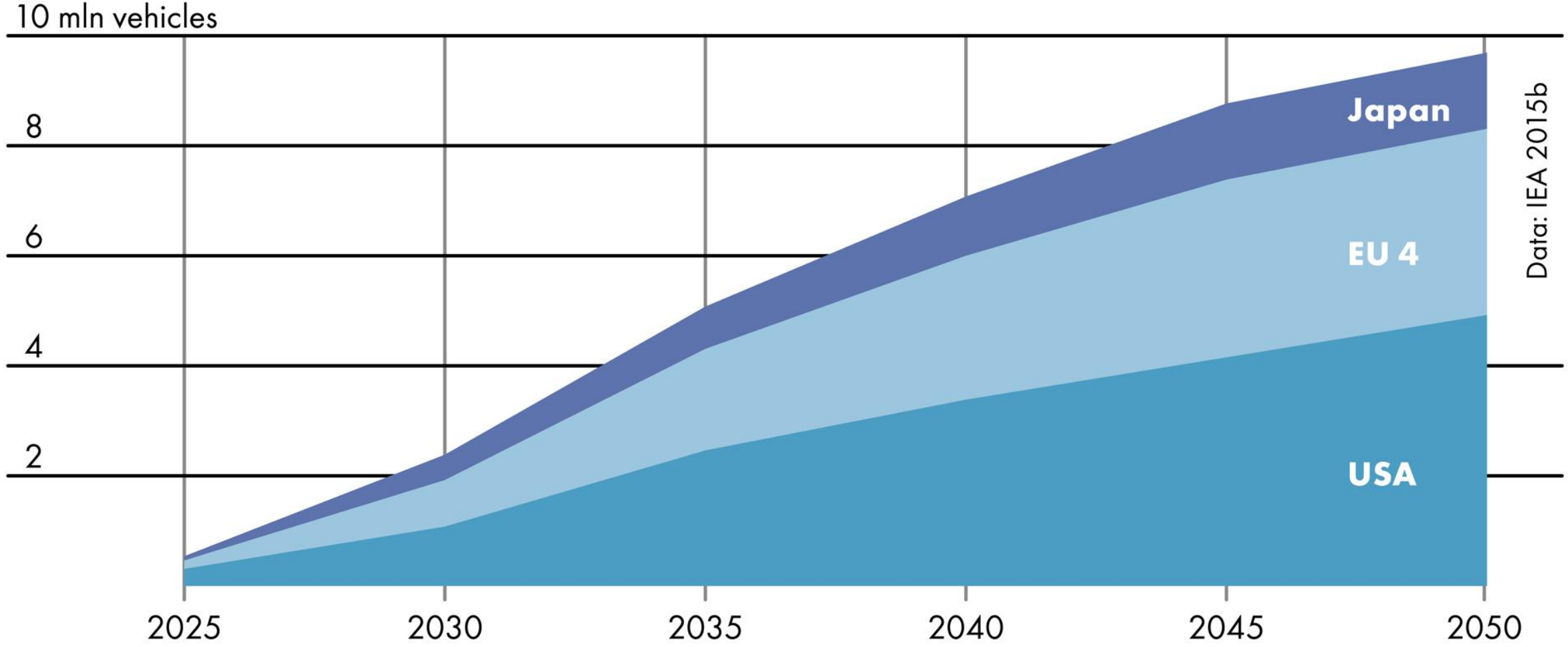
SPECIFIC WELL-TO-WHEEL PASSENGER CAR GREENHOUSE GAS EMISSIONS "REAL WORLD" DRIVING CONDITIONS, EUROPE



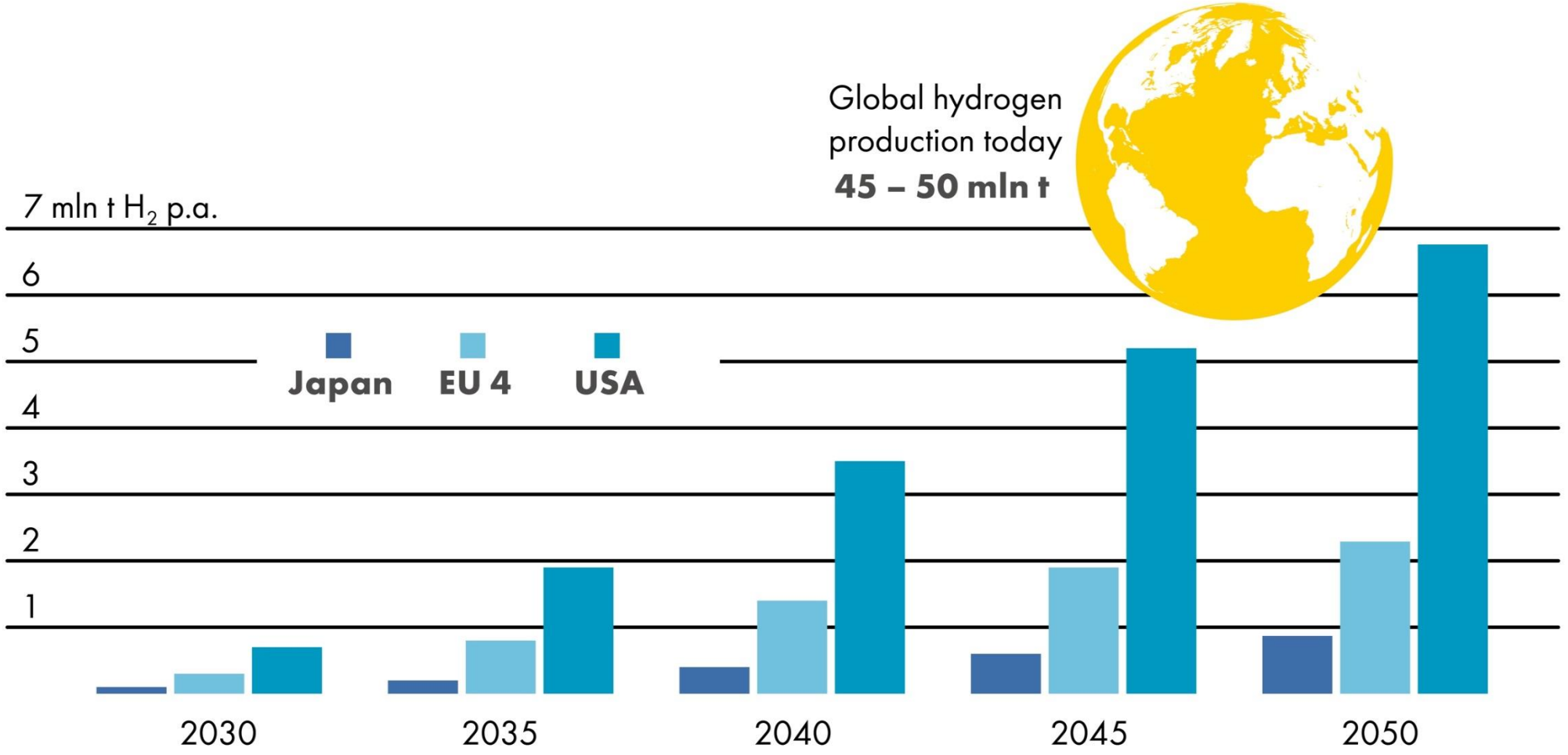
NUMBER OF FCEVS IN SELECTED MARKETS



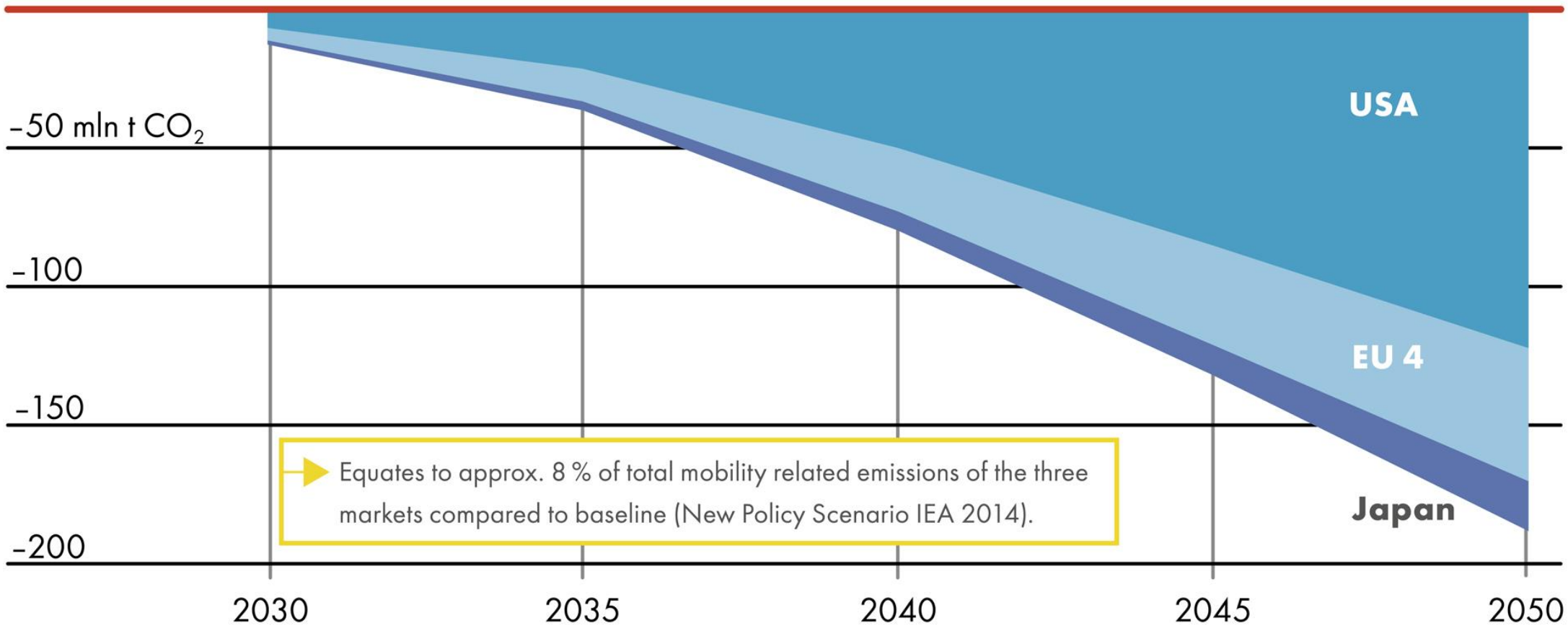
NEW REGISTRATIONS OF FCEVS IN SELECTED MARKETS



ANNUAL H_2 DEMAND OF FCEVS (IN 2DS HIGH H_2 SCENARIO)

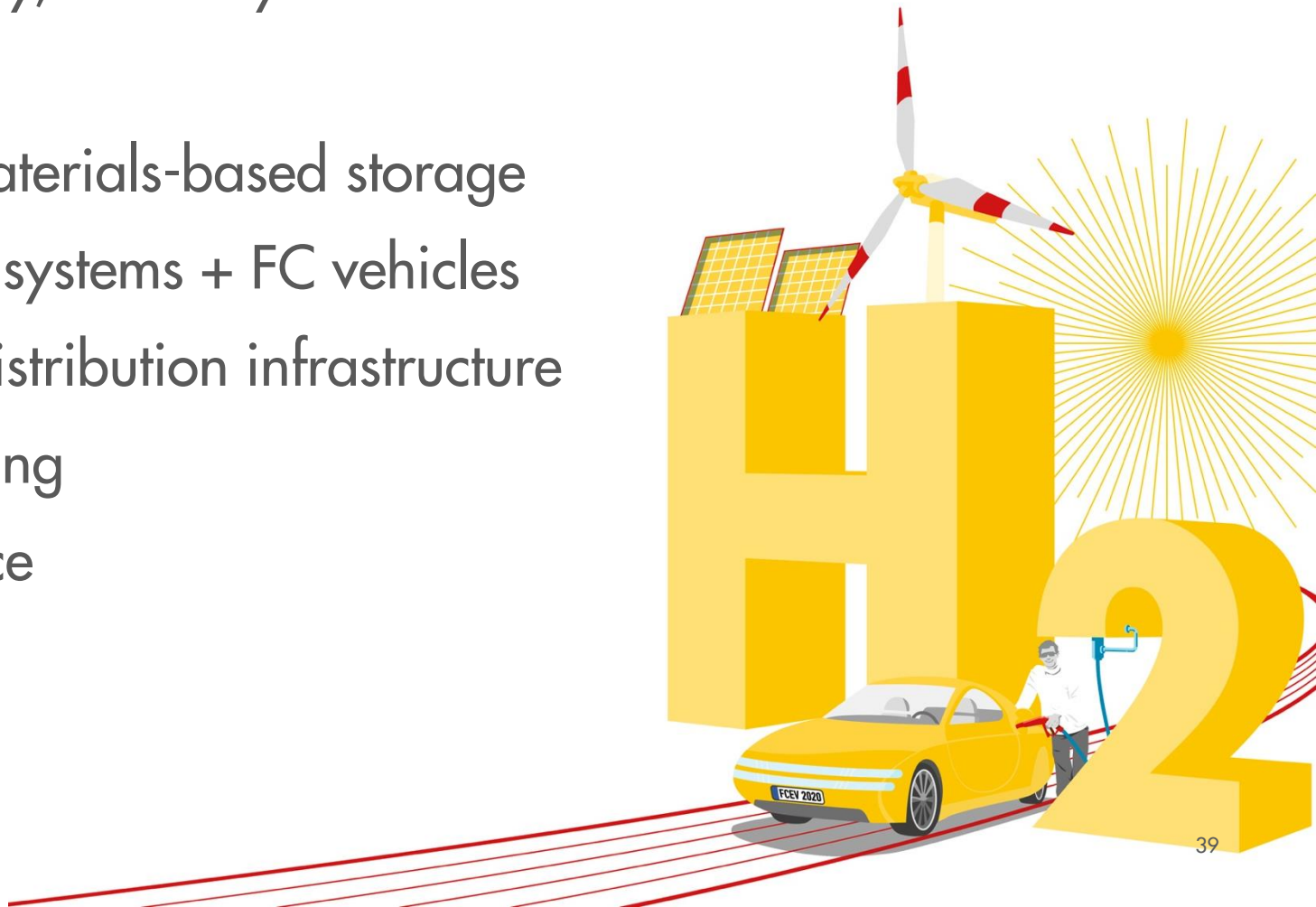


WELL-TO-WHEEL GHG SAVINGS OF FCEVS COMPARED TO PETROL VEHICLES



POLICY ASKS FOR THE HYDROGEN ECONOMY

- Production processes: cost, efficiency, flexibility
- Fuel cells: cost, efficiency, stability
- Long-term mass storage, R&D in materials-based storage
- Support launch of BUP/Micro CHP systems + FC vehicles
- Build-up of hydrogen supply and distribution infrastructure
- "Level playing field" + sector coupling
- Create/ensure consumer acceptance




Shell
Wasserstoff
Hydrogen
Shell
Wasserstoff Hydrogen
BlueEFFICIENCY
F-CELL
zero emission

Questions and Answers

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