Hydrogen
scaling up

A sustainable pathway for the global energy transition

Air Liquide | Pierre-Etienne FRANC VP H2 Energy World Business Unit
EXANE | Déjeuner “Expert Access” | 23 MAY 2018

This study is the first comprehensive, ambitious Hydrogen roadmap

Objectives of the study

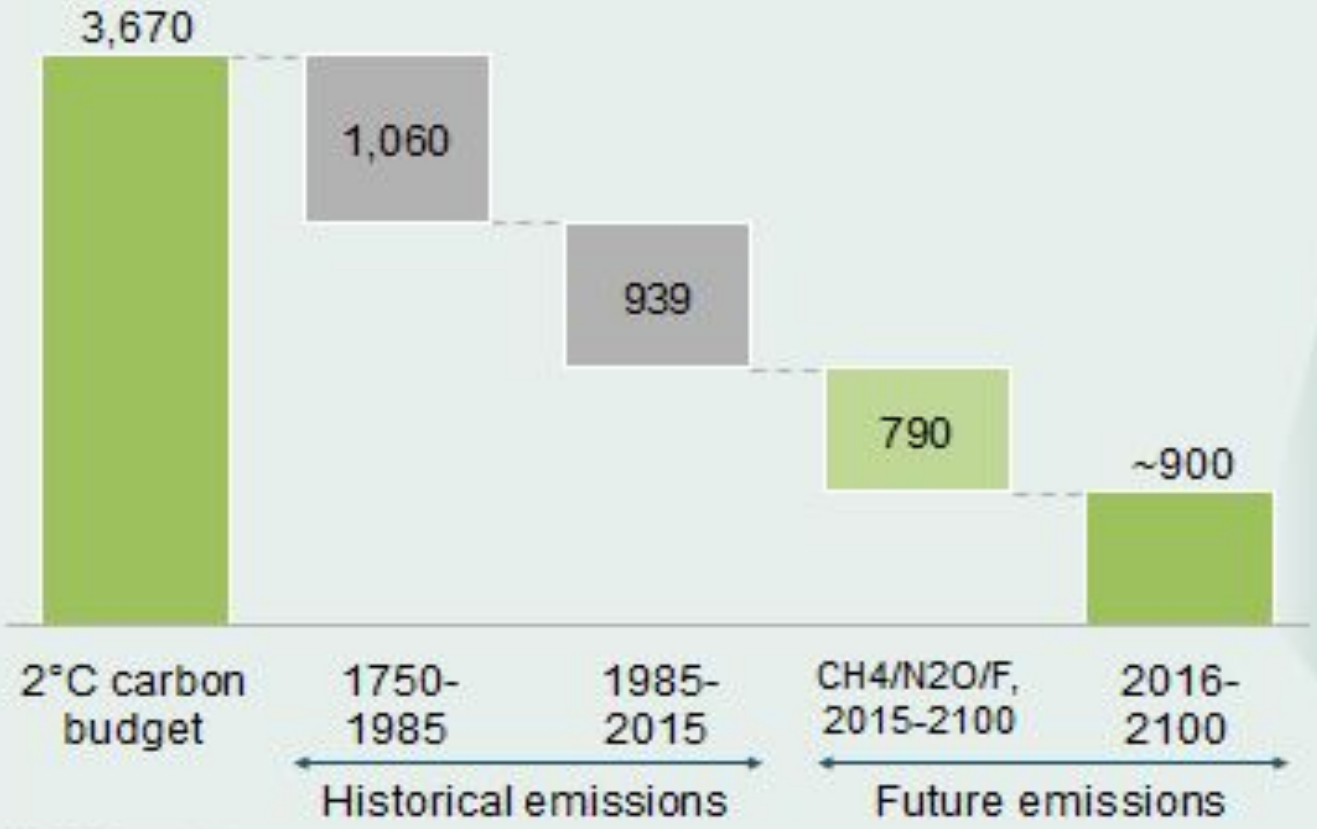
- First **comprehensive quantified vision** and **roadmap** for deployment
- Not a forecast, but an **ambitious yet realistic** scenario
- Answers the question “How could hydrogen contribute to **achieving the two degree scenario**?”

SOURCE: Hydrogen Council

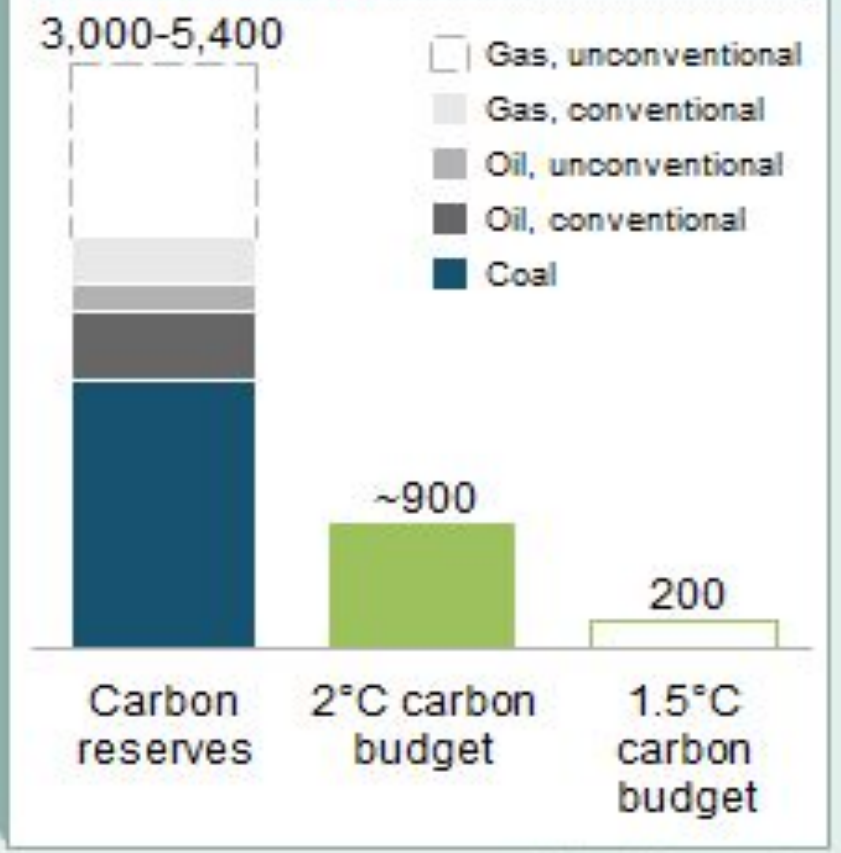
A carbon budget enables us to minimize global warming

Billion tonnes of CO_2-eq

2°C Carbon budget emissions to 2100



Carbon budget compared to carbon reserves



SOURCE: Team analysis

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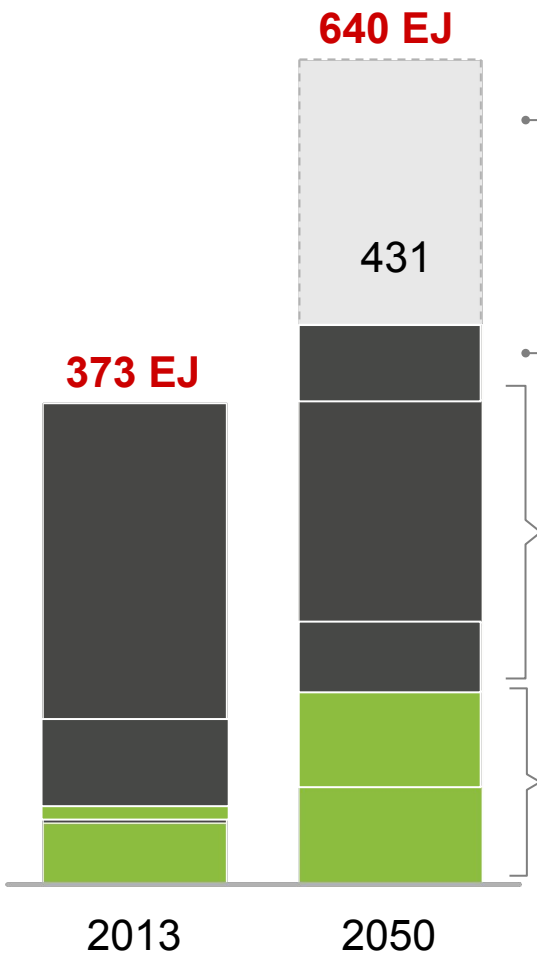
Four major levers are needed to enable the energy transition

Final energy consumption[1,2], 2013 and 2050, in EJ



Fossil fuels

Power sector – Fossil fuels
Power sector – Renewables
Biomass and waste

1. **Increasing energy efficiency** limits the rise of energy consumption

2. **CCS/U** decarbonizes the use of fossil fuels[3]

3. **Switch to zero emission energy carriers,** e.g., electricity or hydrogen

4. **Renewables** replace fossil fuels

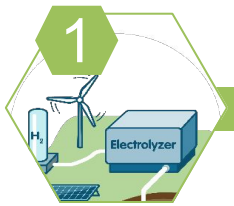
1 Final energy consumption within the 2DS of the IEA
2 Increase of energy demand is determined via the relative increase of CO_2 emissions w/o energy efficiencies
3 The fossil fuels amount processed using CCS/U was determined to be 25% of the total amount of fossil fuels by relating the CO_2 emission reduction compared for the 2DS and 6DS
4 The fossil fuel power sector also includes nuclear energy

Source: IEA ETP 2016

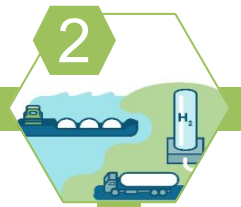
There are **seven** roles for hydrogen in the energy transition

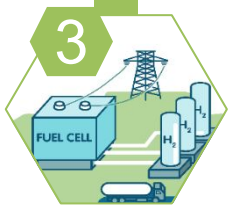
Enable the renewable energy system → Decarbonize end uses

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

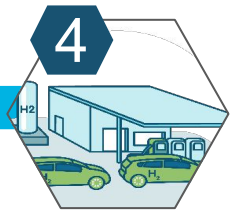


Distribute energy across sectors and regions

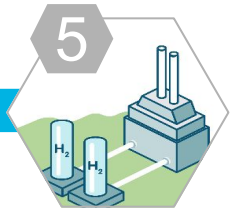




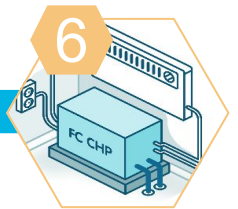
Act as a **buffer** to increase system resilience



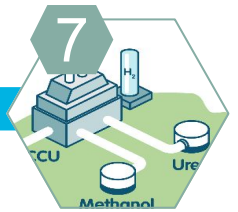
Decarbonize **transportation**



Decarbonize **industry energy** use



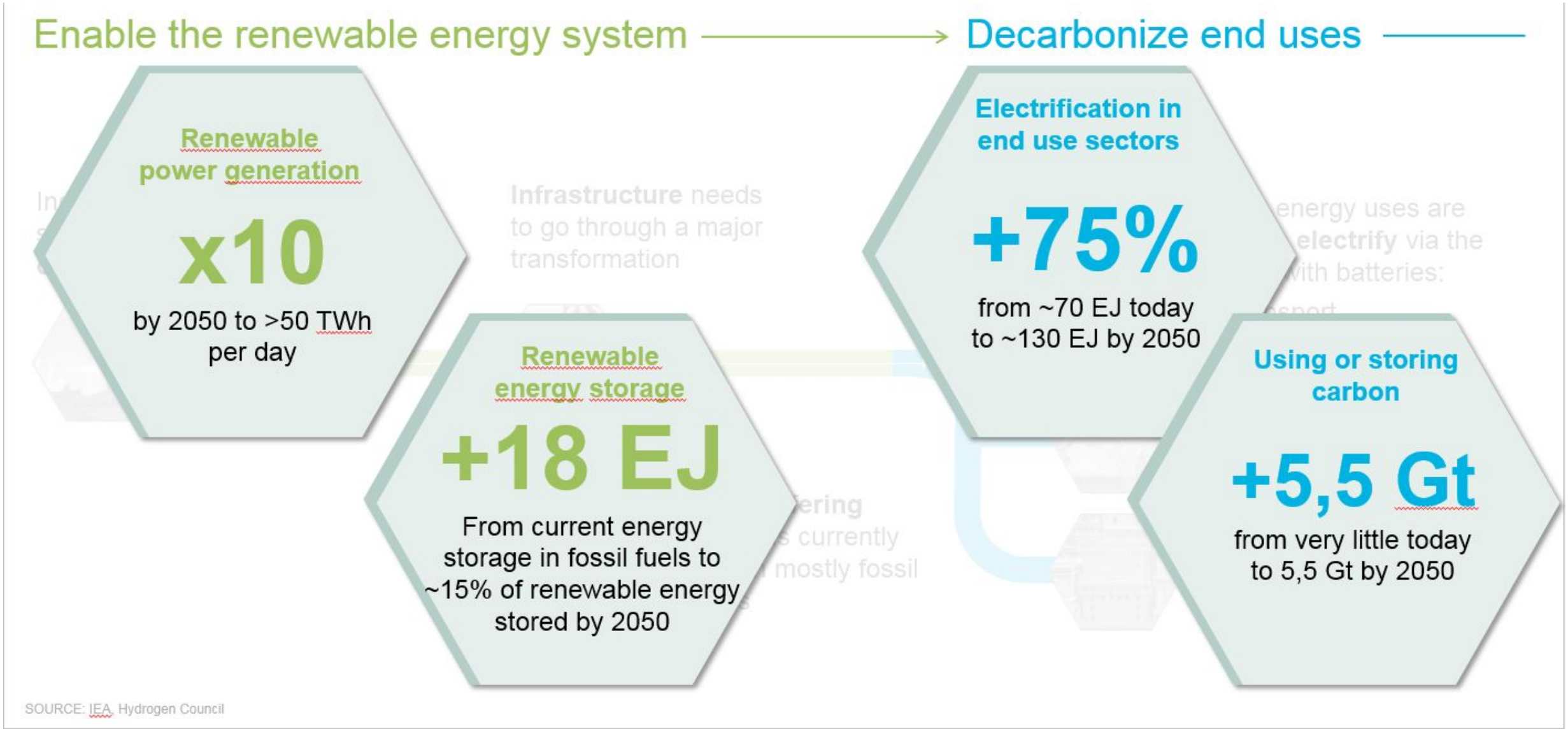
Help decarbonize **building heating and power**



Serve as **feedstock**, using captured carbon

SOURCE: Hydrogen Council

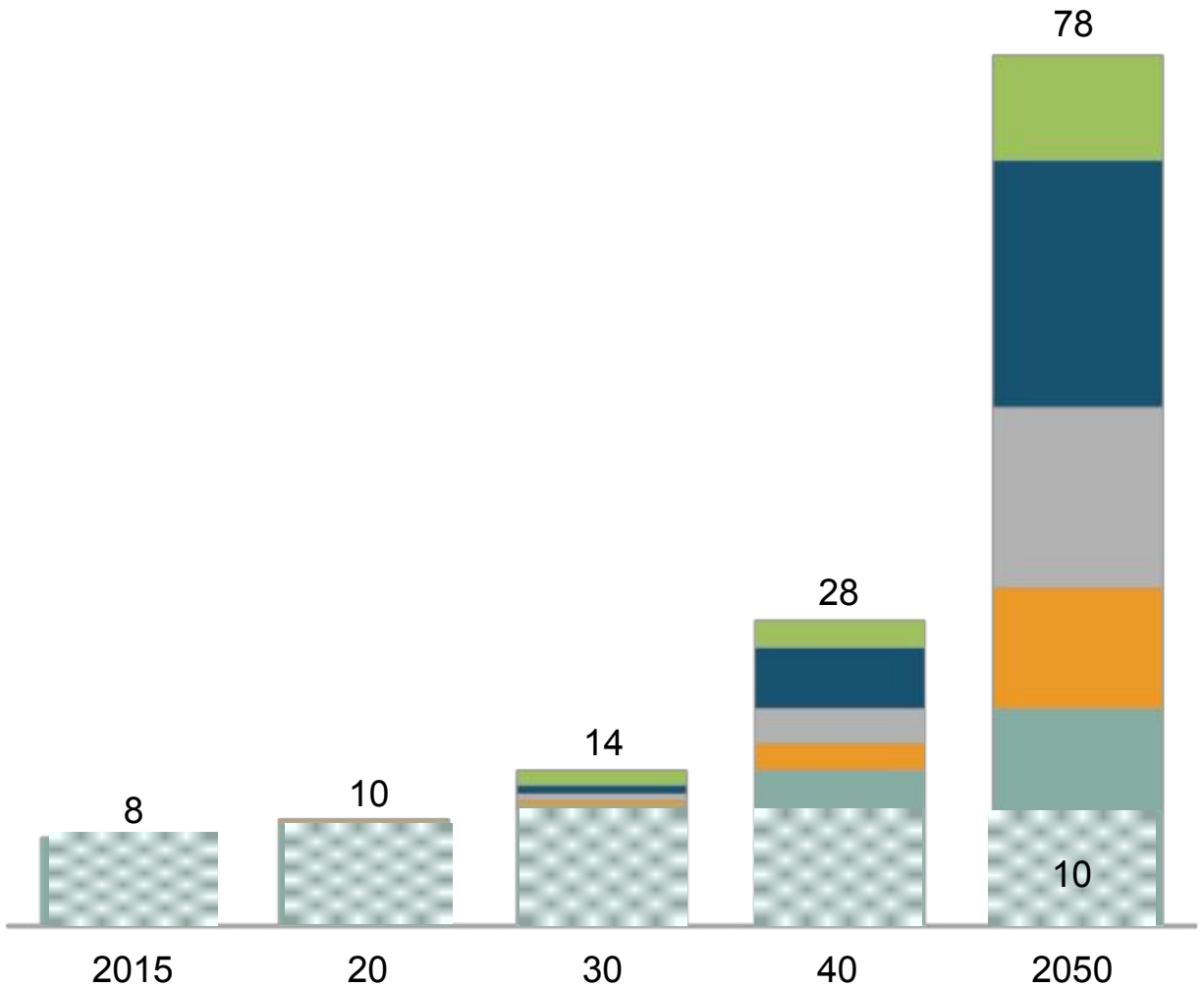
The energy transition creates multiple challenges



SOURCE: IEA, Hydrogen Council

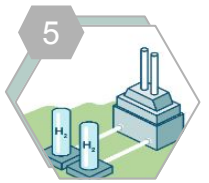
In a 2-degree-world, hydrogen could contribute ~18% of demand

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

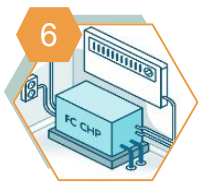


Power generation, buffering

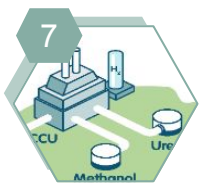
Transportation



Industrial energy



Building heat and power

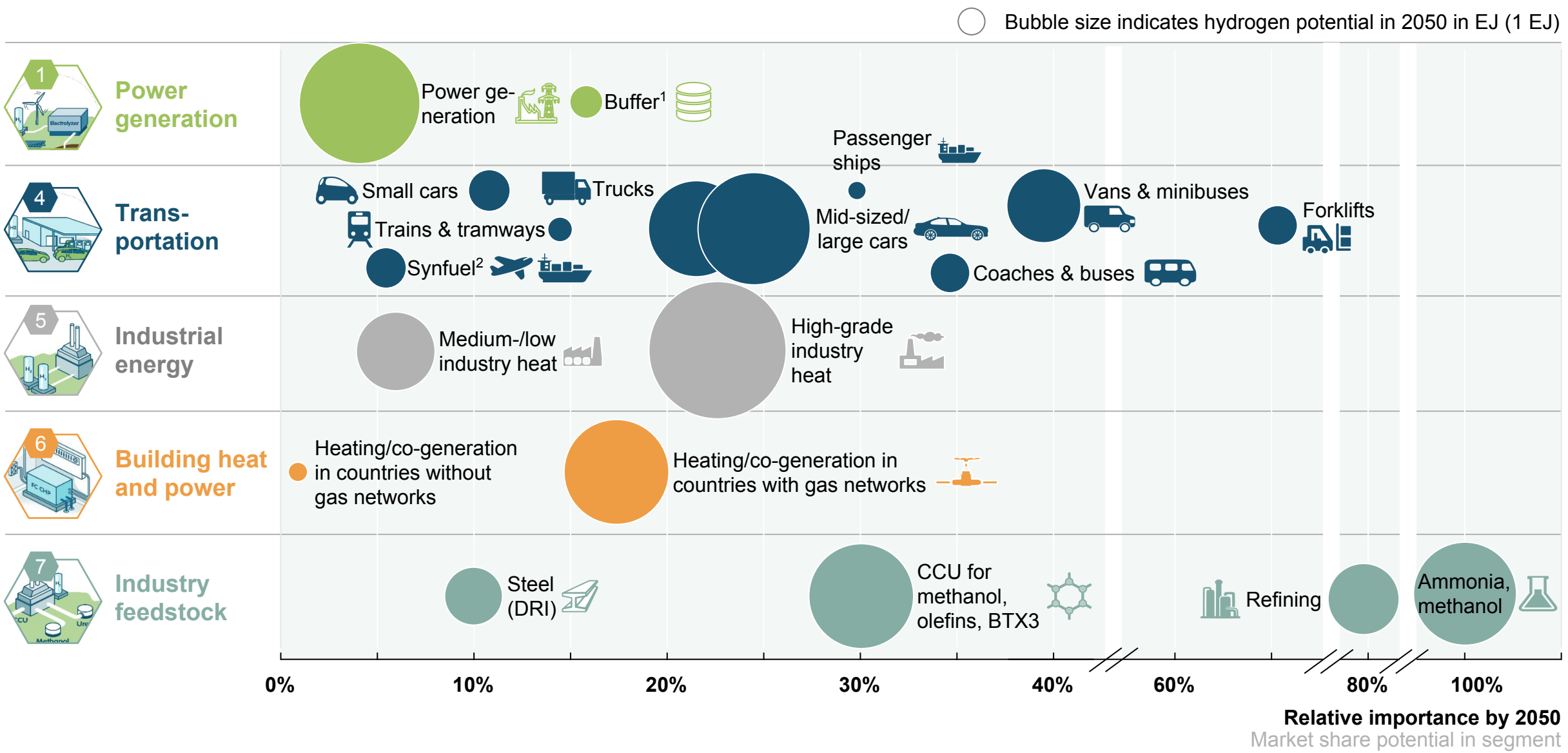


New feedstock (CCU, DRI)
Existing feedstock uses

18%
of final energy demand

SOURCE: Hydrogen Council

Hydrogen has significant potential across all applications

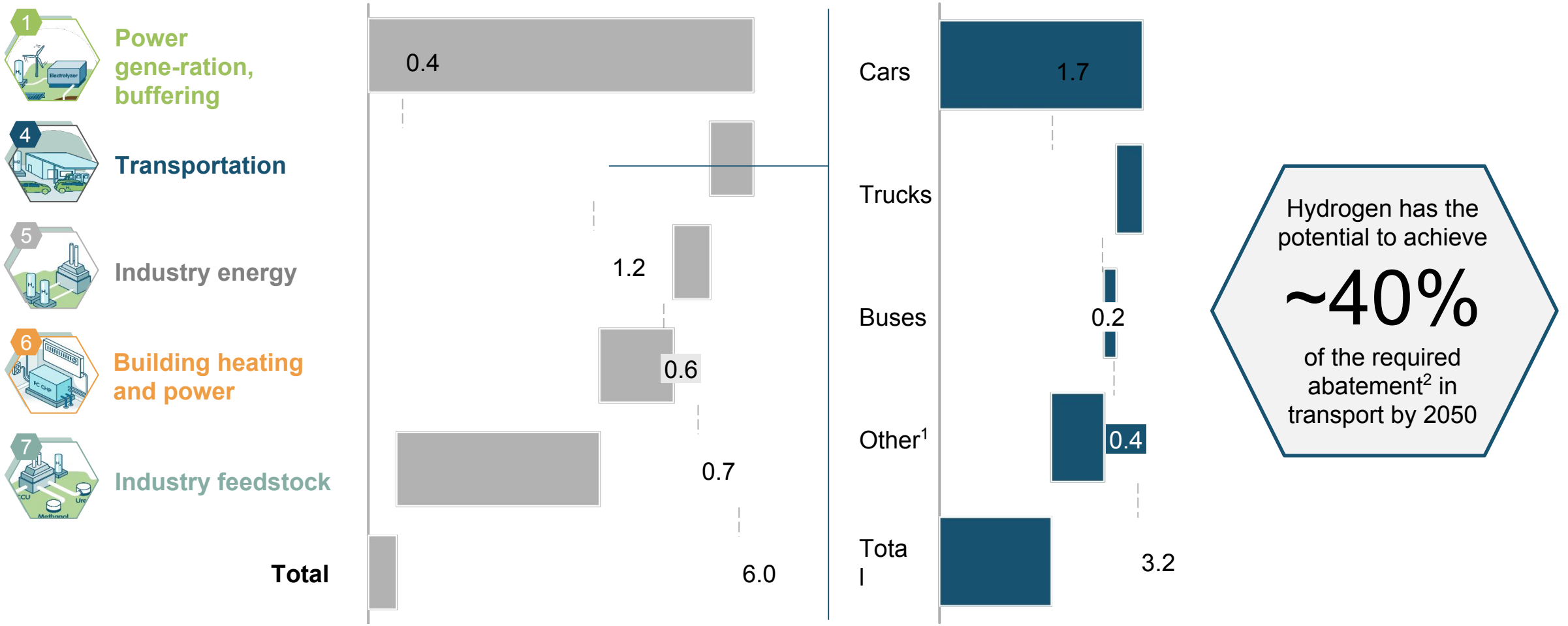


1 Percent of total annual growth in hydrogen and variable renewable power demand 2 For aviation and freight ships 3 Percent of total methanol, olefin, BTX production using olefins and captured carbon

SOURCE: Hydrogen Council

Half of the total CO2 abatement potential will come from transport

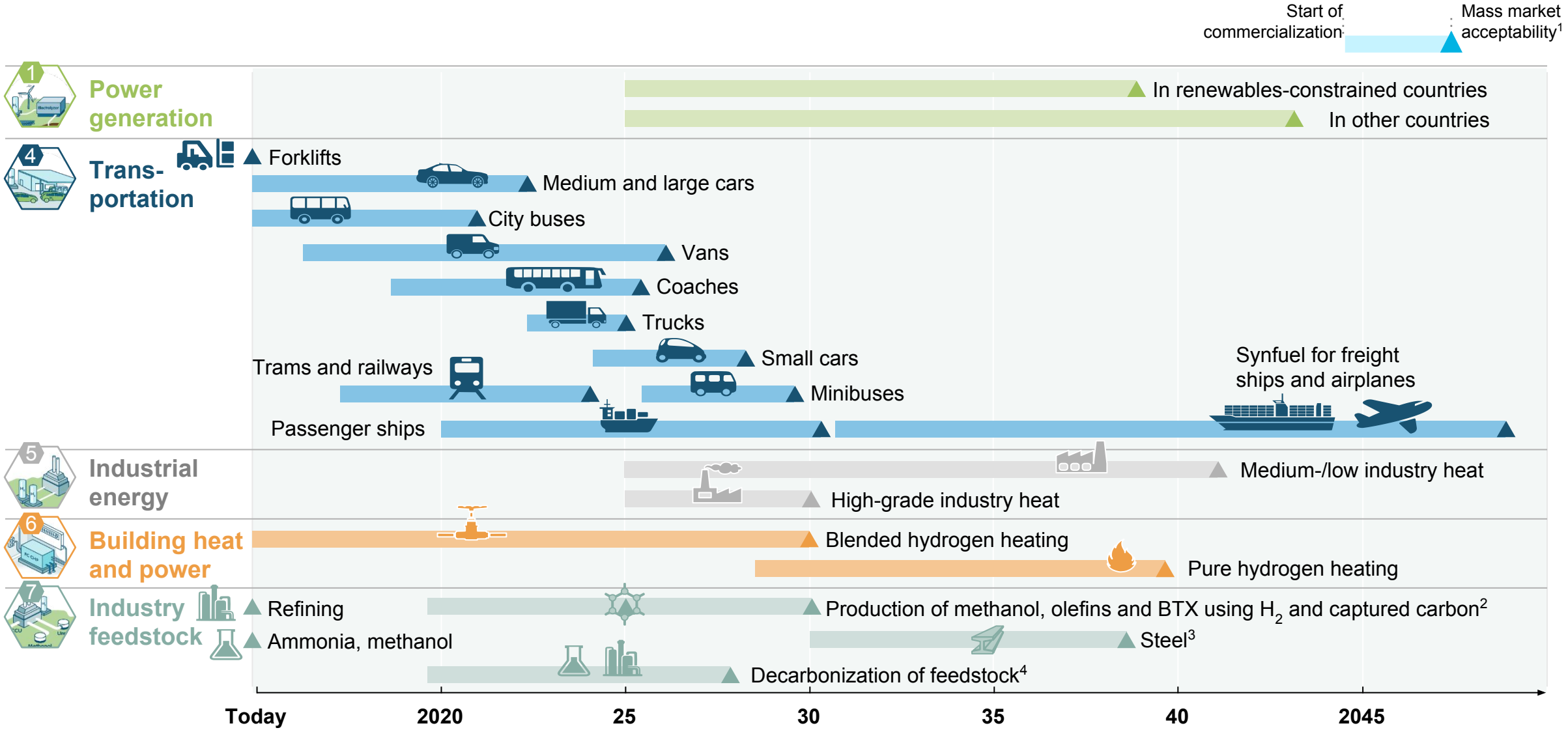
CO2 avoidance potential 2050, Gigatons



1 Aviation, shipping, rail, material handling 2 Difference between IEA Reference Technology and 2 degree scenario

SOURCE: IEA, Hydrogen Council

The technologies exist and are ready to be deployed

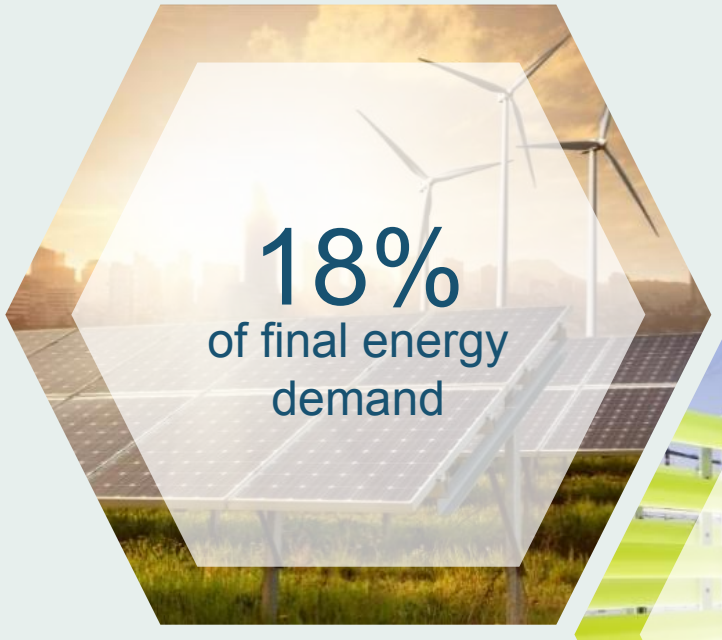


1 Mass market acceptability defined as sales >1% within segment in priority markets
2 Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock
3 DRI with green H_2, iron reduction in blast furnaces and other low-carbon steel making processes using H2
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

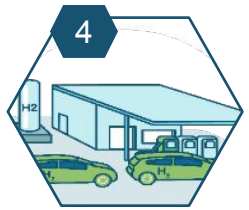
Estimated impact in 2050



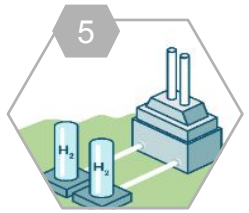
1 Value add of fuel cells

SOURCE: Hydrogen Council, IEA ETP Hydrogen and Fuel Cells CBS, National Energy Outlook 2016

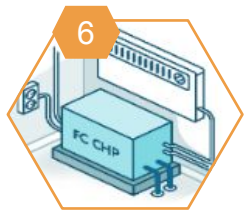
Important milestones already for 2030 to reach the 2050 vision

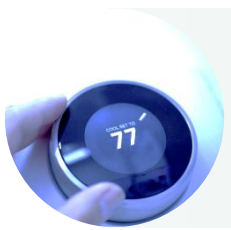


- **1 in 12 passenger cars sold** in early-adoption markets (Germany, California, Japan and South Korea) FCEVs

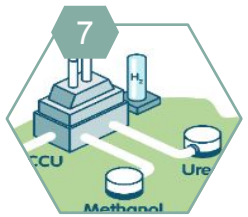


- **3.5 Mt** hydrogen used for **high-grade heat** in first large-scale projects





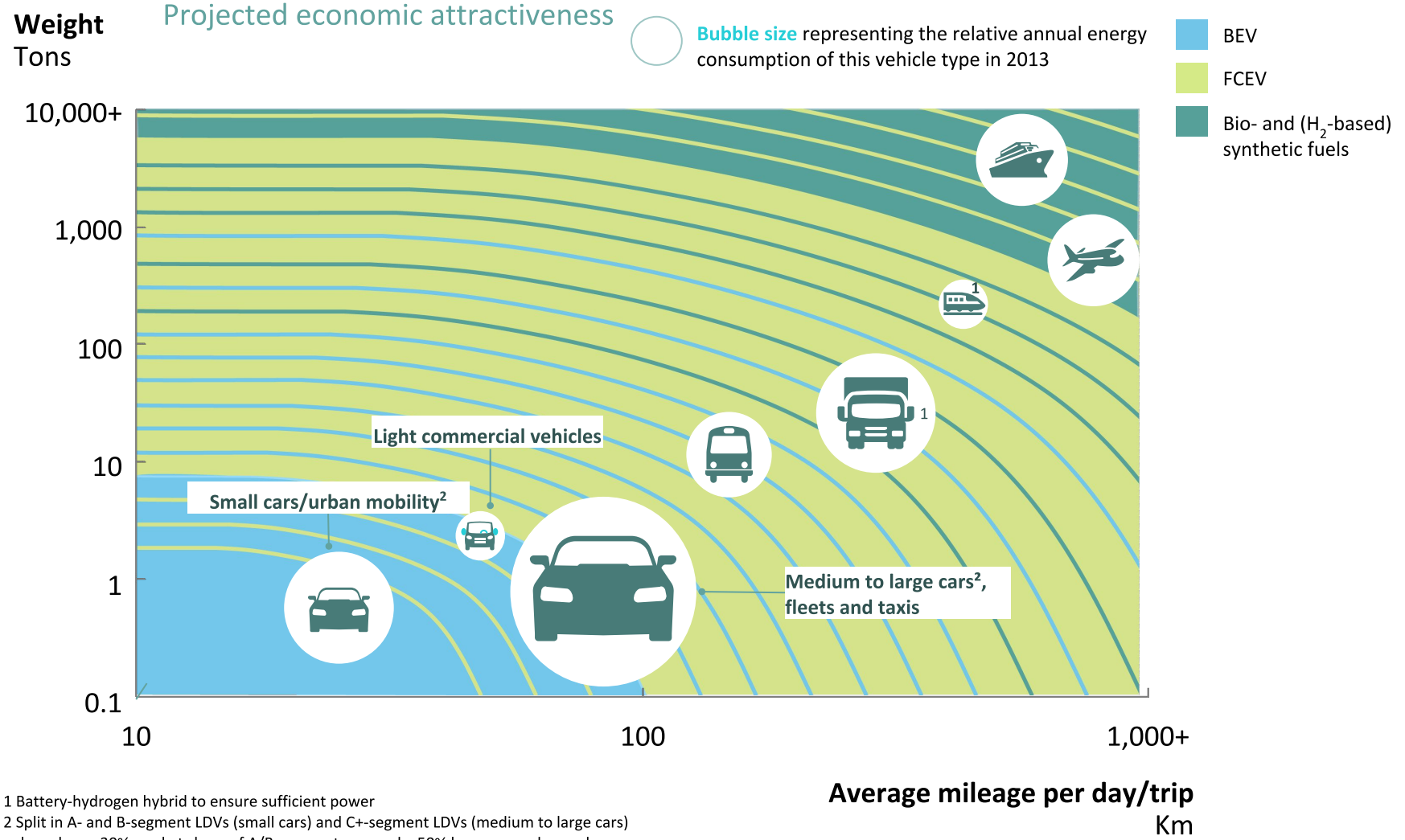
- **50 million households** connected to a network safely blending hydrogen and natural gas



- **20 Mt CO_2** converted to chemicals and intermediates such as **methanol** using hydrogen

SOURCE: Hydrogen Council

Focus on Transport - FCEVs will play an essential role

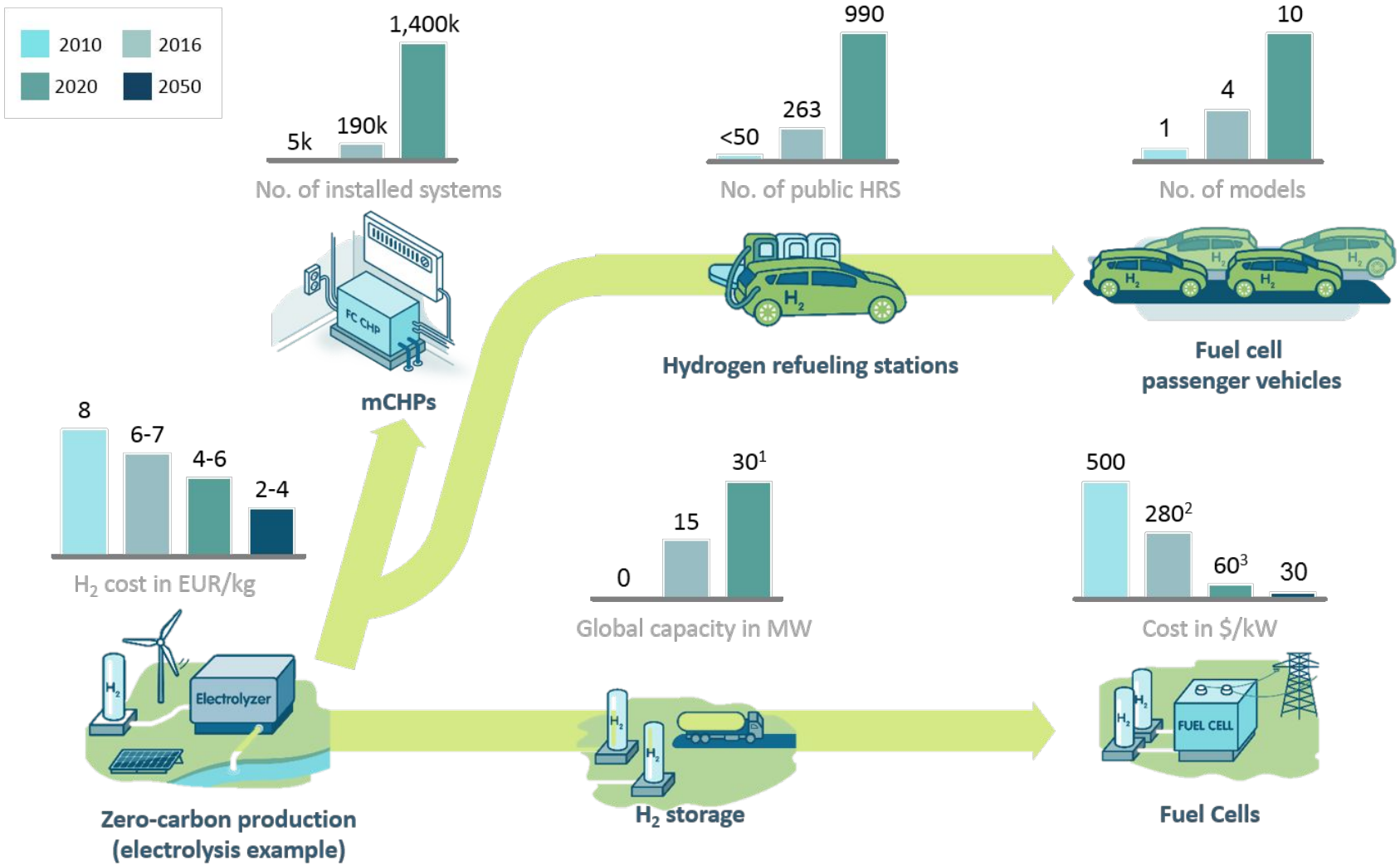


1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Source: Toyota, Hyundai, Daimler

H2 technologies and markets are already ramping up

Selected examples of the hydrogen sector



1 Extrapolating the growth to 20 MW in 2017/2018 from outstanding projects, 2 Assuming 20k units production per year, 3 Assuming 100k units production per year in 2025
Source: IEA, E4Tech, US DOE, Press research

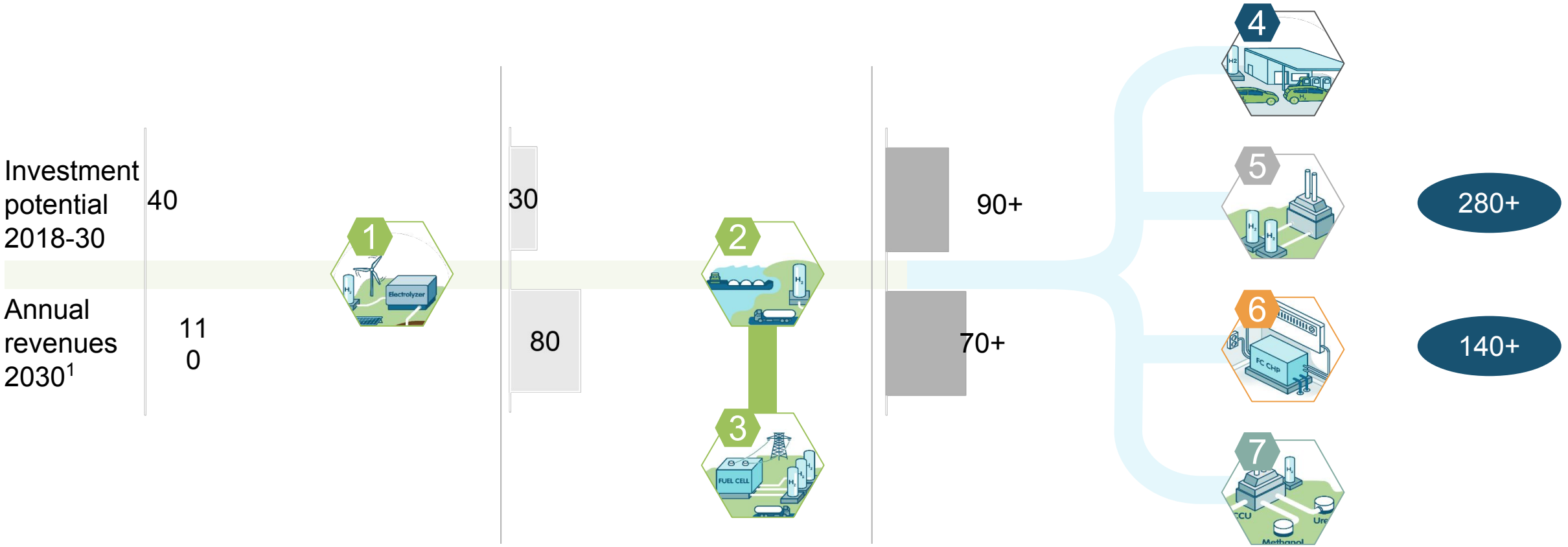
Air Liquide ALSTOM AngloAmerican BMW GROUP DAIMLER ENGIE GM HONDA HYUNDAI Iwatani Kawasaki PLASTIC OMNIUM Statoil THE LINDE GROUP TOTAL TOYOTA

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

$ billion[1]

Enable the renewable energy system → Decarbonize end uses — Total

Hydrogen production ····· Storage, transport, and distribution ····· End-uses in transportation, industry energy, buildings and feedstock



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

SOURCE: Hydrogen Council

Hydrogen Council members have started investing and deploying

Expanded partnership from 13 to 39 companies – a diverse mix of players spanning the value chain as well as key geographies

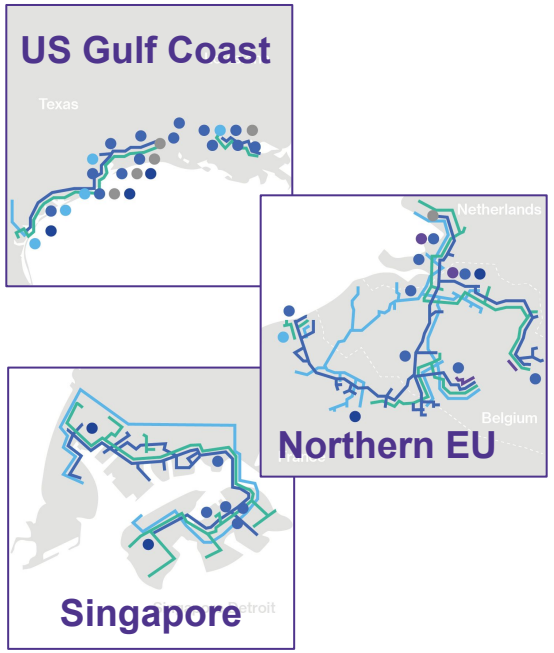
40 years of development in Hydrogen for our customers

Production & Supply chain

Production

Supply-chain

Distribution Networks



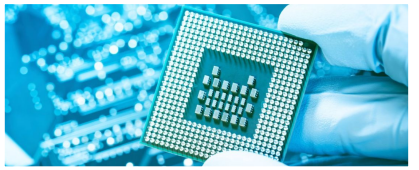
Markets Segments

Process industries

Oil & Gas

Steel, Glass

Electronics



Transportation

Space

Key Figures

> 14 bn m^3/yr

> 1,850 km H_2 pipeline

> 46 large H_2/CO plants

> 40 electrolysers in operation

> 2 bn € sales

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Air Liquide Investments to date (Decisions)

Americas

Mobility for Professionals
US+EU
2013-2017
9 sites

Mobility for Consumers
US North-East
2015
12 HRS + Supply chain

Mobility for Consumers
California
2014-2017
5 HRS

Europe

Power to Gas
Denmark
2014-2015
5 HRS + 1 Electrolyzer

Mobility for Consumers
Paris
2015-2017
3 HRS

Mobility for Consumers
Germany
2014
27% of 100 HRS

ME - Asia

Mobility for Consumers
Japan
2014-2017
6 HRS

Mobility for Consumers
Dubai HRS
2016

Key Figures

> 32 HRS for FCEV (controlled by AL)

> 27% of a network of 100 HRS for FCEV

> 9 HRS for Forklifts

> H2 Supply chain in the US and Denmark

ALIAD Venture Capital

5 Startups

Progressively building the H2 economy: AL initiatives

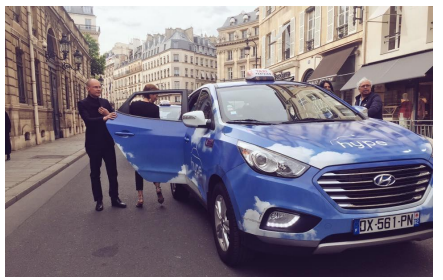
POLICIES

Hydrogen Council

CH2ANGE

Total reach > 10 Million people

MARKETS



TECHNOLOGIES

HyBalance

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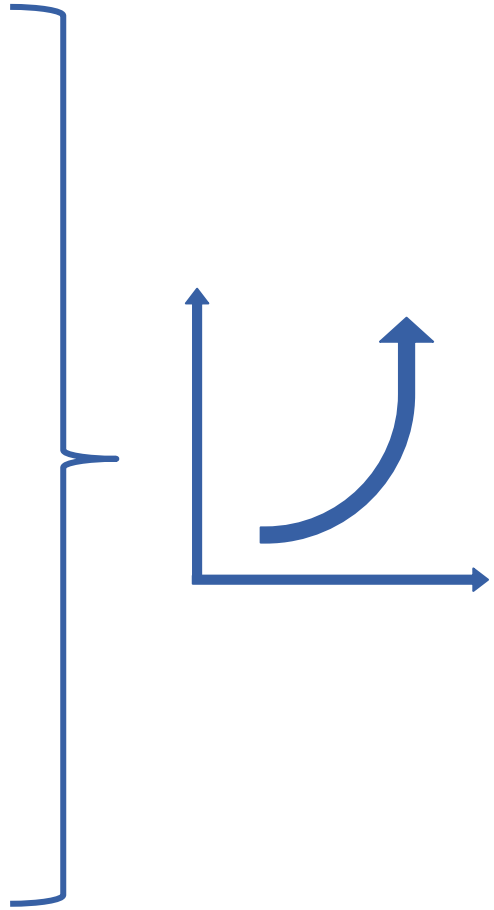
Everything in place for a sound ramping-up

1. A systemic approach required
2. Strong potential for technologies
3. Early markets starting-up
4. Existing supporting policies, but to strengthen
5. Early signs of social acceptance
6. Alignment for deployment initiated



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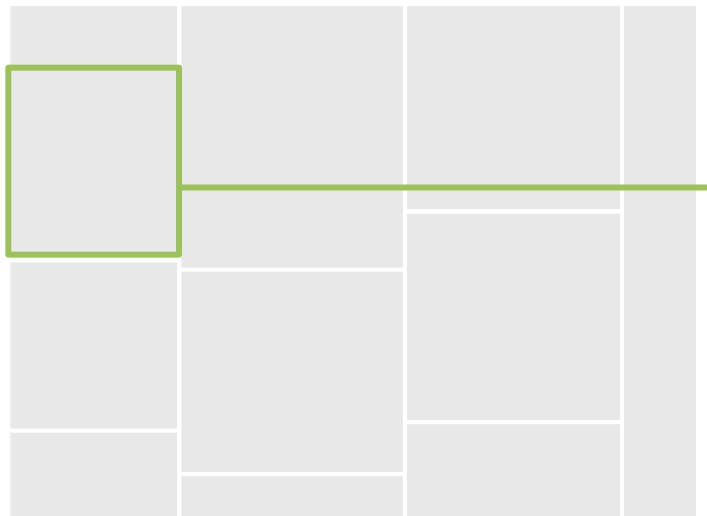
BACK-UP

First comprehensive quantified vision of the long-term potential of hydrogen and a roadmap for deployment

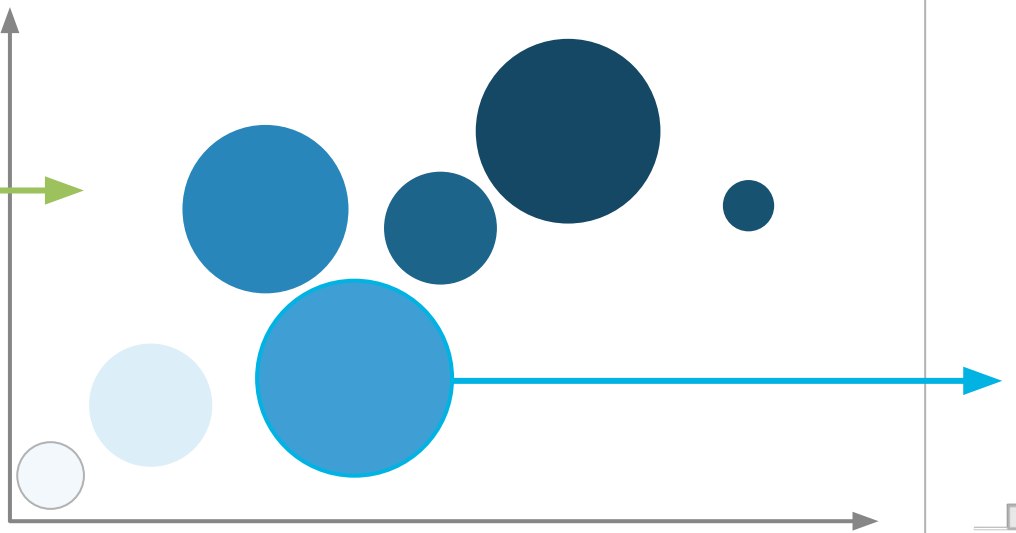
Energy system development

2050 energy system



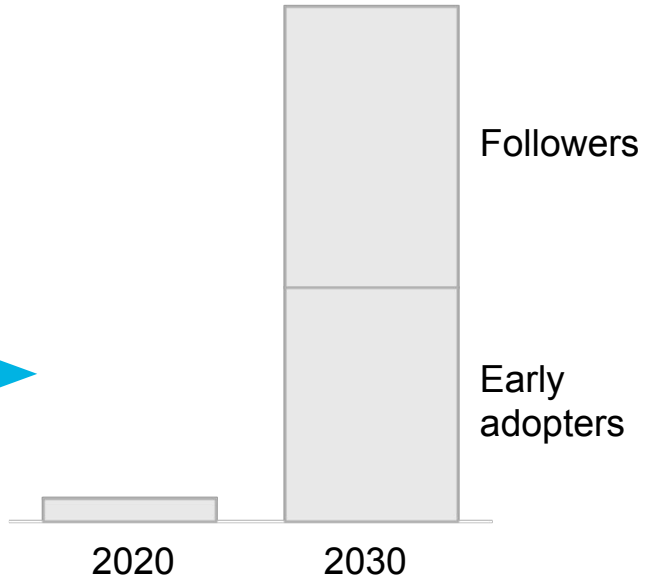
2050 hydrogen vision

Hydrogen adoption in industry segments



2030 hydrogen milestones

Ramp-up logic and investments



An **ambitious yet realistic scenario** of the role of hydrogen in a two degree scenario, based on the perspectives of the Hydrogen Council

SOURCE: Hydrogen Council

Global rollout after 2030 could amplify growth towards 2050

Example: FCEV Rollout – Million Vehicles