



Hydrogen scaling up

A sustainable pathway for the global energy transition

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EXANE | Déjeuner “Expert Access” | 23 MAY 2018

This study is the first comprehensive, ambitious Hydrogen roadmap



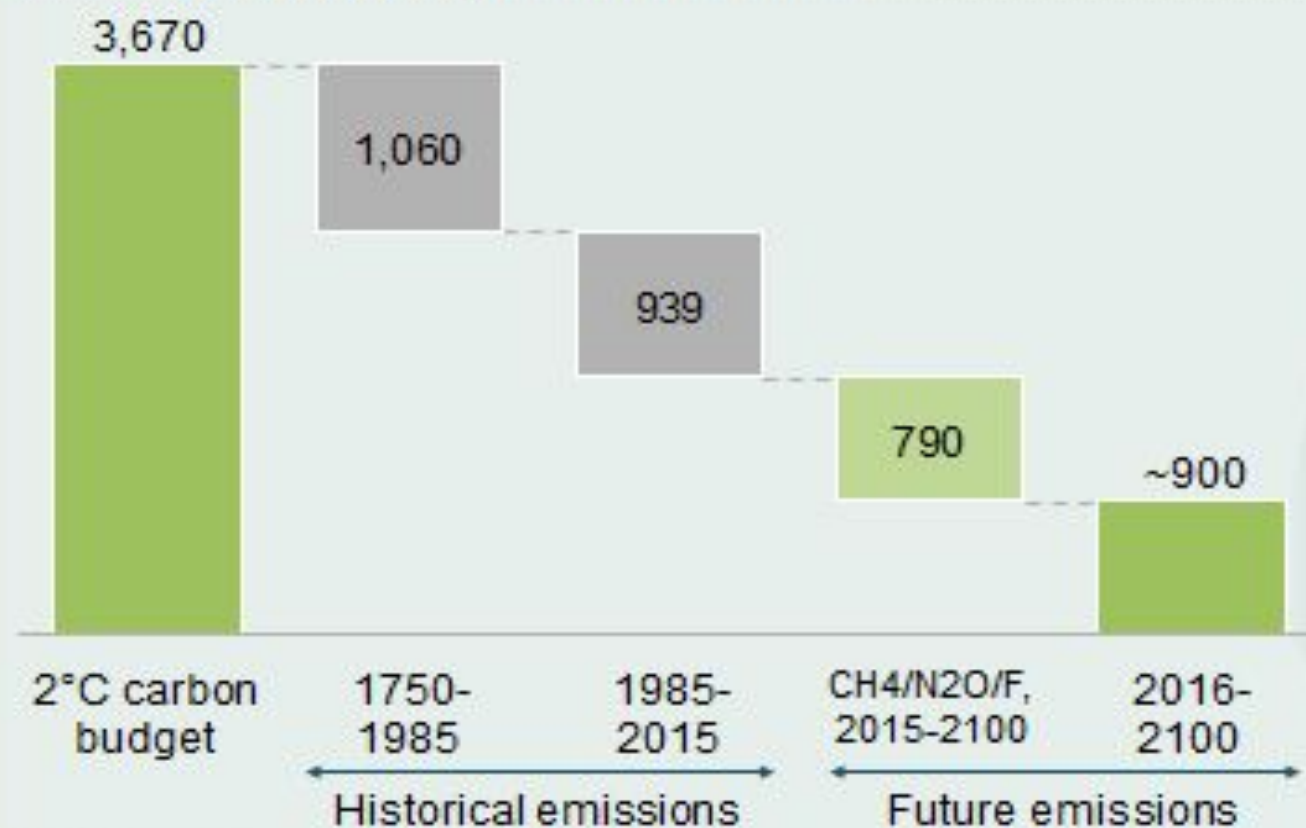
Objectives of the study

- 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?**”

A carbon budget enables us to minimize global warming

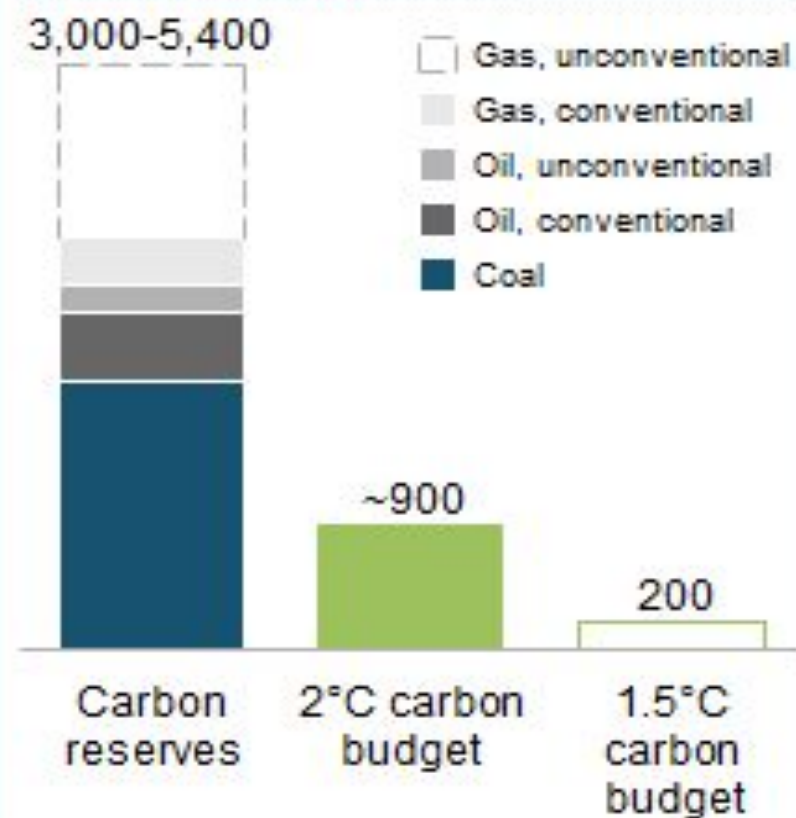
Billion tonnes of CO₂-eq

2°C Carbon budget emissions to 2100



SOURCE: Team analysis

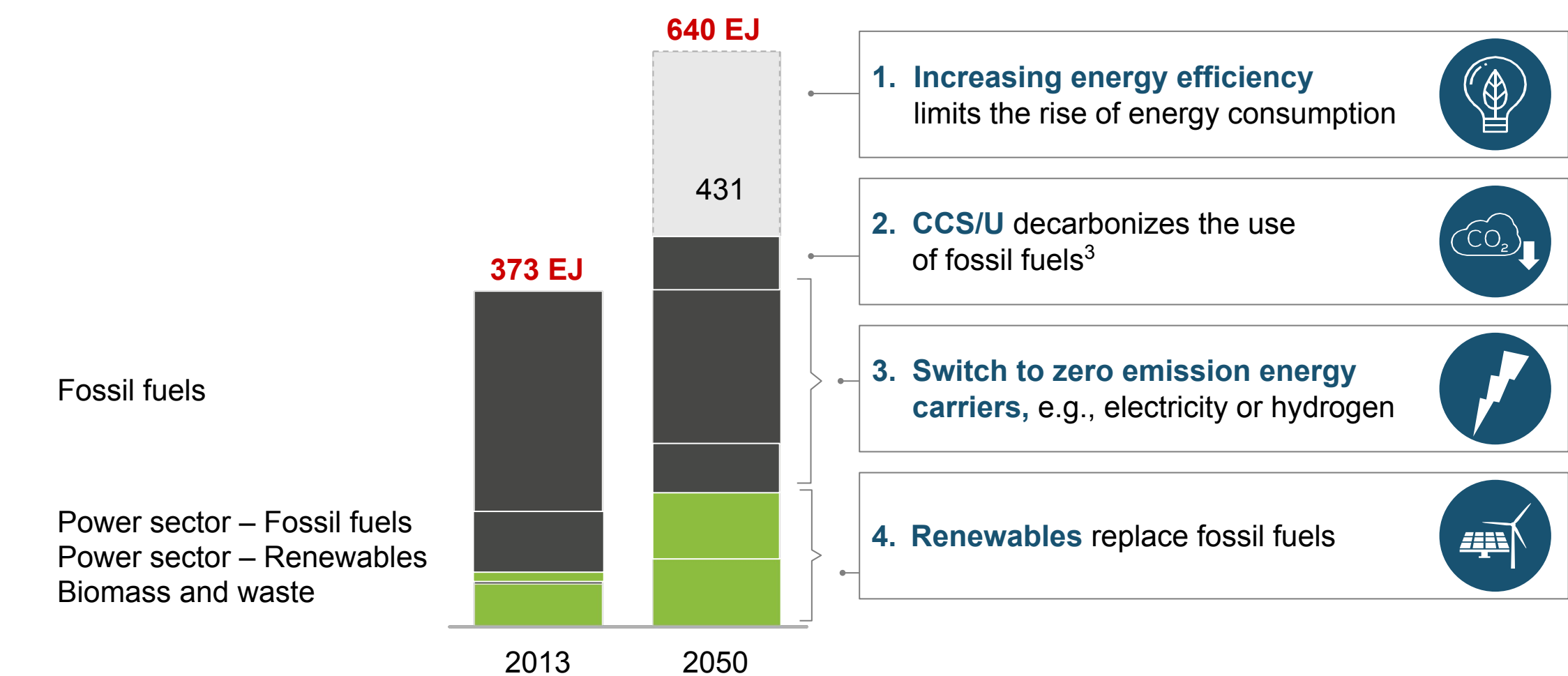
Carbon budget compared to carbon reserves



McKinsey & Company

Four major levers are needed to enable the energy transition

Final energy consumption^{1,2}, 2013 and 2050, in EJ

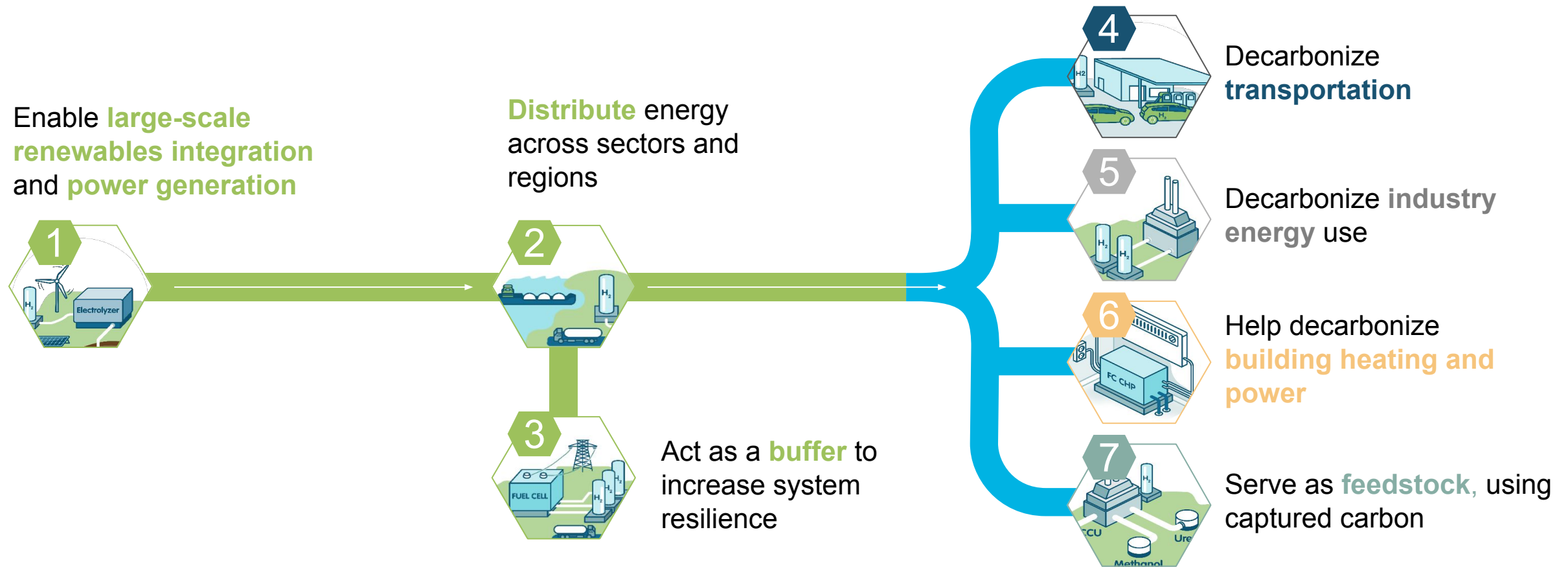


1 Final energy consumption within the 2DS of the IEA
2 Increase of energy demand is determined via the relative increase of CO₂ emissions w/o energy efficiencies
3 The fossil fuels amount processed using CCS/U was determined to be 25% of the total amount of fossil fuels by relating the CO₂ emission reduction compared for the 2DS and 6DS
4 The fossil fuel power sector also includes nuclear energy

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

Enable the renewable energy system

Decarbonize end uses



The energy transition creates multiple challenges

Enable the renewable energy system

Decarbonize end uses

Renewable
power generation

x10

by 2050 to >50 TWh
per day

Infrastructure needs
to go through a major
transformation

Renewable
energy storage

+18 EJ

From current energy
storage in fossil fuels to
~15% of renewable energy
stored by 2050

**Electrification in
end use sectors**

+75%

from ~70 EJ today
to ~130 EJ by 2050

energy uses are
electrify via the
with batteries:

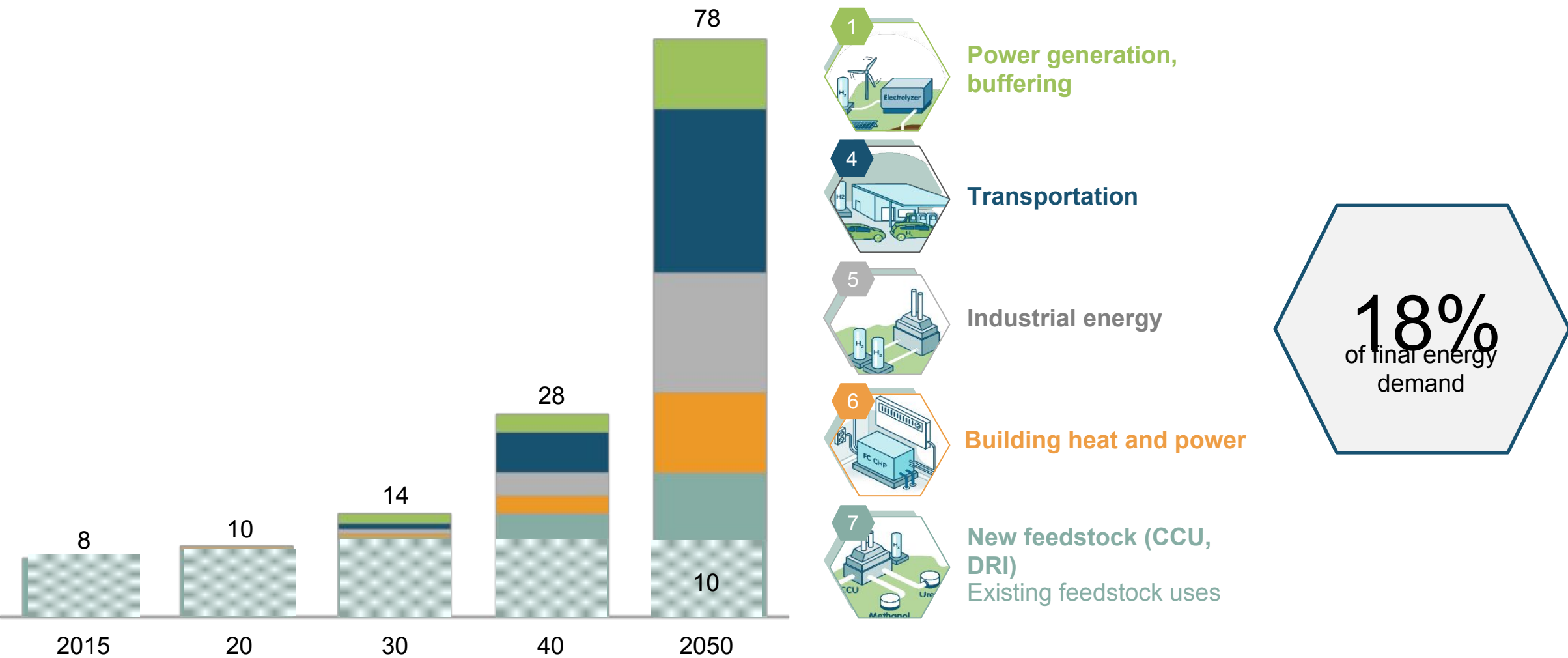
**Using or storing
carbon**

+5,5 Gt

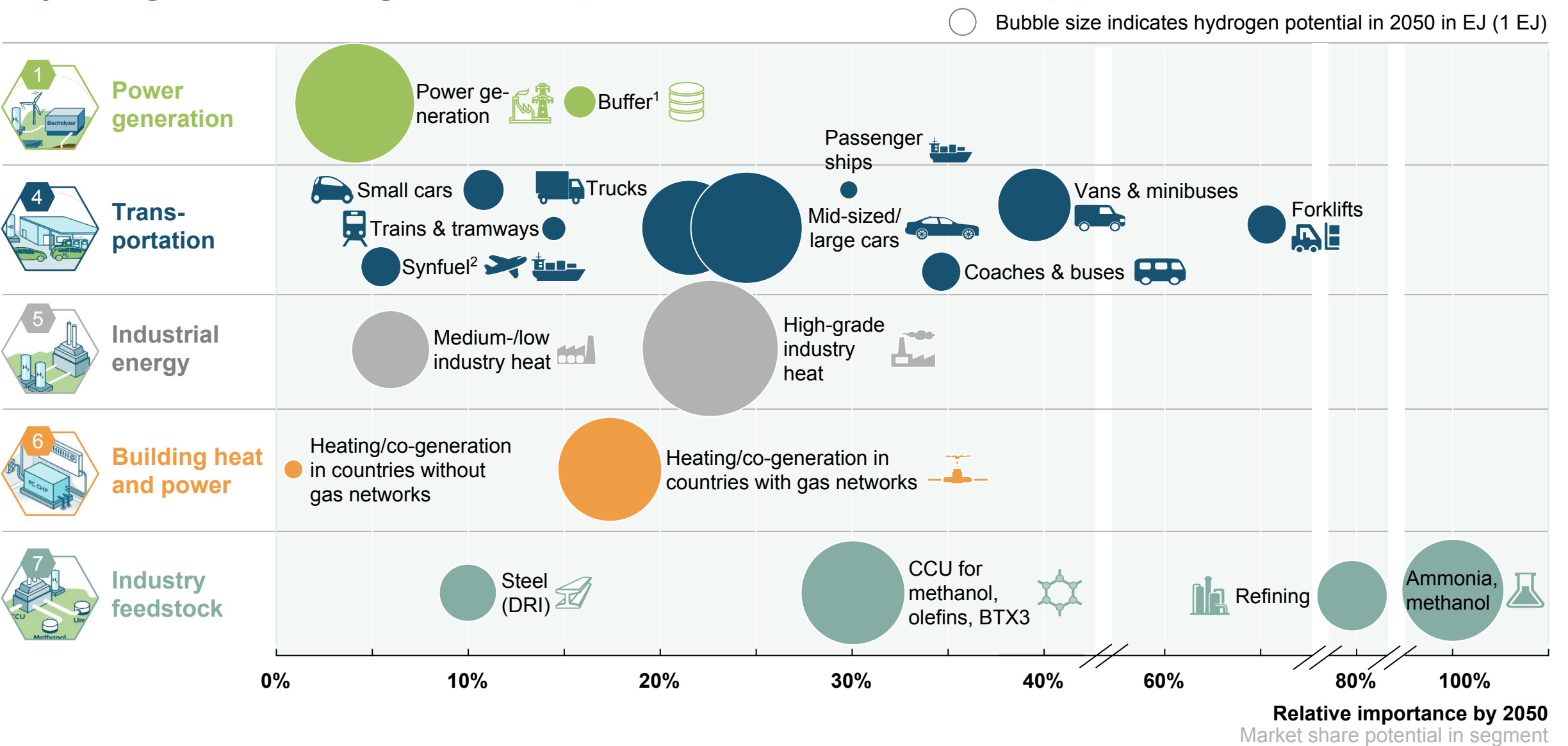
from very little today
to 5,5 Gt by 2050

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

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



Hydrogen has significant potential across all applications



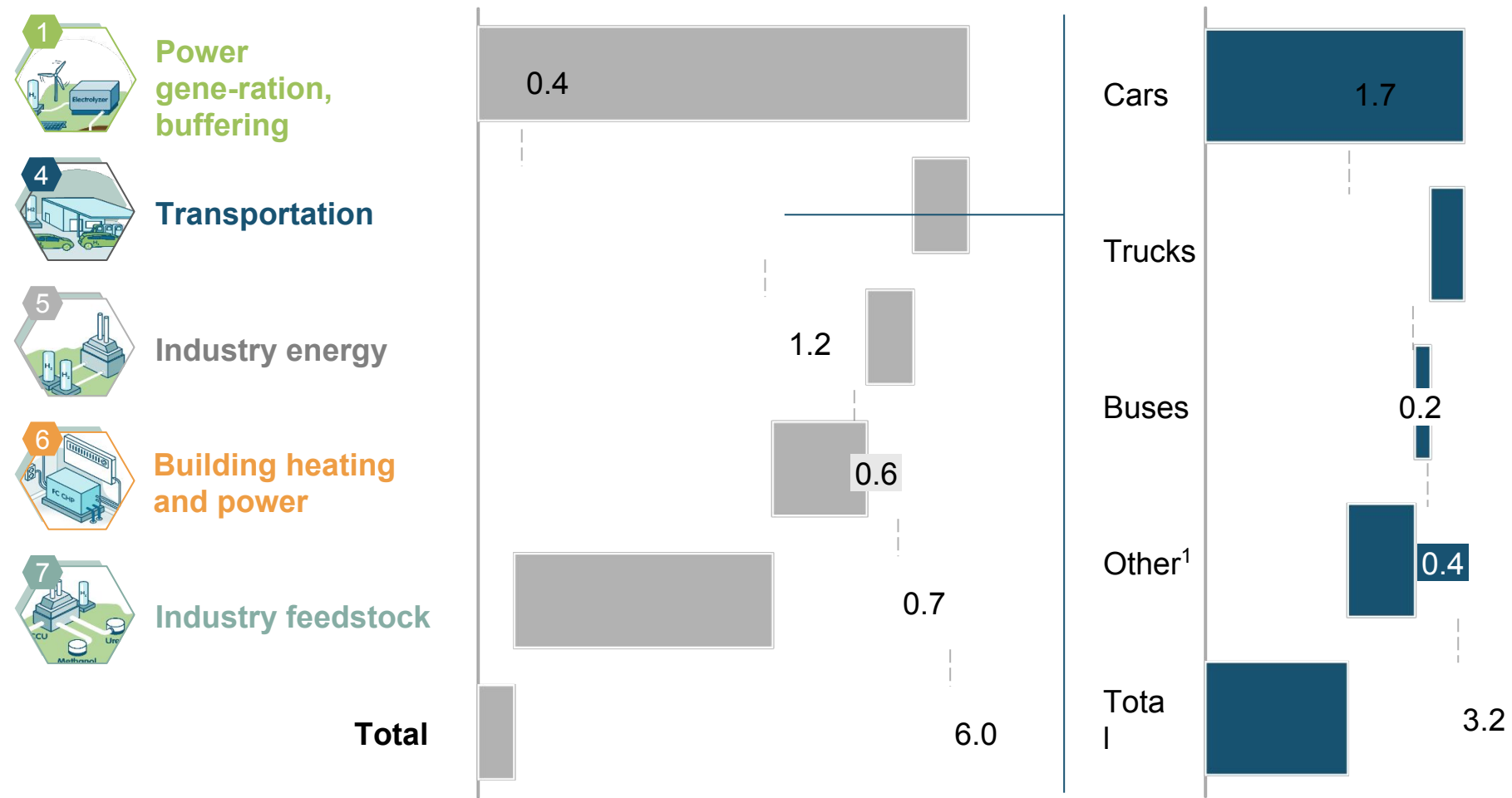
1 Percent of total annual growth in hydrogen and variable renewable power demand

2 For aviation and freight ships

3 Percent of total methanol, olefin, BTX production using olefins and captured carbon

Half of the total CO2 abatement potential will come from transport

CO2 avoidance potential 2050, Gigatons

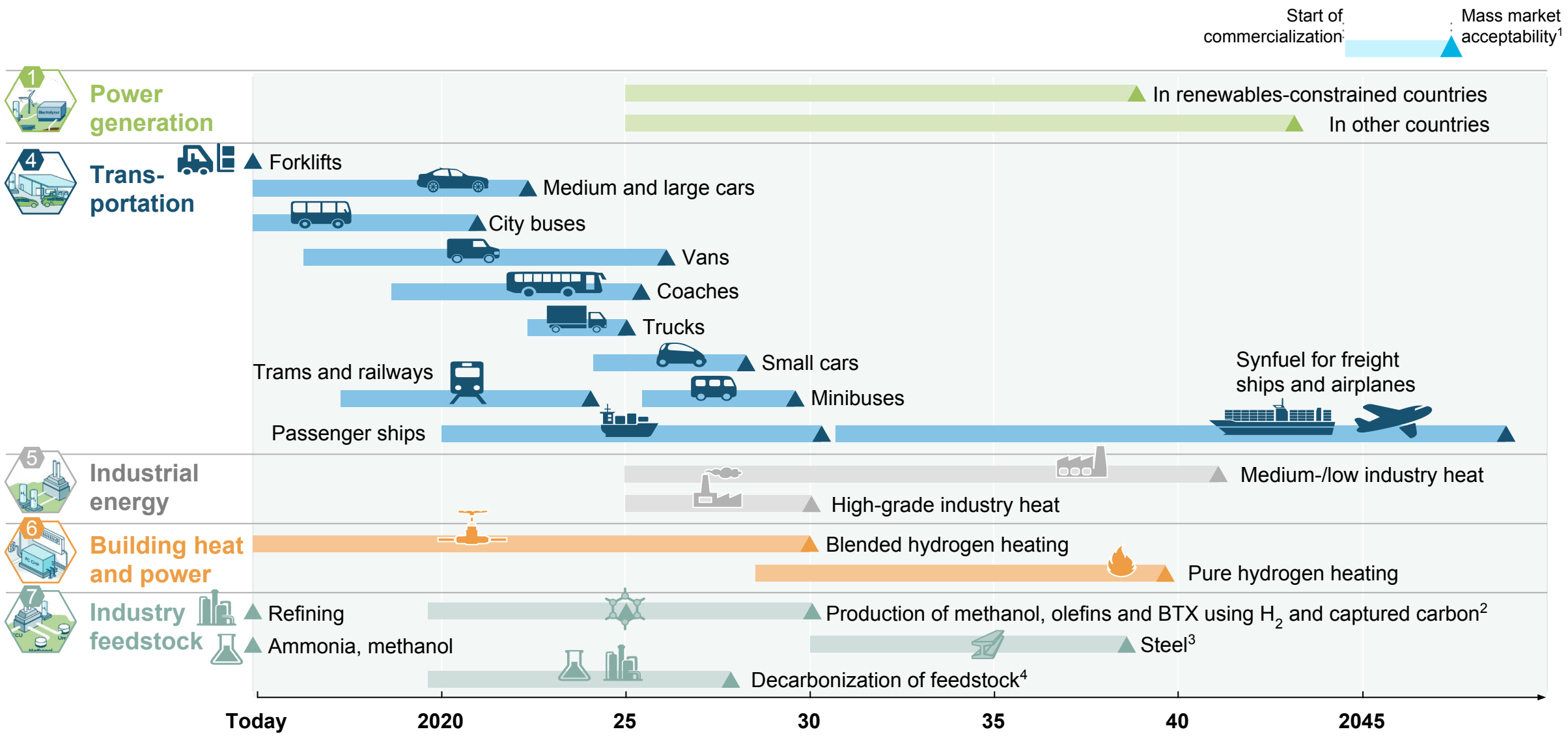


Hydrogen has the potential to achieve
~40%
of the required abatement² in transport by 2050

¹ Aviation, shipping, rail, material handling

² Difference between IEA Reference Technology and 2 degree scenario

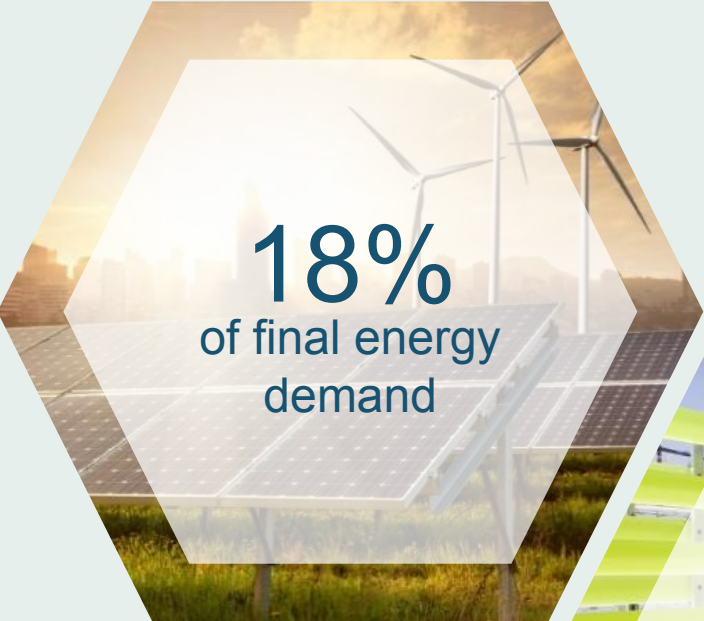
The technologies exist and are ready to be deployed



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 H₂, 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



18%
of final energy
demand



6 Gt
annual CO₂
abatement



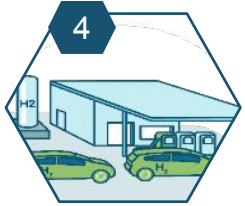
\$2500 bn
annual sales
(hydrogen and
equipment¹)



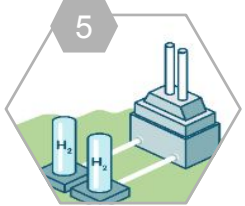
30
million jobs
created

¹ Value add of fuel cells

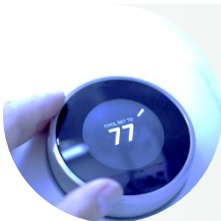
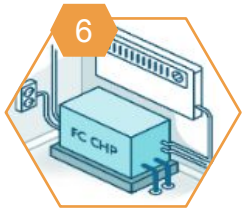
Important milestones already for 2030 to reach the 2050 vision



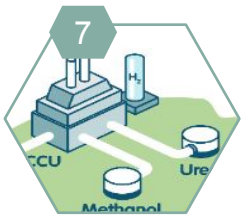
- **1 in 12 passenger cars sold** in early-adoption markets (Germany, California, Japan and South Korea) FCEVs



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

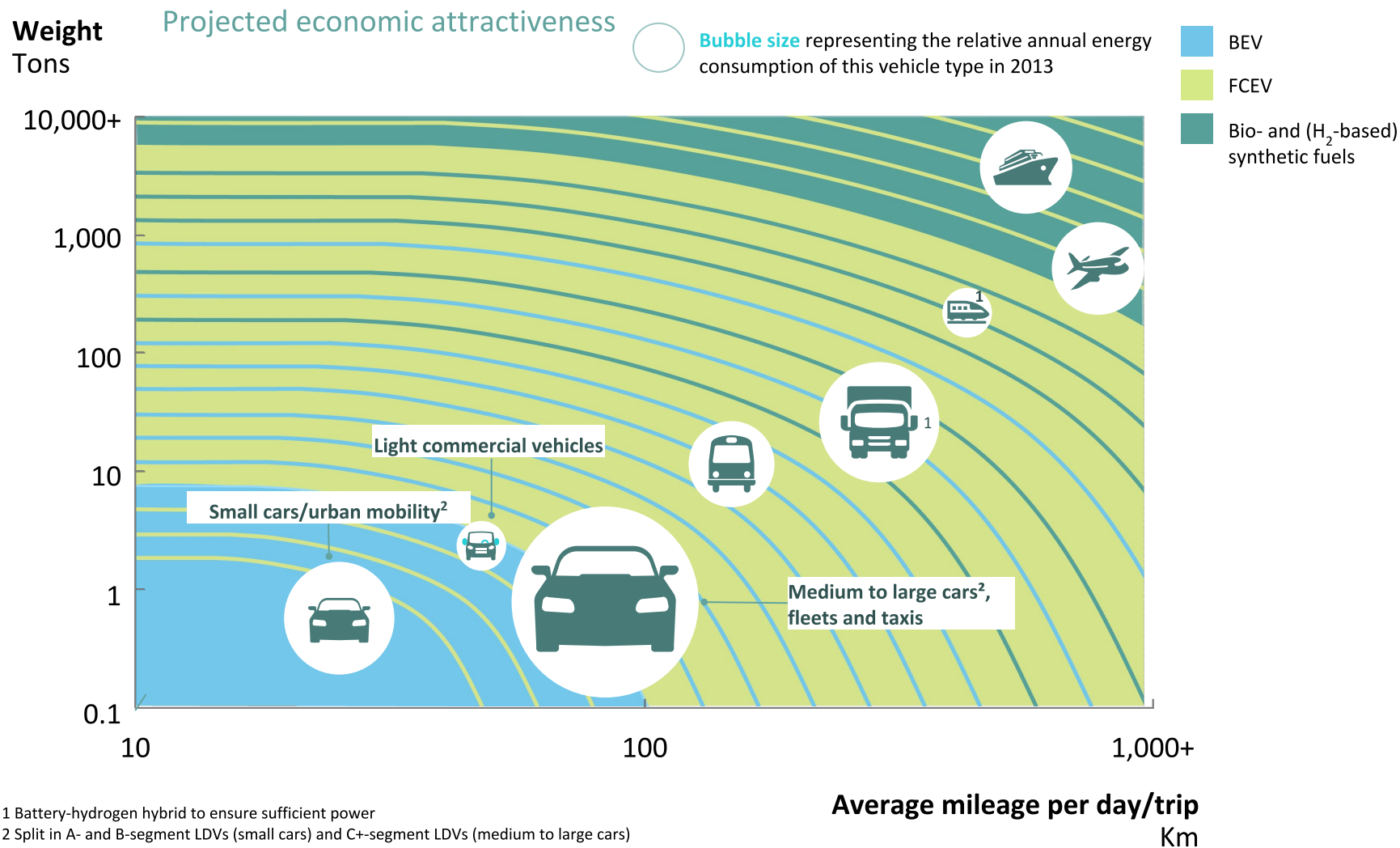


- **50 million households** connected to a network safely blending hydrogen and natural gas



- **20 Mt CO₂** converted to chemicals and intermediates such as **methanol** using hydrogen

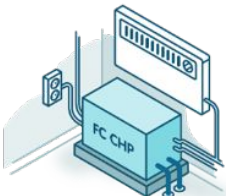
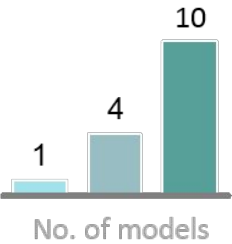
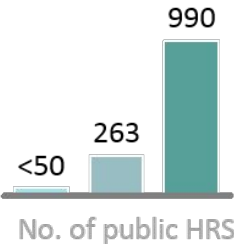
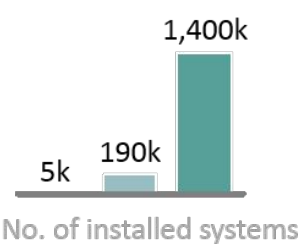
Focus on Transport - FCEVs will play an essential role



Source: Toyota, Hyundai, Daimler

H2 technologies and markets are already ramping up

Selected examples of the hydrogen sector



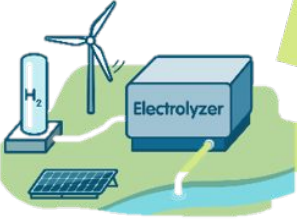
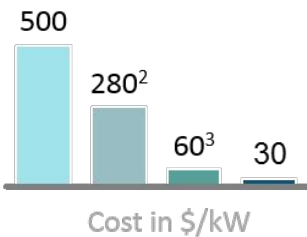
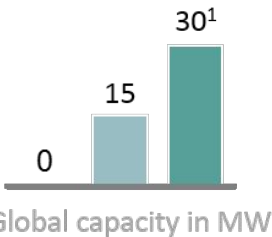
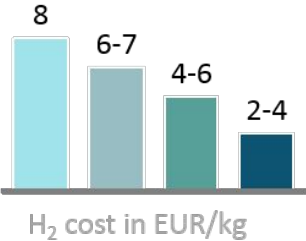
mFCHPs



Hydrogen refueling stations



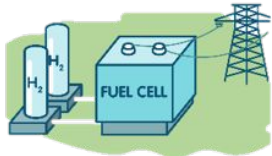
Fuel cell passenger vehicles



Zero-carbon production (electrolysis example)



H₂ storage

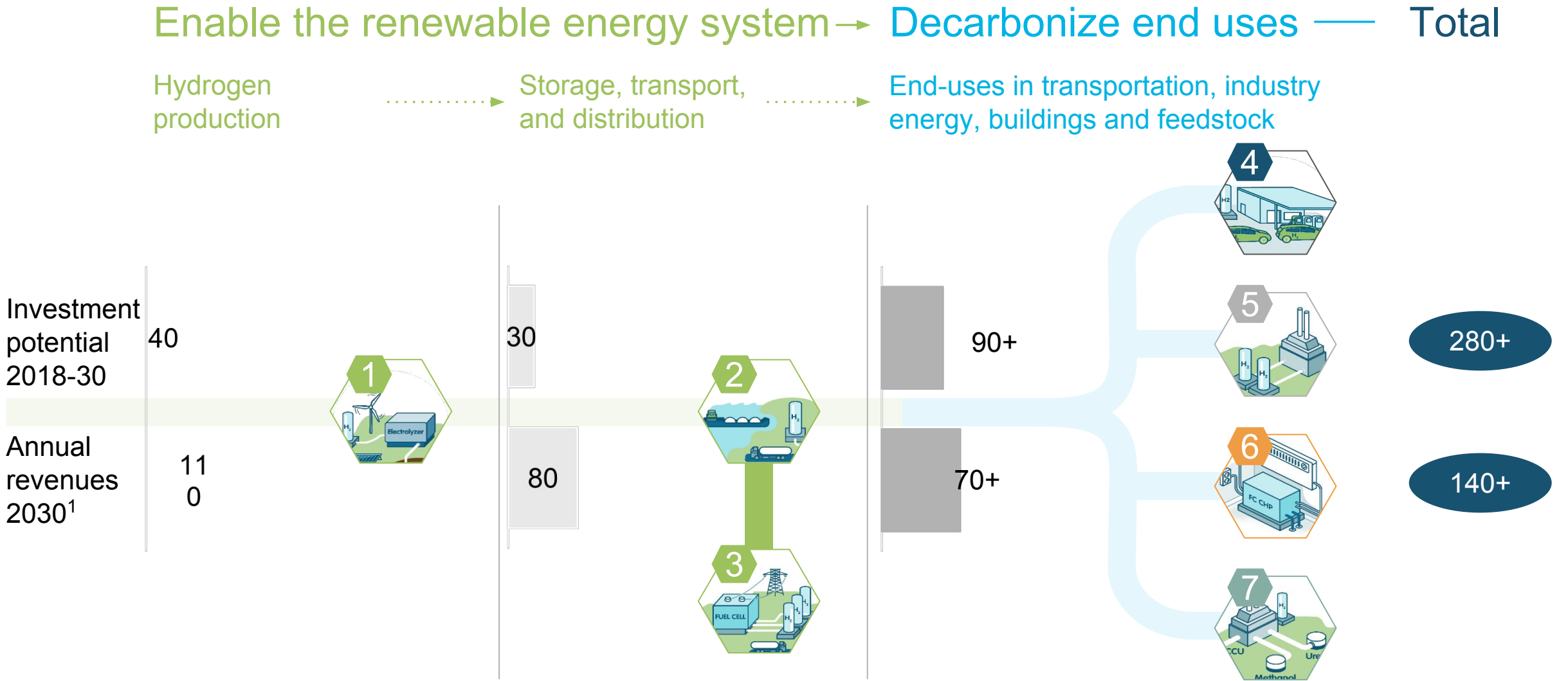


Fuel Cells

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

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

\$ billion¹



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

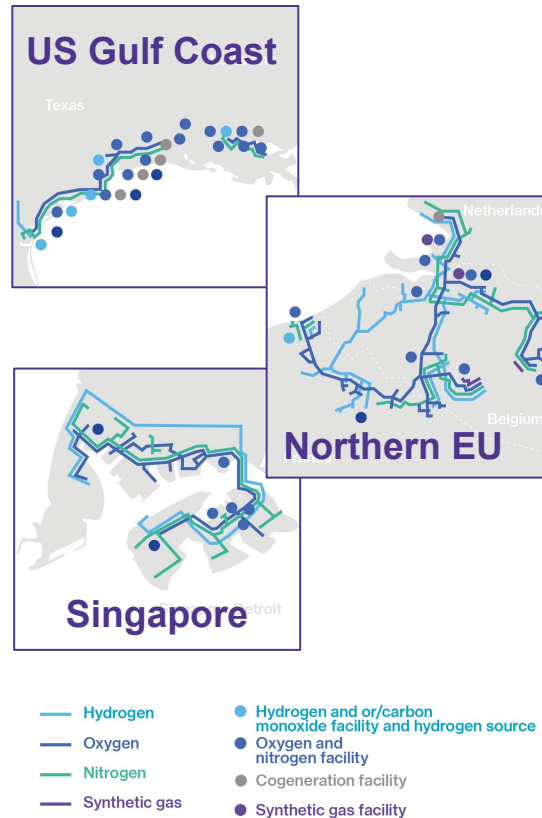
Production



Supply-chain



Distribution Networks



Markets Segments

Process industries

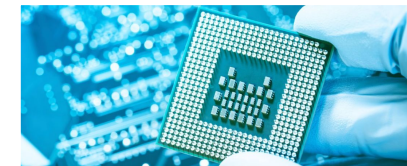
Oil & Gas



Steel, Glass



Electronics



Transportation Space



Key Figures

- > 14 bn m³/yr
- > 1,850 km H₂ pipeline
- > 46 large H₂/CO plants
- > 40 electrolyzers in operation
- > 2 bn € sales

Air Liquide Investments to date (Decisions)

Americas



Mobility for Professionals
US+EU
2013-2017
9 sites



Mobility for Consumers
California
2014-2017
5 HRS



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

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



CHANGE
Total reach² > 10 Million people

MARKETS

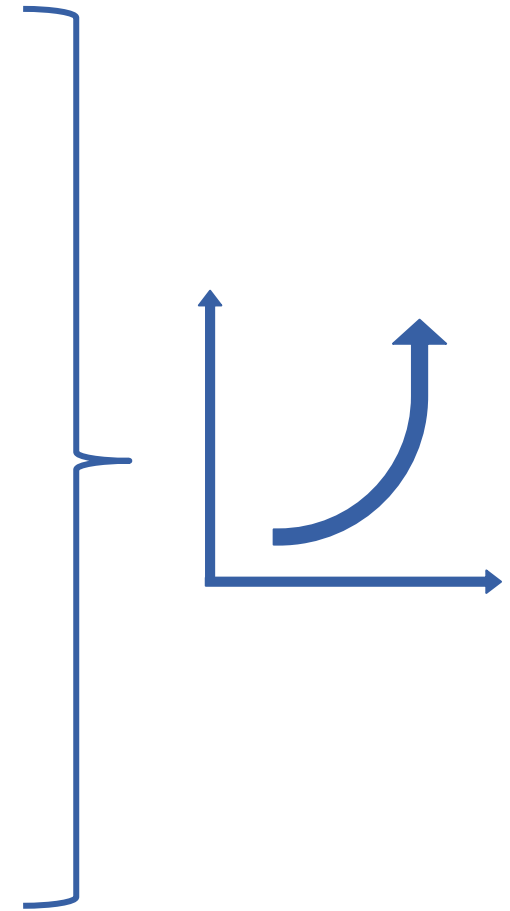


TECHNOLOGIES



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

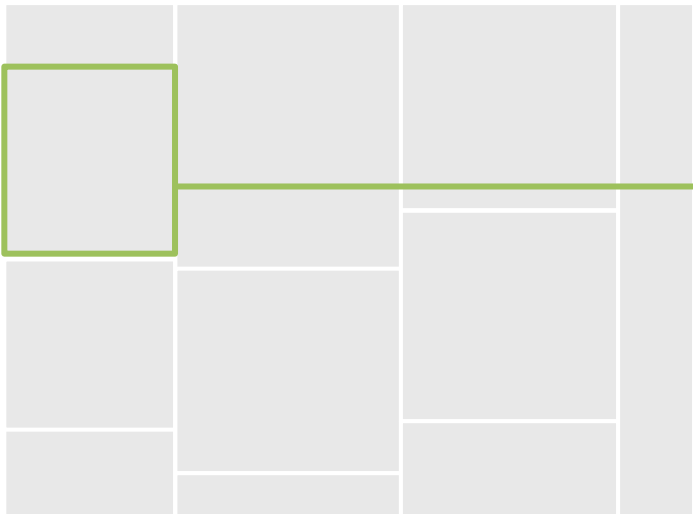


BACK-UP

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

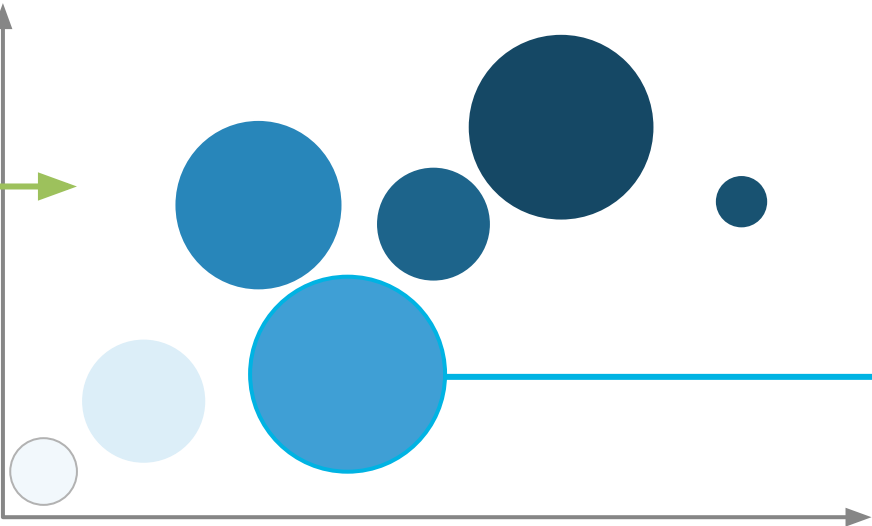
Energy system development

2050 energy system



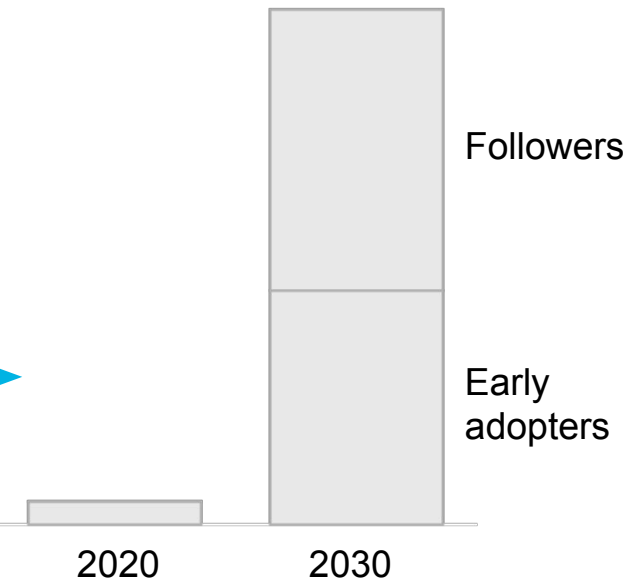
2050 hydrogen vision

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

Global rollout after 2030 could amplify growth towards 2050

Example: FCEV Rollout – Million Vehicles

