Presentation

Hydrogen and Renewable Gas Forum

An introduction to IHS Markit research to date and the ongoing workplan

2020

The IHS Markit Hydrogen and Renewable Gas Forum

- Decarbonisation of gas is becoming a key topic for the industry as governments commit to increasingly ambitious climate targets

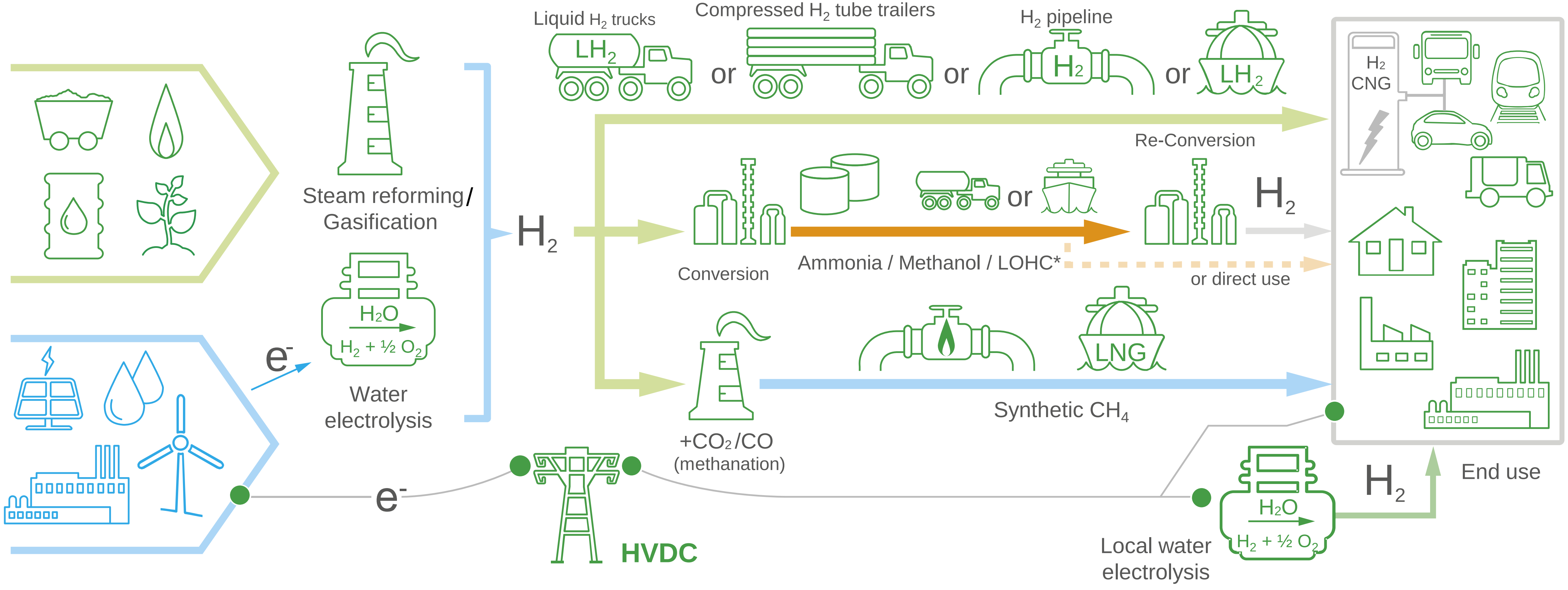
- Over the past 2 years IHS Markit has undertaken a series of multiclient studies analysing the economics of hydrogen and renewable gas and the role it could play in the future

- This work has been brought together in the **IHS Markit Hydrogen and Renewable Gas Forum**

- The Forum will build on an existing research base—widening the geographic scope, increasing the depth of the analysis and providing a review of recent developments

A comprehensive assessment of the low-carbon hydrogen supply chain

IHS Markit Hydrogen supply chain techno-economic analysis



Production | **Transmission, distribution and storage** | **End-use**

Source: IHS Markit * Liquid organic hydrogen carriers

Agenda

- The role of hydrogen and renewable gas in global energy
- Economics of hydrogen production
- The role of hydrogen in a low-carbon economy
- The IHS Markit Hydrogen and Renewable Gas Forum

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Why hydrogen today?

In recent years multiple factors have come together to drive interest in hydrogen

Drivers of increasing interest in hydrogen

Environmental policy

Reduce CO_2 emissions

Improve air quality

Energy independence

Reduce fossil fuel imports

Technology exports

H_2O
$H_2 + ½O_2$

International sales of electrolysers & FCEV

Technology development

Falling costs of renewables

CCS developments

Versatility

Applications in all end use sectors

Source: IHS Markit

Low-carbon hydrogen is being developed globally and cover in all sectors

Demand | Supply

Current status of hydrogen in the energy transition

North America: Retrofit of CCS to SMR at two sites

Canada: Largest PEM electrolyser (20 MW) to be built

UK/France: Blending of H_2 with natural gas studies

Europe: Pilot projects for FCEV for municipal vehicles and trains

South Korea: Demonstration projects for transport and stationary fuel cells for power generation.

China: Made in china 2025 initiative. Transport focus. Currently small-scale demonstrations for commercial vehicles

UK: Conversion of natural gas grid to H_2

Europe: Over 80 P2G projects

California: Evaluating role of H_2 in power and transport. 40 of 60 filling stations nationwide in California

United States: 5,000 FCEV sold since 2015 and 20,000 forklifts

Dubai: DEWA & Siemens solar driven electrolysis facility.

Japan: Expansion of hydrogen fuelling station network 900 stations by 2030

Japan: Aiming to be the first H_2-based society. Tokyo Olympics to be used as showcase

Middle East: Discussions on production of hydrogen for export of low carbon energy

Fuel cells: Global shipments up from 200MW in 2014 to 650MW in 2017.

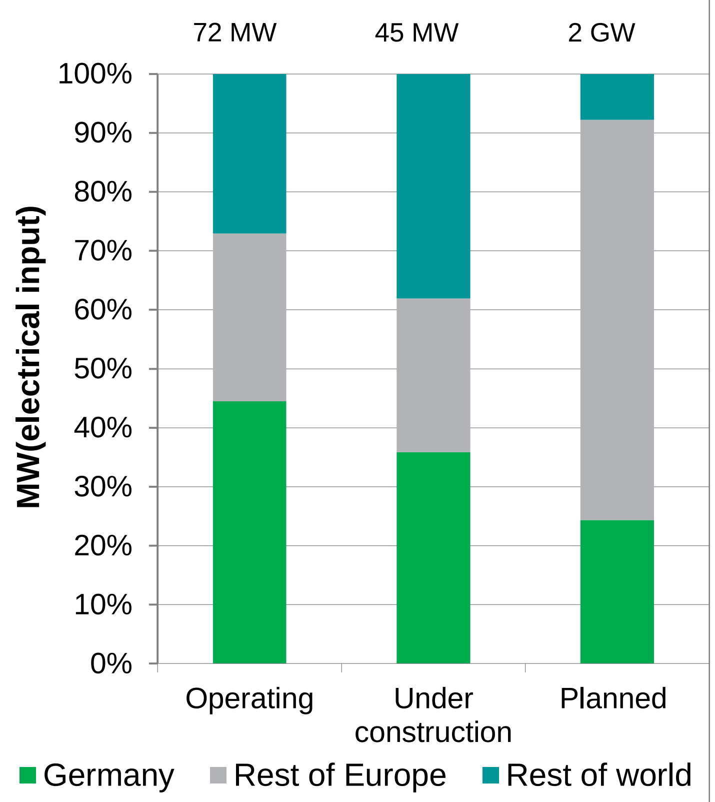
Australia: Demonstration exports of liquid H_2 (from lignite without CCS) expected by 2020.

Source: IHS Markit

Momentum is building for hydrogen

The size of power-to-gas projects is growing rapidly; 10 MW plant under construction, multiple 20 MW and 100 MW planned and expected to become the norm.

Global power-to-gas projects



Source: IHS Markit Power to Gas Tracker

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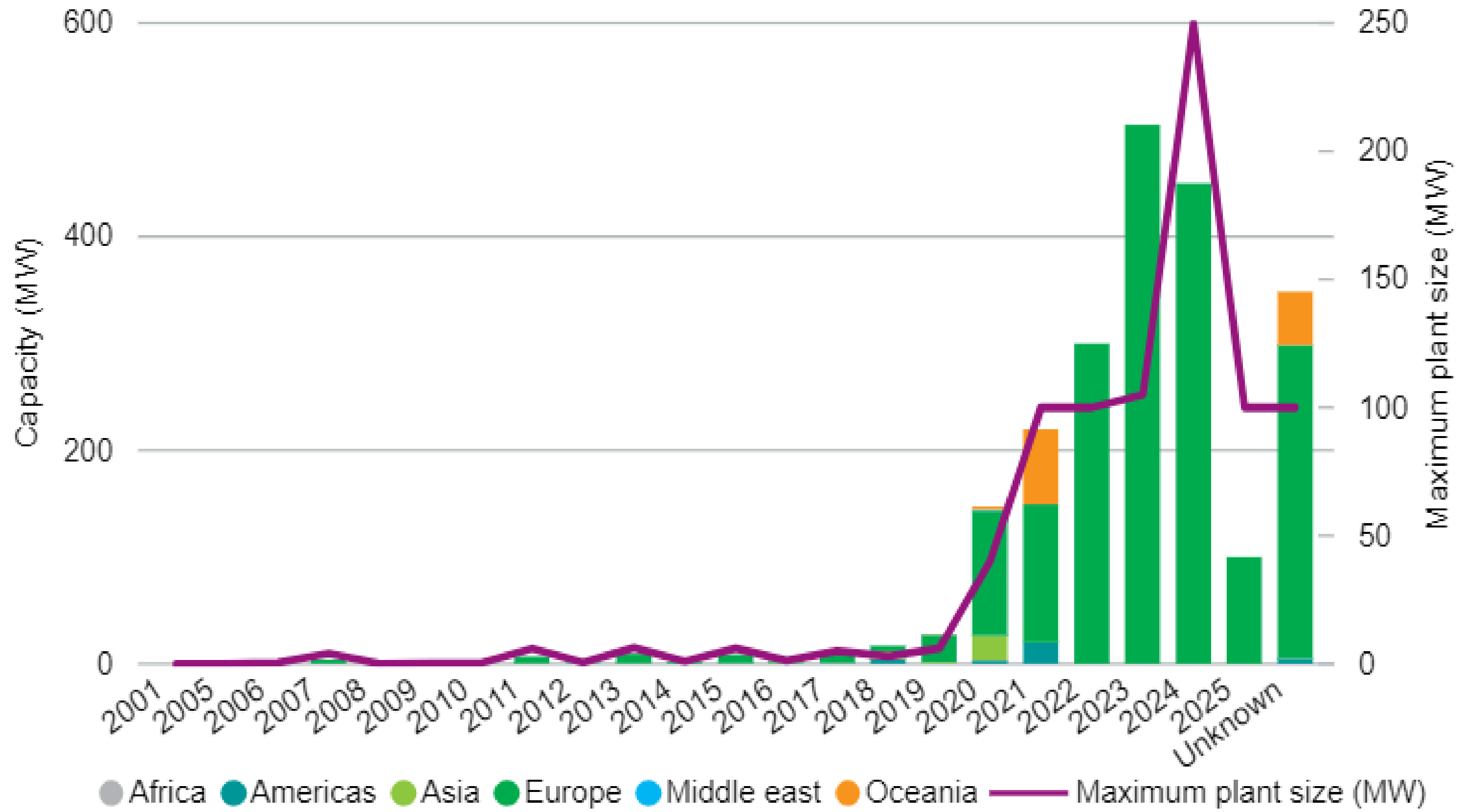
Electrolysis capacity additions (MWe) and maximum plant size (MWe)

(Existing, planned, and plants under construction)



Source: IHS Markit

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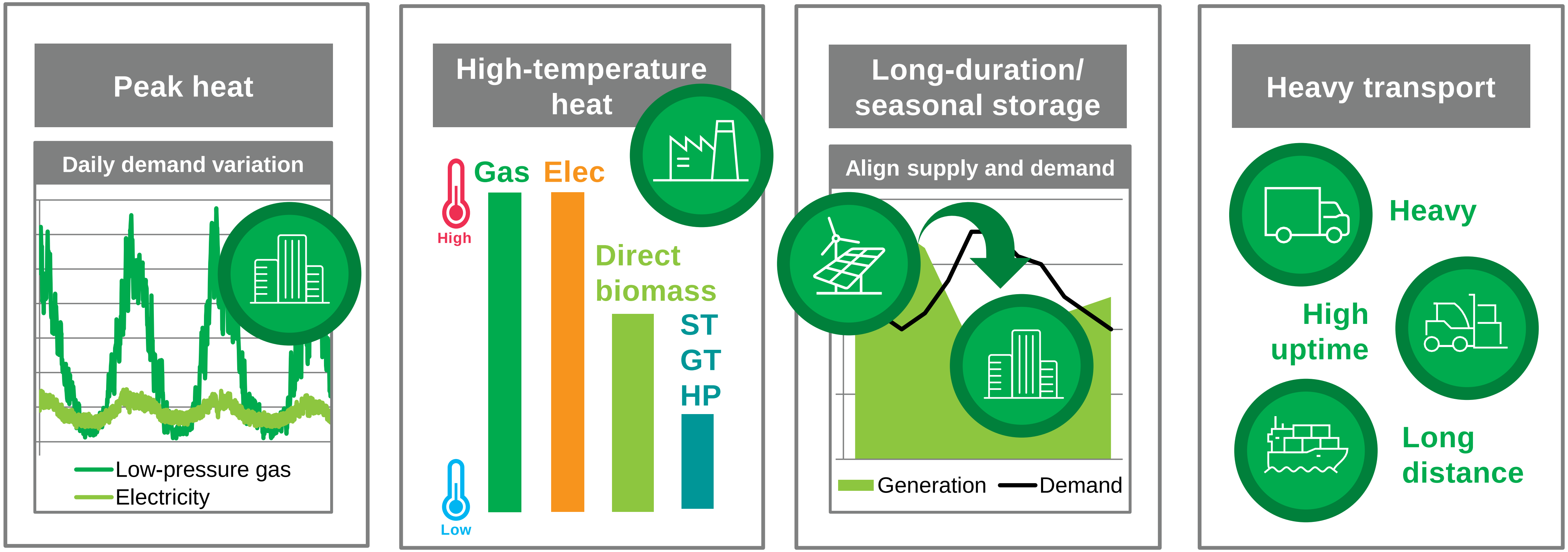
The role of electricity will grow, but gas will remain an important part of a net-zero carbon economy

Roles for gas in a very low carbon energy system



Note: ST = solar thermal; GT = geothermal; HP = heat pump.
Source: IHS Markit

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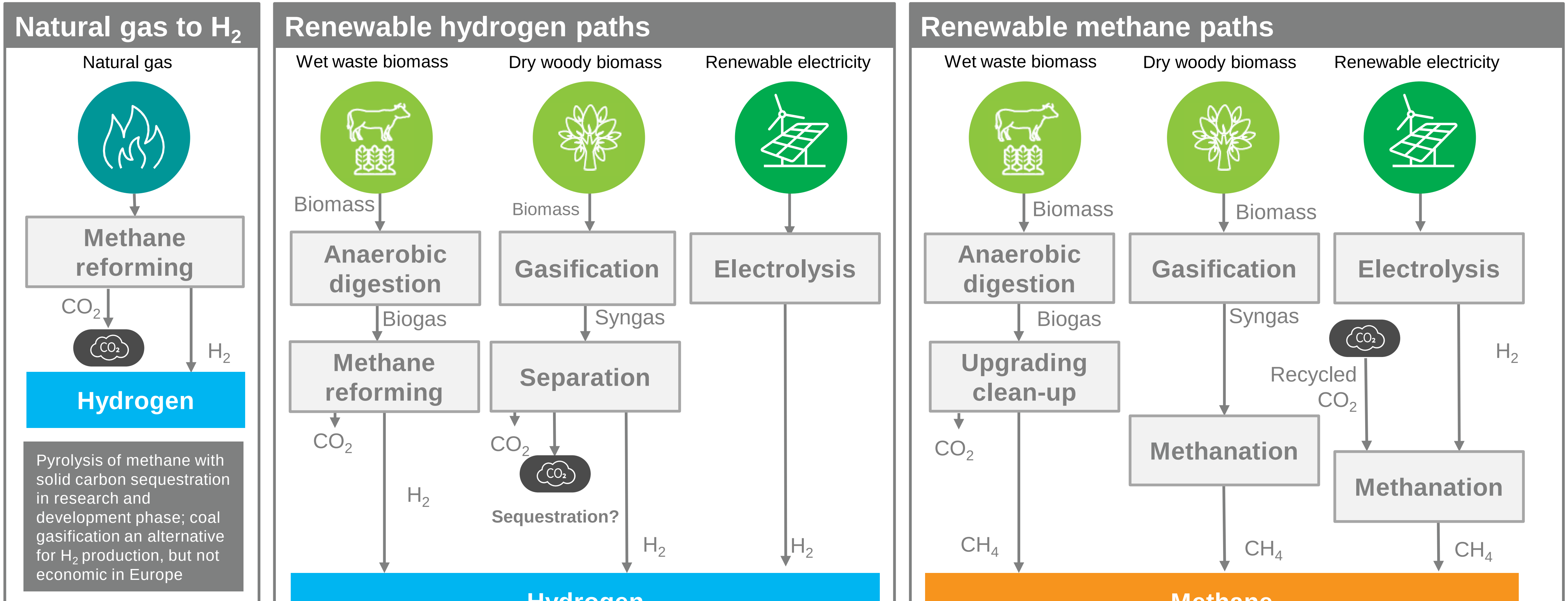
There are many routes to low-carbon gas

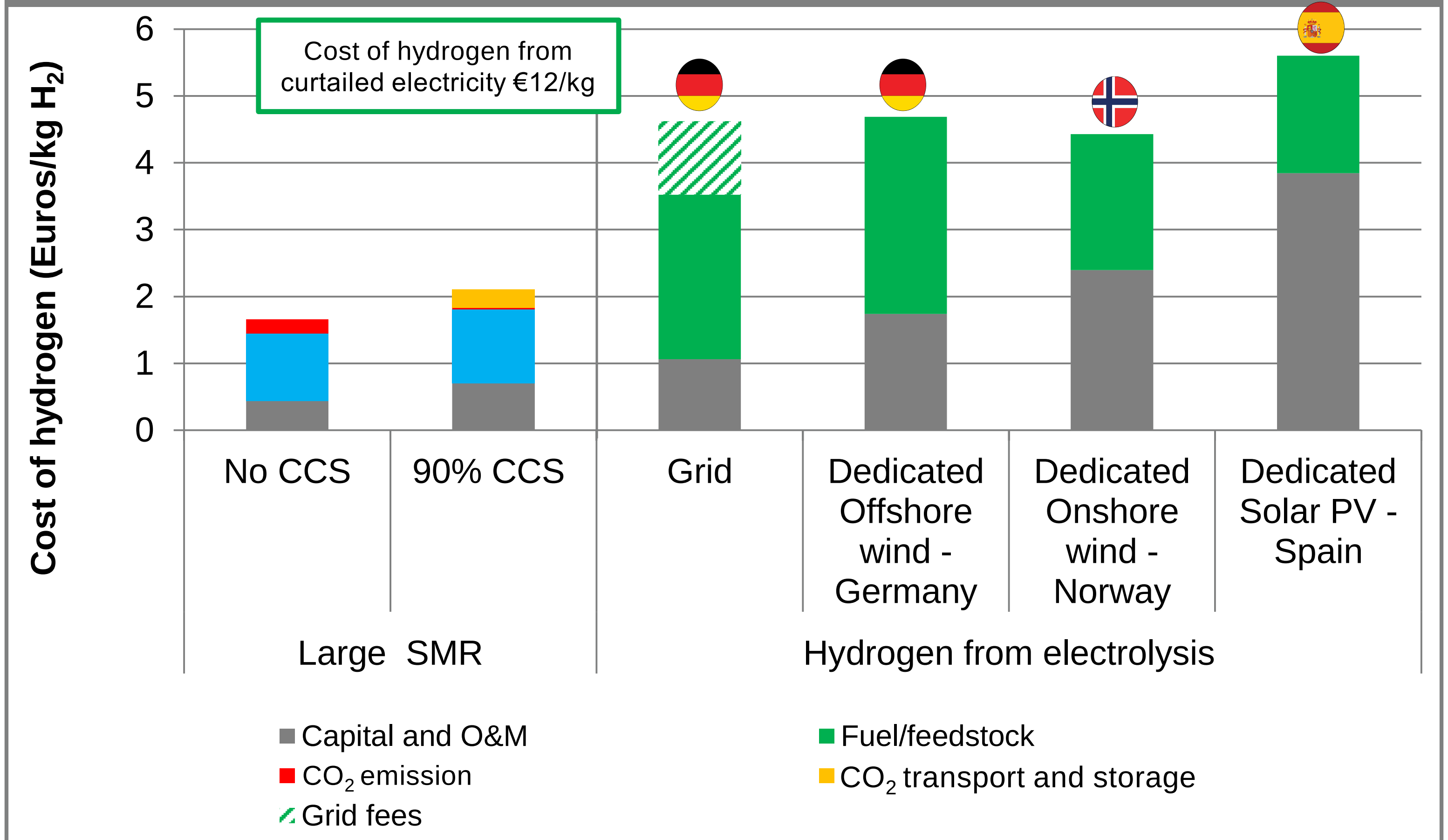
Renewable sources can create low-carbon hydrogen or methane, while fossil fuels with carbon capture and storage (CCS) are a proven source of low-carbon hydrogen



Note: CO_2 = carbon dioxide; H_2 = hydrogen; CH_4 = methane.
Source: IHS Markit

SMR with CCS is the lowest cost method for producing low-carbon hydrogen in Europe today—less than 50% of electrolytic hydrogen cost

Levelized cost of hydrogen at boundary of production facility (2020)



Source: IHS Markit © 2019 IHS

Key assumptions (2020)

PEM electrolyzer capacity (MWe)	10 MWe
PEM electrolyzer capacity in Nm^3/h	2,000
Large SMR capacity (Nm^3/h)	100,000
Carbon price (€/tonne)	25

Source: IHS Markit 2019 IHS Markit

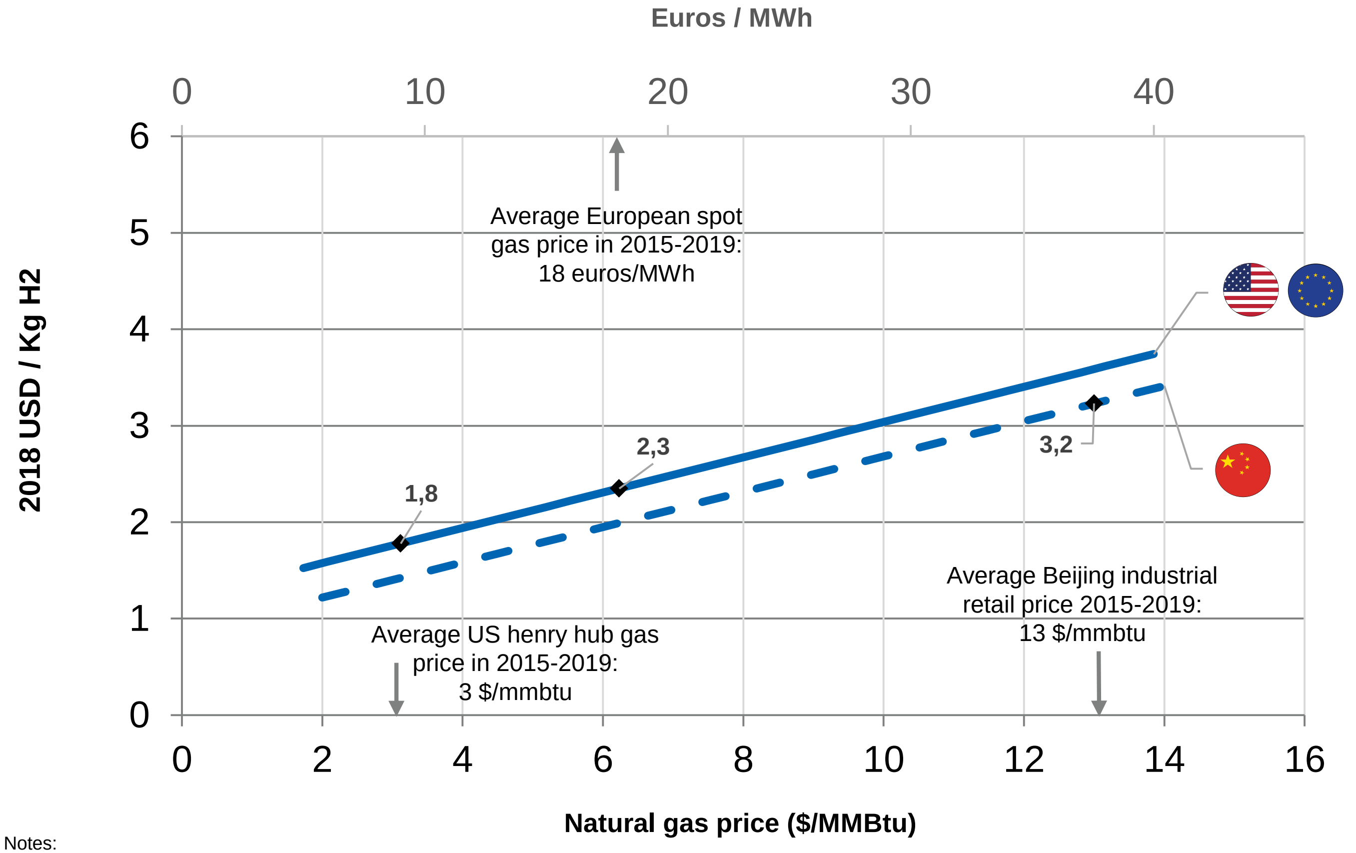
	Fuel price /LCOE €/MWh	Capacity Factor (%)
Natural gas price	20	95%
Grid electricity (wholesale)	45	95%
Grid transmission fees	20	-
Offshore wind - Germany	54	47%
Onshore wind - Norway	37	31%
Solar PV - Portugal	32	18%
Curtailed power	0	5%

Note: LCOE = levelized cost of electricity.

Source: IHS Markit 2019 IHS Markit

The gas price is the key determinant of the cost of hydrogen produced from natural gas. Lower capital costs in China do not offset the higher fuel price

Levelised cost of hydrogen production from steam methane reforming with CCS (with 90% carbon capture) in Europe, North America and China



Notes:

Source: IHS Markit

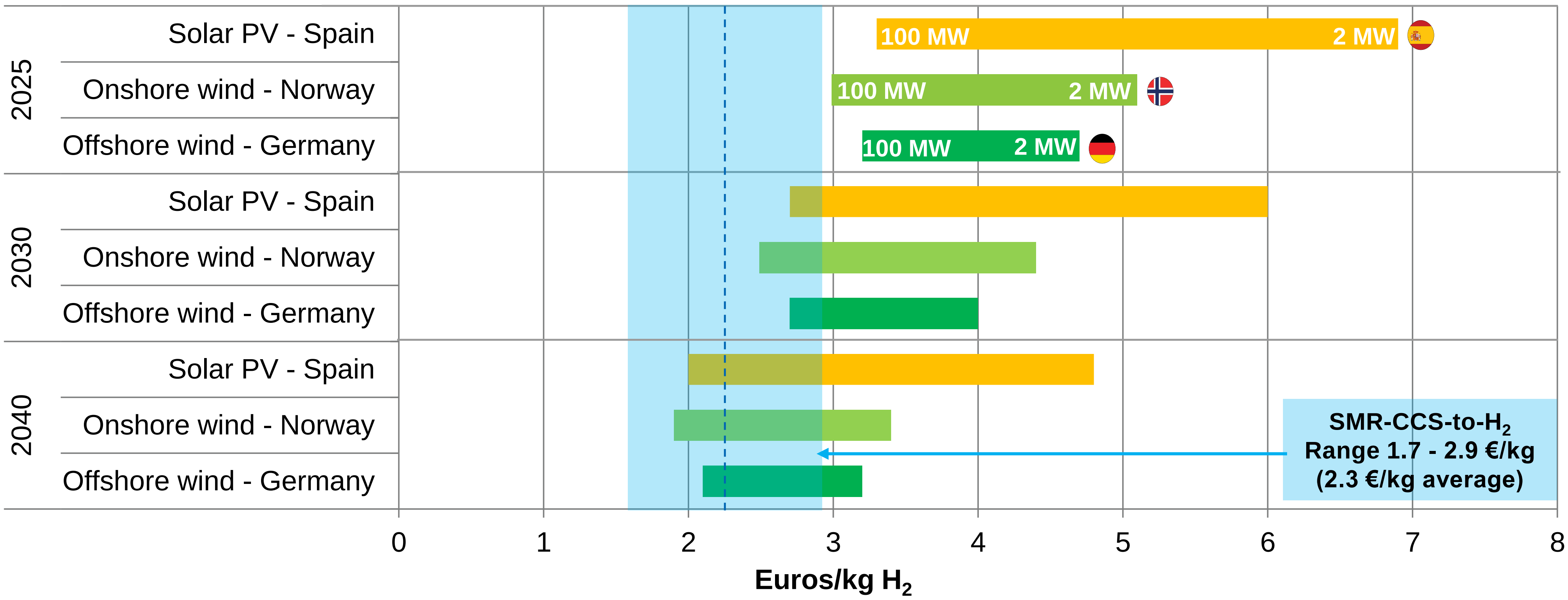
Key assumptions

SMR plant capacity (Nm³/h)	100,000
SMR plant Capex with CCS in Europe and North America (2018 million USD)	405
SMR plant Capex with CCS in China (2018 million USD)	245
Carbon price (USD per metric ton)	40
Plant economic life (years)	25
Weighted average cost of capital WACC (%)	7.5%

Source: IHS Markit

Electrolytic hydrogen costs are expected to fall rapidly

Cost range of hydrogen at the boundary of the production facility in Europe
Hydrogen from renewables vs SMR with CCS

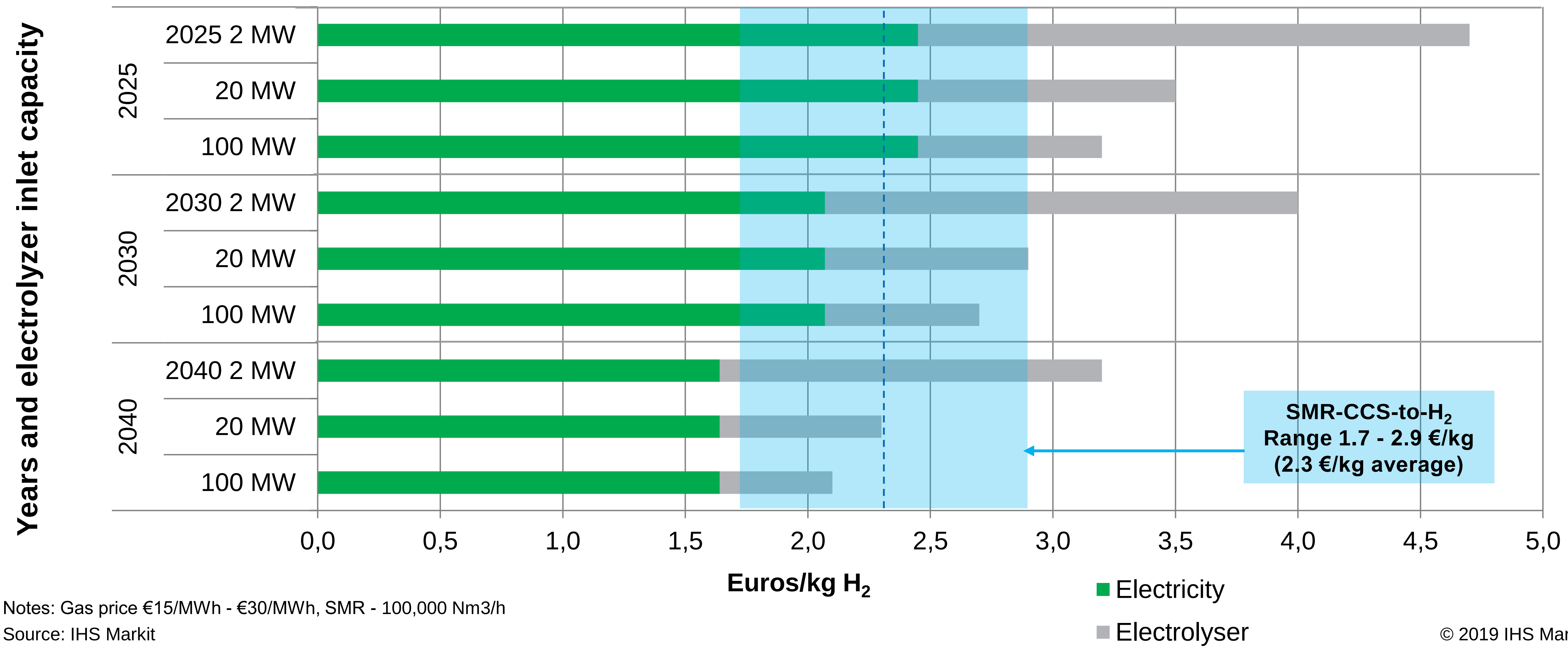


Notes: PEM electrolysers size range: 2-100 MWe. Natural gas price range: €15 - 30 MWh, SMR size: 100,000 Nm3/h

Source: IHS Markit 100 MW 2MW : input capacity range of installed electrolyzer

With a combination of increased scale and lower renewable cost, electrolytic hydrogen can compete with hydrogen from fossil fuels

Evolution of the cost of hydrogen from offshore wind (Germany)



Notes: Gas price €15/MWh - €30/MWh, SMR - 100,000 Nm3/h

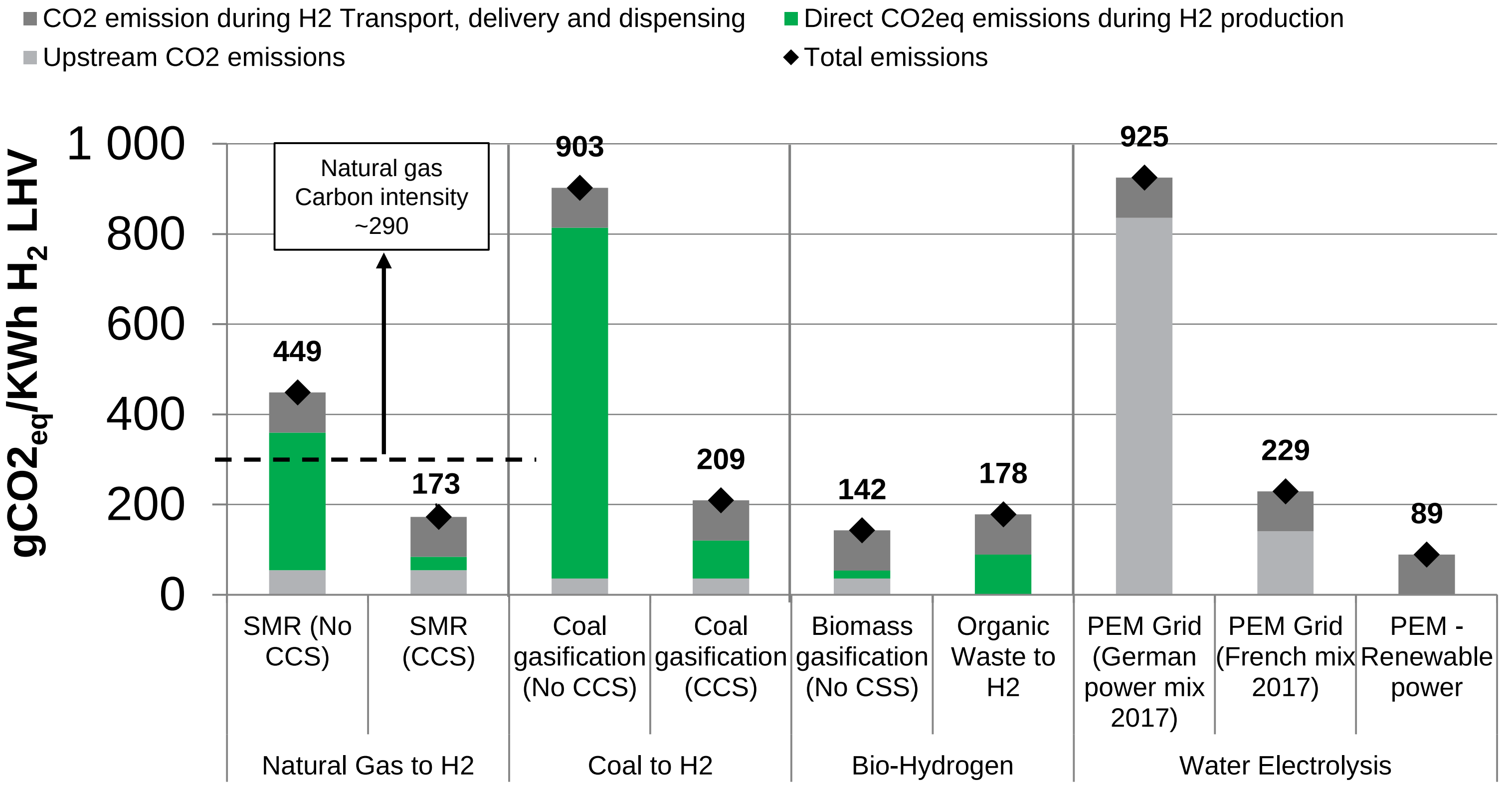
Source: IHS Markit

“Not all H_2 is created equal”

Currently the least-emitting H_2 production pathways are the most costly

- Dedicated renewable power for electrolysis leads to the least–carbon-intensive H_2, but …
- … it is currently the most costly pathway to H_2.
- With some current power mixes (e.g. Germany), electrolysis using the grid is more carbon intensive than SMR, at same level as coal to H_2.
- With CCS, coal gasification to H_2 becomes a reasonable route from an environmental standpoint.

Carbon intensity of studied H_2 routes (life-cycle)



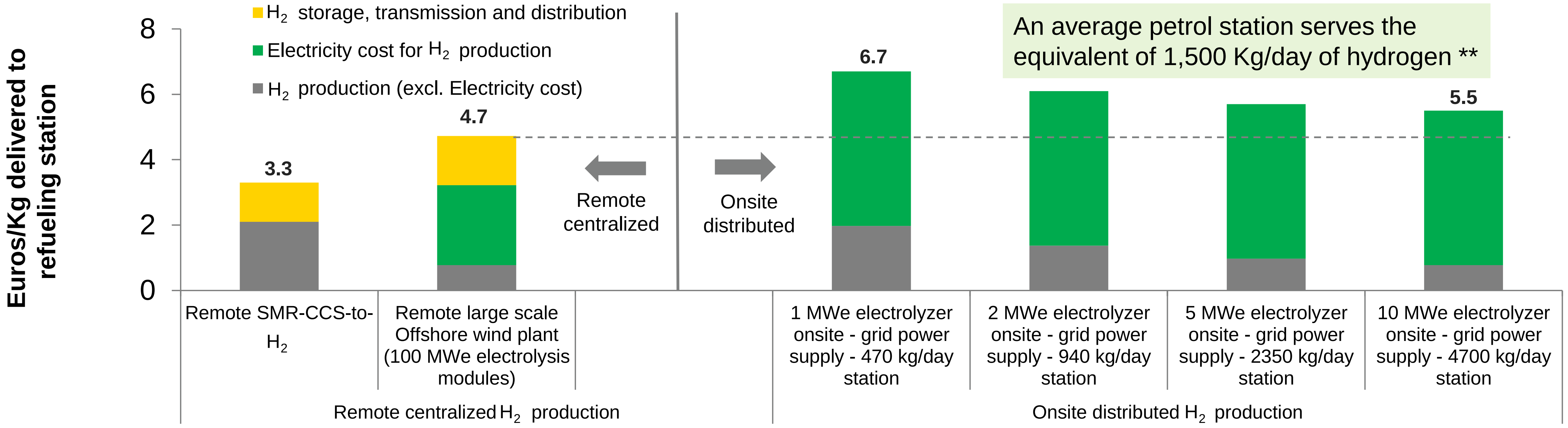
Notes: includes emissions from fugitive methane

Source: IHS Markit, California ARB, A. Moro et al (Electricity carbon intensity in European Member States - 2018)

Provision of large-scale supply likely more cost effective when centralized

The limited economies of scale for small on-site electrolyzers and higher grid tariff penalize the on-site model. Electricity tariff is key to make on-site hydrogen supply competitive (below 60-65 euros/MWh)

Remote or onsite hydrogen for Europe refueling stations in 2025 – Germany (excluding refueling station cost)



Notes: Remote offshore wind LCOE: 47 Euros/MWh (capacity factor 51%). Grid electricity is used for onsite electrolysis at an industrial tariff of 90 € /MWh (assumes a Eurostat IE band for industrial power prices – 20,000 – 70,000 TWh/year). Liquid hydrogen storage, transmission and distribution assumed for remote production over 300 Km supplying 1,000 tonnes of hydrogen per day. ** A petrol station in France serves in average 3500 cars (39 millions cars in France in 2016 for 11,000 gas stations). If those cars were FCEV (requiring 150 kg of H_2 per year), the equivalent capacity in hydrogen would be around 1500 kg H_2 per day.

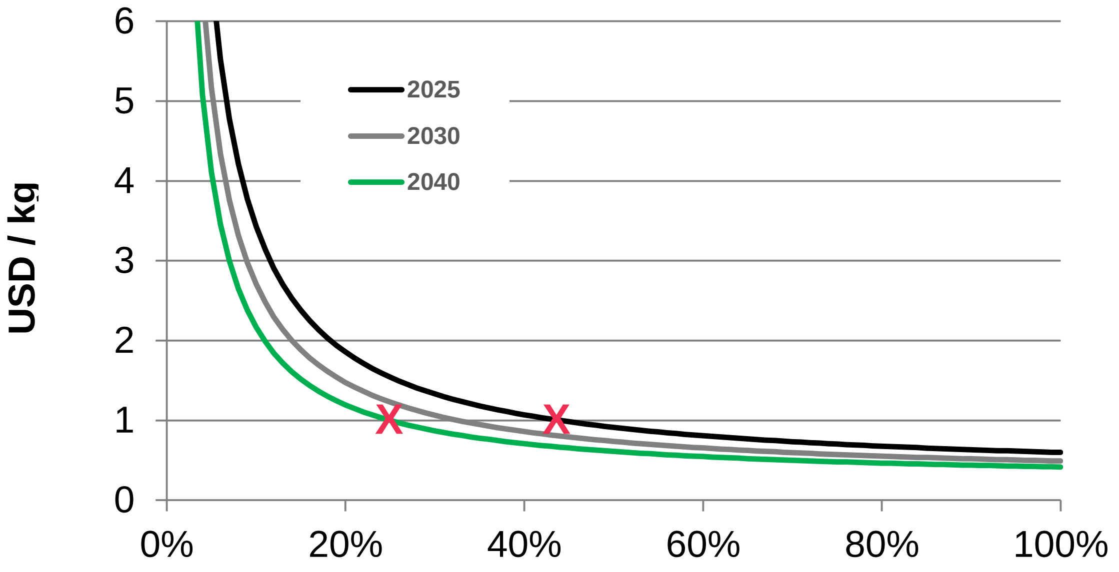
Source: IHS Markit

A 2 MWe onsite electrolyser can be more economical than a centralized renewable electrolysis at a grid power tariff lower than €65/MWh

Operation of a grid connected electrolyser is an optimization problem:

Maximise utilisation to minimise unit capex versus minimise utilisation to minimise electricity price

Non-electricity cost component variation with utilization rate of 100 MW electrolyser



Source: IHS Markit

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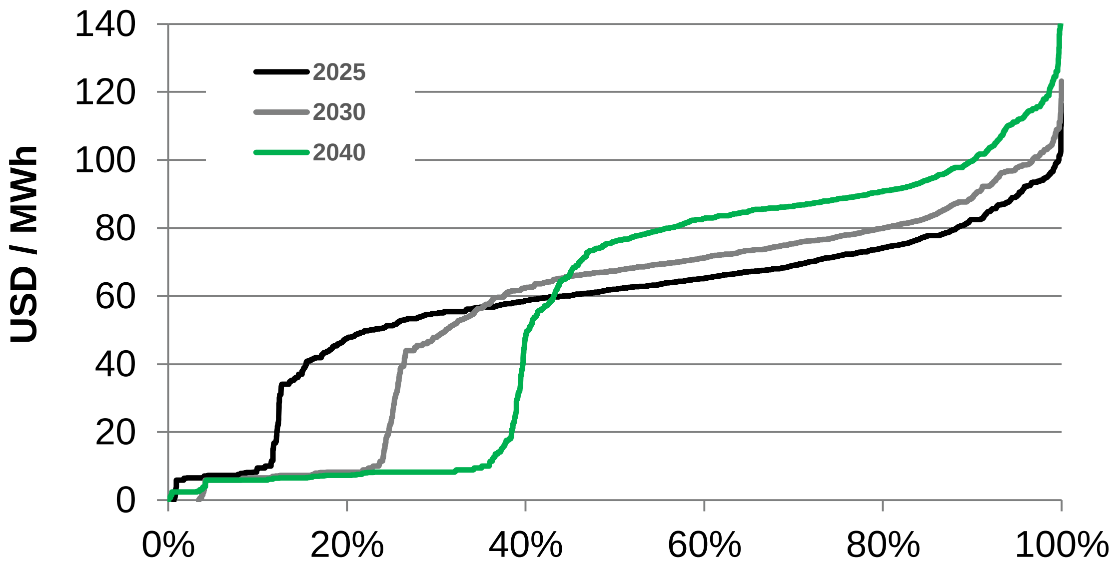
Price duration curve (case of Netherlands) IHS Markit EPA 2019



Source: IHS Markit

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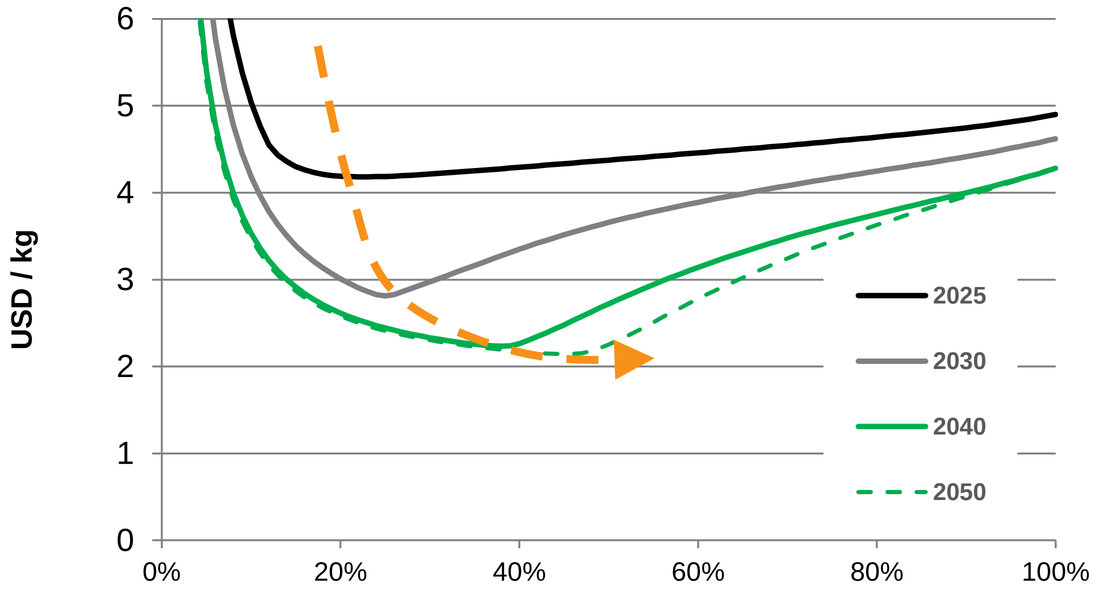
Falling electroyser costs allow for lower levels of economic utilisation. Tipping point moves from over 40% to close to 20%

Increasing levels of renewables will change the shape of the price-duration curve. Frequency of low prices increases as mid-range falls

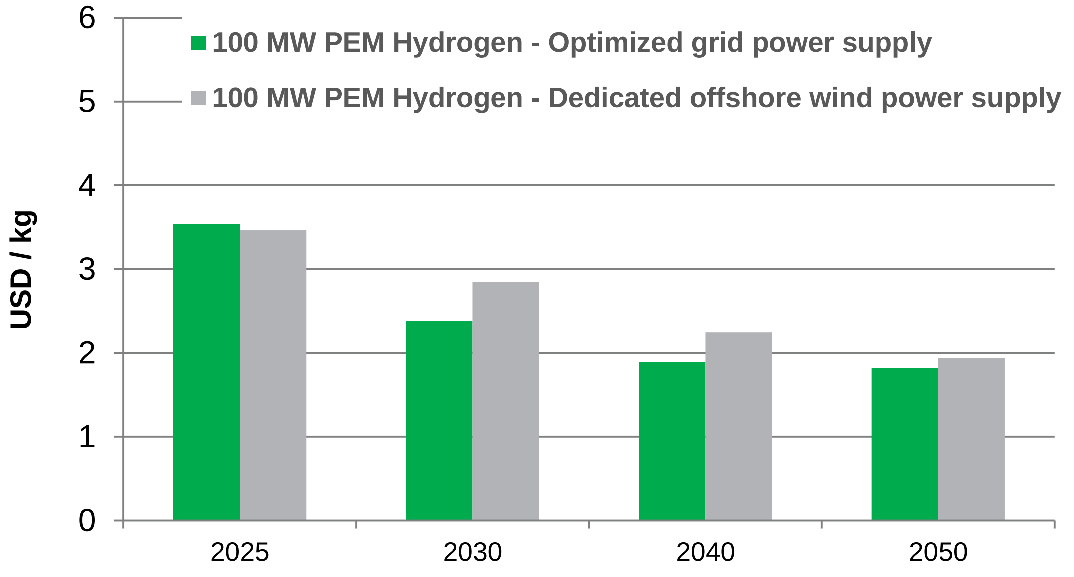
The optimal electrolyser utilization increases as capex falls and penetration of renewables on the grid increases. Can be lower cost than dedicated supply

Cost of hydrogen production from grid electricity Netherlands – 100MW electrolyser / €20/MWh grid fee



Source: IHS Markit

Comparison of grid supply and dedicated offshore wind supply for electrolysis in the Netherlands



Note: grid supply subject to a grid fee of €20/MWh

Source: IHS Markit

Risk of cannibalization if electrolyser additions exceed availability of low cost supply. Raises questions on cost allocation if renewables subject to support

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Hydrogen as part of the future energy mix

IHS Markit have developed outlooks through 2050 that are consistent with regional climate targets

- The long-term demand outlooks build upon the Autonomy scenario—but consider the potential for hydrogen use in all sectors of the economy to meet long-term climate targets
  - California—Executive order seeking carbon neutrality by 2045
  - China—65% CO_2 reduction vs 2015 levels (consistent with "Beautiful China" ambition)
  - Europe—net-zero carbon by 2050
- The supply mix is built-up considering the sector of demand, the pace of demand growth and the outlook for hydrogen production costs

Key messages from hydrogen demand and supply analysis

1. Share of hydrogen in the energy mix is dependent on the **degree of climate ambition**. Where deep decarbonisation is sought the share of hydrogen expected to be > natural gas today

2. Inclusion of aviation in climate targets hugely increases the role for hydrogen as a **feedstock for synthetic jet**—but at a significant cost

3. By mid-century, similar volumes of hydrogen are expected to be produced from **fossil sources and electricity.** Focusing on only one source is likely to slow deployment of hydrogen

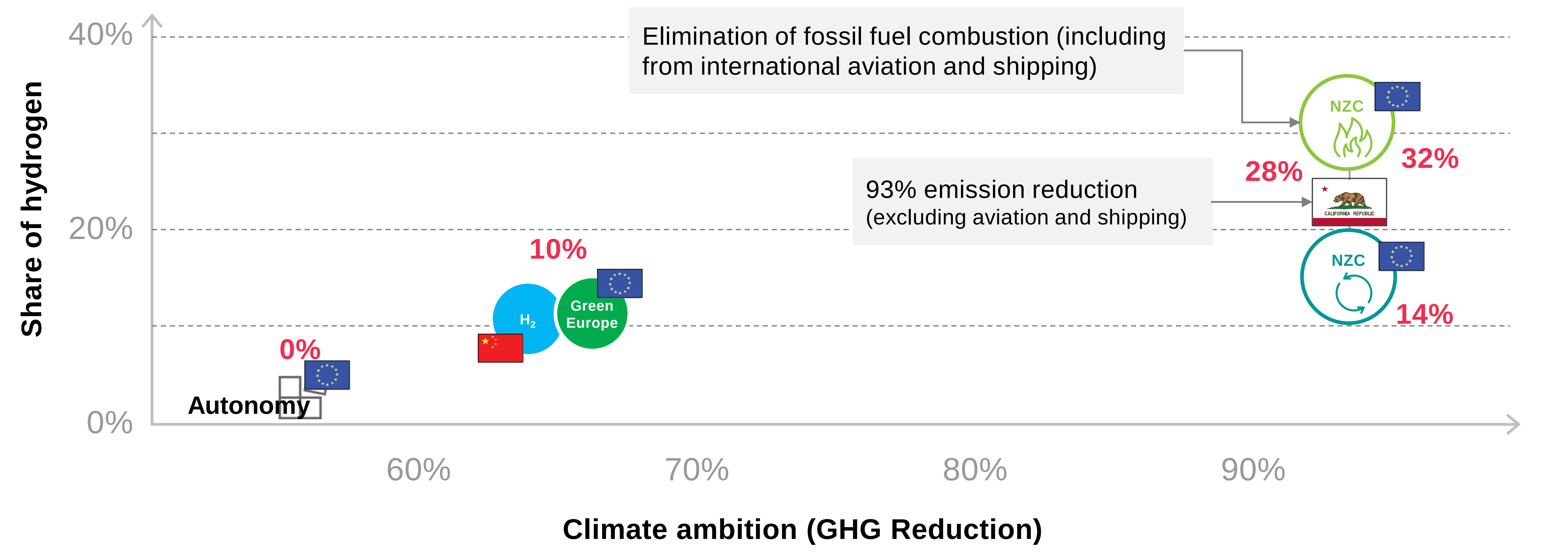
4. **Electricity as a feedstock** for hydrogen production could to dominate electricity demand—in 2050 in the high case for hydrogen in Europe over 50% of electricity demand is used for H_2

5. In **Europe and the US**, deployment of hydrogen provides long-term **security of demand for natural gas** (as a feedstock for methane reforming).

6. In **China**, deployment of H_2 could significantly **reduce natural gas imports** from the early-2030s onwards. Domestic H_2 from coal (with CCS), wind and solar displaces imported gas

The share of hydrogen in final energy demand increases rapidly as climate ambition increases—inclusion of aviation a key driver of increase

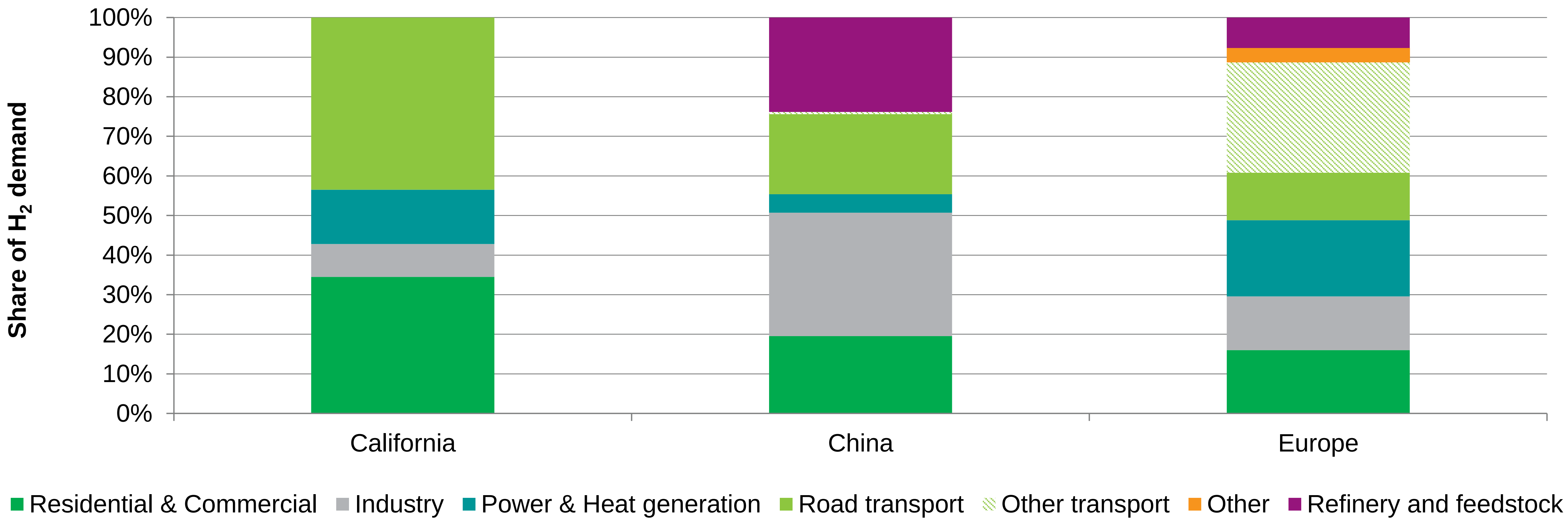
Share of hydrogen in final energy demand in the IHS Markit outlooks - 2050



Source: IHS Markit

Hydrogen can be used in all sectors of the economy

2050 hydrogen demand by sector across all three studies

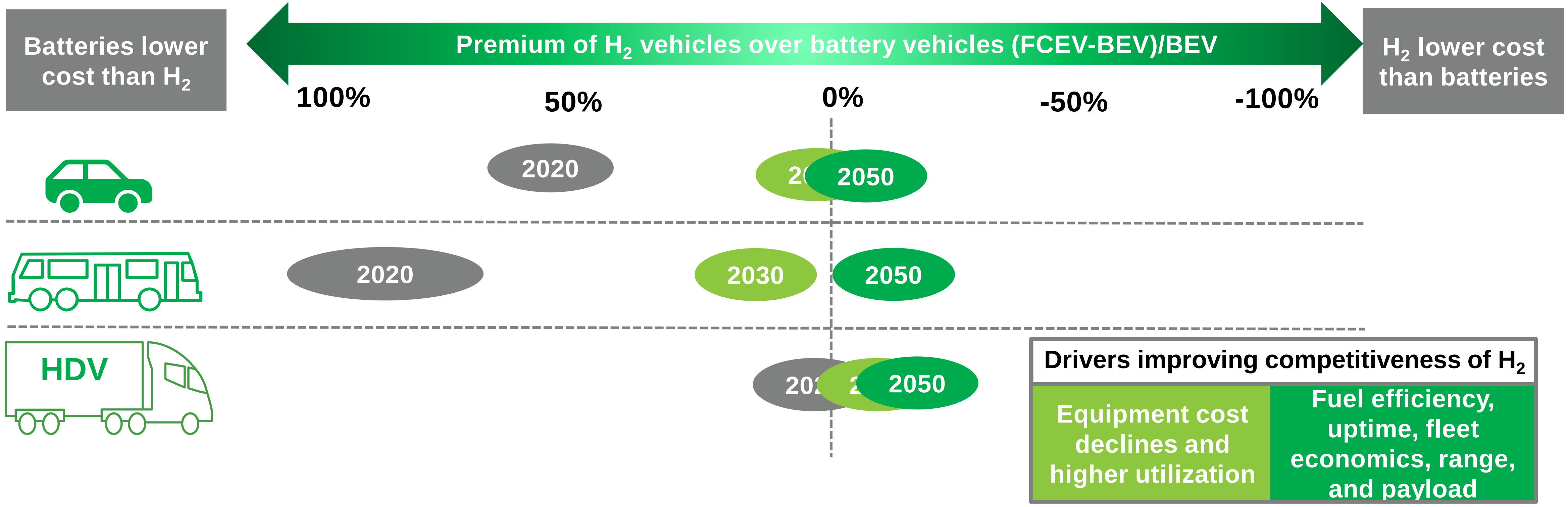


Source: IHS Markit

Trajectory for total cost of ownership for FCEV vs BEV

Municipal operators could play major role to drive initial cost reductions

Driver of cost reduction by sector



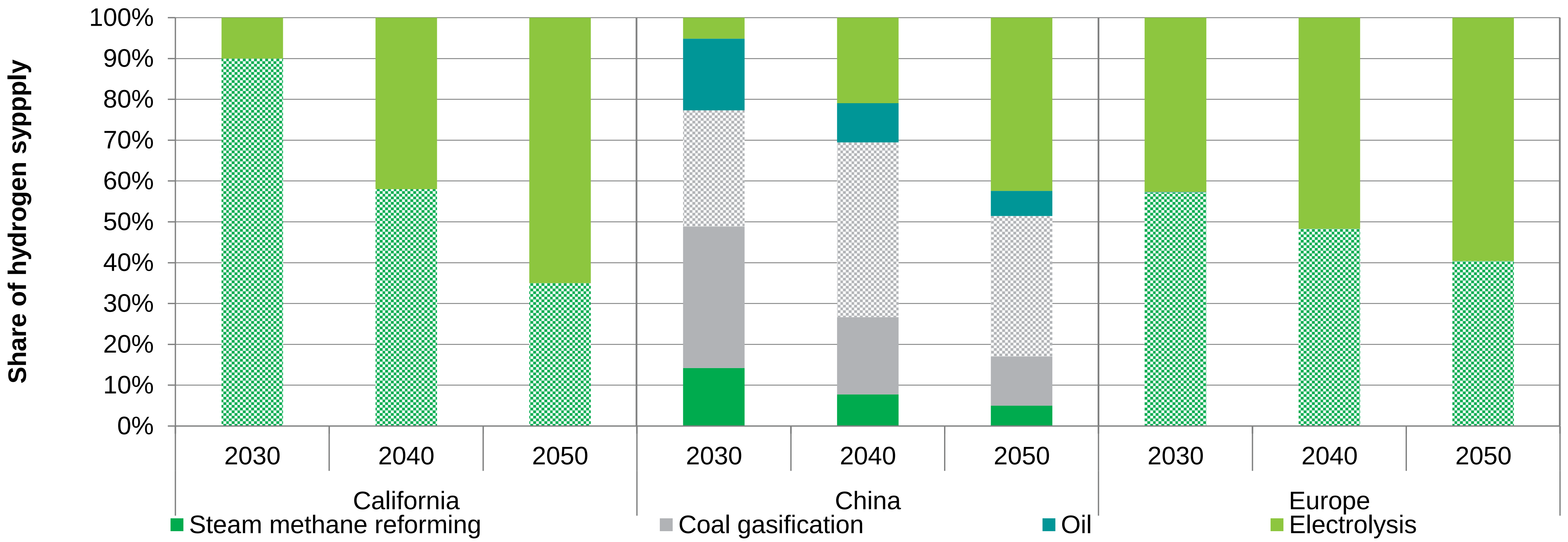
Source: IHS Markit

Reducing fuel prices important driver of competitiveness once initial price premium removed; benefits of hydrogen greatest for large fleets

In the short-term, H_2 from fossil fuels are expected to dominate supply,

but by mid-century electrolysis linked to dedicated renewables will be the largest source of supply

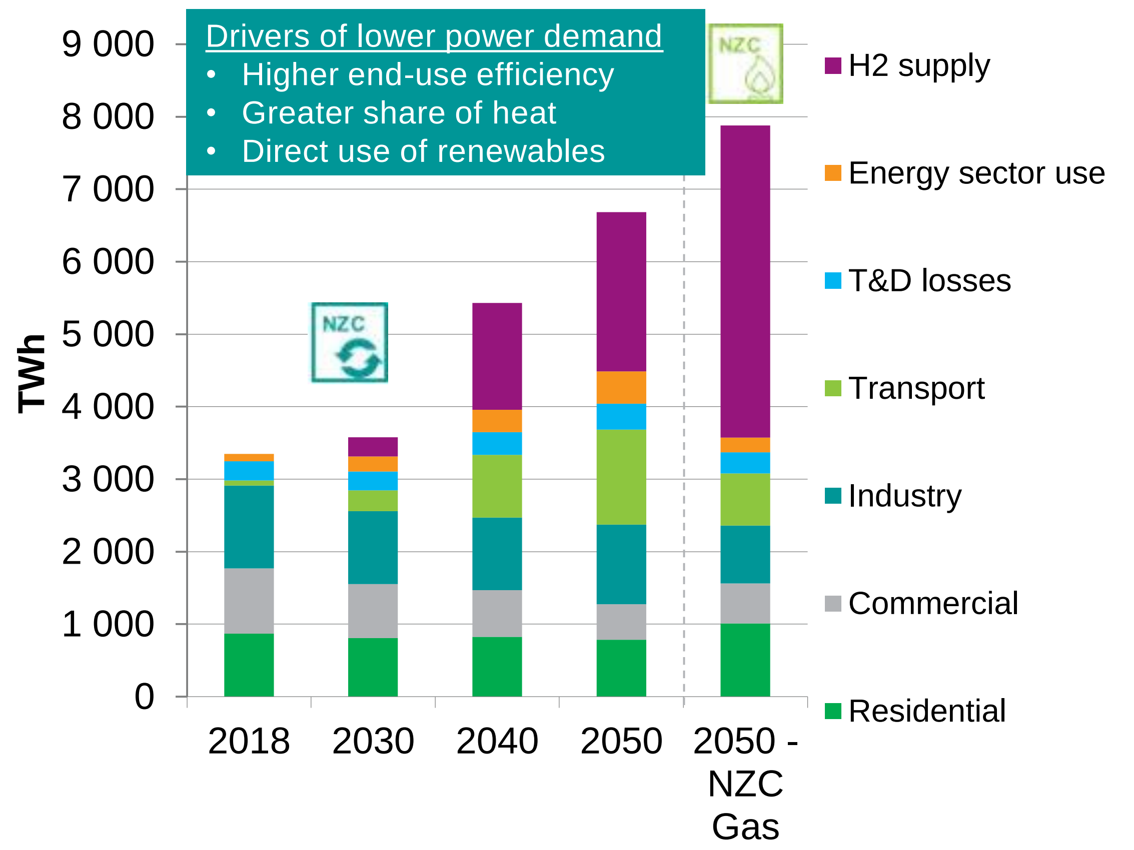
Hydrogen supply by technology and fuel



Notes: Hashed areas represent use of CCS.
Source: IHS Markit

In the long-term, use of electricity as a feedstock for hydrogen supply could be the largest use of electricity in the economy

Power demand by sector: NZC HP



Source: IHS Markit

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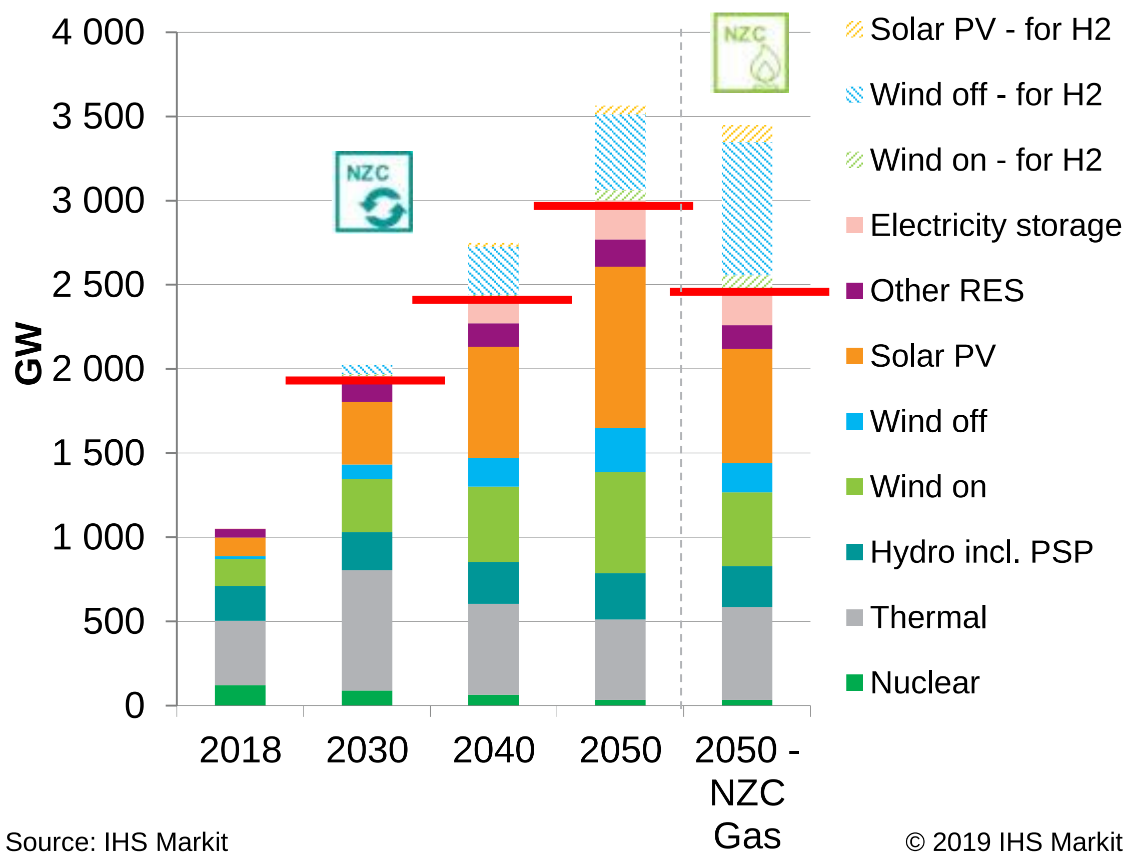
Installed capacity by technology: NZC HP



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IHS Markit Hydrogen and Renewable Gas Initiatives

IHS Markit regional hydrogen studies in 2018/2019 developed with 60+ partner companies

Hydrogen in the Golden State

European Hydrogen Forum

Hydrogen as the Enabler: Meeting China’s Energy Challenge?

Hydrogen and Renewable Gas Forum 2020

Global Coverage

IHS Markit Hydrogen and Renewable Gas Forum
Research pillars

Deliverables of the Hydrogen and Renewable Gas Forum

Market Fundamentals	Data and analytics	Community
Economic analysis of the value chain	Power-to-X project tracker	4 workshops per year 1 in US, 2 in Europe, 1 in APAC
Long-term outlooks for low-carbon gas demand and supply	Levelized cost of hydrogen production model	Hydrogen & renewable gas industry site visits
Full energy balance outlook for major markets	Interactive models for the full value chain	Regular webinars

Source: IHS Markit

What is the Hydrogen and Renewable Gas Forum?

Production / Transportation & Storage / End-use sectors

- Completed
- First half 2020
- Second half 2020
- China completed, Korea/Japan to be completed Second half 2020
- Not applicable

	Hydrogen	Biomethane	Synthetic methane	Ammonia	Methanol
Reforming (with and without CCS)	Europe US China Asia importing countries Exporting countries			Europe US China Asia importing countries Exporting countries	Europe US China Asia importing countries Exporting countries
Gasification (with and without CCS)	Europe US China Australia	Europe US	Europe US	Europe US Australia	Europe US Australia
Methane Pyrolysis	Europe US China				
Electroysis -- AEC	Europe US Asia		Europe US	Europe US Asia	Europe US Asia
Electroysis -- PEM	Europe US China Asia importing countries Exporting countries		Europe US	Europe US China Asia importing countries Exporting countries	Europe US China Asia importing countries Exporting countries
Electroysis -- SOEC	Europe US Asia		Europe US	Europe US Asia	Europe US Asia

Asian importing countries: Korea and Japan | **Exporting countries:** Australia, Middle East and North Africa

What is the Hydrogen and Renewable Gas Forum?

Production / **Transportation&Storage** / End-use sectors

Completed | First half 2020 | Second half 2020 | China completed, Korea/Japan to be completed Second half 2020 | Not applicable

	Hydrogen	Biomethane	Synthetic methane	Ammonia	Methanol	LOHC
Tube trailer	Europe US Asia					
Liquid trailer	Europe US Asia	Injected into gas grid - costs and treatment as natural gas		Europe US Asia	Europe US Asia	Europe US Asia
Pipeline	Europe US Asia					
Liquid ship	Europe US Asia			Europe US Asia	Europe US Asia	Europe US Asia
STORAGE						
Compressed tanks	Europe US Asia			Europe US Asia	Europe US Asia	Europe US Asia
Liquid tanks	Europe US Asia			Europe US Asia	Europe US Asia	Europe US Asia
Salt cavern	Europe US Asia			- - -	- - -	- - -
Depleted oil and gas field	Europe US Asia			- - -	- - -	- - -

Asian importing countries: Korea and Japan | **Exporting countries:** Australia, Middle East and North Africa

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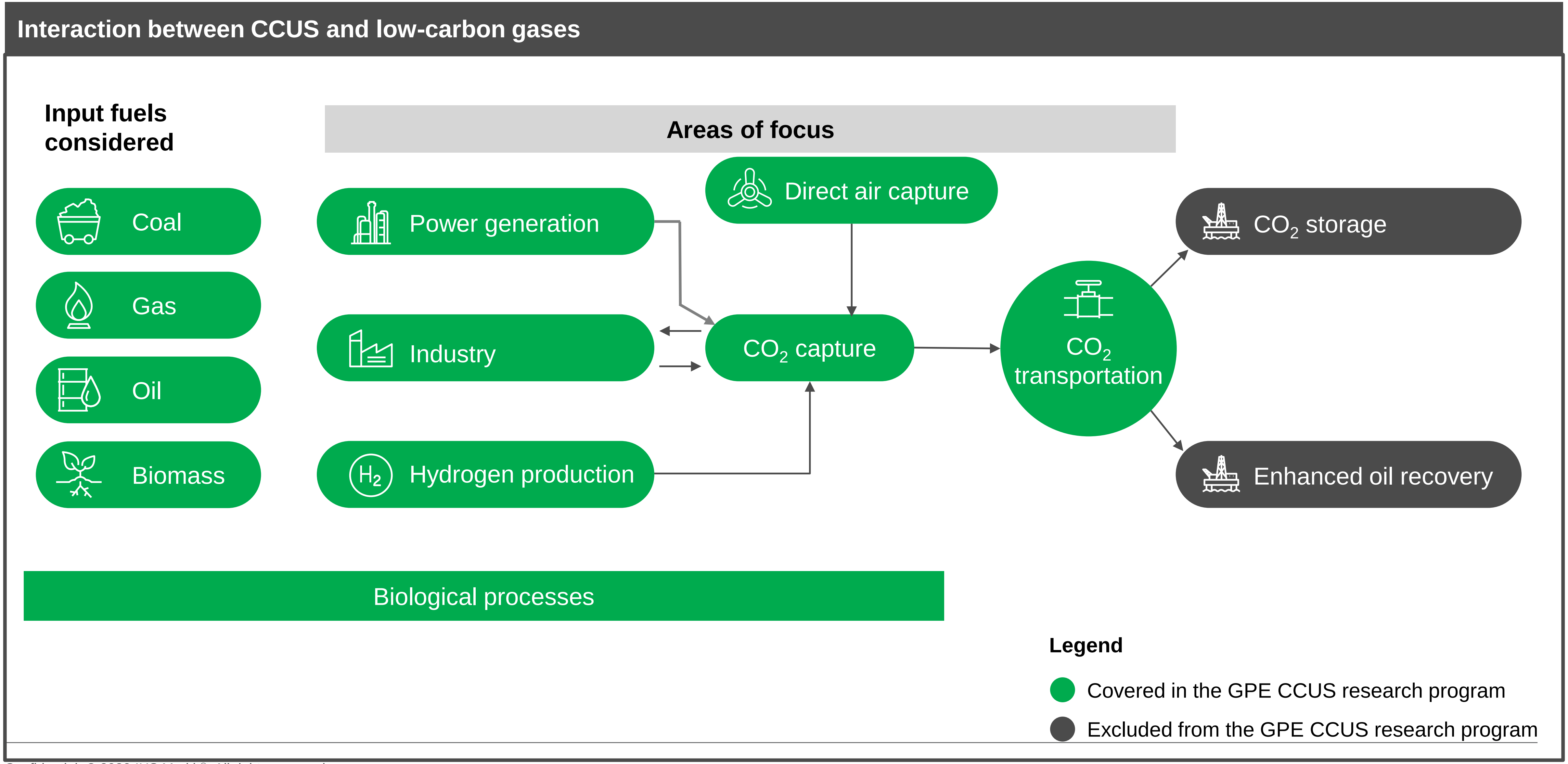
● Completed ● First half 2020 ● Second half 2020 ● China completed, Korea/Japan to be completed Second half 2020 ● Not applicable

	Low carbon fuels						Current dominant fuel (baseline) and other alternatives	
	Hydrogen	Biomethane	Synthetic methane	Ammonia	Methanol	Synthetic jet fuel	Diesel/gasoline/jet fuel	Battery electric
END USE -- TRANSPORT								
Light duty	Europe US Asia	Europe US					Europe US Asia	Europe US Asia
Medium duty	Europe US Asia	Europe US					Europe US Asia	Europe US Asia
Heavy duty	Europe US Asia	Europe US					Europe US Asia	Europe US Asia
Buses	Europe US Asia	Europe US					Europe US Asia	Europe US Asia
Shipping	Europe US Asia	Europe US Asia	Europe US Asia	Europe	Europe		Europe US Asia	Europe US Asia
Aviation						Europe US Asia	Europe US Asia	
END USE - INDUSTRY							Coal	Natural gas
Iron and steel	Europe US Asia						Europe US Asia	Europe US Asia
END USE - RESIDENTIAL AND COMMERICAL							Heat pumps	Direct electricity
Space heating	Europe US	Europe US					Europe US	Europe US
Water heating	Europe US	Europe US					Europe US	Europe US

Asian importing countries: Korea and Japan | **Exporting countries:** Australia, Middle East and North Africa

Deep dive on interaction between carbon capture and storage and low carbon gases

Scope of coverage in Hydrogen and Renewable Gas Forum



Interaction between CCUS and low-carbon gases: Three main areas of research

Areas of research:

1. Current feasibility and status of carbon capture and storage
2. Current feasibility and status of negative emission technologies: BECCS* / DAC*
3. Economics of fuels produced with captured CO_2 vs alternative low-carbon options

*BECCS—Bioenergy with carbon capture and storage

*DAC—Direct air capture

Interaction between CCUS and low-carbon gases

1. Current feasibility and status of carbon capture and storage

- Research
  - High-level overview of policy measures to support the development of CCS?
  - What is the cost of carbon capture and storage? Detailed costing for the various options
  - How does the level of CO_2 capture vary depending on capture process and source of CO_2?
  - What are the options for CO_2 storage?

- Data and analytics
  - Database of carbon capture and storage projects globally
  - Indicative cost comparison for carbon capture, CO_2 transportation and CO_2 storage

Interaction between CCUS and low-carbon gases

2. Current feasibility and status of negative emission technologies

- Research
  - High-level overview of policy measures to support the development of negative emission technologies?
  - What is the status of the BECCS and DAC?
  - What is the cost of BECCS and DAC?

- Data and analytics
  - Database of BECCS and DAC projects
  - Details of assumptions used for economic analysis—capex, opex, etc
  - Current and projected cost comparison for BECCS and DAC

Interaction between CCUS and low-carbon gases

3. Economics of fuels produced with captured CO_2 vs alternative low-carbon options

- Research: End-use cost comparison
  - Cost of synthetic methane vs hydrogen vs direct electricity
  - Cost of synthetic methane vs ammonia and methanol
  - Cost of synthetic jet vs ammonia
  - Cost or pre-vs-post combustion carbon capture—i.e. Use of hydrogen produced from natural gas with carbon capture and storage vs use of natural gas with carbon capture and storage on flue gases

- Data and analytics
  - PowerBI dashboard with cost comparisons

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