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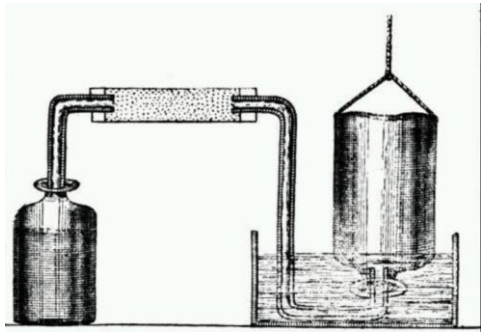
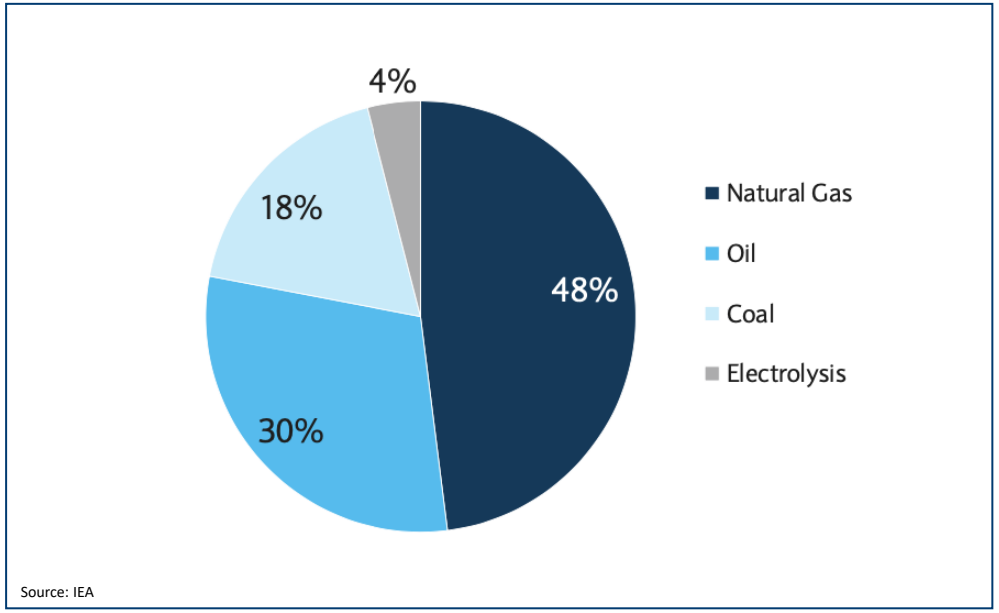
The Hydrogen Landscape

Hydrogen market

Discovered by Boyle (1671) and Cavendish (1766)



Hydrogen production – today



- Current market c. 70mtpa
- >95% made from hydrocarbons – ‘grey hydrogen’
- Emits 830mtpa CO2
- Used in refining, chemicals, steel, other industrials

Paris Agreement and Net Zero
Rapid expansion of hydrogen participants

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- 66+ countries announced Net Zero strategies
- 18+ countries have hydrogen strategies

Source: WWF

>90 membership of hydrogen council

Hydrogen potential as a clean fuel and feedstock

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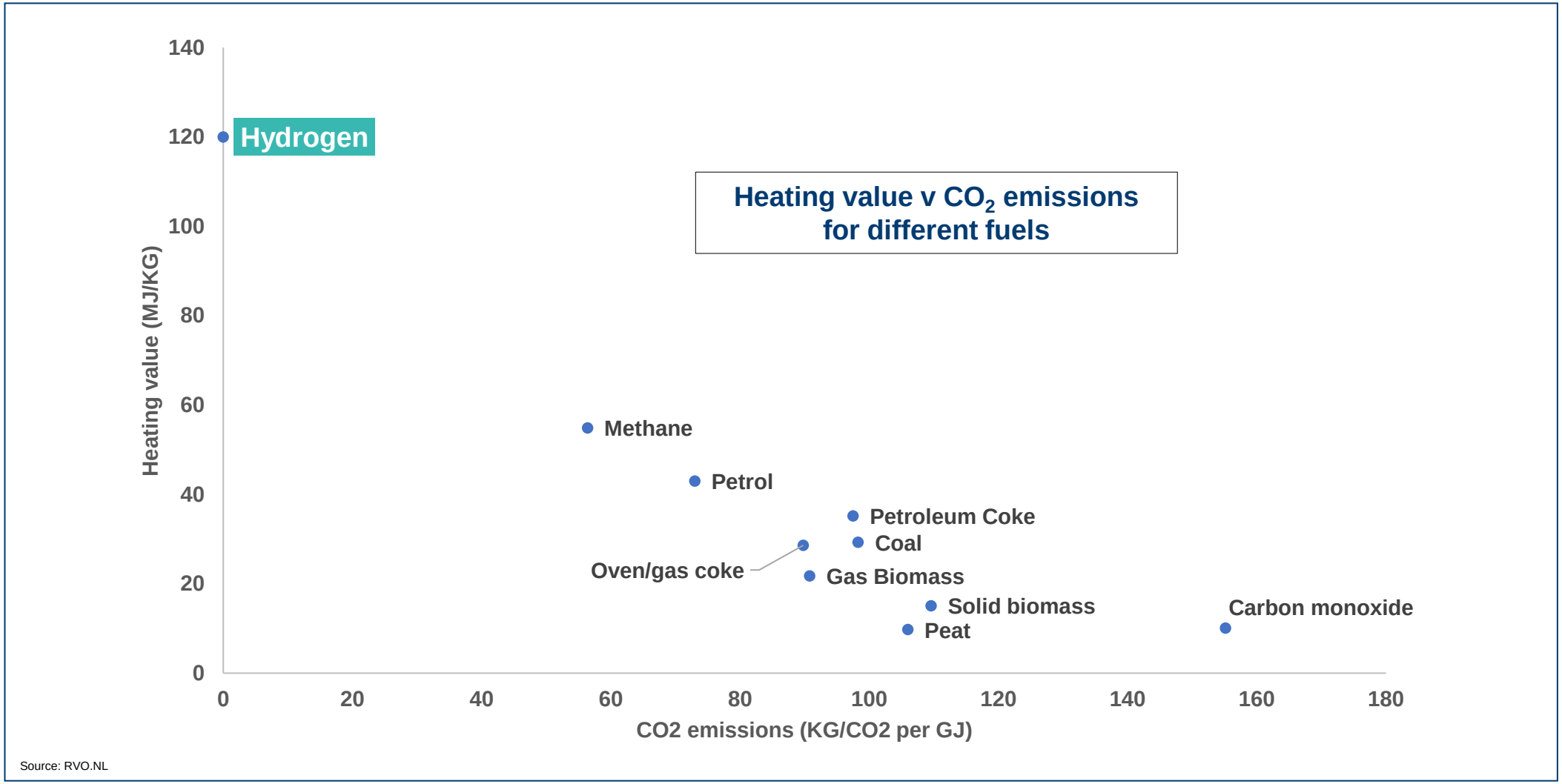
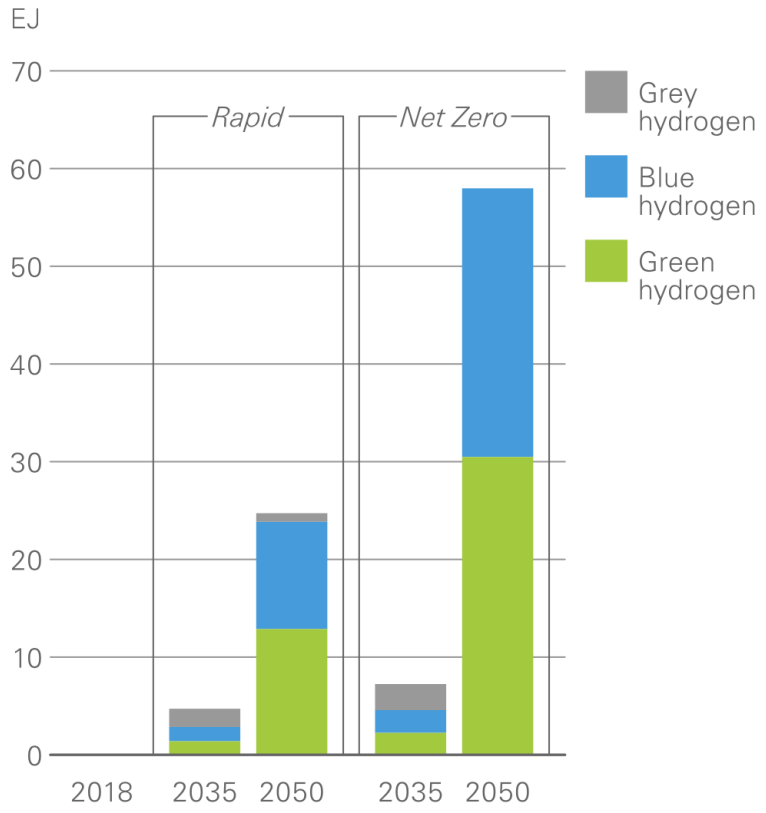


Source: RVO.NL

Hydrogen outlook

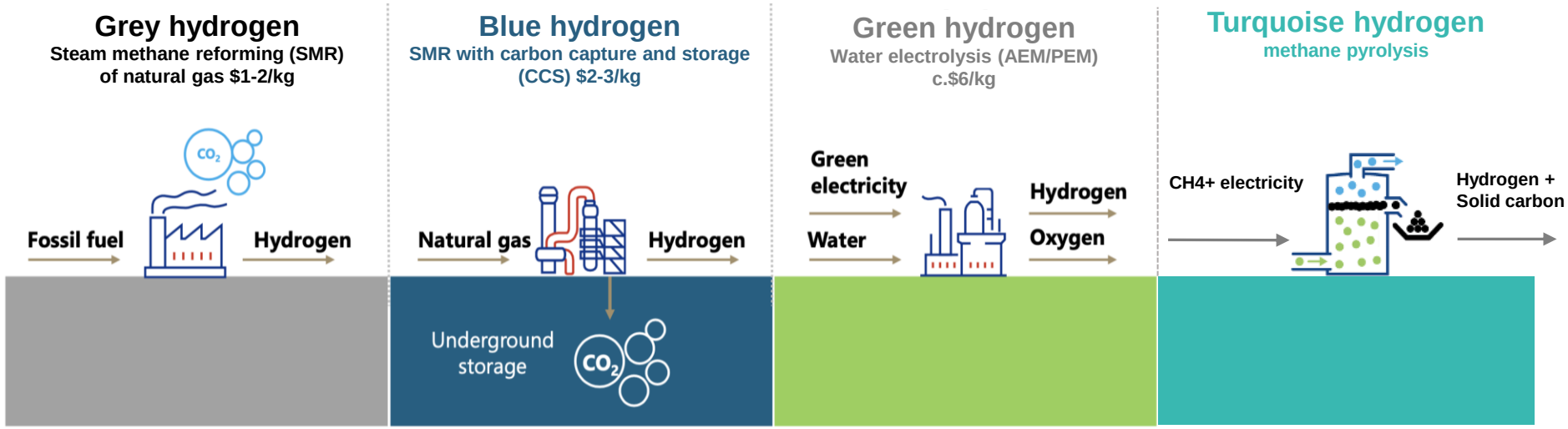
Hydrogen production - outlook



- Increasing importance of hydrogen
  - Decarbonising the energy system - “Net Zero”
  - Improving urban air quality; health - conscious COVID world
  - Innovation leading to clean hydrogen supply sources
- Hydrogen could reach 7-16% of energy consumption 2050
  - 575mtpa potential 2050 (8X today’s levels)
  - c. $500bn capital cost

Source: BP energy Outlook 2020

Hydrogen supply sources



Today

2021-30

2030+

- Multiple potential sources of hydrogen
- Innovation to extend traditional portfolio asset lives: oil & gas facilities, pipeline networks
- Potential for blending and premium markets for clean hydrogen

Hydrogen's role in decarbonising the energy system

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Blue

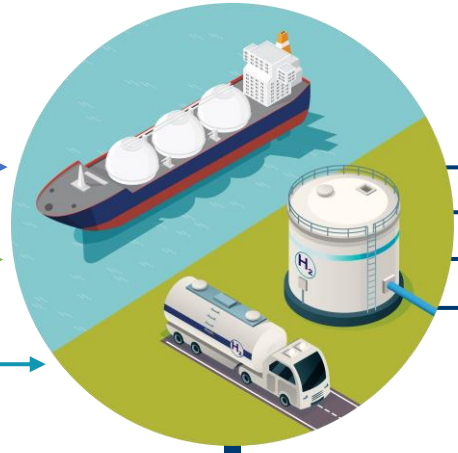
- Clean-up of fossil fuel-derived hydrogen
- CCUS integration

Green

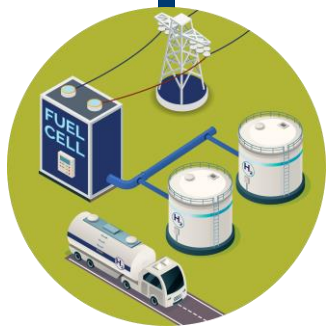
- Large scale renewables
- Electrolysis

Turquoise

- Methane pyrolysis re-tools natural gas grids
- Solid carbon extracted



Distributed energy



Grid scale storage

- Power to gas
- Geological storage
- Ammonia

Transport

Industrial energy

Feedstock

Building heat

Hydrogen’s role in cleaner air

4.2 million deaths worldwide every year are attributed to **ambient air pollution**

91% of the world's population live in places exceeding WHO air quality guidelines

Battery electric (BEV) and fuel cell vehicles (FCV) are zero-emission ‘tailpipe’

- they have no smog-related or greenhouse gas tailpipe emissions
- FCV advantaged over BEV in heavy and long distance applications: trucks, buses, trains, forklift


California: all new passenger vehicles zero-emission by 2035

Toyota/Hino FCV truck JV March 2020

Major contribution to air quality

Blue hydrogen and CCUS

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Blue hydrogen

- CO2 capture at traditional hydrogen manufacturing sites
- CCUS solution cleans hydrogen

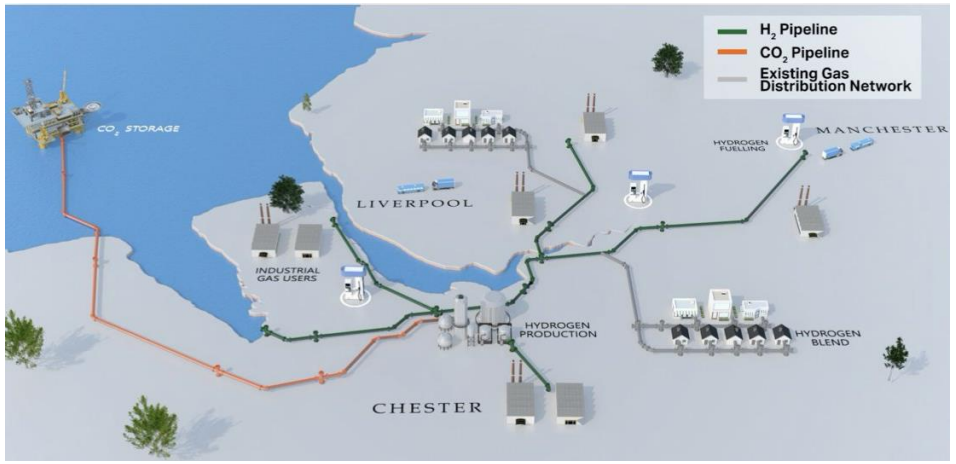
Established and deployed technologies

- Shell Quest (Canada AOSP) 2015; 900 tonnes/day blue hydrogen + CCS
- Valero/Air Products (Texas Port Arthur) 2013; 500 tonnes/day blue hydrogen + EOR
- Saudi Aramco / Japan 2020: blue ammonia export demonstrator; first cargo 40 tonnes + EOR

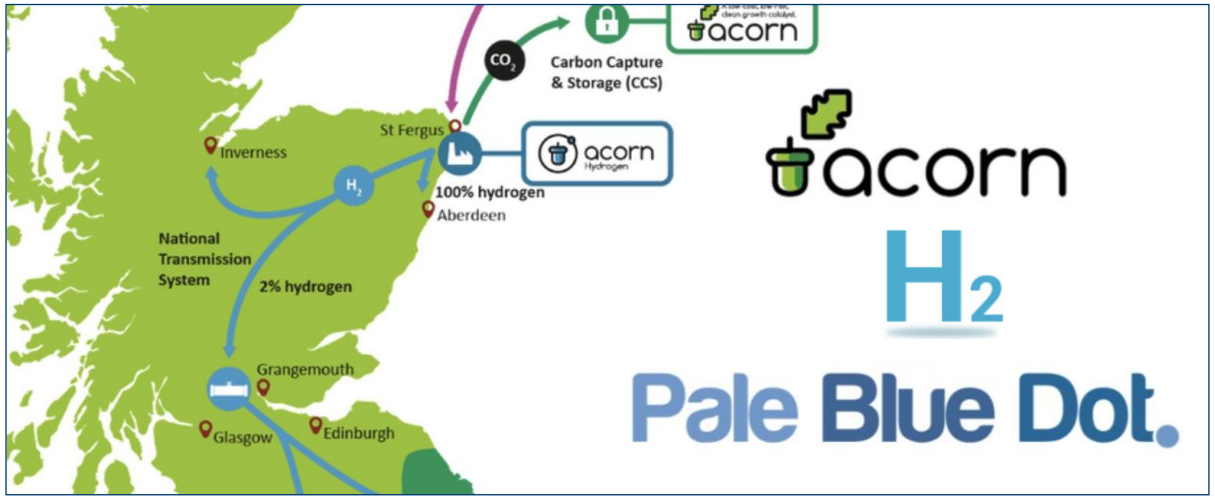
Large project pipeline

- Multiple projects proposed 2022+

Hynet (North West UK). 200t/d blue hydrogen project (2025)



Acorn UKCS (Chrysaor, Shell and Total) CCS + 200 MW hydrogen plant 2025



Green hydrogen and electrolysers

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Green hydrogen

- Renewable electricity and electrolysers
- O2 and heat by-products

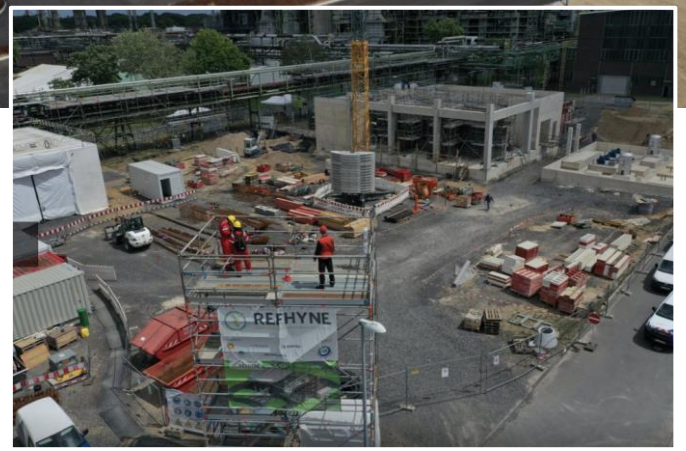
Pilot and small-scale deployment

- 1MW installed 2010 reached 25MW in 2019. Increased project size to 1-5MW (IEA)
- >100GW projected by 2050 (Barclays, 2020)

EU Roadmap 2020

- 6GW electrolysers / 1mt hydrogen by 2024
- 40GW electrolysers / 10mt hydrogen 2030
- Further 40GW electrolysers with export to EU

Japan FH2R (Toshiba/Tohuku/Iwatani) 10MW solar. 2020 start-up



Shell Rhineland SMR replacement. 10MW 2020 start-up

Hydrogen applications build-out

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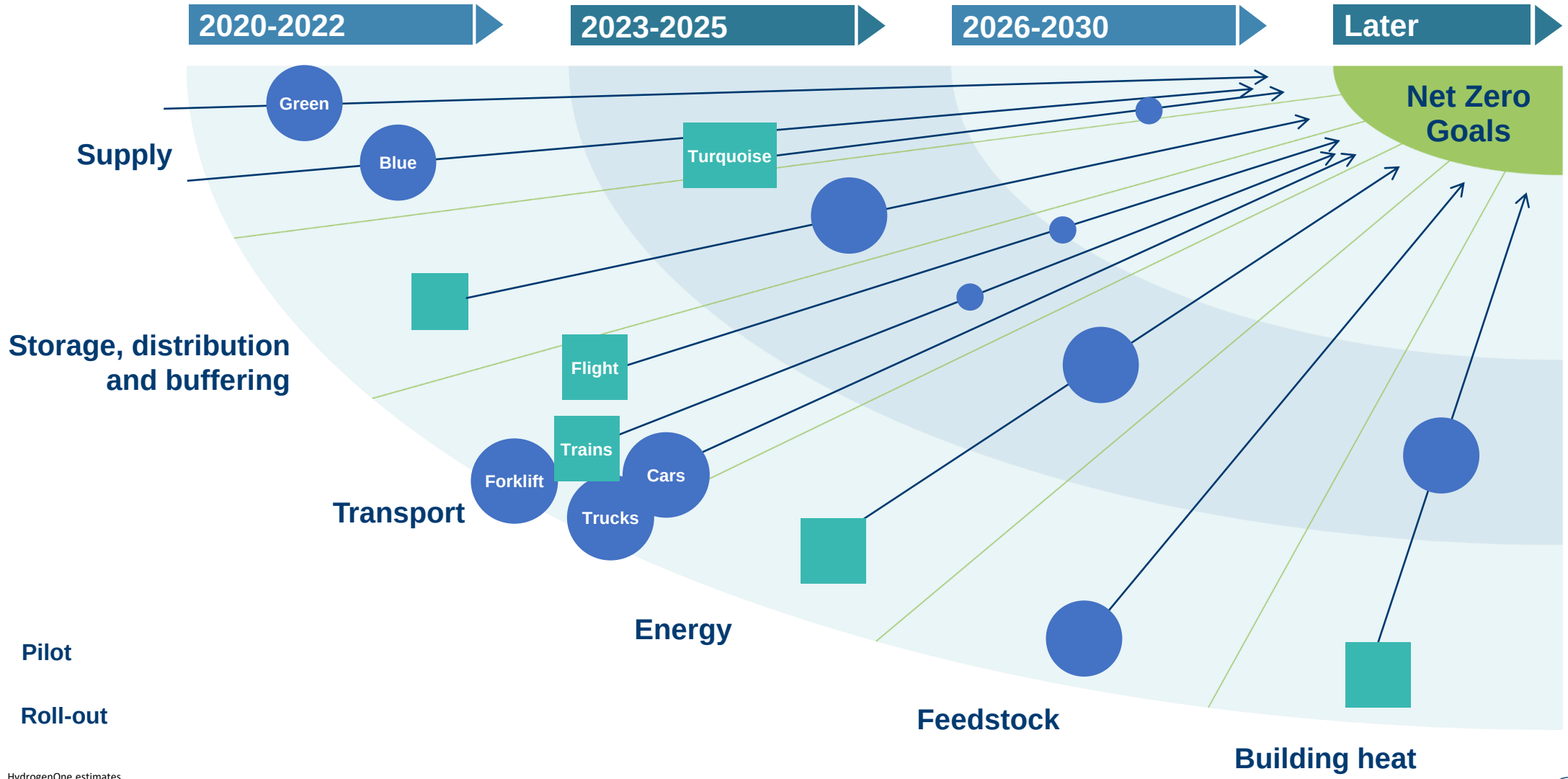

Source: Hydrogen Council, FCHEA, HydrogenOne estimates

Cost competitiveness in hydrogen applications

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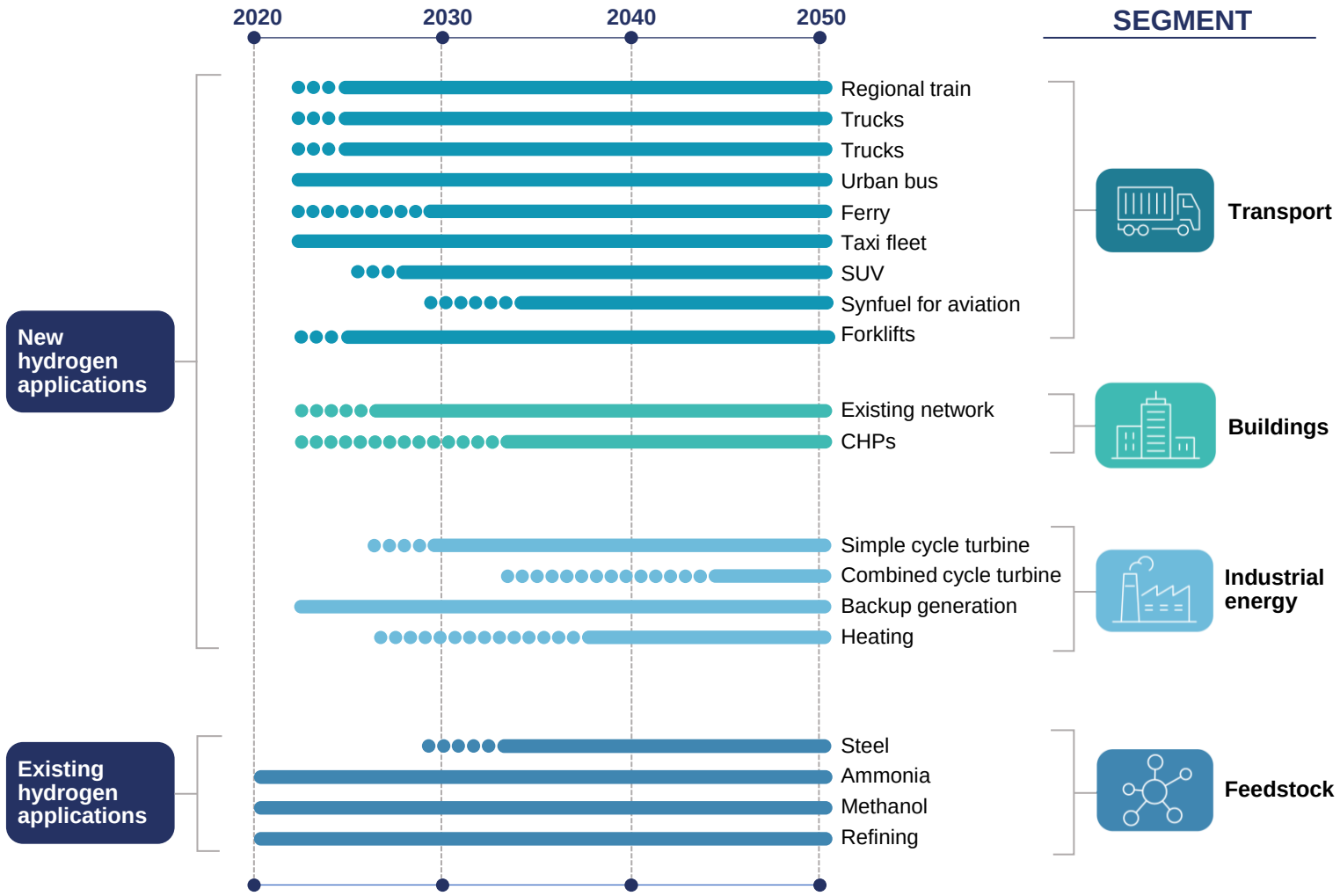
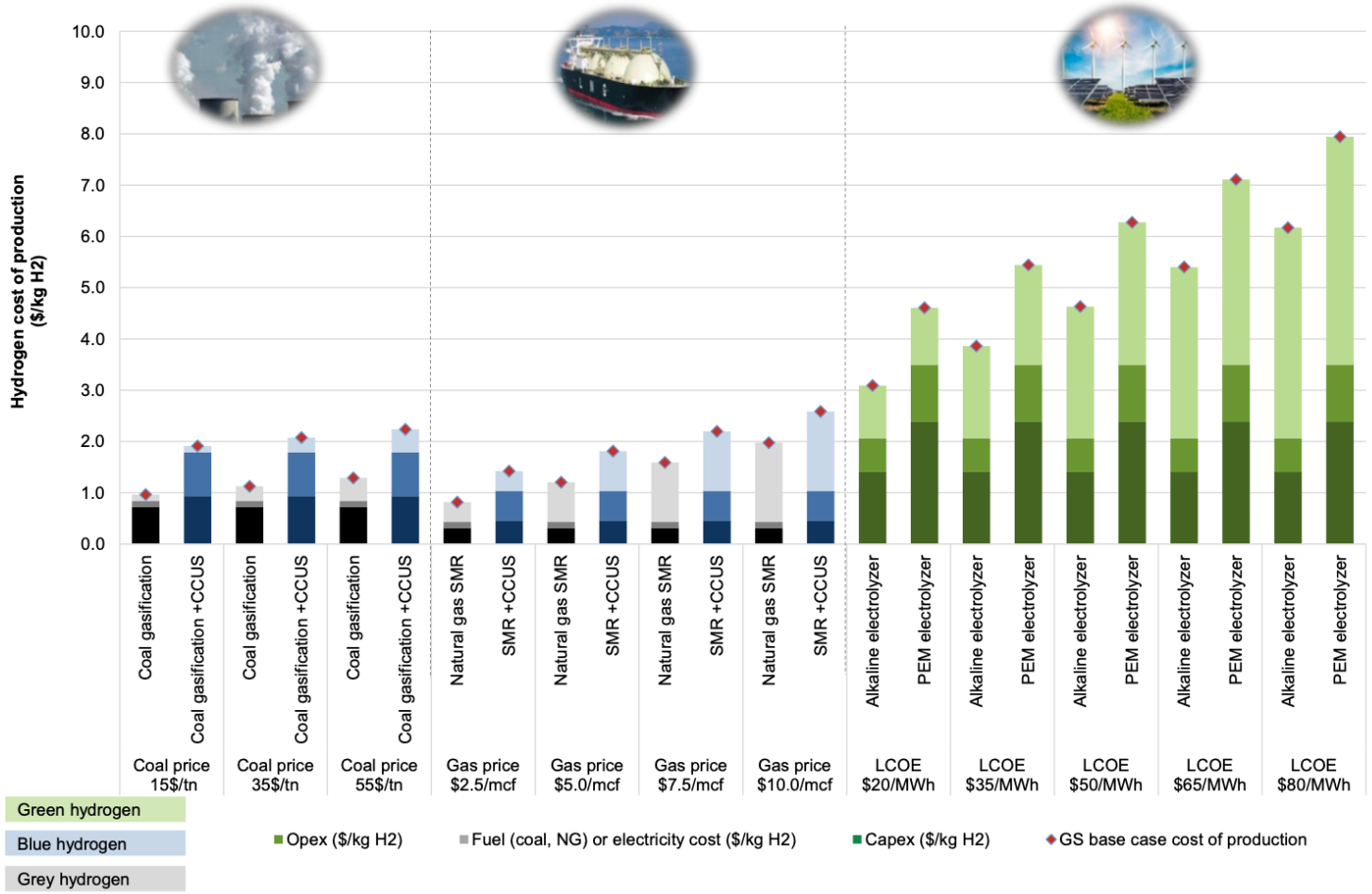
- The 2020 cost of green hydrogen is $6/kg, expected to fall to $2/kg over the next 10 years
- Hydrogen is already becoming competitive for forklifts, heavy transport and backup power
- Hydrogen expected to be cost competitive with a number of conventional alternatives by 2030
- Hydrogen could be the most competitive low-carbon choice for almost all applications by 2050



Source: Hydrogen Council 2020/HydrogenOne Capital

Hydrogen cost structure - supply



Source: Company data, Goldman Sachs Global Investment Research

Hydrogen cost structure – end user

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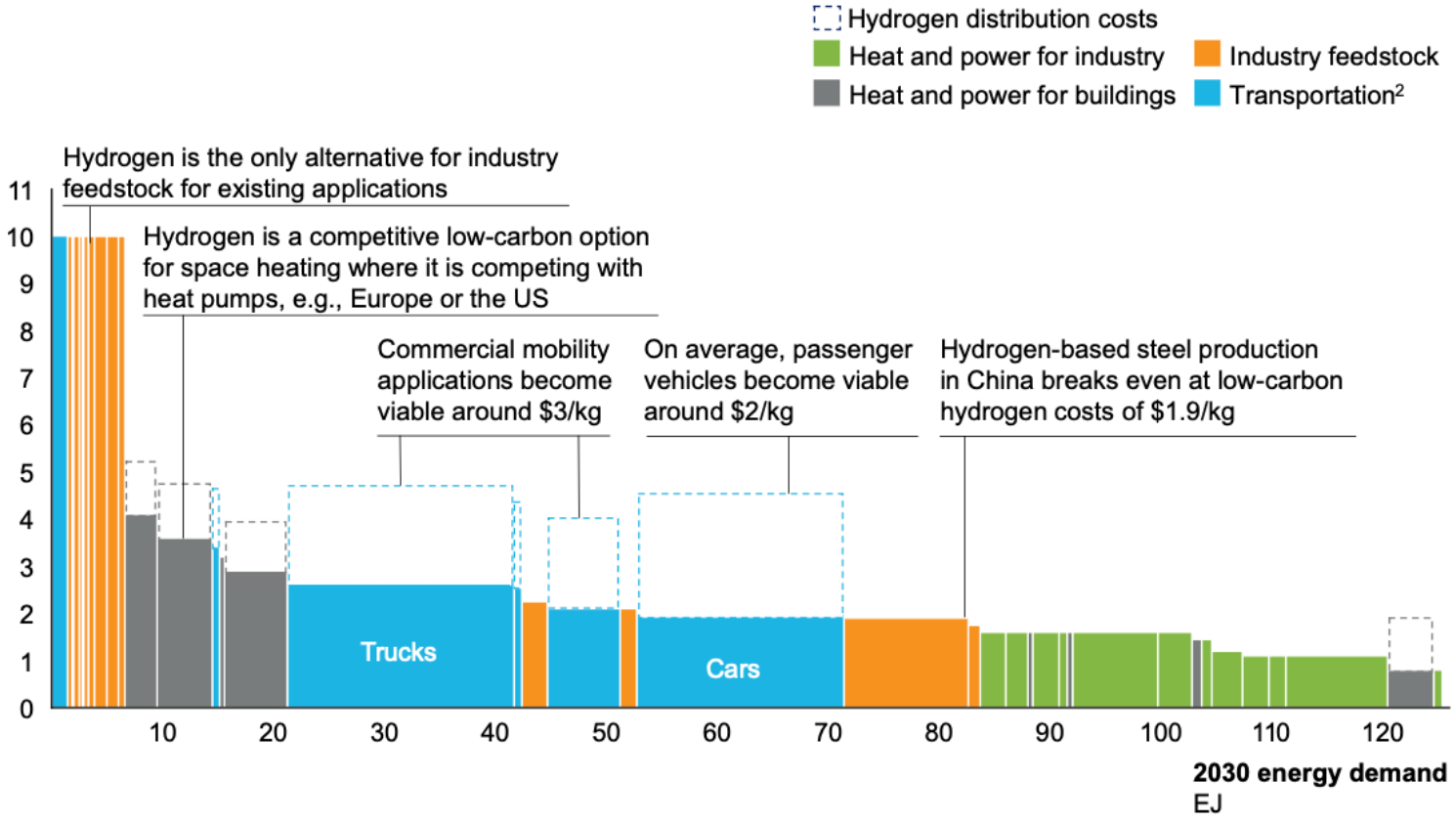
Breakeven hydrogen costs at which hydrogen application becomes competitive against low-carbon alternative in a given segment
USD/kg



1. Regions assessed are the US, China, Japan/Korea, and Europe
2. Transportation segments breakeven calculated as weighted average

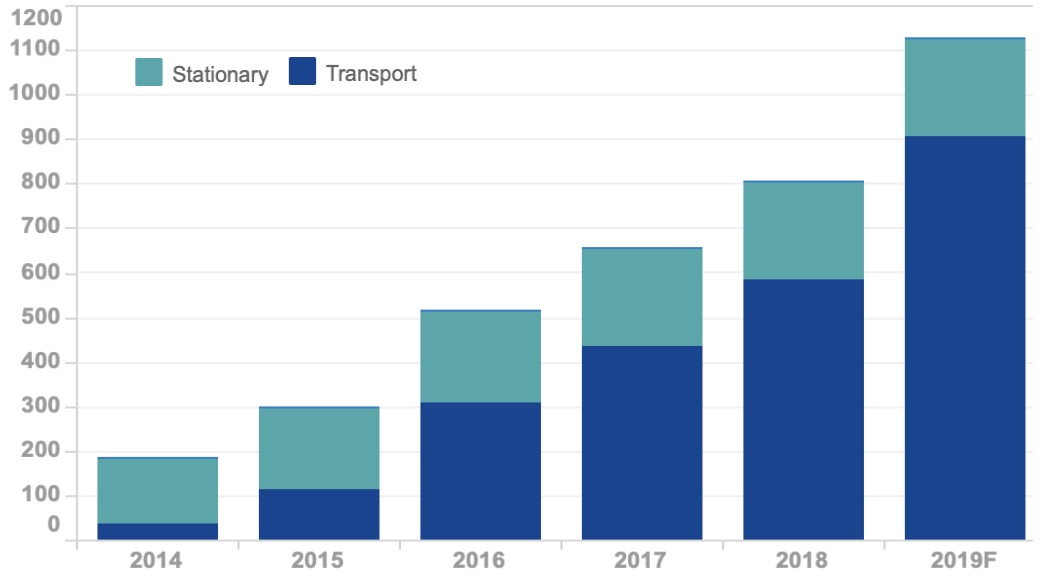
SOURCE: McKinsey; IHS; expert interviews; DoE; IEA

Fuel cells

Fuel cells market growth

- 5X increase in fuel cell sales since 2014
- Market could reach 133GW by 2030 ($12bn/year)
- Growth in heavy transport applications (trucks, trains, forklift)
- Combined heat and power (CHP) 1GW potential 2030 and 18GW 2050

Fuel cells market (MW) by application (Fuel Cells and Hydrogen Observatory)

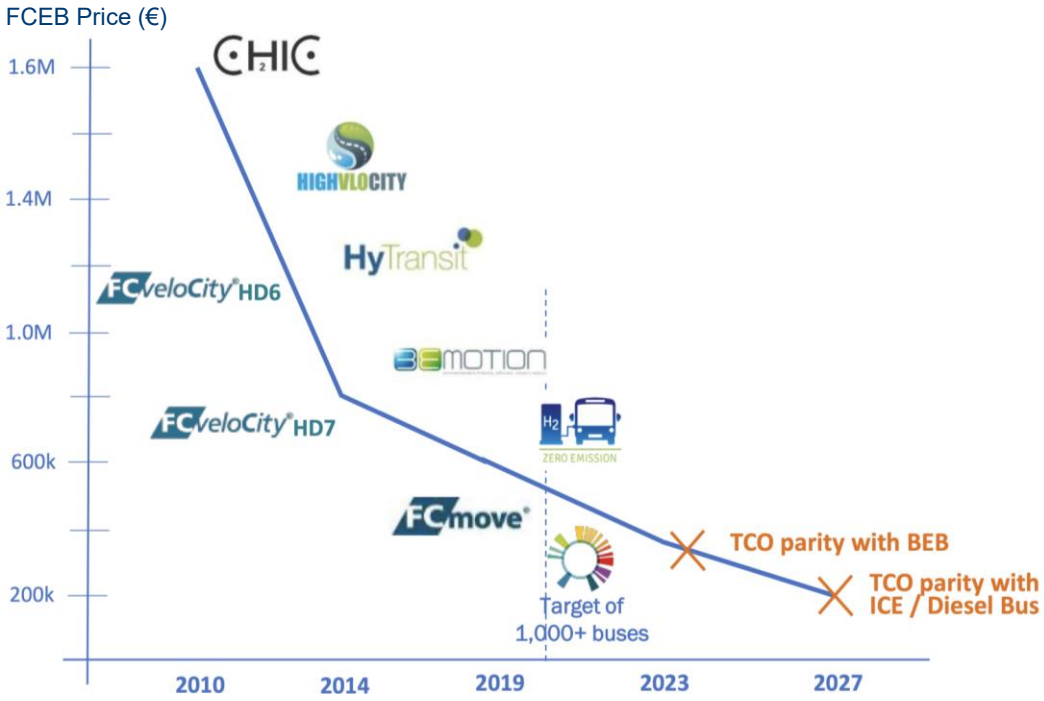


Source: Bernstein, Hydrogen Highway 2020, Ready for prime time, August 2020. Panmure Gordon, The Fuel Cell Market, September 2020.

Cost and scaling opportunities

- Fuel cell costs are set to drop 80% from US$200kW to US$30kW
- Japan, China, South Korea dominate today
- Europe and US potential

Fuel cell costs (buses) - 60% reduction in FCEB price over past 10-years



Source: Ballard

Fuel cell vehicles outlook

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Current and future number of FC vehicles by type and geography

		Passenger vehicles	Buses and Coaches	Trucks	Forklifts	Refuelling stations
US	**Current**	7,271	35 active, 39 in development	Prototype test	>30,000	~42 online
	Target		5,300,000 FCEVs on US roads by 2030		300,000 by 2030	7,100 by 2030
CHINA	**Current**	0	2,000+	1,500+	2	23
	Target	3,000 by 2020 1,000,000 by 2030	11,600 commercial vehicles by 2020			100 by 2020 500 by 2030
EUROPE	**Current**	~1,000+	~76	~100	~300	~152
	Target	3,700,000 by 2030	45,000 fuel cell trucks and busses by 2030			~3,700 by 2030
JAPAN	**Current**	3,219	18	N/A	160	127: 10 in progress
	Target	40,000 by 2020 200,000 by 2025 800,000 by 2030	100 by 2020 1,200 by 2030		500 by 2020 10,000 by 2030	160 by 2020 900 by 2030

Source: Ballard/Deloitte, 2020. Fueling the future of mobility. Hydrogen and fuel cell solutions for transportation

Europe fuels cells bus potential

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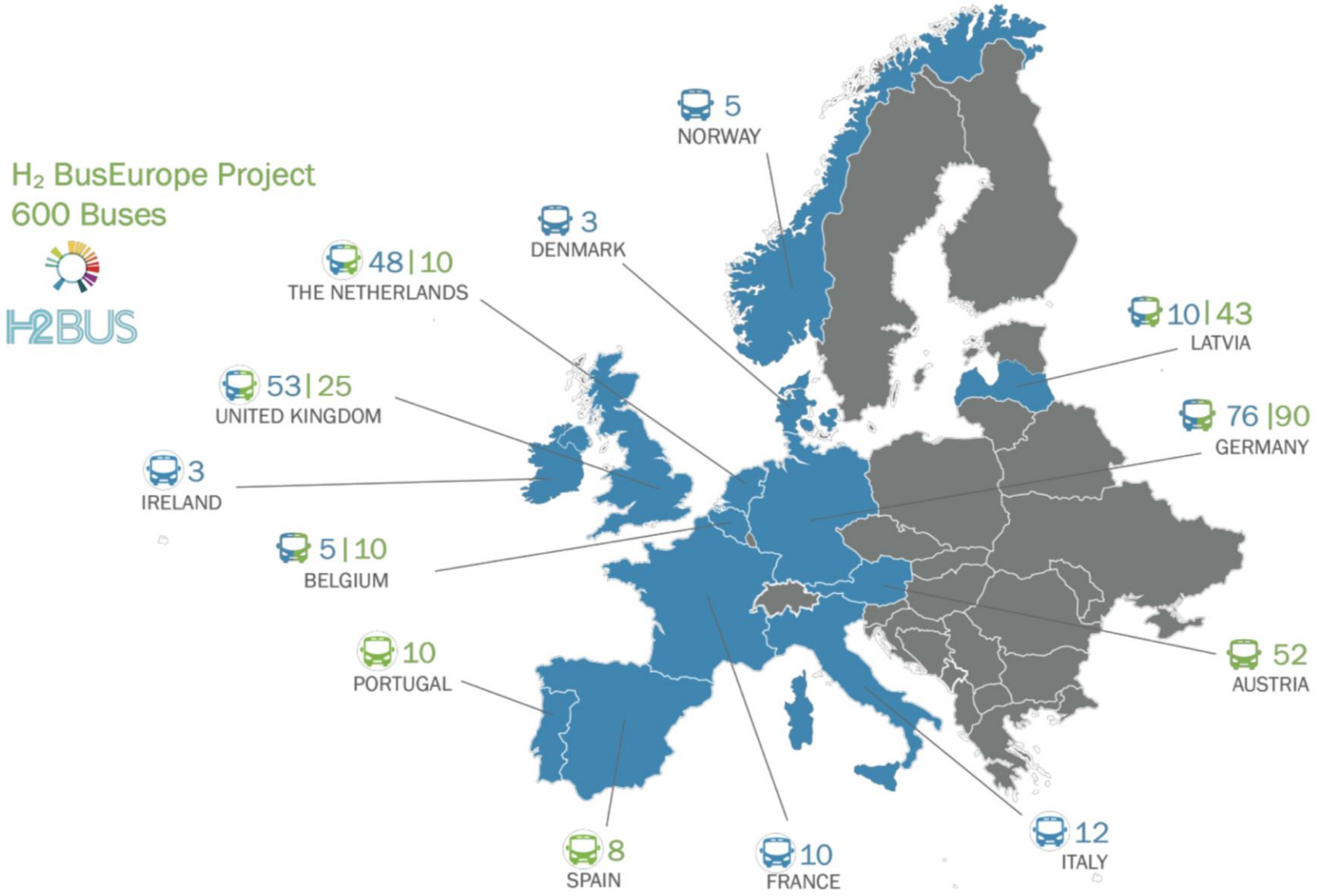
Fuel cell buses Europe

225

Fuel cell buses in revenue service or contracted

248 + 600

Fuel cell buses in planning

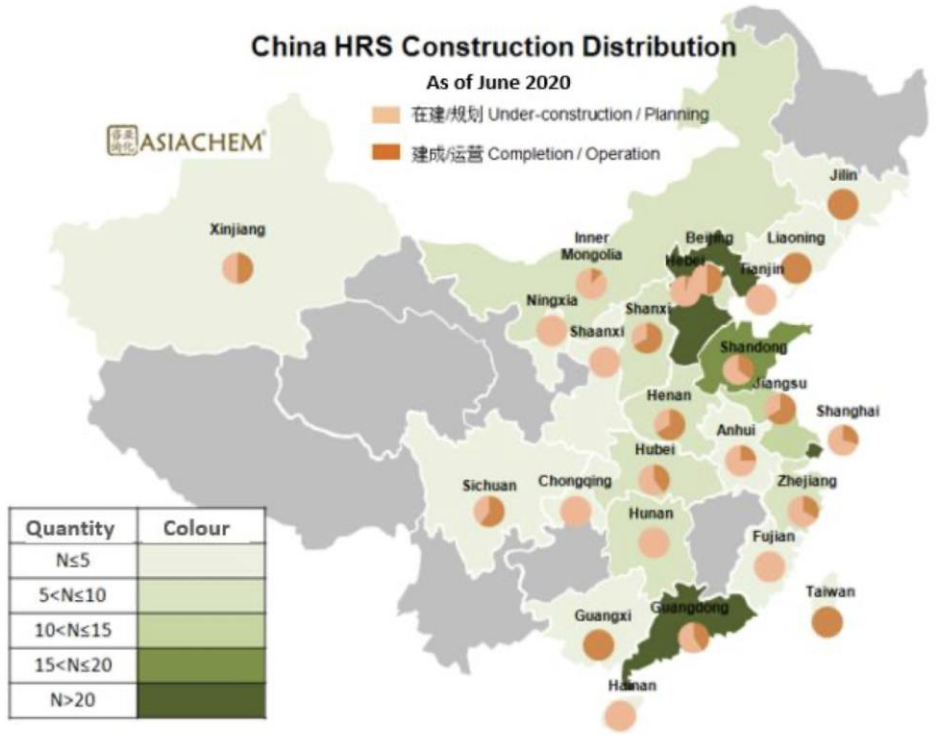


China fuel cell vehicles potential

China FCV Roadmap (2020-2030)			
Year	2020	2025	2030
Number	5,000	50,000	1,000,000

China HRS Development Plan			
Year	2020	2025	2030
Number	100	300	1,000

Source: CAAM



Hydrogen timescales typical of new energy roll-out commercial deployment underway

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- **1960s** – NASA fuel cells on Gemini and Apollo
- **1966** – GM makes first the first FCV
- **1970s** – oil crisis stimulates renewables + hydrogen R&D. First commercial wind farm 1975
- **1980s** – hydrogen used in distributed powergen
- **1990s** – PEM fuel cells emerge for vehicles
- **Early 2000s** - oil spikes and climate change stimulate renewables and hydrogen funding (US/EU)
- **2011-14** onwards – China and Japan hydrogen strategies
- **2014-15** – Toyota and Hyundai launch commercial FCVs
- **2015-present**
  - Modern renewables (wind, solar) reach c.3% of primary energy supply
  - >50,000 FCV and fuel cell forklifts
  - Germany launches first hydrogen trains
  - 5X increase in fuel cell sales
  - Blue and green hydrogen pilots successfully deployed for ‘next-gen’ supplies
  - **Wide uptake of hydrogen in country and corporate ‘Net Zero’ strategies**

Hydrogen economy accelerating

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Key role in the energy mix

8x growth potential in hydrogen supply 2020-2050

Growth driven by net zero targets and air quality improvement policies, combined with lower costs

Hydrogen could be **10%** of energy supply by 2050: 575mtpa

$500bn projected capital cost by 2050

Hydrogen picks up the pace

5x increase in fuel cell sales since 2014 to 1.1GW: 133GW projected by 2030 ($12bn/year)

80% decrease in renewable energy prices since 2010

40x targeted increase in electrolyser capacity to 2030 EU

6 billion tonnes/year **CO_2** potential abatement by 2050

>**50** green hydrogen projects globally announced 2020

Policies and momentum

Government **policy** and industry planning underway. It's a collaborative sector

Trading hubs, blend standards to emerge

Export agenda for renewables from sunny and windy regions eg Middle East, Australia. **Jobs**

EU targeting 14% hydrogen by 2050

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