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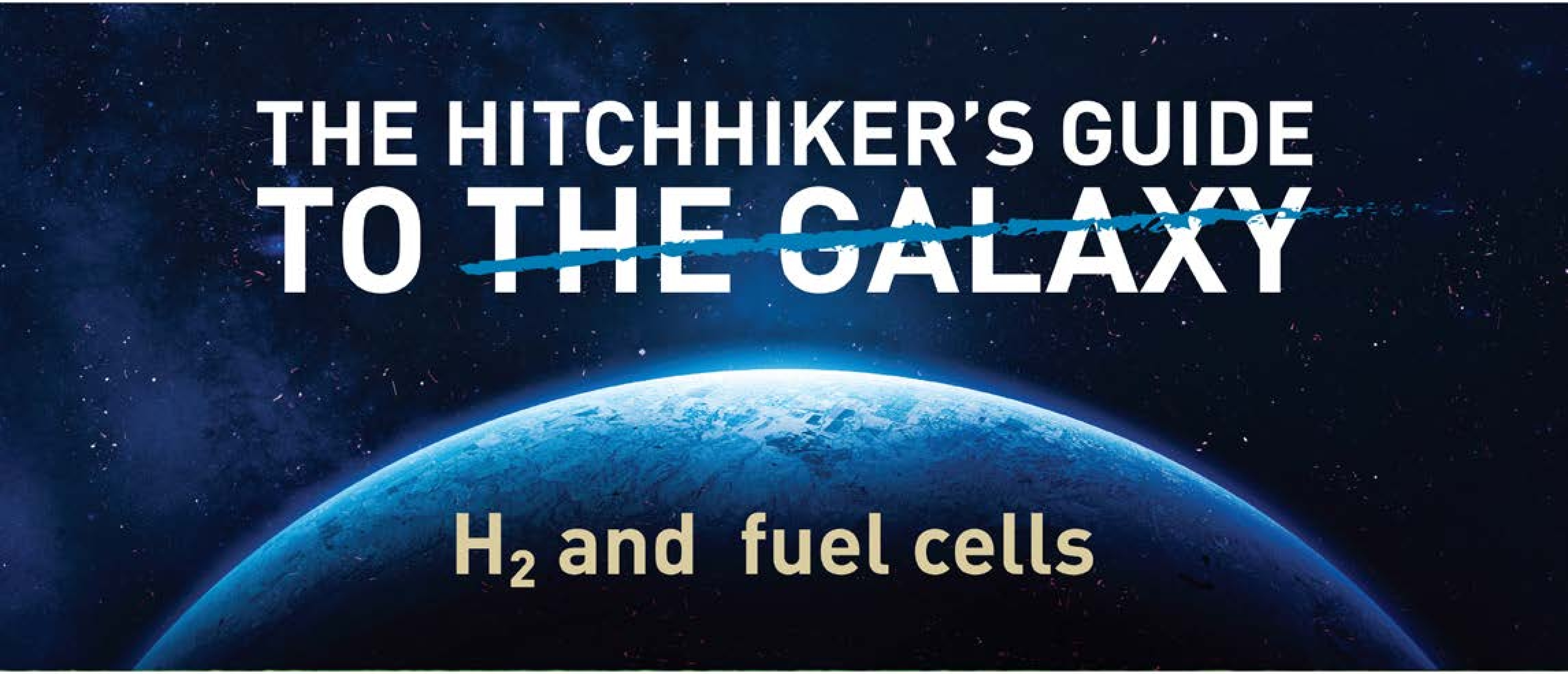
THE HITCHHIKER'S GUIDE TO ~~THE GALAXY~~

H_2 and fuel cells



Real Mining. Real People. Real Difference.

FOREWORD

Chris Griffith
Chief executive officer

Platinum groups metals have a significant role to play in unlocking a global de-carbonised energy system.

The world's current energy system is reliant on carbon intensive fossil and other fuels with the associated negative impact on climate change and global warming. There is however a decarbonised alternative in the form of the hydrogen economy and PGM-based technologies through proton exchange membrane fuel cells and electrolysis to unlock the versatility of hydrogen as an energy source.

The hydrogen infrastructure needed to support the hydrogen economy is already being rolled out in early adopter markets such as California, Europe, Japan, Korea and China. Availability of this infrastructure enables the deployment of proven fuel cell electric vehicles (FCEVs) which are already commercially available and include, amongst others, the Toyota Mirai, Honda Clarity, Hyundai ix35 and Nexo. Alongside these passenger vehicles, hydrogen fuel cell powered forklifts have already realised commercial success. More recently, in heavy duty applications, Ballard announced the planned deployment of 500 fuel cell trucks and 28 fuel cell buses, with another 90 buses to be built by the end of 2018. In addition, Anheuser-Busch has reserved up to 800 fuel cell trucks from Nikola Motor Company for their delivery fleet.

Specifically in China, the Government's New Energy Vehicle programme, and associated subsidies, has been very successful in stimulating the market for electric vehicles, with hundreds of vehicles already being deployed. A comprehensive FCEV roadmap has been drawn up by the Society of Automotive Engineers of China which envisions 50,000 FCEVs on the road in the next seven years and 1 million by 2030. This roadmap is underpinned by the stated objectives for hydrogen and fuel cells in the 13th Five-Year Plan and the 'Made in China 2025' initiative. There are also local government initiatives in cities such as Rugao, Foshan, Suzhou, Taizhou and Yunfu that have set up hydrogen energy town projects to promote the development of an integrated fuel cell and hydrogen industry.

Whilst Johnson Matthey (JM) estimates that around 40,000 ounces of platinum were used in fuel cells in 2017, FCEVs are expected to be an important future demand driver for the metal. JM estimates platinum demand from FCEVs could reach the equivalent of 5% of autocatalyst demand by 2025.

There are still barriers to wide-scale adoption of hydrogen as an energy source, and consequently FCEVs. Hydrogen technology roll-out will require large-scale investment and effort and therefore a stable, co-ordinated, long-term regulatory framework, with associated incentive policies, is needed. We are starting to see this happen in reality, and the Anglo American Platinum 'Demand for PGMs China roadshow' from 12 to 16 November 2018 was intended to showcase some of these developments.

This booklet was developed as a 'hitchhiker's guide' to hydrogen and fuel cells as a background and reference booklet for those attending the roadshow and is also available on the company's website.

PGMS UNLOCK THE HYDROGEN ECONOMY

China is at the forefront of scaling H_2 and FC technology production and adoption

- **Hydrogen (H_2)** will, for several reasons, play a significant role in decarbonising[1] the world's energy
- **Platinum group metals (PGMs)** based technologies (specifically PEM[2] fuel cells and electrolysers) unlock the versatility of hydrogen as an energy source. These are proven technologies
- The use of **fuel cells (FCs)** is growing across a multitude of applications and is no longer in the R&D phase – especially in automotive and other mobility applications
- Platinum is the **only** metal that can withstand the acidic conditions inside a PEM fuel cell and is the most efficient catalyst for speeding up the chemical reactions inside fuel cells and electrolysers.
- PEM platinum containing fuel cells are ideal for FCEVs because they can operate at low temperatures, ideal for stop-start nature of driving, and their power to size ratio is high (good power density)
- Supporting H_2 infrastructure is steadily being built in key automotive markets (e.g. California and China) and governments continue to implement supporting policies to accelerate the adoption of fuel cell electric vehicles (FCEVs)
- With scale comes cost reduction. Today's technologies, if manufactured at scale (~100,000 units p.a.), can already achieve significant cost reductions, coming close to the FC system cost targets set by the US Department of Energy (DOE) for 2020 of USD40/kW
- **China is at the forefront of scaling H_2 and FC technology production and adoption**, offering significant subsidies. Major Chinese auto OEMs are investing in FC development and production. Thousands of FC vehicles (medium duty trucks, buses) are rolling off production lines in the country
- Platinum and other PGMs will continue to play a part in traditional automotive markets **<u>and</u>** they will also play a major part in the clean mobility (and broader industry) markets of the future

1. Key to addressing climate change and the ability to reverse global warming
2. Proton exchange membrane (PEM) fuel cell has platinum on both the anode and cathode

Notes: See page 16 for how a PEM fuel cell works
A list of acronyms is included in the appendix

HYDROGEN

The fuel of the future?

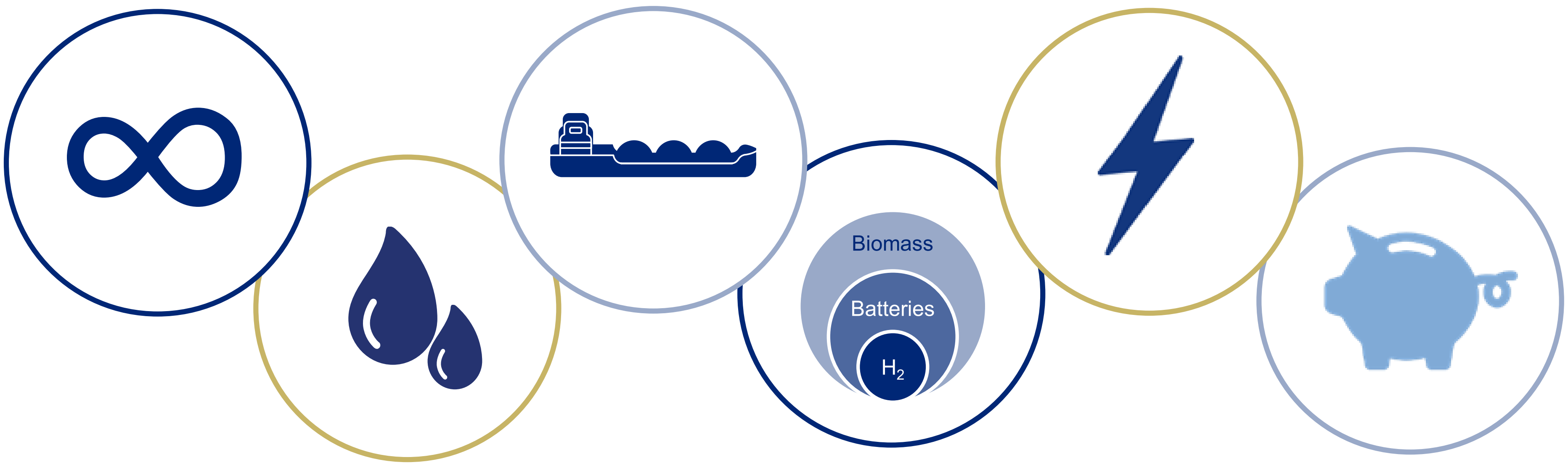
H_2 – VERSATILE, ZERO-EMISSION AND EFFICIENT ENERGY CARRIER

H_2 will play a significant role in decarbonising the world's energy system

Infinite supply

Easily transported
in large volumes

Produces **clean power**
and/or heat at the point of use



Can be produced with
no carbon footprint
from multiple sources

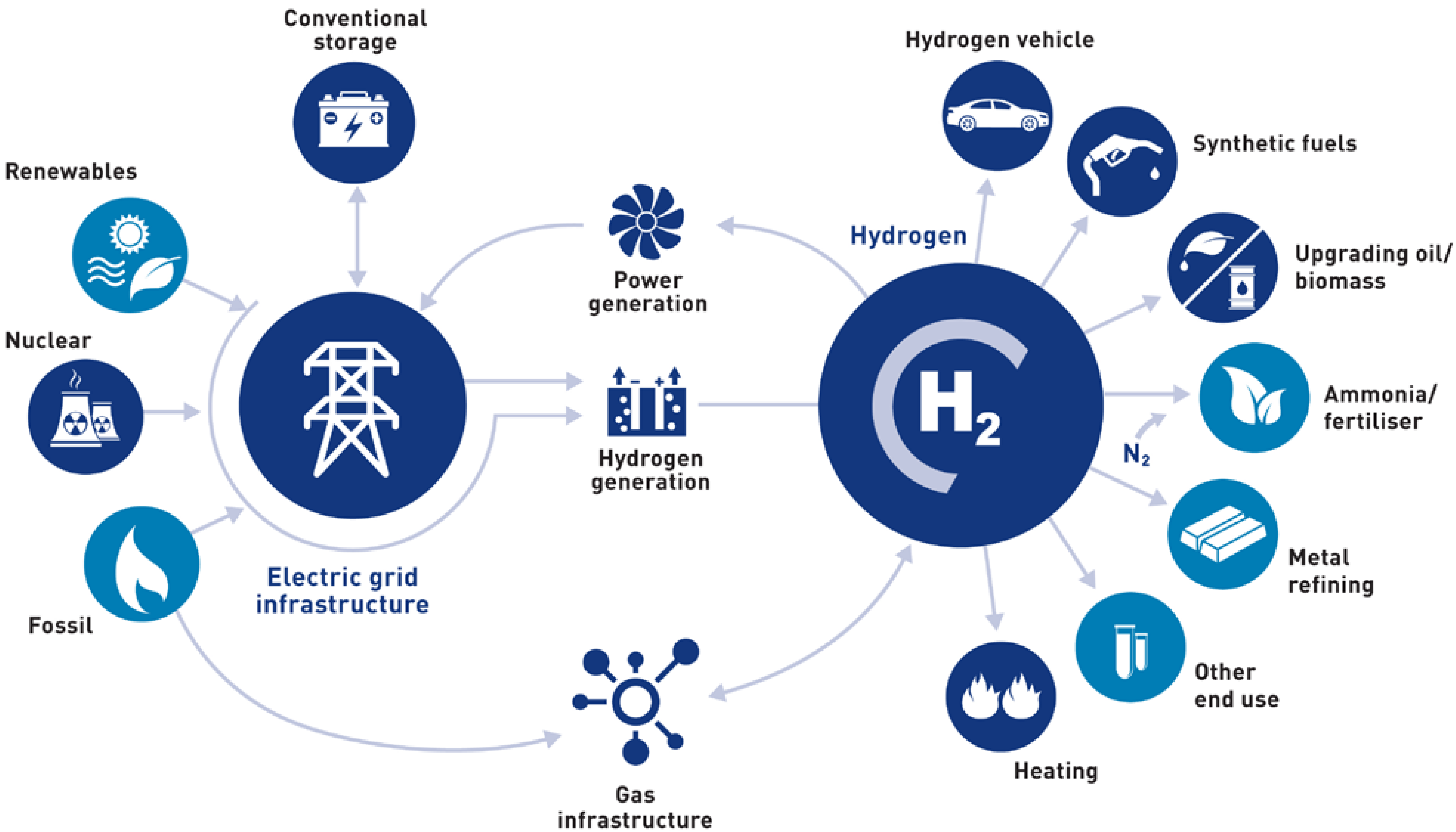
High **energy density**

Can be stored
in large quantities
and for long periods

Source: Hydrogen Council

H_2 ENABLES MULTI-SECTOR DECARBONISATION

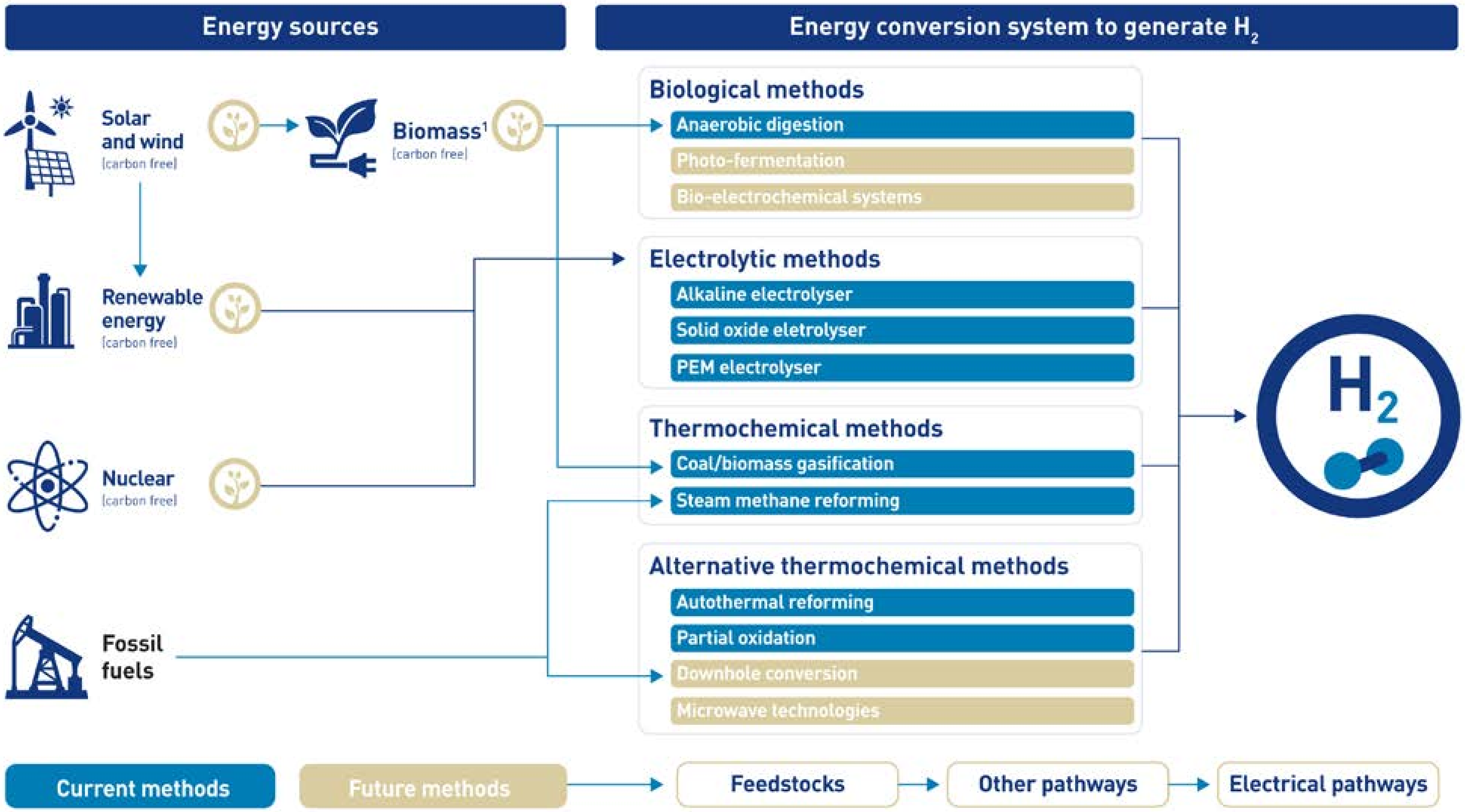
H_2 will play a significant role in decarbonising the world's energy system



Source: US Department of Energy, "H2@SCALE"

H_2 PRODUCED FROM MULTIPLE SOURCES, IN MULTIPLE WAYS

Hydrogen can be 100% carbon-free when produced using renewable energy



Source: The Royal Society: Options for producing low-carbon hydrogen at scale, Jan 2018

1. Biomass: organic matter used as a fuel

See pages in appendix detailing how energy conversion systems listed in the right-hand column work

H_2 AT SCALE, WILL BE COST COMPETITIVE WITH DIESEL AND GASOLINE

H_2 produced via electrolysis (CO_2 free) on track to be competitive with the gasoline

US DOE costs status and targets
H_2 production, delivery and dispensing

- **USD16/gge* to USD10/gge** ← Current technology low-volume estimate
- **USD7.5**/gge** ← High-volume projection (electrolysis)
- **to USD5/gge** ← High-volume projection (natural gas SMR***)
- **USD4/gge** ← US DOE 2020 target for renewable H_2 produced, delivered and dispensed

H_2 ~7.00/gge

Target at which H_2 for FCEVs is competitive on a cost per mile basis with gasoline fuel for competing vehicles in the early market timeframe of 2015 to approximately 2020

H_2<$4.00/gge

This cost results in equivalent fuel cost per mile for hydrogen FCEVs compared to gasoline hybrid vehicles in 2020. (i.e. advanced next generation ICE technology)

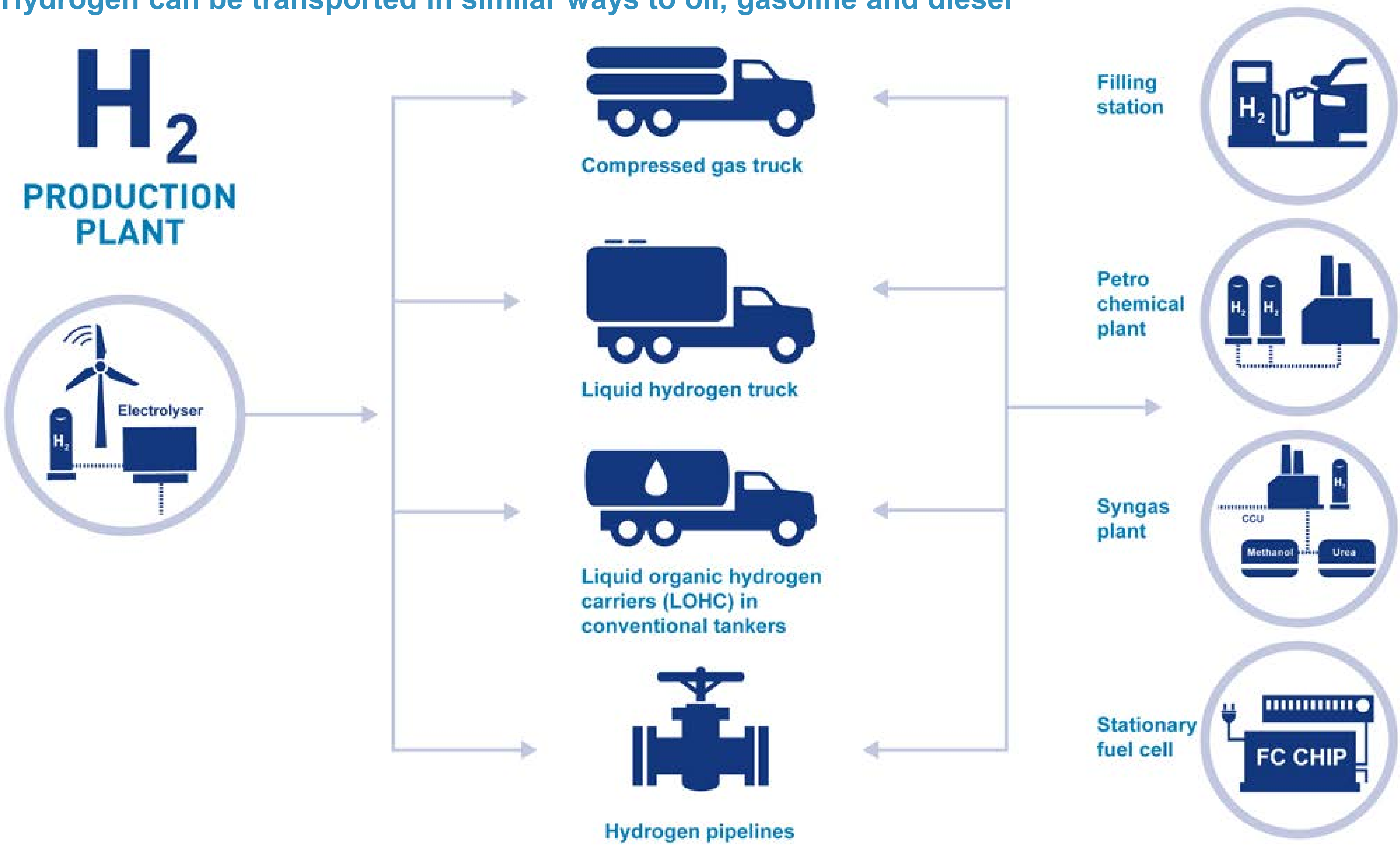
Source: NREL

** US DOE estimates the hydrogen threshold cost – the sweet spot for competition of fuel cell electric vehicles (FCEVs) with hybrid electric vehicles (HEVs) to be USD2.00-USD4.00/gge (*gallon gasoline equivalent) on a cost per mile basis in 2020. Note: 1kg H_2 is ~1gge

*** SMR – steam methane reforming

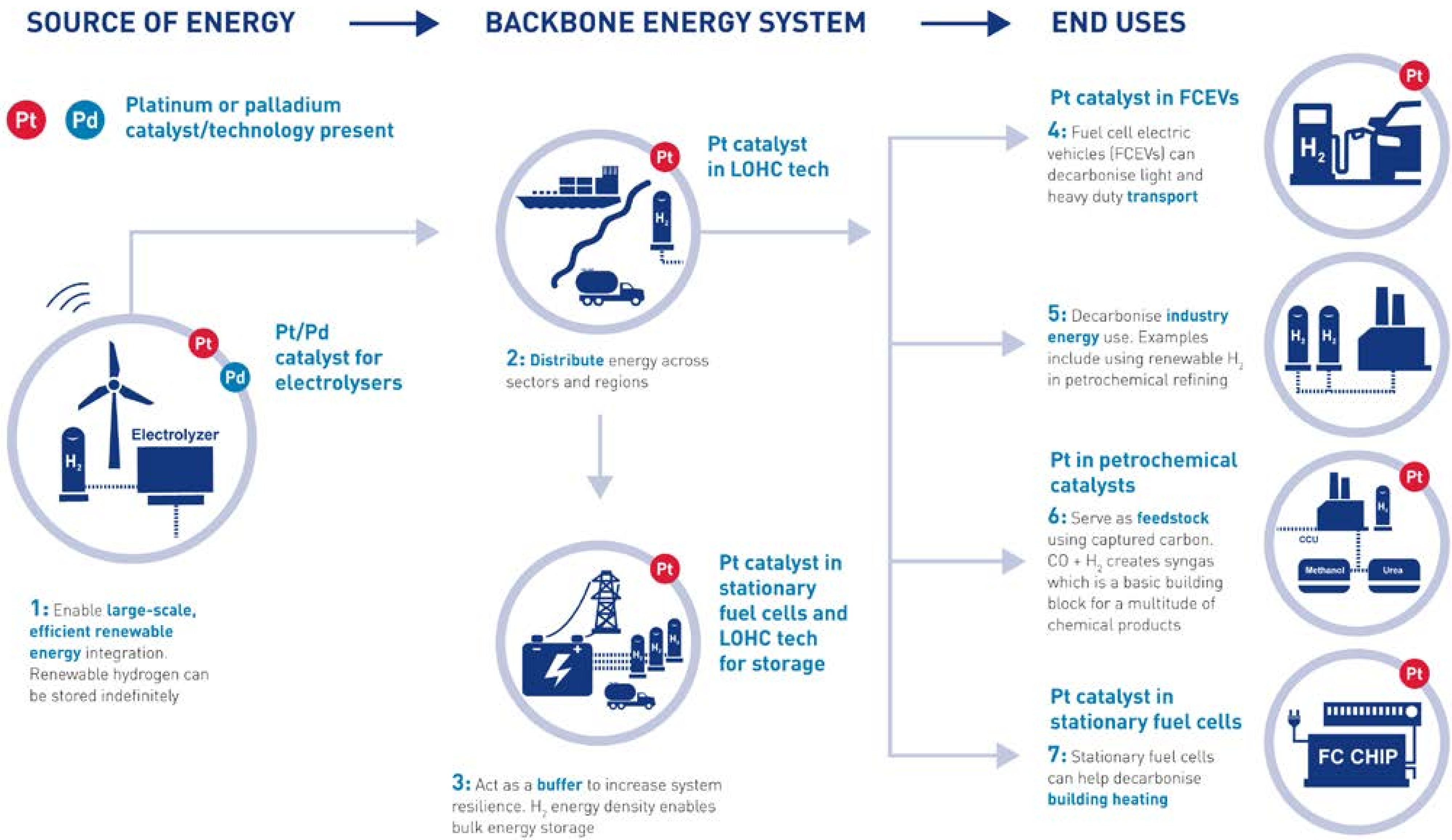
H_2 IS STORED AND TRANSPORTED IN SEVERAL FORMS

Hydrogen can be transported in similar ways to oil, gasoline and diesel



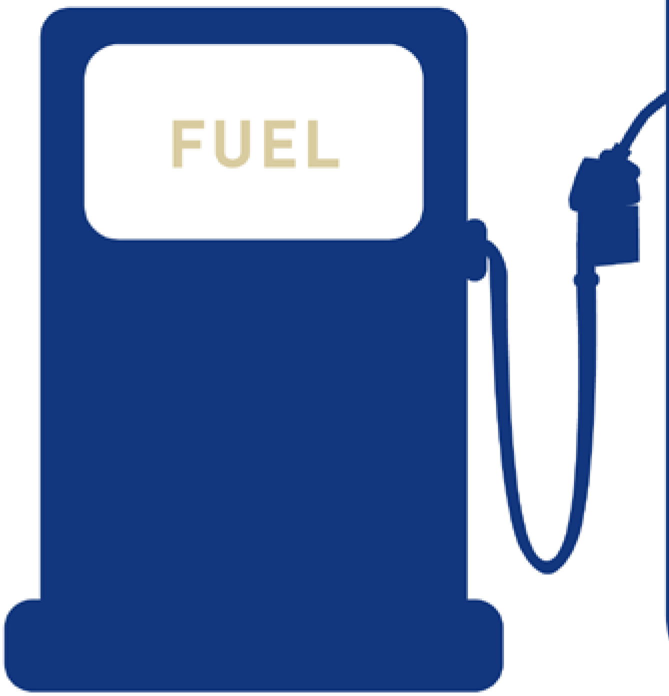
H_2 CAN REDUCE EMISSIONS IN DIFFICULT TO DECARBONISE SECTORS IN SEVEN WAYS

…and this can only be done with two key PGM-containing technologies



Source: Hydrogen Council; Anglo American Platinum

H_2 IS A VERY EFFICIENT CARRIER OF ENERGY



COMPARISON OF THE CALORIFIC VALUE OF VARIOUS TYPES OF FUEL

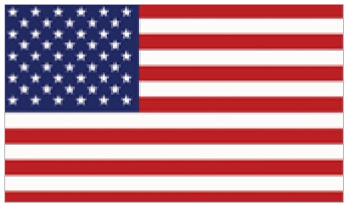
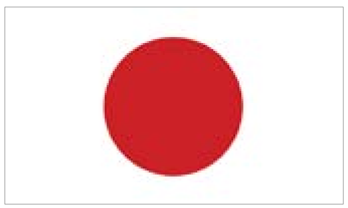
Calorific value is a measure of the thermal energy released when a substance is burned. It is expressed in megajoules per kilo of fuel (Mj/kg) or in kilowatt hours per kilo of fuel (kWh/kg).

The table below compares the gross calorific value of fuels commonly used for heating, transport or electricity production.

	Mj/kg	kWh/kg
• Coal	20	8
• Petrol	47	9
• Diesel	44	10
• Natural gas	50	10
• Hydrogen	142	39

FIRM TARGETS SET FOR H_2 REFUELING STATIONS AND VEHICLES

Roll-out of infrastructure in key automotive markets enables large-scale adoption

Country	Hydrogen station status and targets	Vehicle status and targets
	• Today: ~11 • 2020: 100 • 2030: 520	• Today: ~200 • 2020: 10,000 • 2030: 630,000
	• Today: 65 (open and planned) • 2020: 100 • 2025: 200 • 2030: 1,000* (Industry target)	• Today: ~5,350 (light duty only) • 2025: 200,000 • 2030: 1,000,000 (Industry target)
	• Today: 12 open, 24 planned • 2020: 100 • 2025: 1,000 • 2030: 3,000	• Today: <500 • 2020: 5,000 • 2025: 50,000 • 2030: 1,000,000
	• Today: ~100 open • 2020: 160 • 2025: 320	• Today: ~2,800 (light duty only) • 2020: 40,000 • 2025: 800,000
	• EU: 520 by 2020; up to 2,000 by 2025 (Hydrogen Council) • Germany: 400 by 2023 • France: 100 by 2019	• France: 1,000 by 2020

Note: Not all countries with H_2 activities are included here

FEWER H_2 STATIONS CAN REPLICATE CURRENT REFUELLING NETWORK – Infrastructure smartly rolled out

Well placed and sized refuelling stations can replicate current gasoline network

Density map of 8,000 retail stations in California

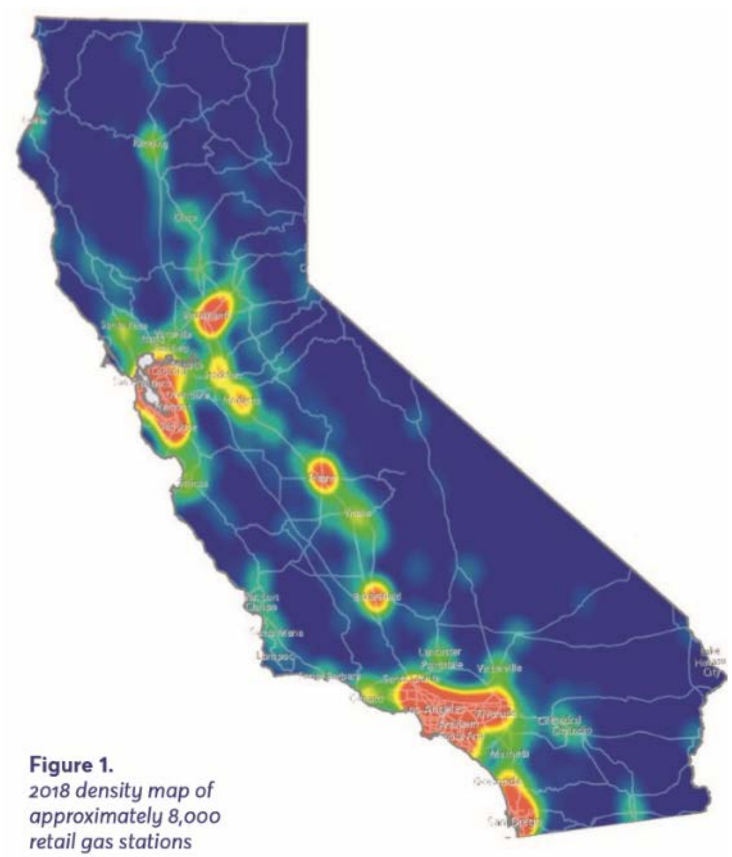


Figure 1.
2018 density map of approximately 8,000 retail gas stations

Density map of 1,000 hydrogen stations in California

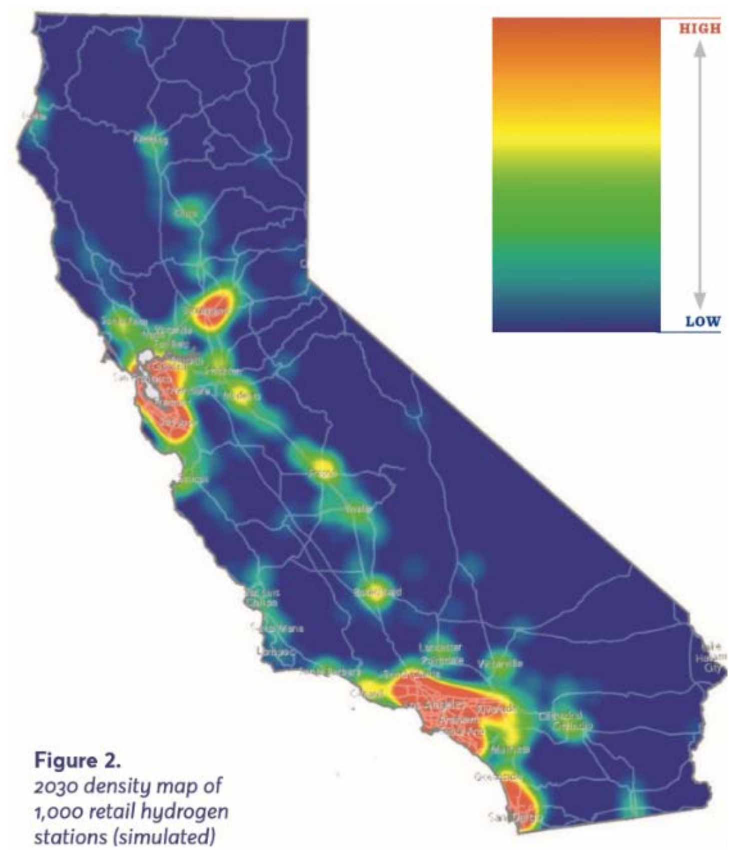
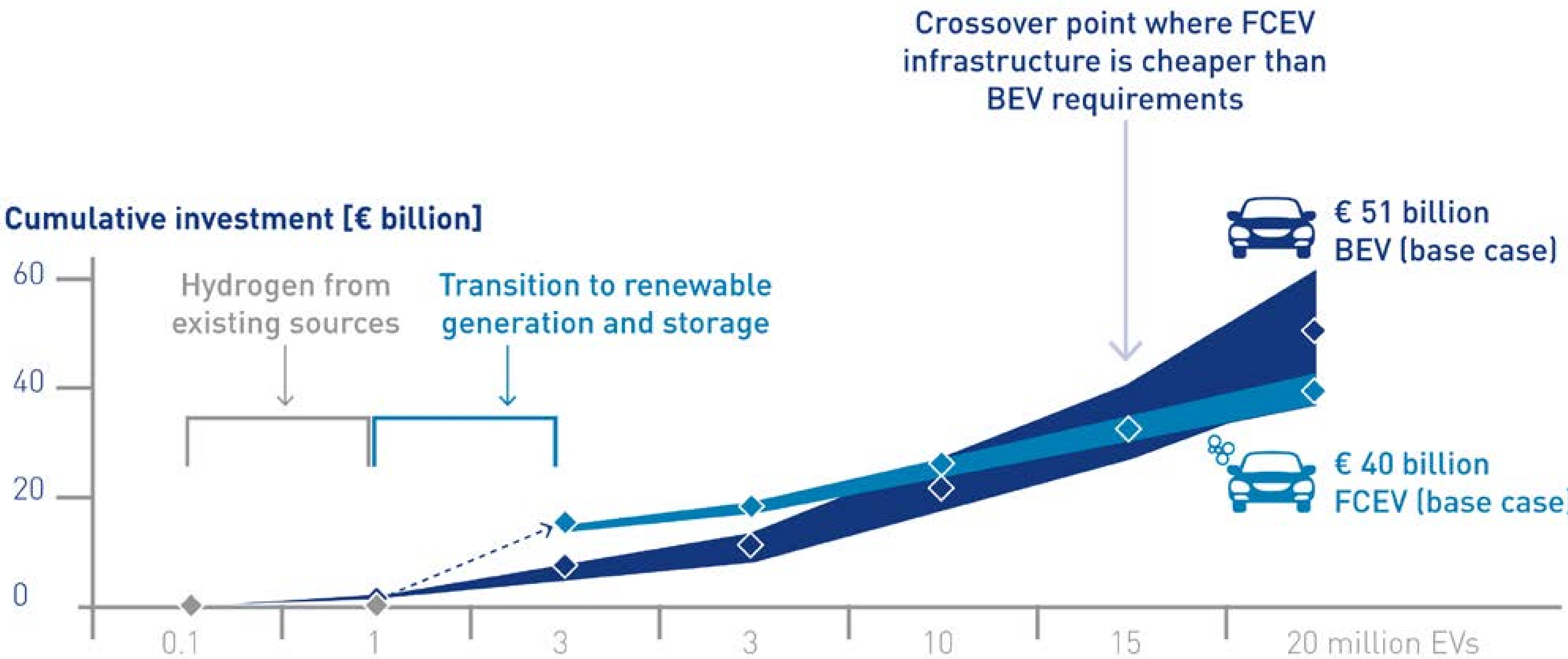


Figure 2.
2030 density map of 1,000 retail hydrogen stations (simulated)

Source: California Fuel Cell Partnership, California Air Resources Board

FCEV INFRASTRUCTURE CAN BE CHEAPER THAN BEV

Cheaper to have H_2 infrastructure for FCEVs once more than 15 million BEV vehicles in use



Cost projection for hydrogen fuelling vs electric charging infrastructure in Germany, as a function of the size of the fleet to be serviced

Source: H_2 Mobility Germany - http://h2-mobility.de/wp-content/uploads/2018/01/Energie-und-Umwelt_408_Robinius-final.pdf
Example based on German automotive market

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FUEL CELLS

2018 Hyundai Nexo Fuel Cell SUV

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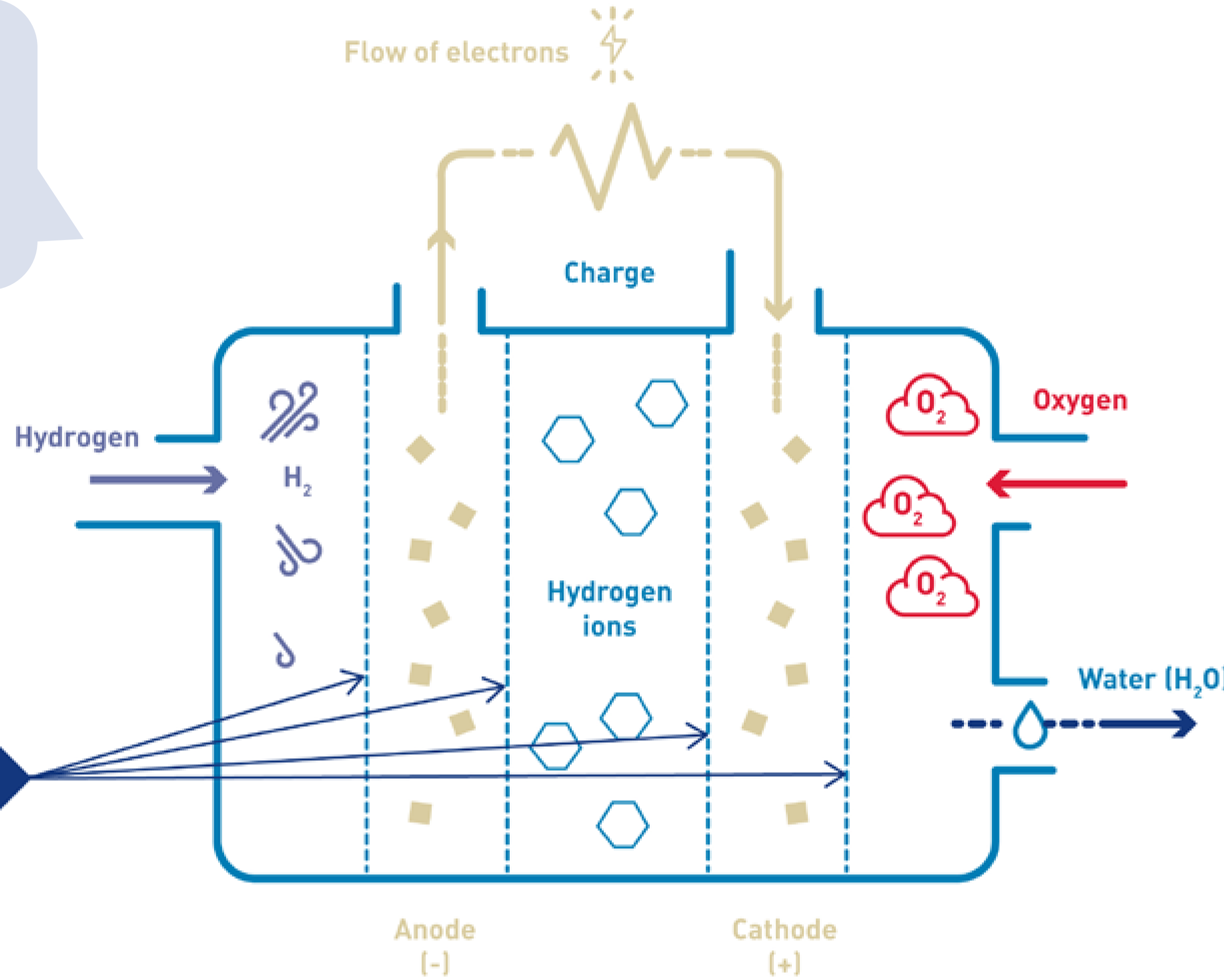
TWO KEY PGM-CONTAINING TECHNOLOGIES IN FUEL CELLS

Fuel cells take in H_2 and O_2 (from the air) and produce electricity and water; **electrolysers** take electricity and water in to produce H_2 and O_2

Platinum is the only metal that can withstand acidic conditions inside a PEM fuel cell and is the most efficient catalyst

PEM fuel cells and electrolysers have platinum catalysts on both the anode and the cathode



Source: Graphic from Airliquide
Proton exchange membrane

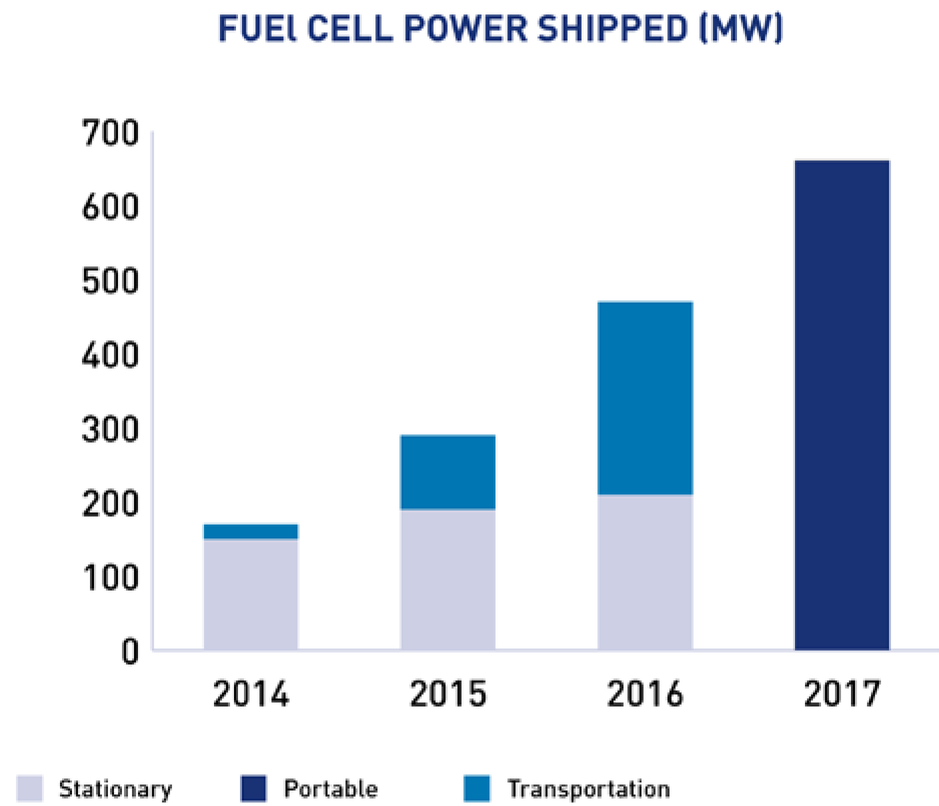
FUEL CELLS ARE USED IN STATIONARY, PORTABLE AND TRANSPORT APPLICATIONS

Stationary

Portable

Transport

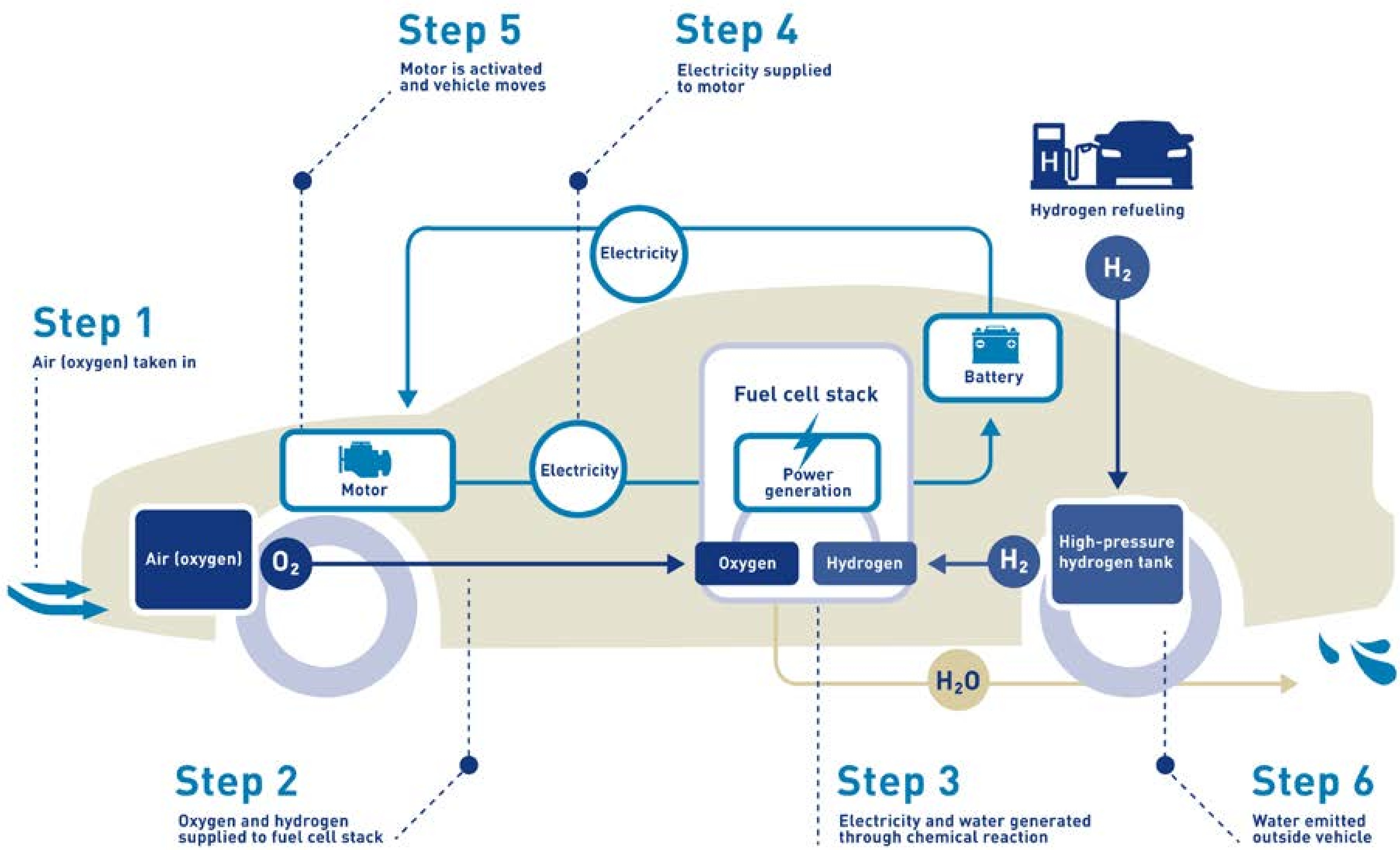
Platinum containing polymer electrolyte membrane **(PEM)** fuel cells now dominate FC sales. Only PEM fuel cells are used in **transport applications** due to energy and heat aspects required as a result of stop-start nature of driving a vehicle



Source: E4 Tech

FUEL CELL ELECTRIC VEHICLE – HOW DOES IT WORK?

Contains between 10g to 20g of platinum in the fuel cell stack, depending on the vehicle size



Source: Toyota

FUEL CELL ELECTRIC VEHICLE TECHNOLOGY EXPLAINED

Understanding the main components of a fuel cell electric vehicle - Toyota Mirai

Fuel cell booster converter

A compact, high-efficiency, high-capacity converter newly developed to boost fuel cell stack voltage to 650 V. A boost converter is used to obtain an output with a higher voltage than the input.

Power control unit

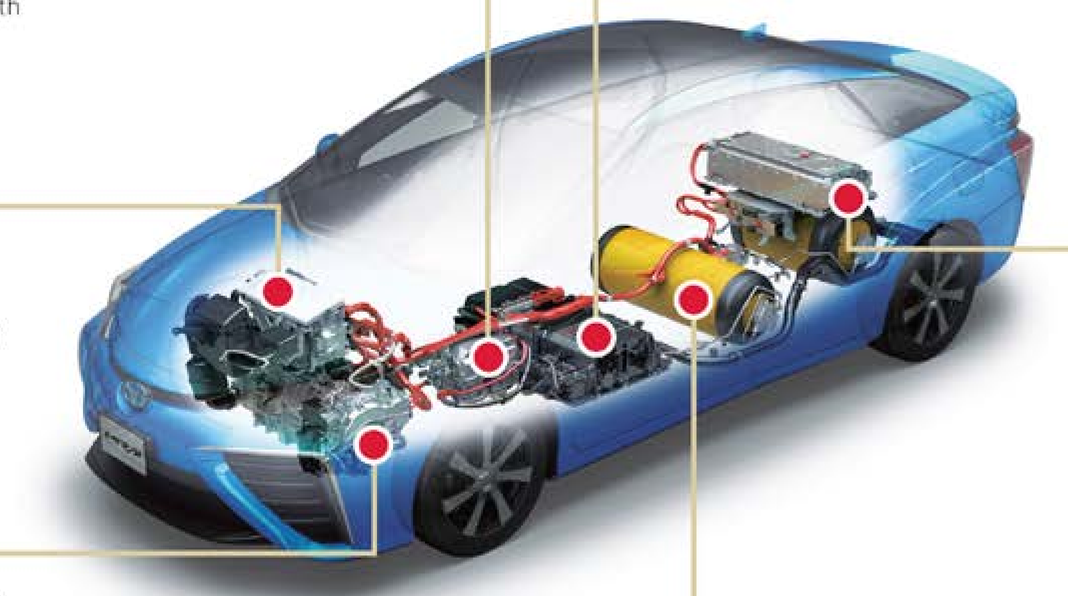
A mechanism to optimally control both fuel cell stack output under various operational conditions and drive battery charging and discharging.

Motor

Motor driven by electricity generated by fuel cell stack and supplied by battery.

Maximum output: 113 kW (154 DIN hp)

Maximum torque: 335 N-m



Fuel cell stack

Toyota's first mass-production fuel cell, featuring a compact size and world top level output density.

Volume power density: 3.1 kW/L

Maximum output: 114 kW (155 DIN hp)

Battery

A nickel-metal hydride battery which stores energy recovered from deceleration and assists fuel cell stack output during acceleration.

High-pressure hydrogen tank

Tank storing hydrogen as fuel. The normal working pressure is a high pressure level of 70 MPa (700 bar). The compact, lightweight tanks feature world's top level tank storage density.

Total storage density: 5.7 wt%

Source: Toyota

FCEVS OFFER SEVERAL ADVANTAGES

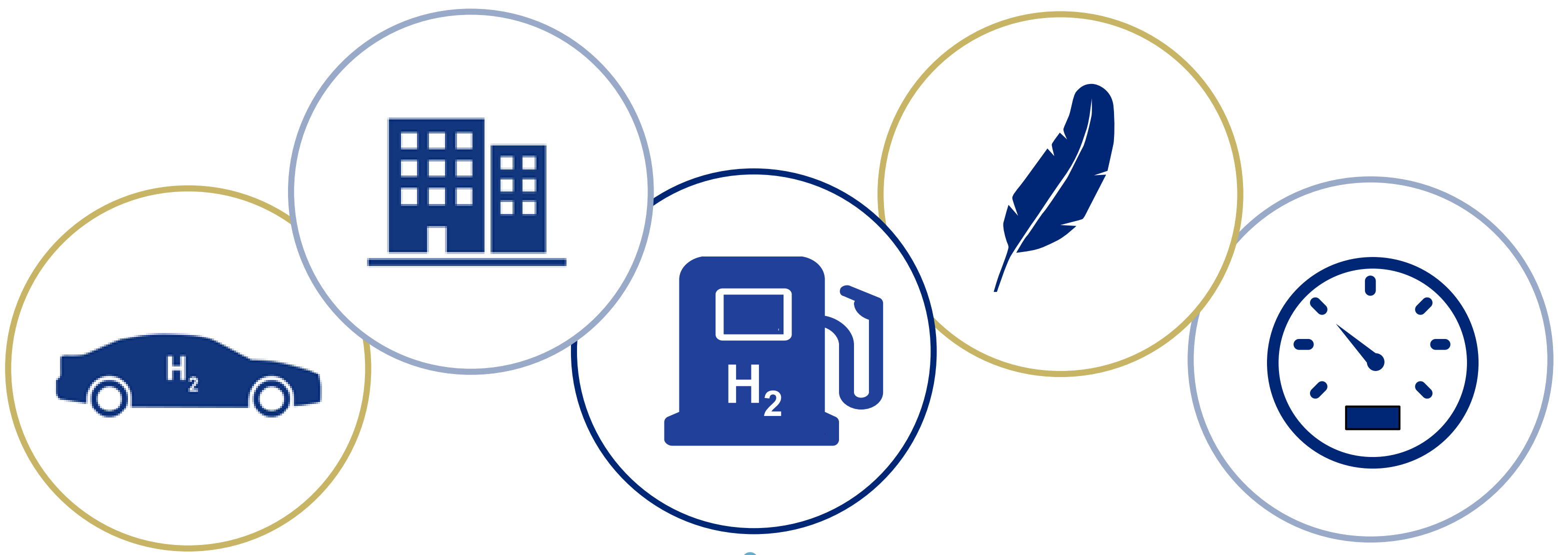
FCEVs compare favourably to gasoline and diesel – fast refuelling and longer driving range

Can build on existing infrastructure

- Help preserve local jobs
- Reuse of existing assets
- Distribution infrastructure

Fast refuelling

- 3-5 minutes
- High customer convenience



Zero local emissions

- No pollutants from vehicle
- No CO_2
- Improved air quality

High energy density

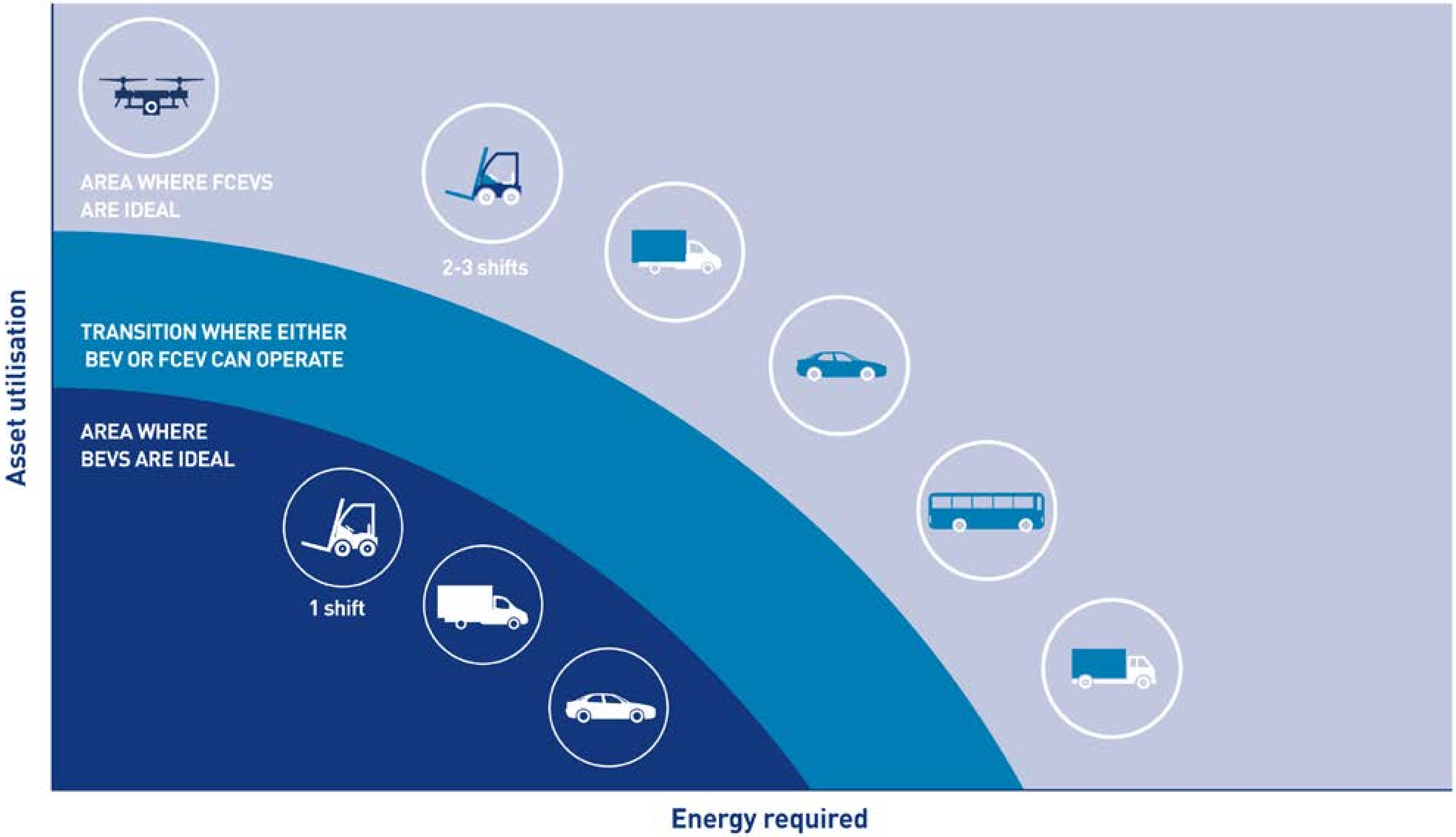
- Less storage weight enhances payload
- Suitable for heavy duty and high utilisation applications

Long driving range

High customer convenience

FCEV: HIGH UTILISATION, HEAVY LOADS, LONG RANGES

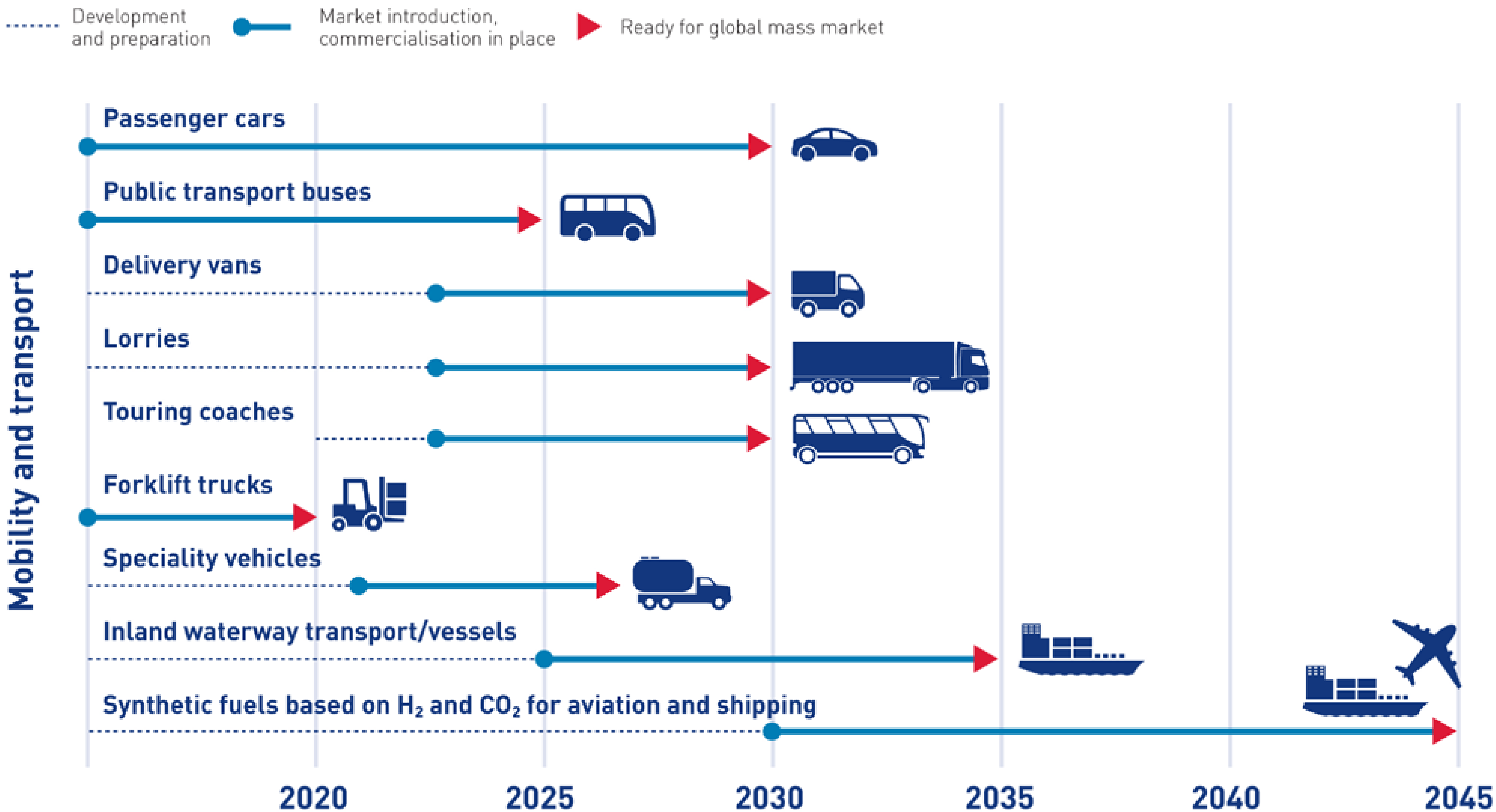
FCEVs ideal for heavy loads, high utilisation and long-range applications



Source: PlugPower

FUEL CELL TECHNOLOGY IN VEHICLES IS HERE TODAY

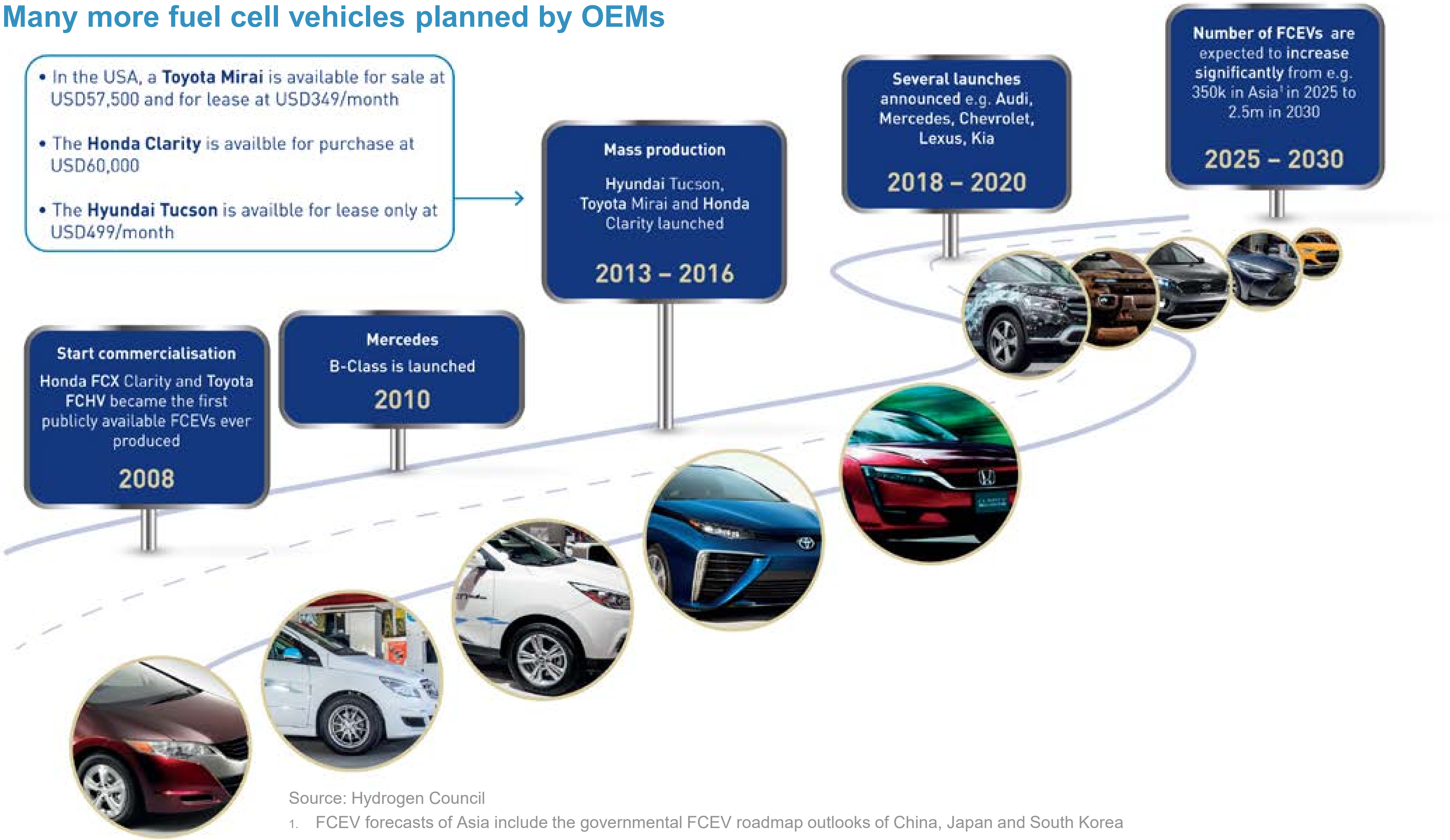
Fuel cells are already finding application across multiple transport applications



Source: TKI NIEUW GAS Topsector Energie – Outlines of a Hydrogen Roadmap

LEADING AUTO OEMS OFFER COMMERCIALLY AVAILABLE FCEVS

Many more fuel cell vehicles planned by OEMs



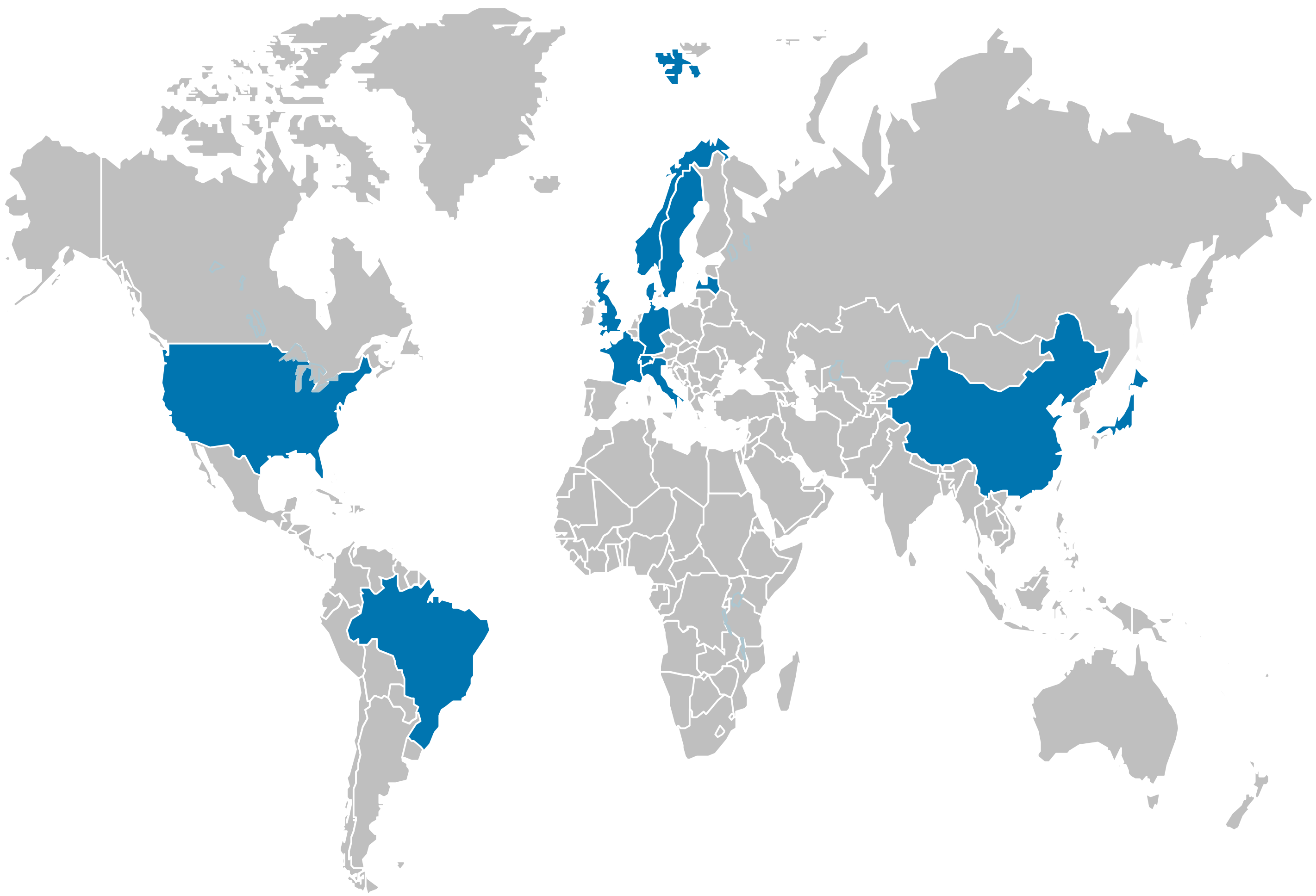
Source: Hydrogen Council

1. FCEV forecasts of Asia include the governmental FCEV roadmap outlooks of China, Japan and South Korea

HUNDREDS OF FUEL CELL BUSES ARE IN SERVICE GLOBALLY

Globally, expansion of FCEV buses is accelerating

COUNTRY		
USA	33	32
Brazil	3	
Netherlands	7	54
Iceland		5
Denmark		23
Norway	5	10
Sweden		5
Germany	16	78
UK	20	88
Belgium	5	
France		26
Switzerland	5	
Italy	10	23
Latvia	1	10
China	20+	800
Japan		100+
South Korea		100+
Total	**125**	**1 100+**



Bus in operation

Bus in planning for deployment in next few years

Source: Ballard

HEAVY DUTY FCEV APPLICATIONS GAINING MOMENTUM

Toyota fuel cell truck – currently being piloted at the port of Long Beach, California

500 Dongfeng fuel cell trucks powered by Ballard FC stacks

Nikola fuel cell truck – >USD10 billion order book

Hyundai FC truck – launching in 2019

OTHER APPLICATIONS PROGRESSING

20,000+ FC forklifts in operation around the world – replacing battery forklifts. No downtime for recharging

US Army recruits the Chevy Colorado ZH2 FCEV

Alstom launched 'world's first' hydrogen-powered train in Germany, September 2018

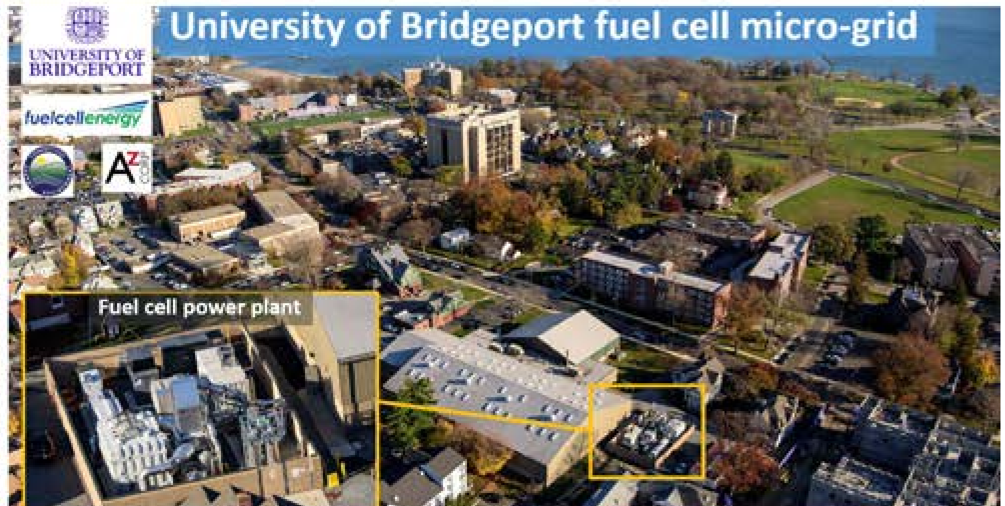
Toyota has sent the world's first hydrogen-powered ship on a six-year voyage

WIDESPREAD DEPLOYMENT OF STATIONARY FUEL CELLS

Telecoms – thousands of units installed globally

Micro combined heat and power (mCHP). Over 200,000 units installed in Japan

Backup and primary power. FC backup power for new World Trade Center in NYC

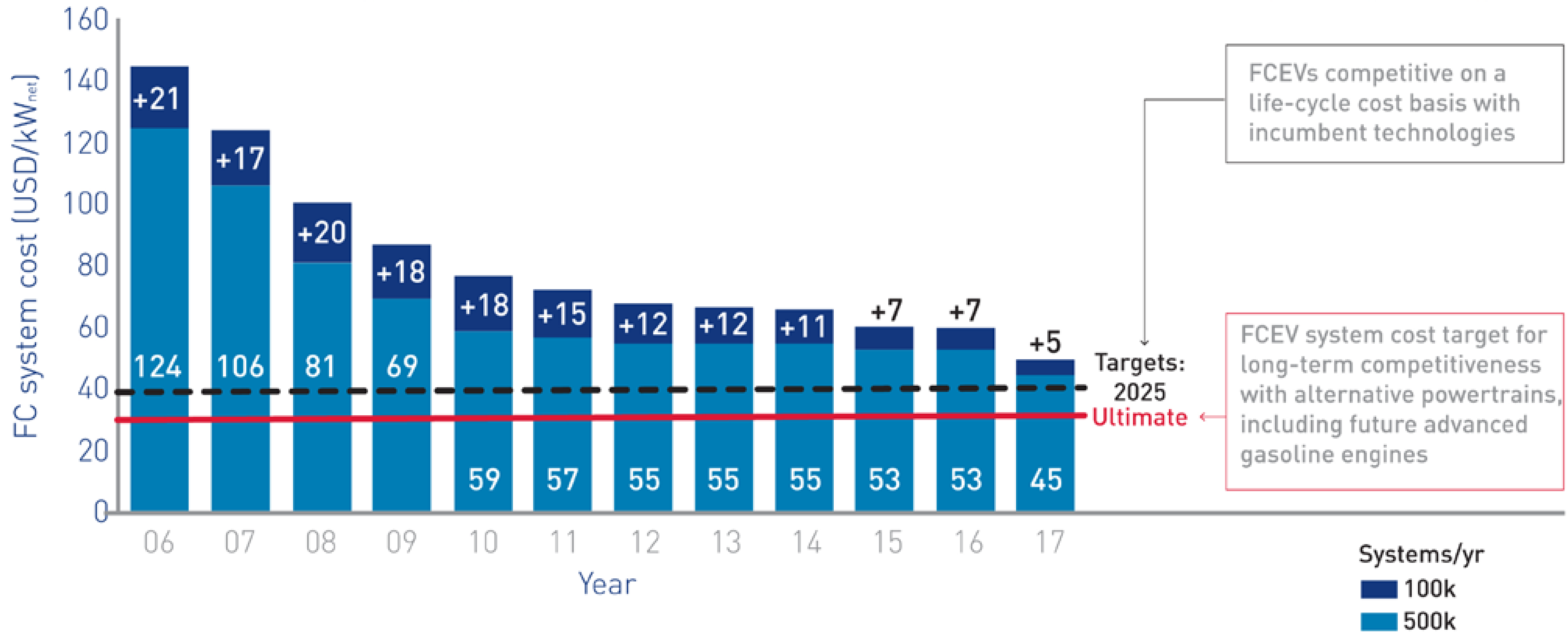


Fuel cell powered micro-grids

AND WITH SCALE COMES COST REDUCTION

In 10 years, the estimated FC system cost at high production volume decreased by nearly a factor of three, due to improved materials and manufacturing techniques

Cost estimate for 80kW light duty automotive manufactured at 100,000 and 500,000 units p.a. respectively



Today's technology close to achieving cost targets if manufactured at moderate scale

Source: Strategic Analysis Inc. For US DOE 2018, Fuel Cell Technologies Office

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CHINA FCEVS AND HYDROGEN

China: Foshan hydrogen fuel cell tram

DEVELOPMENT OBJECTIVES OF HYDROGEN FCEV IN CHINA

		2020	2025	2030
Overall objective		Small scale public sector demonstration in selected areas (5,000 FCVs)	Large-scale development of FC passenger cars and service vehicles in urban areas (50,000 FCVs)	Large-scale commercial deployment of passenger cars and commercial vehicles (one million FCV's)
Overall objective		Fuel cell system production capacity >1,000 units per enterprise	Fuel cell system production capacity >10,000 units per enterprise	Fuel cell system production capacity >100,000 units per enterprise
Hydrogen fuel cell vehicles	Functional requirements	Cold start -30°C, power system structure optimisation, FCV cost close to all-electric vehicles	Cold start -40°C, small volume production, FCV cost similar to hybrid vechile	FCV overall performance comparable with traditional ICE vehicles – achieving competitive advantage
Hydrogen fuel cell vehicles	Commercial vehicle	Cost ≥ RMB 1.5 million	Cost ≥ RMB 1.0 million	Cost ≥ RMB 600,000
Hydrogen fuel cell vehicles	Passenger car	Max speed ≥ 160km/h Lifespan 200,000km Cost ≥ RMB 300,000	Max speed ≥ 170km/h Lifespan 250,000km Cost ≥ RMB 200,000	Max speed ≥ 180km/h Lifespan 300,000km Cost ≥ RMB 180,000
Hydrogen infrastucture	H_2 supply	Decentralised hydrogen production from renewable sources; industrial by-products such as coke-oven gas		Decentralised H_2 production from renewable sources
Hydrogen infrastucture	H_2 delivery	High pressure hydrogen storage and delivery	• Cryogenic liquid * hydrogen delivery	High density organic liquid hydrogen storage ** and delivery at normal pressure
Hydrogen infrastucture	HRS	100 stations	350 stations	1,000 stations

Source: China Technology Roadmap for Energy Saving and New Energy Vehicles

* Cryogenic fuels are fuels that require storage at extremely low temperatures in order to maintain them in a liquid state. Cryogenic fuels most often constitute liquefied gases such as liquid hydrogen

** These liquid organic hydrogen carriers (LOHC) are hydrogenated for storage and dehydrogenated again when the energy/hydrogen is needed

LOCAL GOVERNMENT NEW POLICY SUPPORT ON H_2 ENERGY AND FCEV INDUSTRY

- **Rugao, Jiangsu** announced 'Advice on Supporting H_2 Energy Industry Development'. Maximum RMB10 million subsidy for H_2 energy and NEV research platform. 3-5 H_2 refuelling stations expected by 2020. FECV share is no less than 50% of the new added vehicles in buses, logistics vehicles by 2020. H_2 industry annual output value will break through RMB100 billion by 2030
- **Jiangsu Province** Hydrogen Energy and Fuel Cell Vehicle Industry Innovation Alliance was established in Rugao in October
- **Shandong** announced 'New Energy Industry Development Plan 2018-2028'. It will support leading FCEV and H_2 energy enterprises development and accelerate H_2 energy special industry clusters and demonstration parks development. The H_2 industry annual output value in Shandong Province is expected to breakthrough RMB50 billion by 2028
- **Tianjin** published New Energy Industry Development Action Plan 2018-2020. The hydrogen energy and fuel cell industry annual output value will rise to RMB8 billion by 2020

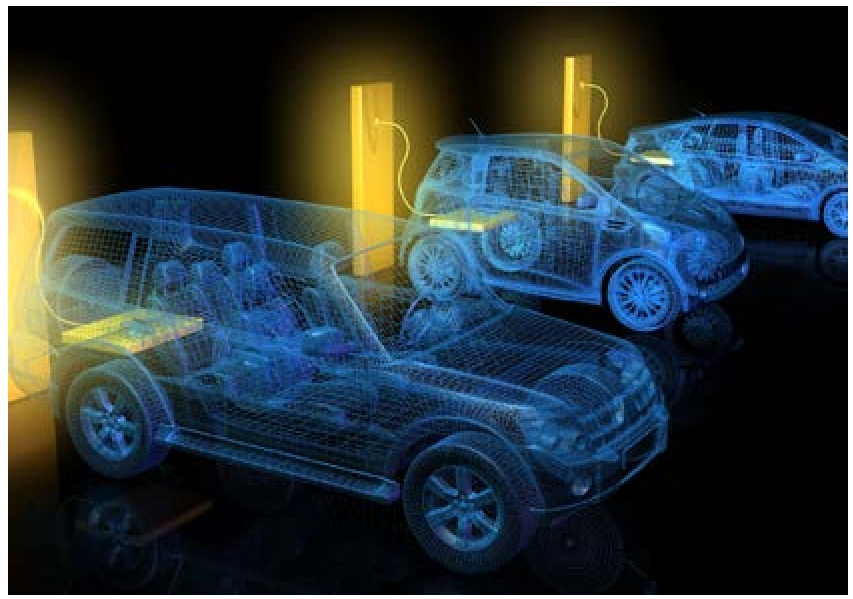
Fuel cell stack

CHINA H_2 AND FCEV INDUSTRY PARTICIPANTS CO-OPERATED WITH INTERNATIONAL PLAYERS

- **Great Wall Automobile invested in H_2 Mobility Deutschland** and became its seventh shareholder aim to promote China's hydrogen infrastructure construction. H_2 Mobility engaged in hydrogen infrastructure construction in Germany. It planned to operate 100 hydrogen refuelling stations in Germany based on its 2019 phase I plan. Great Wall is one of leading FCEV manufacturers in China, planning to launch FCEVs around 2022

- **Beijing Tsinghua Industrial R&D Institute cooperated with Hyundai Motor Company and set up Hydrogen Energy Fund,** which aims to promote global hydrogen energy industry development. The initial target for the fund is USD100 million

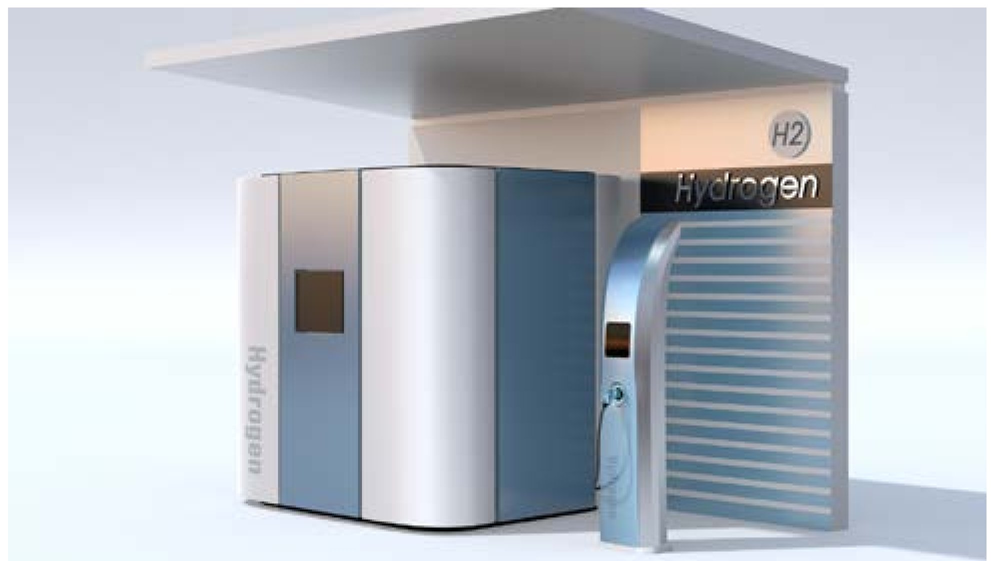
- **Sinopec will cooperate with Japan JXTG Energy Group** to construct hydrogen refuelling station. The cooperation was set up during Japan premier's China visit in October. JXTG is one of the major hydrogen refuelling station (HRS) operators in Japan. Sinopec is the leading energy group in China. It will take advantage of current petrol and natural gas stations' aims to build hydrogen refuelling stations, and petrol and natural gas stations either as separate or combined stations



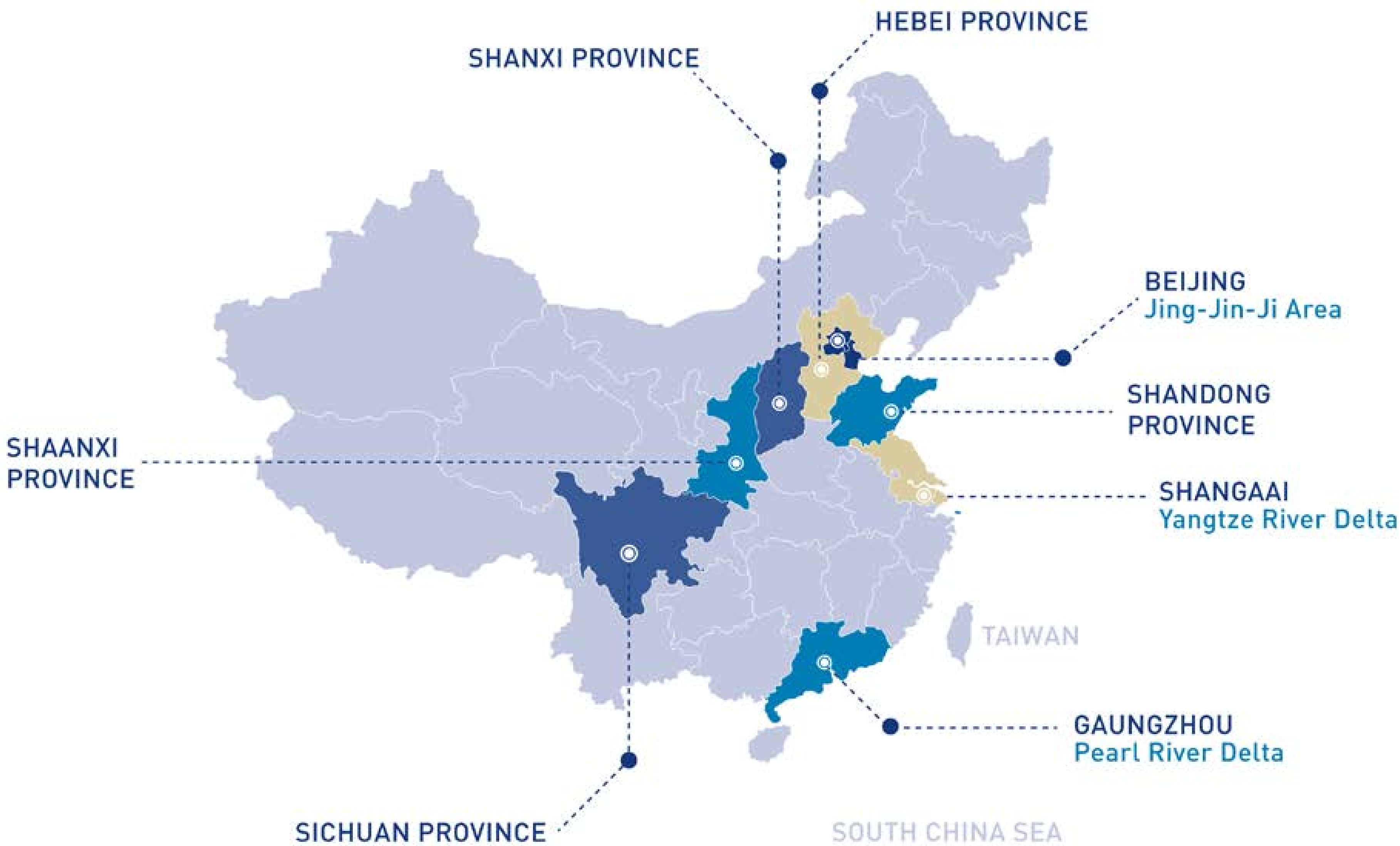
CHINA H_2 ENERGY & FCEV MARKET UPDATE

Snapshot of leading players

- **The 200 ton and above hydrogen energy heavy duty mining trucks research cooperation framework agreement** was signed by Shenhua Zhunneng Group, China Energy Group Hydrogen Energy Technology, Beijing Low Carbon Clean Energy Research Institute and Weichai Group on 11 October 2018
- **State Power Investment Corporation Group's** first hydrogen energy engineering meeting was held on 10 October 2018. SPIC will explore hydrogen energy emerging industry development strategy and set up R&D direction in the future. It is another national power group that has followed China Energy Group into the hydrogen energy industry
- **Guangzhou Hongji Chuangneng high energy density membrane electrode assembly (MEA) with RMB800m investment started construction** on 11 October 2018. It plans to realise 100 thousand sq.m. MEA production scale in 2019 and mass industrialisation in 2020



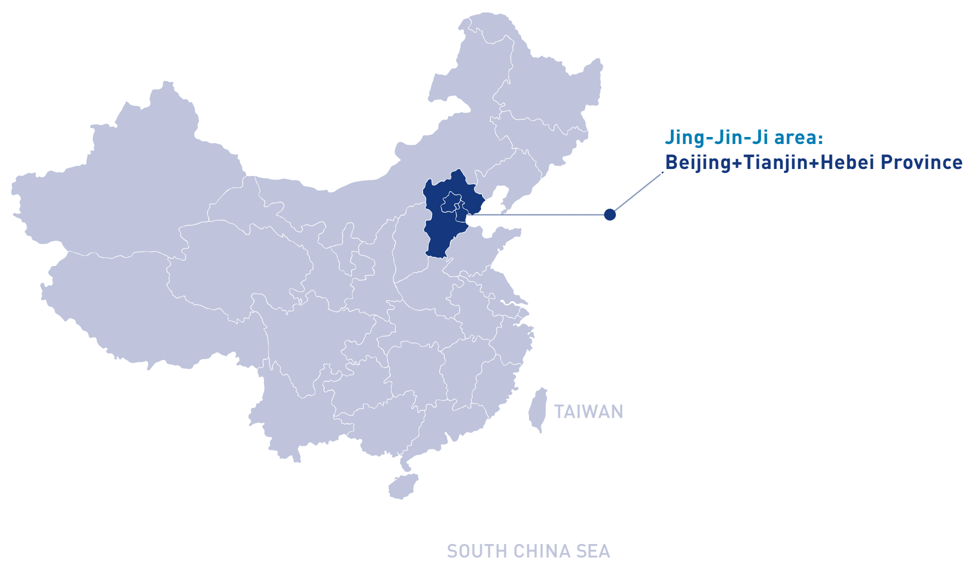
CHINA NATIONAL DEVELOPMENT THROUGHOUT THE COUNTRY



Source: Chinabuses.com

CHINA H_2 AND FCEV INDUSTRY DEVELOPMENT JING-JIN-JI

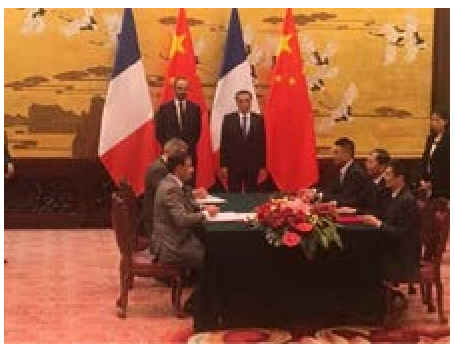
Major cities	Beijing, Zhangjiakou, Tianjin
Demonstration	• Beijing 2008 Olympic Games • 2016 batch application for commuting and rental in Beijing • 2018 Zhangjiakou bus company batch operation, 74 buses in operation
Major enterprises	• Beiqi Foton, Sino Hytec, Nowogen, Bolken Energy Saving, Tunghsu Optoelectronic • CHN Energy, Shougang Gas, Huaneng Group, Tianjin Mainland Hydrogen Equipment
Hydrogen refuelling station	• (1 in use) Beijing Yongfeng Station • (4 under construction) Zhangjiakou Qiaodong District, Qiaoxi District, High Tech District, Economic Development District • (planned) HRS will cover all 19 districts in Zhangjiakou city
Industrialisation base	Zhangjiakou Chuangba Industrial Park, Tianjin Lingang Economic Development Zone (planned), Zhangjiakou Wangshan Industrial Park, Handan (planned), Bazhou (planned) etc.
Industry covered	Fuel cell vehicle, component, stack, system, hydrogen production, storage, refuelling etc.



Source: Chinabuses.com

CHINA H_2 AND FCEV INDUSTRY PLAYERS BECAME MORE ACTIVE IN INTERNATIONAL MARKET

- **China STNE*** co-operated with **Air Liquide**, more than 50 tonnes H_2 refuelling for STNE distributed to date
- **Re-Fire** owns 30% share of STNE's HRS operational company (**Shanghai Jiaqing Industry Ltd**)
- There are about **589 FCEVs** run in Shanghai currently
  - 500 logistics vehicles
  - 50 vans
  - 39 passenger vehicles
- **Shell/Air Products** recently expressed HRS investment interests to **IHFCA****
- Growing consensus in China to invest in H_2 Mobility



Hydrogen Council

Source: TrendBank, AA Marketing
*Shanghai Sinotran New Energy Automobile Operation Company
**International Hydrogen Fuel Cell Association

CHINA H_2 AND FCEV INDUSTRY DEVELOPMENT PEARL RIVER DELTA REGION

Major cities	Foshan (Nanhai), Yunfu, Shenzhen
Demonstration	• 2011 Shenzhen University Games • 2017 Foshan-Yunfu hydrogen fuel cell bus demonstration line started operation
Major enterprises	Feichi Bus, Wuzhoulong Motor, Green Wheel, Yangtze Automobile, Dongfeng Special Commercial Vehicle, Synergy, Synergy-Ballard, Synergy-ReFire, Sunwei HRS, Broad Ocean Motor, Vision Group, Snowman Group, Proton China
Hydrogen refuelling station	• (5 in use) Foshan Danzao Station, Foshan Ruihui Station, Shenzhen Longgang Station, Zhongshan Shalang Station, Yunfu Silao Station • (8 under construction) Yunfu New District Station, Luoding Station, Yuncheng Station, Xinxing County Station, Yunan Station, Foshan Guoneng Liansheng Station, Zhongshan Guzhen Station, Hydrogen Energy Town Station • (10 planned) 2019 Foshan Yunfu 19 stations will be in operation
Industrialisation base	Foshan Yunfu Industrial Transposition Park, Guangdong New Energy Vehicle Industrial Park (Foshan Nanhai Danzao)
Industry covered	Fuel cell vehicle, component, stack, system, auxiliary system, hydrogen production, refuelling etc.

Source: Chinabuses.com

CHINA NATIONAL HYDROGEN ENERGY INDUSTRY SUMMIT IN FOSHAN – H_2 WEEK

H_2 energy industry development in Foshan city played a leading role in China. A comprehensive H_2 and FC industry chain has been established in Foshan. Guangdong government provides strong support for H_2 and FCEV development in Pearl River Delta.

Source: CPCC 2018, H_2 Week

CHINA H_2 AND FCEV INDUSTRY DEVELOPMENT SHANDONG PROVINCE

Major cities	Jinan, Binzhou, Liaocheng, Linyi etc.
Demonstration	2018 planned batch operation
Major enterprises	Weichai Group, Zhongtong Bus, Sino Truck, Shandong Yixing, Binhua Holding, Shandong Saikesaisi Hydrogen Energy, Fengtong Special New Energy, Zibo Jingke etc.
Hydrogen refuelling station	• (2 under construction) Liaocheng Zhongtong Bus Station, Binzhou Binhua Station • (1 planned) Jinan Xianxing District Station
Industrialisation base	Jinan Xianxing District Cuizhai 'China Hydrogen Valley', Binzhou Military and Civilian Integration Industrial Park, Zibo High Tech District Hydrogen New Energy Vehicle Industry Clusters etc.
Industry covered	Fuel cell vehicle, component, system, hydrogen production, refuelling etc.

FC System investment by Weichai:

1. Foresight Shanghai (PEMFC-proton exchange membrane fuel cell) 45% share
2. Ballard (PEMFC) 19.9% share
3. Ceres UK (SOFC – solid oxide fuel cell) 20% share

Source: Chinabuses.com, AA Marketing

LEADING H_2 AND FC PLAYER IN SHANDONG PROVINCE – WEICHAI

- **Weichai** invested USD163 million for 19.9% **Ballard** shares
  - 2,000 FC commercial vehicle FC modules planned in China

Source: local media, AA Marketing

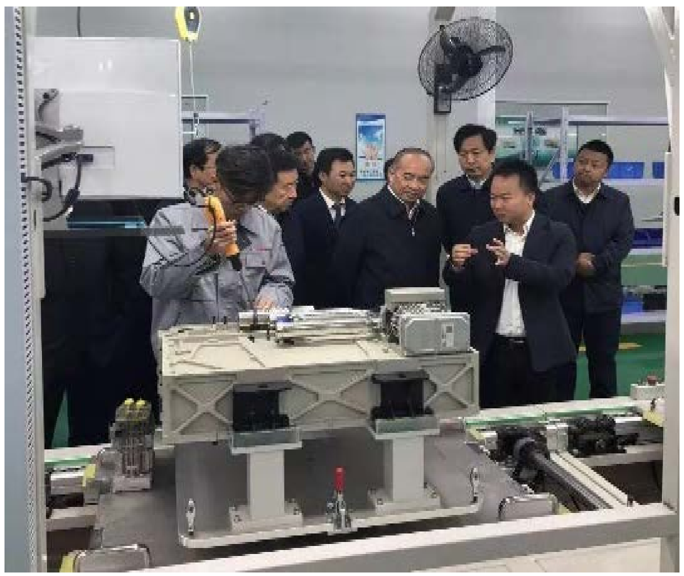
CHINA H_2 AND FCEV INDUSTRY DEVELOPMENT SHANXI PROVINCE

Shanxi Province

- There are three hydrogen refuelling stations and two fuel cell bus demonstration lines planned in Shanxi Datong city. Vision Group H_2 Datong Industry Park started construction in April 2018

Vision Group H_2 Industry Park, Shanxi Datong city

- More than RMB3 billion investment, 50k H_2 fuel cell system infrastructure base built before 2020, to promote more than 5 000 FCEVs in Shanxi Province before 2020
- Phase one, 10k H_2 fuel cell system started operation in 2018, 2 HRS planned to operate by end of November. 50 FC buses demonstration line to begin operation in 2018



Shanxi Province vice governor visited Vision Group H_2 Industry Park

Source: Chinabuses.com, local media

CHINA H_2 AND FCEV INDUSTRY DEVELOPMENT SICHUAN PROVINCE AND OTHERS

Sichuan Province

- There will be 50 hydrogen fuel cell buses on commercial demonstration in Sichuan Province by end of 2018
- The hydrogen fuel cell technology industry is estimated to achieve more than RMB100 billion scale by 2025

Wuhan city

- There will be 50 fuel cell buses in commercial operation in 2019. It is estimated there will be 10-30,000 fuel cell passenger vehicles, buses, logistics vehicles and 30-100 HRS by 2025. Wuhan is targeted to be world's new hydrogen energy city of the future

Xi'an city

- Xi'an New Youngman Holding Group announced to deliver 1,000 fuel cell logistic vehicles and build 8 HRS by 2020

Zhengzhou, Dalian, Zhuzhou cities

- **Air Liquide** invested in a local LNG gas station enterprise **Houpu** to establish an H_2 infrastructure R&D, production and sales JV in Chengdu
- **Xi'an:** 400 FC logistics trucks left in stock tentatively as lack of HRS availability

The first fuel cell bus in **Chengdu city**, developed by **Dongfang Electric** and **Chengdu Bus**; Mobile HRS in Chengdu with maximum H_2 refuelling 500kg/day

Source: Chinabuses.com, local media

3rd UNDP/GEF/MOST FCEV DEMONSTRATION IN IMPLEMENTATION (2018-2022)

Foton FC bus run on Beijing-Zhangjiakou highway

SAIC Maxux FC van in Shanghai

FC bus demonstration line in Foshan Yunfu

FC bus operated in Chengdu city

Kaiwo Taige FC bus launched in Wuhan city

The first FC bus in Shanxi Datong city

Source: Chinabuses.com

2018 HYDROGEN FUEL CELL VEHICLE EXHIBITIONS AND ROADSHOW: YANGTZE RIVER DELTA

Speaker from UNDP Beijing

Fuel cell vehicles on the road

Primary school students painted their ideas of an H_2 energy society

Audience during the exhibition

Primary school students took the H_2 FC bus

Roadshow organisers and staff

Source: IHFCA

FCVS AND HRS OPERATED DURING THE ROADSHOW


SAIC Roewe 950


Hyundai Nexo


Honda Clarity


Toyota Mirai


AP Mobile HRS


SAIC FCV80


Dongfeng special logistics vehicle


Youngman logistics vehicle


Feichi bus


Shanghai Anting HRS


Yutong bus


Youngman bus


Greenwheel bus


Foton FC bus


Bing Energy HRS

Source: IHFCA

ROUTE MAP – FCV EXHIBITION AND TOUR FOR EDUCATION AND PUBLIC AWARENESS - IHFCA

IHFCA 国际氢能燃料电池协会（筹）

International Hydrogen Fuel Cell Association (Preparatory)

4	**3**	**30**	**12**	**24**	**3 million**
Days	Main cities	Enterprises	Domestic and global OEMs	FCV models	Visitors and audiences

Departure:
Rugao, 12 October

Through:
Nantong, 13 October

Arrive:
Shanghai, 15 October

3rd INTERNATIONAL FCVC HELD SUCCESSFULLY IN RUGAO

October 2018

- **CPPCC vice-chairman Wan Gang** pointed out that hydrogen energy and fuel cell development had been listed in China National Strategy.
  - China needs to accelerate FCEV commercialisation especially in long distance bus, intercity logistics, heavy duty truck etc. applications
- **Latest summary from the 3rd FCVC**
  - >3,500 FCEVs and >40 HRS estimated by the end of 2018, 41 FC OEMs developed, 56 FCEV types which covered 25 FC system companies
  - >RMB85 billion investment and planned capital in H_2 & FC industry in 2018
- **UNDP China Director** said IEA predicted that by 2025 FCVs will make up 17.5% of the world’s vehicles. China plans to make core technology for hydrogen fuel cell vehicle applications and those for hydrogen production, storage and refuelling a focus for the latter half of the 13th and 14th Five Year Plan for the country

3rd INTERNATIONAL FCVC HELD SUCCESSFULLY IN RUGAO

October 2018

- High-level international congress with extensive participations (1,600+ organisations from 21 countries and regions)
- 1 panel discussion, 84 keynote lectures
- Congress & exhibition, ride & drive (52 exhibitors, 8,000+ visitors)
- New session on market and investment
- News and new product release platform
- Deep integration with local economy

LATEST H_2 ENERGY & FCEV REPORT FROM AUTHORITATIVE MEDIA AND INSTITUTIONS

- **FCEVs are estimated to make up 15% of passenger vehicles and 50% of commercial vehicles by 2050 in China** said China Hydrogen Energy & Fuel Cell Industry Development Report released at the Hydrogen Energy and Fuel Cell Industry Innovation Strategic Alliance (China H_2 Alliance) Summit on 11 October
- China Central Television (CCTV) reported China is promoting the set up of H_2 Energy Industry Development Strategy Roadmap. **H_2 energy is forecast to account for at least 10% of China's end use energy by 2050**
- People's Daily reported that H_2 energy is important component of China's energy strategy
- Xinhua News Agency reported the development of hydrogen energy in China has been continuously enhanced in recent years. Many local governments had set up large-scale H_2 energy industry development plan

IN CLOSING

China is at the forefront of scaling H_2 and FC technology production, adoption and commercialisation

- The use of fuel cells is growing across a multitude of applications and is no longer in the R&D phase, especially in automotive and other mobility applications such as fork lifts, buses and cars
- Enabling H_2 infrastructure is steadily being built in key automotive markets (e.g. China) and governments continue to implement supporting policies to accelerate the adoption of H_2 and fuel cell electric vehicles
- China is at the forefront of scaling H_2 and FC technology production and adoption, offering significant subsidies and getting the technology into the market and onto the road on a commercial scale
- Major Chinese auto OEMs are investing in FC development and production. Thousands of FC vehicles (medium duty trucks, buses) are rolling off production lines in various provinces across the country
- Platinum and other PGMs will continue to play a part in traditional automotive markets and it will also play a major part in the clean mobility (and broader industry) markets of the future, through fuel cell technology

AngloAmerican

PLATINUM

DEVELOPING MARKETS FOR OUR METALS

Real Mining. Real People. Real Difference.

PROACTIVE MARKET DEVELOPMENT THROUGH CHANNELS APPROPRIATE FOR EACH DEMAND SEGMENT

Demand segment		Channel
1 Investment		World Platinum Investment Council
2 Jewellery		Platinum Guild International
3 Industrial	R&D	AngloAmerican
	Policy advocacy and comms	AngloAmerican
	Venture capital	APVentures ADVANCE & PIONEER

1 INVESTMENT

World
Platinum
Investment
Council

- Prepare and disseminate Pt market insights to investors
- Create new platinum backed investment products
- Improve access to existing Pt investment products through increasing available distribution channels

2 JEWELLERY

- Grow jewellery demand through, developing and marketing new Pt jewellery brands in select markets
- Partner with jewellery stores to optimise distribution
- Develop consumer insights and communication ideas

Source: Platinum Guild International website

3 RESEARCH, DEVELOPMENT AND POLICY ADVOCACY

- Improve the understanding of how and where PGMs can be used by investing in primary R&D
- Support R&D through to early stage commercialisation
- Participate in and spearhead global advocacy initiatives to create a supportive policy and regulatory environment for PGM-bearing technologies

3 VENTURE CAPITAL: AP VENTURES INVESTS IN START-UP COMPANIES THAT USE OR FACILITATE THE USE OF PGMS

USD200 million venture capital fund focused on PGM technologies that solve globally relevant challenges

Sustainable energy integration

Changing demographics

Resource scarcity

APVentures
ADVANCE & PIONEER

altergy systems

United Hydrogen

hydrogenious TECHNOLOGIES

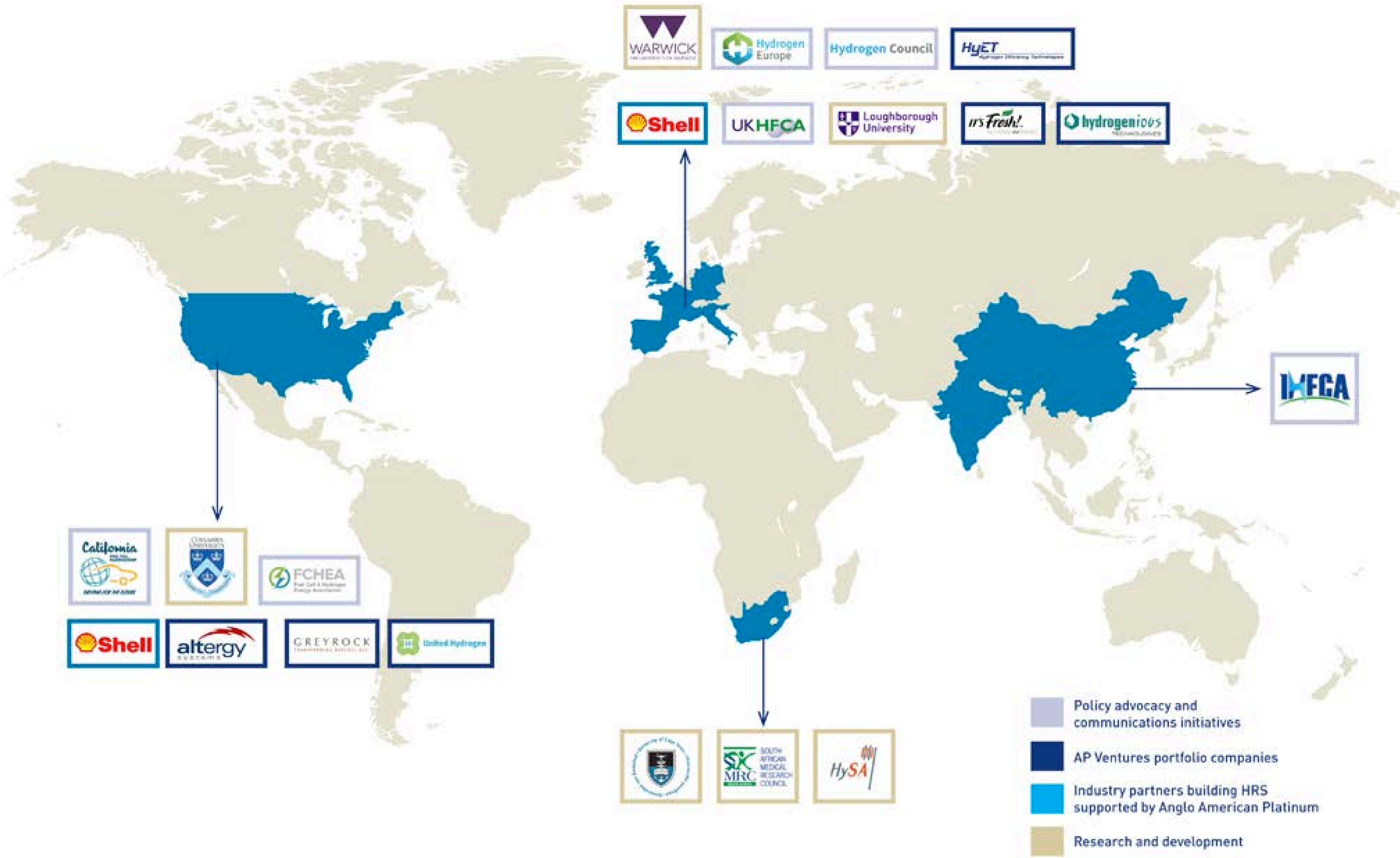
GREYROCK TRANSFORMING NATURAL GAS™

HyET Hydrogen Efficiency Technologies

IT'S Fresh!™

3

ACTIVITIES UNDERTAKEN ARE GLOBAL: FOCUS ON KEY MARKETS FOR HYDROGEN AND FCEVS



3

FUEL CELL AND HYDROGEN INTEREST IN CHINA GROWING
ANGLO AMERICAN PLATINUM DRIVES AWARENESS OF TECHNOLOGY

Hugely successful 2018 Fuel Cell Vehicle Conference in Rugao

2018 FCVC Congress attracted 1,600 delegates along with government representitives, NGOs, car and train manufacturers, and academics from around the world

The 3rd International Hydrogen Fuel Cell Vehicle Congress

China Fuel Cell Association roadshow, organised with Anglo American Platinum's support

4	3	30
Days	Cities	Companies
12	**24**	**3 million**
Domestic and global OEMs	FCV models	Visitors and audiences

Shanghai

IHFCA 国际氢能燃料电池协会（筹）
International Hydrogen Fuel Cell Association (Preparatory)

AngloAmerican

PLATINUM

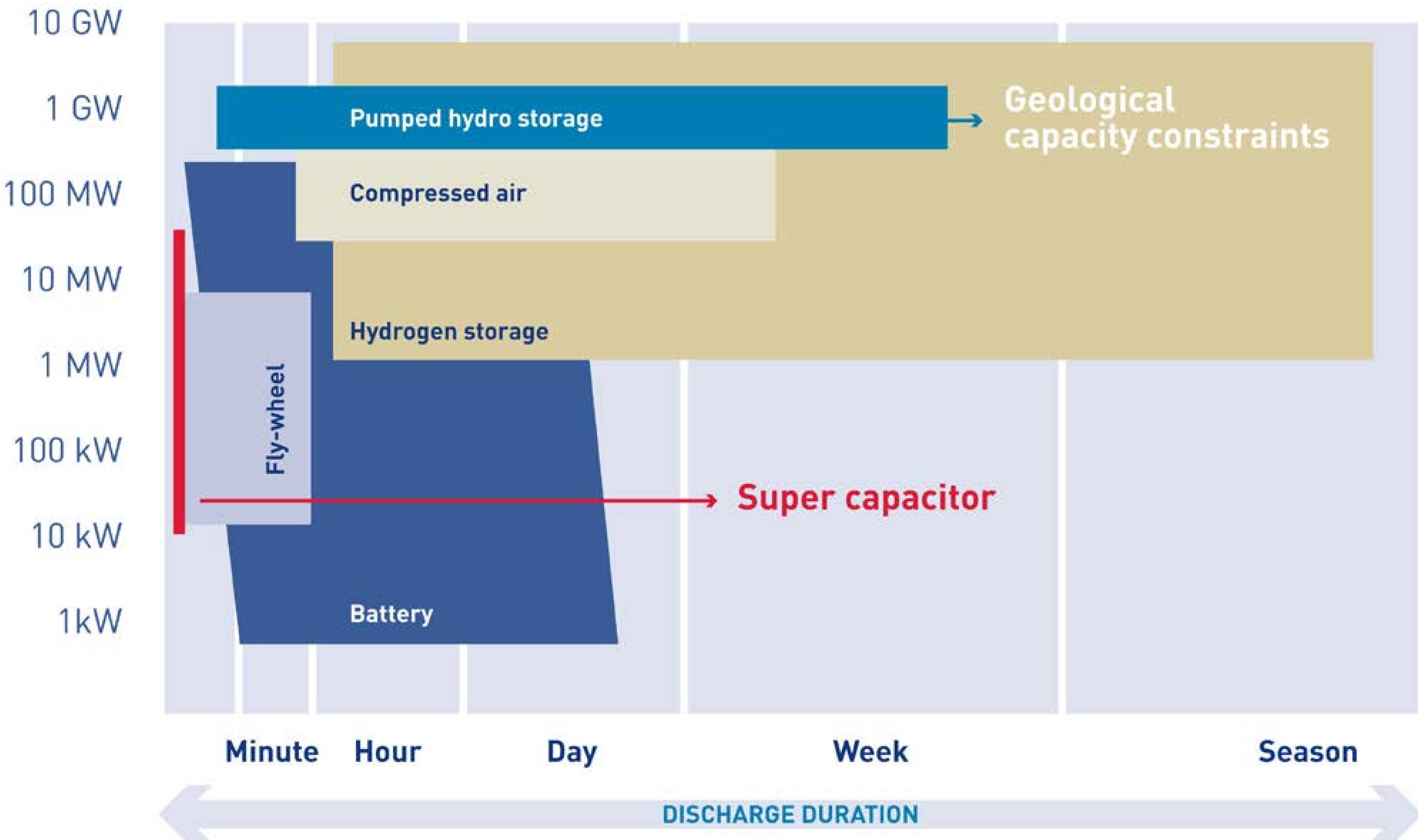
APPENDIX

Real Mining. Real People. Real Difference.

ACRONYMS

BEV	Battery electric vehicle
CCS	Carbon capture and storage
EV	Electric vehicles
FC	Fuel cell
FCB	Fuel cell bus
FCEV	Fuel cell electric vehicle
H_2	Hydrogen
H_2O	Water
HDV	Heavy duty vehicle
HRS	Hydrogen refuelling station
LDV	Light duty vehicle
LHV	Lower heating value
LOHC	Liquid organic hydrogen carrier
mCHP	Micro combined heat and power
MDV	Medium duty vehicle
MW	Megawatt
NREL	National Renewable Energy Laboratory (USA)
O_2	Oxygen
OEM	Original equipment manufacturer
Pd	Palladium
PEM	Polymer electrolyte membrane
PGM	Platinum group metal
Pt	Platinum
SMR	Steam methane reforming
US DOE	United States Department of Energy

WHY HYDROGEN? HYDROGEN STORAGE IS SCALABLE



ANAEROBIC DIGESTION TO PRODUCE H_2 EXPLAINED

Anaerobic digestion has been highlighted as an environmentally friendly method to produce hydrogen from food and animal waste. In this process, microorganisms decompose biomass in the absence of oxygen. Through anaerobic digestion, food and animal waste is recycled to produce hydrogen gas that can be subsequently converted to methane or biogas if needed.

The science behind anaerobic digestion
Anaerobic digestion is a complicated process which involves four major stages. Hydrolysis is the first stage in which large organic polymers present in the biomass are broken down to smaller molecules such as simple sugars. Following this, the remaining components are broken down by acidogenesis to create volatile fatty acids and other by-products.

Acetogenesis is the third stage in which the simple sugar molecules (produced during hydrolysis) are digested to produce hydrogen, acetic acid and carbon dioxide. Methanogenesis is the final stage in which all the products of the previous stages are converted to methane, water and carbon dioxide. While a single reactor can be used to perform all the stages, a two-stage digestion system in which methanogenesis is performed in a separate second reactor has been demonstrated to be more stable and it also boosts biogas production rates.

Using anaerobic digestion to produce hydrogen from biomass
In this regard, UK Researchers have been working to improve anaerobic digestion to continuously produce both methane and hydrogen from biomass-derived sugars in a two-stage process. A continuous flow stirred-tank reactor inoculated with anaerobically digested sewage sludge was used by the team to produce hydrogen from biomass-derived sugar. The resultant hydrogen was subsequently used to produce methane in an up-flow aerobic filter.

It is well known that the energy requirements of anaerobic digestion decrease with increasing concentration of substrate, but as the substrate concentration increases alkali has to be added to maintain the acidogenic hydrogen producing reactor at the ideal pH for the production of hydrogen gas. Therefore, the research team investigated the effects of alkali addition and substrate concentration on the methane and hydrogen yields from their two-stage process and was able to improve the conditions for maximum production of hydrogen and methane.

Source: Wikipedia

ALKALINE ELECTROLYSIS

Alkaline water electrolysis has a long history in the chemical industry. It is a type of electrolyser that is characterised by having two electrodes operating in a liquid alkaline electrolyte solution of potassium hydroxide (KOH) or sodium hydroxide (NaOH). These electrodes are separated by a diaphragm, separating the product gases and transporting the hydroxide ions (OH^-) from one electrode to the other. A recent comparison showed that state-of-the-art nickel based water electrolysers with alkaline electrolytes lead to competitive or even better efficiencies than acidic polymer electrolyte membrane water electrolysis with platinum group metal based electrocatalysts.

Electrolysis requires minerals to be present in solution. Tap, well, and ground water contains various minerals, some of which are alkaline while others are acidic. Water above a pH of 7.0 is considered alkaline; below 7.0 it is acidic. Electrolysis can occur only if the water is acidic or alkaline. The requirement is that there must be ions in the water to conduct electricity for the water electrolysis process to occur.

Technical details

The electrodes are typically separated by a thin porous foil (with a thickness between 0.050 to 0.5 mm), commonly referred to as diaphragm or separator. The diaphragm is non-conductive to electrons, thus avoiding electrical shorts between the electrodes while allowing small distances between the electrodes. The ionic conductivity is supplied by the aqueous alkaline solution, which penetrates in the pores of the porous diaphragm. The state-of-the-art diaphragm is zirfon, a composite material of zirconia and polysulfone. The diaphragm further avoids the mixing of the produced hydrogen and oxygen at the cathode and anode. respectively. Typically, nickel-based metals are used as the electrodes for alkaline water electrolysis. Considering pure metals, Ni is the most active non-noble metal. The high price of good noble metal electrocatalysts such as platinum group metals and their dissolution during the oxygen evolution is a drawback. Ni is considered as more stable during the oxygen evolution.

High surface area Ni catalysts can be achieved by dealloying of Nickel-Zinc or Nickel-Aluminium alloys in alkaline solution, commonly referred to as Raney Nickel. In cell tests the best performing electrodes thus far reported consisted of plasma vacuum sprayed Ni alloys on Ni meshes and hot dip galvanised Ni meshes. The latter approach might be interesting for large-scale industrial manufacturing as it is cheap and easily scalable.

Source: Wikipedia

SOLID OXIDE ELECTROLYSER

A solid oxide electrolyser cell (SOEC) is a solid oxide fuel cell that runs in regenerative mode to achieve the electrolysis of water (and/or carbon dioxide) by using a solid oxide, or ceramic, electrolyte to produce hydrogen gas (and/or carbon monoxide) and oxygen. The production of pure hydrogen is compelling because it is a clean fuel that can be stored easily, thus making it a potential alternative to batteries, which have a low-storage capacity and create high amounts of waste materials. Electrolysis is currently the most promising method of hydrogen production from water due to high efficiency of conversion and relatively low required energy input when compared to thermochemical and photocatalytic methods.

Principle

Solid oxide electrolyser cells operate at temperatures which allow high-temperature electrolysis[5] to occur, typically between 500 and 850 °C. These operating temperatures are similar to those conditions for an SOFC. The net cell reaction yields hydrogen and oxygen gases. The reactions for one mole of water are shown below, with oxidation of water occurring at the anode and reduction of water occurring at the cathode.

Anode: $O2- \rightarrow 1/2O2 + 2e-$

Cathode: $H2O + 2e- \rightarrow H2 + O2-$

Net Reaction: $H2O \rightarrow H2 + 1/2O2$

Electrolysis of water at 298 K (25 °C) requires 285.83 kJ of energy per mole in order to occur,and the reaction is increasingly endothermic with increasing temperature. However, the energy demand may be reduced due to the Joule heating of an electrolysis cell, which may be utilised in the water splitting process at high temperatures. Research is ongoing to add heat from external heat sources such as concentrating solar thermal collectors and geothermal sources.

Source: Wikipedia

PEM ELECTROLYSERS USED TO PRODUCE H_2 EXPLAINED

Proton exchange membrane (PEM) electrolysis is the electrolysis of water in a cell equipped with a solid polymer electrolyte (SPE) that is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes. The PEM electrolyser was introduced to overcome the issues of partial load, low current density, and low pressure operation currently plaguing the alkaline electrolyser.

Advantages of PEM electrolysis

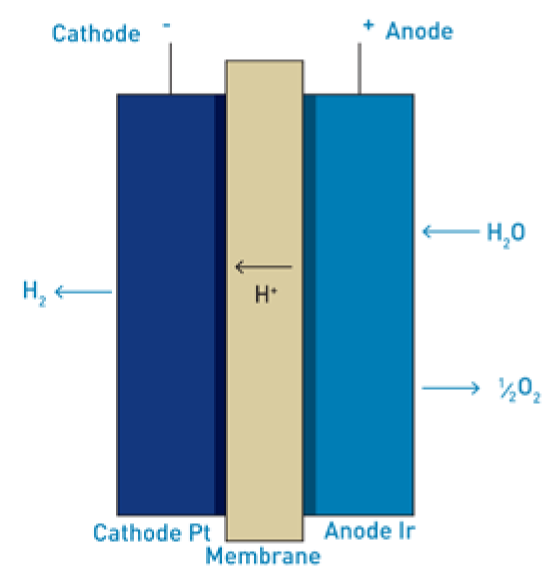
One of the largest advantages to PEM electrolysis is its ability to operate at high current densities. This can result in reduced operational costs, especially for systems coupled with very dynamic energy sources such as wind and solar, where sudden spikes in energy input would otherwise result in uncaptured energy. The polymer electrolyte allows the PEM electrolyser to operate with a very thin membrane (~100-200 μm) while still allowing high pressures, resulting in low ohmic losses, primarily caused by the conduction of protons across the membrane (0.1 S/cm) and a compressed hydrogen output.

The polymer electrolyte membrane, due to its solid structure, exhibits a low gas crossover rate resulting in very high product gas purity. Maintaining a high gas purity is important for storage safety and for the direct usage in a fuel cell. The safety limits for H_2 in O_2 are at standard conditions 4 mol-% H_2 in O_2.

Science

An electrolyser is an electrochemical device to convert electricity and water into hydrogen and oxygen, these gases can then be used as a means to store energy for later use. This use can range from electrical grid stabilisation from dynamic electrical sources such as wind turbines and solar cells to localised hydrogen production as a fuel for fuel cell vehicles. The PEM electrolyser utilises a solid polymer electrolyte (SPE) to conduct protons from the anode to the cathode while insulating the electrodes electrically. Under standard conditions the enthalpy required for the formation of water is 285.9 kJ/mol. A portion of the required energy for a sustained electrolysis reaction is supplied by thermal energy and the remainder is supplied through electrical energy.

PEM electrolysis (20-100°C)



$H_2O \longrightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-$		Anode
$2H^+ + 2e^- \longrightarrow H_2$		Cathode
$H_2O \longrightarrow$	$H_2 + \frac{1}{2}O_2$	Total reaction

COAL GASIFICATION FOR H_2 PRODUCTION

Coal gasification is the process of producing syngas – a mixture consisting primarily of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), methane (CH_4), and water vapour (H_2O) – from coal and water, air and/or oxygen.

Historically, coal was gasified using early technology to produce coal gas (also known as 'town gas'), which is a combustible gas traditionally used for municipal lighting and heating before the advent of industrial-scale production of natural gas.

In current practice, large-scale instances of coal gasification are primarily for electricity generation, such as in integrated gasification combined cycle power plants, for production of chemical feedstocks, or for production of synthetic natural gas. The hydrogen obtained from coal gasification can be used for various purposes such as making ammonia, powering a hydrogen economy, or upgrading fossil fuels. Alternatively, coal-derived syngas can be converted into transportation fuels such as gasoline and diesel through additional treatment via the Fischer-Tropsch process or into methanol which itself can be used as transportation fuel or fuel additive, or which can be converted into gasoline by the methanol to gasoline process. Methane from coal gasification can be converted into LNG for use as a fuel in the transport sector.

During gasification, the coal is blown through with oxygen and steam (water vapour) while also being heated (and in some cases pressurised). If the coal is heated by external heat sources the process is called 'allothermal', while 'autothermal' process assumes heating of the coal via exothermal chemical reactions occurring inside the gasifier itself. It is essential that the oxidiser supplied is insufficient for complete oxidising (combustion) of the fuel. During the reactions mentioned, oxygen and water molecules oxidise the coal and produce a gaseous mixture of carbon dioxide (CO_2), carbon monoxide (CO), water vapour (H_2O), and molecular hydrogen (H_2). (Some by-products like tar, phenols, etc. are also possible end products, depending on the specific gasification technology utilised.) This process has been conducted in situ within natural coal seams (referred to as underground coal gasification) and in coal refineries. The desired end product is usually syngas (i.e., a combination of H_2 + CO), but the produced coal gas may also be further refined to produce additional quantities of H_2:

3C (i.e., coal) + $O_2 + H_2O \rightarrow H_2 + 3CO$

If the refiner wants to produce alkanes (i.e., hydrocarbons present in natural gas, gasoline, and diesel fuel), the coal gas is collected at this state and routed to a Fischer-Tropsch reactor. If, however, hydrogen is the desired end-product, the coal gas (primarily the CO product) undergoes the water gas shift reaction where more hydrogen is produced by additional reaction with water vapour:

$CO + H_2O \rightarrow CO_2 + H_2$

Although other technologies for coal gasification currently exist, all employ, in general, the same chemical processes. For low-grade coals (i.e., 'brown coals') which contain significant amounts of water, there are technologies in which no steam is required during the reaction, with coal (carbon) and oxygen being the only reactants. As well, some coal gasification technologies do not require high pressures. Some utilise pulverised coal as fuel while others work with relatively large fractions of coal. Gasification technologies also vary in the way the blowing is supplied.

Source: Wikipedia

STEAM METHANE REFORMING FOR H_2 PRODUCTION

Steam reforming or steam methane reforming is a chemical synthesis for producing syngas, hydrogen, carbon monoxide from hydrocarbon fuels such as natural gas. This is achieved in a processing device called a reformer which reacts steam at high temperature and pressure with methane in the presence of a nickel catalyst. The steam methane reformer is widely used in industry to make hydrogen. There is also interest in the development of much smaller units based on similar technology to produce hydrogen as a feedstock for fuel cells. Small-scale steam reforming units to supply fuel cells are currently the subject of research and development, typically involving the reforming of methanol, but other fuels are also being considered such as propane, gasoline, autogas, diesel fuel, and ethanol.

Steam reforming of natural gas is the most common method of producing commercial bulk hydrogen at about 95% of the world production of 500 billion m^3 in 1998. Hydrogen is used in the industrial synthesis of ammonia and other chemicals. At high temperatures (700 – 1100°C) and in the presence of a metal-based catalyst (nickel), steam reacts with methane to yield carbon monoxide and hydrogen.

$CH_4 + H_2O \rightleftharpoons CO + 3\ H_2$

Catalysts with high surface-area-to-volume ratio are preferred because of diffusion limitations due to high operating temperature. Examples of catalyst shapes used are spoked wheels, gear wheels, and rings with holes. Additionally, these shapes have a low pressure drop which is advantageous for this application.

Additional hydrogen can be obtained by reacting the CO with water via the water-gas shift reaction.

CO + H2O ⇌ CO2 + H2

The first reaction is strongly endothermic (consumes heat, ΔHr= 206 kJ/mol), the second reaction is mildly exothermic (produces heat, ΔHr= -41 kJ/mol).

The United States produces nine million tons of hydrogen per year, mostly with steam reforming of natural gas. The worldwide ammonia production, using hydrogen derived from steam reforming, was 144 million metric tonnes in 2014.

This steam reforming process is quite different from and not to be confused with catalytic reforming of naphtha, an oil refinery process that also produces significant amounts of hydrogen along with high octane gasoline.

Steam reforming of natural gas is approximately 65–75% efficient.

Source: Wikipedia

AUTO-THERMAL REFORMING (1/2)

Autothermal reforming (ATR) is a process for producing syngas, composed of hydrogen and carbon monoxide, by partially oxidising a hydrocarbon feed with oxygen and steam and subsequent catalytic reforming. Depending on customers' needs (mainly syngas composition or plant capacity), Air Liquide Engineering & Construction can provide ATR as a stand-alone technology or in conjunction with steam methane reforming, a technology known as combined reforming.

Partial oxidation and catalytic reforming

The feedstock for ATR can be natural gas, refinery offgas, pre-reformed gas, Fischer-Tropsch tail-gas, liquefied petroleum gas (LPG) or naphtha. After desulfurisation (optional, depending on feedgas composition), the feed gas is pre-heated and optionally pre-reformed before entering the ATR reactor at 30 to 100 barg via the well referenced proprietary burner. In the first reaction step, the feedgas reacts with oxygen (partial combustion) and steam to produce syngas. This gas mixture enters then, inside the same reactor, a catalyst bed for further reforming in order to achieve a high yield reaching thermodynamic equilibrium. Finally, the syngas stream is cooled in a process gas boiler, generating high-pressure steam which can be exported to neighboring units or used for power generation.

The syngas can be used as feedstock for various synthesis processes, mainly methanol and Fischer-Tropsch synthesis. Alternatively, syngas components can be separated into pure hydrogen, carbon monoxide and carbon dioxide.

Advantages

- Well referenced technology for large plant sizes using natural gas
- According to the best fit solution available as a standalone technology or as combined reforming (with steam methane reformer)
- Syngas adjustable to downstream usage offering a wide field of application
- High-pressure steam can be generated

Source: Wikipedia

AUTO-THERMAL REFORMING (2/2)

Partial oxidation

Hydrogen production from natural gas or other hydrocarbons is achieved by partial oxidation. A fuel-air or fuel-oxygen mixture is partially combusted resulting in a hydrogen rich syngas. Hydrogen and carbon monoxide are obtained via the water-gas shift reaction. Carbon dioxide can be co-fed to lower the hydrogen to carbon monoxide ratio.

The partial oxidation reaction occurs when a sub stoichiometric fuel-air mixture or fuel-oxygen is partially combusted in a reformer or partial oxidation reactor. A distinction is made between thermal partial oxidation (TPOX) and catalytic partial oxidation (CPOX).

The chemical reaction takes the general form:

$CnHm + n/2\ O_2 \rightarrow n\ CO + m/2\ H_2$

Idealized examples for heating oil and coal, assuming compositions $C_{12}H_{24}$ and $C_{24}H_{12}$ respectively, are as follows:

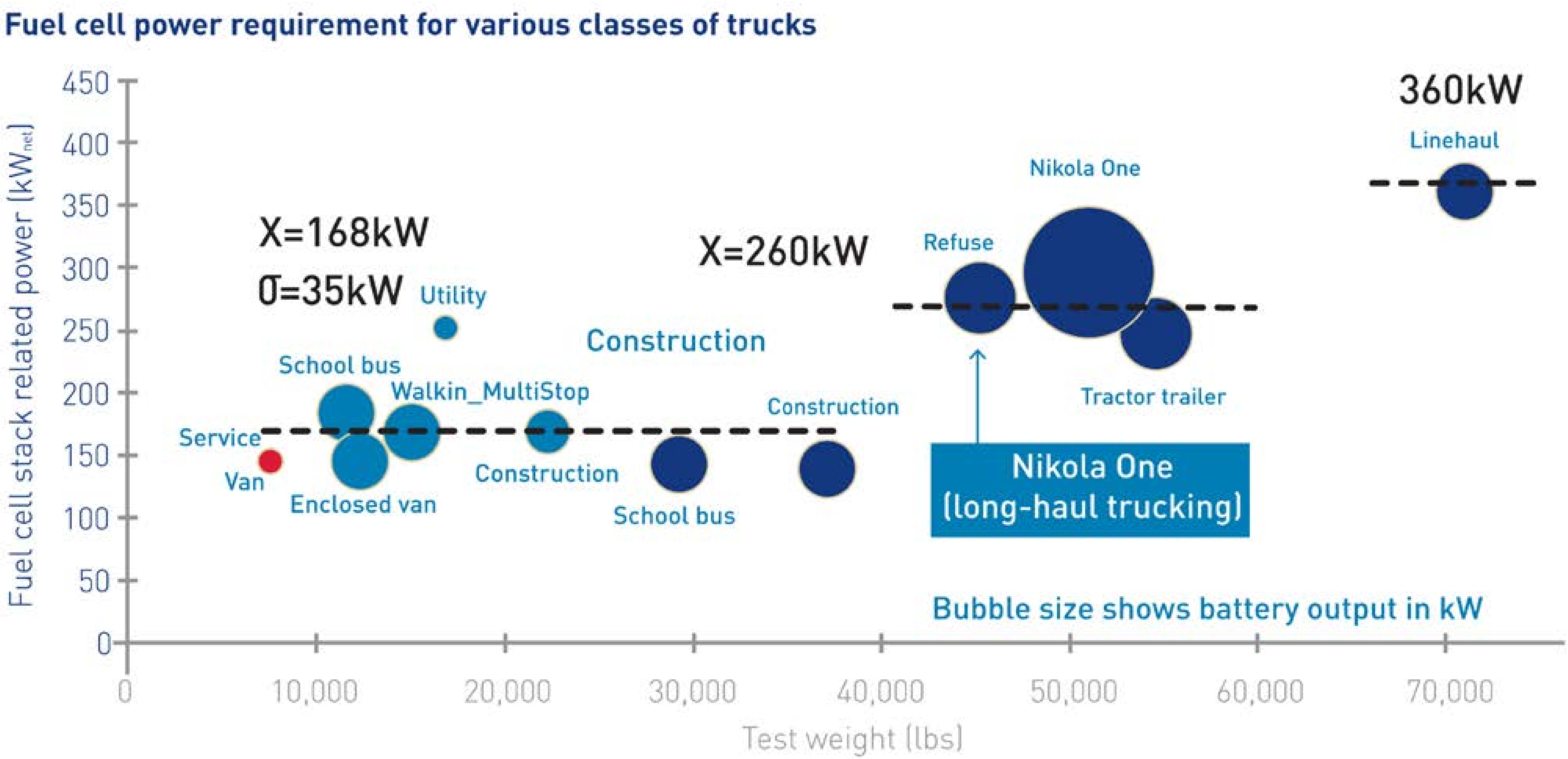
$C_{12}H_{24} + 6\ O_2 \rightarrow 12\ CO + 12\ H_2$

$C_{24}H_{12} + 12\ O_2 \rightarrow 24\ CO + 6\ H_2$

Source: Wikipedia

MANY FC APPLICATIONS ARE BEING BUILT OFF COMMON FUEL CELL PLATFORMS, ENABLING SCALED PRODUCTION

Medium duty vehicles (MDV) and heavy duty vehicles (HDV) fit into 3 power-level bins

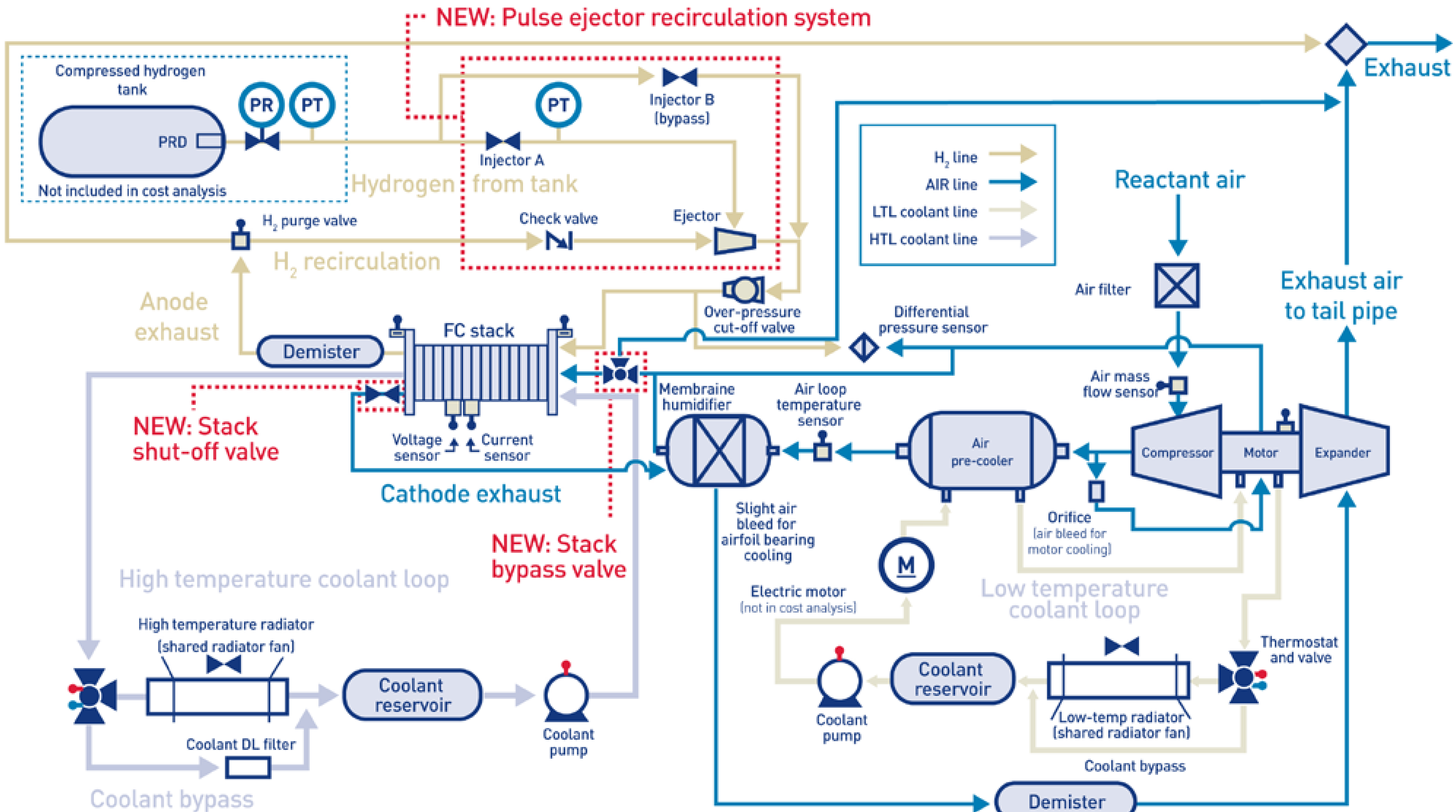


Two power levels capture most MDV/HDV applications, while all applications can be built from ~80kW FC modules (the average FC power output in today's FCEVs).

Source: Strategic Analysis for US DOE

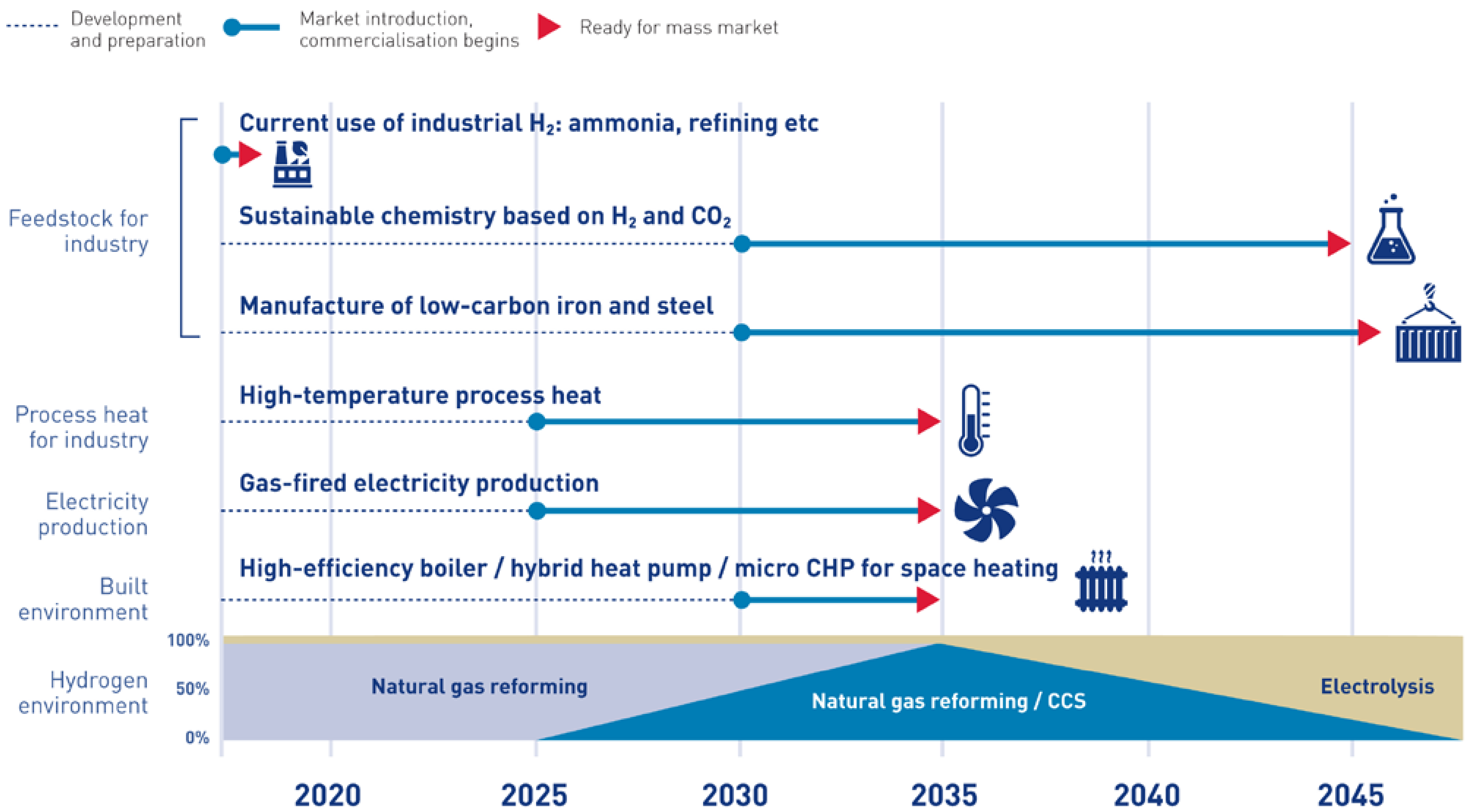
WHAT GOES INTO CALCULATING FC SYSTEM COST?

Configuration for an 80kW light duty vehicle



Source: US OE 2018, Fuel Cell Technologies Office

SCHEDULE OF IMPLEMENTATION FOR A RANGE OF INDUSTRIAL HYDROGEN APPLICATIONS



Source: TKI NIEUW GAS Topsector Energie - Outlines of a Hydrogen Roadmap

LEADING CHINESE COMPANIES ACTIVELY INVESTING IN FC AND HYDROGEN (1/2)

Company	Investment	FC/FCEV	H_2/HRS
Hongji Chuangneng	RMB800 million	High energy density membrane project	
Dongyue Group	RMB2 billion	Thousand sq.m. fuel cell membrane materials project	H_2 Energy Research Centre
Yizhi Power Energy		60,000 fuel cell system, 80,000 H_2 FC logistics vehicle	
Donghu New Energy Vehicle Group		2,000 fuel cell buses	
Xinyan Hydrogen Energy	RMB800 million	10,000 set FC stacks	
Lead Group	RMB5 billion (semi-conductor base included)	Phase I: 200 fuel cell stack	Phase II: H_2 production and storage study and industrialisation

Source: internal Anglo American Platinum market development research

LEADING CHINESE COMPANIES ACTIVELY INVESTING IN FC AND HYDROGEN (2/2)

- **FCEV-SAIC and Shanghai Chemical Industry Park** cooperated and promoted FCEV commercial operation. Shanghai Chemical Park will contribute the supply of H_2 by-product from the chemical giants in the park and it will be developed as H_2 energy and FCEV demonstration base
- **H2&FCEV-Sanhuan Group, Wuhan Hynertech and Wuhan Jinhuang Industry** launched the first normal temperature and pressure liquid organic hydrogen storage fuel cell logistics vehicle in Wuhan in June
- **H2-Shanghai Pujianag Special Gas** plan to start the construction of a 70Mpa HRS in Shanghai chemical Industry Park in 2018. It will utilise the pipe network system and by-product H_2 in the park
- **H2-Zhongshan Broad Ocean Motor and Hydrogenious Technology** cooperated and planned to develop large-scale removable hydrogen infrastructure construction in 2019
- **FCEV-China Communication Construction Group** invested **RMB 10b** and signed agreement with Hebei Bazhou government to build hydrogen fuel cell based new energy vehicle production base. **20,000** buses planned for this project

Source: internal Anglo American Platinum market development research

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Notes to editors:

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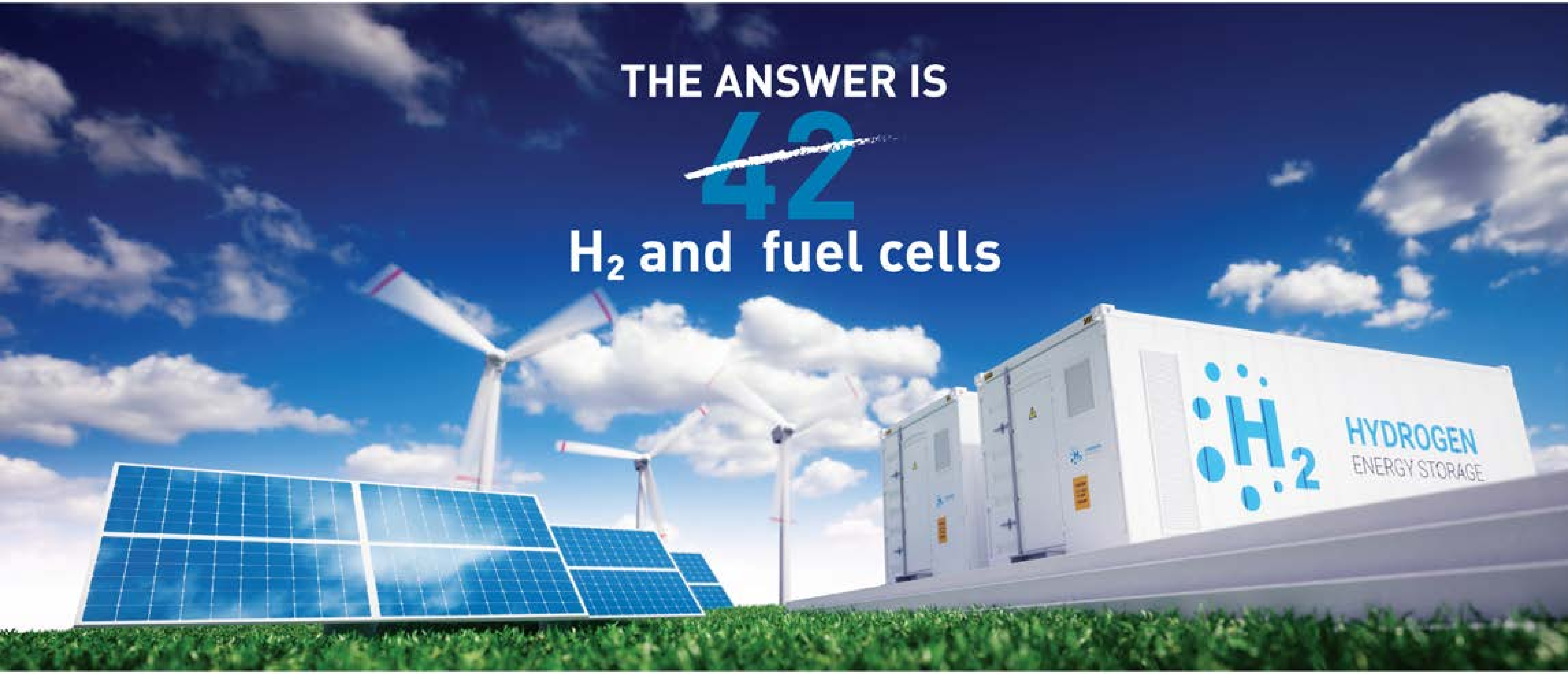

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