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# The Fuel Cell Industry Review 2018

**ACKNOWLEDGEMENTS**

We gratefully acknowledge the contribution of many individuals and companies within the fuel cell industry in providing information for and assistance with the compilation of the Fuel Cell Industry Review 2018. The Fuel Cell Industry Review 2018 is based on information available up to November 2018.



**LIST OF ABBREVATIONS**

AFC – Alkaline Fuel Cell
AFCC – Automotive Fuel Cell Cooperation
AHEAD – Advanced Hydrogen Energy Chain Association
AIP – Air-Independent Propulsion
APU – Auxiliary Power Unit
ARPA-E – Advanced Research Project Agency – Energy
BEV – Battery Electric Vehicle
CEO – Chief Executive Officer
CHEM - Chung-Hsin Electric and Machinery Mfg Corp
CHIC – Clean Hydrogen in European Cities
CHP – Combined Heat and Power
CIP – Critical Infrastructure Programme
CRRC – China Railway Rolling Corporation
CT – Connecticut, USA
DMFC – Direct Methanol Fuel Cell
DoE – US Department of Energy
DTI – Department of Trade and Industry
EFOY – Energy For You (SFC Energy fuel cell products)
FC – Fuel Cell
FCE – FuelCell Energy (USA)
FCEB – Fuel Cell Electric Bus
FCEV – Fuel Cell Electric Vehicle
FCH JU – Fuel Cells and Hydrogen Joint Undertaking (EU)
FCT – Fuel Cell Today
FY – Fiscal Year
GE – General Electric
GM – General Motors
HFC – Hydrogen Fuel Cell
HRS – Hydrogen Refuelling Station
HT – High Temperature
ICE – Internal Combustion Engine
IE – Intelligent Energy
IPO – Initial Public Offering
IP – Intellectual Property
ITC – Investment Tax Credit
JIVE – Joint Initiative for hydrogen Vehicles across Europe
JV – Joint Venture
kW – Kilowatt
LGFCS – LG Fuel Cell Systems
LNG - Liquefied Natural Gas
LOHC – Liquid Organic Hydrogen Carrier
LoNo – Low or No Emission Vehicle Deployment Program
MCFC – Molten Carbonate Fuel Cell
MEA – Membrane Electrode Assembly
MHPS - Mitsubishi Hitachi Power Systems
MoU – Memorandum of Understanding
MW – Megawatt
NEV – New Energy Vehicles
NEW-IG – Hydrogen Europe
OEM – Original Equipment Manufacturer
PACE – Pathway to Competitive European FC mCHP market
PAFC – Phosphoric Acid Fuel Cell
PEM(FC) – Polymer Electrolyte Membrane (Fuel Cell)
PPA – Power Purchasing Agreement
PV – Solar Photovoltaics
R&D – Research and Development
RoW – Rest of the World
SAFC – Solid Acid Fuel Cell
SAIC – SAIC Motor Corporation
SARTA – Stark Area Rapid Transit Authority, Ohio
SOFC – Solid Oxide Fuel Cell
SURUS – Silent Utility Rover Universal Superstructure
SUV – Sports Utility Vehicle
TTSI - Total Transportation Services Inc.
UAV – Unmanned Aerial Vehicle
UPS – Uninterruptible Power Supply
UTC – United Technologies Corporation
UUV - Unmanned Undersea Vehicle
VDMA – German Mechanical Engineering Industry Association
W – Watt
ZE – Zero Emission

December 2018

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# China, China, China… Korea?

Let's start with hydrogen. As we said last year, the increased availability of low-cost renewables – coupled with pressure on local and $CO_2$ emissions – is helping major corporations consider hydrogen as part of their serious big-picture, long-term option for remaining in business. Political interest is rising: a European Hydrogen Initiative was signed by Energy Ministers in Linz during the Austrian Presidency of the EU; Mission Innovation has added a Renewable and Clean Hydrogen Innovation Challenge to its portfolio; Tokyo hosted the first Hydrogen Energy Ministerial; and a senior Chinese official reiterated the logic of China's commitments. Hydrogen is, of course, a very useful input to many fuel cells, and increasing belief in its potential is strongly driving interest in fuel cells.

While we retain our focus on fuel cells for this review, we include a brief overview of electrolyser developments, a sector where we're also very active.

The industry overall shipped about 4,000 more units than 2017, an increase of 145 MW. Total power shipped was just over 800 MW – 74,000 units. Two-thirds or so were in Japan, where Ene-farm has remained a stable market, and Toyota's continued lead in vehicle shipments – another 3,000 or so Mirais were put into customer hands – means that Japan is well situated on the supply side. A little over 11,000 transport units were put into the market in total. Big stationary systems are also rolling out, with the US policy scene more supportive and Bloom Energy successfully going public. Doosan's investments in manufacturing and deployment are paying off, with increasing numbers of PAFC systems on the ground, and solid orders looking forward to 2019.

PEM remains the dominant chemistry, certainly for transport, though both DMFC and SOFC variants of vehicle systems are under development. SOFC is making good headway in stationary systems

for Ene-farm, and is increasingly considered sufficiently mature for large, commercial-scale products. Companies like Ceres Power and SolidPower are well positioned.

Fuel cells themselves have made good progress. In addition to transport sales, stationary systems – many not using hydrogen – roll off production lines, and total industry shipments continue to rise. But although shipments are up slightly on 2017, the main progress in 2018 was in the development of underpinning strength. Costs are coming down, the supply chain is just starting to firm up. Investment is flowing into the industry, and big companies are building positions. As an indicator, established automotive supply-chain players like ElringKlinger, Michelin, Bosch and Plastic Omnium are continuing to quietly and steadily develop capacity, while pure-play fuel cell companies like Plug Power, Ceres Power, Hydrogenics and FuelCell Energy are seeing tens of millions of dollars of investment from public markets or industrial partners.

Last year's Review highlighted the importance of China in the fuel cell dynamic. That remains, both in the insatiable demand for technology and skills transfer, and the potential for Chinese supply chain companies to come in and disrupt existing positions. Most non-Chinese companies have an eye on China, an alliance in China, or a fear of China. But lack of infrastructure coupled with problems licencing vehicles have led to slower roll-out than anticipated, negatively affecting both local developers and their overseas counterparts such as Ballard and Hydrogenics.

The real extent of this is hard to gauge: the situation moves very fast, and reported 'facts' are inconsistent and difficult to check. But we have seen dozens of trucks parked in lots, seemingly awaiting the chance to operate, and Foton is parking buses on roads around Beijing as they await the opportunity to put them into service. And stationary fuel cells are not really on the Chinese radar – a few companies have offerings in backup power or are developing other systems, but policy support is absent.

This may all be simply symptomatic of what many consider China's approach to new technology, putting large amounts of money into many players in a chosen industry and seeing how things turn out. Or it may show the inherent weakness and complexity of the sector.

We tend to the former view, having seen very credible and ambitious systems developers – Re-Fire is a good example – and increasing capabilities in component supply.

fuel cells are seen by many as essential for trucks to maintain a place in the delivery infrastructure. Buses are following a similar path, with far more deployed than trucks, and an upswell of interest that has manufacturers struggling to keep up with demand.

What surprised us in 2018 was the dramatic re-emergence of Korea. In 2017's Review we mentioned that the Government was taking a renewed interest, and Hyundai has been bullish for many years. But the scale of some of the announcements has been impressive. An ongoing push for stationary systems was expected, but Hyundai's announcement of 1,000 trucks for Switzerland over the coming few years, followed by a similar-sized programme for buses in Korea to 2022, and then the year-end commitment to scale car production to 40,000 units has set some stretch targets for other companies to match.


Although most indigenous technology is not yet technically competitive with overseas sources, it will be soon.

The Chinese story remains mainly one of heavy-duty applications. The buses and trucks mentioned above are only part of bigger fleets, with several hundred vehicles operating full commercial services in Shanghai and other regions. Trains and light rail generally are of interest too.

And outside China, heavy-duty is of increasing interest. Nikola and Hyundai are moving forward on ambitious plans for trucks, initially in the US and Switzerland; Alstom has successfully started operating hydrogen passenger trains in Germany; the marine sector is gearing up. Poor air quality in cities is leading politicians to ban polluting vehicles – and in some cases forcing new ones to be zero emission. Pure battery vehicles cannot cover all the route, load and refuelling requirements and so

In fact, Hyundai seems so convinced that it has articulated its 'FCEV Vision 2030': moving Hyundai beyond transportation into other sectors, and producing 700,000 FC units annually by 2030.

From our perspective, 2018 has been a great year, and a difficult one. The news has come in thick and fast – so much so that sometimes we have struggled to keep up. We greatly missed the perception and writing of Bob Rose, a founding member of our team, who passed away before he could see this 5th anniversary edition of the Review.

Nevertheless, as the industry grows, we will continue to gather and publish these statistics. We'll do our best to stay on top of the most important developments, and continue to support the industry through this and through our various consulting engagements. We look forward to the challenge.

# About the review

## Applications

To ensure consistency, we categorise our shipment data in specific ways. For applications, these categories are Portable, Stationary and Transport, defined as follows:

| Application type | Portable | Stationary | Transport |
|---|---|---|---|
| Definition | Units that are built into, or charge up, products that are designed to be moved, including small auxiliary power units (APUs) | Units that provide electricity (and sometimes heat) but are not designed to be moved | Units that provide propulsive power or range extension to a vehicle |
| Typical power range | 1 W to 20 kW | 0.5 kW to 2 MW | 1 kW to 300 kW |
| Typical technology | PEMFC<br>DMFC<br>SOFC | PEMFC<br>MCFC<br>AFC<br>SOFC<br>PAFC | PEMFC<br>DMFC |
| Example | • Small 'movable' APUs (campervans, boats, lighting)<br>• Military applications (portable soldier-borne power, skid-mounted generators)<br>• Portable products (torches, battery chargers), small personal electronics (mp3 player, cameras) | • Large stationary prime power and combined heat and power (CHP)<br>• Small stationary micro-CHP<br>• Uninterruptible power supplies (UPS)<br>• Larger 'permanent' APUs (e.g. trucks and ships) | • Materials handling vehicles<br>• Fuel cell electric vehicles (FCEV)<br>• Trucks and buses<br>• Rail vehicles<br>• Autonomous vehicles (air, land or water) |

Portable fuel cells encompass those designed or able to be moved, including small auxiliary power units (APUs); Stationary power fuel cells are units designed to provide power to a 'fixed' location, also including APUs on e.g. trucks and large vessels; Transport fuel cells provide either primary propulsion or range-extending capability for vehicles.

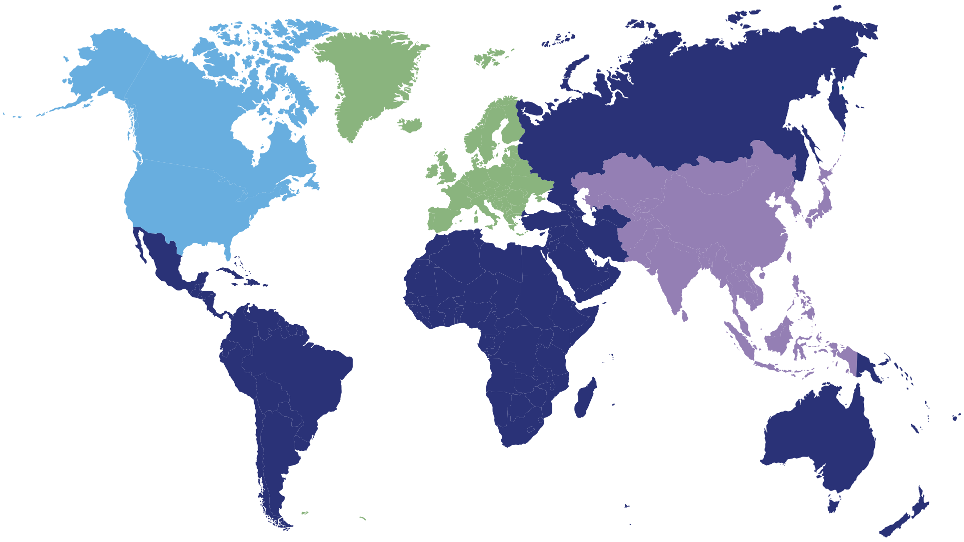
## Fuel cell types

Shipments by fuel cell type refer to the six main electrolytes used in fuel cells: proton exchange membrane fuel cells (PEMFC), direct methanol fuel cells (DMFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and alkaline fuel cells (AFC). High temperature PEMFC and low temperature PEMFC are shown together as PEMFC.

Explanations of these six main types of fuel cells can still be found on the FCT website http://www.fuelcelltoday.com/technologies

## Geographic regions

We maintain FCT's four main geographic regions of fuel cell adoption: Asia, Europe, North America and the Rest of the World (RoW).



- RoW
- Asia
- North America
- Europe

## Reported shipment data

Tables of data can be found at the back of this Review. Data are presented for each year in terms of annual system shipments and the sum total of those systems in megawatts, both of which are reported by application, region and fuel cell type as described in the section below.

Shipments are reported by numbers of units (systems) and by total megawatts shipped annually.

Shipment numbers are rounded to the nearest 100 units and megawatt data to the nearest 0.1 MW. Where power ratings are quoted, these refer to the electrical output unless stated otherwise. In general we use the nominal, not peak power of the system, with the exception of transport. Because continuous power depends heavily on system design and how it is used, we report peak power for these units.

The reported figures refer to shipments by the final manufacturer, usually the system integrator. In transport we count the vehicle when shipped from the factory. This is because the shipments of stacks or modules in a given year can be significantly different from the shipment of final units (e.g. vehicles) in the same timeframe. We use stack and module shipment data to help us sense-check numbers between years. The regional split in our data refers to the countries of adoption, or in other words, where the fuel cell products have been shipped to, not where they have been manufactured. Where it is possible to differentiate, we do not include shipments for toys and educational kits.

## Data sources and methodology

E4tech has been publishing this Review for five years now. For clarity and consistency, we have taken the decision to no longer include historical data from the Fuel Cell Today Industry Review.

We have been in direct contact, either verbally or in writing, with over 100 companies globally for this report. Some of these are not yet shipping units, other than small quantities for tests, but of those that are shipping very few declined to give us primary data.

For those – but also for others, as a way to sense-check our numbers – we have collected and cross-referenced data from publicly available sources such as company statements and statutory reports, press releases, and demonstration and roll-out programmes, in addition to discussions with other parties in the supply chain. We do not count replacement stacks in existing applications, and where possible we also do not count inventory, only systems that are shipped to users.

Our dataset is based on firm numbers for the period January to October 2018. For the remaining period we use forecasts shared with us by individual companies or prepared by us in discussion with industry. We will revise data for 2018 in our 2019 edition as appropriate. We have slightly revised the figures for 2017 in this report: unit numbers were reduced by about 3% and megawatt numbers reduced by less than 2% compared to our published 2017 forecast.

We thank all of the companies that have responded to our requests for data and clarification. If you ship – or plan to ship – fuel cell systems and we have not been in touch with you, please do contact us so that we can further improve our coverage for future editions.

# The fuel cell world in 2018

2018 was good for fuel cells. Other than for one or two companies, neither units nor MW shipped saw significant growth, but a lot of groundwork was laid, serious players entered, and money came into the sector. Bloom finally listed, and many other companies raised finance, some through strategic joint partners. China continued to excite and confuse, while Korea re-entered the market with a vengeance.

Looking back, the abiding feeling is of consolidation. Companies that for years have had promising technology development, like Ceres and Solidpower, started to put significant manufacturing in place, with big partners apparently keen to deploy. Blue World Technologies, founded by the team that built and sold Serenergy to Fischer Group, announced plans for the world's largest methanol fuel cell manufacturing plant in Aalborg, Denmark.

Automotive tier 1 suppliers ElringKlinger, Michelin, Plastic Omnium, Bosch – and others – all demonstrated commitment to components and stacks, strengthening a supply chain that for so long has been the domain of only automotive companies like Toyota or pure-play fuel cell makers like Ballard.

Buses started to get real traction. Hundreds are expected to enter service over the very near term, bringing costs down, solidifying the supply chain further, and raising public awareness of the 'other' zero emission solution.


They could be joined by other heavy-duty applications sooner than we had imagined, with Hyundai's 1,000 truck announcement for Co-op in Switzerland following Nikola's 800 for Anheuser-Busch. Medium-duty truck fleets are already delivering day-in, day-out in parts of China. Fuel cell trains are in daily operation, and more are on the way. And on the water, fuel cell boats are being built.

Fuel cell race cars remain a thrill – a new initiative called 'Mission H24' plans for a hydrogen racing class at the classic Le Mans 24 hours race. A partnership between the Automobile Club de l'Ouest (ACO) and Swiss company GreenGT, the project will promote and develop hydrogen-powered vehicles ahead of their anticipated Le Mans debut in 2024. An ACO/FIA working group is already in place. And Gumpert Aiways showcased a methanol-fuelled fuel cell supercar, built with Serenergy, at the Beijing Motor Show. Methanol is making a small comeback in fuel cells, especially in China where it is already used as a fuel, and where Weltmeister is also developing a fuel cell car – using a DMFC.

Otherwise news around passenger cars was muted in comparison with heavy duty. More Mirais and more Claritys are on the road, the Daimler GLC was finally released, almost in slow-motion, and the universally-acclaimed Hyundai Nexo came out too. BMW, VW and others still mention post-2020 for any fuel cell efforts. Capacity is being built in China, though nothing serious will launch until 2021 or 2022. But both Toyota and Hyundai announced increased manufacturing capacity investment. Toyota will increase its capacity for MEAs and tanks 10-fold, in line with stated aims for 30,000 cars per annum in 2020, and Hyundai will put in place a factory to build 40,000 units by 2022.

A lot of the impetus is still government related – subsidy carrots or policy sticks. Some of this must continue, until the industry really does become an industry and not a disparate collection of suppliers, but a few applications buck the subsidy trend.

These are dominated by high-value back-up systems and military applications, where SFC Energy has been making a living for several years. This year SFC got more serious, announcing several big orders and showing enough appetite to acquire hydrogen PEM IP from the defunct Heliocentris stable, to supplement its DMFC platform. And more players entered potentially self-supporting markets such as UAVs.

The signs are that policy will continue to support the sector. Climate change is omnipresent in the discussion, as is air quality, with studies showing India has overtaken China as the country with the deadliest air, and cities worldwide looking at banning diesels and other internal combustion engines. And Australia has a new hydrogen roadmap, joining an increasing number of countries that see opportunity to produce, export or use a green fuel to complement electricity. More hydrogen availability will be good for fuel cells.

In the stationary sector, big units are starting to proliferate. Doosan seems to be operating both its factories close to capacity, FuelCell Energy has picked up after a hard couple of years, and Bloom shows little sign of slowing down. Each of these companies uses a technology sometimes derided as below state-of-the-art – not the cheapest, or most efficient, or most elegant.

But the market suggests it will take time for the new generation to catch up, and there is headroom in many of the existing designs. The newer technology types are however dominant for smaller systems, though promises of very low cost and very robust performance need to be proven in customer hands.

Not all was rosy. Big Chinese plans have not always been followed through – for example Synergy's inability to honour its take-or-pay deal with Ballard led to end-of-year rejigging, and Hydrogenics faces similar issues. The number of vehicles actually running on Chinese roads remains short of those built. With luck and organisation, some of those capacity problems will be dealt with in 2019.

A concern remains. The dramatically increased interest in 'bulk' hydrogen is driving interest, and market expectations are rising. Yet fuel cell companies – or divisions – remain largely sub-scale and unprofitable, with fragile supply chains. More strength, and more choice, is needed in materials, components and even systems.

This is a conundrum, because only with real markets and big deployment will enough money be generated to allow more supply chain entrants and more competition, while allowing profits to be taken. So the fuel cell industry remains in flux, for another year or so at least.

# Corporate highlights

2018 has been a generally positive year for fuel cell companies. For most of the period there was little in the way of high-profile withdrawals, failures or even near-death experiences, and some notably important and encouraging events occurred. However, Intelligent Energy's apparent rescue a year ago looks like a false dawn.

**Bloom Energy floats, at last, and others tap markets**

One of 2018's most significant market events was Bloom Energy's IPO. Bloom had repeatedly claimed it would go public, and filed 'in secret' in 2016, only to withdraw because the US Investment Tax Credit was suspended. But at the end of July, Bloom successfully placed 18 million shares at US$15 each on the New York Stock Exchange, valuing the business at around US$2 billion. This is almost twice the combined value of four other major publicly quoted North American fuel cell businesses. The IPO and subsequent public document releases have opened a window into Bloom's famously secretive workings, exposing for example an early unit decommissioning programme which is costing money. The share price more than doubled within 6 months, then dropped to 70% of its launch value by the end of 2018, echoing the roller-coaster endured by other fuel cell businesses

The few other fuel cell companies listed on stock markets also raised further funds. Plug Power, quoted on Nasdaq, placed US$100m of convertible senior notes in March, and US$35m of convertible preferred stock in November. In August FuelCell Energy, also on Nasdaq, placed $30.7m of convertible preferred stock.

Ceres Power, quoted on London's AIM exchange, has raised significant capital from several strategic partners. It completed a deal with Weichai Power in May for joint development of systems for automotive markets, linked to an initial £17m investment from Weichai. In August it revealed a tie-up with Bosch to develop stationary distributed power generation, starting with a 5 kW system, then a 10 kW system for the market and with a total value to Ceres to 2020 of £20m, including licencing, engineering services etc. This came on top of a £20m share placement, and Bosch also bought £9m worth of Ceres shares – around 4.4%. Weichai (also partnering with Bosch) put in another £1m to avoid dilution of its 10% stake, and a further £28m is linked to finalisation of a strategic collaboration in December.

Finnish business Convion launched a €4m round in May, which reportedly raised 210% of its target. Weichai hedged its fuel cell bets by also investing in Ballard. It bought just under 20% of the company for US$163m, which triggered an additional investment in Ballard by existing partner Broad Ocean, who put in US$20m to maintain its 9.9% stake. In June, Ballard also signed up with the Swedish-Swiss electrical giant ABB to develop its PEM technology for use in marine applications, and extended its partnership with Audi for fuel cell vehicles by a further 3.5 years. Ballard's tie-up with Weichai will establish a JV in Shandong Province for stack production and fuel cell module activity to supply Weichai's automotive interests. And Bosch also backed two horses, though with similar technology, partnering with SolidPower to give it distribution rights in Germany for Solid Power's BlueGen SOFC micro-CHP units.

Other fundraisers included Hydrogenics, which late in December announced a placement of shares with 'The Hydrogen Company' (a subsidiary of Air Liquide), bringing in US$20.5m and giving Air Liquide an 18.6% stake in the company. Hydrogenics also announced a US$7.8m order for fuel cell power systems from undisclosed Chinese customers for use in Zero Emission Vehicles. Watt Fuel Cell raised capital mid-year, and the founding team behind Serenergy announced a new venture, Blue World Technologies, which plans to build the world's largest methanol fuel cell factory in Aalborg, Denmark. Serenergy continues under the ownership of the Fischer Group. Conventional markets are not the only option for fundraising either – Riversimple successfully closed its second £1.1m crowdfunding round in March.

## Not all news was positive

Despite the positive mood in the market, some companies did suffer. Vancouver-based AFCC, jointly owned by Daimler and Ford, finally announced publicly that it would cease activities. The two OEMs each repatriated their technology to R&D locations in Germany and the USA, whilst Ballard Power took ownership of assets at the Burnaby site, reintegrating what was split out when AFCC broke from Ballard a decade before. The move released a large number of highly qualified fuel cell experts onto the market, with some setting up their own consulting businesses, others going into existing companies, and more taking advantage of China's continuous demand for expertise. AVL also saw an opportunity, picking up around 30 ex-AFCC employees and starting a fuel cell stack centre of excellence in Vancouver alongside its investment in test stand experts Greenlight.

And late in 2018 LB-Shell, the renamed Intelligent Energy Holdings, announced that the company would be delisted from the LSE and wound up. While no specifics were given, a "Letter of Claim" relating to the conduct of Intelligent Energy's IPO and its subsequent sale to Meditor was considered so likely to lead to litigation that the preferred route was to shut it down. It is unclear if there will be any impact on Intelligent Energy itself. Much earlier in the year, Ballard fell victim to a short-seller who put out a claim that promised Chinese buses and system orders were not real. While the situation in China is complex – and recent events have shown the problems in putting vehicles into service – the information put out was distinctly one-sided and clearly served the short-seller more than anyone else.

Even though the overall mood music is upbeat, the supply chain is not yet robust. 3M announced it would stop producing MEAs, following a strategic review. While other companies were more obviously active, losing a major player is always disappointing.

## The industry remains fluid

As well as raising money and ceasing activity, companies continued their divestments, mergers and acquisitions.

Ballard sold the non-core power management assets of Protonex to Revision Military Ltd for up to US$16m, dependent upon certain sales targets being met. Plug Power acquired American Fuel Cell of Rochester, NY, giving access to AFC's MEAs for Plug's ProGen stack, increasing power density and longevity. The AFC team built their expertise in General Motors fuel cell activities, reinforcing the view that very little is lost in the fuel cell world, but it does get frequently recycled. Plug has opened a new production facility at Clifton Park, NY and is now incorporating the AFC technology into its stacks.

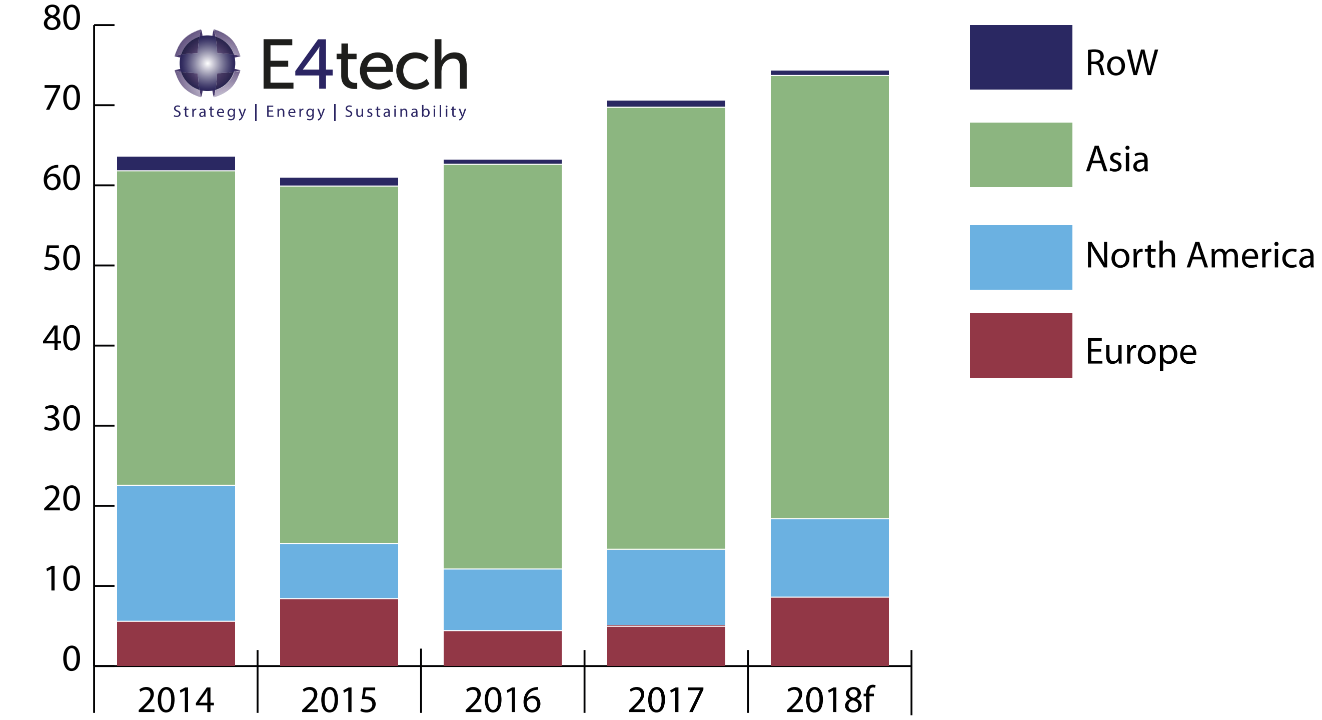
In Europe, Sunfire acquired the micro-CHP systems know-how from its erstwhile partner Vaillant. Vaillant put its micro-CHP activities on hold in 2017, leaving Sunfire without a route to that market. The acquisition means Sunfire can offer its core SOFC technology for micro-CHP systems. and in particular accesses to the PACE project and German KfW 433 programme. Sunfire also acquired all the shares in new enerday GmbH, and concentrated its stationary SOFC activities in Neubrandenburg. SFC Energy licenced the IP behind Heliocentris, P21 and FutureE's technology portfolio from adKor, also gaining access to the existing product portfolio. This gives SFC a leg-up into hydrogen fuel cell technology and a larger power range than they have been able to target with their original DMFC products. And Freudenberg picked up the assets of Elcore, the micro-CHP developer which entered administration in 2017, and to which it was a supplier.

## The market remains uncertain

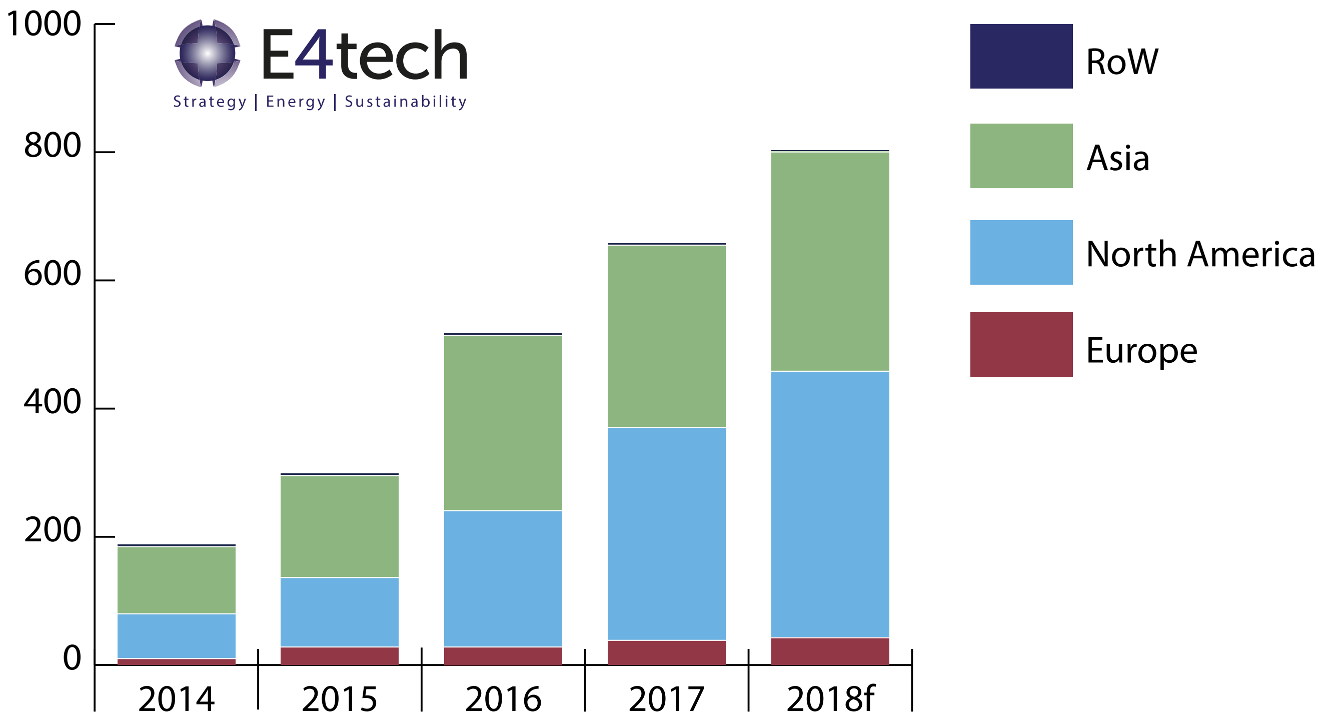
The positive story is also counterbalanced somewhat by uncertain markets. Despite China's ambitious plans, both Ballard and Hydrogenics have noted slowdowns in orders, with Ballard removing Guandong-Synergy's remaining contract from its order backlog. While China continues to support fuel cell vehicles strongly, lack of refuelling station capacity and a slow process for licencing vehicles have both led to a lower than expected number on the road. Other markets are perhaps more stable, but almost all continue to rely on government carrots or sticks, at least for now.

# Shipments by region

Shipments by region of adoption 2014 - 2018 (1,000 units)




Megawatts by region of adoption 2014 - 2018




2018 is our forecast for the full year, based on firm data from January to October.
We have slightly revised the figures for 2017 in this report.

# Shipments by region

The global distribution of fuel cell markets in 2018 mirrors 2017: North America has further increased in terms of megawatts and Asia leads in unit numbers. Europe is catching up in unit shipments but lags substantially in megawatts. The Rest of the World (RoW) barely figures.

North America's unit shipments increased by 4% to 9,800 units, but the megawatts raced ahead to 415 MW, 25% up, and over half of all the shipments expected in 2018. This reflects a continued rise in transport fuel cell shipments, comprising 310 MW in 2,800 passenger cars, plus around 5,000 material handling vehicles. Demand for buses, trucks and UAV applications make up the remainder of the transport systems.

The resurrection of the US Federal Investment Tax Credit for stationary fuel cell systems, plus individual State incentives and regulations, are helping the three large stationary manufacturers. However, it will take until 2019 to execute many of the bigger projects announced. Around 1,000 back-up power and off-grid systems will be shipped this year for the North American market, including both stationary and portable units.

In Asia, the 55,300 units shipped are much the same as 2017, but the megawatts have risen by 20% to just above 340 MW. Korea accounts for almost all 110 MW of Asia's 100 kW+ stationary shipments. The Renewable Portfolio Standard continues to be a strong incentive, and Doosan has become the dominant supplier after Posco Energy's exit.

And Bloom Energy finally entered the Korean field, announcing their first multi-megawatt project. The vast majority of units globally remains in Japan, though, with nearly 50,000 units (roughly 35 MW) of residential micro-CHP systems added in 2018 under the Ene-farm programme. Slightly larger commercial sized systems (several kW) are starting to ship in both Korea and Japan, and Japan saw some backup systems introduced in 2018, plus portable units including 500 MyFC USB chargers.

Japan and Korea, home to the three world-leading fuel cell car OEMs, will see an estimated 1,300 fuel cell cars hit the road in 2018, plus a small number of fuel cell buses. However, it is China that leads commercial vehicle shipments, with an estimated 1,000 in 2018.

Europe showed a healthy uptick over 2017, with unit numbers up 70% to 8,600 and 43 MW more – up 12%. The general absence of the very strong support schemes of North America and Asia keep the market smaller though. The exception is the German KfW433 funding scheme for small scale, mainly micro-CHP systems, which is driving the growth in unit numbers. Around 4,000 are expected to be approved for support in 2018, joined by hundreds of units shipped under the pan-European PACE project. An estimated 500 stationary back-up units, plus several thousand portable fuel cells, were shipped in 2018.

This reflects some European strength in these applications. In contrast, deployment of larger stationary units has been very limited.

Transport fuel cell systems in Europe benefited from about 300 OEM car sales, totalling 30 MW. More fuel cell buses also entered service, a trend expected to continue, even accelerate. Importantly, Europe also saw the world's first passenger fuel cell train begin operation in Germany, with more units to come. Around 100 material handling vehicles were put in service this year, and announcements for the future are also positive. Maritime applications, light- and heavy-duty trucks are starting to show promise, with numbers expected to grow as soon as 2019.

Fuel cell system shipments in the Rest of the World remain very small: about 600 units, totalling 1.4 MW. Both of these numbers are down on 2017. These comprise mainly stationary and portable back-up and off-grid units delivered to a range of countries. Of interest are developments in India, where the first fuel cell bus began operations, and systems for telecom towers are due to begin delivery this year. Fuel-cell based telecoms systems are also due to start deployment in Kenya.

# Cars trundle on

In marked contrast to buses, forklifts and potentially even heavy-duty vehicles, cars remain hard to deploy. The OEMs have been distracted by the need to get battery vehicles on the road to meet emissions targets, and slow infrastructure development has not helped. The politics also remain complex, as rollout in Germany – which has one of the best refuelling networks and ostensibly powerful and motivated OEMs – has been hamstrung by Daimler's continued backtracking on launch dates and numbers, the general image problems and direction of the VW group, and BMW's 'softly softly' approach to fuel cells.

Probably the most important vehicle launch of 2018 was Hyundai's Nexo, generally acclaimed as the best production fuel cell car around. Designed ground-up around the fuel cell, the SUV has longer range and better storage space than its immediate rivals, and sets a benchmark for others. Daimler's GLC plug-in hybrid fuel cell vehicle was also released, late in the year, but to a small number of fleet owners only and with a production run expected to be small. Daimler has indicated an interest in focusing on heavier-duty applications in the near term. Toyota's Mirai and Honda's Clarity Fuel Cell continue to sell, and are well-liked by their owner.

In China, development is feverish. Only SAIC has a road-tested vehicle in the Roewe, but Great Wall Motors is deploying very large amounts of capital to build a production plant next to its new R&D facility outside Beijing. Hydrogen and fuel cell experts continue to join the team, and Great Wall demonstrated the breadth of its interests late in the year by joining the German H2Mobility programme for hydrogen refuelling stations. The move seems to be mainly linked to the company's desire to develop and own not only fuel cell vehicles, but also supporting infrastructure, and will give it access to detailed insight into what to do – or what not to.

Still in China but moving in a different direction, Weltmeister showed a prototype hybrid car powered by a 10 kW DMFC, using technology originally developed by Oorja Power in the US, and subsequently acquired by a Chinese investor. High power DMFC vehicles have long been considered unlikely because of the intrinsic cost of the technology, but China already uses methanol fuel and the approach may allow simpler refuelling station build-out than does hydrogen. Every other Chinese OEM seems to be focused on the latter fuel though, and while very few vehicles have been announced at least a dozen OEMs are in the prototyping stage – mainly using external expertise and outsourced stack technology.

China's new drive towards fuel cells was once again endorsed at a high level, with Wan Gang, a deputy chairman of the Chinese People's Political Consultative Conference directly advocating the technology in the Chinese press. His opinions have weight; he was formerly Minister of science and technology.


## North America still leads

North America accounts for about two-thirds of annual light duty vehicles sales, thanks in large part to the existence of infrastructure. To be clear, almost all of those sales are in California, which continues to doggedly support the build-out of hydrogen refuelling stations. Toyota, which has the leading market share for conventional vehicles in California, commanded more than half of the 2018 fuel cell sales with the Mirai – as well as showcasing a fuel cell-powered Tundra pick-up capable also of cooking a Pizza! The vehicle, shown in nondescript livery as the 'mystery vehicle' in last year's Review, continues Toyota's line of quirky marketing. Despite its lack of pizza, the Hyundai Nexo – an SUV – could challenge Toyota in 2019; perhaps three-quarters of the U.S. auto market consists of light trucks, and the Mirai is a sedan. And reinforcing the infrastructure point, delays in New England have postponed the launch dates for fuel cell vehicles in that region; half a dozen hydrogen stations are in various stages of permitting and/or construction, and deployments are expected once they are in place.

In Canada, Toyota announced a fleet of 50 Mirais for the provincial government of Quebec in 2019, with the opening of the province's first public hydrogen station. 8 hydrogen stations were announced in British Columbia, along with a ZEV mandate of its own – stricter than those of Quebec and California – at the end of 2018.

Asia accounted for about 30% of fuel cell vehicle sales, split primarily between Hyundai in South Korea and Toyota in Japan. Hyundai has announced a goal of surpassing Toyota's fuel cell vehicle sales in 2019, aiming to exceed the Japanese OEM's target of 3,000 vehicles. The race between the two is hotting up nicely. Toyota said it would increase fuel cell stack production 10-fold, investing in new production facilities for both membrane electrode assemblies and fuel tanks, which matches its ambition to move from 3,000 to 30,000 vehicles per year by 2020.

In general, Toyota seems to be broadening its offering, and may see the demand for forklifts and trucks as an opportunity to increase production volumes and reduce fuel cell costs. Hyundai countered by announcing a 40,000-vehicle capacity in 2022, with its manufacturing affiliate Mobis breaking ground on a second fuel-cell system plant in Chungju.

Europe accounts for the relatively small balance of sales in relatively small pockets – for example the Paris 'Hype' taxi fleet is now 100 vehicles strong – but plenty of innovation is underway. In the UK, Riversimple continues to develop its Rasa and plans to have up to 20 vehicles in the hands of customers in 200 households for field trials and familiarisation. Microcab's Vianova is a more 'van-shaped' vehicle than the previous car, and will launch in 2019. Streetscooter in Germany, a Deutsche Post DHL subsidiary, has publicly announced the development of 100 or so fuel cell vans for its delivery routes, and many more could follow.


French company Symbio continues to supply Renault Kangoos with its 5 kW systems, though is moving towards the heavy-duty sector with a new 40 kW range extender product, and AVL in Austria has a major programme on stacks and systems for different vehicle types.

**The need for fuel cell speed?**

The car segment still attracts those who want to showcase the sexy side of fuel cells. While still working in parallel on heavy duty, GreenGT continues development of its supercar segment. It was back on the racetrack at Spa in September, running demonstration laps in its latest vehicle – the LMPH2G – to support the announcement of a new hydrogen class for the 24 Hours of Le Mans.

The initiative comes from the top of the sport: the Automobile Club de l'Ouest (ACO) and Federation Internationale de l'Automobile. Excitingly, the GreenGT vehicle's top speed of around 300 km/h is now apparently matched by a new development, using a methanol fuel cell platform. Gumpert Aiways has built a light-weight, high-performance, battery electric supercar with a methanol fuel cell power plant from Serenergy – with a top speed exceeding 300 km/h. Aiways Ltd, Gumpert Aiways' parent, is apparently working on further vehicles, including an SUV.

# Buses

Fuel Cell Electric Buses (FCEBs) are increasingly regarded as an essential option to partner battery-electric fleets in the zero-emission cities of tomorrow. Increasing numbers of transport authorities are intending to enact zero emission vehicle legislation, and in a very short timeframe. The availability of buses is improving, with larger orders looking for providers, and capital costs being driven down. Vehicles look like and feel better than their ICE equivalents, with similar operational performance over 18-hour shifts, 10-15 minute refuelling cycles and 300-450km range.

**Europe still in front – just**

Europe has consistently led the deployment of FCEBs, with around 50 FCEB on the road already, and many cities have aggressive zero emission vehicle procurement policies. From 2025, London will only buy zero emission vehicles for its 9,500 fleet, as will Paris, Madrid and Athens. Much of the groundwork has been laid by major public investment – the FCH-JU funded JIVE II project, launched in January 2018 will subsidise deployment of 152 FCEBs in cities and regions across nine European countries. Together with JIVE I, launched a year earlier, about €57m of European funds, plus national and regional government finances is being used to deliver almost 300 FCEBs, plus hydrogen refuelling stations, to 22 European cities and regions by 2023. Prices remain high, but the trajectory is good. Pooling orders can help manufacturers to benefit from scale economies, and JIVE buses are being priced around €550-650k. But it's important that the bus specifications are identical or similar, and that the timing of different projects and partners is aligned. February's joint Cologne-Wuppertal order for 40 buses from Van Hool – the largest ever order outside China – should meet those requirements and drive prices lower again. FCH-JU targets are for €500k per bus by 2023, and manufacturers say they can achieve €400k, or even €350k, given orders of 100+ buses per year.

In October, 11 more FCEBs and a hydrogen refuelling station were ordered by ebe EUROPA in the Rhein-Main region, this time from Autosan in Poland. Vehicles from both German orders are expected to be on the road in 2019. Autosan joins Van Hool, Mercedes/Evobus, Wrightbus, APTS/Phileas and VDL as a bus supplier, most using Ballard fuel cells, and Portuguese manufacturer Caetano is now an integrator for Toyota fuel cell stacks into buses in Europe. In the UK, Alexander Dennis announced the addition of a double-decker fuel cell bus to its range, with fuel cells integrated into its Enviro400 by partner Arcola Energy.


**Momentum is building in the USA**

The USA has supported FCEBs in one form or another for two decades, both Federally and through State initiatives. The Federal Transit Administration funds the US$90m National Fuel Cell Bus Program, and other sources including the LoNo (Low or No Emission Deployment) programme, used to support FCEBs in several States. A dozen or so FCEBs are expected to enter service in 2018, bringing the number of vehicles in service to more than 40 by the year end.

25 New Flyer and ElDorado buses are running in California, which has the longest running demonstration in the USA, including three transit authorities: Alameda-Contra Costa (AC Transit), Orange County and SunLine of Thousand Palms.

The AC transit buses have blazed a trail, and notched up significant achievements in 2018: two fuel cell modules hit the 25,000 operating hour mark, whilst miles between road recalls, stood at 24,000. Both already exceed US DOE targets for 2025. To date, AC Transit's fleet of 13 vehicles have logged 2.8 million miles, with one fuel cell clocking 30,000 hours. Ten new vehicles will join it for 2019. Sunline will also add buses – twelve more to join the current four. At least one is expected to be an ElDorado battery bus with a fuel cell range extender from US Hybrid, integrated by BAe Systems. And Orange County has ordered ten Xelsior 40ft buses from New Flyer, using Ballard HD7 fuel cell modules and 80 kWh batteries. At US$1.2m each, these US FCEB remain more costly than European ones, in large part because of the much smaller order numbers.

Outside of California, the Stark Area Rapid Transit Authority FCEB fleet will expand to 13, with funding for two additional buses announced in September. And in an unusual but intriguing outreach move, SARTA has started a 'Borrow a Hydrogen Fuel Cell Bus' scheme, supported by ElDorado and BAe, to make sure fuel cell buses are part of the dialogue so often dominated by batteries. Any US transit authority can borrow – for free – one of their ElDorado buses to assess the technology and raise local awareness. The Central Midland Transit Authority of Columbia, South Carolina will be the first to try.

Small numbers of FCEBs are operating in other States, including Illinois and Hawaii. Champaign-Urbana has two New Flyer 60 foot articulated buses, and plans two more. Honolulu will run FCEBs at the international airport as part of Haiwaii's Clean Energy Initiative.

In something of a coup for fuel cell proponents, the Honolulu bus is a modified BYD battery vehicle with a fuel cell range-extender added by US Hybrid Corporation to avoid charging dependency.


## Asia looks set to overtake

Asia has been slower to roll out FCEBs, but that is about to change. China has big ambitions, set within the framework of the Five Year Plan and further supported by regional governments. Their battery bus fleet is by far the world's largest, and FCEB ambitions are big, too. CNY 500,000 (US$74,000) are offered in subsidy for each vehicle by the national government (subject to strict conditions), which can be doubled by some cities or regions.

Activity in China is frenzied, with small and large regional manufacturers scrambling to take advantage, but it's not clear how many buses are actually on the road. Each New Energy Vehicle in China requires a special licence plate, which takes time to issue, and in most areas the refuelling infrastructure is not yet adequate for large numbers of vehicles, which may be shipped but not running. Nevertheless, announcements in 2018 include 50 FCEBs planned in Sichaun by the end of 2018; 30% of Shanghai's electric bus fleet to be FCEBs; Shangdong Heavy Industry's commitment to make 2,000 buses, following its takeover of Zhongtong Bus Corporation; and a purchase of 300 FCEBs by Datong, including ten 8.5m and 40 10.5m vehicles from Ruiding New Energy Automobile.

An order for 74 FCEBs came from Zhangjakou City in preparation for the 2022 Winter Olympics; comprising 49 Foton AUV 10.5m buses from Beiqi Foton Motor and 25 of fuel cell battery hybrids from Zhengzhou Yutong Corporation.

Chengdu ordered four Dongfang Electric Corporation FCEBs to add to the six in service. And in a sign of things to come, Foshan Feichi Automotive Manufacturing signed a deal to supply three buses to Sarawak State in Malaysia.

The fuel cells for these buses come mainly from Ballard and Hydrogenics, increasingly as part of their various joint venture and licence agreements with Chinese businesses, but Chinese fuel cell developers are keen to enter the market, including companies like Foresight Energy. And while most systems are PEM, using hydrogen, Weichai announced a deal with Ceres Power in which it would use the SOFC technology as a range-extender for battery electric buses, giving flexibility to operate on other fuels. Ceres already has a partnership with Nissan for ethanol-powered engines.

Korea, initially a strong hydrogen proponent but more recently focused on stationary fuel cells, is back with big ambitions. A ₩2.6 trillion (US$2.3bn) public-private partnership will accelerate deployment of fuel cell vehicles to 2023. 1,000 buses, and associated fuelling infrastructure, will be operating by 2022, and by 2030 all new trucks and buses may be zero emission. Hyundai is the only player in town. It provided six FCEBs for the Pyeonchang winter Olympics, and will put 30 more into six major cities in 2019, with buses already rolling out in Ulsan and Seoul. Refuelling infrastructure will be funded by a special purpose company called HyNet, funded by an industry consortium in much the same way as the German H2Mobility group.



Japan, somewhat surprisingly, is lagging. Toyota's Sora FCEB, a 10.5m hybrid vehicle with two 114 kW Mirai fuel cell stacks and ten 70 MPa hydrogen tanks is in operation in Tokyo, and 100 are to be used in the Tokyo 2020 Summer Olympics, but its ambitions do not seem to match China or Korea. And in India, Tata Motors and the Indian Oil Corporation are testing Tata's FCEB at its Pune facility.

# Trucks, large and small

**Heavy-duty leads the way**

Fuel cells are increasingly considered the leading option for zero-emission heavy-duty vehicles, as battery electric technology becomes less competitive as range and weight increase – not to mention the difficulty of recharging huge amounts of batteries. 2018 has confirmed this interest, with important orders being placed and momentum starting to develop.

Upstart Nikola Motor, just 4 years old, plans to change the heavy-duty fuel cell vehicle market much like Tesla is doing for battery electric. The company claims to have taken US$11 billion in pre-orders for its semi-trucks, with an additional US$380 million in pre-orders for a recently-unveiled European model (the Nikola Tre). American brewer Anheuser-Busch has signed up for 'up to' 800 long-haul trucks, enough to replace all of the company-owned trucking fleet. Taking hints from Tesla's tactics, Nikola initially took advance deposits for vehicles, but this year announced they would return them – while keeping customers' places in the waiting line. Perhaps designed to demonstrate Nikola's financial stability, deposits had reportedly been returned to reservation-holders by the beginning of November.

Nikola's partnerships are with PowerCell for the fuel cell stack, Bosch for the powertrain and controls – and Nel for the hydrogen fuelling stations. Nikola plans to offer a full-service model, including fuel and maintenance, rather than selling the trucks themselves.


And the design seems to be evolving: while early press releases suggested a stack output of 300 kW, more recent releases suggest 240 kW. If the latter is correct, Nikola's stack output will be roughly on par with Toyota's Project Portal fuel cell drayage (short-haul) semi-trucks in California. The latter use a pair of Mirai stacks, rated at 114 kW apiece, to provide a total power of 228 kW.

Until now, Nikola's grandiose ambitions have not been reflected in hardware. But 2019 should see the first, very small, number of test vehicles for validation. The Nikola Tre is aimed for production in 2022/23. Nikola's partnership with Nel should see 28 large-scale (8 tonnes $H_2$ per day) hydrogen refuelling stations roll out beginning in 2020.

Toyota is updating its drayage truck – the second-generation vehicle (Project Portal "Beta") was unveiled in summer. The system integration has been refined, extending the range slightly, and removing more than one tonne of weight. The main interest is in Southern California, for reducing emissions at ports, and in late autumn the California Air Resources Board awarded US$41 million to Toyota, Kenworth and Shell to deploy an additional 10 class 8 fuel cell trucks, along with two large-capacity hydrogen refuelling stations. Kenworth already partners with Ballard for fuel cells, and Hydrogenics, the other major heavy-duty fuel cell provider, is teamed up with vehicle integrator TransPower to produce six heavy-duty fuel cell Navistar Class 8 drayage trucks for deployment early 2019.

Loop Energy will be integrating its fuel cell range extenders into two more Class 8 drayage trucks (using Peterbilt Motor Co.'s 579 truck gliders) to create a fuel cell hybrid-electric powertrain. 2019 will see these vehicles in the Los Angeles and San Diego areas.

**Mid-size trucks are also gaining ground**

Hyundai also has big plans, though for slightly smaller trucks, announcing an agreement to supply 1,000 18-tonne fuel cell trucks to Switzerland from 2019-2024, in partnership with H2 Energy. The fuel cell system produces 190 kW and claimed vehicle range is 400km. Discussions suggest that 350 people are working on the truck development and assembly in Korea.

Swiss supermarket Co-op is one of the private companies in a consortium that will use these vehicles, continuing the company's commitment to replace most of its fleet with zero-emission vehicles and support hydrogen infrastructure.

The Swiss situation is advantageous, as heavy-duty vehicles are subject to a performance-related charge of between 2 and 3 Swiss centimes per tonne-km. The cost for a single 40-tonne truck over a year can be CHF 70,000. For now, the Swiss Government has exempted hydrogen and battery-electric trucks from this charge, dramatically improving the economics, though there is no guarantee as to how long this policy will be maintained.

Hundreds of smaller trucks are already on the road in China, too, though how many are in day-to-day operation is hard to establish. Estimations of thousands of vehicles produced in total must then be filtered to understand how many have been licenced and put into service. But over 500 have been integrated by Shanghai's Re-Fire using stacks from Ballard's Chinese operations, and well over 100 are in full daily operation in and around Shanghai. The vast majority of Chinese trucks use a fuel cell of around 30 kW, which hits a subsidy sweet-spot.

### Delivery vans complete the portfolio

Scaling down further, fuel cell delivery vans are also increasingly of interest, as solely battery-powered vans cannot always cope with busy delivery routes, where long range and short recharge time are paramount.


FedEx and UPS are both trialling fuel cell range-extender Class 6 delivery vehicles, with Ballard providing 30 kW systems to Calstart for integration into UPS vans, and Plug Power supplying systems (2 x 10 kW per vehicle) to Workhorse to integrate into their electric vans for FedEx. The market could be significant, with ~650,000 Class 4-7 vehicles in the US alone. In Europe, Symbio has supplemented its 10 kW Kangoo product with a 40 kW fuel cell range extender kit that can be integrated into vans, buses and even heavy-duty trucks. Deutsche Post DHL group subsidiary, StreetScooter, plans to have fuel cell range extended vans in operation by 2020, for use internally by DHL express – and is looking at 500 vehicles for its fleet. Westnetz, an Innogy subsidiary, is also co-developing a fuel cell range extended van with StreetScooter, to match the rather specific energy network operator service vehicle requirements.


European OEMs Volkswagen and Daimler developed concept fuel cell vans in 2018, based off the Crafter and Sprinter models, respectively, with Daimler, unexpectedly choosing a motorhome configuration to show off the new Sprinter F-CELL. This follows Hyundai's H350 Fuel Cell concept van in 2016. The concepts are said to be ready for production, once fuel infrastructure arrives and component costs drop.

Toyota, for many years focused on passenger cars, continue to diversify its line-up, developing fuel cell trucks for the 7-11 convenience store chain in Japan. Vehicles are scheduled for deployment in 2019, ahead of the Tokyo 2020 Summer Olympics. A handful of Japanese 7-11 stores already offer hydrogen fuel, and fuel cells for on-site power generation could be added to the mix.

# Electrolysers – making hydrogen for fuel cells?

As we noted last year, the potential for low-cost green hydrogen is now helping drive interest in fuel cells. Collapsing wind and solar power costs make renewable hydrogen from water electrolysis a competitive option with fossil sources – at least on paper. And the potential for hydrogen to help decarbonise energy and industry is driving policy and investment. Helpfully, hydrogen is supremely flexible – it can be made from many compounds, and into many others. So it can be used 'pure' or used to make other fuels and energy carriers – gaseous, like methane, or liquid, like jet fuel.

Water electrolysis has been an important source of hydrogen since its industrialisation in the 1800s. But cheap natural gas largely displaced it for hydrogen production. Only in the last few years has it come back into vogue, with the increasing fraction of renewables in electricity generation and the advent of the hydrogen economy. And from a small base, electrolyser companies are growing rapidly. 2018 saw new project announcements, product platforms that can scale to 100 MW+ systems, manufacturing capacity additions and hiring campaigns. Yet the industry is fragmented, dominated by SMEs who need big partners to address the emerging market opportunities – companies like AkzoNobel, Voestalpine, Yara International and Shell, all active in important projects. And new companies see opportunities – H2V Industry chose HydrogenPro, a supplier of pressurised alkaline electrolysers, to work with for its anticipated 5 x 100 MW Dunkirk hydrogen project.

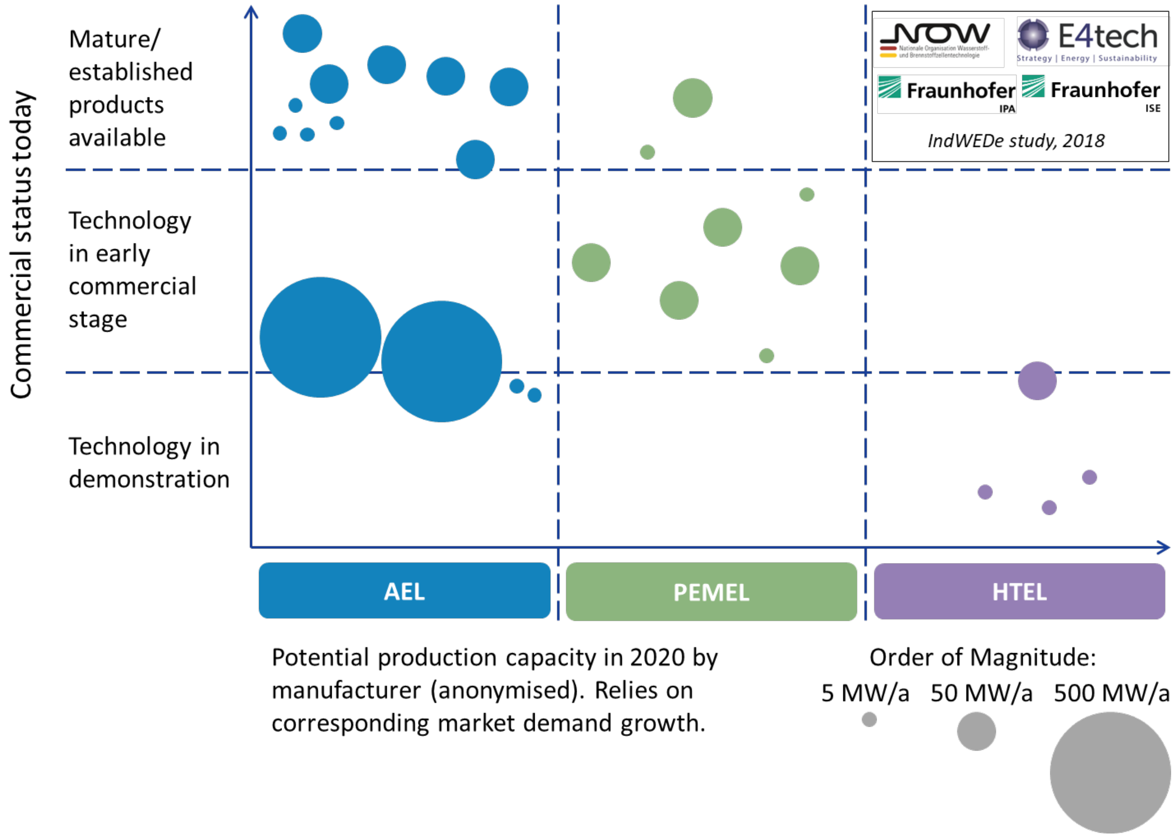
Nevertheless, the water electrolyser industry is currently even smaller than its fuel cell counterpart. Deployment in 2018 will likely remain below 100 MW, and in such a small industry individual projects can cause big fluctuations year-on-year – one reason we have chosen not to report figures. But very large projects, like Dunkirk , have been announced, others are in the pipeline, and the industry is putting significant capacity upgrades in place. The UK's ITM Power is expanding its manufacturing facilities, and Nel of Norway is building the world's largest electrolyser production plant – at 360 MW, it is an order of magnitude larger than Nel's current capacity.

The increasing demand for electrolysis equipment is coming mainly from two directions – hydrogen refuelling stations and integrated energy solutions. The latter are often summarised as 'power-to-X', where power is turned into hydrogen. This is used either to refuel vehicles, for industry, for injection into the gas grid, or as a feedstock for other fuels and chemicals. But electrolytic hydrogen remains expensive, for now. Historically, this was partly related to low manufacturing capacities and a lack of automation, leading to high capital costs. At the same time, systems could be better optimised, leading to higher efficiencies. But manufacturers are now communicating price levels for 100 MW+ installations today of €500/kW – well below what had been forecast for 2030. And manufacturing capacity is not a bottleneck: the industry claims it can scale to gigawatts as early as 2020, if orders are placed today.

Instead, a big barrier to growth seems to be the price of electricity. Germany, where most power-to-gas demonstrations have been built, illustrates the problem. Electricity prices are heavily influenced by taxes and levies, not always matched for fossil fuels used in heating and transport. This makes shifting renewable power into fuels and chemicals hard. Using 'excess' renewables is also not a great business case. As in many countries with ambitious decarbonisation targets, much wind and solar must be added before green electricity becomes abundant. Although substantial, the volumes of excess renewables curtailed today are limited to a few hours per year – making a poor business case for electrolysis because of low equipment utilisation.

Unlike in fuel cells, Europe has been the centre of gravity for power-to-X projects. But the market frameworks in Europe for fully commercial deployments are complex, as regulation for electricity, gas, storage and other sectors struggles to keep up with technology.

Global energy players are looking at developing large scale projects elsewhere, as high full load hours from combined wind and solar can make viable the production and export of hydrogen – or renewable fuels which use it as a feedstock.



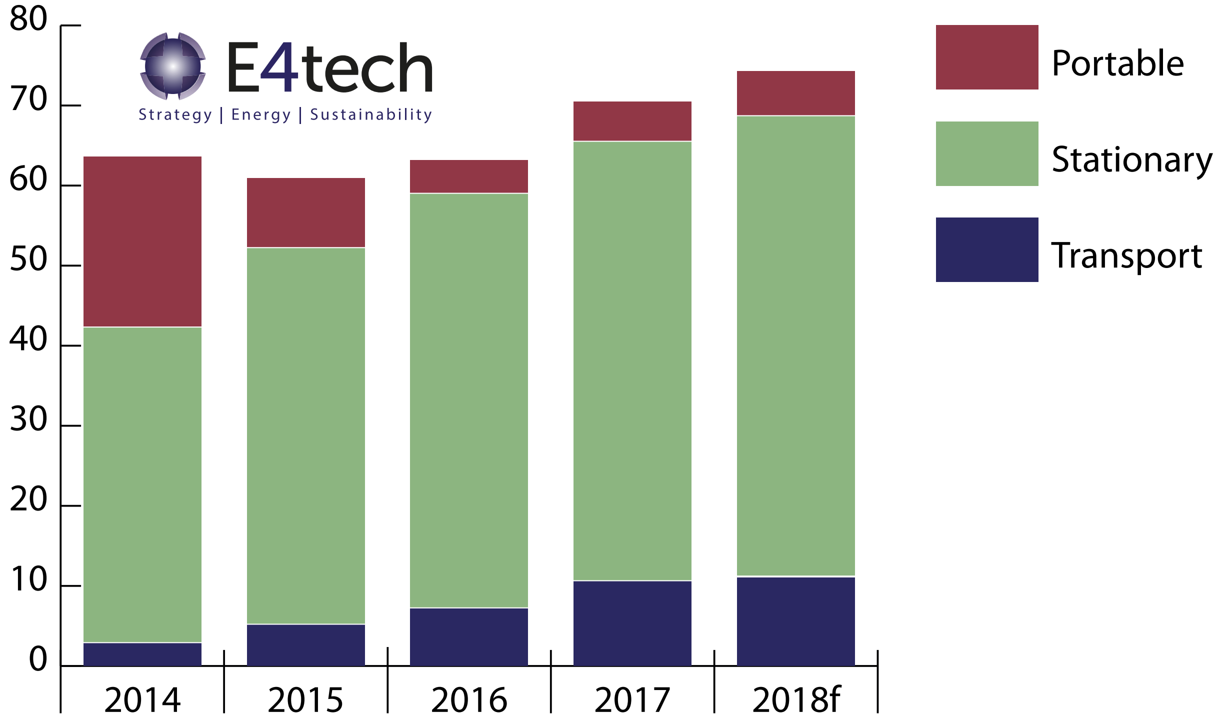

*Industry status and manufacturing readiness for Alkaline, PEM and high temperature electrolysis*

It seems the technology, cost, markets and long-term drivers are in place to support gigawatts of electrolyser deployment – a comparatively small example being ITM Power's award of a feasibility study in Canada to study 300 MW of electrolysis for domestic and international hydrogen provision. And companies like Engie have announced bold plans to become 'hydrogen majors' – like the more conventional oil and gas majors.

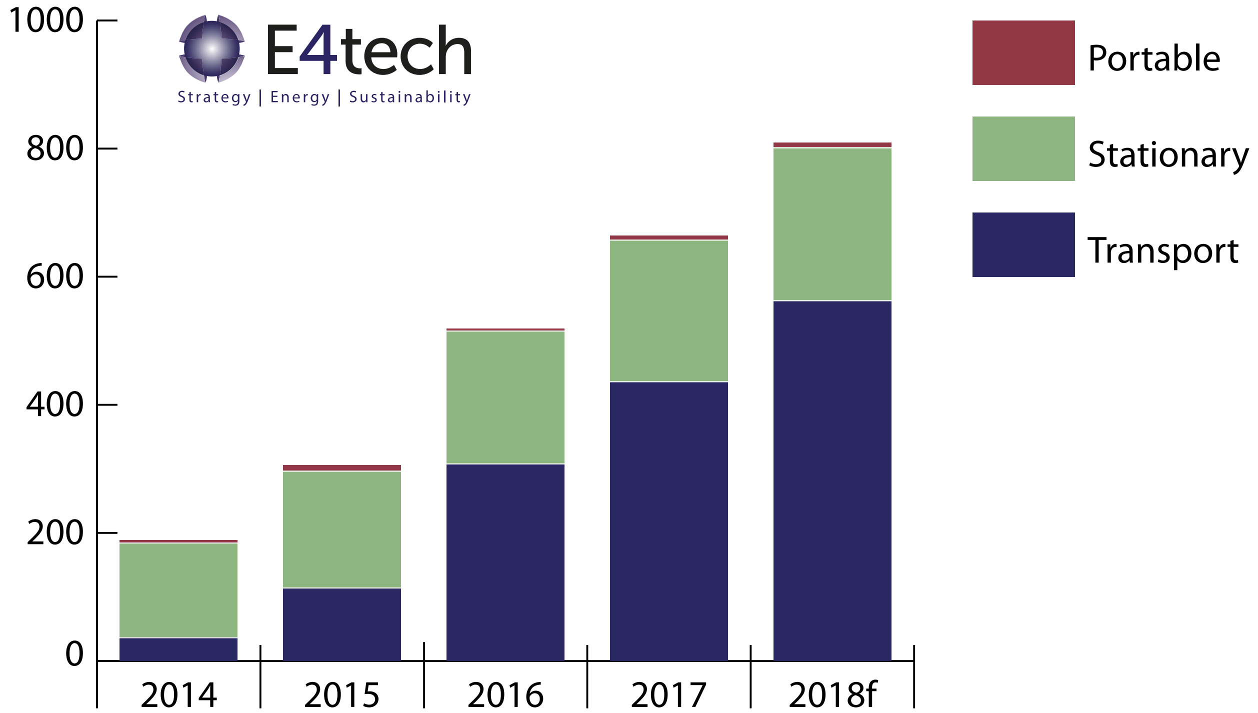
The signals suggest that the electrolyser industry could respond reasonably fast to a dramatic increase in demand. As renewable power continues to drop in cost, electrolysers will be instrumental in 'turning electrons to molecules', supporting the decarbonisation the world so desperately needs.

# Shipments by application

Shipments by application 2014 - 2018 (1,000 units)




Megawatts by application 2014 - 2018




2018 is our forecast for the full year, based on firm data from January to October.
We have slightly revised the figures for 2017 in this report.

# Shipments by application

Total shipments of fuel cells keep rising, in 2018 reaching an estimated 75,000 units totalling 800 MW. Over 4,000 more units were shipped than in 2017, and 145 MW.

The megawatt total continues to be dominated by transport applications – about 560 MW – with circa 475 MW in passenger car shipments alone. And unit numbers remain strongly influenced by Ene-farm residential micro-CHP shipments in Japan, with roughly 50,000 installations expected in 2018. While new shipments haven't quite hit that total, we believe that in 2018 total global production of stacks and systems for all purposes, i.e. both original equipment and replacements, could be close to the gigawatt mark.

The 560 MW shipped in transport applications represent around 11,500 units in 2018, increases of 29% and 6% respectively. Most of the megawatt number comes from the addition of around 4,500 passenger cars to the global fuel cell fleet, from Toyota, Honda and Hyundai, largely to Californian, Japanese and Korean markets. Slightly more material handling vehicles are expected by year-end, with roughly 5,000 shipped by Plug Power – the market leader – Nuvera and others, including Daimler. Fuel cells continue to find their way into UAVs, and marine and train applications, although growing, have yet to affect the overall numbers.

The cumulative total of Toyota Mirais on the road in 2018 is expected to be 7,500, close to Toyota's long-announced plans. And Hyundai's Nexo vehicle has received both positive press and positive sales, with 200 shipped in October alone, and a possible 1,000 on the road by year end. Honda is also expected to ship something approaching 1,000 of the Clarity Fuel Cell in 2018, mainly for the US fleet. No other OEMs figure strongly, with Daimler only releasing the first few GLC F-Cell vehicles late in the year.

Fuel cell buses, while far from mainstream, are becoming an accepted option. They are being deployed in Europe and to a lesser extent the USA Japan and Korea, though the latter has announced an ambitious programme going forward. Meanwhile fuel cell trucks, speciality vehicles and delivery vans are increasingly making an appearance, including in the US.

However, it is China that leads the way in unit numbers; deployment of around 1,000 light trucks and buses, often using 30 kW systems as range extenders, is possible this year. Numbers are not as high as anticipated, as the vehicle permitting is complex and hydrogen infrastructure has proven a bottleneck to deployment and utilisation of vehicles.

Stationary fuel cell shipments also continue to grow, but the increase in units by 5%, to an estimated 57,500, and megawatts by 8% to 240 MW, are modest compared to transport. The unit shipments are mainly residential micro-CHP systems; the megawatt mainly larger stationary systems. Outside of Japan, the residential market is supported most strongly in Germany through the KfW233 initiative, which saw 2,600 approvals for funding in the first nine months and where up to 4,000 units may be supported through the full year.

Stationary fuel cell systems over 100 kW are still almost exclusively deployed in Korea and the USA and installations are often multi-megawatt in nature. Korea's strong government support has allowed Doosan to build manufacturing capacity and install more units, and shipments in the USA appear to be recovering from a difficult couple of years, mainly thanks to the re-introduction (and retroactive application) of the Federal Investment Tax Credit.

Japan and Korea are turning their attention to mid-scale commercial units, with initial deployments from companies such as Kyocera, Miura and Hitachi Zosen.

Smaller back-up and off-grid units continue to sell into a range of markets, including telecoms tower markets. Between 2,500 and 3,000 systems are likely to be deployed in 2018 by a range of businesses. And fuel cell systems for portable applications are selling in reasonable numbers, an estimated 5,600 in 2018, but these individually small units only amount to about 700 kW of power. Auxiliary power systems include consumer and industry use, plus military customers. These units can be less than one kW, and often in the hundreds of Watts. SFC Energy is the largest player in the sector. Only MyFC seems to be active at the battery charger scale, shipping 500 portable USB chargers to each of Japan and China.

# Trains

Hydrail is here! The world's first fuel cell passenger train entered revenue service in 2018. Alstom's Coradia iLint started operations with Eisenbahnen Verkehrsbetriebe Elbe-Weser (EVE) on a 100km regional line in Lower Saxony, marking the start of an alternative electrification option for short and medium passenger lines across the world.

Electrification offers substantial benefits over diesel technology: the trains are less noisy and smoother, more efficient and less polluting. Propulsion performance is superior too – especially acceleration and deceleration – and they should be easier and cheaper to maintain. To date, electrification has meant overhead catenary or third rail systems, which are expensive and disruptive to install on existing tracks, and vulnerable to extreme weather events.

Battery-only trains would require too many batteries. So new investment in overhead systems tends to be limited to long distance, high-speed mainlines, or high density urban and suburban routes. Other routes use diesels. Fuel cells can be put where diesel units used to be, and so with suitable hydrogen refuelling infrastructure the route can be electrified.

Alstom's trains are built at Salzgitter, although traction design is French. It has taken its standard Coradia diesel design and incorporated a Hydrogenics liquid-cooled HyPM-HD 180 fuel cell with 200 kW output for each car. These, plus hydrogen storage tanks, sit on the roof, and each car also has a 225 kWh battery. The train can go up to 140 km/h with a range of 1000 km, enough for several daily services over most unelectrified lines. It's 60% less noisy than a diesel and, even using 'brown' hydrogen from natural gas, emits 45% less $CO_2$. Using green hydrogen it is zero.

Like fuel cell cars, it's heavy, weighing seven tonnes more than its diesel cousin. Capital costs are higher, too, but cheaper than electrification. EVE has started with two trains, and more are due from now till 2021, to make a fleet of 14. Hydrogen comes from Linde with a refuelling station at Bremervörde. Lower Saxony is estimated to have 25% of Germany's wind power, so plentiful green hydrogen is possible. Alstom has further letters of intent or orders from Nord-Rhein-Westphalia for 14 trains, Hesse for 20 and Baden-Wurttemberg for 10 plus an option on 5 more.

Siemens' partnership with Ballard on the Mireo fuel cell train has been financed in part by €12m from the German Government's National Innovation Programme. Like the Coradia, the existing Mireo will have the diesel swapped for Ballard's 200 kW fuel cells, with operation anticipated in 2021. The Alstom-Siemens merger announced in 2017 trundles on, though the EU has reiterated concerns about the market power of the merged business, and the reduced choice for European customers.

The UK is also looking at fuel cell trains. Projects are underway to convert existing Electric Multiple Units (EMUs) to run in hybrid fuel cell configurations. Alstom will work with the UK's Rail Safety and Standardisation Board and Eversholt Rail, a rail vehicle leasing business, to convert a Class 321 unit for 2020/21. And Porterbrook, another rail leasing business, will work with the University of Birmingham on the HyFlex project, using a Class 319 EMU.

MetroLinx's Toronto project is also moving forward. Concept designs are under way for fuel cell hybrid locomotives to replace diesel units instead of conventional electrification. These will haul 12-car trains, of which 50-70 will be needed. Another study is looking at fuel cell hybrid EMUs with Alstom and Siemens, with 84 four-car units required. A procurement process, open to both hydrail and overhead wires, will decide the eventual outcome, which promises electrification by 2025.

The timing may prove tricky for the locomotives, in particular, which will need to go through full engineering design, proving, acceptance etc. for a roughly 3 MW unit in the timeframe.


Hydrogen trains are not only for Alstom and Siemens. In Austria, Stadler has been chosen to supply five fuel cell EMUs for Zillertal. A prototype is scheduled for 2020, and the other four trains for 2022. The line currently uses diesels, and had planned overhead electrification, costing €156m. Opposition from local authorities meant a re-think, and the fuel cell project now chosen will cost €80m and use renewable hydrogen from local hydropower. Showing how fast interest has risen, Alstom did not bid as it had no capacity to deliver, and a competing Chinese offer raised quality concerns.

# Forklifts – finally going global?

Material handling vehicles (MHVs) are still dominant in fuel cell transport in terms of units deployed. North America has represented almost the entirety of the global MHV market, with little activity across the rest of the globe. But while North America remains by far the largest market, developments elsewhere are starting to take root.

For example, Europe now has over 300 fuel cell forklift trucks in operation. Carrefour has the largest fleet, now 217 strong, adding 137 forklifts this year to a new distribution center in France. The fuel cell systems were supplied by Plug Power, who made an agreement with Linde Material Handling to unlock the European market further, preparing Linde MHV products – electric tow trucks and different electric forklift trucks, to be Plug fuel cell compatible. In Japan, the fleet has increased to approximately 100 fuel cell forklifts, aiming for 10,000 in 2030, and previously untouched markets are opening up to fuel cell MHV trials. Australia trialled its first fuel cell forklift in April from Hyster-Yale (Nuvera) and Toyota placed a forklift at their own Australian parts centre in November. Two forklifts were reported in operation in China, and local development is ongoing.

Plug Power still provides the majority of the units, shipping nearly 3,000 units up to Q3 2018, though this is down slightly on last year's 3,845. Tragically, a Plug forklift was involved in a fatal accident this year, when one of its units apparently exploded, killing the operator. The exact cause remains unclear, with investigations ongoing.

Also in North America are Hyster-Yale's Nuvera, who reported further growth, shipping 210 'battery box replacement' products up to the end of Q3 2018 – they shipped 47 in 2017, over the same period. The company is eyeing profitability in 2019 if this growth continues. Other companies, like Toyota, are increasing fuel cell forklift plays, though Toyota's are mainly deployed at Toyota sites. 20 forklifts were added the two demo forklifts unveiled in 2017 at Toyota's Motomachi plant in Japan.

Austrian company Fronius has also emerged as a player, producing fuel cell systems for forklifts and partnering with Linde Material Handling to deliver 70 power tow trains (indoor tow tractors) to the BMW Group facility in Leipzig. And Ballard has supplied stacks to Infintium, who have produced fuel cell systems to go into MHVs at the Daimler facility in Alabama.

# Ships and boats

As part of the trend towards heavy-duty applications, fuel cells are increasingly of interest in shipping, though hydrogen in internal combustion engines has traction too. This responds both to greenhouse gas and local emissions concerns, in terms of compliance to Sulphur Emission Control Area (SECA) requirements in the North Sea, the Baltic Sea, the Caribbean and the coastline of North America. Superimposed on this are national emissions reduction initiatives, notably in Japan, Germany and particularly Norway, where fuel cells and hydrogen have sparked considerable interest. And the development and proving efforts underway could hugely increase the market for fuel cells – but not yet. Fuel cells remain expensive, are not available in the quantities or sizes required for many shipping applications, and require a not-yet available fuelling infrastructure.

In Germany, the Government NIP initiative is funding Pa-X-ell 1 (a ferry fitted with a SerEnergy methanol reformer/high temperature PEM providing a 60 kW contribution to the overall 120 kW hotel load requirement), SchIBZ 1 (a seagoing vessel using a diesel-fuelled Sunfire 100 kW SOFC), the cruise vessel RiverCell (also with a SerEnergy HT-PEM) and the Elektra tug boat, with its powertrain still in the design phase. Further development is anticipated, to increase stack sizes and performance, with commercialisation from 2025. River cruise boats are an important target for northern Europe, where most of the continent's inland navigation is located. Nobiskrug and H2-Industries plan to build the first fully electric superyacht with a Liquid Organic Hydrogen Carrier (LOHC) system on board. The ship is a pilot project to establish the use of the technology for every-day operation in fuel cells, and will gather data to determine how the technology can be applied and adapted in larger and heavier ships for long journeys.

In Norway, the immediate emphasis is on using fuel cells for short shipping (particularly ferries). This fits with the overall objective for a 40% reduction in greenhouse emissions nationally by 2030. Both quayside power and fuel cells for propulsion are being explored, generally as hybrids. ABB Marine and Sintef are looking at how a system 2 x 30 kW stacks could respond, with a view to MW-scale propulsion. Sintef also released a major gap analysis relating to hydrogen infrastructure in Norway to meet the 2030 target, including its use in engines. For example, in May, Boreal Sjø and Wärtsilä signed a cooperation agreement to develop a hydrogen-powered ferry for the Hjelmeland–Skipavik–Nesvik route in southwestern Norway.

Ferguson Marine Concept Hydrogen Ferry

FCH JU-funded projects continue. In Maranda, a 165 kW fuel cell system using 2x PowerCell S3 stacks, with compressed hydrogen fuel is to provide power to the electronics and positioning system of an ice-breaking research vessel. Sea trials are planned for 2020. Ferguson Marine in Scotland is building a renewable hydrogen powered ferry as part of the HySeas project consortium, using Ballard fuel cells, for launch in 2021. Also in Scotland, the FCH-JU's BIG HIT in Orkney is examining fuel cells for quayside power for ferries in Kirkwall. The hydrogen comes renewably from wind and tide power plus electrolysis, from nearby Shapinsay (1 MW electrolyser) and Eday (0.5 MW). This ensemble is a model for scattered remote communities rich in renewable resources, and here can also provide hydrogen for 10 fuel cell vehicles, CHP and other uses. In a similar vein, the SEAFUEL project aims to use hydrogen for local transport fleets of cars and to support the shift towards a low-carbon economy in three remote Atlantic regions in Europe: the Canary Islands in Spain, Madeira in Portugal, and the Aran Islands in Ireland.

PowerCell, known for fuel cell provision for heavy-duty trucks, signed a MoU with Siemens to develop fuel cell-based drive and power generation systems for propulsion and power generation in the maritime segment. And September marked the end of the 15-year

FellowSHIP research project, in which Eidesvik Offshore, Wärtsilä Norway, and DNV GL explored the use of battery, hybrid and fuel cell technology in the maritime industry.

Ballard also joined the party in July, signing an MoU with ABB to develop next-generation, MW-scale PEM fuel cell power systems for the marine market, with an initial focus on cruise ships.

Regulation in the marine sector is no less complex than others. For fuel cells to gain market share, the appropriate codes must be in place – and large conventional players such as ABB and CMB need to engage actively in development. Progress is being made – in 2018 Yanmar finished a 3-year project verifying the safety requirements of fuel cells and hydrogen on ferries, and Norwegian-based Hyon received approval-in-principle from DNV GL for its module-based fuel cell solutions, adapted for maritime use. Sintef found no 'showstoppers' for introducing hydrogen fuel into speedboats in and out of Trondheimsfjorden. Again in Norway, high speed ferries incorporating fuel cells are in planning for 2021, to be powered by wind and tide energy, through electrolysers, to create 16 TWh capacity in the Floroe locality. And the Netherlands is active, with the FELMAR consortium developing a new generation fuel cell electric energy system for inland-sea and coastal vessels. Nedstack is the fuel cell partner.

In Greece, the EVERYWH2ERE project plans to deploy 8 x 25 kW containerised plug and play hydrogen gensets, using PowerCell stacks, for quayside power for ferries.

Following last year's feasibility study, Bay Ship and Yacht Co., based in Alameda, California is now building the first large-scale hydrogen fuel cell passenger vessel in the US, for service by September 2019. The customer for the 'Water-Go-Round' vessel is Golden Gate Zero Emission Marine (GGZEM), a Bay Area company on a mission to eliminate maritime pollution. Dual 300 kW electric motors from BAe Systems will be powered by 360 kW Hydrogenics PEM fuel cells plus Li-ion battery packs.

Fuel cells are not the only option, and use of ICEs can help justify development of hydrogen infrastructure. At the end of 2017, Antwerp maritime group CMB announced the development of the Hydrovill catamaran, the world's first accredited passenger vessel powered by hydrogen in a diesel engine. It is intended to test hydrogen technology for applications in large seafaring ships, commuting daily between Kruibeke and Antwerp to provide CMB employees with efficient, environmentally-friendly transport. Initially, the hydrogen will provide power to an auxiliary engine. And in Liverpool, ULEMCo is developing a hydrogen-fuelled marine engine as part of the Interreg HYLANTIC project.

# Stationary Power

Stationary power remains a fundamentally important and diverse part of the fuel cell landscape. Decades of development effort have resulted in the current dominance of PAFC, MCFC and some SOFC in the large-scale end of this sector, though both PEM and SOFC remain strongly present at smaller scales. But as we say every year, policy support is what drives the industry.

**Ene-farm**

Japan remains by far the leader in the development and deployment of small-scale systems, through the Ene-farm programme which provides subsidies for purchase of residential fuel cell systems for domestic CHP. The total number deployed is approaching 300,000 at the end of 2018, a year-on-year gain of 50,000. Little changes on the outside from year-to-year, though significant effort is going in to cost reduction and system optimisation. The installation of Ene-farm units is done by the regional gas companies, such as Tokyo Gas, and is still supported by subsidies from central government and, in some cases, local/regional governments. For example, Yokohama, where 13,000 units were already in place by March, has ¥30,000 per unit available to fund some 300 more units locally – though the price remains high at around ¥1.14m. ¥7.7bn was set aside by national government in FY 2018 for residential, commercial and industrial fuel cell systems.

Only two manufacturers are left supplying these units: Panasonic with its 700 W PEM system and Aisin Seiki's 700 W SOFC unit. Panasonic is now on its fifth iteration of the technology, whilst Aikin Seiki released an updated version in June. And while sales remain steady, and the programme is the most successful in the world, the long-standing goal of 1.4million units by 2020 will clearly not be met. Hitting the longer-term government goal of 5.3million units by 2030 also seems unlikely.

**Commercial Fuel Cells in Japan**

Commercial scale fuel cell systems show promise in Japan, but lack the unrelenting focus that Ene-farm has enjoyed. The Government has ambitious plans here too though, hoping for 1 GW of larger systems by 2030, and is supporting several development efforts. At least 21 SOFC and 50 PAFC systems were operating in Japan by March, though 1 GW remains a long way off.

The Hitachi Zosen SOFC system installed in Osaka City last year has been in test mode, showing promising efficiency of 52% in a continuous 4,000 hour operation test. Commercialisation is intended from 2020 onwards. Miura's 4.2 kW SOFC system, announced last year, seems to have had little uptake, and news is also sparse about Kyocera's 3 kW SOFC unit. Denso – the automotive components business – has a similar sized unit in development, and several other developers are getting R&D support. Brother industries, better known for its printers, is seeking orders for its 4.4 kW BFC4-5000 fuel cell system from commercial customers.

In a promising indication of market belief, Fuji Electric – the 'other' PAFC producer – lists both its FD-100i units and its immature SOFC as growth products in its strategy documents. 67 PAFC are installed in Japan and 18 overseas. Designed for Japan's methane-rich city gas, versions using hydrogen and biogas are available, and stacks will live for 60,000 hours. The SOFC development is in the tens of kW scale. And IHI has operated a 1 kW SOFC directly on ammonia, but has not announced what it will do next.

**Toshiba's Pure H2 Play**

Toshiba continues to develop and showcase its pure hydrogen systems. The H2Rex PEM technology comes in 700 W, 3.5 kW and 100 kW packages. A 7-Eleven store in Kawasaki is running a unit on hydrogen supplied by Iwatani. If no hydrogen is available, Toshiba's H2ONE system will make its own using renewable energy, and store this for use by the in-built 100 kW PEM. One is operating in the Rakuten Kobob Stadium in Sendai; and another in a Tokyu hotel, supplied by a chemical company which extracts hydrogen from waste plastic. Even more ambitious is the H2ONE MultiStation, a system that can refuel up to eight FCEVs a day, as well as providing power from the 100 kW fuel cell.

**Korea keeps growing**

Korea and the USA are the undisputed leaders in industrial scale fuel cell installations. At the start of 2018 around 300 MW of fuel cells were in operation across Korea, typically of multi-MW size. Most are MCFC systems supplied by POSCO, from its old alliance with FuelCell Energy of the USA, and PAFC from Doosan. Project completions in 2018 added around 30% to the 2017 number, including FuelCell Energy's 20 MW installation of eight SureSource 3000 units for Korea Southern Power company. Having taken over sales and marketing from POSCO Energy, FCE will be seeking more in Asia. POSCO is now focused on supporting its existing fleet.

50 MW of Doosan PureCell 400 units are going into a Hanwha-owned chemical complex in South Chungcheong for Daesan Green Energy. Where most PAFC units to now have run on natural gas, these are modified to use (by-product) hydrogen, and a pure hydrogen PAFC is now available in Doosan's brochure alongside the traditional unit. Doosan has dramatically increased its manufacturing and deployment since acquiring the PAFC technology, with 140+ MW installed globally, of which 104 MW are in Korea.

Another 108 MW are being built in Korea and 31 MW more are already contracted, suggesting Doosan's 60 MW capacity factories in Connecticut, USA and Iksan, Korea are very well utilised.

**Going up in the world?**

Making best use of available space, Doosan and others are putting fuel cell systems on rooftops. While this has been done in the past, this is a whole new scale, with over 30 MW of units planned to go onto a new building in a residential area, for operation in 2020. And Bloom Energy entered the Korean market for the first time with an 8.35 MW installation of its Energy Servers at Bundang for KOEN (Korea Southeast Power Company). This is novel both in that it is the first time for SOFC technology to be deployed at scale in Korea, and also because the installation is over three storeys – possibly a response to scarcity and prices of land in Korea's urban areas.

Gyeonggi Energy Park, Hwasang is the world's largest single fuel cell installation, with 59 MW of MCFC systems installed by POSCO. That could be overtaken by an 80 MW installation proposed for Jincheon by Korea Western Power and Hanp Inc, who set up a special purpose company in partnership with KB Securities to finance the project.

A price tag of ₩525bn (US$471m) has been announced, with work due to start in September, for operation within a year. But given the limited manufacturing capacity available globally, the lead time seems optimistic, and no news of the fuel cell supplier has emerged to date.

Demand for large-scale fuel cell systems in Korea is likely to remain healthy. Korea's Eighth Electricity Supply and Demand Plan targets 20% of power from renewables by 2030, and – as reported in the past – fuel cell systems count as 'renewable'. And Korea's Renewable Portfolio Standard sets renewable power production targets for twenty-one of Korea's largest power generators. Up from 2% in 2010, 6% was required in 2018, and this will rise to 10% by 2023.

Korea has seen something of a boom in fuel cell developers of late. Modelled on Ene-farm, the country's first foray into residential scale fuel cells fizzled out nearly a decade ago. But it seems to be back: Doosan is offering a new range of CellVille PEM units sized from 600 W to 10 kW, running on natural gas – though a hydrogen version of the 1 kW unit also exists. EG Corporation and HnPower are developing and integrating stacks for the residential market, alongside MiCo and STX. HnPower started in reformers for different fuels, and acquired SOFC technology from KAIST and access to HT-PEM technology from Serenergy.

**Up-tick in the USA**

North America vies with Korea for top spot in stationary fuel cell deployment. Though almost all the installations are in the USA and come from FuelCell Energy, Doosan Fuel Cell America, and the recently-public Bloom Energy. 2018 has been positive for these companies, with February seeing the re-introduction of the Federal Investment Tax Credit for fuel cell systems. The credit was not renewed at the end of 2016, and suppliers apparently cut prices, despite minimal margins, to maintain sales. The ITC has in fact been retrospectively applied, helping developers to recoup some of that 'lost' revenue, and also raise prices. The credit is now due to run through 2021, but decline from 30% to 22% of capital investment.

Fuel Cell Energy has also benefited from State of Connecticut laws. Senate Bill 9 of May 2018 allows the Connecticut Department of Energy and Environmental Protection (DEEP) to increase the State's procurement of power from 'renewable technologies', including fuel cell systems, from 4% to 6%, and the Renewable Portfolio Standard will rise to 40% by 2030.

Partly on the back of this, 22.2 MW of FCE's SureSource MCFC units were selected by DEEP projects in Derby and Hartford, CT, to be operated under 20-year Power Purchase Agreements. In Q3, FCE reported 84.5 MW of orders to fulfil, including one from Campbells Soup for a 2.4 MW system for California. FCE has also started work on 2017's 39.8 MW order from the Long Island Power Authority, and for two SureSource 4000 units, or 7 MW, for the US Naval base at Groton, CT.

This means that FCE's manufacturing unit at Torrington, which completed a capacity expansion to 100 MW per annum at the end of 2017, is growing again. Although annualised production fell to 13 MW in summer 2017, FCE expects to increase it to 55 MW by April 2019, recruiting more than 100 additional staff, presumably including some of those laid off at the end of 2016 and early 2017.

FCE continues to focus on Power Purchase Agreements and Service Agreements to create long-term revenue streams. In July it signed a twenty-year agreement with Korea Southern Power for the 20 MW system mentioned above, and has sold fuel cell system assets with service agreements to NRG Yield and AEP Partners. It also recently agreed to take over the 14.9 MW Dominion Energy Bridgeport Fuel Cell Park for US$36.6m, adding to its own generating portfolio.

Doosan, also Connecticut-based, will look to benefit from the State's power procurement activities. Sales are growing in any case, with 44 PureCell 400 units to provide 20 MW of power to the Energy Innovation Park micro-grid at New Britain, CT, a US$1bn data centre development.

And Bloom Energy, finally, achieved its IPO, floating on the New York Stock Exchange in July. The re-instatement of the FITC allowed Bloom to revive its latest attempt to float, raising prices and recovering some revenue; financial results in Q1 2018 were much better than in the Q1 of 2017. It hit another milestone in May, producing its millionth SOFC. Finally making many of its numbers public, Bloom claimed an installed base of 328 MW of its Energy Servers in mid-2018. The vast majority are in the USA, with a few in India and Japan, and 2018's new market, Korea. Amongst specific developments in 2018 was the completion of five of thirteen data centre installations for Equinix in New York and California; 1.8 MW for the SUNY Medical Center in New York, and 1.1 MW for JSR Micro in California. Like FCE, Power Purchase Agreements and Service Agreements are essential to Bloom, and it has arranged US$100m financing from Key Equipment Financing – enough for 10-15 MW of Energy Servers.

Hydrogenics and its Canadian peer Ballard are the other two main fuel cell players in North America. Their focus of late has been heavily on transport (and electrolysis, for Hydrogenics), with stationary fuel cell system activities ticking over in the background. Toyota Tshusho Corporation, for example, reported a sale of five Ballard H2PM units for the Fukushima Prefecture in Japan, with further smaller sales in Europe. Ballard's is part of the FCH JU project ClearGen Demo, which has finally found a home for its 1 MW stationary plant in the French territory of Martinique, at a refinery, which has a source of hydrogen. Smaller players in North America include Altergy, working with Faith Technologies, to install a 30 kW Freedom Power System for a micro-grid in Appleton, Wisconsin.

**Europe growing, slowly**

Europe still lags. Support mechanisms and incentives exist, but rarely with the scale or consistency of Japan or Korea; the definition of 'renewables' for Renewable Portfolio Standards is much stricter than Korea or the USA; and the markets are far less homogeneous. For residential fuel cell systems, the demonstration and deployment programmes of the FCH JU and of Germany remain paramount.

The FCH JU's €90m residential micro-CHP PACE project is entering its third year. Suppliers SolidPower, BDR Thermea (under the Senertec brand), Viessmann and Bosch have been joined by Sunfire, to install up to 2,800 units across ten European countries by 2021.

This should generate some cost reduction, while accelerating in-field learning for operational performance improvements. Belgium seems an attractive market with SolidPower selling 200 BlueGen units and Viessmann 150 VitaValor units. The PEM inside Viessmann's VitaValor 300-P comes from Panasonic (and has hence benefited from the experience of tens of thousands of units in Japan), as does that in the next generation VitaValor PT2, which promises an 80,000 hour lifetime. An SOFC based unit, also of 750 W electrical output, will join the line-up. Sales of 5,000 PEM units a year are targeted initially in Germany and Belgium, later in the UK and France, and possibly Italy

SolidPower announced the 1,000th BlueGen SOFC 1.5 kW unit in operation in January, and an agreement with Bosch to sell BlueGen units under the Buderus brand in Germany. With sales increasing, its German Heinsberg facility is said to have 90 staff working in shifts, able to produce 1,500 units per year, and a 50 MW Italian facility is due to open. The next generation BlueGen is due to be released in 2019. SolidPower is also making forays into the USA, with a data centre power project at Microsoft and a link with New York-based Aris Energy to offer localised BlueGen products of 1.5, 6 and 12 kW.

Sunfire's inclusion in PACE results from Vaillant's suspension of its fuel cell activities, which left Sunfire without a route to market for its SOFC technology. Sunfire has acquired Vaillant's know-how and can now offer a complete SOFC micro-CHP system on its own, also contributing to its commercial scale developments.

The German KfW433 programme is Europe's largest stationary fuel cell support mechanism. To March, 2,630 systems had been supported, and we estimate 4,000 to be approved for support through the whole of 2018. Other nations have limited schemes: in the UK OfGEM has approved fuel cell systems for the MicroGeneration Certification Scheme (MCS) which could allow payments of £6,000 per unit over ten years. But MCS is part of the current Feed in Tariff scheme, due to end April 2019, and it is unclear what might replace it.

Europe's commercial system deployment is even smaller. 23-25 SOFC units will be supported through the FCH JU ComSos project, valued at €10m. The systems, in the 10 to 60 kW range, come from SolidPower, Convion and Sunfire. Convion will focus on the larger sizes with its C50 system, Sunfire will field its 20 kW SOFC, currently under development and SolidPower is said to be looking at 12 kW units, a similar size to the one for Korea's KEPCO.

Sunfire is also reported to be installing two 50 kW SOFC units in China. Convion, a spinout from Wartsila's fuel cell programme, currently has 58 kW biogas-fuelled units, using Fraunhofer IKTS/Plansee stacks, in demonstration in the DEMOSOFC project in Italy. The C50 will be further deployed under the LEMENE project in Finland, as part of a smart grid, and it is reported that Convion will switch to stacks from the Estonian SOFC developer, Elcogen. Convion reports increasing interest for commercial scale products, and has MoUs in place for India and Japan.

UK SOFC developer Ceres Power and alkaline business AFC Energy are making progress to commercial scale. AFC announced a deal with its partner Southern Oil of Australia, to run a unit of between 200 and 400 kW on hydrogen at the Gladstone bio-refinery in Queensland. In a structure akin to some battery providers, AFC will sell the balance of plant, but lease the stack. With a current two-year lifetime, AFC's electrode technology is supplied on a replacement basis, though a roadmap to a four-year life exists through its Italian partner, De Nora.

Ceres Power continues to add or disclose strategic partners, including a tie up with Bosch. Ceres' SteelCell SOFC technology will be the base of a 5 kW system, intended to lead to a 10 kW system for commercial distributed generation. This is part of a larger agreement, with Bosch taking a 4% stake in Ceres. Ceres also has a data centre focused activity with Cummins. Ceres has raised several traches of capital, some of which will go towards a new 2 MW per annum UK manufacturing facility.

The SteelCell is evolving: 55% electrical efficiency has been demonstrated in a customer's multi-kW system, and 60% in Ceres' labs, also with increased power density.


**Telecoms**

Telecoms power remains a tantalising market for fuel cells, with potential markets in the tens of thousands, apparently clear environmental and logistics fuel benefits over batteries and diesel gensets, and – in principle – good economics.

The latter include the somewhat surprising benefit of fuel cells and their fuels being of considerably lower value to thieves than other technologies, where security and replacement costs can be extreme. The markets are dominated by strong incumbents though, and have not proven easy to penetrate. PlugPower's GenSure PEM systems have made some progress, as have Altergy's Freedom Power system, Ballard's H2PM and Hydrogenics HyPM-XR. Two more businesses are making headway: Chung-Hsin Electrical and Mechanical (CHEM) Corporation of Taiwan and GenCell of Israel.

CHEM's methanol reformer-based fuel cell technology came from Ballard, and is sold as the ME2Power system. CHEM has a deal with Vodafone India to sell 3,000 systems over two years to power telecoms towers in North East India, as part of a longer, 10-year deal worth US$100m. Other discussions included Bharti Infratel, for 250 systems. And GenCell has been progressing quietly until this year, when it announced a sale to Adrian Kenya for 800 base stations across the country.

The 'other' alkaline FC company, GenCell has built impressive capability in its Israeli facilities, bringing together know-how, IP, staff and equipment from companies such as Medis, ZeTek and Elenco – familiar to those of us with an eye for fuel cell history. It has focused on hydrogen-powered backup units to date, for example providing systems for battery rooms for Southern Company in the USA. The telecoms units will run on ammonia, stored in tanks on-site, and 'cracked' to produce hydrogen to run the 5 kW A5 fuel cell. 12 tonnes of ammonia will allow full replacement of diesel gensets, running 24/7 for a year.

Fuel cell systems for telecoms in developed economies has been limited, apart from some uptake in resilience for critical communications networks. This year the German Federal Ministry of Transport and Digital Infrastructure tendered for fuel cell systems to power critical and off-grid infrastructure. The €5m budget should cover 500-600 systems. And for a similar application, Proton Motor put a fuel cell emergency backup system into a Deutsche Bahn railway station control centre.

**Bigger – and more efficient**

Current stationary fuel cell systems have higher electrical efficiencies than most competing combustion systems, and new technologies promise efficiencies of 60-65% – and more.

FuelCell Energy's MCFC SureSource 4000 is configured for power, not CHP usage, and claims 60% electrical efficiency. FCE is also developing a high efficiency SOFC technology, funded in part by the US Government, with field trials of its 200 kW system underway, and 62% electrical efficiency the target. LGFCS, a JV between Korea's LG and Rolls-Royce, is to demonstrate a high-efficiency 250 kW pressurised system following two decades of development.

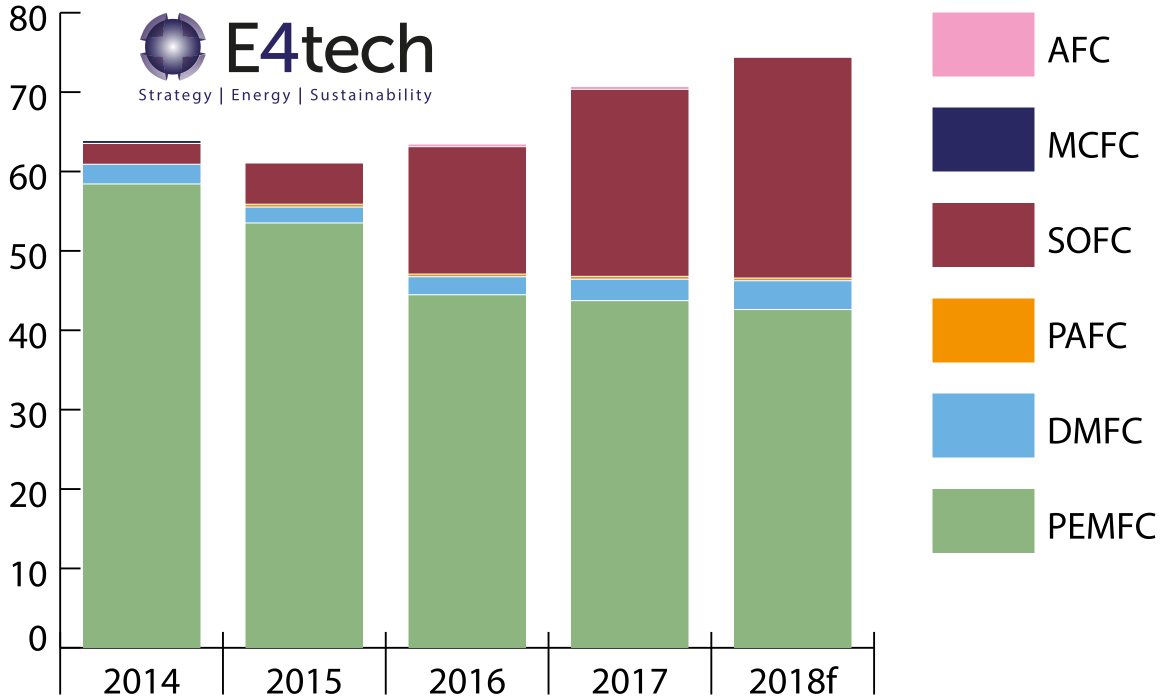
The award, with Stark State College, Ohio, is funded through the same DoE Fossil Energy programme, run through the National Energy Technology Laboratory. GE Fuel Cells is also part of the same programme, but GE's broader financial worries have strongly affected the fuel cell work. Scaled back since 2016, the emphasis, publicly at least, is on technology development.

Japan's MHPS sold its first 'commercial' Hybrid SOFC system to Mitsubishi Estates, replacing the power plant in its Marunouchi Building in Tokyo. Running day and night, peak power efficiency is 65%, and also good over part-load. Financial contributions have come from the Japanese Government fuel cell programme as well as Tokyo Metropolitan Government.

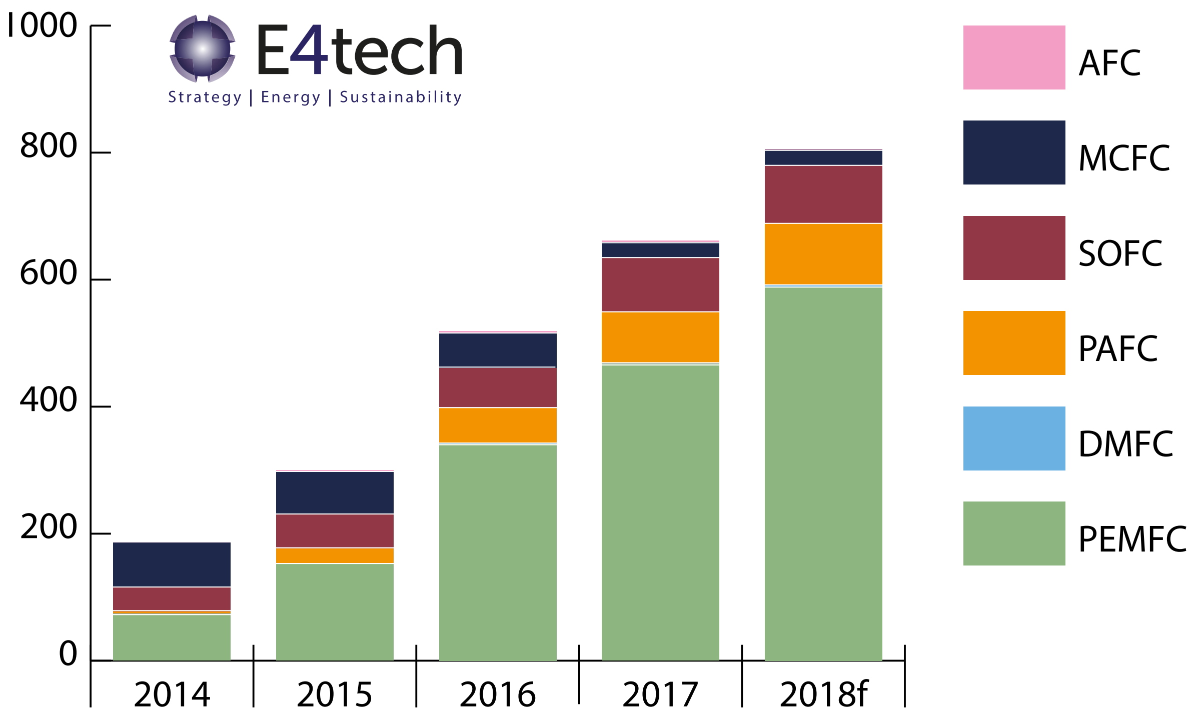
The system has been in the works for over a decade, and is available as 250 kW and 1 MW units. 250 kW units have been demonstrated at MHPS itself, Kyushu University, Tokyo Gas, Toyota Motor (the system's micro-turbine supplier) and NGK Spark Plug (a JV partner with MHPS in Solidia, the cell and stack manufacturer). Further development might one day take the electrical efficiency to more than 70%.

# Shipments by fuel cell type

Shipments by fuel cell type 2014 - 2018 (1,000 units)




Megawatts by fuel cell type 2014 - 2018




2018 is our forecast for the full year, based on firm data from January to October.
We have slightly revised the figures for 2017 in this report.

# Shipments by fuel cell type

**PEMFC** continues to dominate shipments by type, with 590 MW, up by almost a quarter. But **PAFC** shipments grew substantially – 20% higher than 2017 at 97 MW; and SOFC unit shipments rose too.

**PEMFC** is the technology of choice for transportation, as shown by the numbers. Other technologies are better suited to power generation. So 475 MW of the 590 MW transport systems come from fuel cell cars alone, almost all from Toyota, Honda and Hyundai. The rest is made up of systems for material handling vehicles, around 5,000, and further units for heavier vehicles: buses, trucks and specialised vehicles, as well as rail and maritime applications.

The PEMFC used in stationary applications mainly come from Panasonic, following Toshiba's withdrawal from the Japanese Ene-farm programme. This also caused PEMFC unit shipments to drop slightly overall. **SOFC** units from Aisin have picked up that slack. The rest of the PEMFC systems are mainly deployed for back-up and off-grid stationary uses.

Doosan has increased the loading of the new factory in Korea, and 2018 has seen the deployment of **PAFC** stationary systems grow faster than competing SOFC and MCFC products. Fuji Electric of Japan accounts for the rest of the PAFC shipments globally.

**SOFC** fuel cell unit shipments have risen about 17%, but megawatts are only up by 7%. This reflects the increase in deployment of Aisin's SOFC micro-CHP systems, which now account for roughly 50% of overall Ene-farm shipments. A variety of manufacturers shipped SOFC micro-CHP systems in Europe, under Germany's KfW433 programme and the European PACE project. The SOFC megawatt count continues to be dominated by Bloom Energy, primarily selling in the US, though they sold a multi megawatt system to Korea in 2018 for the first time.

**MCFC,** manufactured by FuelCell Energy is the other large-scale stationary technology. Shipments seem to be roughly flat, at about 25 MW for 2018. However, significant contract wins announced in the USA are expected to allow production to be raised to over 50 MW in 2019

**DMFC** technology represents the other significant fuel cell technology shipped in 2018 – at least in terms of numbers. 3,700 units are estimated for the full year, or about 0.4 MW. SFC Energy of Germany dominates the sector, though one or two other companies remain.

Alkaline fuel cell **(AFC)** technology is used by both AFC Energy and GenCell, and while relatively few shipments were made in 2018, both companies announced sales which should convert to greater shipment numbers in 2019.

# Portable and military power

Initially viewed as being 'better than batteries', the portable sector has seen more fuel cell companies fail than any other. The initially strong logic behind the statement was countered by rapid developments in battery technology and the ubiquity of charging sockets. Portable fuel cell strategies evolved to focus on their potential to offer better performance than incumbent technologies, in high-value niche markets. This could be for direct power in electronic equipment, for recharging the batteries that are ubiquitous in many of those applications, or even to provide emergency power for a home, office or tactical command centre. They can enable longer unattended operation for off-grid requirements such as meteorological or water flow modelling in rivers, in remote SCADA delivery, or temporary road works.

An illustration of the difficulties inherent in the sector was Intelligent Energy's decision to seek purchasers of elements of its diverse patent portfolio no longer core to its product development roadmap. This subset includes more than 1,100 patent assets, primarily related to portable fuel cells, low-power fuel cell and energy storage applications – and many of which had themselves been acquired from previous portable fuel cell exits, including BIC and Angstrom Power. And one of the few remaining 'very small' systems providers, MyFC, suffered as many others have.

Its deal with Telling in China, intended to already have delivered 100,000 shipments failed to get beyond the first 1,000 because of '…changing consumer behaviour…' and expired at the end of November. Its JAQ Hybrid charger has however received PSE certification in Japan, and MyFC continues to explore use of its compact planar PEMFC design at a dramatically different scale, as a range extender in passenger cars. eZelleron, which raised crowdfunding for a portable charger several years back, failed to deliver, and went silent, may be trying to reinvent itself as a fuel cell supplier to automotive.

More positively, the clear fuel cell industry champion in this area is SFC Energy, with over 40,000 of its DMFC units in operation worldwide and over 500 distributors of its product in Europe. Now employing over 250 people, the company finally reached positive underlying EBITDA in 2018, a rare achievement for a fuel cell company. Its products include the Comfort range (for RV camping), Pro series (for industry) and a range of military fuel cells.

Perhaps ironically for a low emissions technology, the oil & gas sector represents the strongest segment for SFC Energy, at over 40% of sales by value. This largely serves remote monitoring and other off-grid needs, latterly targeting SCADA and other critical infrastructure, with its Canadian Simark subsidiary. Although the company was built on DMFC, SFC Energy has taken advantage of its strength to diversify, closing a deal with adKor GmbH to access the hydrogen PEM IP of the former FutureE, P21, and Heliocentris organisations.

This allows SFC Energy to serve applications up to 100 kW, where the DMFC membrane and electrocatalyst costs would be too high. The other strong component of SFC's portfolio is military, with repeat orders from various international defence organisations, and an agreement with Advanced IT Concepts (AITC) of Florida to supply its Pro series fuel cells to military test ranges and training ranges in the US.

Horizon Energy Systems maintains a strong focus and presence in UAVs, from its Singapore base and offices in Paris and Texas, and Intelligent Energy has also continued to develop its UAV capability, building from a strong air-cooled stack technology base. Doosan has also joined the UAV fray, offering a professional PEMFC powerpack priced at US$29,000.


Broadening the fuel cell application space further was Thunder Tiger, showing off its HXC2 Jupiter fuel cell-powered helicopter. It uses a 6 kW fuel cell module and carbon fibre cylinders to store the hydrogen, and is slated to have three times greater endurance than traditional electric helicopters.

USSI maintains its own market niche, providing critical trackside power for rail applications, amongst other things, through its SOFC product for commercial backup (Performer series, marketed by RedHawk Energy Systems in the US).

It also supplies into lightweight portable power (the Defender series) and compact systems for UAVs (for example, the Lockheed Martin Stalker XE), and in ground vehicles like the MTRS Talon. BOC continues to sell its Hymera profitably into construction site and similar applications, e.g. for long-duration lighting. And Ballard has digested what it could of its Protonex acquisition, mainly the PEM component, and let the SOFC business go. The latter now operates under the name Upstart Power, with former Protonex staff. The Protonex name continues under Ballard, while PEMFC activities specific to unmanned aerial vehicles are rebranded under the Ballard name. Ballard secured orders for 13 UAV systems in July. WATT Fuel Cell unveiled its Imperium system, based on a micro-tubular SOFC built entirely using additive manufacturing, in an EHGNA E-Trek recreational vehicle right at the end of 2017, and aims its products at other recreational markets and at oil and gas. The SOFC system uses a hybrid power manager to optimize fuel cell and solar capabilities while maximizing energy storage, rather like SFC Energy.

It is perhaps worth noting that many of these applications do owe their market to being genuinely 'better than batteries'.

# 2019: bigger, better, faster, more?

It would be nice to think that the groundlaying we saw in 2018 will lead to increased fuel cell business in 2019. In general, we think that will be the case, though there will still be winners and losers. The conversations in the sector, and the kind of work we are being asked to do, show a real interest in deployment, scale-up and sustainable business propositions. Supply chain companies will continue to increase their capabilities, investors will continue to invest. Governments are indicating that fuel cells and hydrogen are not only of value in helping meet environmental targets, but also industrial and economic ones. Europe in particular is keenly feeling the automotive industry value loss for largely missing the battery vehicle wave. Nobody wants to miss a potential fuel cell wave.

The boundary conditions continue to be positive. The interest in hydrogen will not die down soon, and in practice is more likely to grow. Policy screws will continue to be tightened on air quality, and probably on $CO_2$ emissions.

From the industry side, the existing and promised investment in fuel cell manufacturing capacity will not be lightly discarded. The backlog of orders in the large-scale stationary sector suggests a further solid year of shipments, and commercial scale fuel cell offerings will start to become available. Japan still supports the Ene-farm rollout and the number of installations there will likely match – or slightly exceed – the past few years. Germany's support programme will also continue to drive uptake. Strong positive announcements by companies like Ceres Power could start to translate into products, and the trend towards larger-scale systems will strengthen.

Some sectors will continue to struggle. The micro portable sector is already almost empty, and new entrants are unlikely. Cars may still not see the pick-up that has been hoped-for to date. While infrastructure is getting better, joining it up with manufacturing, delivery and support capacity is still hard. The supply chain still needs support, and it will take several more years before it settles down and a true competitive market evolves for many components.

But it's likely that several more large organisations will go public with plans for light- and heavy-duty vehicle production, and others with plans for deployment of fleets. These will be linked to their own hydrogen refuelling networks, getting around some of the initial low utilisation and resulting high cost issues faced in the past. Rail is also a strong sector. Roll-out will inevitably be slow as it takes a long time to build and deploy trains, but Germany's lead has already pushed the UK and others to show strong interest.

Above all, the increasing availability of products will enable new business models. Entrepreneurs will increasingly be able to see whether a fuel cell will help them solve a problem. Huge corporations who already have interests in infrastructure, logistics, supply chain, energy, transport or other areas may start to join up their thinking, using hydrogen and fuel cells as the 'glue' to bring them together.

2020 has been on the radar for some time as an important target year – the Tokyo 'Hydrogen Olympics', manufacturing ramp-up by Toyota and Honda, vehicle launch from several other OEMs, and a significantly increased Chinese presence. But it does look like the groundwork done up till now will make 2019 an interesting year for fuel cells too – in a very positive way.

# Data tables

| Shipments by application | | | | | |
|---|---|---|---|---|---|
| **1,000 Units** | **2014** | **2015** | **2016** | **2017** | **2018f** |
| Portable | 21.2 | 8.7 | 4.2 | 5.0 | 5.6 |
| Stationary | 39.5 | 47.0 | 51.8 | 54.9 | 57.5 |
| Transport | 2.9 | 5.2 | 7.2 | 10.6 | 11.2 |
| **Total** | **63.6** | **60.9** | **63.2** | **70.5** | **74.3** |

| Shipments by region of adoption | | | | | |
|---|---|---|---|---|---|
| **1,000 Units** | **2014** | **2015** | **2016** | **2017** | **2018f** |
| Europe | 5.6 | 8.4 | 4.4 | 5.1 | 8.6 |
| N America | 16.9 | 6.9 | 7.7 | 9.4 | 9.8 |
| Asia | 39.3 | 44.6 | 50.6 | 55.3 | 55.3 |
| RoW | 1.8 | 1.0 | 0.5 | 0.8 | 0.6 |
| **Total** | **63.6** | **60.9** | **63.2** | **70.5** | **74.3** |

| Shipments by fuel cell type | | | | | |
|---|---|---|---|---|---|
| **1,000 Units** | **2014** | **2015** | **2016** | **2017** | **2018f** |
| PEMFC | 58.4 | 53.5 | 44.5 | 43.7 | 42.6 |
| DMFC | 2.5 | 2.1 | 2.3 | 2.8 | 3.7 |
| PAFC | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 |
| SOFC | 2.7 | 5.2 | 16.2 | 23.7 | 27.8 |
| MCFC | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| AFC | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 |
| **Total** | **63.6** | **60.9** | **63.2** | **70.5** | **74.3** |

2018 is our forecast for the full year, based on firm data from January to October.
We have slightly revised the figures for 2017 in this report.

# Data tables

| Megawatts by application | | | | | |
|---|---|---|---|---|---|
| **Megawatts** | **2014** | **2015** | **2016** | **2017** | **2018f** |
| Portable | 0.4 | 0.9 | 0.3 | 0.6 | 0.7 |
| Stationary | 147.8 | 183.6 | 209.0 | 222.3 | 239.8 |
| Transport | 37.2 | 113.6 | 307.2 | 435.7 | 562.6 |
| **Total** | **185.4** | **298.1** | **516.5** | **658.6** | **803.1** |

| Megawatts by region of adoption | | | | | |
|---|---|---|---|---|---|
| **Megawatts** | **2014** | **2015** | **2016** | **2017** | **2018f** |
| Europe | 9.9 | 27.7 | 27.4 | 38.9 | 43.4 |
| N America | 69.8 | 108.4 | 213.6 | 331.8 | 415.0 |
| Asia | 104.5 | 159.7 | 273.8 | 285.8 | 343.3 |
| RoW | 1.2 | 2.3 | 1.7 | 2.1 | 1.4 |
| **Total** | **185.4** | **298.1** | **516.5** | **658.6** | **803.1** |

| Megawatts by fuel cell type | | | | | |
|---|---|---|---|---|---|
| **Megawatts** | **2014** | **2015** | **2016** | **2017** | **2018f** |
| PEMFC | 72.7 | 151.8 | 341.0 | 466.7 | 589.1 |
| DMFC | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 |
| PAFC | 3.8 | 24.0 | 56.2 | 81.0 | 97.3 |
| SOFC | 38.2 | 53.3 | 62.9 | 85.2 | 91.0 |
| MCFC | 70.5 | 68.6 | 55.7 | 24.7 | 25.2 |
| AFC | 0.0 | 0.2 | 0.5 | 0.6 | 0.1 |
| **Total** | **185.4** | **298.1** | **516.5** | **658.6** | **803.1** |

2018 is our forecast for the full year, based on firm data from January to October.
We have slightly revised the figures for 2017 in this report.

# Notes

- Data for 2014 to 2018 have been collected directly from fuel cell manufacturers and integrators where they were able to share it. For those who were not able to share primary data, and to sense-check our numbers, we have collected and cross-referenced data from publicly available sources such as company statements and statutory reports, press releases, and demonstration and roll-out programmes, in addition to discussions with other parties in the supply chain.
- Our 2018 figures are a forecast for the full year. The dataset contains firm numbers for the period January to October 2018, and for the remaining period we use companies' own forecasts, shared with us, or ones we prepare in discussion with industry.
- We will revise data for 2018 in our 2019 edition as appropriate. We have slightly revised the figures for 2017 in this report: Unit numbers were reduced by about 3% and megawatt numbers reduced by less than 2% compared to our published 2017 forecast.
- Unit numbers are rounded to the nearest 100 units. An entry of zero indicates that fewer than 50 systems were shipped in that year.
- Megawatt numbers are rounded to the nearest 0.1 MW. An entry of zero indicates that less than 50 kW was shipped in that year.
- The reported figures refer to fuel cell system shipments by the final manufacturer, usually the system integrator. In transport we count the vehicle when shipped from the factory.
- We do not count replacement stacks in existing applications, and where possible we also do not count inventory, only systems that are shipped to users.
- Portable fuel cells refer to fuel cells designed to be moved. They include small auxiliary power units (APU), and consumer electronics (e.g. phone chargers). Toys and educational kits are not reported.
- Stationary fuel cells refer to fuel cell units designed to provide power at a 'fixed' location. They include small and large stationary prime power, backup and uninterruptable power supplies, combined heat and power (CHP) and combined cooling and power. On-board APUs fixed' to larger vehicles such as trucks and ships are also included.
- Transport fuel cells refer to fuel cell units that provide propulsive power or range extender function to vehicles, including UAVs, cars, buses and material handling vehicles.
- Our geographical regions are broken down into Asia, Europe, North America and the Rest of the World (RoW), including Russia.
- Shipments by fuel cell type refer to the electrolyte. Six main electrolyte types are included here. High temperature PEMFC and conventional PEMFC are shown together as PEMFC. Other types of fuel cells currently in an early stage, such as microbial fuel cells and solid acid fuel cells, are not included in the numbers shown.

# About E4tech and the authors

Since 1997, E4tech has helped clients to understand and profit from opportunities in sustainable energy, with deep expertise and long experience in many sectors. Fuel cells and hydrogen are particular areas of strength, and we have carried out projects for early stage companies, SMEs, large companies, financiers and governments worldwide. These projects range from market and competitor analysis through business strategy, technical and commercial due diligence, to support for policy development. See **www.e4tech.com**.

The Review effort is led by those below, and supported by many members of E4tech, in data gathering, drafting and interpretation in different languages, such as Chinese.

**Prof David Hart** is a Director of E4tech, responsible for the Fuel Cell and Hydrogen Practices. In 20+ years in the sector he has consulted and carried out research for national governments, major industrial companies, start-ups, financial organisations and NGOs. He has been an invited keynote speaker at conferences on six continents.

**Franz Lehner** is a Managing Consultant at E4tech, with a focus on fuel cells and hydrogen generation technologies.

**Dr. Stuart Jones** is E4tech's Energy Technology Knowledge Manager. He has extensive industry experience with fuel cells, hydrogen and battery technologies.

**Jonathan Lewis** has over twenty years' experience in business development, from strategy and policy through business plans to technology commercialisation. More than 10 years in the fuel cell and hydrogen area, he was with Rolls-Royce Fuel Cell Systems Ltd, and is now an independent adviser. He has extensive experience, including in a variety of roles with the FCH JU.

**Matthew Klippenstein** is an independent consultant with 15 years' engineering experience in fuel cells. He chronicles the hydrogen and fuel cell sectors for GreenTechMedia.com, and tracks the Canadian electric vehicle market for the National Observer and at CanadaEVsales.com. His cleantech-centric communications consultancy Electron Communications can be followed on Twitter at @electroncomm.

**IN MEMORIAM**

This edition of the FCIR has sadly missed the insight of our friend and colleague **Robert Rose**, who passed away in October. Bob was immensely important to fuel cells. His Breakthrough Technologies Institute advocated for fuel cells from 1991, and he founded the US Fuel Cell Council in 1998 and was Executive Director for 10 years, bringing together disparate players across the community and tirelessly supporting it. He wrote and lectured widely about fuel cells and hydrogen energy and received numerous industry awards.

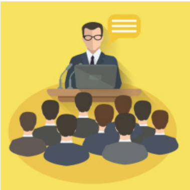
He was always prepared to help, had a quick wit and a lust for life. He will be sorely missed, by us, by his family, and by his friends and colleagues around the world.

We would also like to acknowledge the helpful support of the Working Group Fuel Cells of the German VDMA (Verband Deutscher Maschinen- und Anlagenbau, German Mechanical Engineering Industry Association). The VDMA carries out a survey on the German fuel cell industry and is kindly assisting us in liaising with its members.

# Can we help?

Would you like to know more about the fuel cell or hydrogen industries? What we think the future looks like? How it affects you? We have supported organisations in the fuel cell and hydrogen sectors globally for 20 years, as well as companies in many other areas who may be touched by these developments. We would be delighted to discuss the Review with you, formally or informally, and any needs you may have.

Our services include:



## Bespoke Expert Briefings:

– Would you like a focused discussion on the detail of the fuel cell sector for your team or your management?

We can tailor a **presentation** or **workshop**, long or short, to cover the big picture or the fine detail.

## Market and Supply Chain Analyses:

– Do you need to better understand the **supply chain**, the **global market** opportunities or the **competition?**

We have carried out detailed analyses for large and small corporations worldwide, feeding into technology and supplier choices, **business development** and **strategy.**

## Commercial and Technical Due Diligence Evaluations:

– Are you thinking of **investing** in or **acquiring** a technology or company?

Our many **technical and commercial analyses for due diligence** purposes have helped diverse **investors** to understand risks and opportunities.

## Business and Strategy Support:

– Could your business plan or **strategic approach** be strengthened?

We have **data, projections** and a deep understanding of the fuel cell sector, its past and **possible future** to help you develop and stress-test your strategy or accelerate its implementation.

## Objective Review and Expert Resource:

– Do you need an **external perspective** or some **extra resource**?

We can evaluate your strategy or your programmes, bring in views you may not have considered, or simply provide expert resource to your team for a specific project or task.

We are always happy to discuss aspects of the sector and questions you may have. Please contact us directly through **www.e4tech.com** and we'll find the right person for you to talk to.

# Picture Credits

Would you like to know more about the fuel cell or hydrogen industries? What we think the future looks like? How it affects you? We have supported organisations in the fuel cell and hydrogen sectors globally for 20 years, as well as companies in many other areas who may be touched by these developments. We would be delighted to discuss the Review with you, formally or informally, and any needs you may have.

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|---|---|---|
| 4 | Fuel cell vehicle line-up at FCV Conference, Rugao | David Hart |
| 5 | Re-fire hydrogen fuelling station, Shanghai, China | Re-Fire |
| 8 | Artist's impression of Hyundai fuel cell truck | Hyundai Motor Company |
| 9 | Fuel cell trucks outside Bing Energy, Rugao, China | David Hart |
| 14 | Weltmeister prototype DMFC car | David Hart |
| 15 | Toyota Tundra fuel cell pizza pick-up | Toyota Motor Corporation |
| 15 | Microcab Vianova | Microcab |
| 16 | GreenGT H24 | GreenGT |
| 16 | Aiways methanol fuel cell supercar | Gumpert Aiways |
| 17 | Alexander Dennis/Arcola fuel cell bus | David Hart |
| 18 | BYD fuel cell-battery hybrid bus for Hawaii | BYD Auto Co., Ltd. |
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| 40 | Doosan PAFC 'farm' | Doosan Corporation |
| 41 | Thunder Tiger fuel cell helicopter | Thunder Tiger |
| 42 | WATT Imperium fuel cell | WATT Fuel Cell |
| 43 | Hyundai Nexo fuel cell car | Hyundai Motor Corporation |

**Note on currencies:**

The following exchange rates can be used as guidance to convert currencies mentioned in this report. These are the average mid-point exchange rates from 30th November 2017 to 30th November 2018.

| | | | |
|---|---|---|---|
| US$1 = € 0.8448 | €1 = US$ 1.1846 | 1£ = US$ 1.3392 | 1¥ = US$ 0.0090 |
| US$1 = £ 0.7470 | €1 = £ 0.8842 | 1£ = € 1.1311 | 1¥ = € 0.0076 |
| US$1 = ¥ 110.65 | €1 = ¥ 131.01 | 1£ = ¥ 148.18 | 1¥ = £ 0.0068 |

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