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The
Fuel Cell
Industry
Review
2017

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LIST OF ABBREVIATIONS

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

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China's demand pull and hydrogen's supply push

The fuel cell sector continues to grow. About 30% more fuel cell power was shipped in 2017 than 2016, and nearly 10,000 more units. And while nobody is finding it easy, there seem to be glimmers of light ahead. One positive indicator – if frustrating for us – is just how hard it has become to stay on top of the multiple announcements of deals and shipments.

The headline figures for transport are strong, with nearly 5,000 more units shipped than 2016, amounting to 50% more MW. But the signals overall are mixed. Far more car companies are investing much more money on battery electric vehicles, and orders of magnitude more BEVs are being sold. It is not yet clear that consumer demand for fuel cell cars will match even the currently modest expectations of the auto industry. China, though, is helping by reducing its BEV subsidies and pushing its industry towards light duty as well as heavy duty fuel cells. Norway is talking of a 'Tesla tax'. Many countries offer purchase subsidies. We have seen auto and energy industry consortia form in Europe and Japan and an ambitious private sector Hydrogen Council debut. But we have seen no new ambitious announcements from the current auto industry players.

We know that an impressive new Hyundai model should debut early in 2018, and other OEMs will launch something in the coming years, but Toyota's announcement of manufacturing capability for 30,000 cars in 2020 is matched only by rumblings from Chinese corporates. Some commentators claim the death of the FCEV, not a new refrain, though others point to charging infrastructure problems and battery materials issues as early warning signs of a need for Plan B. Fiat-Chrysler is looking at fuel cells, not batteries, and exploring a tie-up with Hyundai. A Dutch company claims to have 'improved' a Tesla by adding a fuel cell range-extender.

Perhaps surprisingly, heavier-duty fuel cell vehicles have accelerated into a position of prominence – literally, in the case of Toyota's drag-racing Kenworth truck conversion. In a world of increasingly strict air quality constraints, where major cities such as London are banning diesel buses, heavy duty vehicles have the advantage of better range and faster refuelling than battery ones. In some places it's also easier to build a hydrogen filling station than a similarly sized battery charger, while in others the pure electric solution makes more sense. China's near-term ambitions are firmly anchored in trucks and buses, with around 2,500 vehicles integrated this year, compared to almost none in 2016. But with only 7 refuelling stations in China as we went to press, many of those vehicles are not yet moving far. Trains and marine markets are another step along the way.

The stationary fuel cell sector did not advance as much. Shipments were up by about 4,000 units, and just a few MW. Big growth in PAFC was matched by a fall in MCFC sales, though it looks like these will recover in 2018. SOFC continued growing too, with a greater percentage of Ene-farm sales the main contributor and Bloom, despite headwinds from the absent federal tax subsidy, maintaining a roster of loyal customers.

Some of those poor sales figures were caused by company problems. POSCO and Toshiba reduced their commitments because of troubles elsewhere in the corporate structure, though each maintains some fuel cell support. Heliocentris went into bankruptcy, as did Elcore, and Intelligent Energy ran out of cash, was effectively bought by its largest investor, and de-listed from the stock exchange. Much more positively, Ceres Power, FuelCell Energy, SolidPower, Hydrogenics, AFC Energy and others all raised money, some with a view to significant manufacturing expansion.

Arguably the most interesting deals were between Canadian fuel cell suppliers and Chinese stack and system companies; the deals involve technology sharing but the potential returns are significant in a country that makes a half-million buses annually, Chinese companies, following government money and edict, are very determined to build indigenous fuel cell capability. Recruiters are using every avenue possible to entice experienced talent, and Chinese firms with big chequebooks are seeking to buy technology – and entire companies. An interesting dance has resulted, where those with the technology seek ways to access the money without giving too much away. One interesting development was the teaming up of Dewei and Power Train Technology to form Fuel Cell Powertrain, based in Chemnitz and headed by former Proton Motor executives.

In forklifts, Plug Power's creative deals with retail giants WalMart and Amazon for up to US\$600 million in purchases each were the highlight of the year, though the deals came at the cost of part ownership in Plug Power. Backup power systems are still in – admittedly modest – demand but in consumer electronics fuel cells have not gained traction. There is some demand in military markets and in unmanned vehicles of all kinds, an area that may well see significant growth in 2018 if 2017 sales and demonstrations pan out.

The market for fuel cell test systems, an important bellwether, seems very busy.

Taking a step back, 2017 was a good year for an industry that still has not crossed the risk threshold, and the larger societal and industrial drivers seem more compelling than ever. The promise of carbon free energy via a partnership between electricity and hydrogen has never been more urgently needed nor more widely recognised by governments and leading private sector organizations.

Large-scale carbon-free hydrogen helps decarbonise industry and join energy sectors together. It is seen by corporations like Engie as an essential part of its future... as a 'hydrogen major'.

Fuel cells complete the vision by providing a low pollution technology to transition from carbon fuels and ultimately by offering pollution free conversion of hydrogen to useful energy. But vision is one thing and cold hard cash is quite another. Fuel cells still need to find the marketplace drivers to match the policy drivers. That will be the task for 2018 and beyond.



About the review

Applications

To allow year-on-year data comparisons, we base our categorisation of shipment data on that defined by FCT. 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 (APU)	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 DMFC SOFC	PEMFC MCFC AFC SOFC PAFC	PEMFC DMFC
Example	<ul style="list-style-type: none"> • Small 'movable' APUs (campervans, boats, lighting) • Military applications (portable soldier-borne power, skid-mounted generators) • Portable products (torches, battery chargers), small personal electronics (mp3 player, cameras) 	<ul style="list-style-type: none"> • Large stationary prime power and combined heat and power (CHP) • Small stationary micro-CHP • Uninterruptible power supplies (UPS) • Larger 'permanent' APUs (e.g. trucks and ships) 	<ul style="list-style-type: none"> • Materials handling vehicles • Fuel cell electric vehicles (FCEV) • Trucks and buses • Rail vehicles • Autonomous vehicles (air, land or water)

Portable fuel cells encompass those designed or able to be moved, including small auxiliary power units (APU); 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

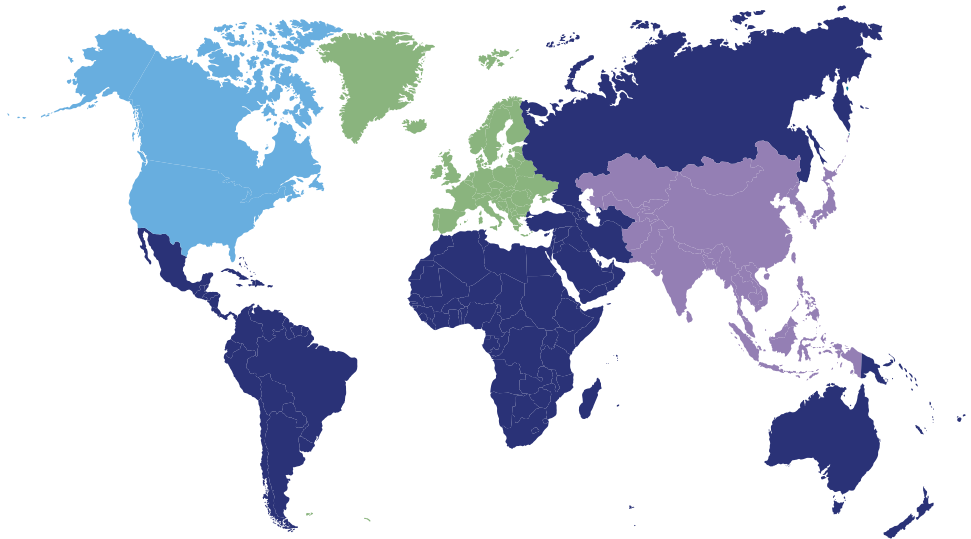
Shipments by fuel cell type refer to the six main electrolytes used in fuel cells: proton exchange membrane fuel cells (PEMFC), direct methanol fuel cells (DMFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and alkaline fuel cells (AFC). High temperature 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, including historical information from FCT dating back to 2012. Data are presented for each year in terms of annual system shipments and the sum total of those systems in megawatts, both divided 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 possible, we do not include shipments for toys and educational kits.

Data sources and methodology

For the years 2012-13 we have retained the figures published in the Fuel Cell Today Industry Review 2013. The 2013 figures in that report were a forecast

to the full year 2013. While some of the actual 2013 shipments differ from the 2013 forecast, we have no access to the underlying data and have hence not revised their 2013 numbers, though we believe that fewer SOFC systems were shipped than forecast for the Japanese Ene-Farm project.

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, 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 2017. For the remaining period we use forecasts shared with us by individual companies or forecast prepared by us in discussion with industry. We will revise data for 2017 in our 2018 edition as appropriate. We have slightly revised the figures for 2016 in this report: Unit numbers were reduced by about 3% and megawatt numbers increased by about 8% compared to our published 2016 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.

Looking back on 2017

We've thought for a while that many of the companies who will succeed in fuel cell technology are already there. Our view is starting to change. Since our 2016 Review we have seen further winnowing of the existing field, with a few more long-standing names exiting and a few others strengthening their position. Oh, and one or two new entries. The market is growing, even if it's still small. There is positive mood music. But the sector remains fragile.

Cars were an important part of 2016's buzz, but the noise has been muted in 2017. Toyota maintains its rhythm and its public commitment to be able to make 30,000 cars a year by 2020, but it has not announced interim production plans. Honda has started well, though is unlikely to move to greater scale until 2020 when its partner plant with GM starts up. Hyundai's sales remain consistent but relatively low, a challenge that may be solved by introduction of its new 2018 vehicle. And Daimler's GLC F-CELL is expected to be on the road in 2018.

Fortunately, almost every other mode of transport is buoyant (some literally!). Symbio is building its range-extender Kangoo vans; ULEMCo in the UK is developing a fuel cell conversion for Nissan e-NV200. Toyota showcased its Class 8 drayage truck by drag-racing it against a diesel, and is developing delivery vehicles with 7-11 in Japan. Nikola Motor signed up Bosch and PowerCell as suppliers. Buses were big news too – Europe expects several hundred over the coming years. And China continued to buy and build stacks, systems and vehicles for light duty and bus applications (though many are in parking lots rather than on the road). We even saw light rail in operation, and regional trains in test, in Europe and Asia. In the marine sector, fuel cell-powered ferries, and the announcement of a cruise ship project made news.

Interestingly, the small scale stationary front seems to be advancing in the same way as transport: from smaller to larger applications. The Japanese bravely continue to subsidise Ene-Farm, still by some margin the largest and most successful rollout of fuel cells to date, but residential CHP remains a hard sell – as we've said before. Like cars, residential heat and power systems have to be very cheap and very reliable, with ubiquitous service networks and very high availability. They are two of the toughest markets one could imagine. But commercial CHP, and even power-only systems, can all be lower cost per kW than residential units, and without the need to cater to hundreds of thousands of individual customers.

In larger power generation markets fuel cell companies continue the trend toward becoming unregulated utilities, selling power rather than units through long term purchase agreements. Korea's deep subsidies for fuel cell power are shaping the opportunity and there is hope that subsidies will return to the US marketplace in 2017.

Speciality products remain important. Forklifts are often touted as one of the few true commercial markets, but they have benefitted strongly from subsidies, and the offering is dominated by a single supplier. Only recently have they started to look promising outside of the huge North American warehouse opportunity. But telecoms reinforcement, remote small power and military markets are all semi- or genuinely commercial. Paradoxically, fuel cells often succeed in these applications because batteries don't – but batteries remain very much the headline technology for now.

While batteries are improving all the time, and will certainly play an enormous role going forward, limitations in supply, capability and disposal – never mind charging infrastructure for mobile applications – will keep opportunities open for other technologies. A case can also be made that better batteries will improve the viability of fuel cell hybrid systems – and vice-versa.

We see other important changes occurring. Major automotive suppliers – Bosch, Elring Klinger, Umicore and others are investing in production capability – and the supply chain is evolving. It is far from robust, but the level of investment is meaningful. At the same time, discussions about the external energy system are developing. The Hydrogen Council, formed in 2017, has so far talked a good talk; the companies involved are serious, stand to benefit from a ‘hydrogen economy’ – and many are unsure how to deal with an all-electric future. They are individually starting to place some reasonably big bets on hydrogen, which at some point will certainly help fuel cells.

We think the most obvious symbol of 2017 is the pivot to Asia. While Europe progresses, numbers are small, and N America has lost some traction. Meanwhile, Japan maintains funding levels across a wide range of technologies and applications, and the hydrogen economy remains a pillar of policy. Korea continues its own brand of support.

But, as we alluded to last year – China is on a mission. It wants new, clean, value-added industries. It understands the future opportunity for fuel cells much as it did for PV. It must respond to public demands for better air quality. And in a huge command economy it can support development, mandate uptake, and shut out competition effectively. At the moment the main drive is for technology acquisition – joint ventures and investments, both successful and not. But indigenous technology is what the country really wants, and will try every avenue to get. China will change the fuel cell industry. It may drag it into profitability in the near term, and help to build capacity, but non-Chinese providers definitely need to be thinking about what happens next, as Chinese companies will be the new entrants we had not seriously considered until now.



Corporate news

This has been another year of ups and downs in the fuel cell industry. Some companies have attracted fresh capital from public or private sources. Several companies' stock prices are much improved from appalling 2016 lows. But other companies have sunk under the weight of cash flow requirements and gone private or gone dark. Significantly, three major industrial companies have scaled back their fuel cell activities in 2017, underscoring the fragility of the industry beneath our overall positive reports of unit and megawatt sales. There is very little competition yet in systems or supply, and markets are either subsidised or high-value speciality markets... sometimes both.

We expect the trend to continue in 2018. An initial public offering of stock from Bloom Energy is possible, though it has been promised many times before. This would provide a fresh test of investors' appetite for fuel cells. But we also expect at least one or two more long-running, high profile fuel cell efforts to close their doors.

On the positive side, several high profile and potentially lucrative partnerships were announced in 2017, with China Inc. firming up its stakes in Hydrogenics and Ballard, and with Plug Power linking financially with major customers WalMart and Amazon. Some "tidying up" has also happened, such as Ballard's acquiring the outstanding shares in Ballard Power Systems Europe, formerly Dantherm Energy.

The manufacturing and supply chain, already distributed internationally, appears likely to remain an international proposition as the developing markets (India, China, Korea) expect technology sharing and jobs in return for market access. This trend is simply a natural aspect of market growth, but companies will do what they have to do to stay alive and expand. If that comes at a cost of licensing their technology or sharing corporate ownership, that is what will happen.

It is clear money markets are not exhausted. But companies – even deep pocket companies – must measure their commitment to fuel cells against their other financial needs, better market prospects, and the sheer size of the ticket their management and shareholders expect.

GE, POSCO and Toshiba are three examples from 2017 where fuel cells took a backseat to other imperatives, though they continue on in some shape or form.

It's (still) all about the cash

Developing a technology to the stage where a product works well enough to launch onto the market requires considerable human, intellectual and financial capital. Manufacturing and selling the product into a very competitive market, with well-established incumbent technologies and generally conservative end users, requires an order of magnitude more. In the absence of a profitable revenue stream, fuel cell businesses require cash from owners/investors. And persuading investors to part with their cash – again and again – is not easy; 2017 reminds us what happens when the cash runs out.

Intelligent Energy de-listed in what was effectively a takeover by its main shareholder, who had provided cash to keep the business afloat when a big India deal unravelled. The workforce was dramatically cut, and the motive power programmes put on hold. IE carries on, but more cash will be needed. In some respects it was a surprise not to see the company acquired by another player – the likes of Ballard have shown enthusiasm for picking up other companies in the past.

Elcore GmbH, the German micro-CHP PEM system developer and producer, filed for bankruptcy in the German courts. Vaillant, the German domestic boiler business, put its microCHP fuel cell activity "on hold," in spring, citing lack of a clear path to commercialisation. Heliocentris filed for bankruptcy late in 2016 and in 2017 sold its assets to a Dubai company, with some of the facilities intending to continue operating under the name ODASCO Heliocentris GmbH. That also went bankrupt, though some, at least, of the Heliocentris family seems to have escaped the black hole, as FutureE was resurrected under another investor.

Toshiba's June announcement that it was to cease manufacturing its PEM micro-CHP, after deploying an estimated 80,000 units, was a blow to the Ene-Farm programme – but a result of Toshiba's catastrophic finances stemming from its failed nuclear business. Korea's POSCO Energy also announced an exit from MCFC, which it had assiduously developed over a number of years. It was apparently 'persuaded' by the Korean government to maintain at least some presence. GE moved its SOFC commercialisation activity back under its research division and shed 60% of its workforce, but it is unclear where the business will end up. Like Toshiba, the other two companies were reacting to significant financial pressures external to their fuel cell businesses.

The money raised for fuel cell companies has gone to several homes. SolidPower reported an investment of €40m from an unnamed private investor in September – to be used to expand to the order of 50 MW of manufacturing capacity per annum. Not far behind is FuelCell Energy. After major restructuring at the end of 2016, the business has had an encouraging 2017. FCE has raised an estimated US\$41m, in two lots, to support activities including the expansion of its project portfolio. As we note elsewhere, FCE is also making the transition from technology supplier to unregulated utility, announcing to shareholders that it can make more money selling electricity via long term power purchase agreements than via system sales. This will fundamentally affect its balance sheet. It is consistent with the trend in fuel cell power generation; Doosan announced a financing mechanism with Wells Fargo Bank that will allow it to do the same thing, though Doosan's current focus is the Korean market.

AFC raised £8m (US\$12.4m) in two tranches, to sustain its development activities, while Ceres Power received £20m more from investors, on top of £20m from October 2016. Hydrogenics raised US\$21m in a private placement from Hejili Equity Investment Partnership in July. Nikola Motors, the start-up developing heavy duty truck cabs, raised at least US\$110 million from private sources, according to its CEO.

Pragma used crowdfunding to finance its hydrogen powered bicycle developments, though a tweet in November announced that the initial bicycle had been stolen in Paris. Maintaining their sense of humour, they proclaimed it a 'first for the industry'!

Partnerships help too

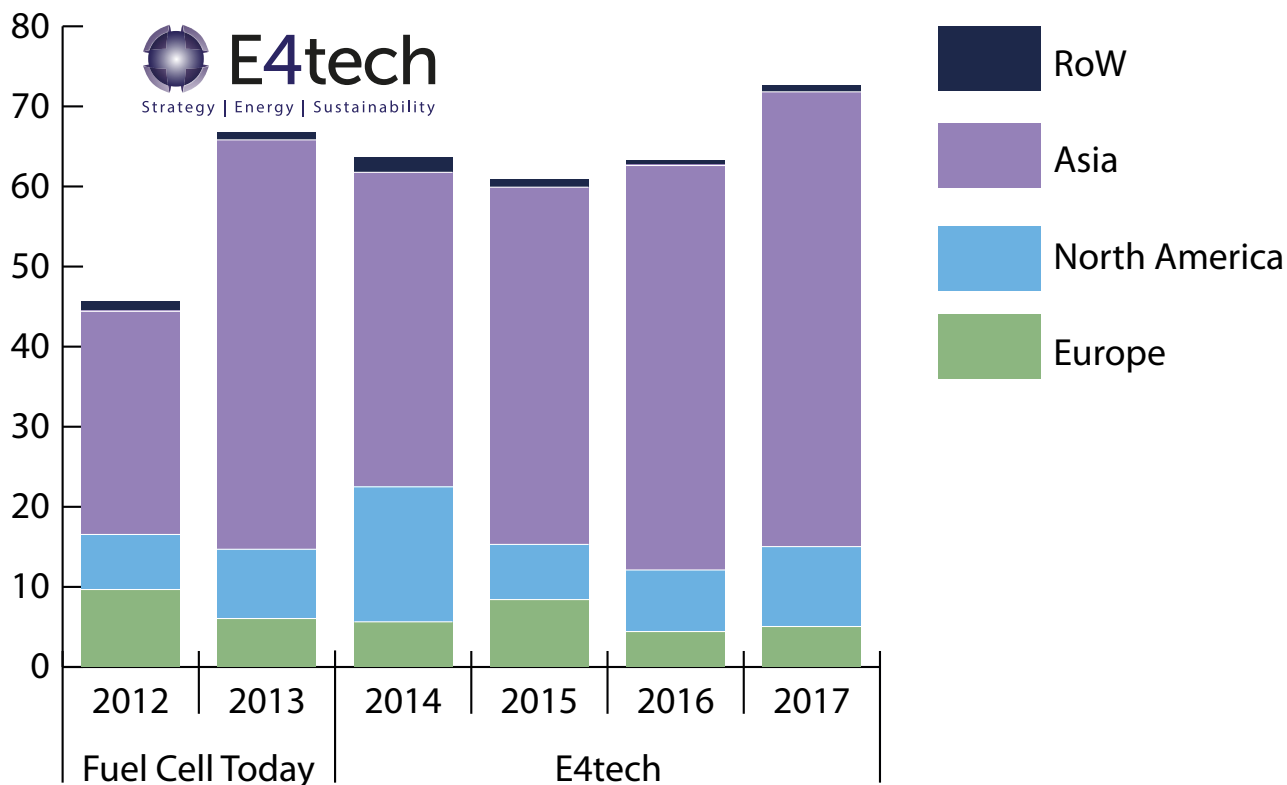
Strategic partnerships remain an important source of capital and market entry opportunity. Ceres Power continues to follow this route, and has started to talk about product development with some of its partners. Ballard and Hydrogenics are strengthening relationships with Chinese partners: Zhongshan Broad-Ocean Motor Co., already Ballard's largest shareholder, is building three manufacturing facilities using Ballard technology, while Hydrogenics announced a purchase and technology licensing agreement with Blue-G New Energy Science and Technology Corporation, an existing Chinese partner. And in a move which may illustrate how hard it is to attract seasoned fuel cell talent to the less attractive parts of China, Fuel Cell Powertrain GmbH was founded in Chemnitz (Germany) as a joint venture of Dewei (Beijing) and Power Train Technology (Germany). The company will have close ties to the Technical University of Chemnitz, and around €120m of investment is planned over three years, half for buildings and hardware, and half for development. The focus will be on fuel cell powertrains, with manufacturing ultimately intended to be in China. Dewei already has a joint venture with US Hybrid.

Bloom IPO: Groundhog day?

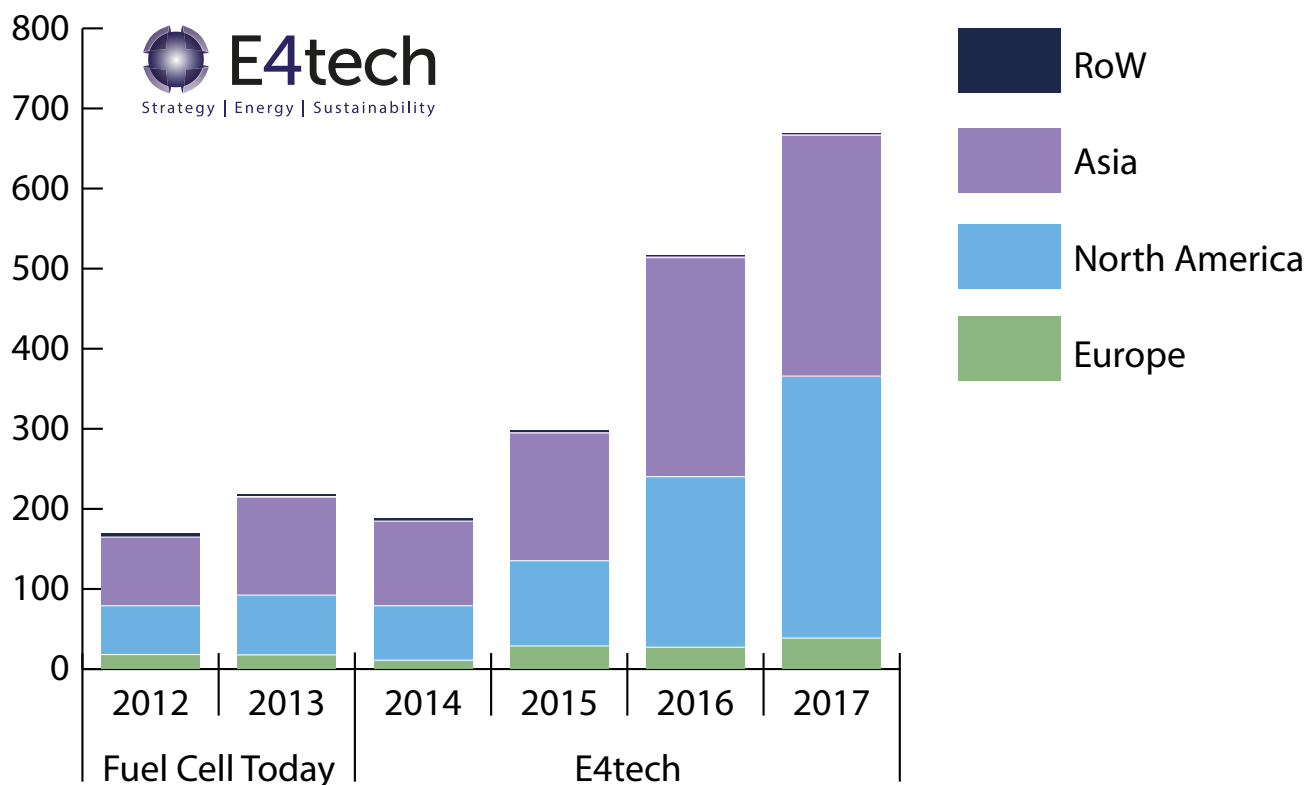
Bloom has been threatening an IPO for a number of years. In 2016 it finally filed for one, using a special US law that enabled it to do so "privately" – but with a rider that made the IPO contingent on the existence of the US power generation tax credits. A year later and this is still in limbo. But even with the good performance of some of the fuel cell "pure play" stocks in 2017, it is not clear that Bloom can realistically get close to its desired valuation (said to be US\$2.7 billion a few years ago already) and whether there will be any cash left for development once early investors are paid off.

Shipments by region

Shipments by region of adoption 2012 - 2017 (1,000 units)



Megawatts by region of adoption 2012 - 2017



Footnote to charts: Data from 2012-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2017 is our forecast for the full year, based on firm data from January to October. We have slightly revised the figures for 2016 in this report.

Shipments by region

In 2017 global fuel cell power shipped grew by 30% to 670 megawatts, and units by 15%, to more than 70 thousand systems. At first glance, global distribution follows the pattern of recent years: Asia leads by far in unit numbers, with 80% of the additional systems. In megawatts, Asia and North America have been neck-and-neck since 2015, and competing for the lead – with 95% of the market between them. Look deeper, however, and the picture changes.

In Asia, the mix of national markets and applications shifted in 2017: The number of fuel cell cars added by Toyota, Honda and Hyundai within Asia was down from about 1,500 in 2016 to roughly 1,000 in 2017 – though many more were shipped to North America. Despite this, and what seems a temporary weakness in large stationary deployments in Korea, Asia has grown both in units and megawatts. The number of systems shipped grew by more than 6,000 year-on-year, about half attributable to the Ene-farm programme. Another 1,000 units came from myFC's portable charger JAQ, delivered to their client in China, and each much too small to affect the megawatt count. But the main change, already apparent through our internally tracked stack shipments of 2016, was China. Transport applications there have grown from very few new vehicles in 2016 to an estimated 2,000 "available" fuel cell buses and delivery trucks by November 2017. The figure is changing rapidly and we include 2,500 vehicles (about 80 MW) in our 2017 totals. If we were to include inventory of modules, stacks and MEAs, these numbers would more than double.

The ramp-up in China more than compensated for a decline in large stationary deployments in Korea. Doosan's rapidly growing output could not compensate for fewer shipments from its peers. However, this segment should grow again in 2018, as order books have filled during 2017. Over in Japan, Ene-farm programme growth was moderate, contributing about 35 MW. In 2018, we expect commercial scale units in Japan. Several megawatts of back-up and off-grid power systems are also in use in telecom cell towers in China and other parts of Asia.



North America saw double-digit MW growth in the large stationary segment, including

utility-scale power and onsite generation at data centres, but the bulk of the 50% increase in megawatts shipped compared to 2016 came from fuel cell cars. Toyota, Honda and Hyundai together added nearly 2,000 fuel cell cars in 2017, more than 70% up on 2016. While 2016's focus was Japan, the US (i.e. California) was the target in 2017. Systems shipped to or within North America grew by 30%, to about 10,000. Some of these were cars, but material handling is set to grow 40% year-on-year, if Q4 goes according to plan. Fuel cells are also being shipped as back-up power solutions, UAVs and portable power, both civilian and military.

Megawatts installed in Europe grew by more than 40%, but that still amounts to less than 50 MW in total; almost hidden on the charts. About 300 cars came from the Asian OEMs to Europe, 50% more than 2016. Vehicle roll-out remains slower than in Japan and the US, despite comparable hydrogen refuelling infrastructure.



Vehicle numbers are augmented by range-extended delivery vans, including some that run on methanol, and by buses. Several companies have deployed fuel cell forklift trucks but the numbers remain very small.

The number of systems shipped also grew in Europe, mainly from the roll out of residential and small commercial CHP units in Germany, where 1,500 new systems are expected by the end of 2017. Units were also added under the European ene.field programme, and more should follow under the PACE project. A few large stationary systems have also been shipped, including those of Fuji N2telligence and FCE. Europe also has many small systems, in particular sub-100 W portable power generators and stationary back-up power systems of several kilowatts each.

The Rest of the World (RoW) still accounts for very few installations, mainly small stationary back-up power or off-grid applications, and portable off-grid power, with one or two vehicles.

The car conundrum

Although fuel cell cars continue to loom large in discussions, and Mirai and Clarity billboards compete for views on LA's freeways, no dramatic progress was made in 2017. For the supply chain cars remain very important. At the industry's nascent scale, their relatively large (~100 kW) stacks mean that cars account for much of the growth in megawatts of fuel cell shipments for each of the past three years. Toyota Mirai 2017 sales alone are equivalent to one and a half times 2014's industry-wide MW shipments, and four times the PEMFC shipments.

The Mirai continues to pace the field. It is estimated that Toyota will sell approximately 2,300 this year. While production is believed to have been close to the stated 3,000 vehicle target, delays in the rollout of hydrogen infrastructure have reportedly slowed sales. Toyota also remains bullish on FCEVs, reiterating its plans for sales of around 30,000/year for the next-generation stack (2020 timeframe) and 300,000/year for the following generation (2025 timeframe), when fuel cell powertrain costs should match those of gasoline hybrids. Next up is Honda, projected to sell approximately 600 Clarity FCX sedans this year¹, three-quarters in California, and with a long line of eager customers. Honda and General Motors' joint-venture fuel cell factory is expected to begin production in the 2020 timeframe. Target production volumes have yet to be published, but thousands of units would probably be required to make commercial sense, and would be consistent with competitor announcements. Between them, Toyota and Honda are responsible for more than half of the 500 MW of PEMFC shipments in 2017, which should in turn be helping the supply chain, for example Toray and W.L. Gore, whose components are used in both vehicles.

Hyundai's pace has slowed somewhat, though it is expected to sell approximately 250 Tucson ix35s this year, and maybe reach 1,000 in total. The company may be holding back slightly, as it will premiere its second-generation fuel cell SUV at the Consumer Electronics Show in January 2018. The car is expected to feature in the PyeongChang Olympics in February, alongside a fuel cell bus Hyundai should soon unveil. The new SUV has an impressive specification – efficiency is up from 55% to 60%, and range to 800 km on the (old) New European Driving Cycle. Durability

is said to be better, and the car can start from -30°C. The three equally-sized hydrogen tanks mitigate some of the packaging challenges of large cylinders. Production is slated to begin in the first half of 2018 at an annualised rate of 4,000 units, so if all remains equal Hyundai will surpass Toyota's FCEV sales levels in 2019, until Toyota ramps up for its targeted 30,000 annual production in 2020-2021.

Daimler has long promised fuel cell cars, and finally the Mercedes Benz GLC F-CELL debuted at the Frankfurt Motor Show in September. But limited rollout – several hundred per year perhaps – is expected only in early 2018. Stack power has not been disclosed, but previous vehicles have had 90 kW stacks, which could combine with the battery to power the 147 kW motor. The battery, 13.8 kWh lithium ion, is paired with 4kg hydrogen capacity, for a range of perhaps 500 km. The idea is sensible – having both battery charging and hydrogen fuelling options enables true zero emissions permanently, and with infrastructure flexibility that should help both users – initially fleet customers – and infrastructure providers. The trade-off is a heavy and probably more expensive vehicle than some competitors, with less impressive performance. Daimler's AFCC partner Ford has been silent on fuel cells, though an unmarked and unannounced hydrogen version of a Ford Fusion was spotted in the wild in Berlin late in 2016.



¹<http://www.ev-volumes.com/>

The automotive fuel cell sector is likely to face some shocks in the coming years. June's announcement by Government-supported cell platform development agreement with Daimler and Ford (joint owners of AFCC), BMW (collaborating with Toyota) and Volkswagen (working with Ballard), among other consortium partners, was intriguing and surprising. While development agreements do not guarantee follow-on contracts, a shared platform could be compelling for the Big Three German auto OEMs, though it throws into question the future of AFCC, and whether fuel cells will figure much in BMW's Toyota agreement. Powercell's ties with electrolysis and infrastructure provider Nel and composites manufacturer Hexagon, through their joint venture Hyon Energy Systems, add further options, giving prospective clients a single point of contact for several parts of the hydrogen and fuel cell value chain. The challenge for their stack development, however, may be to maintain a coherent and efficient path through the trade-offs and design priorities required by so many different participants.

Riversimple continues its alternative journey. It raised over £1m in crowdfunding and launched an appeal for beta-testers in July. 750 people signed up, and the first vehicle is scheduled to be running in January 2018, with 20 on the road by June. Microcab is also building vehicles, with its first left-hand drive versions sent to Germany in April, and a plug-in fuel cell vehicle showcased in the UK in September.

Progress in China is increasingly important. November's 2nd International Fuel Cell Vehicle Congress was well attended, with the impressive international roll-call demonstrating how seriously it was being taken. SAIC recently debuted its FCV80 fuel cell passenger van – it also has a fuel cell version of its Roewe E950 – and Great Wall has announced plans to release FCEVs in 2022. But all of China's automotive companies seem to be building fuel cell capabilities and fuel cell teams – the weekly contacts many in the industry receive from Chinese headhunters bear further witness to the strength of the desire, as does the Dewei move in Germany discussed above.

Late in 2017, Weichai Power, a diesel commercial vehicles specialist, signed an agreement with Robert Bosch GmbH to develop and market FCEVs and related technology in China.

The supply chain is reacting. Already-established players, including Freudenberg and SGL, are being joined by companies such as Faurecia. And other companies, such as Elring Klinger, are developing strong competencies in metal-plate stacks. This may be interpreted as a signal – perhaps enough automotive volume is being discussed to be interesting?

Certainly a fresh round of analyses published in 2017 suggests the fuel cell vehicle future is a realistic prospect. KPMG's survey of automobile executives² showed that they believe infrastructure gives FCEVs an edge: "... 62% ... believe that BEVs will fail. In contrast, a full 78% of executives believe fuel cell electric vehicles will be the golden bullet of electric mobility ...". And a McKinsey and Company study for the Hydrogen Council³ concluded that BEVs may actually facilitate the uptake of FCEVs. "The relative strengths and weaknesses of these technologies ... suggest that they should play complementary roles."



² <https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2017/01/global-automotive-executive-survey-2017.pdf>

³ http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-Scaling-up_Hydrogen-Council_2017.compressed.pdf

Another bus will be along soon

The momentum behind Fuel Cell Electric Bus (FCEB) deployment continues. Every region with FCEBs has seen additions to the fleet, and anticipated deployments are piling up. The buses are liked by operators and the general public, and the increasing number of cities seeking zero emissions urban transport is helping the case for full commercial fleets, and not just projects.

Most FCEBs are true zero emission vehicles. Usually hybrids, they use (typically PEM) fuel cells plus batteries or supercapacitors and electric motor drives. Hydrogen is stored in pressurised tanks, usually at 35MPa, though 70MPa vehicles are becoming available. But some buses in China are using methanol as the fuel, reformed on board to hydrogen, and these do have low levels of emissions.

The buses are performing extremely well: they are more flexible than battery buses in terms of route, and can be fuelled faster – useful in busy cities when the only downtime is between 1 and 4am. The fuel cells are proving highly reliable; the stack in one London FCEB this year surpassed 25,000 hours of operation without any parts replacement. Costs remain higher than for diesels, though mass procurement is starting to bear fruit, and capital costs are dropping significantly. And although FCEBs demonstrate higher fuel efficiencies than diesel buses, failure rates are still higher for the less mature technology.



Europe

While the first fuel cell buses were demonstrated in service in the US, Europe has led the rollout of FCEBs, in publicly-supported demonstrations and now in pre-commercial deployment. The FCH JU has supported five major projects: CHIC, HighVLocity, Hytransit, 3Emotion and JIVE, and a sixth, JIVE 2, is in negotiation. Project emphasis has shifted from technology proof of concept to operating larger numbers and lowering capital costs through larger orders. JIVE (Joint Initiative for hydrogen Vehicles across Europe) was launched in January, and represents a step change in FCEB deployment: 142 FCEBs, in fleets of 10-30 buses, in nine cities across Italy, the UK, Germany, Latvia and Denmark. The project will provide experience with fuelling, operating and maintaining large numbers of vehicles. An aligned 'Connecting Europe' project, Merhlin, is focused on deploying the HRS.

A planned follow-on, JIVE2, has the even more ambitious objective of deploying 152 FCEBs at a capital cost of €625,000 each. The capital cost reduction is significant: the early CHIC vehicles cost €1.2m-1.6m. These are single-deck buses with the typical amenities of a modern fleet, such as easy accessibility. A fuel cell double-decker is also in development for London, with the first one showcased back in November 2016.

Regional transport authorities are also accessing national funds. In Germany, Regionalverkehr Köln was awarded €7.4m to purchase 30 FCEBs and two HRS. This fleet, expected to be in service in 2019, will join approximately 65 buses expected to be operating in Europe by the end of 2017, including four in the 3Emotion project in London and Rotterdam (another 17 will come in 2018-19, also to Rome, Versailles, Aalborg and Pau) and a further five in national projects in Benelux and Germany. Van Hool, WrightBus, Solaris, Daimler (Evobus) and APTS/Phileas are involved, and other European OEMs such as VDL, Rampini and Alexander Dennis are also working on FCEBs. Ballard and Hydrogenics will be the primary fuel cell suppliers, although Horizon Fuel Cells has supplied a fuel cell range extender bus development in Holthausen, Netherlands.

These buses will drive European deployment closer to the 400 target for 2020 envisaged by the Fuel Cell Bus Coalition, a liaison body between the different cities and projects.

National and regional efforts to reduce or eliminate diesel use will sweeten the FCEB opportunity in Europe. Paris, Madrid and Athens have announced that diesel buses will be phased out by 2025, and cities such as Hamburg and London are even bolder. Hamburg will only purchase zero emission (ZE) buses from 2020 onwards, the Netherlands says 2025, while London's new single deck vehicles will be ZE from 2020 and double deck vehicles from 2025 – the whole fleet will be ZE by 2037. Battery buses will fulfil some requirements for many cities, but fuel cells will be needed too.

With thousands of potential sales to come, the capital costs of FCEBs should fall still further from the €625,000 target of JIVE2. A Scandinavian Fuel Cell bus project, Hydrogen Valley, indicated that an order exceeding 100 buses could result in a capital cost per bus of €450,000. Such reductions would make FCEBs directly competitive with diesels, hybrids and battery buses. We have seen similar projections before of the impact of volume on price and it appears this will finally be tested.

USA

The USA has a long history of bus demonstrations, many in California, but numbers have never been high. The US Federal Transit Agency has funded a Fuel Cell Bus Program since 2006, and including other sources such as the LoNo Program, \$180 m of funding is estimated to date. And the newly-formed Fuel Cell Electric Bus Commercialisation

Consortium is also promoting deployments, supported by the California Air Resources Board.

In 2017, 26 FCEBs were reported to be operating in four locations across the USA, 19 in California and five in Ohio, where SARTA (Stark Area Rapid Transit Authority) plans to establish the largest FCEB fleet outside of California. Massachusetts Bay Area Transportation Authority celebrated its first FCEB and HRS in summer 2017; one bus is operating in Michigan.

There are at least 41 buses in the planning stages, 33 in California, 7 in Ohio and one in Illinois. Prices remain high; SARTA's latest additions to the fleet cost US\$1.4m each, down from US\$2.5m but still much higher than Europe's stated prices.

US cities are looking to eliminate emissions from their public transit fleets – the mayor of Los Angeles, for example, set an objective of 2030 for an emissions-free fleet. This and other local government activism on climate may increase the opportunity for FCEBs in the US, though to date there has been little evidence of a willingness to pay a substantial premium for lower emissions.

China

As we noted last year, China's fuel cell bus ambitions are big. Hundreds, and then thousands of buses were planned for 2017 onwards, and the supply chain has been readying itself to cope. Once again Ballard and Hydrogenics are benefiting. Ballard has significant agreements and investments from Chinese businesses, most notably Broad Ocean, to licence and manufacture some parts of its technology for fuel cell vehicles in China. Broad Ocean in turn supplies China's top



conventional and electric bus OEMs, Foton and Zhongtong bus. In 2017 Ballard's stack JV with Synergy began manufacturing FCvelocity 9SSL stacks in Yunfu, Guangdong province, and Ballard concluded two agreements totalling US\$29m for 600 fuel cell modules with Broad Ocean; whilst also signing up to a US\$25m technology transfer, licence and supply agreement for 30 kW and 85 kW fuel cell modules. Ballard will also provide ten 30 kW FCvelocity systems to Yinlong Bus.

Hydrogenics is not far behind. In December 2016 it announced a US\$4m order from a Chinese integration partner for bus fuel cell modules and technology. And in summer 2017 a purchase and licensing agreement was signed with Blue-G New Energy Science and Technology Corporation for the technology and supply of 1,000 fuel cell modules for FCEBs, over a ten-year period, of which 200 may be operating in Beijing by the end of 2017.

Indigenous businesses are also developing their own fuel cell systems for buses. Re-Fire of Shanghai is working on a series of systems, the Caven 3, 4 and 7, of 30 kW, 42 kW and 72 kW power outputs, designed for FCEBs of 6.9m to 12m.

It is uncertain when all of these trucks and buses, typically equipped with 30kW fuel cells, will actually start day-to-day operation. But while reports suggest that regulatory hurdles and the slow build-up of hydrogen refuelling stations are delaying vehicle roll-out, Chinese enterprises keep building vehicles. Fuel cell companies, power train integrators and OEMs have formed partnerships with established overseas fuel cell technology providers, and further substantial MEA, stack and module shipments during 2017 have laid the base for rapid growth throughout 2018, when several of the newly built local system integration lines should increase their output. While efforts are underway to manufacture and source MEAs locally in China, it will take time to reduce the need for imported technology.

Other Asian bus ambitions

Surprisingly, given broad support for hydrogen in Japan and Korea, few FCEBs have been deployed. Hyundai has published plans for a 200 kW fuel cell battery hybrid bus, using 700 bar hydrogen tanks, a departure from previous designs which featured supercapacitors and 350 bar tanks. The first buses are expected to be in operation for the Pyongchang Winter Olympics in 2018. Also with the Olympics in mind, but this time the 2020 Tokyo summer games, Toyota delivered its first two FCEBs to Tokyo Metropolitan Government in February and March 2017. These are the precursors to 100 of Toyota's SORA vehicles which will be in service by summer 2020. These 10.5m buses use a hybrid configuration based on Toyota's Mirai fuel cell system: two 114 kW fuel cell units and a nickel metal hydride battery. A brief trial was run this summer at Kansai airport using an Itawani HRS.

India also has FCEB ambitions. TATA Motors, which alongside Ashok-Leyland supplies most of India's conventional diesel bus fleet, reported that it would build a fuel cell variant of its 12m StarBus, developed in conjunction with India's Space Research Organisation.

Light and heavy trucks

Goods vehicles require reliable drivetrains with long lifetimes, and easily available refuelling stations. Fuel cells have been considered for this sector before, but only recently has it really emerged as a strong opportunity, largely because emissions from heavy-duty transport need reducing, while the demand for commercial vehicles is set to increase. The US Department of Transportation projects a US freight volume increase of 45% by 2040, a trend that will be reflected in many areas of the world as globalisation and movement of goods continue to expand. Reducing emissions while maintaining growth means new technologies, and while Daimler and Tesla talk about all-electric trucks, Tesla's claims are not achievable with current batteries or chargers. Fuel cells and hydrogen could give noticeably better range, refuelling times and payload.

location in Southern Michigan' – though the YouTube video shows a Ricardo-branded tool bench in the foreground.

The effort in the Ports of Los Angeles and Long Beach reflects the priority the State of California has put on reducing emissions from goods movement. California has launched a US\$1 billion Goods Movement Emission Reduction Program and published a Sustainable Freight Action Plan. A string of five hydrogen stations is envisioned along the heavily-used Interstate 710 highway which links the ports with the rest of the country. The US DoE is supporting demonstrations of a variety of medium duty vehicles, including 15 airport ground support vehicles, 20 Federal Express delivery vans, 21 Nissan NV200 vans and two power modules for heavy truck refrigeration units, though most demonstrations are due to wind down in 2018.



Nikola Motor, an upstart fuel cell truck developer, partnered with Bosch in 2017, and at the end of the year augmented that partnership by announcing a tie-up with PowerCell to provide 300 kW stacks; commercialisation is claimed for 2021. A la Tesla Model 3, Nikola took reservations for its Nikola One cab, asking for a refundable \$1,500. Nikola also partnered with Norway's Nel on a planned 16 station fuelling network covering 2,000 miles.

Fuel cell vehicle research programmes underway in California's San Pedro Bay ports are an important part of activity in this application: US Hybrid, in partnership with Dewei, produced two vehicles that will be demonstrated by TTSL, a national drayage company. Ballard Power Systems will supply Kenworth Truck Company with 85 kW fuel cell engines to power 8 drayage trucks in a two year demonstration programme. And Toyota is trialling its modified Kenworth extended-length chassis heavy duty HFC vehicle on pilot routes in these ports. Two Mirai fuel cell stacks and a 12 kWh battery have replaced the conventional 10.8 litre diesel engine, in what was apparently a three-month conversion in 'an undisclosed

Switzerland's Co-op supermarket chain has continued to operate its 34-tonne truck prototype, also using a PowerCell stack. Co-op plans to add more trucks to its fleet, replacing most of its current 34-tonne fleet with HFC vehicles by 2023, and at the same time supporting hydrogen refuelling infrastructure expansion in Switzerland, with a target of ten trucks per refuelling station. Switzerland has two public refuelling stations at the moment. Hydrogenics systems will be integrated into four Scania trucks for Norwegian grocery wholesaler ASKO, with the first expected to be operating at the end of 2018. ASKO's transition to HFC trucks is complemented by its strategy to replace its

current forklift fleet with fuel cell lifts, partly to benefit from the shared refuelling infrastructure. Other supermarkets are considering similar moves.

Vancouver-based Loop Energy is demonstrating a fuel cell range extender system in a prototype yard truck in partnership with China National Heavy-Duty Truck Company.



Meanwhile Toyota has confirmed a deal with Seven-Eleven Japan for HFC trucks based on Toyota's Hino refrigerated vehicle platform. These smaller Hino trucks complement the Kenworth conversion Toyota is trialling in Long Beach; testing is expected to start in 2019. A fuel cell version of its Tundra work pickup is also circulating, though rarely mentioned.

Deutsche Post is also looking to FC delivery vehicles, as their current battery vehicles do not fulfil all of their range and route requirements. Its subsidiary electric vehicle provider Streetscooter will integrate fuel cells into 500 vehicles as a trial from 2018. The fuel cell provider is not yet public.



Symbio FCell is fulfilling a large range-extender Kangoo order, but has plans to make a more heavy duty van commercially available in 2018, based on the Renault Master ZE. Supply chain player Magna is showcasing capability by building a range-extender van with Proton Motor stacks, and Plug Power is integrating systems into Chinese delivery vans. Also in China, SAIC has developed a fuel cell version of its V80 van, and Horizon is developing a 7.5t truck platform, linked with its planned release of 30 kW and 60 kW metal-plate stacks in 2018, to be built in its Rugao automotive plant, currently under construction.

Hydrogen refuelling stations

The pace of construction of hydrogen infrastructure quickened worldwide in 2017, though it remains tough to get them built on time. Governments and private sector consortia are implementing plans for what will be several hundred stations worldwide in the next three to five years. In Europe the station network is slowly extending east and south from its core in the north and the UK should add further stations through a recent government funding programme. In the US, California's deep subsidy programme for the installation and operation of stations continues, although the State reckons it will fall short of its goal of 100 stations by 2020. Ground was broken for two stations in the Northeast US, though Toyota's goal of 100

in that region by 2020 appears ambitious. In Japan, the goal of 160 stations by 2020 is in sight. And Korea's plan calls for expanding the current station total of 12 to 100 by 2020 to support 10,000 cars.

Perhaps most encouraging, two private sector consortia are now taking leading roles in station deployment, in Germany H2Mobility continues, and in Japan Toyota, Nissan and Honda have signed up along with the major gas and energy suppliers – in total 11 companies have joined. It has been reported that both Japan Oil (40 stations) and Iwatani (20) are considering bringing their stations under the consortium umbrella, which would have advantages in standardisation and data sharing. And Shell, which has been out

of the US market, has re-entered in California. Without private sector money and profit motive, it is hard to see an adequate infrastructure developing.

Honda's distributed approach

Honda has developed a new version of the Smart Hydrogen fuelling station that it plans to install across Japan beginning in 2018. Working with local governments, Honda plans to have around 100 of the new stations built by 2020, up from 15 today. The significance lies in the fact that these stations generate renewable hydrogen on site; they are small, quiet, relatively cheap (in part because they have no mechanical compressor), and easily installed – but the total hydrogen available daily is small.

Hydrogen Refuelling Experience

There are plenty of projections, but real world experience is beginning to confirm the potential scale of the hydrogen fuel market. In California alone, with fewer than 3,000 FCEVs registered, True Zero, which operates most of the fuelling stations, reported sales of 250,000 kilogrammes of hydrogen in less than 18 months, supporting 17 million vehicle miles. If one assumes the overall experience in California is consistent, the California fuelling network dispensed 430,000 kilogrammes in fewer than 18 months, about \$4.3 million in fuel sales assuming \$10 per kilogramme.

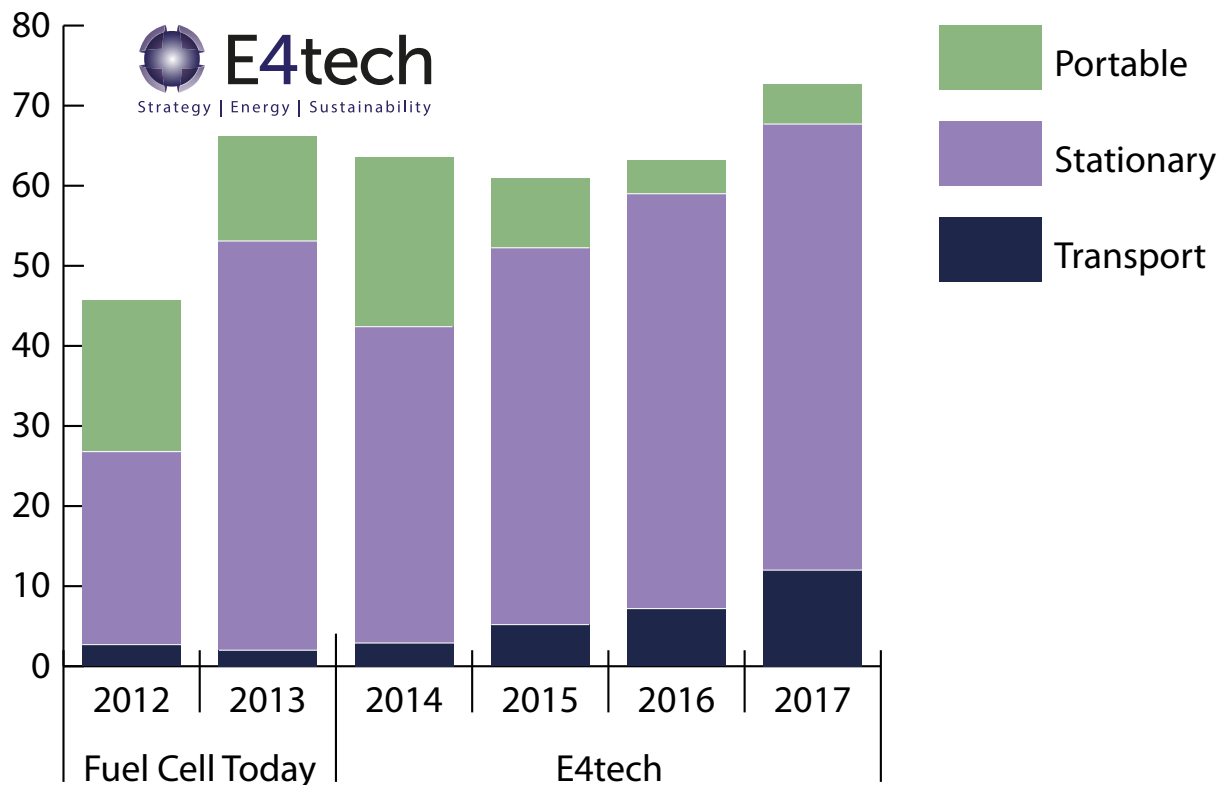
The California Air Resources Board, relying on surveys of manufacturers, projects 37,400 vehicles on the road in 2023 (approximately 2,800 FCEVs are expected to be registered in California by the end of 2017). The survey is annual, and this appears to represent a one-year delay in anticipated vehicle deployments. "At least some portion of the observed delays in hydrogen fuelling station deployment are due to obstacles that developers in general would face, regardless of the nature of the project." California's designated single point of contact for station development keeps a running list, including "I never have liked the look that station, can you make it look better? Come back with a design proposal in 60 days"; and "It turns out, we don't allow unattended fuelling in our town." That single point of contact nevertheless gives California the chance to share learning, reducing the likelihood of such problems going forward.

Hydrogen demand is greater at the moment in the lift truck segment. For the claimed 20,000 trucks on the road and with reasonable assumptions about availability, operation and fuelling needs, the current hydrogen demand is about 36,000 kg per day, worth nearly US\$135 million at US\$10 per kg. These numbers represent only a small percentage of worldwide hydrogen sales, or vehicle and gasoline sales for that matter – a reflection of the enormous size of the transportation and transport energy market. And lift trucks currently consume a great deal more hydrogen than passenger vehicles, given their duty cycle and deployment numbers. Nevertheless, companies like True Zero are finding niches, and maybe some prospect of profits.

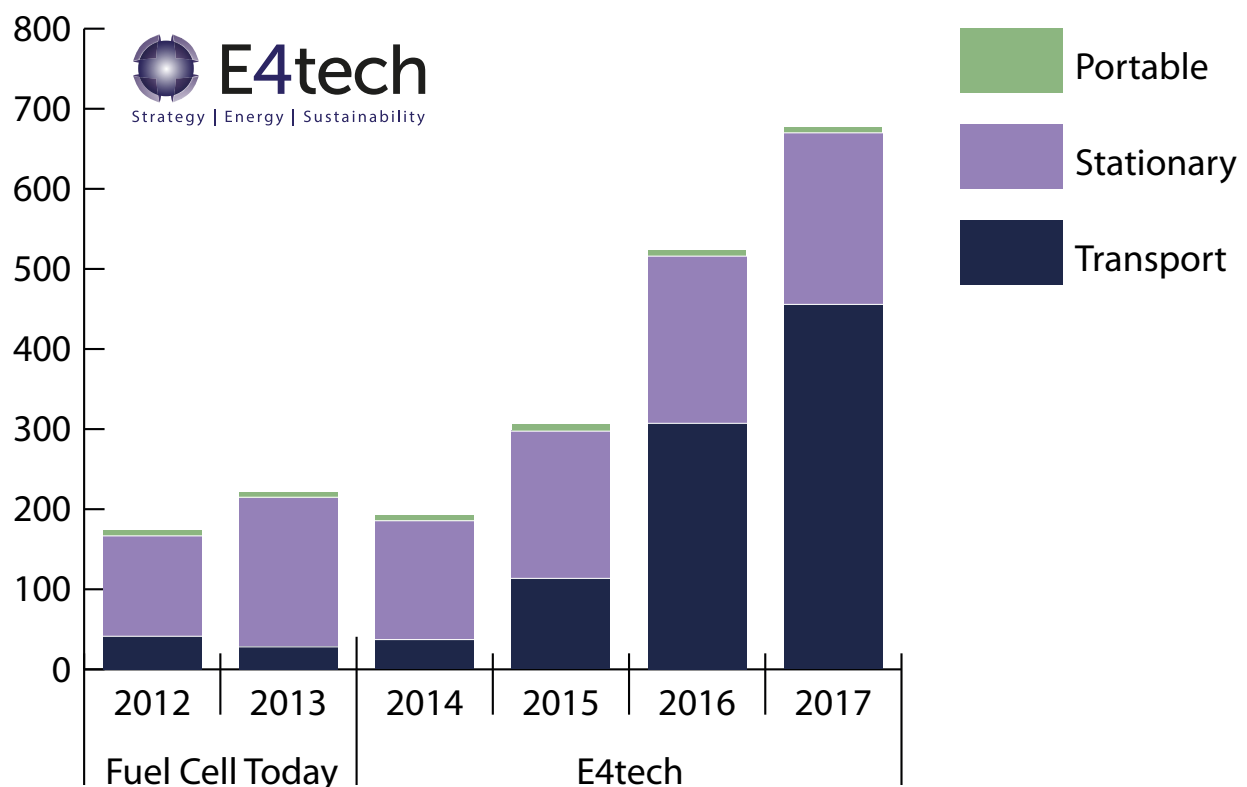


Shipments by application

Shipments by application 2012 - 2017 (1,000 units)



Megawatts by application 2012 - 2017



Footnote to charts: Data from 2012-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2017 is our forecast for the full year, based on firm data from January to October. We have slightly revised the figures for 2016 in this report.

Shipments by application

Splitting the fuel cell shipments by application shows the increasing dominance of transport – Toyota, Honda and Hyundai together still have more than 50% of the 455 MW shipped, and their 3,000 or so vehicles account for nearly 350 MW of the total. Toyota remains the largest individual supplier of fuel cells. Transport MW are up nearly 70% over 2016. But signs of things to come can be seen in the shrinkage of the OEMs' cumulative share, as activity in China ramps up, notably for vehicles with 30 kW power plants. These are a 'sweet spot' for government support.



Buses remain a smaller contributor than light duty, but shipments leapt because of China's efforts. China's trucks were up too, and together account for about 2,500 vehicles, dominating the two categories. In total nearly 80 MW of truck and bus power was shipped globally. And nearly 6,000 materials handling vehicles were put in service worldwide, 40% more than 2016 and half of the overall vehicle total.

Overall, stationary units shipped were up slightly, from about 52,000 to roughly 56,000 units, about 50,000 of which were in Japan. But all stationary units together contributed 214 MW of power, very close to 2016 figures. Because stationary power

has not grown as transport has, its contribution is proportionally even smaller than in 2016, and noticeably smaller than the shipments of just the automotive OEMs combined.

In utility scale power generation, the impact of Doosan's new factory broadly compensates for lower numbers from FCE. Overall about as much large (100 kW+) stationary power was installed as in 2016, at just more than 160 MW. In the smaller stationary category, the number of Ene-farm units installed is expected to be moderately greater in calendar year 2017 than 2016, and will contribute more than 35 MW to the installed base.

A much smaller effort so far, the other major deployment in the small stationary sector was in Germany, where the KfW433 programme is expected to support 1,500 units of between 0.25 and 1.5 kW in 2017. Small- and medium-scale commercial CHP, of several kW to 100 kW units, has not contributed much in 2017, though activity is growing, and where an uptick in shipments is expected in Japan in 2018.

Only around 20 companies are shipping grid- and off-grid backup stationary power units, and some ship very few. Total power installed was nevertheless still below 10 MW. In the portable segment about 25% more APUs were shipped in 2017, but they were bigger units on average so the power contributed nearly doubled. While most units are hydrogen-fuelled, a number operate on propane or methanol, typically via a reformer. Only MyFC shipped a substantial number of consumer electronics units (of a few watts only): 1,000 of their JAQ product were delivered to Telling in China as part one of a multi-phase agreement. But if they manage to ship some or all of the 400,000 Phase 2 units to China before year-end, as originally planned, then numbers will be up sharply. We will revise them in future editions.

Trains and trams

Fuel cells have been considered for trains at least since the 1980s, but technology readiness and a reluctance on the part of rail operators to switch to gaseous fuels have hindered commercialisation. Many in the industry believed they would only become relevant after cars, buses and trucks were deployed in numbers.

But the steady pace of development – and somewhat unexpectedly good performance, recently shown – of heavy duty fuel cell modules has enabled companies to start deploying fuel cells in rail applications. Ballard cites one of its older bus modules, still in use in London after 25,000hrs of revenue operation, as an example of the longevity that can already be achieved in certain duty cycles. In principle, the relatively limited dynamic cycling and long periods of fairly steady power draw on trains will allow long lifetimes too – essential, as typical trains are in use for about 30 years. At the same time the decarbonisation of train services, coupled with increasing urban air quality concerns, has risen in importance, and the cost-effective procurement of hydrogen (even from renewables) looks increasingly plausible, but the 30-year life means that installation of future low-carbon options should start now.



Electrification of rail using overhead cables can assist in achieving both decarbonisation and low pollutant emissions, but is expensive, disruptive and very time-consuming. If a diesel locomotive can 'simply' be switched for a fuel cell one then the costs may be dramatically lower, as long as the train is reliable and performs at least as well as the diesel. In fact performance can be better –

electric trains accelerate and decelerate faster, so journey times are shorter, and use of rolling stock can be better optimised.

There is also a fuel saving, since the typical rail duty cycle includes long periods at a very inefficient idle. Analysis in Germany suggested that for regional rail the cost-benefit equation was in the favour of fuel cells. Alstom started building trains using Hydrogenics fuel cell systems – calculations suggest 2 x 200 kW units in each train car – and unveiled the Coradia iLint in 2016, with the first test run in March 2017 and safety testing ongoing. Full trial operation is expected in early 2018 in Lower Saxony, in Germany, where operator LNVG has signed an order for 14 trains, with an option on 33 more. The 14 are anticipated to be in full service at the end of 2021. Hydrogenics would supply all of those modules and has an overarching agreement for 'at least 200 engine systems' worth €50m over ten years. Other German states have signed letters of intent for orders, with options on 14 for North Rhine Westphalia, 20 for Hesse and 10 (and possibly 5 more) for Baden Wuerttemberg, all within the same timeframe.

On Hydrogenics' home turf in Canada, Metrolinx, the government agency for transport in the greater Toronto area, has already conducted assessments on electrifying its whole rail network. However, given the cost and disruption that would be caused by the large amount of new infrastructure and the modification of current infrastructure, fuel cells are also being considered. Metrolinx has requested proposals for concept designs from manufacturers, including Alstom, and Hydrogenics will support during the design phase. Metrolinx hosted a full-day symposium on the subject in November to gather expert and public opinion.

The UK has also shown some interest in hydrogen-fuelled rail, hoping to maintain its clean growth strategy despite scaling back full electrification plans for rail. Alstom's success in Germany has prompted the UK government to engage in talks with them over a possible fuel cell demonstration project on a refurbished Liverpool to Chester line. This proposal is strengthened by the possibility of sourcing hydrogen from refineries local to the area.

Ballard is also benefitting from the interest in rail, most recently through an agreement with Siemens Mobility Division to develop a 200 kW fuel cell suitable for powering its Mireo electric multiple-units, a competitor to Alstom's Coradia Continental. 2021 should see the first deployment of a fuel cell powered unit. Ballard also has an MoU with Latvian Railways for the refurbishment of three fuel cell shunt locomotives, to be delivered through 2019, and has participated in projects in the US and Japan, as well as powering small underground mining locomotives in S Africa.

Shunt locomotives are particularly well suited to FC application as they are usually confined to the rail yard and do not require a network of refuelling stations.

They also are often simply retired, inefficient, heavily polluting older locomotives. Typically used for moving loads over small distances, their emissions can become concentrated in the local area. Using FCs eliminates these emissions and may also increase operating efficiency over such short distances.

Interestingly, Siemens and Alstom have signed an MoU to merge Siemens' Mobility business into Alstom, in part to provide the strength to compete against Chinese giant CRRC, which is starting to enter markets outside China. Even with regulatory approval, the deal will not be closed before the end of 2018. Until it is done, the businesses remain separate and competitive. The ultimate impact of a merger on the supply of fuel cell modules or train units is thus some time off.

Indian Railways also has fuel cell plans, looking to build a hydrogen fuel cell and battery powered 300 kW broad-gauge locomotive. Diesel Locomotive Works in Varanasi has invited tenders for two shunt locomotive systems, each using a maximum of three 100 kW-plus air-cooled stack modules.

In addition, the 'world's first' FC tram began commercial operation in October for CRRC Tangshan Rail, in Tangshan, China. The 200 kW fuel cell system comes from Ballard, which has a further deal with CSR Sifang to provide 8 similar FC trams to the city of Foshan. As in regional rail, the technology allows for a clean, long range tram network without the need for electrification infrastructure. China is currently the only country to be installing HFC trams, though Ballard FCs will go into the 8 tram-buses made by Van Hool and expected to begin operation in 2019 in Pau, France.



Materials handling

Forklifts remain the most successful fuel cell vehicle to date – with around 20,000 deployed, almost exclusively in North America.

Plug Power continues to dominate equipment supply, with a claimed market share of over 95%, and they maintained leadership in 2017, making deals worth up to US\$600 million with both Amazon and Walmart, to expand the number of warehouses running on fuel cell forklifts. Ten Walmart and 11 Amazon warehouses are expected to make the transition from lead acid battery to fuel cell this year. The deals involve Plug warrants that could offer Amazon, for example, over 20% ownership in the company.

Plug is succeeding in selling its GenKey hydrogen fuelling stations alongside its fuel cells. For Walmart alone it will add fuelling stations at up to 30 additional sites in North America over the next three years; 10 by the end of this year.

Hyster-Yale's Nuvera continues its own forklift development; in 2017 47 units had been shipped by October, compared to 39 reported shipments

in 2016 – also mainly in North America. The Hyster brand is developing electric versions of its Big Truck line, which will allow them also to use fuel cells in the future. Historically, the US has had the right ingredients for success, with large warehouses allowing the costly hydrogen refuelling infrastructure to be amortised over many forklifts, three-shift operation, and strong financial backing from the Federal Investment Tax Credits.



Since the credits expired at the end of 2016, the continued sales in the industry are therefore down at least in part to real economic benefits, though observers suggest that the Amazon and

Wal-Mart deals were structured in a way that allowed the equivalent of the tax credit to flow to the buyers, helping the economics. With luck, some of the cash will flow to Plug's bottom line, which (like all fuel cell companies) continues to show red.

There has been some expansion into other regional markets; Plug has a deal with Toyota Material Handling Norway to supply fuel cell forklifts to the warehouses of the Norwegian grocer ASKO. The company has new or extended contracts with Carrefour, Colruyt, Prelocenter, BMW, Daimler and Honda UK. Belgian supermarket company Colruyt plans to expand a fleet of 75 fuel cell forklifts currently in operation, interlinked with its onsite renewable power strategy to produce the hydrogen from low-carbon sources. Fronius (Austria) has also continued with fuel cell systems for forklift applications in the European market.

Other regions show less activity, though Toyota continues to put fuel cells into its own forklift fleet, with 2 units this year at its Motomachi plant, and 20 planned for next year, rising to 170-180 units by 2020. Further up the supply chain, Ballard should benefit too, with a projected 20-40% increase in their revenues from material handling in 2017 over 2016. A chunk of this came from a contract with Walmart Canada to supply 95 fuel cells for electric lift trucks at its sustainable refrigerated distribution centre in Alberta. The deal highlights the benefits of fuel cell technologies compared to battery operated forklifts in cold environments. This attribute is being marketed to increase uptake in regions outside the US, where support for the replacement of battery operated forklifts with fuel cells is historically lower.

Marine

Fuel cells may even play a role in the decarbonisation of the marine sector, which is under increasing regulatory pressure; batteries alone become infeasible as vehicles become larger and travel farther. Fuel cells are being used as auxiliary or complementary power sources in at least a dozen projects.

At the larger end of the scale, Norwegian operator Viking Cruises announced its interest in September to build a liquid hydrogen-fuelled zero-emissions fuel cell-powered cruise ship, with Statoil selected as the hydrogen supplier. This strongly suggests they are focusing for now on a PEMFC solution, as the use of MCFC or SOFC stacks could allow them to use other fuels, such as LNG. LNG terminals are less expensive and significantly more widespread than liquid hydrogen infrastructure, but of course do not offer zero emissions, which may offer economic – or at least marketing – value.

With the cruise ship unlikely to berth more than twice a month at any port, storing the large amounts of liquid hydrogen required might be hard. Storage for multiple cruises' worth of liquid hydrogen might be needed to ensure continuity of supply, and opportunities may also develop for companies proposing to store hydrogen in the form of ammonia, or liquid organic hydrogen carriers (LOHCs). Backwards compatibility of the latter with existing refinery infrastructure could prove to be an advantage, though a typical LOHC stores less hydrogen by weight than ammonia.

America's Royal Caribbean Cruises has also announced tests of a Ballard 100 kW fuel cell system, chosen by ABB, on its Oasis-class ships in preparation for expected deployment with its LNG/distillate dual-fuel Icon class vessels in 2022 and 2024.

Norway also hosts the HYBRIDShip project, which aims to demonstrate a battery/fuel cell hybrid ferry by 2020, but will first assess the technical and regulatory requirements and test the fuel cell systems under marine conditions, before the ferry is built and put in operation. And another Norwegian demonstration involves the Osterøy car ferry between Valestrand and Breistein. One of the ferry's two diesel engines will be replaced by a 200 kW PEM fuel cell. Project involvement by Hexagon Composites hints at a possible Powercell fuel cell stack, given the two companies' Hyon joint venture.

In Germany a river tour boat, the "MS Innogy", uses 35 kW of Serenergy HT PEM and hydrogen from reformed methanol to recharge the on-board battery during the day. The 330-litre tank contains renewable methanol (Vulcanol™) produced by Icelandic company Carbon Recycling International, from water and CO₂ off-gas from a geothermal power plant. The river boat is complemented on land by two Nissan e-NV200 electric vans with Serenergy range extenders.



More ambitious – at least in terms of global coverage – are two autonomous boat concepts, using renewables, batteries, hydrogen and fuel cells. The Race For Water⁴ vessel is based on the world’s first solar round-the-world boat – Planet Solar – which has had hydrogen and fuel cell capability added. And the French Energy Observer⁵, also powered by renewables with H2 storage, batteries and PEM FCs, launched for a round-the-world voyage in August. Both are promoting awareness of environmental problems, including climate change and the appalling levels of plastic pollution in our oceans, as well as showcasing autonomous renewable hydrogen systems.

Various other water-based projects are under study. Sandia National Laboratories evaluated a 150-passenger fuel cell ferry concept for the US Department of Transportation in 2016 and revised it in 2017. “The project team found no major barriers to construction or operation, either for the vessel itself or the associated hydrogen fuelling operations.”

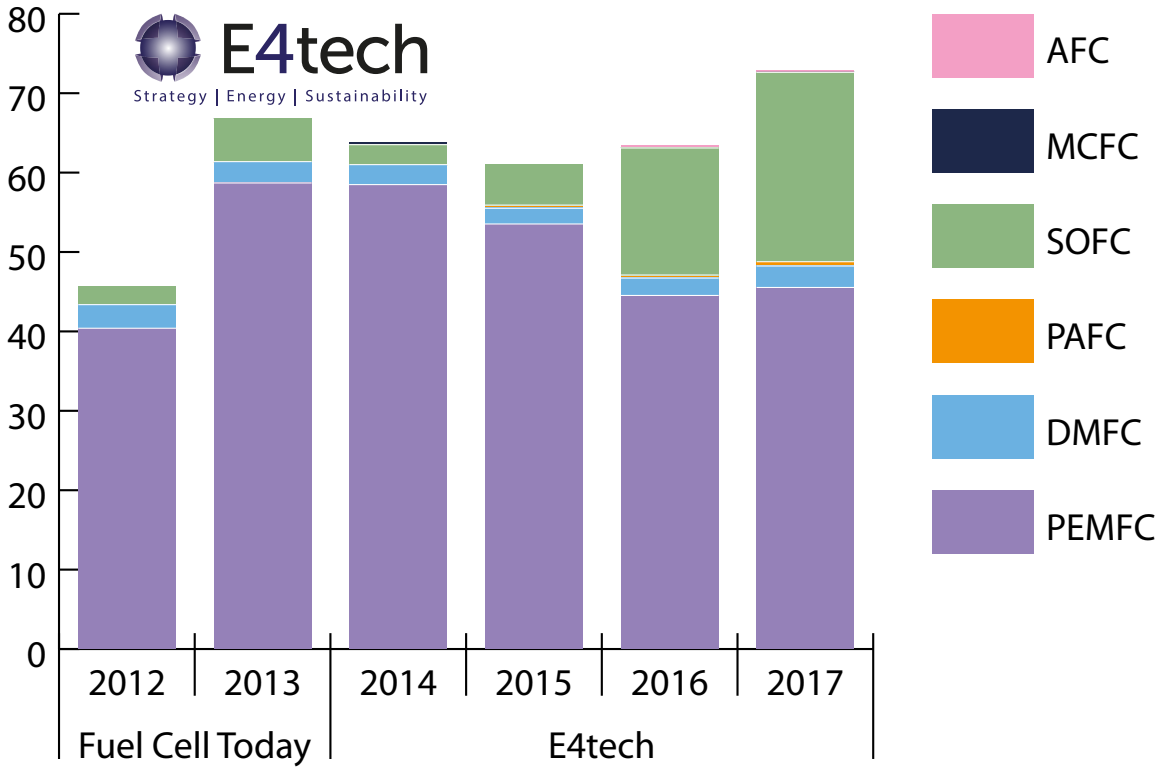


⁴ <http://www.raceforwater.com/>

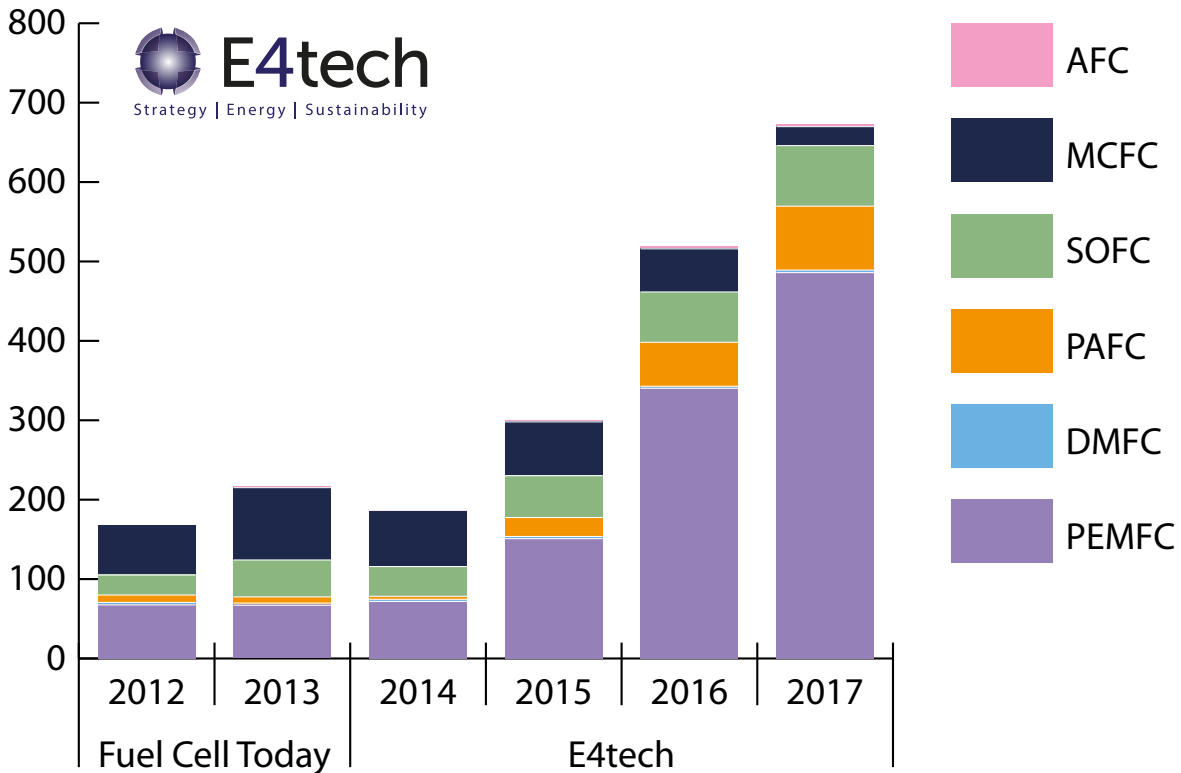
⁵ <http://www.energy-observer.org/en/>

Shipments by fuel cell type

Shipments by fuel cell type 2012 - 2017 (1,000 units)



Megawatts by fuel cell type 2012 - 2017



Footnote to charts: Data from 2012-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2017 is our forecast for the full year, based on firm data from January to October. We have slightly revised the figures for 2016 in this report.

Shipments by fuel cell type

Almost 490 MW of **PEM** fuel cell systems were shipped in 2017, further increasing their share of total industry megawatts, from roughly 65% in 2016 to nearly 75%. This does not include a substantial inventory of MEAs, stacks and modules, planned for integration into vehicles in 2018. In 2017, more than 90% of the PEM megawatts went into transport; the remainder was shared by stationary CHP, prime power, off-grid and back-up systems. About half of the 0.5 MW in the portable segment were PEM.

While total power rose as a result of shipments of relatively large transport fuel cells, the number of PEM systems shipped remained almost constant at about 45,000 units. The growth in transport was balanced by a decline in stationary units, as the balance in Japan's Ene-farm tipped further to SOFC. Aisin's SOFC product continues to increase its market share, aided by Toshiba halting its PEM sales. So while in 2015 less than 10% of Ene-farm units were SOFC, this grew to about 30% in 2016 and could reach more than 40% in the 2017 calendar year. PEM fuel cell systems with methanol reformers have been common for a long time in off-grid and back-up power applications, as well as for on-board APUs. These usually have a several kilowatt power rating. In 2017, some companies have shipped units as range extenders for delivery vehicles and even electric boats.

Direct Methanol Fuel Cells (**DMFC**), typically rated below 100 W, remain common in portable systems, including small on-board APUs in campervans, boats and lighting. A few companies remain active in this field, with SFC Energy clearly leading the segment.

The number of **SOFC** shipments grew by about 50% year on year, mainly due to Ene-farm, but also because of more CHP units in Europe and some in portable and UAV applications. Several SOFC manufacturers are in the process of entering the Japanese market with small commercial systems – a few kilowatts of electrical power. These units could contribute significantly to the totals in 2018. We estimate 76 MW of SOFC was shipped globally technology in 2017, mostly from Bloom Energy and deployed in the US for onsite power generation.



PAFC is currently only produced by two companies: Fuji Electric and Doosan. The latter opened a second factory in Korea in the middle of the year, which together with its US base helped PAFC shipments grow by 45% – to more than 80 MW in 2017. The main market for these systems remains utility scale power generation in Korea. However, Fuji Electric, together with its German branch Fuji N2telligence, is increasingly targeting a special market where their product acts as active fire prevention – by reducing available oxygen, and simultaneously generating power.

2017 has been a difficult year for **MCFC** technology. Posco's Korean factory appears to be almost idling, whilst in December 2016 FCE reported halving its manufacturing rate for its Torrington plant, to an equivalent 25 MW per annum, and in June 2017 that dropped further to 15 MW per annum. Estimated shipments of MCFC amount to 25 MW in 2017, though will very likely grow again in 2018 following the announcement of several potential projects in the US.

AFC technology was mainly deployed in smaller stationary systems for back-up power. Only AFC Energy and GenCell supply this technology, so final shipments in Q4 of 2017 could still visibly affect our numbers for the full year.

Stationary fuel cell systems

Markets for stationary power fuel cells are still uneven geographically, with the larger systems and smaller systems enjoying the most marketplace success. Market strength varies dramatically across the globe. Government support, both regulatory and financial, remains essential, though even in Japan and Korea where support is favourable, it has not been sufficient for some companies. And in the US, there were encouraging signs that the use of Power Purchase Agreements is opening some markets despite the lapse of installation tax credits.

Ene-Farm still rules the numbers

Ene-Farm is the world's largest fuel cell programme by a considerable distance. Ene-Farm residential CHP fuel cell sales are at similar levels to recent years – the 200,000th installed unit was announced with surprisingly muted fanfare in May, eight years after the first installation and public figures of 223,000 were released in October. We estimate total units shipped for calendar year 2017 will be at around 50,000, still subsidised by the national government. That subsidy has fallen steadily since 2009, and now stands at ¥300k per unit – bringing the price of the approximately 700 W units down from ¥1.5m (US\$13,300) to ¥1.2m (US\$10,600) for the purchaser.

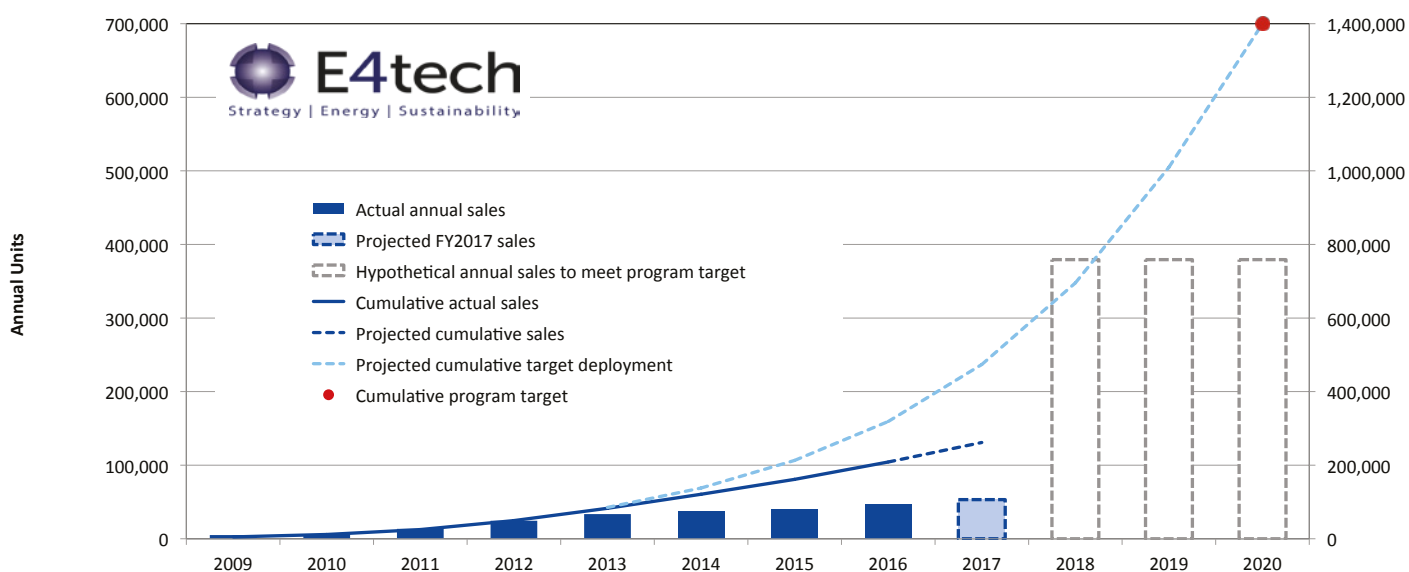
But even this hugely subsidised programme is tough. Panasonic, ENEOS Celltech and Toshiba were the launch manufacturers in 2009; all had marketing deals with Japanese regional gas companies. Aisin Seiki joined in 2016, but ENEOS

dropped out, and this year Toshiba also ceased to manufacture and install.

Toshiba's departure, announced in June, is thought to be a result of corporate financial problems related to its bankrupt nuclear reactor business, rather than related to the fuel cell market itself, though the latter is certainly not yet making profits. Toshiba will continue to support an estimated 80,000 units now in operation – and in fact will also continue to pursue its 'pure hydrogen fuel cell technology' at both the commercial scale and the residential scale as part of Toshiba Energy Systems and Solutions. We comment elsewhere in this report on resurgent interest in hydrogen.

Progress continues on the technical front. Panasonic's most recent 5th generation system achieves durability of 90,000hrs, up from 70,000, with weight down by 12kg to 65kg. In parallel, it is working on a 5kW pure hydrogen system.

Japan's targets for residential micro-CHP fuel cell systems are high: 1.4m units installed by 2020, rising to 5.3m units by 2030. While the installations have been more or less on track against official targets to date, the targets could only be achieved with dramatic sales growth, as illustrated below.



While prices are slated to fall to ¥800k for PEM units by 2019, and to ¥1,000k for SOFC units by 2021, achieving 1.4m units by the end of 2020 will require a leap from around 50k units shipped per year to more like 400k – an implausible number as things stand, even if new companies enter the market. Nevertheless, the Japanese Government is holding up its end of the bargain, proposing Yen¥8.9 billion in FY 2018 for subsidies for Ene-Farm and small commercial systems.

Commercial-scale units (roughly 3 kW and up) have long been considered more likely to be economically viable than residential systems, which face challenging price constraints. But up to spring 2017 only 48 commercial fuel cells were installed in Japan, although more are in demonstration.

Miura, Japan's largest boiler manufacturer, plans to sell its 4.2 kW SOFC unit to small commercial applications, claiming overall efficiency of 90% plus, and electrical efficiency of 48%. A similar sized unit is said to be under development by Denso, and Kyocera has said that it will work with Osaka Gas for the distribution of a 3 kW SOFC system. Initial sales of 500 units are targeted, at a price per unit of less than ¥5m (US\$45,500).



For larger commercial energy users, Hitachi Zosen and Fuji Electric are moving towards

release of their stationary SOFC systems. Hitachi Zosen installed a second pilot 20 kW SOFC system at an Osaka Research Institute in April, using NGK Spark Plug's planar SOFC stack. Fuji continues to deploy its 100 kW PAFC units, including one in Air Liquide's new research centre in France.

Coming from a different angle, Toshiba's H2One product, designed for autonomous operation, contains an electrolyser, hydrogen storage, a battery and a fuel cell. It can provide heat and power from stored renewable energy or an available hydrogen source, and act as an emergency energy supply in times of natural disasters, a sales point particularly relevant in post-Fukushima Japan. Several units started up in 2017.

Korea focuses on size

Korea has strongly pursued stationary fuel cells, though it backed away from deeply supporting residential units a few years back to focus on larger stationary systems. Fuel cells are eligible as part of Korea's aggressive renewable portfolio standard. Large fuel cell installations have helped major power companies meet their obligations under this mechanism, and co-generation requirements for new building developments have helped further.

The Korean Government's ambition has outpaced local technology development, however, and Korean businesses have gained access to technology in North America and Europe through acquisitions and joint development agreements. 2017 saw the Korean Electric Power Company sign a technology agreement with Solidpower, with a 10 kW unit now being demonstrated, and Horizon has plans to enter the country, having been selected by Ulsan TechnoPark to provide liquid-cooled 30 kW PEM units for a 200 kW demonstrator using waste hydrogen. A 1 MW unit is the ultimate aim.

POSCO Energy, working with FuelCell Energy, built what was for some time the world's largest fleet of commercial scale fuel cell systems – 170 MW over 18 sites. It retains the largest single fuel cell installation, 59 MW, at Hwasung City. But even after investing heavily in manufacturing facilities at Pohang and in technology development, POSCO announced its intention to exit the sector in 2016. It seems that the Korean Government was unhappy with this suggestion, and POSCO and FCE have since then negotiated the principles of an agreement which would see POSCO retain responsibility for servicing the existing fleet, and committing to purchase an estimated 300 MW of modules for the existing service agreement.

The agreement also sees FCE take over the marketing and sales of its SureSource product (previously the DirectFuel Cell) in Korea and the wider Asian market. Korea Southern Power Company has ordered a 20 MW plant for Incheon, which will be operational in 2018. FCE is also expected to operate and maintain the plant under a 20 year agreement.

In contrast, Doosan, Korea's other major commercial scale fuel cell system manufacturer, has significantly ramped up its Korean capability, with its ₩40bn (US\$36m) Iksan manufacturing facility able to produce 144 units of the 440 kW PureCell PAFC systems annually, or 63 MW. The Iksan facility augments Doosan's US plant in South Windsor, Connecticut (home of the original PAFC technology), which shipped 70 PureCell models for KHNP's Busan energy plant project earlier in 2017. Together the plants allow 'Made in the US' and 'Made in Korea' labels to be applied; often important for local subsidy eligibility.

Doosan's order pipeline includes Bundang Phase 4, a 38-unit 16.7 MW plant, and Petroconergy's 14-unit plant for Ansan, in Seoul, plus a six-unit, 2.64 MW PureCell order from Samchully ES. Doosan is also involved in the 50 MW Daesen Fuel Cell plant, using hydrogen from Hanwha Total PetroChemical. The company is apparently also examining other technology options, notably SOFC.

North America – home of the PPA

For stationary fuel cells, 'North America' means the US. Here the markets and the financial and regulatory framework are rather different from Japan and Korea, with electricity generation more competitive, energy choices wider and energy prices lower. Regulatory and financial support has included a national investment tax credit augmented by incentives and preferences programmes in several states. Support has declined significantly, however, with changes in California's deep subsidies and the lapse of the tax credit.

Fuel Cell Energy faced a difficult 2016 with a slowing of orders for its SureSource MCFC products, compounded in autumn 2016 when POSCO Energy announced its intention to exit. In December FCE announced a reduction in annual output from 50 MW to 25 MW, and the loss of 96 positions, 17% of the total workforce, and other cost control measures designed to save US\$6m a year. But 2017 has seen significant

orders: Long Island Power Authority's FIT IV Programme for clean and resilient energy will install 39.8 MW of FCE units at three sites, Korean Southern Power Company will take 20 MW, and 7.4 MW will go to the Connecticut Municipal Electric Energy Cooperative in Groton to supply power and heat to the US Navy's submarine base.

FCE, located in Connecticut, will probably benefit from Connecticut State Public Act 17-144, aimed at clean energy plants providing grid resilience and reliability, and which could include up to 30 MW of fuel cell plant. Smaller orders continue too, from California, Connecticut and New York.

FCE has announced it is shifting its business model from equipment sale to Power Purchasing Agreement (PPA), following Bloom Energy's lead. All new US orders and some of 2017's completions have been signed with PPAs of varying durations, usually 20 years. This way the customer is not deterred by a high upfront capital cost; instead operations and maintenance costs are borne by the provider for guaranteed annual revenue that also recoups capital spend. The provider takes on risk, for example for future fuel (though this is negotiable) and replacement stack costs. But FCE has said outright that the direct PPA model, in which it owns units and sells power to end users, makes the company more money than selling units to a utility or independent power producer.

But funding the PPA model requires a lot of capital, if the assets are to be held on the books rather than sold on to a specialist financing business. With a growing order book, FCE needs finance, and it has been to the money markets twice in 2017, raising US\$13.8m in May and a further US\$28m in September for '...working capital, project financing and general corporate purposes...' Interestingly, it has also negotiated a US\$5m credit facility from the Connecticut Green Bank for a previously announced 3.7 MW project in Danbury, CT.

Bloom Energy, based in California and Delaware, has led the way in the commercialisation of larger-scale SOFC technology. Its Energy Saver

product comes in different power versions, with claimed electrical efficiencies of up to 65% for their latest generation. Well over 200 MW of units are installed, primarily in the US. Bloom is also strong in developing strategic alliances with financial players, allowing it to offer PPAs. In 2016 it lined up with PowerSecure, a finance business owned by US utility Southern Company, to supply 50MW of Energy Servers with PowerSecure storage solutions, all under PPA deals; 37 MW of units for 12 Equinix data centres in California and New York State will be installed from 2017 through 2018.

Bloom's customers are loyal: IKEA's fleet now numbers five units, including one coupled to a 940 kW solar array. And in April an Energy Server unit was switched on as part of the Parkville, Hartford, CT micro-grid. However Bloom has fallen slightly foul of an agreement in Delaware which should have seen 900 Bloom jobs come to the state, in return for US\$12m of up-front state funding. Only 302 jobs have been created to date. Bloom has returned \$1.5m of the initial grant.



Ballard's Canadian peer Hydrogenics has likewise said little on stationary markets. Its 1 MW PEM pilot at Daesen, Korea, developed jointly with Kolon, ran through to its planned completion in 2016. Three 5 MW projects are said to be under review, and Hydrogenics is building experience in combined fuel cell and electrolyser projects – a 200 kW fuel cell working with an electrolyser for Glencore Mining North Quebec, plus the Lamtakong, Thailand, project announced in 2016. In South Africa, the 8 MW Doosan PAFC scheduled to be installed at Implats in 2017 and operating January 2018 seems to have received "Critical Infrastructure Programme (CIP) approval from the Department of Trade and Industry (DTI)" and should be on order soon. And in an unexpected move, Daimler announced discussions with Hewlett Packard Enterprises and Microsoft to deploy its automotive PEM technology in data centres. Microsoft has been testing different fuel cells, including Solidpower's SOFC, for the application. It claims ambitions to deploy a 10 MW unit in the next few years, and ultimately many more "once the supply chain is ready."



Doosan Fuel Cell America has signed an agreement with Wells Fargo Vendor Financial Services to finance Doosan Energy Solutions, and can now offer PPAs for power and heat from its PAFC units. They will be similar to one for three PureCell units for Naugatuck in Connecticut which came online this year under a 20 year PPA.

Other stationary fuel cell system market activity was muted for most of 2017. Canada's Ballard has largely exited the sector with its sale of the telecoms back-up business to Taiwan's Chung-Hsin Electrical and Machine Manufacturing Company. It does retain interest in Europe, where it is supplying a 1 MW ClearGen PEM system to an Akzo-Nobel plant near Bordeaux, France. Ballard also retains its direct hydrogen technology at Ballard Power Systems Europe in Denmark.

US SOFC Research

Several US Companies are sharing US \$30 million annually in research support from the US Department of Energy to develop SOFC power generation systems. Programme participants include FuelCell Energy, LG Fuel Cell Systems, Redox Power Systems and Acumentrics along with a number of university research centres.

In contrast, in November 2016, GE absorbed its standalone fuel cell SOFC hybrid development unit into GE Global Research in Saratoga, USA, laying off 27 employees and transferring 16 more. R&D has continued, in part funded by Federal programmes, but GE has not announced further internal investment in the technology and it is not clear where it may eventually land.

Europe's installations receive a (small) boost

Europe's stationary fuel cell installations have always lagged Asia and North America. In part this may be linked to the characteristics of Europe's fuel cell developers: technically innovative, but often small, commercially inexperienced and resource-constrained in comparison with Asian and North American corporations. Europe has also lacked the opportunism and funding of the US or the consistent and relatively generous government support available in Japan or Korea. Europe's current fleet of micro-CHP fuel cell systems is two orders of magnitude smaller than Japan's, whilst commercial scale systems have been installed in tens, not the hundreds of units in Korea and the USA.

The long-running ene.field demonstration project ended in 2017. It supported 1,046 PEM and SOFC micro-CHP units from 300 W to 5 kW, of which only 200 units had been installed by end of 2015, but 300 plus in the final 12 months. In contrast with Ene-Farm's remorseless focus and pace, this flagship European project supported multiple, often immature technologies and companies; ten developers fielded 12 different PEM and SOFC systems. Ceres Power pulled out of the project during their funding crisis, then re-joined, while some small businesses changed ownership mid-project, such as Hexis (acquired by Viessmann) and Dantherm (by Ballard), and further changes may occur. In May Vaillant, whose xcellPOWER

system used Sunfire's SOFC stack, put fuel cell development on hold, citing a lack of market. And in October Elcore filed for bankruptcy – even after negotiating distribution agreements with EOn, an investor in the business, and Solvis.

But prospects have improved, with the 2016 announcements of the FCH JU supported PACE (Pathway to Competitive European micro-CHP) project and the German Federal Government's KfW 433 programme (see our 2016 Review).

The latter was extended beyond residential applications to small scale commercial units this year, with size-dependent capital grants of €7,050 to €28,200 available. The German association ZukunftERDGAS expects 1,500 units to be installed in 2017. Official government figures note 1,100 applications for funding in the twelve months to July 2017. The PACE project is more focused than ene.field: the first of at least 2,500 units across ten countries will come in 2018, and features only four developers: Solidpower; BDR Thermea's Senertec system (replacing Vaillant); Viessmann (with Panasonic PEM technology); and Bosch (with Aisin of Japan).

Success in this market will depend partly upon relatively high volume demonstrations such as PACE and market activation programme KfW433, but still needs cost reduction, reliability improvement, and clever ways to enter the conservative consumer market. Bosch, BDR Thermea and Viessmann have deep pockets and good access.

The dedicated fuel cell businesses will need partners. Ceres Power continues this approach, announcing a joint development agreement in May, with an 'existing partner OEM', to apply its SteelCell technology to residential CHP. It also has partners for commercial markets: it is developing a product for data centres with Cummins, and a



joint development agreement with an unknown OEM for a multi-kW commercial scale system was announced in December 2016.

Solidpower is exploiting its acquired BlueGen SOFC technology, with agreements to supply Elugie, in Belgium, with up to 1,200 units (550 ostensibly due this year), and 300 kW of units to Egg Technology of Italy. Ecotraris in Germany will integrate BlueGens into units for commercial end users. These will all be supplied from the Heinsberg manufacturing plant. Solidpower is expanding manufacturing using the €40m recently raised. Solidpower is also developing a commercial offering, evidenced by the 10 kW unit in Korea and an installation for a Microsoft data centre in Seattle.

Europe relies on overseas companies for commercial scale fuel cells; current and past units have come mainly from Doosan (and its predecessors), FuelCell Energy and Fuji Electric, while European engineering businesses (Alstom, Siemens, Ansaldo, Haldor Topsoe) have more or less exited the sector, deciding that fuel cells were a distraction from core activities. Rolls-Royce only retains a small part of its development in the UK; the rest is in the US. The trend continues: three of Doosan's PureCell units will provide power and heat to the new Aberdeen Exhibition and Conference Centre. Due to open in 2019, the 1.3 MW installation will be the largest in the UK. Bordeaux in France should see a 1 MW Ballard CleanGen PEM unit coming online, while an FCE unit should start up in Germany, supplied through E.On Connecting Energies for a Radisson Blu hotel.

Some European companies do have ambitions in the sector: Convion, spun out of Wärtsilä, is developing and proving out a circa 60 kW SOFC CHP unit. In October the unit started operations in Italy, using biogas from waste. Two further units should be installed before 2021. In a domestic Finnish project, two of Convion's units will join PV and gas engines as part of a smart micro-grid from 2018. And they also announced a venture, with H2e Power Systems of the USA, to enter India's energy market. They will work with Jain Irrigation to deploy fuel cells into rural areas. AFC Energy, now working alongside the DeNora

group, has announced a small-scale system for a waste gasification plant in North West England, and is designing a 1 MW system for Covestros' Brunsbuttel Park in Germany.

Hybrid SOFC still tantalises

MHPS (Mitsubishi Hitachi Power Systems) continues its development and commercialisation of a hybrid pressurised SOFC system. In mid-2017 its Kyushu University unit was reported to have achieved 10,000 hours of cumulative operation and further units are planned for NGK Spark Plug's Komaki City plant, Toyota's Motomachi plant in Toyota City, and Taisei Corporation's technology centre in Yokohama. These locations are 'friendly' – NGK supplies the cylindrical SOFC cells/stacks to MHPS, and Toyota the high speed micro-turbine. MHPS plans to scale the current 250 kW product up to a 1 MW unit.

Telecoms and other power support

Fuel cells for telecoms, either as back-up or prime power in off-grid locations, have attracted many suppliers over the years, seeking to displace inefficient, heavy and short-lived diesel gensets, batteries, or both. Fuel cells systems are claimed to be lighter, with lower emissions and higher fuel efficiency. In theory fuel supply logistics and total costs of ownership should both be better than incumbents. But the market is tough, with conservative buyers who need to be persuaded of the benefits, and in complex environments such as parts of Asia and Africa.

Alteryg of California remains in the US market, supplying 5 kW fuel cell systems to two of the big four carriers, in addition to smaller businesses. It has a new partnership with broadband solutions provider Alpha Technologies to deploy Alteryg systems into Alpha infrastructure.

The US's other big player is PlugPower, which acquired ReliOn's telecoms legacy in 2015 and markets a range of products under the GenSure brand, from 200 W to 2500 W. Southern Linc operates a 500+ unit network in the southern USA which it says offers a 64% reduction in operating costs, 99.6% reliability and a smaller footprint than conventional technologies.

Chung-Hsin Electric and Machinery Manufacturing Corporation (CHEM) in Taiwan continues to buy Ballard stacks following its acquisition of Ballard's old business. Now part of CHEM's Renewable Energy business group, the product has been renamed ME2Power. CHEM signed a distribution deal with Toyota Tsusho in June 2017, covering the Japanese market.

Fuel cells provide support in other markets too. Israel's GenCell has developed a 5 kW AFC system with a non-precious metal catalyst and the capability to use ambient air. A main target market is utility company substations, where it acts as a backup unit for companies including San Diego Gas and Electric, and the Israel Electric Company, but it could equally serve as backup in many other markets.



Military and special markets

Various military organisations have been good customers for fuel cells over the years, helped along in the US by Congressionally-directed purchases of power generation units. More recently, well-funded developments have helped soldier power and portable fuel cell systems, various navies use fuel cells in submarines, and a fuel cell military-use vehicle has been developed by GM. Military customers can be reliable, and pay premium prices for the right equipment. They have needs (quiet operation, low heat signature, long run-time) that batteries struggle to provide. Of course they are also exacting in their specifications and qualification processes, and a strong preference for a single fuel – typically a kerosene variant that fuel cells do not run well on – makes very wide use of fuel cells unlikely in the near term. Nonetheless, systems have made inroads into applications where they provide significant operational advantages – in increased autonomy or stealth for example.

Soldier Power

Fuel cells for soldier power have been in development for many years, to counter the increased power requirements of the 'digital battlefield', notably for surveillance and communication, and the resulting increased weight of batteries carried. Replacing or augmenting batteries with fuel cell charging systems helps. The German Army uses two of SFC Energy's JENNY DMFC systems to reduce weight for a 72-hour mission by up to 80%. It also uses SFC's EMILY 3000, a larger charger integrated into vehicles for charging running equipment, in place of diesel generators. During 2017 the army has ordered multiple systems, including an extended

version of the MKEV100 comprising two JENNY fuel chargers and a power manager. Trials are also reported with the UK Ministry of Defence, and earlier in the year the Indian Ministry of Home Affairs ordered 80 units.

HES of Singapore has developed the wearable SoldierPak system with several Australian entities, including the Australian Defence Science and Technology Organisation. This 10 W-constant, 20 W-peak system uses HES PEM technology, fuelled by 160 Wh sodium borohydride cartridges. The portable Field Fuel Cell Charger uses separate, jerrycan-sized low weight dry cartridges which, when mixed with water, provide up to 4000 Wh of power.

In the US, back in December 2016, the Department of Energy's Advanced Research Project Agency – Energy (ARPA-E) granted SAFCell US\$3m to develop, with UltraCell, a 50 W Solid Acid Fuel Cell system operating on liquid or gas cartridges. UltraCell also offers several other reformed methanol fuel cell recharging systems of between 50W and 150W, and cartridges with between 440 Wh and 12,500 Wh of capacity.

Protonex, a Ballard subsidiary, reported that its wearable soldier power packs received approval



Ballard's non precious metals catalyst

While higher-temperature fuel cells do not need precious metal catalysts such as platinum, lower-temperature technologies rely on them for their stability and performance. Their cost is relatively high, and alternatives have been sought for many years. In September, Ballard announced the world's first PEMFC product incorporating a non-precious metal catalyst. Developed as part of Ballard's tie-up with Nisshinbo Holdings (a 1.9% owner of Ballard) the carbon "nanoshell"-based cathode catalyst is used in the 30-watt FCgen-1040 fuel cell stack. The catalyst will be offered for UAV applications, perhaps offering the trade-off of lower cost for lower lifetime. A "standard" platinum catalyst-based stack is likely to be offered as well. This initial stack is very small, and the catalyst technology will need to be deployed in larger markets to realise truly commercial potential. Ballard and Nisshinbo have already announced a contract to develop it further for forklift applications.

from the US Army for full production and deployment, a significant milestone that clears the way for large scale orders. Protonex sales have been modest, based on Ballard's most recent quarterly report.

Drones: Civil and Military

Unmanned Aerial Vehicles, UAVs or drones, are increasingly finding both military and civil uses. They monitor battlefields or patrol at sea, the operational environment of assets, or the assets themselves. Pure battery or small internal combustion engine propulsion systems are not always reliable, or provide only low flight endurance. Bigger UAVs and heavier payloads have created opportunities for fuel cells.

Protonex is working on Unmanned Aerial Vehicles (UAV) with "several global aerospace customers" and in 2017 landed its first civilian order, from South Africa-based FlyH2. Protonex has over a decade of experience in developing PEM fuel cell systems of up to 1.5kW to augment or replace batteries and ICEs. Lockheed Martin has used Protonex's systems, as has the US Naval Research Laboratory for its Ion-Tiger and Sea Robin projects.

Earlier in 2017 Intelligent Energy agreed to supply its air-cooled PEM fuel cells to PINC of California for UAVs used in inventory management. In September, at the Interdrone conference, they announced a further tie-up with US UAV developer FlightWave, to supply fuel cells for the Jupiter- H2 multi-rotor UAV. It is not clear whether or if Intelligent Energy's financial issues this autumn will affect these relationships.

In Asia, Singapore's HES produces the 200 W Aerostak, hybridised with a Li-Ion battery. With a choice of liquid, gaseous or solid hydrides as fuel sources, it is used in the Singapore Aerospace SkyBlade. Shanghai's rapidly-growing Re-Fire Technology business has a range of interests including UAVs. Its 500 and 650 W fuel cells work with a Li-Ion battery to provide flight times of 60 to 90 minutes.



Submarines

Conventional diesel-powered patrol submarines are supplemented by versions which use PEM fuel cell systems to extend underwater endurance. Conventional submarines are limited by their battery systems; when these are exhausted, often after a few days, the submarine must surface or use a snorkel to run the main power units to re-charge the batteries, placing the vessel at risk. PEM fuel cell systems have been improving endurance in German Type 212a submarines for well over a decade; one has reportedly achieved 18 days of submerged operations. Whilst nuclear powered submarines can operate underwater for months at a time, this is a significant benefit for the smaller and more affordable vessels.

Siemens developed the 34 kW SINAVY PEM fuel cell system for the German Navy in the 1980s, to work alongside the MTU diesel. The German and Italian navies have both used submarines based on the original U31 vessel. Seven other nations have also ordered; the latest being Singapore and Norway, while South Korea has nine vessels in service or planned. These are built locally, by Daewoo and Hyundai, although all use the Siemens PEM system. 45 vessels of the German design are said to be in service, or on order, as of mid-2017.

Fuel cell submarine designs for Russian Lada class vessels have also been demonstrated, whilst the Indian Navy has two Franco-Spanish 'Scorpene' vessels on order which will, apparently be fitted

with phosphoric acid fuel cell systems developed in India for AIP operations. Work has been done on on-board reforming, in an attempt to get away from storage of hydrogen; methanol has been trialled in Germany. The Spanish Navy's S-80 class submarines use reformed bioethanol to provide hydrogen for UTC fuel cells, with liquid oxygen providing the oxidant.

Unmanned Underwater Vehicles (UUV)

Quiet operation and range are major selling points for fuel cell UUVs, both manned and unmanned (e.g. torpedoes). Challenges include a very difficult physical architecture in which to fit the fuel cell and fuel.

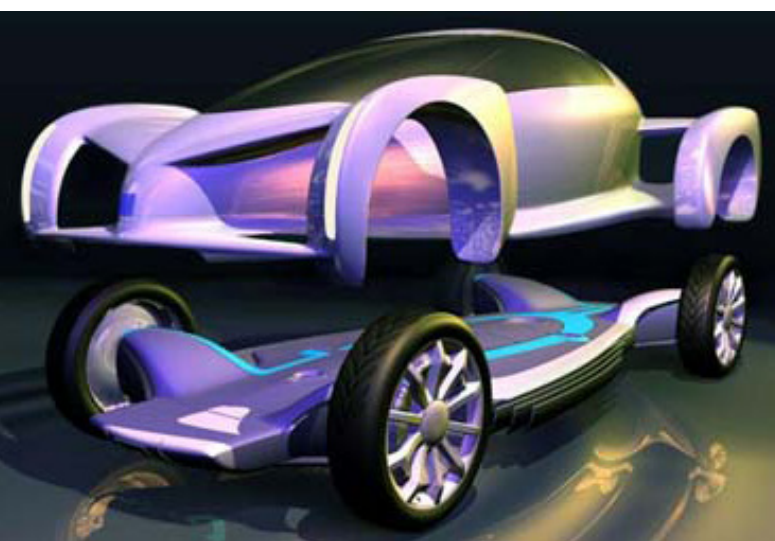
United Technologies (UTC) retained parts of its fuel cell portfolio when it sold its PAFC business and its motive PEM stacks and IP. It offers modules for manned and unmanned underwater vehicles (UUV) through its UTC Aerospace Systems division. GM has a development programme with the US Navy to demonstrate its fuel cell in an unmanned undersea vehicle (UUV), aiming to substantially increase patrol times to more than 60 days. Protonex also has UUV projects including oceanic recharging buoys. A number of US Defense Department research programmes are under way, many of them not public.

The Navy, for example, is testing GM's fuel cells in a UUV and a SOFC power system for Marine Corps forward bases. WATT fuel cell is developing a small fuel-flexible power system for military uses though no sales have been disclosed.

Fuel Cell Fighting Vehicles

Developers have been attempting since the 1980s to build fuel cell powered military vehicles. Benefits include low heat and noise signatures, on-board charging capability and performance compared to battery vehicles. The latest effort is from General Motors, which has announced significant progress. Last year's ZH2, a militarised version of GM's Colorado SUV, is in trials with US Army and Marine Corps units, and GM recently unveiled a truck platform called the SURUS (Silent Utility Rover Universal Superstructure) aimed at military adoption. A range of different bodies fits on what looks like a more rugged version of GM's old 'skateboard' concept from the days of the Autonomy vehicle. SURUS uses GM's Hydrotec fuel cell system.

For ultimate deployment the 'one fuel' policy critical to efficient and effective military supply chains means that somehow diesel or JP8 will need to be converted to a usable fuel for PEM FCs. Whilst efforts are being directed at systems to clean up and process diesel and JP8 for fuel cell use these remain bulky, heavy and expensive.



Government support

Despite great strides in reducing cost and building smarter business models, supportive policy remains the primary reason fuel cells are making headway. And of course policy support changes with government ideology and with budget priorities.

US Government Programmes

Although there is no apparent animus toward fuel cells specifically, the Trump Administration emphasises fossil fuels, and proposed cutting the Department of Energy's vehicle related fuel cell budget from US\$101m in FY2017 to US\$45m in FY2018. Congress is certain to restore some of the cut; the final number is likely to fall between the US\$54 million approved by the US House of Representatives, and the US\$85 million approved by the Senate. A separate budget for SOFC is expected to be US\$30 million, in line with current spending. Some basic science research programmes also support fuel cells.

DOE's fuel cell budget is much reduced from its high of over US\$300 million a decade ago, and very little of the money flows directly to fuel cell companies. It still funds a few small vehicle demonstrations but focuses mostly on research; there is no direct funding for commercialisation. But it is an important participant in a wide range of efforts to make systems, fuel supply and refuelling infrastructure more economically competitive and deep cuts would erode DOE's leadership. For what it's worth, Energy Secretary Perry appeared to enjoy a recent ride in a Toyota Mirai. However, while the new fiscal year began on October 1, the government is operating until early December on a Continuing Resolution which only allows spending at the lower \$54 million level.

The most significant national level commercial support program, the Business Investment Tax Credit for fuel cells (and various other advanced and renewable energy generating technologies) was allowed to lapse December 31, 2016. Its restoration is still in limbo, despite strong bipartisan congressional support. The credit, up to \$3,000 per kilowatt, could be earned for power generation and fork lift units. Restoration of the ITC is caught up in the larger US debate over tax and spending policy. A proposed extension to 2022, with a phase-out, is included for now in a major tax reduction bill being debated, although

final approval is far from assured. Renewed credits for fuel cell vehicles were not included in the bill though, and indeed the credit for battery electric vehicles would be terminated.

US State Level Programmes

Several states have their own programmes to support fuel cell deployment; these include California, New York, Connecticut, Washington, New Jersey and several others. Both California and New Jersey scaled back in 2017. New Jersey rescinded its support for fuel cell power-only projects (mostly affecting Bloom Energy), and California's Self Generation Incentive Program, the reason why 60% of all US fuel cell power generation is installed in that state, now focuses mostly on power storage projects and offers only reduced subsidies for fuel cells.

Japan

Fuel cells and hydrogen remain a pillar of government energy policy, though sentiment is mixed even within Japan about whether this will make Japan a global leader or simply isolate the country from other technologies. But Prime Minister Abe refers to the importance of developing a hydrogen society, and total FY2017 Government funds for fuel cells and hydrogen are around ¥39billion (US\$355m), consistent with previous years. The request for FY2018 is around ¥30billion.

Part of the budget goes to the highly successful Ene-Farm residential fuel cell programme, other stationary fuel cells, fuel cell vehicle purchases, and hydrogen developments and demonstrations. All this is tied into the effort to make the 2020 Tokyo Olympics a prominent showcase for hydrogen and fuel cells.

Europe

2017 marks the tenth anniversary of Europe's Fuel Cell and Hydrogen Joint Undertaking: a public-private partnership between Europe's fuel cell industry and research communities on the one hand and the European Commission on the other. The FCH JU has been instrumental in fuel cell development and commercialisation activities in Europe: developing an agreed strategy, co-ordinating efforts and committing dedicated long-term funding. From 2007 to 2020 the FCH



JU will directly provide about €1.2bn to R&D and deployment projects.

It is fair to say that the FCH JU has been instrumental in catalysing activity across all applications in Europe. Without this positive policy, it is doubtful that Europe's fuel cell activities would be anywhere near their current level, especially in critical sectors such as FCEBs and green hydrogen production. Furthermore, FCH JU investment is being matched at a ratio of €1 : €3.5 when all other private and public investment in projects is taken into account.

There will continue to be a need for policy instruments and funding to accelerate fuel cell deployments. Such deployments will significantly contribute to Europe's ambitious climate change, air quality and energy security goals. Continuing the FCH JU even beyond its current period could be important.

The Asian Pivot: Dragons at Large

Asia remains a huge driver of the fuel cell industry – Japan and Korea have been strongly supportive for decades, but China – again – is looking to usurp them. The pace of change coupled with conflicting information make the Chinese situation hard to fully decipher, but we comment on some aspects below.

We suggested in 2016 that the slumbering dragons in China were waking to fuel cells, and indeed China has become the transport sector story of the year. Fuel cell system and vehicle manufacturing capacity has expanded rapidly, judging from public reports, from hundreds of units to tens of thousands. Much of this capacity will feed a nascent fuel cell bus and heavy duty vehicle market shoved along by deep federal and local subsidies and abetted by western technology. China is the world's largest bus market and produces more than half a million units annually.

Driving this surge in fuel cell interest is a longstanding desire to modernise its technology base, clean up urban smog and (more recently)

reduce reliance on carbon fuels. In the vehicle sector, these goals are embodied by its five-year plan for New Energy Vehicles (NEV), which combines regulatory pressure, development financing, manufacturing incentives and purchase subsidies. China set a goal in 2017 of 2 million NEV by 2020 and 20% of the new car fleet in 2025 (perhaps 7 million units).

To underscore just how generous the programme is, SAIC, China's largest auto manufacturer, is offering a light fuel cell passenger van through its MAXUS subsidiary; the FCV80 will retail for about US\$200,000 but federal and local subsidies appear to bring the end cost down to about US\$45,000.

Lack of hydrogen infrastructure is, as usual, a drag on commercialisation. China had only 7 public stations as of November 2017, with 20 more planned or under construction. But there are several other refuelling facilities – for fleet vehicles – and plans are underway to build hydrogen stations along a new expressway that will link Beijing and Zhangjiakou in time for the 2020 Winter Olympics which the two cities are co-hosting.

The boost to fuel cells is also down to some larger forces at play in China. It has offered to pick up the mantle of leadership on climate change following the US abdication; it has a leadership opening presented by the collapse of the Trans Pacific Partnership; and President Xi, whose commitment to technology modernisation and to China's place in manufacturing it is absolute, consolidated his power in 2017. Hydrogen and fuel cells become handy tools in this context.

Western Technology

As we comment throughout, China has reached out to the west to jump start its fuel cell capacity expansion. Chinese companies cemented relationships with Ballard, Plug Power and Hydrogenics that now include technology licensing and manufacture in China. Bosch has just announced a co-operation framework with Weichai to develop fuel cell technology, while Nedstack and HyMove are working with Dongfeng Commercial Vehicles to develop and test 30 kW systems for motive power; 30 kW is the system size of choice for Chinese commercial vehicles, because of the government's subsidy structure.

Manufacturing Scale-up

With hundreds of buses on order or anticipated in various field demonstrations, Chinese manufacturers are ramping up their production, with eye-popping capacity estimates, including:

- Broad-Ocean plans a fuel cell system plant capable of producing 17,000 fuel cell vehicle systems per year by 2019.
- Feichi, in partnership with National Synergy, dedicated a fuel cell stack and system integration production line with an annual capacity of 20,000 stacks. Ballard is a 10% owner.
- Foton (Sino Hytec) Zhangjiakou Fuel Cell Vehicle Production Base inaugurated a production line with a capacity of 2,000 units, expandable to 10,000.
- Furui, in partnership with Plug Power, plans to deploy 13,500 vehicles over three years.
- Re-Fire is developing fuel cell vehicle prototypes and working with OEMs as a specialised powertrain integrator. Capacity for thousands of sets is planned near-term.

R&D

- Two major Chinese automakers, FAW Group Corp. and Dongfeng Motor, announced plans in 2017 for a joint innovation centre focusing on smart connectivity, fuel cells and lightweight technologies.
- Zhongtong Bus Holding Co., a major state-owned Chinese bus maker, is partnering with electric motor manufacturer (and Ballard shareholder) Broad Ocean Electric Motors Co. to develop fuel cell powered buses including powertrains and a new vehicle platform.
- Shanghai rolled out its own technology initiative supported by preferential tax and financing policies designed to attract more than 100 suppliers, technology companies and engineering firms by 2020 to support fuel cell vehicle development. Shanghai plans to build as many as 50 fuel stations and create a fleet of 20,000 passenger vehicles and 10,000 commercial vehicles by 2025.
- Beijing Hydrogen Fuel Cell Engine Engineering Technology Research Center was set up by SinoHytec and supported by Tsinghua Industrial Development Research Centre.

Deployment

Despite all the production capacity, the actual number of fuel cell vehicles on the road in China is small, perhaps slightly more than 100, both because of fuelling station limitations, and a hiatus between earlier demonstrations and the five vehicle projects now under way or gearing up. Also it seems the national subsidy is given to vehicle producers, not purchasers, so the incentive is to build vehicles, not immediately to put them on the road. However, the subsidy of some of the regional governments is only paid out after the vehicle has operated for a certain mileage. Estimates for November suggest 2,000 vehicles were “available” in China, however, so the number on the road ought to grow rather rapidly as infrastructure comes on line.

The Vehicle Purchasing Tax Free New Energy Vehicle catalogue, which lists vehicles eligible for subsidy, added 6 models in 2017, though a dozen more are being developed. It is telling that on the list, there are 7 buses, 5 trucks, and only one passenger car. Clearly China aims at heavier vehicles in its near-term fuel cell vision.

China is already by far the world’s largest battery vehicle market, with sales of 50,000 vehicles reported per month despite reports of fraud and other difficulties in the subsidy programme and a cut in the subsidy amount as China phases it out and shifts to a cap-and-trade scheme for manufacturers. Sales of battery vehicles have fallen in line with the subsidy. With auto manufacturers under heavy pressure to reduce their fleet emissions, that opens the door to fuel cell cars, whose subsidies have not been cut, and to commercial vehicles and buses.

Given that North America and Europe have seen bus demonstrations of varying size and success since the early 1990s, China can avail itself of a relatively mature, if expensive, electric vehicle option more or less on the shelf. The manufacturing scale in development in China certainly will test whether fuel cells as currently designed can be made affordable via volume increases.

Portable and off-grid power

Off-grid power is often expensive and unreliable. Demands may be small or transient, so grid connection is uneconomic, or the grid may simply be absent, as in the case of camping and caravanning, monitoring and surveillance for industrial needs such as oil and gas pipelines, and telecommunications, for example. Here, fuel cells can potentially out-perform batteries and other solutions – or augment them. While the price may be higher, the total cost of ownership can be lower, through reduced fuel or maintenance costs, longer run times, or greater reliability.

SFC Energy's civilian DMFC technologies complement the military hardware discussed elsewhere. The EFOY Pro series supplies off-grid power from 45 W through to 500 W, usually charging batteries. After over ten years in the marketplace, SFC may be heading towards breakeven in 2017, with reported sales up over 25% by Q3, primarily in oil and gas, security, and industry; the leisure sector has not grown. Distributors such as Fuel Cell Systems note that sales are becoming more straightforward with technology acceptance and greater awareness.

Horizon Fuel Cells is also selling methanol-fuelled systems for off-grid power solutions, with the option of a trailer-mounted hybrid including solar and batteries. The MFC 200, plus a 20 litre methanol tank, provides 90 hours of 200 W power, while Mini 100 will run 12 days on 10 litres at 30 W. BOC's Hymera continues to be deployed into small off-grid markets too.

Atrex Energy and Ultra Electronics are targeting similar markets, but using SOFC. Atrex, part of Acumentrics, uses micro-tubular SOFC in its 500-1500 W ARP series. Ultra's P250i product, fuelled by propane or natural gas, backs up railroad signalling. Railroad downtime is fantastically expensive, so Ultra and its partner Red Hawk Energy can charge a premium for a reliable installation.

AquaFairy of Japan originally developed consumer electronics chargers, but has pivoted to emergency power units, which are important to local consumers. Its AF-EF E 30 H is a 30 W continuous, 100 W peak unit, using calcium hydride fuel cartridges of 600 to 1200 Wh.

Consumer Chargers

Each year we report that fewer fuel cell companies are targeting the consumer device market. This year's main casualty is Intelligent Energy, which has stopped developing the Upp following its restructuring. eZelleron maintains a low profile, claiming to be still developing a charger to deliver to its crowdfunding customers. The delivery date keeps being pushed back. At the same time, batteries get better and it gets harder to compete with the ubiquitous 'power bank'.

MyFC has managed to stay in the game, however. Its JAQ launched in 2016, and at the end of 2016 MyFC signed an agreement with the Chinese business Telling to sell the product into China. The three-phase agreement stipulated an initial shipment of 1000 units, which have shipped, then a jump to 400,000 and 900,000 by end 2018. MyFC 'intends to initiate' Phase 2 before the end of 2017.

The JAQ product is now the JAQ Hybrid – with battery and fuel cell charger providing 4000mAh and 'recharging' using a PowerCard cartridge storing hydrogen in the form of a salt. MyFC's ambitions do not rest with battery chargers however; it also plans a vehicle range extender.



Where will 2018 take us?

If 2017 proved anything, it was how critical government policy still is to the commercial prospects of fuel cells. The most successful policies – those that spawned the most pre-commercial and early commercial activity – include not just positive frameworks and support for demonstrations, but market interventions combined with a vision of where and how fuel cells fit into the nation's larger societal goals for energy, environmental quality and economic development.

The best examples so far are Japan, which has stayed the course on residential fuel cells and pushed the industry on hydrogen production and shipment, and on refuelling infrastructure and vehicle deployment; Korea, which has become the number one market for fuel cell power generation by including fuel cells as a renewable technology; California, which continues to finance infrastructure construction and operation and has begun to push the industry to develop heavier vehicles; Germany, whose push for renewables has helped create options around green hydrogen; and now China, where fuel cells fit into its five-year plan for high-tech industry development, smog reduction and reduction in carbon intensity.

Largely as a result of this public sector leadership, many of the signs from industry are positive for 2018. Firstly, we've seen credible public announcements, and had credible private conversations, that suggest that continued significant orders are out there. That is essential for an industry seeking scale, to bring down cost and to get the supply chain properly engaged. The different technologies are also performing well – buses and cars run, stationary units produce heat and power. That gives companies something to point to as they sell into other markets. Costs are still high, but business models are changing to compensate, most obviously through the use of PPAs in stationary power and other applications. We expect to see more models of this sort, taking the pain of up-front cost away from the consumer.

There are no guarantees. The United States let its power generation tax credit expire, at least temporarily, and has proposed deep cuts to fuel cell research (along with other advanced and renewable

energy technologies). California has shifted its power generation subsidy largely away from fuel cells toward power storage. With BEVs, China has shown that it is happy to cut as well as advance subsidy, though we don't think cuts are likely. China could have an opportunity to do with fuel cells what it did with solar PV, and our discussions suggest further and deeper financial, industry and policy engagement. It's also possible new public sector leadership will emerge or strengthen, in Scandinavia, Asia or the Middle East, particularly if China succeeds.

It is possible 2018 will be the year that the broader supply chain becomes more meaningfully engaged in partnership with its fuel cell system customers, not just as vendors but as partners. What happens in China will affect parts of the industry deeply – especially the PEM supply chain and what happens in transport. But we expect to see the phenomenon of supply chain engagement elsewhere, as and if markets grow toward truly commercial levels. China is also looking for better power generation technologies, and good SOFC companies are in demand. Tension will remain between what can be fully acquired, what will stay offshore, and when and how fundamental technology gets transferred. New payment models and new structures are already being set up to try to deal with these issues.

We know of some interesting plans for 2018. The fact that several companies have raised funds in 2017 is positive, and the discussions we've been party to suggest two more things: some companies will break cover with important product or partner announcements; and some of the quieter companies will close funding and move closer to the limelight, win performance competitions and announce game-changing orders.

We think some familiar names may exit, as was the case in 2017. And while supportive policies have enticed customers to the table there is not yet a sizeable market that fuel cells supply on truly commercial terms, nor is one likely to emerge in 2018.

Get in touch

We spend our time following this and other industries, talking to those involved, and figuring out what happens next. Opportunities for hydrogen and for the electrolyser industry are one ongoing theme; the shape of the future car industry is another; so is insight on China.

If you have more specific questions then please do get in touch. If they're easy we'll try and answer them quickly. If you need something more complicated, detailed or bespoke, such as a risks-and-opportunities evaluation or our forecast for a segment, region or technology – or for the industry as a whole – then we'll be happy to discuss a consulting engagement. Some of our offerings are laid out on page 50.

Data tables

Shipments by application						
1,000 Units	Fuel Cell Today		E4tech			
	2012	2013	2014	2015	2016	2017
Portable	18.9	13.0	21.2	8.7	4.2	4.9
Stationary	24.1	51.8	39.5	47.0	51.8	55.7
Transport	2.7	2.0	2.9	5.2	7.2	12.0
Total	45.7	66.8	63.6	60.9	63.2	72.6

Shipments by region of adoption						
1,000 Units	Fuel Cell Today		E4tech			
	2012	2013	2014	2015	2016	2017
Europe	9.7	6.0	5.6	8.4	4.4	5.1
N America	6.8	8.7	16.9	6.9	7.7	9.9
Asia	28.0	51.1	39.3	44.6	50.6	56.8
RoW	1.2	1.0	1.8	1.0	0.5	0.8
Total	45.7	66.8	63.6	60.9	63.2	72.6

Shipments by fuel cell type						
1,000 Units	Fuel Cell Today		E4tech			
	2012	2013	2014	2015	2016	2017
PEMFC	40.4	58.7	58.4	53.5	44.5	45.5
DMFC	3.0	2.6	2.5	2.1	2.3	2.8
PAFC	0.0	0.0	0.0	0.1	0.1	0.2
SOFC	2.3	5.5	2.7	5.2	16.2	24.0
MCFC	0.0	0.0	0.1	0.0	0.0	0.0
AFC	0.0	0.0	0.0	0.0	0.1	0.1
Total	45.7	66.8	63.6	60.9	63.2	72.6

Footnote to tables: Data from 2012-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2017 is our forecast for the full year, based on firm data from January to October. We have slightly revised the figures for 2016 in this report.

Data tables

Megawatts by application						
Megawatts	Fuel Cell Today		E4tech			
	2012	2013	2014	2015	2016	2017
Portable	0.5	0.3	0.4	0.9	0.3	0.5
Stationary	124.9	186.9	147.8	183.6	209.0	213.5
Transport	41.3	28.1	37.2	113.6	307.2	455.7
Total	166.7	215.3	185.4	298.1	516.5	669.7

Megawatts by region of adoption						
Megawatts	Fuel Cell Today		E4tech			
	2012	2013	2014	2015	2016	2017
Europe	17.3	17.3	9.9	27.7	27.4	39.1
N America	61.5	74.7	69.8	108.4	213.6	325.5
Asia	86.1	122.9	104.5	159.7	273.8	303.0
RoW	1.8	0.4	1.2	2.3	1.7	2.1
Total	166.7	215.3	185.4	298.1	516.5	669.7

Megawatts by fuel cell type						
Megawatts	Fuel Cell Today		E4tech			
	2012	2013	2014	2015	2016	2017
PEMFC	68.3	68.0	72.7	151.8	341.0	486.8
DMFC	0.3	0.2	0.2	0.2	0.2	0.3
PAFC	9.2	7.9	3.8	24.0	56.2	81.0
SOFC	26.9	47.0	38.2	53.3	62.9	76.4
MCFC	62.0	91.9	70.5	68.6	55.7	24.7
AFC	0.0	0.3	0.0	0.2	0.5	0.5
Total	166.7	215.3	185.4	298.1	516.5	669.7

Footnote to tables: Data from 2012-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2017 is our forecast for the full year, based on firm data from January to October. We have slightly revised the figures for 2016 in this report.

Notes

- 2012-2013 figures are as published in the Fuel Cell Today Industry Review 2013. Note that the figures for 2013 were a forecast to full year, which we have not changed retrospectively.
- Data for 2014 to 2017 have been collected directly from fuel cell manufacturers 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 2017 figures are a forecast for the full year. The dataset contains firm numbers for the period January to October 2017, 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 2017 in our 2018 edition as appropriate. We have slightly revised the figures for 2016 in this report: Unit numbers were reduced by about 3% and megawatt numbers increased by about 8% compared to our published 2016 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 is

a Visiting Professor at Imperial College London, chairs the Steering Committee of the Grove Fuel Cell Symposium, and has been an invited keynote speaker at conferences on six continents.



Franz Lehner is a Senior Consultant at E4tech, with a focus on fuel cells and hydrogen generation technologies. His work includes supply chain and cost analyses as well as market and energy scenario analyses. He is regularly presenting

E4tech's work at conferences and seminars and is well connected in the fuel cell and hydrogen community.



Robert Rose is Executive Director of the Breakthrough Technologies Institute, an independent nonprofit advocate for technologies with environmental benefits to society, and fuel cell activities since 1991. Following senior

communications and policy positions in US government, Rose advises state and regional governments, nonprofit organisations, and the private sector. Rose was founder of the US Fuel Cell Council in 1998 and Executive Director for 10 years. He writes and lectures widely about fuel cells and hydrogen energy and has received numerous industry awards.



Jonathan Lewis is an independent consultant with over twenty years' experience in business development, from strategy and policy development through business plans to technology commercialisation activities. 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 to the private and public sectors. He has extensive experience in Europe, from the Board of the FCH JU and the NEW-IG, and more recently in a variety of roles with the FCH JU.



Matthew Klippenstein is an independent consultant with 15 years' engineering experience in fuel cells. The first person to chronicle the Canadian electric vehicle market, he does so for GreenCarReports.com. He also contributes fuel cell coverage to

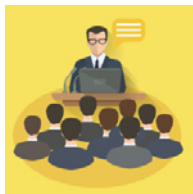
GreenTechMedia.com and co-hosts the CleanTech Talk podcast. He heads Electron Communications, a cleantech-centric communications consultancy, and can be followed on Twitter at @electroncomm.

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?

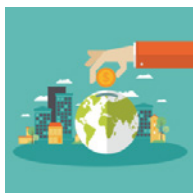
We can tailor a **presentation** or **workshop**, long or short, to cover the big picture or the fine detail.



Market and Supply Chain Analyses:

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

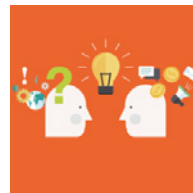
We have carried out detailed analyses for large and small corporations worldwide, feeding into technology and supplier choices, **business development** and **strategy**.



Commercial and Technical Due Diligence Evaluations:

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

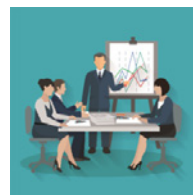
Our many **technical and commercial analyses for due diligence** purposes have helped diverse **investors** to understand risks and opportunities



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

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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 2016 to 30th November 2017.

US\$1 = € 0.8982	€1 = US\$ 1.1158	1£ = US\$ 1.2781	1¥ = US\$ 0.0089
US\$1 = £ 0.7830	€1 = £ 0.8726	1£ = € 1.1467	1¥ = € 0.0080
US\$1 = ¥ 112.10	€1 = ¥ 125.04	1£ = ¥ 143.26	1¥ = £ 0.0070



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