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The Fuel Cell Industry Review 2016

ACKNOWLEDGEMENTS

We gratefully acknowledge the contribution of many individuals and companies within the fuel cell industry in providing information for and assistance with the compilation of the Fuel Cell Industry Review 2016. The Fuel Cell Industry Review 2016 is based on information available up to early November 2016.

LIST OF ABBREVIATIONS

AFC – Alkaline Fuel Cell
APU – Auxiliary Power Unit
BEV – Battery Electric Vehicle
CFCL – Ceramic Fuel Cells Limited
CHEM - Chung-Hsin Electric and Machinery Mfg Corp
CHP – Combined Heat and Power
CTCG – Chaozhou Three Circle Group Ltd
DLR - Deutsches Zentrum für Luft- und Raumfahr
DMFC – Direct Methanol Fuel Cell
DoE – US Department of Energy
EFOY – Energy For You (SFC Energy fuel cell products)
EPS – Electro Power Systems
EV – Electric Vehicle
FC – Fuel Cell
FCE – FuelCell Energy (USA)
FCEBs – Fuel Cell Electric Buses
FCEV – Fuel Cell Electric Vehicle
FCH JU – Fuel Cells and Hydrogen Joint Undertaking (EU)
FTA – US Federal Transit Administration
FY – Fiscal Year
GDL – Gas Diffusion Layer
HRS – Hydrogen Refuelling Station
HyESS – Hybrid Energy Storage Systems
IAA - Internationale Automobil-Ausstellung
ICE – Internal Combustion Engine
IE – Intelligent Energy
IPO – Initial Public Offering
IP – Intellectual Property
JV – Joint Venture
kW – Kilowatt
LGFCS – LG Fuel Cell Systems
LNG - Liquefied Natural Gas
LMP - Le Mans Prototype
LoNo – Low or No Emission Vehicle Deployment Program
MCFC – Molten Carbonate Fuel Cell
MEA – Membrane Electrode Assembly
METI - Ministry of Economy, Trade and Industry (Japan)
MHPS - Mitsubishi Hitachi Power Systems.
MOST - Ministry of Science and Technology (China)
MoU – Memorandum of Understanding
MTU – Motoren und Turbinen-Union (part of Rolls-Royce)
MW - Megawatt
NIP – German National Innovation Programme for HFC Tech
NOW – German National Organisation HFC Technology
OEM – Original Equipment Manufacturer
PAFC – Phosphoric Acid Fuel Cell
PEM(FC) – Proton Exchange Membrane (Fuel Cell)
PFSA - Perfluorosulfonic Acid
PHEV – Plug-in Hybrid Electric Vehicle
R&D – Research and Development
RoW – Rest of the World
SAFC – Solid Acid Fuel Cell
SAIC – SAIC Motor Corporation
SARTA – Stark Area Rapid Transit Authority, Ohio
SOFC – Solid Oxide Fuel Cell
STEP - Société du Taxi Electrique Parisien
TTSI - Total Transportation Services Inc.
UAV – Unmanned Aerial Vehicle
UPS – Uninterruptible Power Supply
UTC – United Technologies Corporation
UUV - Unmanned Undersea Vehicle
W - Watt

November 2016

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Progress evident, but vision helps: The Fuel Cell Industry in 2016

The fuel cell 'industry' continues to grow, according to the numbers. We think the supply chain is starting to solidify, though it is far from robust, and much of the policy environment is positive. But the industry remains small, fragile, and almost entirely driven by government support. Japan seems to be maintaining its resolve, drawing in more big corporations, and Korea continues to aspire to something similar. In Europe and North America things continue at their typical pace. Enough support is provided to keep most of the players alive, but not enough either to drive real commercial growth – or to prove it can't be done. Only China seems to wish to step up, with evidence emerging of a near-term dramatic increase in fuel cell deployment alongside ongoing support for science and technology.

The Paris agreement sent a very clear signal that mankind faces a global problem and that we need to deploy every solution we can to solve it. It gave some impetus to clean technology solutions and some big-name investors. Energy systems models suggest hydrogen and fuel cells can play an important role. But the economic doldrums felt by many countries, coupled with some significant political turmoil, seem to be paralysing many attempts to speed up deployment.

On the positive side, many more MW of fuel cells were shipped in 2016 than any year before – an increase of two-thirds from 2015. Annual PEM shipments doubled to over 300MW,

transport more than doubled to nearly 280MW. The two are strongly linked, as much of that increase was down to fuel cell vehicles, and specifically to the Toyota Mirai. Transport MW shipped overtook stationary for the first time.

The number of fuel cell units shipped did not increase as much. Total shipments were nearly 5 thousand units more than the 60 thousand in 2015. The Japanese Ene-Farm programme is once again the main driver and its annual shipments are likely to number around 50,000 units by year-end. Many more of those units are SOFC than previously, probably around 10,000. Numbers of portable units continue to drop, though these have historically been dominated by very small chargers and so this has limited influence on the supply chain, and almost none on the MW numbers. Applications such as UAVs and military support devices continue to be important in the sector. PAFC shipments nearly doubled, a sign that Doosan is starting to master the technology it picked up from UTC a couple of years ago, though news of layoffs at Doosan in the US was sobering. MCFC and SOFC MW look flat overall, though in the SOFC breakdown the shares of different companies and applications have changed.

Underlying all this is good news. The industry has responded well to policy and market signals, and some companies are finding solutions that do not rely on policy but on economic advantage, on customer wants or on corporate ambitions. UAV-type applications and the conversion of warehouses and heavy-duty fleets to hydrogen and fuel cell operation fit somewhere in that space. All of this should help to drive technology development and increase the number of serious players in the supply chain. As we seem to say every year, some companies may even start to derive profitability from fuel cells. Ballard, Hydrogenics and Ceres Power all showed that big orders

and fundraising are still entirely possible. But the failed funding round that led to Intelligent Energy cutting more than half its workforce, the fuel cell job losses at Doosan and POSCO and the news that Samsung SDI has thrown in the towel and sold its fuel cell IP to Kolon, are all signals that the sector remains a tough place.

Highlighted by Paris, governments are again looking hard at how to meet their climate change commitments. Although this will need systemic change, previously enacted measures show how fast and how dynamically this can occur. Germany and Portugal now have vast amounts of renewable power on their grids at certain times, and balancing is required. Fuel cells and hydrogen can help through energy storage, through more efficient decentralised generation (even using fossil fuels), though inherently low emissions and by their controllable and dispatchable nature. The UK has published a study on decarbonising heat through the widespread use of hydrogen in the place of methane in the gas grid, and a roadmap on how to exploit the potential of hydrogen and fuel cells. Both show that fuel cells and hydrogen are important weapons in the arsenal against climate change and air pollution. France is declaring 'Hydrogen Territories', the US is examining 'Hydrogen at Scale' across multiple National Laboratories, and in Japan hydrogen remains a pillar of government energy strategy.

Decarbonising road transport also depends on new technologies. Battery vehicles are an increasingly important part of that, but fuel cells have advantages of range and refuelling time, and may be easier to implement in heavy vehicles. The increased number of buses deployed and the emergence of fuel cells in trucks show the way. The VW emissions scandal, and the evidence that other car companies are far from blameless, put further pressure on bringing new solutions to bear.

But the sort of reductions required cannot be achieved by fuel cells alone, nor by any individual technology. Nor will they result from small-scale pilot and demonstration programmes. Many of the benefits of fuel cells and hydrogen are achieved at a national system level, not just by individual users or suppliers. Bold visions are needed, like that expressed by the Japanese Government, which is almost single-handedly building an industry and has many major corporations in support. China shows signs of developing the same scale of vision, though it is not yet articulated as forcefully. Each is supporting research, development and large-scale rollout, driven by economic motives of course, but also by the need to solve environmental problems. By comparison, the picture elsewhere is disappointing. Large-scale system change will not arise – at least not for a very long time – through small disjointed programmes. Fuel cells are not a 'silver bullet' solution and should not be viewed as such. Some companies and some technologies will not survive. But mankind needs all of the technologies at its disposal against climate change, and we risk taking fuel cells off the table through neglect before they can really show their value.

About the Review

Applications

As in previous years, to allow year on year data comparisons, we use the categorisation of shipment data 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 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 400 kW	1 kW to 100 kW
Typical technology	PEMFC DMFC	PEMFC SOFC MCFC PAFC AFC	PEMFC DMFC
Examples	• Non-motive APU (campervans, boats, lighting) • Military applications (portable soldier-borne power, skid mounted generators) • Portable products (torches, battery chargers), small personal electronics (mp3 player, cameras)	• Large stationary combined heat and power (CHP) • Small stationary micro-CHP • Uninterruptible power supplies (UPS)	• Materials handling vehicles • Fuel cell electric vehicles (FCEV) • Trucks and buses

Portable fuel cells encompass those designed to be moved, including auxiliary power units (APU); Stationary power fuel cells are units designed to provide power to a fixed location; Transport fuel cells provide either primary propulsion or range-extending capability for vehicles. We have slightly extended the FCT 'typical' portable power range, starting at 1W rather than 5W. This is simply for clarification and does not change the shipment data; smaller units were anyway included in the past.

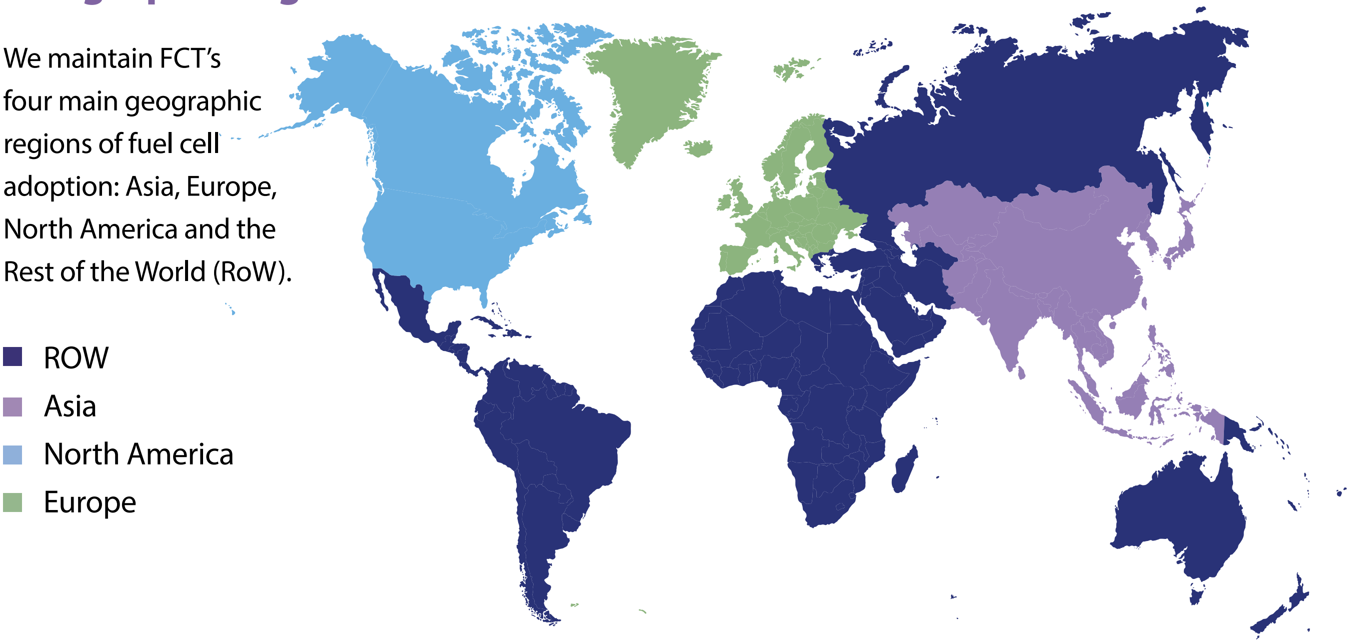
Fuel cell types

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).



Reported shipment data

Tables of data can be found at the back of this Review, including historical information from FCT dating back to 2011. 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. The regional split in our data refers to the countries of adoption, or in other words, where the fuel cells have been shipped to.

In accordance with previous reports by FCT, we do not include shipments for toys and educational kits.

Data sources and methodology

For the years 2011 to 2013 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.

Our 2016 figures are a forecast for the full year. We have been in direct contact, either verbally or in writing, with close to 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 only 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.

We will revise data for 2016 in our 2017 edition as appropriate. We have slightly revised the figures for 2015 in this report.

How was 2016 for the fuel cell 'industry'?

The fuel cell industry remains a challenging place. While some companies and technologies inch further up the mountain face towards the summit of commercial achievement, others hang in crevasses or have been engulfed by avalanches. In the most simplistic terms, 2016 was a great success, with shipments rising again, and by a good number. Some 65,000 units were shipped, an increase of around 10% over last year. MW shipments increased by two thirds – with much accounted for by vehicle sales.

Of course, behind those positive shipment numbers the details are more complex.

Some headlines remain comfortingly stable: the deployment of sub-kW residential CHP units into the Japanese Ene-Farm programme remains high, with another 50,000 or so expected to be running by the end of 2016. The news here is more about an apparent though gradual shift towards SOFC, with a much higher number of units than before. Fuel cell forklifts are still a growing business, and are now making inroads in Europe, with Carrefour and Colruyt amongst major corporations to deploy vehicles. Toyota continues to make and ship Mirais, more or less according to their previously announced plans, and Honda's cautious release of the first Clarity Fuel Cell cars to chosen customers meant they joined Toyota and Hyundai on the slopes of the mountain. Less well-known, but with quite a different approach to solving the roll-out challenge, was UK start-up Riversimple's unveiling of the Rasa, a car intended to be leased, not sold, as part of a mobility solution. At the other end of the spectrum, Pininfarina showcased a fuel cell supercar in Geneva.

China, previously often mentioned in passing, now seems considerably more serious about fuel cells. A major Government support scheme for New Energy Vehicles, and with strong support for fuel cell buses in particular, is reinforced by funding for hydrogen infrastructure, and by projects developing roadmaps, monitoring and supply chain capability. Dragons may be stirring in those fuel cell mountains. And Germany, always strong in its support, has announced a major new funding initiative for fuel cell CHP, akin to Ene-Farm. Coupled with continued support for the NOW organisation and the NIP, it remains an important fuel cell supporter. So does the US: California in particular, continue to influence both vehicle and stationary installations and the Department of Energy seems keen to fund market development activities in addition to R&D. Korea appears to have ambitious plans to convert from natural gas buses to hydrogen fuel cells, and Japanese funding remains amongst the highest in the world. In other jurisdictions, India produced a hydrogen roadmap, as did the UK, looking at where it makes sense to act in the near term.

Companies that did well in terms of orders this year include Ballard and Hydrogenics. Ceres Power raised a further £20m and publicly announced its partnership with Nissan. SymbioFCell attracted investment from French energy giant Engie, and Bloom Energy announced plans for an IPO – though it did so in secret and the IPO appears dependent on the extension of the US 30% per kW tax credit, which is scheduled to expire in December. China got its first publicly listed hydrogen energy company: Beijing SinoHytec, and other

JV investments. Doosan showed that PAFC was back in the game with many more shipments than the previous year, but also cut back its North America operations, where the market seems to remain hard going.

The highest profile disappointment was probably Intelligent Energy's failure to close a financing deal early in the year, leading to a precipitous share price drop, the shedding of over half the workforce and a major adjustment in strategy. IE received a rescue cash injection from one of the existing investors, but its path forward is not yet free of very icy patches. Disappointment hit FuelCell Energy, whose planned 63MW Beacon Falls project, under the New England Clean Energy programme, was eventually turned down, and whose links to POSCO were looking shaky early in November following an announcement that POSCO was looking to divest its fuel cell business. Heliocentris entered a period of voluntary insolvency in October, though its fundamentals seem stronger than this news suggests.

In addition to the Chinese funding, and 22 buses actually going on the road in Foshan and Yunfu, announcements of good-sized fleets were made in Europe. Vehicles other than cars received generally good press, in fact, as increasing numbers of range-extender trucks for local deliveries were built and delivered, and Alstom unveiled its first light-rail application in Germany. News suggested that Easyjet was testing fuel cells for nose-wheel power, though no provider was specifically mentioned, and Royal Caribbean claimed it would work with Finnish shipbuilder Meyer Turku on fuel cell use in its new LNG-powered Icon line of ships, testing them from 2017 and scaling up the size of the fuel cell over subsequent years.

Paris announced a fleet of hydrogen fuel cell taxis, and Linde bought 50 Hyundai cars to make available under their car-sharing programme BeeZero in Munich, in a move to introduce potential customers to fuel cell vehicles. Linde particularly wants people to shun the usual car sharing mode of short city trips and take the cars into the mountains for the weekend, so they can experience the range that differentiates fuel cell vehicles from battery EVs.

Away from most of the headlines, the supply chain continued to build, exemplified by such announcements as Impact Coatings of Sweden tying up with China Hydrogen Energy to supply high volume coating equipment into the Chinese market. Japan is strengthening its own indigenous supply chain capabilities but is open to global manufacturers, as Toyota's use of WL Gore's fuel cell membrane attests. In Korea, Kolon Industries first acquired Samsung SDI's fuel cell equipment and IP as it stopped its R&D programme, and subsequently made its own deal with Gore to use its MEA technology.

Overall 2016 was another positive year for fuel cells, but the reliance on government support remains very strong. Fuel cells do not have a 'halo' product as Tesla's cars have been for battery EVs, nor do they have the same strength of advocacy and momentum. Fuel cell companies continue to struggle toward profitability even as the overall growth in shipments and units continues to signal positive market growth. The signing of the Paris agreement is a positive sign for all technologies with carbon reduction credentials, and appalling air quality in many regions means that all options for improvement ought to be strongly pursued, so the slope of the mountain may be slightly less than in the past – but intention needs to be turned into action.

Fuel cell transport: the expanding offering

Fuel cell cars are in many senses the bellwether of the industry. To equal their ICE competitors, fuel cell vehicles need to match and arguably improve upon 110 years of development and refinement, providing extremely cost-effective, ubiquitous and reliable transport. Achieving that is taking time, enormous amounts of money, and several false starts. Since 2013 however, when Hyundai's first small-series production vehicles became available, the picture has improved. The Toyota Mirai followed with great fanfare; Honda's Clarity Fuel Cell became available to some lucky customers in 2016; Daimler has announced its GLC for next year. But these flagship vehicles are increasingly surrounded by others, many less sexy, but just as important. And the environment – literally – is changing. Norway, the Netherlands and Germany have voted in some way to ban polluting vehicles by 2025, the former two by 2030, though implementation remains unclear.

Fleets: introduction by stealth?

Selling cars to individual consumers, especially when refuelling infrastructure is hard to find, is tough. Putting together a fleet package with a refuelling station or two makes good sense both for vehicle provider and fuel station operator, and so in many places this is under way. In Munich, Linde became the world's largest FCEV fleet operator when it put 50 Hyundai vehicles on the road in its BeeZero car-sharing programme. Designed to allow sharers to really experience the benefits of FCEVs, pricing is set to incentivise longer drives, perhaps into the mountains for the weekend, unlike typical short-term schemes. In Paris, home to a fleet of five Hyundai taxis since late 2015, another 60 will arrive in the coming months. The STEP start-up (Société du Taxi Electrique Parisien) intends to expand the fleet to several hundred vehicles over the next five years. France is home to other fleets – its H2Mobilité programme strategy underpins their roll-out in conjunction with fuelling stations. Many are provided by a tie-up between fuel cell producer SymbioFCell and

Renault, where the latter's electric Kangoo vans are modified by adding a 5kW FC range extender for a range of 300-400km. The conversion kit is produced by Symbio and part-owner Michelin to automotive specifications, and integrated into the vehicle by Renault. A standard Kangoo listed at €23,500 costs an additional €32,000 to convert. They are being used by French postal services, firemen and many other businesses.

In the UK, Riversimple showcased its Rasa car earlier in 2016. A ground-up design from the man behind the new Fiat 500, the car is small, light and aerodynamic. It needs only 8.5kW of fuel cells, coupled with four in-wheel motors and supercapacitors for regenerative braking. Riversimple says they will never sell a car, but sell mobility at an all-in price for car, maintenance, insurance and fuel. They are prepared to sell shares in the company, however. UK developer Microcab is also working on small vehicles for fleet operation. UK fleets got a further boost as the organisations to be supported by the government's £2m scheme were announced. Australia has started to move on hydrogen fleets too. Canberra has ordered 20 Hyundai cars for 2018, along with a refueller from Siemens, to join Sydney's existing operation.

By far the biggest fleets announced have been in China, however. National and local government support for buses, vans and refuelling stations has ramped up dramatically, with hundreds of buses scheduled to be coming into service starting from 2016. Support extends into cars too, where until now the only apparent developments have been Sunrise Power's production of FC systems for SAIC. Around a hundred of those units should be going into test vehicles.

Other cars kept coming

More Mirais and more Tuscon UC X - iX35s were sold in 2016 – a good thing. Perhaps even better, announcements came on many other cars. Daimler finally unveiled its launch vehicle – a GLC SUV, which is not only a fuel cell but also a plug-in hybrid. Rumours suggest Honda's next Clarity will also come in PHEV and BEV flavours. The PHEV makes some sense. Though potentially more expensive than a straight FCEV or BEV because of the multiple systems on board, in practice those systems can be optimised and balanced against

each other, leading to reasonable final costs. More importantly, for short trips the car can rely on the all-electric range and recharge at existing sockets, and for long trips only limited hydrogen infrastructure is required. The best of all worlds?

The GLC is scheduled to be available in 2017. The Clarity may be available in California by the end of 2016, for an anticipated $60,000 or on lease for $500 per month. Toyota's own leasing option was made much cheaper mid-2016, as demand was slack in California – mainly because of severe delays to HRS rollout. The lease dropped from $499 to $349 per month, though buying it still costs $57,500 – minus an $8,000 federal tax credit (scheduled to expire at the end of 2016) and a $5,000 California rebate. A smaller, cheaper version could be out in 2019

though, to complement the rumoured Lexus launch in 2020. Hyundai will have its own new vehicle out in 2018, and daughter company Kia is working on another.

Also in 2016, Audi showed its h-tron Quattro at the Detroit motor show, rumours suggested Ford might have a vehicle out in 2017, and BMW reiterated its plans to only launch in the next decade. BMW's erstwhile head of hydrogen fuel cells moved to Great Wall Motors in China to run their new fuel cell business. GM, who built the very first fuel cell van and led technology development over the years, remains coy about its timing. Their executive director of global fuel cell activities was quoted as saying that they could produce a vehicle, but only with antiquated propulsion units. GM has been active in other segments though, with Chevrolet producing a military FCEV called the Colorado ZH_2, and GM stack technology being used by the US Navy.

The award for most unexpected fuel cell car went to Nissan, who announced a Ceres Power bioethanol SOFC system in a so-called e-Bio vehicle for testing in Brazil, ostensibly to overcome infrastructure problems with hydrogen while moving towards sustainable mobility.

Trucks start to make headway

Battery cars are making headlines worldwide. The prices are projected to keep coming down, more models are available, and some level of charging is installed in many regions. For many journeys BEVs make absolute sense. But the bigger the vehicle, the more batteries it needs, and the harder it gets to deliver against expectations. Buses are hard, and trucks even more so. Long distance trucks are the trickiest of all. Some say hydrogen fuel cells have the answer, though performance expectations are even tougher here than for passenger cars. Still, 2016 saw several announcements pushing fuel cells for trucks. For smaller vehicles like vans, things are comparatively straightforward, as some of the previous discussion suggests. Hyundai for example showed its H350 Fuel Cell Concept van at the 2016 IAA Commercial Vehicle Show in Hanover, Germany. Able to carry either 14 people or up to 455 cubic feet (13m3) of cargo, the van should get just over 400km of range.

Bigger vehicles are coming into service though, encouraged in part by the State of California's interest and financial support, but also by some corporations seeking greener supply chains. Following Renault's 4.5t Maxity truck, converted to a fuel cell range extender by SymbioFCell in 2015, has come a series of other announcements. The San Pedro Bay ports in California will be trialling fuel cell drayage trucks with Ballard, BAe Systems and TTSI. Hydrogenics is also working on a drayage truck solution with Siemens and TTSI. Loop Energy, previously Powerdisc, in Vancouver is working with both Peterbilt and Hunan CRRC Times Electric Vehicle Co., Ltd of China to develop fuel cell trucks, while Nikola Motor Company is making big claims for its own hydrogen powered semi-truck and allegedly has 300 hydrogen fuelling stations in waiting in the US. Toyota has talked about its exploration of a fuel cell semi-trailer truck in California. More

prosaically, perhaps, the Co-op chain of supermarkets in Switzerland has actually launched the world's first 34t fuel cell truck. Sweden's PowerCell provided the 100kW stack, integrated by SwissHydrogen and ESORO. The electric motor provides a steady 250kW and seven 700bar Luxfer tanks stacked behind the cab give the truck 32kg of usable hydrogen, and a range approaching 400km.

Trams and trains

Continuing and expanding the heavy duty theme, fuel cells are now being demonstrated in light rail applications and locomotives. While overhead or ground electrification is an excellent way to eliminate local emissions from rail, it can be expensive or impractical, and again hydrogen may offer a solution. Hydrogenics announced last year that it would supply fuel cell systems to Alstom for use in light trains in Germany, and the first tests were carried out on the train itself just after summer. Tests will continue through 2017 and should culminate in type approval by the end of the year, but Alstom expects firm orders for 40-70 trains in the coming months. In China, the first commercial fuel cell tram line is aimed to begin operating in late 2017 in the city of Foshan, with Ballard supplying the fuel cell modules. CRRC in Tangshan is also using Ballard systems and demonstrated its hybrid tram in May. Shunt locomotives with FC APUs have been demonstrated in India, and fully powered shunt locomotives demonstrated in the US.

Forklifts trundle on

Around 10,000 fuel cell forklifts are currently in daily use, the vast majority made by PlugPower and used in the US. They remain the most successful fuel cell vehicle to date. While the business case in North America has enabled them to get traction, however, things in other regions have been harder. Smaller

fleets, fewer operating hours, different regulations and lower subsidies have all worked against them. Things are starting to change though, as Europe and Japan both show interest in the business model. Europe's initial foray came – as is often the case – through FCH JU funded projects, HyLIFT-EUROPE and HAWL. The former has had operating lift trucks since 2015, the latter recently added 36 units to the European fleet in a French warehouse. Indeed France seems to be the main home for the units (possibly because of Plug Power's base in France and its links to Air Liquide), as Carrefour has announced it will take 150 of Plug's GenDrive units for operation starting in 2017. Belgian retailer Colruyt Group is 'dropping in' 75 of the units into its class 3 pallet jacks at its Dassenveld distribution centre at Halle near Brussels, and will have 200 by the time it is finished.

Nuvera, owned by Hyster-Yale, is developing lift truck solutions for both warehouses and ports, while Toyota further builds out its hydrogen vision through a project in Kawasaki and Yokohama, in Japan, where 12 of its forklifts will run on renewable hydrogen. Linde has had fuel cell forklifts in operation with a few customers, including BMW and Daimler. BMW appears to be committed to hydrogen powered forklifts for its facilities worldwide.

Car or Supercar?

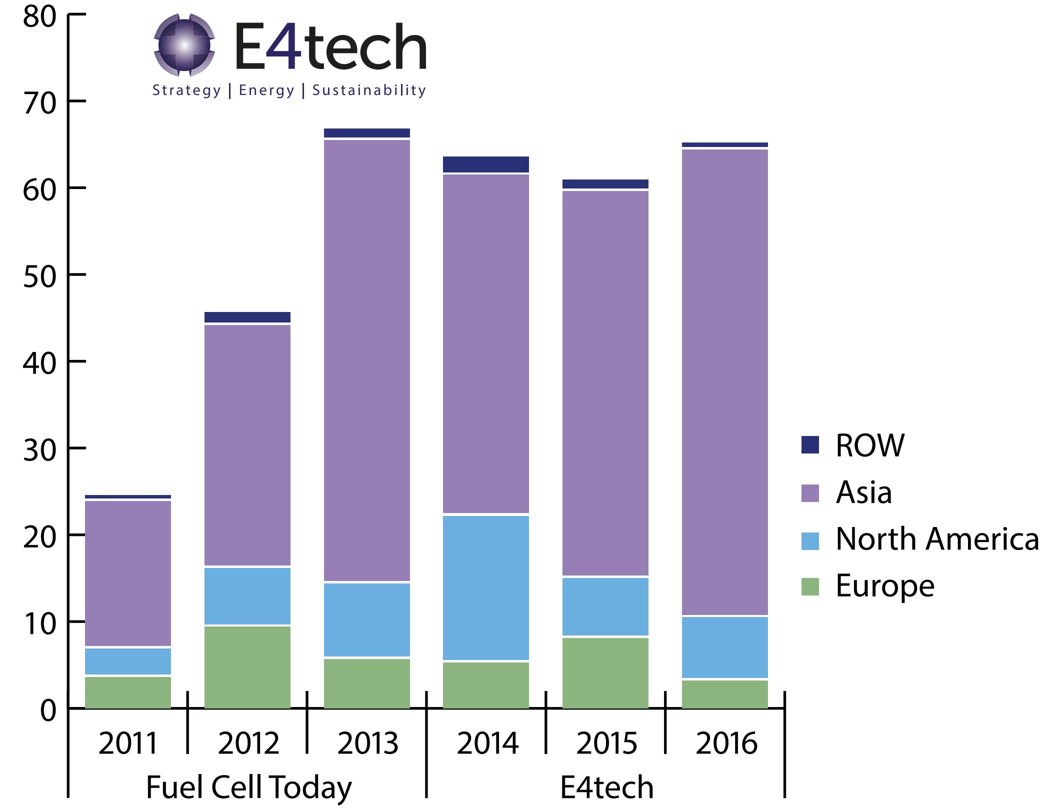
Having inhaled Tesla's dust for several years, seriously fast fuel cell cars are in the works. Audi now thinks it has the technology to build a fuel cell version of an LMP1 for Le Mans, which has announced that it has set up a working group to look at allowing hydrogen fuel cell cars to compete fully. GreenGT, the Swiss start-up that secured a 'Garage 56' slot for its own FC car at Le Mans several years ago, but failed to take it up, finally got to the track and completed several circuits just before this year's 84th 24 Hour race. It was the first FCEV to do so. GreenGT also starred at the Geneva Motor Show, where its Pininfarina-designed H2Speed was unveiled, winning best Concept car. Reports suggest that ten of the 500bhp, 300kph cars will be produced for ten environmentally conscious speed freaks, at $2.5m each.

"…and boats and planes…"

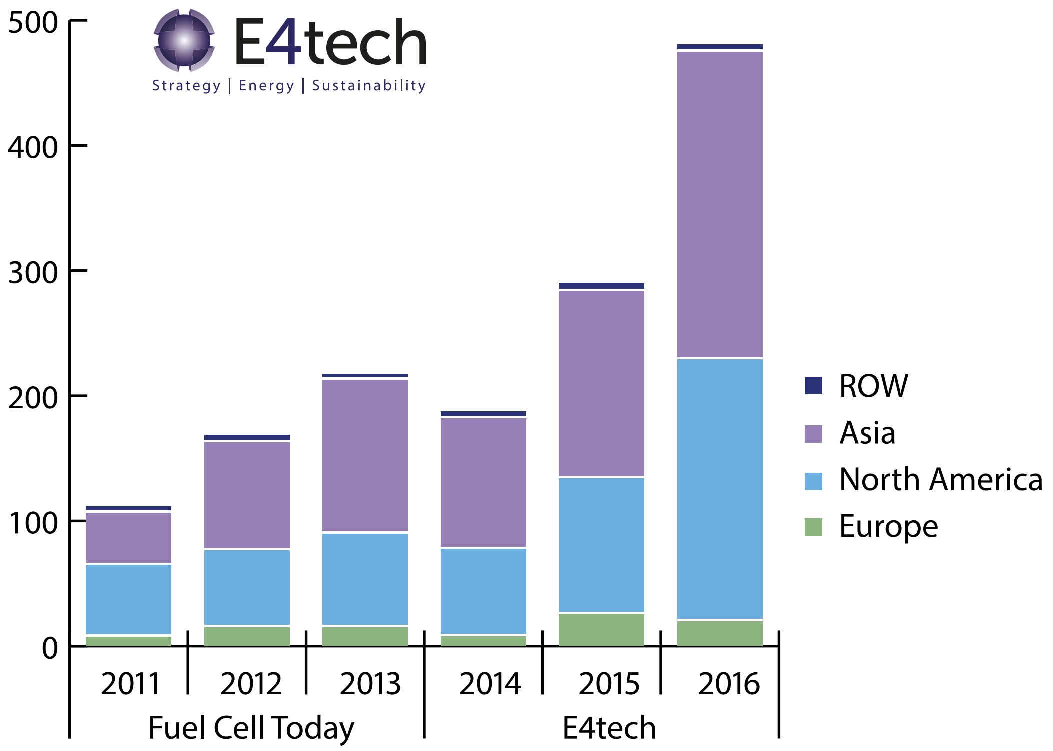
In addition to land-based vehicles, fuel cells are moving to the air and sea. Reports suggested that European low-cost flight provider Easyjet was testing a fuel cell powered nosewheel for taxiing, and Hydrogenics has worked on similar tests with German Aerospace. DLR's Hy4 plane was demonstrated in a flight from Stuttgart Airport – the plane again relies on Hydrogenics FC technology. On water, Sweden's Powercell received orders for two fuel cell stacks to be integrated into a solar-powered ship, and Royal Caribbean says it is moving towards use of fuel cells on its LNG-powered cruise liners. It will test units from 2017, and hopes to be fully operational by 2022. Finnish shipbuilder Meyer Turku is responsible for the build; no mention has been made of the fuel cell supplier.

Shipments by region

Units shipped by region 2011 - 2016 (1,000 units)



Megawatts shipped by region 2011 - 2016



Footnote to charts: Data from 2011-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2016 is our forecast for the full year. We have slightly revised the figures for 2015 in this report.

Shipments by region

Once again Asia leads the global deployment of fuel cell systems. Nearly 54,000 of the total of just over 65,000 FC systems, and 246MW of the global 479MW will be installed there in 2016. Japan continues to deploy large numbers of stationary fuel cells and, increasingly, FCEVs. Korea will once again be the largest market for utility scale fuel cell deployments. China is just starting to deploy numbers of FCEVs and this could rapidly accelerate over the next few years, as indicated by a large number of stacks and subsystems shipped to China in 2016, and more orders announced for integration into various types of road vehicles.

That Asia leads in deployment is no surprise given the very large investment and support by both Government and major private sector corporations. Japan is expected to add more PEM and SOFC micro-CHP FC systems this year than last, supported by the Ene-Farm programme and Panasonic, Toshiba and Aisin's partnerships with Japan's major gas suppliers. At the larger scale Mitsubishi-Hitachi has commissioned another 250KW hybrid SOFC, whilst Fuji Electric has installed further PAFCs. Toyota is rapidly introducing Mirais and Honda its own FCEVs to the Japanese car parc, further bolstering the numbers of PEM systems. Korea maintains its very supportive policy regime for fuel cell systems: 2016 has seen the installation of numbers of larger MCFC and PAFC FC systems from FCE, Doosan and POSCO. While Korea's incentives for deployment through the Renewable Portfolio Standard remain strong, POSCO's investment in the technology is now under review. China has some valuable financial incentives in place for FCEVs – and the hydrogen stations to fuel them - which is encouraging the adoption of the technology. Chinese policymakers are clearly trying to address the environmental issues in China's cities and towns, and the commissioning of 22 fuel cell electric buses in Autumn 2016 is likely to be the start of something much bigger. 2016 also saw the launch of Nedstack's 2MW PEM unit at the chlor-alkali plant of Ynnovate Sanzheng Fine Chemicals.

North America has also witnessed a major increase in 2016: although unit numbers are only up slightly, the MW shipped has almost doubled. This owes much to the delivery of Toyota's Mirais and other FCEVs, notably to California, plus the continued success of lift trucks. These FCEVs are driving both unit numbers and power up. As

has been the case for several years, reasonable numbers of larger stationary fuel cell units have been installed: MCFC, PAFC and SOFC by FCE, Doosan and Bloom respectively. This is especially the case in those States with supportive policies, notably California and Connecticut. The position of stationary fuel cells may be adversely affected by changes to the California tax regime. US installations of smaller stationary systems are also increasing – for powering telecoms towers, and for other back-up uses. These are supplied by Atrex Energy and Altergy amongst others. To date the region has seen few micro-CHP units deployed.

Europe's position behind Asia and North America is worsening. We estimate that annual unit numbers of fuel cells installed have fallen from 2015, essentially because of a lack of shipments of portable consumer chargers, though these add almost nothing to the MW total. The drop by about five megawatts to 22MW in 2016 is not indicative of specific trends, but a sum of several smaller effects. The relative lack of supportive public policies, including financial support, is the major factor behind the limited deployment of stationary fuel cells. At least for small systems, this will change with the start of a German Federal grant scheme for fuel cell micro-CHP, and with a further large European FCH JU funded micro-CHP fuel cell system project, PACE. These should encourage some major European and other corporations to invest more in the technology beginning in 2017. In FCEVs Europe's deployment also lags Asia and North America. The major European automotive OEMs are somewhat behind the Asian leaders, which are exporting limited numbers of their products to Europe's markets. However, there are encouraging signs for vehicles using range extender fuel cells, in which SymbioFCell is well placed. Similarly 2017 will see a number of fuel cell buses introduced into the European fleet as part of the 3Emotion project, which should be followed by the 142 buses of the JIVE project.

The 'Rest of the World' shipments continue to be minor. Both unit numbers and power shipped are down on 2016. Because they are small these numbers have been volatile to date, with a handful of projects sufficient to show swings in both units and power delivered. Companies continue to target these markets however, and shipments could increase steadily if the telecoms back-up and off-grid power markets develop, notably in India. South Africa also has ongoing ambitions for larger fuel cell system deployments, but plans have yet to mature.

China: slumbering dragons awaken

With most shipments of fuel cells still going to the old order in Asia, North America and Europe, China has been quiet. Chinese fuel cell producers do make sales both inside and outside the country, and imports of fuel cell systems for a variety of applications have been ongoing for a number of years. Chinese policy rhetoric has varied in its support for fuel cells, with a big push for vehicles around the Shanghai Expo and Beijing Olympics not strongly followed through. The picture is now changing.

Chinese national government policy on New Energy Vehicles has until now been more strongly focused on batteries and hybrids. That focus switched recently, with BEV subsidies gradually ramping down over the next few years, while fuel cell funding stay high. China also has good funding for hydrogen refuelling infrastructure; while the regions give additional vehicle subsidies. A policy that runs in tandem with the national government is designed to spur local bus makers into making fuel cell buses. China has the world's largest bus market and many producers, who tend to have a regional focus. Local and national policy combine to give the greatest subsidies to local manufacturers, but only if a certain percentage of buses is nevertheless imported. This supports local employment while preventing monopolies from arising, and is anticipated to result in 'thousands' of fuel cell buses being put on the road over the coming few years, almost all range extenders.

Automotive companies are also building up their skills. The long-term leader is SAIC, which has in the past worked with GM. They are receiving systems from Sunrise Power in Dalian. Others are also looking to build teams – the former head of BMWs programme is now at a Chinese OEM. And the Chinese government is more broadly seeking to restructure its industry base. From competing on price, but at low quality and with poor environmental and safety regimes, incentives are now going to companies who can show real added value, and with the right certification and track record to export overseas. Most Chinese component manufacturers are not yet close to achieving the levels of technical excellence required to be fully competitive globally, but are moving ahead fast. Indeed a Chinese supply line for MEAs was put in place in Wuhan for supply to ReliOn after an agreement back in 2007. In October the Wuhan city government, known as China's Motor City, linked up with two top Chinese universities – Tongji and China University of Geosciences – to jointly set up a fund worth 200m RMB ($30m) to support the hydrogen energy automobile industry. The UNDP, which has long had a relatively small programme supporting the implementation of fuel cell buses in China, launched several requests for proposals towards the end of 2016. In partnership with MOST, these are squarely aimed at rapidly developing Chinese capabilities in fuel cell component supply, and in developing and implementing roadmaps – for the country as a whole as well as for specific regions.

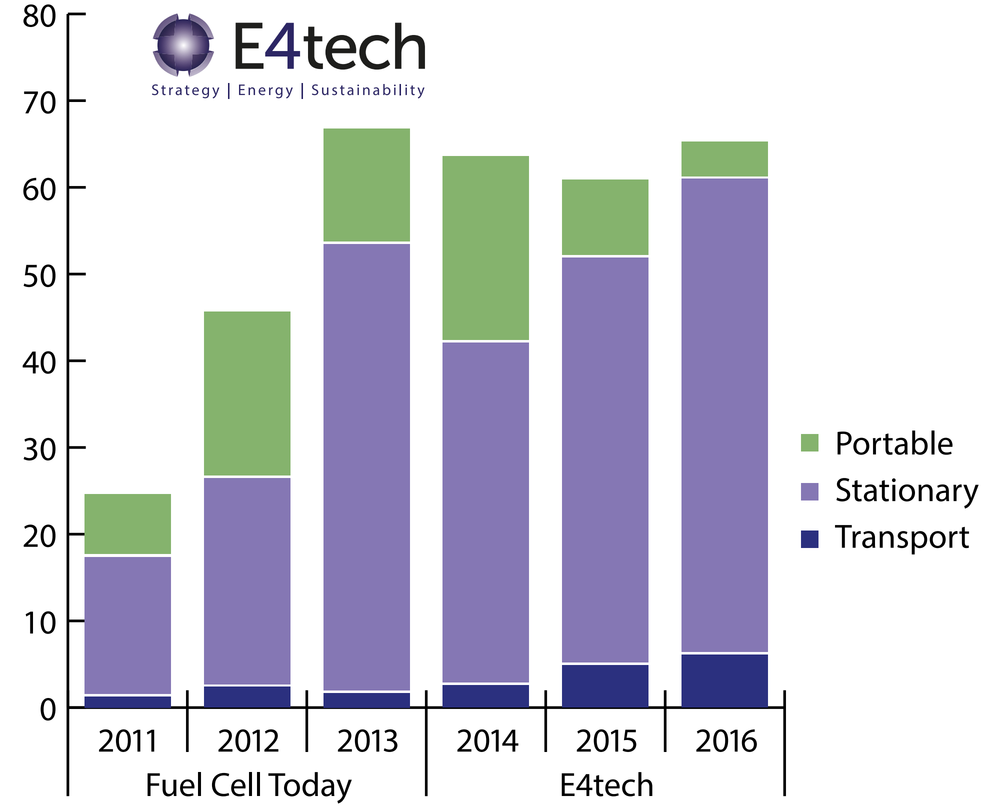
2016 saw several other important milestones, with China's first publicly listed hydrogen energy company: Beijing SinoHytec Co., Ltd., listed on the China National Equities Exchange in January. Hydrogenics has signed a $13.5m deal with the company to deliver fuel cell systems for bus and truck integration. Ballard signed a deal with Guangdong Nation Synergy to manufacture fuel cell stacks in Yunfu city. Ballard's deal, which includes a 'take or pay' agreement for MEAs, is worth $170m over 5 years. 22 buses have been deployed in Yunfu and Foshan. Ballard's erstwhile CTO is now CTO at the Guangdong-based JV.

Opportunities exist in the stationary sector too. Netherlands-based Nedstack inaugurated its 2MW power plant on a chlor-alkali facility in October. Installed on a site owned by Ynnovate Sanzheng Fine Chemicals, it uses otherwise vented and hence 'free' hydrogen to produce power; the latter is an expensive commodity in China. Much more hydrogen exists to be exploited. And Swedish company Impact Coatings has signed its own €10m deal to be a strategic partner of China Hydrogen Energy – which makes propulsion technology for FCEVs in Suzhou – and deliver coating technology for high volume production. Plug Power recently signed an MOU with Zhangjiagang Furui Special Equipment Co, along with a leading Chinese industrial vehicle manufacturer.

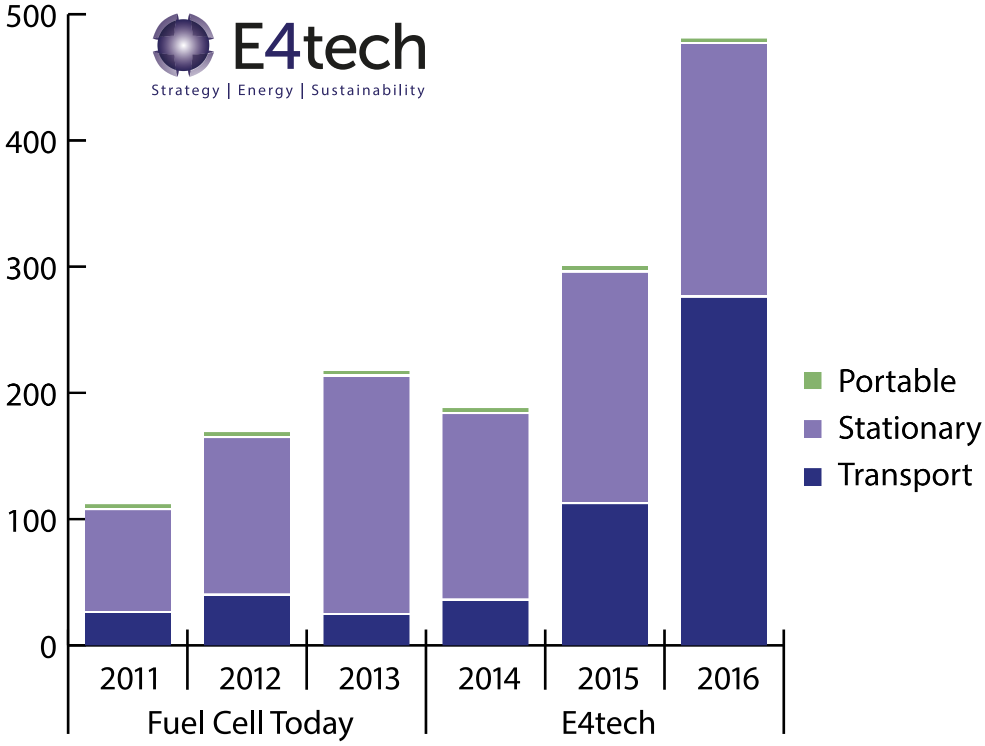
Chinese government policy and subsequent industry development has had global implications in the solar industry, in battery vehicles, and in other areas. It will be very interesting to watch what happens in fuel cells.

Shipments by application

Units shipped by application 2011 - 2016 (1,000 units)



Megawatts shipped by application 2011 - 2016



Footnote to charts: Data from 2011-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2016 is our forecast for the full year. We have slightly revised the figures for 2015 in this report.

Shipments by application

2016 will be another record year for shipments. We estimate that 65 thousand fuel cell systems totalling 478 MW will be shipped in 2016. While the total number of units has remained relatively stable, the MW shipped represents a two-thirds increase over 2015. This is driven largely by fuel cells for transport. Although stationary shipments increased 10% up to 200MW, transport shipments have more than doubled year on year, reaching nearly 280MW.

Importantly, for the first time, the transport sector will surpass the stationary sector. This increase is primarily driven by the introduction of the Toyota Mirai into Japan and California and to a lesser extent into Europe. 2,700 Mirais are expected to be delivered between its launch in 2014 and the end of Japan's 2016 fiscal year. Honda and Hyundai will also deliver more cars, and in total just over 2,200 will go to customers in calendar year 2016. Since the stacks of ten such fuel cell cars add to a MW of PEM fuel cell capacity it is easy to see what has driven this increase.

2016 has seen continued stable growth in materials handling – a trend already observed over several years. Over 10,000 fuel cell powered forklifts are in operation, with nearly 4,000 added in 2016. Mass deployment in this segment comes essentially from Plug Power, but several companies globally offer fuel cell lift trucks. In 2016 Nuvera Fuel Cells, now part of Hyster-Yale Materials Handling and hence with excellent channels to market, began shipping their own systems. Manufacturing is ramping up and their target is to reach some 700 units per quarter by early 2018 – a production volume similar to Plug Power today. Both companies offer 'full solutions', i.e. including hydrogen refuelling equipment.

More fuel cell buses have been deployed than in 2015, and 2016 has seen rapid growth in various other vehicle sub-categories. Range extenders, such as in small electric buses, light trucks and delivery vans, are popular, including those from SymbioFCell of France. China now provides incentives for similar applications, and rewards adding a fuel cell to electric vehicles. This has led to massive growth in fuel cell shipments to vehicle integrators in China in 2016. Because we count final products, most of those vehicles will only go on the road and appear in our statistics in 2017.

Transport's trajectory seems somewhat clear, as Toyota and others follow their plans to increase vehicle deliveries to the market by 2020. Simultaneously the predicted shipments from Ballard, Hydrogenics, Plug Power and others to China for commercial vehicles, buses and trams will underpin growth in this area in the coming years, while Chinese manufacturers build their capabilities. Shipments of large systems for trams in China and trains in Germany give further reassurance.

Shipments of stationary fuel cells will see reasonable growth in numbers (from 47,000 to about 55,000 units), and MW (184 to 200 MW) in 2016. The former will be largely determined by Japan's Ene-Farm programme for domestic micro-CHP systems, whilst the latter is driven by the output of the larger system producers, FuelCell Energy and its Korean partner POSCO, Bloom Energy, Doosan Fuel Cell and Fuji Electric. 2017 should see some increase following from the German subsidy programme described elsewhere. Nevertheless stationary power will not be as dominant as previously, as the relatively low levels of publicly announced orders date in 2016 bear out.

The portable sector appears to have taken another tumble in 2016. Although the combined power of this sector amounts to much less than a MW, unit numbers are likely to fall from 2015, itself a substantial reduction on 2014. Although the auxiliary, off-grid and back-up power markets appear to be steady or growing, the long-discussed growth in consumer chargers always seems to be somewhere in the future.

Developments in stationary systems

Asia's deployment increases, US sales flatten, and Europe remains low. Stationary fuel cells have not yet shown their competitiveness in many markets, and support programmes are under pressure in some areas, notably in the USA. But the stubborn persistence of the Japanese market and the launch of a dedicated support scheme for residential fuel cells in Germany are positive for the sector. In other markets, activity remains sporadic, though efforts continue to bring fuel cells into developing nations, and activity in China is increasing.

The inexorable rise of Japan's Ene-Farm

Japan is the consistent world leader in the adoption and installation of residential CHP fuel cell systems. In 2016 the annual deployment anticipated increased from 40,000 units in 2015 to nearly 50,000. Total deployment had reached 180,000 units by the end of September 2016, and should easily get to 190,000 by the end of the year.

These micro-CHP fuel cell systems are still primarily PEM units produced by Panasonic and Toshiba. However, the deployment of SOFC-based units from Aisin Seiki has grown fast following market entry in 2014. All of the units produce up to a maximum of 700 (Toshiba, Aisin Seiki) to 750 (Panasonic) Watts power, as well as heat. While the PEM units achieve 95% overall energy efficiencies, Aisin's units are 87% efficient overall, but the latter have 52% electrical efficiency, superior to the PEM units' typical 39%. With electricity prices higher than gas, this high electrical efficiency increases the annual savings and helps the householder justify a purchase.

The adoption of these unparalleled numbers is a result of the Japanese Government's on-going support for the Ene-Farm programme, the 'brand' adopted by all the different micro-CHP fuel cell systems producers. The programme provides a subsidy for each unit installed. The subsidy has tapered downwards over time as the cost of producing the units has fallen and was originally to stop at the end of 2015. But costs had not come down as far as hoped by that point, and the subsidy was extended for 2016, with ¥9.5 billion ($88m) reported to be available. Current indications are that it will now run through to 2019.

While 190,000 units dwarfs any other fuel cell market, Japanese industry has been working towards an ambitious target set by the Japanese Government for achieving 1.4 million installations by 2020, with 5.3 million by 2030. To achieve these numbers will require a big step-change in the annual rate of installations: 50% more units (around 300,000) will need to be installed each year to 2020 than have been installed in the whole programme to date. Not achieving the target does not suggest that setting it was a mistake, however, nor does it indicate failure. The most important indicator of policy success will be future unsubsidised markets that continue to grow.

Significant reductions in the cost of the micro-CHP systems are essential to achieving this. For 2015, METI estimated retail prices for PEM units of on average ¥1.36m ($12,600) and ¥1.75m ($16,200) for SOFC. With payback periods of an estimated 18 years at full price, it is hardly surprising that the take-up of micro-CHP fuel cell systems requires a significant subsidy, though security of power supply and other factors do play a role in the buying decision.

METI indicates that the retail price targets for PEM units are ¥800,000 ($7,400) by 2019 and ¥1m ($9,250) for SOFC by 2021. This would reduce the payback period to 7-8 years, which would be more acceptable to the vast majority of consumers, though the 2030 target of a 5 year payback is inevitably more compelling.

To reduce costs to these levels the fuel cell developers must continue their value engineering activities to improve and simplify designs, as well as make best use of supply chain expertise and negotiations to reduce the cost of materials, components and sub-systems. All of the players are large industrial organisations with long experience of such cost-reduction exercises. At the same time they will need to keep

their marketing efforts high with their distribution partners, the Japanese gas companies. Panasonic has now expanded its partners from 17 to 20 city gas companies, so that its offering is now available in almost all of Japan. This continued broadening of the market should lead to more sales and thus enhance the opportunity for mass manufacturing and lower unit costs. Partnerships in Europe, where sales should increase slowly as the new German subsidies come into play, should further increase market volumes, though the units in Europe and Japan are not identical, and it will take some years for sales to come even close to those in Japan.

As the Japanese government has an ambition for micro-CHP fuel cells, so it does for larger commercial fuel cell systems. 2017 is slated to be the year for the market launch of a number of 5 kW to 50kW fuel cell systems.

Larger commercial scale fuel cell systems have been produced by Fuji Electric for a number of years. Its FP100i 100kW PAFC systems are used for large building applications, for example hospitals, office buildings and sewage treatment plants, and have been installed in Japan, Germany, South Africa and the US. Smaller scale commercial units under development by a number of Japanese businesses include a 20kW CHP system reported at Fuji Electric and a 50 kW System at Hitachi Zosen; whilst Miura, Japan's largest boiler manufacturer, has a 5kW CHP system in the pipeline. The latter uses Sumitomo's SOFC stacks for its system. This latter unit will be used in smaller commercial applications such as restaurants, has a reported electrical efficiency of 48% and is due to be available in 2017.

Korea: a bump in the road?

The big news from Korea is POSCO Energy's review of its MCFC business. POSCO has been a major installer of fuel cells, adding local production capability in Korea to its investment in FuelCell Energy of the US. During 2016, reports have suggested problems in the business, including reductions in the 400-strong workforce by as much as 40%, and more recently news has emerged of the losses POSCO sustained on sales in 2014 and 2015. These are reported at 51bn Won ($44m) in 2014 and 99bn Won ($87m) for 2015. Sources suggest that POSCO is approaching companies and private equity firms with a view to a sale.

This could be as significant as UTC's decision to divest its fuel cell assets in 2013, and previous similar decisions by MTU and, to a lesser scale, Topsoe Fuel Cells. POSCO has been a major contributor to Korea's roll-out of larger scale fuel cell systems over the past few years. Supported by a range of favourable Government policies, alongside substantial investment by Korean corporates, Korea is now reckoned to have the world's largest fleet (by MW) of stationary fuel cell systems, including the world's largest fuel cell park at Hwasung, with 59MW. This growth has supported both indigenous production of fuel cell units as well as imports, mainly from the US. Despite this support and the resulting growth, POSCO's review suggests that the costs of the roll-out are not currently sustainable, even for a business as large as POSCO Energy and with a relatively large conventional energy systems business.

POSCO Energy was reported to have installed over 154MW of MCFC 300 kW and 2.5MW systems in 20 locations over the years, either as single units or in the form of fuel cell parks. This figure grew during 2016 with the addition of installations announced in 2015. This includes the 20MW fuel cell park for Noeul Green Energy Co., in Seoul. This fuel cell park will support Seoul City's sustainable energy action plan and is due to be operational towards the end of 2016.

Doosan Fuel Cell America's installations in 2016 also followed on from 2015 announcements. Over 80 units were due for shipment and installation in 2016 for two projects: the Busan Green Energy project comprising 70 PAFC units totalling 30.8MW, and the Korea Western Power 5MW plant of 11 PAFC units in Incheon. The latter became operational in April 2016; the former is due to commence operations in early 2017. Doosan does not yet have the same amount of installed power as POSCO, but has rapidly made inroads into the market.

But following the flurry of orders in 2015, 2016 has proven to be relatively quiet for Korea, with announcements in 2016 mainly notable by their absence, suggesting a probable slowdown in 2017. It's likely that this absence of forward orders links strongly to the layoffs of workers reported for POSCO Energy and Doosan (30 of approximately 200 workers laid off at South Windsor, Connecticut, USA in July 2016). A consistent pipeline of orders is necessary to keep busy POSCO's Pohang manufacturing plant and Doosan's South Windsor facility, and without Korean orders fewer opportunities are likely to be available.

It's not clear when the delivery picture may improve: while multi-MW fuel cell plants are reportedly in the pipeline for Korea, the uncertainties around POSCO in particular are a concern, coming after partner FuelCell Energy's Asian market update in summer 2016 noted a 400MW pipeline of fuel cell parks and installations. Hydrogenics in a November call revised its focus from a number of 50MW plants to 5MW plants, due to financing risks for the larger units. Much more positively, Korean Government policies continue to support the further expansion of fuel cell unit numbers. The Renewable Portfolio Standard requirement applies to all generators producing more than 500MW. The required proportion of power generated from 'new and renewable energy sources' was set at 3.5% for 2016, but rises to 10% by 2020, and fuel cells count towards the RPS. The recently introduced Renewable Heat Obligation also keeps up the pressure on utilities and other large energy users to adopt 'renewables', in this case including fuel cells in CHP mode. However, RPS targets can be met in other ways, as POSCO Energy with its wind and solar PV farms is well aware.

US markets flattening in 2016?

The USA is home to three of the worlds' leading fuel cell manufacturers: FuelCell Energy (FCE) and Doosan Fuel Cell America, respectively in Danbury, and South Windsor, Connecticut; and Bloom Energy of California and Delaware. Producing MCFC, PAFC and SOFC based stationary fuel cells of 100kW to several MW, each has benefited from government support for R&D and subsequently for fuel cell installations at home, in California and Connecticut in particular, and overseas, notably Korea. They also increasingly use power purchasing

agreements and project financing to make their units attractive to customers.

Activity in these businesses in 2016 seems mainly to have come from announcements and orders made in 2015. Thus Doosan has been producing its PAFC PureCell units primarily for the Korean market, and FCE has been shipping its DirectFuelCell MCFC technology units to its US customers, for example a waste water power project at Riverside California and the Irvine Medical Centre also in California. It also supplies components to its Korean Partner POSCO and to the German 1.4MW fuel cell built for Friatec AG and commissioned in Mannheim in September. FCE has exploited its project finance facility of $30m agreed with PNC Energy Capital at the end of 2015, using it to fund new installations.

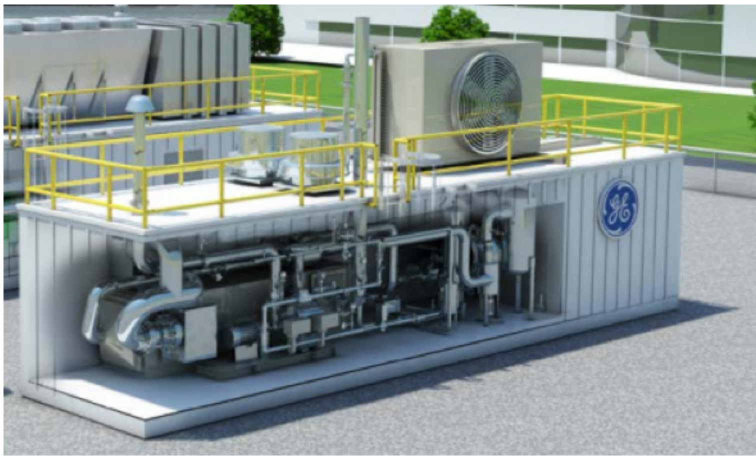
FCE has also announced orders over the past twelve months, including a 5.6MW project for two DFC3000 units for Pfizer in Groton, Connecticut, a 3.7MW project in Connecticut, and a further order from E.ON Connecting Energies of Germany, following on the earlier Friatec plant. Unfortunately the Beacon Falls Energy Park for 63MW of DFC units, also in Connecticut, which would have surpassed Hwasung to become the world's largest, was not selected in the New England Clean Energy programme. The proponents of the project intend to pursue the project by 'other routes.' FCE has other projects awaiting decisions, including further Connecticut-based projects due for decision in early 2017 and a potential 40MW installation on Long Island.

Overall, 2016 was slower than 2015 for FCE, and its product backlog fell from $98m in July 2015 to $35m a year later. Balancing that, however, is FCE's increased service business, so the overall services and product backlogs have risen from $323m to $334m.

Bloom's activities in 2016 have included both new and repeat customers. Apple is installing Bloom's SOFC Energy Servers at its new campus at Cupertino, California, whilst IKEA has added its products to four California stores and one at New Haven, Connecticut. In New York City, Morgan Stanley selected a Bloom unit for its high-rise HQ. Like FCE, Bloom has benefited from Connecticut support under the Department of Energy and Environmental Protection's micro-grid programme. One example is the micro-grid in Hartford under construction and intended to provide 800kW of power to selected public buildings, to make them self-reliant in case of severe weather outages. This project is supported by Constellation, with whom Bloom signed a financing agreement in summer 2015. Their latest business development initiative was announced in October 2016: a strategic alliance with Southern Energy's Power Secure subsidiary should lead to Power Secure purchasing 50MW of units. The combination of Bloom's Energy Servers with Power Secure's energy storage technologies, notably lithium-ion batteries, may be a smart response to California's subsidy switch towards energy storage, and away from fuel cells. Bloom has also signed an MoU with GAIL (India) Limited, a major Indian natural gas supplier which already supplies a multi-MW Bloom SOFC plant at a Bengaluru Technology plant. They now aim also to promote Bloom's products in India.

The US outlook is clouded by the pending termination in December, 2016, of the federal 30% tax credit that, along with State subsidies, has been an essential tool to market entry for power generation systems and forklifts. An extension has been promised, but is opposed by influential oil and gas interests. Congress was scheduled to take up an extension with bipartisan support after the US election but there is no guarantee of approval.

Hydrogenics of Canada, in addition to its transport fuel cells and electrolysers, has an interest in the stationary fuel cell sector. It delivered a 1MW PEM unit to Korea in 2015 and is seeking to expand on this. It also announced an order from Thailand for



its 1MW PEM HyLyser electrolyser, in conjunction with 300kW of its HyPM PEM fuel cell power systems, as part of a wind-hydrogen project. It has also doubled the size of its Mississauga facility to support growth in its PEM based technology products (both fuel cells and electrolysers).

SOFC Hybrids keep coming

While FCE, Bloom and Doosan have been making their case by installing plant, their technologies are considered by some to be behind the scientific cutting edge. They have been extensively tested and production capabilities built, but other fuel cells have the potential to be more efficient and lower cost – if they can be proven with the same degree of rigour. Hybrid fuel cell systems – often an SOFC supplemented by a gas turbine – have been in development for a number of years, but marrying two complex technologies has proven difficult till now.

Most notable is the September Mitsubishi-Hitachi announcement of a second demonstration of its 250kW SOFC/micro-turbine hybrid system at the Senju Techno Station of Tokyo Gas. This follows the Kyushu University system, operating since spring 2015, and will be followed itself by three further units at Toyota Motors, which makes the high speed turbine; at NGK SparkPlug, the stack manufacturing partner; and at the Taisei Corporation. Commercialisation is intended from in 2017, with a suggested price tag of Yen300m ($2.75m) though previous experience in the sector suggests that moving from such demonstration or pilot plants to commercial ones is not easy.

Nevertheless, in this complex technology Mitsubishi has stolen a lead on LGFCS, which is running tests on its own SOFC/micro-turbine system, and on GE Energy, which has plans for an apparently lower-cost hybrid marrying an SOFC fuel cell with a Jenbacher reciprocating engine to make a 1.3MW CHP system.

Europe looks ahead

Europe has stood for a long time on the deployment sidelines. Only limited numbers of larger stationary fuel cell systems have been installed, and only hundreds of micro-CHP units, despite the many very capable technology businesses with ongoing development activities. The faster rollout elsewhere is partly due to public support, but also to market structures. Notable differences are the inclusion of fuel cells in Renewable Portfolio Standard definitions in some USA States and in Korea, the less monolithic and regulated energy market structures in USA and Asia, but also the often more robust and reliable energy networks in parts of Europe, which require less backup. Some European support is available at the European level from Europe's refreshed Fuel Cell and Hydrogen Joint Undertaking (FCH 2 JU) and also from various national governments, notably Germany, but until now it has been small in comparison to the global leaders.

Micro-CHP fuel cells at least are likely to benefit from developments in 2016. The five-year, €90m PACE (Pathway to Competitive European micro-CHP market) project kicked off in 2016 with €34m from the FCH 2 JU. This will support the deployment of 2,650 micro-CHPs of around 1kW power output from four European producers: SOLIDpower, Bosch, Vaillant and Viessmann. The project was announced in 2015, began in June 2016, runs to February 2021 and should support installation of at least 500 micro-CHP fuel cell systems from each of the above suppliers. These will be spread across a number of Member States for extended and fully monitored trials with real customers. The units will include: Bosch's 700 Watt SOFC unit, developed with Aisin of Japan; Viessmann's 750 Watt PEM VitoValor system with stacks from Panasonic; the Hexis system, Viessmann's SOFC successor to their Galileo model; SOLIDpower's 1.5kW BlueGen and 2.5kW EnGen systems; and Vaillant's 700W SOFC unit. This relatively large numbers of units, by European standards at least, should help the manufacturers to achieve 30% cost reductions through supply chain standardisation and manufacturing process improvements. Equipment standardisation should also make the installer's task easier.

The PACE project follows the FCH JU-supported €26m Ene.Field project due to end August 2017. This project was to support installation of up to 1,000 micro-CHP fuel cell units across Europe, but is likely to fall short, with perhaps 750 or so units installed towards the end of 2016. But UK developer Ceres Power will re-join the programme, installing its SteelCell SOFC technology units in the UK by the beginning of 2017. They report 50% electrical efficiency for the 1kW domestic micro-CHP system. Ceres is also seeking to expand its stationary offering to other markets. In 2016 it announced an award from the US DoE together with Cummins, to support development of a 5kW SOFC modular stationary system for use in data centres. The units could be used in multiple installations of up to 100kW.

SOLIDpower, the Italian headquartered developer of the BlueGen and EnGen micro-CHP SOFC units, has further consolidated its integration of the former German CFCL business, establishing agreements with German utilities, including EWE. They apparently have a 10kW unit under development. SOLIDpower's Heinsberg manufacturing site has started receiving cells from its Chinese supplier, Chaozhou Three Circle Group Ltd, to build the stacks for its BlueGen units. Ceramics and electrical component manufacturer CTCG acquired certain CFCL IP in 2015.

Germany's own (small) Ene-Farm programme

Bigger than the FCH JU projects, but not as big as Ene-Farm, a long awaited Market Technology Introduction Programme has been launched by the German Federal Ministry for Economic Affairs and Energy (BMWi). It is targeted specifically at residential CHP fuel cells up to 5kW, disappointing actors producing larger systems. Part of the Power Energy Efficiency policy, support includes a base grant of €5,700 plus an additional €450 for each 100 Watts of power installed. Only fuel cells between 0.25kW and 5kW are eligible, the latter receiving the lower of €28,200 per installation or 40% of overall cost (including an obligatory full maintenance contract guaranteeing at least 26% electrical efficiency). Sales prices for 0.7 to 1kW mCHP fuel cell systems in Germany range currently from €19,000 to about €25,000 per unit, plus tax. Some come as a full heating solution including an auxiliary burner. So after the incentive is deducted, e.g. €8,850 for a 0.7 kW system, or €10,200 for a 1kW system, it should be possible to market the fuel cell systems as an attractive investment to home owners interested in self-generation, especially as the guarantee means they will have a good idea of total costs up-front.

€165m is earmarked annually until 2018, for mCHP fuel cells and other efficiency measures. In theory this could support deployment of several tens of thousands of systems in Germany, and it will be interesting to see which companies can actually deliver that many systems in the short term. Continuation beyond 2018 is possible, but will depend on its success, amongst other things.

As we reported in 2015, the principal go-ahead for the programme in fact dates back to May 2015, marking a success for an alliance of German boiler manufacturers as well as power and gas utilities who have long argued for an incentive programme to reach cost reduction through volume deployment. But the details of the programme remained unclear until mid-2016, and while reservations for funding can already be submitted, deployment under the programme can only start from December 2016, meaning no uptick in shipments during 2016.

Although this incentive programme should greatly assist the European micro-fuel cell system developers, they nonetheless face an ongoing challenge: how to sell technically complex and high cost units into a consumer marketplace which is already highly competitive, and at the same time essentially conservative. Brand recognition, a reputation for reliability, as well as the service and maintenance offer, will need to be compelling to develop this market, as the subsidy will only be available to private individuals. Since these are usually addressed by local installers it can take several months to move from identifying early adopters until the systems are on site. The branding issue is clearly a consideration, as shown by Viessmann's decision to market the Hexis SOFC micro-CHP Galileo product and its successor, due in 2018, under its own brand, well-recognised in the German domestic heating market. In 2015 BDR Thermea chose to use the Senertec brand for its micro-CHP fuel cell products developed by Baxi Innotech, which use Toshiba's PEM stack technology.

Outside of micro-CHP, European business developments in commercial and industrial scale stationary systems have been slow. FCE, Fuji Electric and Doosan are represented and actively developing business in Europe, but market conditions are less favourable than in the US and Korea. Fuji Electric and FCE have deployed larger units in Germany in the past, and FCE has installed units in 2016, but conditions could worsen in 2017, unless industry efforts secure extended support for large CHP that will otherwise expire at the end of 2016. Nedstack of the Netherlands successfully delivered its 2MW PEM system to the Chinese chlor-alkali facility at Yinkou in autumn. As in Korea and the USA, there are rumours in China of possible large scale fuel cell CHP development activities, but no official announcement.

Technology developmental work continues. AFC in the UK achieved over 200kW power output with its KORE alkaline fuel cell technology at Stade in Germany, part-funded by the FCH JU; further Generation 2 stacks began testing in September 2016. AFC also signed a joint development agreement with Italian electrochemical business and electrode supplier, De Nora.

Convion in Finland, the ex-Wartsila fuel cell development activity, successfully validated its commercial scale SOFC system, producing 20kW of output. It will deliver three of its C50 systems to the FCH JU's DEMOSOFC waste-gas project in Italy at the end of 2016. Convion intends to target the commercial space with its 50kW to 300kW systems, capable of 52% net electrical efficiencies. Convion has made significant efforts to reduce part count, weight, volume and instrumentation from its initial

designs of 2012, to improve its chances in the market. It plans to demonstrate and certifity units through to 2018, followed by pre-commercial deployment in 2019.

Outside of the heat and power space, Italy's EPS has achieved significant technology demonstration targets and certification for its HyESS (Hybrid Energy Storage Systems) product with a project in Chile earmarked for initial deployment.

Telecoms - growing?

The use of fuel cells as either prime power or back-up power for telecoms towers and other infrastructure has been pursued by a number of businesses. Cost competitive and clean fuel cell systems are being deployed in countries around the globe. With falling power requirements for some types of telecoms towers, fuel cells are becoming more attractive thanks to their modular nature. For power demands of only a few kilowatts, diesel generators have long been the standard solution, but fuel cells can significantly reduce maintenance and footprint, and tend to have superior economics compared to battery-only solutions if long run-time backup is required. Several regions of Germany use fuel cells to back-up radio towers for emergency services. Given the rarity of grid outages, fuel supply has little impact on operational costs here, but in India or parts of South East Asia, where back-up power systems need to run much more frequently, hydrogen availability is still a barrier for mass deployment. Some fuel cell companies address this through methanol fuelled systems, which eases the refuelling challenges to some extent.

In the US, Altergy has been a pioneer, with its 5kW to 15kW PEM systems used by two of the big four nationwide carriers, as well as by smaller entities. They are replacing batteries and diesel generators which are increasingly seen as expensive, short lived and/or environmentally dirty. Altergy has reported a total 8.3MW of systems deployed in this and other sectors, though this figure has not been updated recently.

Canada's Ballard, another long-term player in the sector, announced a review of its telecom business early in 2016. It received an order in April from Telia Corp for 55 ElectraGen systems for use in Nepal, and not long afterwards entered into a definitive agreement to sell certain of the Company's methanol Telecom Backup Power business assets to Chung-Hsin Electric and Machinery Manufacturing (CHEM) Corporation of Taiwan for $6.1m. CHEM committed to purchase a minimum of $2m of stacks from Ballard going forward. In July Ballard announced a further deal, with Guangdong Nation Synergy in China, for the licence to manufacture and sell FCgenH2PM back-up systems. China Tower Corporation, formed from the assets of three Chinese mobile telecoms companies, and now responsible for installation and maintenance of these towers, is a prime target for Guangdong Nation.

PlugPower acquired ReliOn in 2015 and now markets its E-series products under the GenSure brand, with power outputs available from 200 watts through to 2500 watts. Since 2015 PlugPower has had a multi-annual deal in place with SouthernLINC for up to 500 units. Intelligent Energy, which has suffered significant financial turmoil and laid off many staff since the spring of 2016, reported in September that seven of its so-called "305" systems are deployed in trials in India for telecoms towers with either no grid or very weak grid access. IE remains in discussion with GTL about the long term supply to 27,000 towers in India through Essential Energy, though with no guarantee of a final contract. IE is also looking outside India, including Africa and China, but has to find investors to support its plans.

NIP 2: Germany maintains its drive

An important policy development in Germany in 2016 was the long-awaited formal approval of phase two of the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP II), with funding of about €1.4 billion over ten years. NIP I ran from 2007 to 2016, with a budget of €700 million for R&D activities to bring technologies to market readiness. It was never intended to directly support deployment, other than in demonstration projects. This second phase acknowledges the need to help technologies into the market through supported early commercial deployment. The recently launched incentive programme for residential fuel cells, discussed elsewhere, is an example: while NIP I supported demonstrations in the Callux project, NIP II targets the end customers. They will get an incentive for installing a fuel cell system, chosen from commercially available products, at their home. The incentive makes the upfront cost similar to other heating systems, if revenues from electricity generation over the system lifetime are considered.

The renewed programme remains jointly funded by several German federal ministries. Transport and Digital Infrastructure alone committed €250m up to 2019. Some of the ministry budgets are not exclusively available to fuel cells and hydrogen though: one example is the incentive programme for energy efficiency measures, under which residential fuel cells are supported. This programme has €165m available through to 2018 for a range of building efficiency measures, not just fuel cells. The preferences of applicants will ultimately determine how much will be used for fuel cell deployment.

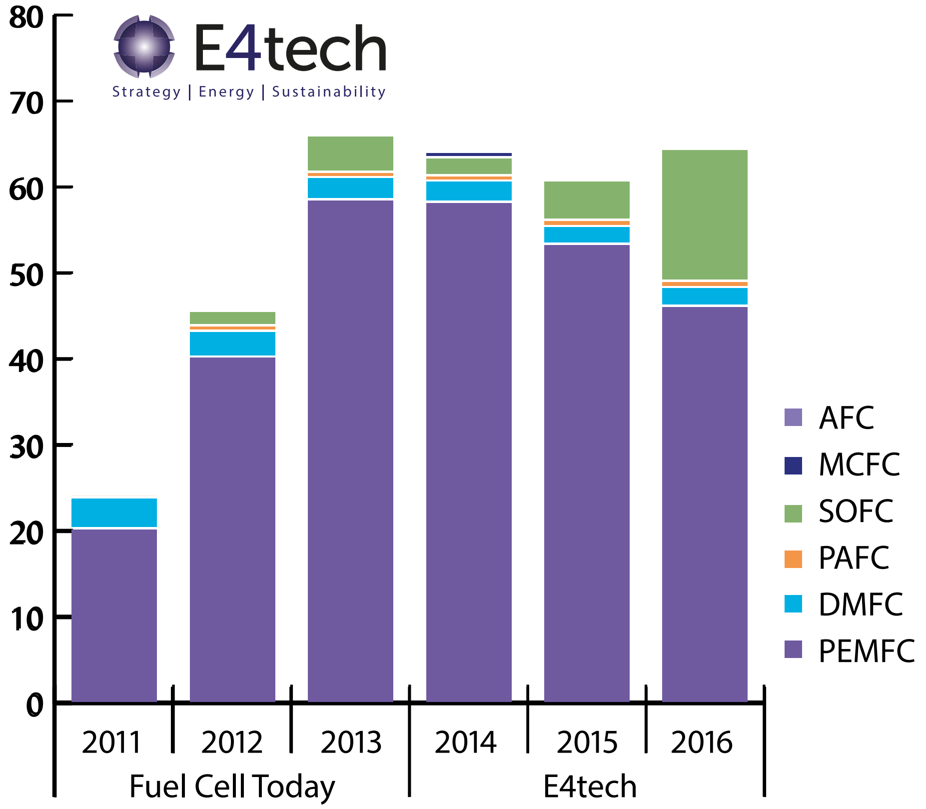
Road transport will remain a focus area of the NIP II, including hydrogen infrastructure. Other transport applications also continue to be covered: trains, ships, aviation and material handling. The German government's mobility and fuel strategy identified water electrolysis as a key technology for the energy transition, and this area also gets support, even as far as examining regulatory issues of coupling electrolysis with renewable electricity.

Stationary fuel cells at residential, commercial and utility scale are specifically included, although so far the market introduction incentives are limited to systems of up to 5kW. NIP I supported special applications too, such as back-up power solutions for critical infrastructure, and the new programme will continue to support cost reduction efforts in this area, among others. Larger demonstrations may also be possible.

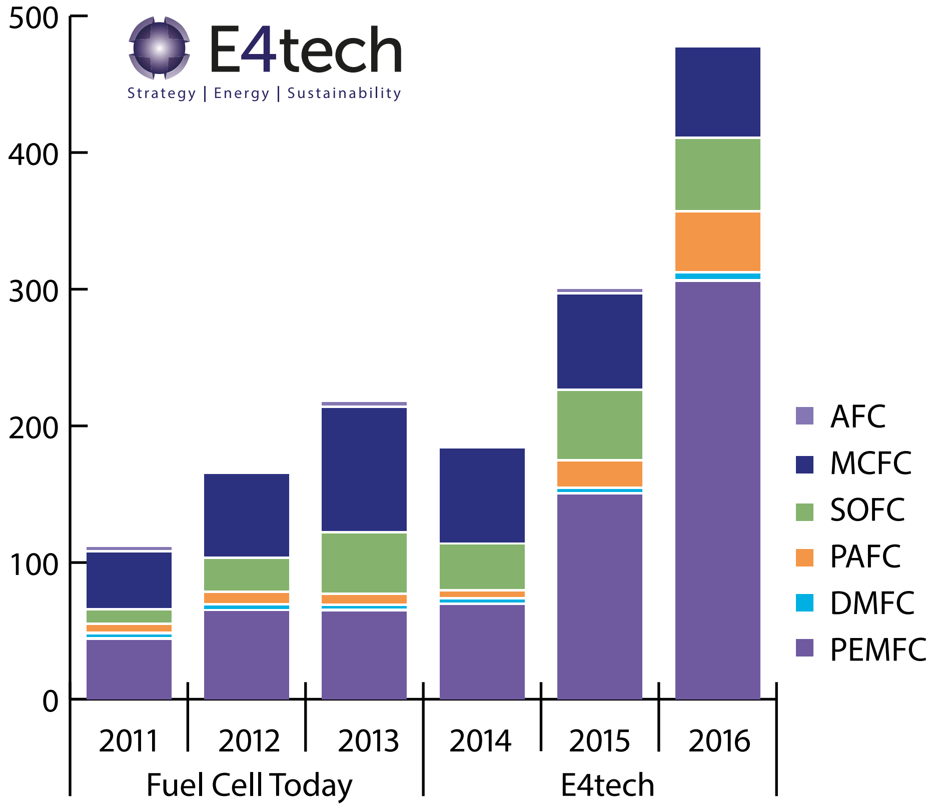
The intent of the programme is to target small and medium sized companies (SMEs) in particular, and to foster collaboration with applied and fundamental research. As NIP I was set to expire in 2016, the German government has sent an important signal with this formal continuation. NIP II is planned to have more funds than the European FCH 2 JU programme. And perhaps more importantly, NIP II is intended to support deployment of fuel cell and hydrogen technology in large numbers, whereas often European support is focused on demonstration projects.

Shipments by fuel cell type

Units shipped by fuel cell type 2011 - 2016 (1,000 units)



Megawatts shipped by fuel cell type 2011 - 2016



Footnote to charts: Data from 2011-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2016 is our forecast for the full year. We have slightly revised the figures for 2015 in this report.

Shipments by fuel cell type

PEM fuel cell systems dominate both unit numbers and total power shipped in 2016: 72% of units and 65% of power. Unit shipments look to be down on 2015, but shipments by power are slightly up. This dominance reflects the simple fact that FCEVs use PEM technology and so once again the Toyota Mirai is changing the shape of the curve. Further PEM systems for other cars by Hyundai and Honda, and fuel cell buses and other FCEVs complete the transport picture.

PEM technology is also used extensively in stationary fuel cell systems, from Nedstack's 2MW Chinese project to the 700-750W domestic micro-CHP fuel cells of Toshiba and Panasonic in Japan. The latter two companies still account for the majority of PEM units shipped, but with increasing FCEVs predicted for Asia this may shift sometime in the near future. Indeed as the technology of choice of the transport sector, PEM is likely to be the leading technology way into the future.

Japan's Ene-Farm programme is also responsible for the tripling of SOFC shipments. Aisin Seiki has ramped up the production and installation of its SOFC micro-CHP units over the past year and could be approaching 10,000 shipments. Further SOFC micro-CHP units have been introduced in Europe by SolidPower, Vaillant and Viessmann, and Ceres Power will join them for the end of 2016. SOFC technology is also used by Atrex in the US and NewEnerday in Germany for their respective off-grid and back-up fuel cell systems. Furthermore Ultra Electronics and Protonex offer small SOFC units for back-up and portable power. Fraunhofer IKTS in Germany is working on commercialisation of their SOFC stacks for off-grid power through a number of collaborations. Elsewhere Bloom Energy is the big installer of SOFC, used in its Bloom Servers primarily in the US, and Mitsubishi has 250kW hybrid SOFC systems. As Bloom's Servers have 160-250kW power outputs, these represent the majority of the SOFC power shipped in 2016.

Future shipments of SOFC technology should improve with the continuation of the Ene-Farm programme, the start of the PACE project, the successor to the Ene.Field project and Germany's Federal grants for micro-CHP. Larger SOFC units from Convion of Finland, and amongst others Miura of Japan may also contribute to future totals from 2017. And SOFC developer Sunfire of Germany has delivered their reversible fuel cell and electrolysis product to their US partner Boeing. The system can either generate hydrogen, or electricity.

The larger 100kW to multi-MW MCFC and PAFC units all go into stationary applications. FCE of the US, and POSCO in Korea, together with Doosan in the US, have all benefited from larger orders in 2015 feeding into this year's manufacturing and shipment schedules. We estimate Doosan has been able to more than double PAFC shipments from 2015. In September 2016 MCFC leader FCE reported a production level comparable to 2015. The future of shipments of these technologies will in part depend upon decisions by POSCO on its future investment in MCFC and especially on the support frameworks in the US and Korea.

DMFC technologies are used in portable fuel cell systems, mainly by SFC of Germany. Shipments, by units and power, appear to be relatively stable in 2016. We have seen no further shipments of AFC technology in 2016, though AFC Energy appears to be consolidating its technology position ready for 2017.

Corporate Activity

Some stability returned to 2016 after a series of shocks in 2015. Few mergers and acquisitions occurred, though a few more companies closed. Some other significant events occurred: both positive and disturbing for the sector.

Cash remains king

We repeat regularly our view that neither fuel cell technology nor building a fuel cell business is straightforward. A fuel cell may have fewer moving parts than incumbent combustion-based energy technologies, but it does have complex materials and leading-edge chemistry. It requires sophisticated integration of a range of both functional and structural components built to exacting specifications, and sophisticated system controls and management software. And even once the technology is ready, the markets are fiercely competitive. Fuel cells compete with mature technologies and strong incumbents, often with a century of experience. These mature technologies also improve in performance, cost and availability. Fuel cells must meet end-user needs while competing on cost, eventually without Government support. Although history tells us that developing and introducing new technology typically takes decades, especially in the energy space, the shortage of major success stories in fuel cells has not helped to keep investor interest.

Intelligent Energy, the UK based PEM systems developer, suffered a major set-back in early 2016 when expected funding was cancelled soon before it was expected to arrive. IE could not support its activities and cash-burn became unsustainable. Though an investor stepped up with £27m of rescue funding, a material restructuring of the business was required. Development has shifted from a multi-platform and multiple-market approach with three divisions, to a single focus on the short term opportunities for its air cooled PEM technology in the sub-1kW to 20W range. The joint venture plant with Suzuki in Japan continues to operate. Inevitably headcount has been reduced: 355 employees in September 2015 had been cut to 138 a year later. The business believes that it has enough cash for the short/mid-term, but must now exploit its technology for revenue in a more nimble fashion than previously.

Others have been even less fortunate. eZelleron, the German smart phone charger development company, exhausted its crowdfunded investment before it could ship products and was declared insolvent in the first half of 2016. It appears that the founder intends to continue through his Kraftwerk Inc. business, based in Palo Alto, California, and still aims to ship product at the end of 2017. Heliocentris, a German fuel cell business that traces its roots back to 1995, chose a strategic insolvency in Autumn 2016. Unlike eZelleron, Heliocentris had revenues and appeared to have been successful in securing orders for back-up fuel cell systems, and is reported to be seeking to restructure.

Raising the Cash

Many smaller fuel cell businesses depend upon equity investors, who have suffered along with the companies themselves. Business plans are under intense scrutiny. Ceres Power, the UK based SOFC business, went into near-bankruptcy several years ago, following technical issues and subsequent cash concerns. This led to major restructuring and re-focusing, and Ceres has subsequently managed to raise several rounds of investment and secure several big name partners. In September 2016 it raised £20m (before expenses) on the markets. Other fuel cell businesses have also raised funds from existing and new shareholders over the past 12 months. One example is Hydrogenics, which successfully placed shares for $17.9m in December 2015. Ballard benefited from a $28.3m investment by Broad Ocean of China; and FuelCell Energy issued further instruments to raise $37.3m before expenses. French utility Engie invested in SymbioFCell, following Michelin's stake in 2014.

Deep Pockets?

The fuel cell activities of the largest businesses in the sector are funded through corporate accounts: the Japanese automotive OEMs and the stationary fuel cell CHP producers are obvious examples: Toyota, Honda, Panasonic and Toshiba have established cash generation businesses to fund their work in the fuel cell space, albeit supported in part by public finances. However, it appears that even some of the deepest pockets in the fuel cell industry do have a bottom. In November 2016, POSCO Energy of Korea appeared to be seeking a buyer for its fuel cell business. POSCO has been a major investor in the stationary fuel cell sector and led the move by Korean corporates into the space. However, the business sustained multi-million dollar losses on sales in 2014 and 2015, and mid-2016 saw reports of further poor returns for the year. Workforce reductions and the implementation of an early retirement programme were instituted. Unfortunately these issues have come against a back-drop of poor business performance for POSCO Energy as a whole, and may have come under scrutiny because of that. If POSCO does sell, following exits by MTU and Topsoe in the past, it will lead to renewed questions for the stationary fuel cell sector.

IPO for cash

Bloom Energy has long been active in the fuel cell space, developing and building a business around its stationary SOFC technology and funded by equity investors. The precise finances of the business are not published, but well over $1bn has been invested in the company to date; 'big fuel cells' require 'big money.' After almost annual rumours, Bloom has finally filed for an IPO – though using a special US law that enables it to do so 'privately.' Whether the IPO goes ahead will apparently depend on extension of certain relevant US tax breaks, but would be a very interesting marker for the sector, as the valuation will need to be of the order of $2.5bn – more than the value of all public "pure play" fuel cell companies combined – to generate a suitable amount of cash and reward.

Sharing the load

2016 has seen its fair share of joint development agreements, strategic partnerships and traditional distribution agreements. Distribution agreements are especially important for small fuel cell businesses with limited resources who seek entry into large consumer markets; for example those in the portable sector such as MyFC and SFC. However, market access is complex enough that larger businesses also enter into such agreements: in India, Intelligent Energy has a presence focused on the telecoms tower opportunity, whilst Bloom Energy has signed up with GAIL, one of India's largest gas companies, to exploit stationary fuel cell systems' potential. Arcola Energy of the UK has partnered with SymbioFCell, Ballard and ITM Power to further its integration business, and a more recent development has seen Arcola enter into a JV with Norwegian transmission systems experts IMS ECUBES to develop sustainable energy and transport solutions for the Indonesian province of South Sumatra. Fuji Electric took over N2telligence early in 2016 – the latter installed Fuji's systems in any case. And ExxonMobil showed an interest in stationary fuel cells, announcing a location for a combined fuel cell and carbon capture plant it is jointly developing with FCE.

Much is under way in China. Ballard is pursuing an aggressive strategy and 2016 has seen agreements with Zhongshan Broad Ocean, Guangdong National Synergy and Shenzhen UpPower Technology. The first two include setting up a production line for FCvelocity-9SSL stacks, and licencing and local assembly of power modules for the Chinese vehicle market. Ballard will be able to sell MEAs to Synergy and will receive $18.4m of technology solutions revenue to set up the line, ultimately owning 10% of the joint venture. Ballard sold certain of the company's methanol telecom back-up power assets to Chung-Hsin Electric & Machinery Manufacturing Corporation, a Taiwanese power equipment company. Competitor Hydrogenics signed up with SinoHytec of Beijing, a partner of several years' standing, for fuel cell power module development and power systems supply based on Hydrogenics technologies. It follows agreements in November 2015 with several Chinese electric vehicle integrators, including Yutong, China's largest bus OEM. Hydrogenics' electrolyser capability gives it additional options in developing Chinese business. PlugPower is also part of the trend. It recently signed a memorandum of understanding (MOU) with Zhangjiagang Furui Special Equipment Co, and a leading Chinese industrial vehicle manufacturer, to develop new fuel cell vehicle applications and fuelling solutions.

Names and structures change to meet changing demands: Ballard renamed its Danish Dantherm acquisition Ballard Power Systems Europe A/S, but Protonex, acquired in 2015, maintains its brand, which is valuable in the US defence market. Viessmann is dispensing with the Hexis brand for consumer marketing purposes. PlugPower has aligned the former ReliOn products with its overall marketing approach adopting the brand GenSure. Nuvera continues to have its own brand within its new parent Hyster-Yale.

Portable Power

Auxiliary Power

Fuel cells hybridised with batteries have long been used in auxiliary power applications. The fuel cell is typically used to charge the battery, either trickle charging a few watts for leisure camping and caravanning applications, or recharging when the battery has discharged, such as in many industrial applications. Fuel cell products are available with outputs of tens of watts, through to hundreds, and even into the kW class. In this auxiliary power segment the boundary between 'stationary' and 'portable' products is rather fluid. It is not always clear if an installation is meant to remain movable or remain permanently on-site. So while some of the shipments discussed in this section are accounted as 'stationary' in our data, they could serve as portable units in other applications.

SFC Energy of Germany celebrated the 10 year anniversary of its EFOY products in 2016. The EFOY COMFORT, a DMFC of 40W to 105W, is aimed at the leisure markets for caravans and campers, whilst its EFOY Pro series of 45W to 500W has been developed for the industrial and defence/security sectors. Since these units provide remote or off-grid power for sensors, monitors and lighting, unattended reliability and runtime are critical, and larger 60 litre fuel cartridges have been developed. Two cartridges can be hooked up in tandem to lengthen runtime further. The EFOY 12000 Duo system can apparently run at 50W continuous output for 1300 hours.

Significant orders for SFC include those from the UK Wireless CCTV business which will deploy EFOY products with its security towers, and Singapore's Innoverde PTE which has ordered several hundred EFOY Pro 2400 models. The latter will also include solar hybrid versions where the EFOY fuel cell is connected to a solar and battery system to provide exceptionally long duration autonomous operations. Such systems are valuable in latitudes where winter daylight is very limited, and have proven to be popular in the oil and gas sector for pipeline and remote production sites. BOC's Hymera is also used to power off-grid sites.

Horizon has also taken the hybrid route with its reformed methanol MFC series fuel cells. Its MFC 150 models can now be configured with solar PV. The RFC 120 is an integrated fuel cell and electrolyser with energy storage, capable of self-generation. The larger methanol fuelled MFC 3000 series are suited to off-grid solutions, with versions available from 1kW to 5kW.

Other businesses in the auxiliary power space include UltraElectronics, whose SOFC propane-fuelled P250i (250W) has been successfully deployed in, for example, railroad wayside power; and Atrex Energy of the US.   Formerly Acumentrics SOFC, Atrex has four models of tubular SOFC fuel cells in their RP range with outputs of between 250W to 1.5kW. A larger system of up to 5kW is being developed with US DoE funding.

Each of the businesses above is reinforcing its ongoing technology developments by commercial developments in the hope of increasing routes to market. Atrex announced three distributor partnerships in 2016: Ensol in Canada, Winn-Marion Barber for the US Rocky Mountains and PCE Pacific for the North-West US. SFC has linked up with Conrad Elektronic in Germany to access the individual consumer and small business customers. It has also announced an agreement with FCTecNrgy of India for distribution and sales in India. UltraElectronics has an established partnership with RedHawk Energy Systems of the US.

Selling fuel cell systems into varied markets as alternatives to battery-only products or diesel generators has encouragingly increased sales. SFC reports industry and leisure sector growth of more than 10% in the first nine months of 2016, although sales to the oil and gas sector are down. Fuel Cell Systems, a UK based integrator and fuel cell distributor, also reports growing sales from a range of industries.

Military

Fuel cell systems for military use are designed to provide significant benefits in terms of weight, flexibility, power and lower noise and heat signatures, over both batteries and generators. Since in the digital battlefield the average combat unit is hungry for power for a range of devices, e.g. communications, sensors and monitors, superior performance is an advantage. On a power to weight basis fuel cell developers claim that a fuel cell generator with fuel and battery can be significantly better than the pure battery equivalent. For example UltraElectronics states that its propane fuelled SOFC fuel cell systems, the Defender 350 and the hybrid fuel cell/battery Defender 245XR, have a six-fold benefit over a battery system of the same weight. SFC estimates that its methanol DMFC EFOY systems can be 80% lighter than a battery system. SFC sells these and its EMILY and JENNY auxiliary power generators to a range of European and international armed forces.

UltraCell of the US markets its Blade Reformed Methanol Fuel Cell XRT series of up to 165 watts for silent and rugged continuous power. It continues to innovate in the space, and has a joint development with California-based SAFCell for a 50W Solid Acid Fuel Cell running on propane. Protonex, now part of Ballard, offers a 200W fuel cell running on propane, using a tubular SOFC technology.

The advantages of power and weight are also of interest in unmanned vehicles – ground-based, aerial or marine – where operational duration is important. The Unmanned Aerial Vehicle (UAV) application has attracted the attention of UltraElectronics and others. For example HES of Singapore has its Aeropak PEM system for various UAV applications. It followed up on its 2015 trial with Scottish based Raptor UAS with further 2016 trials on a Singapore Aerospace Skyblade UAV. Here the fuel cell system provides twice the flight duration of the battery version. More recently it demonstrated its 7kg weight class Hywings system in a drone from H3Dynamics, its parent company, also in Singapore. Protonex has tested its PEM fuel cell systems on the Boeing ScanEagle UAV, and the US Navy is integrating fuel cell technology from General Motors into an unmanned undersea vehicle (UUV).

Although the UAV application is potentially attractive in non-military use from a technology perspective, the longer term market has yet to be established. The use of UAVs is growing for civilian monitoring and sensor purposes, but current and future battery technologies are adequate for many requirements, technologically proven and relatively cheap.

Consumer chargers – still waiting?

Developers across the globe have long lauded the consumer market for charging devices, notably smart phones and tablets, as suited to small fuel cells, generating a few watts of power. Confident predictions of sales running at tens of thousands, if not hundreds of thousands of units a year, with relatively high price per Watt paid by consumers, have been used to launch development programmes in a number of businesses across the globe. Reports in 2016 suggested that autonomy and battery

technology still could be improved: Intelligent Energy reported that 70% of younger users viewed battery life as an issue with smart phones; 'battery anxiety' is said to have become the smart phone equivalent to BEV 'range anxiety' for these younger users; whilst Pokemon Go is reported to have highlighted the need for 'on the go' charging. Exploding Galaxy Note 7s have underlined the technology challenges of delivering more power and runtime for smart phones using current battery materials and management technologies.

But as we reported last year, for all the confident predictions and positive external events fuel cell chargers remain primarily 'in development'. Reliable batteries are continually improving in performance and cost, while very few fuel cell chargers are actually on the market.

Only the Brunton MiniPak is 'widely' available. Neah Power of the US showcases the BuzzBarSuite incorporating its BuzzCell fuel cell, but it also secured US DoE finance to support its PowerChip lithum ion battery technology in August 2016. Other products predicted to be available in 2016, or earlier, such as eZelleron's Kraftwerk charger, have yet to be released, whilst the businesses behind them have struggled with technology development plans and funding challenges.

eZelleron, which had ambitious plans for its Kraftwerk 10 watt peak power product in 2016 and raised over $1.5m in a crowd funding effort, has so far been unable to deliver. German eZelleron was declared insolvent in spring 2016. The development programme was reported to be taking longer and costing more than originally planned. It appears that the founder intends to take on the technology through Kraftwerk Inc. based in Palo Alto, California. How this is to be achieved if the original company owned the technology and is insolvent is unclear, as is the position of the 'crowd funded' investors. Some reports suggest an updated shipping date for the initial chargers for end of 2017, two years behind the initial schedule.

MyFC discontinued its original PowerTrekk product line in 2015, but presented its JAQ 900mAh charger at the end of 2015. The first units, complete with PowerCard fuel system, were provided to telecommunications company '3' in Sweden for evaluation in early 2016, but are not yet available to the public. It has also signed up with the Hong Kong Company, Novel Unicorn, to create a JV to exploit opportunities in Asia. This has paved the way for a modest but nonetheless significant 1,000 unit ($50,000) order from the Chinese mobile distribution business Telling. Telling supplies some of China's largest mobile operators, and this order for delivery from 2017 may lead to bigger things.

Intelligent Energy, whose Upp charger for smart phones was announced a couple of years ago, has suffered across the business in 2016, and no further news on Upp has emerged. While IE did announce a £5.25m joint development agreement with an emerging Smart Phone developer in February 2016 to 'embed' its fuel cell technology in the device, the company's financial problems and personnel cuts mean that project progress is uncertain. The embedded approach would pair a fuel cell with a battery to create a hybrid, which when refuelled regularly could provide continuous off-grid power – a concept also said to be of interest to MyFC.

Fuel Cell Electric Buses

Fuel cells have long been touted as highly suitable for buses operating in environmentally sensitive urban areas. Local air quality is a headline issue not only in China and India but in Paris and London, and diesel buses are definitely part of the problem. Like battery electric buses, Fuel Cell Electric Buses (FCEBs) have zero emissions at the tailpipe and zero emissions overall, if using green sources of energy. One of Ballard's first demonstrators was a transit bus, and development has been ongoing for more than two decades, including bus manufacturers such as VanHool, Wrightbus and Daimler in Europe, NewFlyer and ElDorado in the USA and Canada, Toyota's Hino Motors in Japan, and Hyundai in Korea. Such buses use fuel cells as part of an integrated propulsion system, usually including a battery for energy storage, but sometimes combined with supercapacitors. Importantly, the development phase is close to over: Daimler claims that its Citaro E-Cell and F-Cell buses will be production standard by 2018.

The benefits of FCEBs can be significant: in addition to zero emissions they require no 'on-route' energy infrastructure, neither charging points for battery buses, nor overhead wires for trolley-buses. They are thus flexibly able to operate on any route and can refuel at their home depot, typically in less than 10 minutes. The driving experience is similar to conventional diesel buses, with daily in-service times of up to 18 to 20 hours. But FCEBs are still expensive – typically in the past upwards of a million dollars each, and thus hard to justify for a local authority or typically underfunded transit fleet operator. Over the past 5 years however, major demonstration and support programmes have provided enough incentive for manufacturers to be able to gradually bring down prices, and bigger fleets will mean further reductions to come. This is important: bus fleets will change dramatically from now to 2030, when conventional diesel buses will likely not be allowed in countries and cities with progressive environmental policies.

Europe

Europe currently has the largest number of FCEBs in service, around 60, all funded through demonstration programmes. 18 buses are operating in the UK, in Aberdeen and London; 17 in Germany, across Hamburg, Cologne, Karlsruhe, Stuttgart and Frankfurt. Others are in Milan, San Remo and Bolzano in Italy; Antwerp in Belgium; Olso, Norway and Eindhoven, The Netherlands. Support comes from the European FCH JU and local and regional governments. The EU has been an essential supporter of FCEB development and demonstration in Europe since the first CUTE and HyFLEET CUTE projects in the 2000s. And since its formation in 2007 the FCH JU has provided further support through successive demonstrations projects: CHIC, HighV.LoCity and HyTransit, and most recently 3Emotion. These latter four projects have a total cost of €169m, with FCH JU support of €61m. 3Emotion will add a further 21 buses in 2017 in five countries, including France, for the first time, where Cherbourg will deploy five FCEBs. Together with additional locally funded buses in The Netherlands, more than 90 FCEBs should be on European roads at the end of 2017. These buses comprise 12 metre vehicles and articulated buses manufactured by Van Hool, Daimler (Evobus), WrightBus, APTS/Phileas and Solaris. Fuel cell systems are provided by Ballard and US Hybrid, which partnered with Sumitomo in 2016 to augment its FC capability. Hydrogenics also has a strong bus programme.

The FCH JU has also acted as an important catalyst to bring together a Fuel Cell Bus Coalition to develop the case for FCEBs and determine how to advance commercialisation. November 2014 saw a joint letter from five European bus manufacturers confirming plans for commercialisation, followed by an FCH JU-funded commercialisation study which identified pathways to success: improved reliability, harmonisation of regulations across markets, and lower capital cost are critical. Then in 2016 a further FCEB project was announced, JIVE: Joint Initiative for hydrogen Vehicles across Europe. This project aims to deploy 142 more FCEBs across the UK, Germany, Italy, Denmark and Latvia, aiming to achieve a 30% reduction in cost per bus, with a stated target of €650,000. Of course further costs must be considered: maintenance facilities, training of maintenance staff and the cost of hydrogen refuelling. Yet another FCH JU study on bus fleet engineering issues identified areas for improvement for larger fleets in particular, such as the challenge of refuelling larger numbers of FCEBs on a daily basis and simply having enough hydrogen available. Current fleets of five to ten FCEBs can be serviced and maintained relatively easily; fleets of a hundred plus will require new techniques.

Japan begins market deployment; Korea aims high

Toyota affiliate Hino Motors demonstrated a fuel cell hybrid bus comprising two 90kW PEM units and a nickel metal hydride battery system back around 2000, and the Japan Hydrogen and Fuel Cell Demonstration project which ran through to 2009 saw five vehicles trialled, but the main Japanese transport focus has been cars. However, autumn 2016 saw an increase in bus activity: Toyota announced its ambition to have 100 or more FCEB on the roads in time for the Tokyo Olympic and Paralympics, with deliveries starting in 2017. These will use Toyota's Mirai technology, two 114kW stacks plus a 235 kWh hydride battery. Like the Mirai's power take-off option, the bus system could be a stand-alone emergency power source in times of grid outages.

Korea is also sounding bullish on FCEBs. 2016 saw Hyundai and the Korean Government announce the intended replacement of up to 26,000 Compressed Natural Gas fuelled public transport buses with FCEBs. This would be accompanied by 200 HRS, and lead to environmental benefits for Korean urban areas and potential economic benefits for Korea as a whole. However, an ambition of this scale would require considerable policy and regulatory underpinning, as well as some form of financial support over an extended period, and detail has been elusive so far. In the meantime, FCEBs are planned to run at Korea's Pyeong Chang Winter Olympics in 2018.

China moves up the gears

Chinese policy has strongly supported so-called New Energy Vehicles for several years. Hundreds of thousands of battery electric vehicles run on Chinese roads, and it seems the Government is keen to move to the next technology. At the Beijing Olympics in 2008, 12 FCEBs from bus manufacturers including Daimler and SAIC Motor were demonstrated. China's thirteenth five-year plan, with its environmental emphasis, notably on improved air quality in China's urban areas, has now become a significant driving force behind the deployment of FCEVs, including buses. In 2015 it was announced that 300 FCEBs would be deployed in Foshan and Yunfu with deliveries starting in 2016, and in fact thousands of buses across many Chinese regions are anticipated.

Twelve buses were indeed deployed in Foshan in September 2016, and ten more commissioned in Yunfu in October. The former made by Foshan FeichiBus in two designs: an 11.5m 85kW vehicle and a 6.9m 30kW vehicle. Each uses Ballard PEM units. Ballard is also supplying 10 FCVelocity MD-30kW PEM modules to Xian King Long United for a 12m design, with deployment expected in 2017. To fulfil some of these orders, and larger ones expected going forward, Ballard signed up with Zhongshan Broad Ocean Motor Company to produce fuel cell modules in China for buses, as well as commercial vehicles, in selected cities. Broad Ocean has a subsidiary that buys and leases electric vehicles, now to include fuel cell vehicles. Ballard also has a JV with Guangdong Nation Synergy for the production of FCvelocity 9SSL modules, again for the Chinese commercial vehicle market. Hydrogenics is also actively shipping fuel cell modules to China in 2016, working with several vehicle integrators. Two of these have already ordered about 100 FCs for buses this year, and so far 60 units have been shipped, with 100-150 anticipated before year-end.

China is well-placed to put FCEB fleets into operation. The large numbers of BEV and hybrid vehicles on the road mean that integration skills, components and platforms already exist. Most of the buses will be FC-battery hybrids, with a smaller FC than in European or Japanese buses, not least because the Government subsidy is per bus and not per kW, making it more appealing to use a smaller stack. Government targets are large, and several thousand FCEBs could be in the near-term pipeline. Even with the first few hundred orders, China will overtake Europe as the lead market for FCEB deployment.

US a veteran in FCEB deployment – but is it keeping up?

While the leadership on fuel cell transit buses appears to be shifting to China, and Europe if the announced programmes come to fruition, the US retains a relatively modest research and demonstration program financed by the Federal Transit Administration. In a shift from past years, where the fuel cell bus program was independently financed, FTA's FC bus program is supported by the "Low and No-Emission Vehicle Deployment Program," and FC bus proposals must compete against battery electric and other technologies. Transit agencies in Ohio and California are operating or have in the pipeline nine buses between them, financed by Low-No in FY2015. A few other federally funded buses are also operating.

Alameda-Contra Costa Transit Authority currently runs 13 vehicles and two HRS, the largest single fleet in the world, and one of the longest running. The 40 foot (approximately 12 metre) buses are integrated with the conventional fleet operating on a number of non-commuter routes from the Emeryville and Oakland depots, whilst also being maintained by a common servicing department. A new 60 foot FCEB, the Xcelsior, developed by New Flyer Industries Inc. entered a 22 month trial with Alameda Transit in April. The propulsion system comes from Ballard and Siemens. SunLine Transit has been operating five ElDorado and NewFlyer FCEBs since 2011. These are to be joined by a further five FCEBs by early 2017.

Outside of California fuel cell buses have been less common. Stark Area Rapid Transit Authority

(SARTA) of Ohio announced a programme in 2016 to introduce a fleet of seven FCEBs by the end of 2017, serviced by a $1.6m HRS. This $19m project is reported to be funded 75% by the Federal Government. These 35-person capacity buses will be manufactured by ElDorado using Ballard fuel cells and BAeSystems drivetrains. If the plans are followed through, SARTA will operate the third largest fleet in the US and the largest outside California. Other active buses were in Austin, Texas; Birmingham, Alabama; Flint, Michigan; Delaware and California. The Austin, Birmingham and Flint buses were reported to have been withdrawn or transferred in 2016, with some ending up in Boston and New York State.

Competition comes from battery electric buses which are seen as having a lower infrastructure threshold; the FY 2016 Low-No program invested more than $50 million in battery buses. A similar pattern is emerging in California, the state with the greatest interest, regulatory and R&D support for fuel cell buses. In all, an estimated 50 fuel cell buses are on the road or planned in six states, though if the past is any guide some or many of these plans will not come to fruition.

Real bus route services: where the rubber hits the road

Demonstrations and trials in the US and Europe have set exacting performance targets for FCEBs, to match their conventional diesel competition. To the public 'a bus is a bus is a bus', an FCEB that breaks down is of no use even if it is 'green', whilst it also undermines the confidence of the bus drivers and the operator's management. So the US DoE and Federal Transit Authority have set a series of performance targets: 90% reliability, 25,000 hour plant lifetime, 300 miles range and eight miles per diesel gallon equivalent. NREL continually assesses US buses and statistics show ongoing improvement. Reliability averages 74%, although without two 'problem' buses in the fleet off the road for months, this could have been 86%, very close to target. Up to 2,900 miles are covered per bus each month, whilst nine of the fuel cell systems have clocked over 12,000 hours and one more than 22,000. FCEBs achieve close to 50% fuel efficiency improvements over diesel buses. But more is needed: better component reliability and durability; an improved supply chain to support buses when off the road; better training of drivers and maintenance operatives. Unsurprisingly, similar issues are identified in Europe, though reliability levels for FCEBs in the CHIC project are up from 50%-60% in the first year to an average 2015 level of 80% plus, with some cities over 90%.

Capital and running costs are critical to operators. The DoE/FTA target cost per FCEB is $600,000, but they are still much higher. FCEB operating costs are also higher, a function of various factors including a fuel cost that is four times as high as diesel. Lower external costs arising from lower emissions are hard to monetise for most transit operators, who are not responsible for health budgets. Nevertheless, local authorities are mandated to improve air quality, and many see FCEBs as part of the solution.

The hard-to-justify high prices of FCEBs for transit agencies has always been a brake on deployment, but it seems that there is now momentum behind the sector, and if China deploys as it has rapidly in other sectors, then things will get very interesting, very fast.

The development of fuel cell supply chains

The tip of the fuel cell industry iceberg is those companies that make, badge and deploy systems. Pure-play companies such as Ballard, Hydrogenics and FuelCell Energy are well known to those who follow the industry, and giants such as Toyota, Hyundai, Toshiba and Panasonic are famous far more widely. But supporting all of those organisations lie tiers of suppliers – far more companies than are reported on in this review. Some are also household names, but many are small, specialist and almost unknown. Companies like Honeywell, Sandvik or Bosch work side-by-side with start-ups and SMEs, many providing unique components, materials or capabilities.

This mix is not uncommon in any sector, but fuel cells are unusual in that very few of these organisations yet make good, repeatable or indeed any profits, and the complexity of a fuel cell system is such that many components are sole-sourced, or at least hard to interchange. This makes for a fragile and dynamic picture.

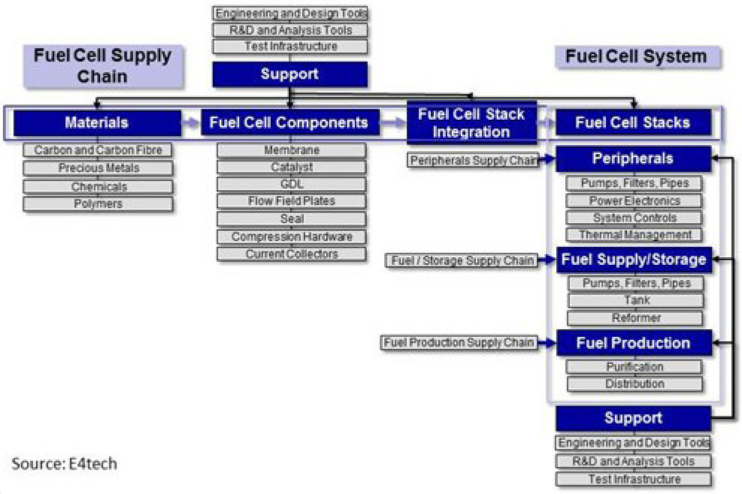
The underlying fragility has different implications for different applications. For an automotive OEM, a mature fuel cell industry can only be contemplated if the supply chain fulfils certain criteria. Suppliers must understand and show they can stick to the extremely high standards already demanded of the ICE chain, in quality, defect rates, delivery timing and in their own stability. A company that cannot demonstrate the ability to supply sufficient numbers of parts, at near-perfect quality, on-time – and with only small profit margins – will not long be retained. More than that, at least two independent suppliers must be available for any component or subsystem, so that the OEM does not entirely depend on any single link in the chain.

For a stationary fuel cell provider many of these requirements hold true to some degree, but it is rare for industries outside automotive to exercise the same extreme power and control over their suppliers. Nevertheless, protecting access to critical materials and components sometimes means drastic measures – when Ceramic Fuel Cells Ltd (now SolidPower) was setting up manufacturing, a powder supply capability was part of their structure, as they felt that only this way could they guarantee availability and quality of product. Other SOFC companies have invested as far upstream as mining, to provide some guarantee against supply disruption of critical materials.

Despite the onerous requirements, the relationship between supplier and purchaser need not be brutal or antagonistic – in many cases the supplier has deep expertise unavailable within the OEM and can suggest modifications to components that improve performance or reduce cost. The terms can include prepayments, co-development, OEM direct capital investment into plant housed at the supplier, and other means of sharing risk. In some cases companies will invest into ownership of others, or co-invest to create them. Solvay (fine chemicals) and Umicore (noble metals and catalysts) joined forces in 2006 to create Solvicore, a PEM MEA manufacturer. In 2015 the company was sold to Toray, who makes high-grade carbon and GDLs, and the company was renamed Greenerity.

Such examples may come from a strategic desire to capture a potentially higher value part of the supply chain, but some may emerge from necessity: many fuel cell companies have developed components they would rather have bought.

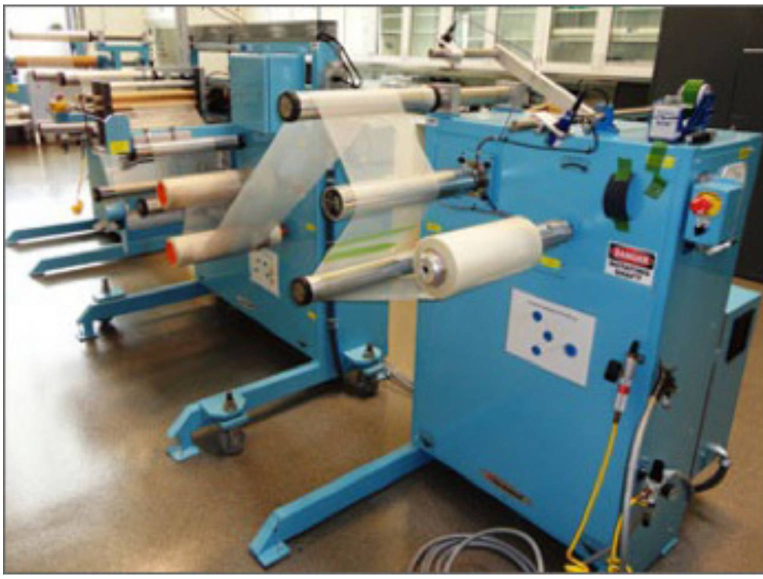
A high level indication of the complexity of an automotive fuel cell supply chain is shown below. The schematic represents a generic system, without indicating the specifics of what material or process feeds into which part, nor where or how manufacturing would be accomplished. It illustrates the wide range of components and skills required to complete an FCEV. For each box in the chain, many more- or less-specialised companies compete for orders and market share.



Source: E4tech

As the shipments we track increase, these companies face different challenges in scaling up. Toyota's announced production of 700 Mirais in 2015, 2,000 in 2016 and 3,000 in 2017 can be fulfilled with small numbers of components, essentially manufactured in batches. The 30,000 FCEVs they have announced for 2020 will require some suppliers to already have entered a mass-production regime. For others the components needed will represent only a tiny fraction of a mature production line.

For example, bipolar plates are somewhat similar in configuration and manufacturing



process to cylinder head gaskets in conventional ICE vehicles. Each ICE needs one gasket. But each FCEV needs 350-400 plates, so 30,000 FCEVs need plate production capacity equivalent to 10-12m of today's cars. That's a big step up in just a few years, and requires high-throughput machinery, very fine tolerances, high quality control and low scrap rates. Moving from what can be done now to that level of sophistication will require major investment in plant, tooling and logistics. A further requirement is an intermediate 'freeze' in the bipolar plate technology, to allow certainty that the plant and tooling investment can be paid back before the next design iteration makes it obsolete.

At the other end of a very wide spectrum, the amount of ionomer required to make the membranes for the same number of cars is only in the few thousands of kg. The chemistry required to produce the current industry standard ionomer (a perfluorosulfonic acid (PFSA) polymer) is complex and requires stringent safety precautions and licences. No plant will be built soon simply for making ionomer for fuel cells, nor can much cost pressure be brought to bear on the suppliers for a long time to come. Fortunately the product is currently produced for uses other than fuel cells, which makes supply reasonably stable, if expensive.

Small companies fit more comfortably into the early years of fuel cell industry development, where they can differentiate themselves on pure-play expertise. Large companies, much more likely to meet the requirements of large end-buyers in mature markets, struggle when orders are far below their typical critical mass. The fuel cell market is not yet big enough to justify investment other than on future sales, and the time taken to get to maturity may make the C-suite and shareholders nervous.

But production is already scaling. In Japan, Toshiba and Panasonic produce tens of thousands of fuel cell CHP plants for the Ene-Farm programme each year. Their production has become steadily more streamlined and more sophisticated, the systems have been rationalised and simplified, all while increasing performance and reducing cost. Nevertheless, the production scale is not yet fully commercial: some components are supplied by only a single source and the market is still too small to encourage competition. So component prices are not as low as they could be, and supply risk is higher.

Suppliers of larger fuel cells, Bloom or FuelCell Energy perhaps, face different challenges. They have built significant capacity in-house, but manufacture fewer, much larger units: tens to hundreds, not tens of thousands. Some cost reduction will still arise from their manufacturing scale and increasing purchasing power, but they also are changing their technology as the science advances, and so

optimising production is not simple. For balance of plant units such as heat exchangers or pumps, which can come from suppliers worldwide, costs are high as volumes are not yet sufficient for cost reduction programmes.

Supply chains for SOFC are also likely to be different from PEMFC – at least for many producers. While some companies already buy in complete cells and assemble them, many manufacture in-house from purchased substrates or powders. This means that they have process control but need their own large furnaces and other process equipment – something which is expensive to scale. PEM companies can, and often do, buy many of their components to specifications and have the in-house knowledge to assemble the parts into a highly efficient whole.

As the industry develops, many of the supply chains will solidify. As we have said about the likely long-term players in fuel cells themselves, many of the long-term players in components and materials are likely to be in the game already, building know-how and relationships. For some highly specialised components such as catalysts, it is hard to see how smaller organisations can enter the game at all, without the equipment and techniques for scaling up manufacture (described by many as a black art), and the extreme security and traceability that comes with handling large quantities of precious metals. But they can certainly provide innovation into the sector, and partner with the bigger companies on the ideas that work.

More fuel cells are being sold each year. The supply chain becomes more sophisticated each year. It is moving from the somewhat chaotic structures of today, where suppliers may be anywhere on the planet - because either they are the only ones who can provide what is needed, or the only ones who will - to an optimised and efficient structure that is fit for its purpose.

The outlook for 2017

The outlook for 2017 is more turbulent than we could have imagined a year ago. The mood music from the Paris Climate Change Agreement has turned to a strong marching beat, but some factors will hold countries back from taking near term steps.

The implications of Brexit and other potential EU political upheavals will unfold during 2017. An economic downturn, expected by many, could suppress public budgets, though the fuel cell industry's high-tech story remains a reason for innovation funders to assist the sector. Fortunately, Germany has recently committed to the next few years of support programmes, and the FCHJU has an established budget through to end of 2020.

When President Trump takes office in January, we may know more about his policies. A climate change denier and supporter of increases in US coal production, he may reduce the support available to fuel cells through the US Department of Energy and other bodies. Strong optimists may see opportunity for support of 'made in the USA' technologies operating – at least in some cases – on natural gas.

China may emerge as a leader in fuel cells. It has made commitments to rollout and to capacity building under the five year plan, which are unlikely to change. Hundreds of buses and other vehicles should go on the roads in 2017 in many different provinces, and China's automotive companies are actively developing their programmes, both internally and with partners. Change will happen fast, and if the solar sector is a guide then it could be felt globally.

Likewise Japan remains on track, firmly focused on the 2020 Olympics as a showcase for its transition to hydrogen for energy and motor fuel. Japanese buses will enter service, following more cars and refuelling stations. Toyota should put another 3000 Mirais into customers' hands in 2017, with many in California and some coming to Europe. At the same time they will be developing the BEV they announced in November 2016, aiming to have that ready by 2020, the same year they want to sell 30,000 FCEVs

In the US, California continues to provide the only significant market for fuel cell vehicles, given lack of infrastructure – and lack of policy maker interest – elsewhere. California continues deep subsidies for infrastructure development and has announced a programme to support development of medium and heavy duty fuel cell vehicles (along with other technologies). Toyota is rumoured to want to enter Northeast US markets in 2017. To do so it may be forced to build a skeletal infrastructure with its own resources. Barring an unanticipated regional infrastructure program announcement, it appears it will be 2020 or later before significant numbers of vehicles will be available outside California.

Most other car companies are moving slowly. Hyundai is selling globally and working on a new model, and Honda's Clarity deliveries should ramp up. The launch of Mercedes' GLC should give a further boost, although no ambitious sales targets have been mentioned to date and Daimler has disappointed before. Non-traditional players are moving ahead: SymbioFCell should be ramping up its deliveries of range-extender Kangoo vans, while Riversimple intends to build and test a series of its Rasa cars.

Japanese support for Ene-Farm is expected to continue. If prices to the consumer carry on falling as intended, 2017 may see 40-50,000 more units installed. However, the step-change to 300,000 per year will not occur yet. Energy market conditions will change as the effects of the de-regulation in April 2016 work through the system, but the effects on stationary fuel cells, both large and small, remain unclear.

Important for many fuel cells, and certainly for many of the companies making them, is an increasing interest in hydrogen, not only for transport. In 2016 a report on the conversion of natural gas grids to hydrogen was released in the UK. It was positive about the opportunity and received widespread interest both locally and internationally. In the longer term, using hydrogen may be the answer to decarbonising sectors, like heat, that are otherwise difficult. Support for some fuel cells would logically follow increased support for hydrogen and the developments required to implement it. Hydrogen Europe, the renamed industry body affiliated with the European FCHJU, appointed a Secretary General in 2016 and is looking to raise the profile of hydrogen and fuel cells as a solution to climate change, air quality and broader issues. It is supported by large corporations with the ear of governments. Expect to hear more from them. In the US a consortium of national laboratories has begun to evaluate Hydrogen at Scale, reaching the preliminary conclusion that via hydrogen a 50% reduction in greenhouse gas emissions is possible by 2050.

Japan's ongoing support of a future hydrogen economy could be helpful in reinforcing the trend. Toshiba, Tohoku Electric Power Co. and Iwatani are investigating an option to use renewable power plants, to be built in Fukushima prefecture, to produce up to 900 tonnes of hydrogen a year (150,000 fuel cell cars' worth). If it goes ahead it would come on line in 2020 and could produce hydrogen for use at the Olympics.

Large stationary fuel cell units remain hard to sell in great numbers. Bloom's IPO filing suggests it feels it has a solid pipeline and sales cycle and can convince investors. FCE has announced several large projects, but the number of orders across the sector does not seem to be increasing, and the layoffs at Doosan and POSCO signal trouble. Of greater concern still is POSCO's review of its decade long investment in MCFC. On a more positive note, MHPS plans to continue installations of its 250kW hybrid SOFC system, and continue to work on increasing the size of the final commercial unit. GE and LGFCS are still developing and testing their competing products.

The future of the fuel cell industry is far from certain. But we see the likelihood of another substantial increase in shipments in 2017 over our numbers this year. The majority will be in transport, spread over a range of applications, so the PEM supply chain is likely to strengthen. SOFCs are likely to continue eating into PEM's share of Ene-Farm sales, but otherwise shipments will be spread across a range of applications and companies, none yet likely to achieve critical mass – though a successful IPO from Bloom Energy would be dramatic and important news for the technology and the sector.

The mountain remains steep, but not impassable, and snow is clearing on some of its slopes.

Data Tables

Shipments by application						
	Fuel Cell Today			E4tech		
1,000 Units	2011	2012	2013	2014	2015	2016
Portable	6.9	18.9	13.0	21.2	8.7	4.0
Stationary	16.1	24.1	51.8	39.5	47.0	54.8
Transport	1.6	2.7	2.0	2.9	5.2	6.4
Total	**24.6**	**45.7**	**66.8**	**63.6**	**60.9**	**65.2**

Shipments by region						
	Fuel Cell Today			E4tech		
1,000 Units	2011	2012	2013	2014	2015	2016
Europe	3.9	9.7	6.0	5.6	8.4	3.5
North America	3.3	6.8	8.7	16.9	6.9	7.3
Asia	17.0	28.0	51.1	39.3	44.6	53.9
ROW	0.4	1.2	1.0	1.8	1.0	0.5
Total	**24.6**	**45.7**	**66.8**	**63.6**	**60.9**	**65.2**

Shipments by fuel cell type						
	Fuel Cell Today			E4tech		
1,000 Units	2011	2012	2013	2014	2015	2016
PEMFC	20.4	40.4	58.7	58.4	53.5	46.9
DMFC	3.6	3.0	2.6	2.5	2.1	2.2
PAFC	0.0	0.0	0.0	0.0	0.1	0.1
SOFC	0.6	2.3	5.5	2.7	5.2	16.0
MCFC	0.0	0.0	0.0	0.1	0.0	0.0
AFC	0.0	0.0	0.0	0.0	0.0	0.0
Total	**24.6**	**45.7**	**66.8**	**63.6**	**60.9**	**65.2**

Footnote to charts: Data from 2011-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2016 is our forecast for the full year. We have slightly revised the figures for 2015 in this report.

Data Tables

Megawatts by application						
	Fuel Cell Today			E4tech		
Megawatts	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Portable	0.4	0.5	0.3	0.4	0.9	0.3
Stationary	81.4	124.9	186.9	147.8	183.6	200.8
Transport	27.6	41.3	28.1	37.2	113.6	277.5
Total	**109.4**	**166.7**	**215.3**	**185.4**	**298.1**	**478.6**

Megawatts by region						
	Fuel Cell Today			E4tech		
Megawatts	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Europe	9.4	17.3	17.3	9.9	27.7	22.0
North America	59.6	61.5	74.7	69.8	108.4	209.1
Asia	39.6	86.1	122.9	104.5	159.7	245.9
ROW	0.8	1.8	0.4	1.2	2.3	1.6
Total	**109.4**	**166.7**	**215.3**	**185.4**	**298.1**	**478.6**

Megawatts by fuel cell type						
	Fuel Cell Today			E4tech		
Megawatts	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
PEMFC	49.2	68.3	68.0	72.7	151.8	311.2
DMFC	0.4	0.3	0.2	0.2	0.2	0.2
PAFC	4.6	9.2	7.9	3.8	24.0	46.6
SOFC	10.6	26.9	47.0	38.2	53.3	53.7
MCFC	44.5	62.0	91.9	70.5	68.6	66.9
AFC	0.1	0.0	0.3	0.0	0.2	0.0
Total	**109.4**	**166.7**	**215.3**	**185.4**	**298.1**	**478.6**

Footnote to charts: Data from 2011-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2016 is our forecast for the full year. We have slightly revised the figures for 2015 in this report.

Notes

- 2011-2013 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.
- Our 2016 figures are a forecast for the full year. Data for 2014-2016 have been collected directly from fuel cell manufacturers where they were able to share it; through interviews with industry experts; careful review of publicly available sources such as company statements and statutory reports, press releases, and demonstration and roll-out programmes
- 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 100 kW was shipped in that year.
- Portable fuel cells refer to fuel cells designed to be moved. They include fuel cell 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.
- 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 type 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 been helping clients to seize 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**

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Robert Rose is Executive Director of the Breakthrough Technologies Institute, an independent nonprofit advocate for technologies that carry environmental benefits to society; BTI's fuel cell activities date back to 1991. Rose has served in senior communications and policy positions in the US government, and as an advisor to state and regional governments, nonprofit organisations, and the private sector. Rose founded the US Fuel Cell Council, the trade association of the fuel cell industry, in 1998 and was Executive Director for 10 years. He writes and lectures widely about fuel cells and hydrogen energy and has received numerous industry awards.

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Can we help?

We would be delighted to discuss any aspects of the report with you, formally or informally, along with any other needs you may have. We have supported organisations in the fuel cell and hydrogen sectors globally for 20 years, as well as companies working in other areas of sustainable energy.

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.

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- Do you need to better understand the supply chain, the global market opportunities or the competition?
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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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PG	IMAGE	IMAGE CREDIT
4	Linde's BeeZero carsharing fleet of Hyundai cars	Hyundai Motor Company
5	Fuel cell bus assembly line, Foshan/Yunfu City, China	Ballard Power Systems Inc
8	Yutong fuel cell bus, China	Yutong Group
9	Hyundai taxi in STEP (Société du Taxi Electrique Parisien) fleet	Hyundai Motor Company
10	The Riversimple Rasa	Riversimple
11	Daimler's GLC plug-in hybrid fuel cell car	Daimler AG
11	Chevrolet's Colorado ZH2 military vehicle	Chevrolet
12	Nikola Motor's forthcoming fuel cell electric truck	Nikola Motor Company
12	34t truck for the Coop supermarket in Switzerland	Coop Group Switzerland
13	Pininfarina H2Speed powered by GreenGT	Pininfarina S.p.A.
13	Alstom Coradia iLint train with Hydrogenics fuel cells	EDIweekly.com
15	Doosan PureCell® Model 460	Doosan Babcock
16	Atrex SOFC remote power solution	Atrex Energy
20	Toshiba pure hydrogen residential fuel cell	Toshiba Fuel Cell Power Systems Corporation
22	1.4-MW FuelCell Energy fuel cell at FRIATEC, Germany	FuelCell Energy Solutions
23	Cutaway of GE's SOFC gas engine hybrid	General Electric
25	Dachs fuel cell CHP unit	SenerTec Kraft-Wärme Energiesysteme GmbH
26	2MW Nedstack PEM fuel cell at Ynnovate, China	Nedstack BV
29	Panasonic's condominium design fuel cell	Panasonic Corporation
29	Convion SOFC system	Convion Ltd
32	Yale forklift powered by Nuvera fuel cell	Nuvera Fuel Cells LLC
33	EFOY COMFORT fuel cell in leisure vehicle	SFC Energy
34	Ultra Electronics military SOFC	Ultra Electronics USSI
35	HES UAV on test flight	HES Energy Systems Pte. Ltd
37	Fuel cell bus assembly line, Foshan/Yunfu City, China	Ballard Power Systems Inc
39	New Flyer XHE60 fuel cell bus	New Flyer Industries, Inc.
40	Toyota Mirai manufacturing line	Toyota Motor Corporation
41	Small-scale manufacturing line at NREL's Energy Systems Integration Facility	National Renewable Energy Laboratory
42	GE's fuel cell manufacturing facility	General Electric
44	Nissan e-Bio ethanol SOFC van	Nissan Motor Company Ltd.

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 31st October 2015 to 31st October 2016.

US$1 = € 0.9016	€1 = US$ 1.1091	1£ = US$ 1.3994	1¥ = US$ 0.0091
US$1 = £ 0.7172	€1 = £ 0.7955	1£ = € 1.2621	1¥ = € 0.0082
US$1 = ¥ 110.40	€1 = ¥ 122.37	1£ = ¥ 155.01	1¥ = £ 0.0091

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