



E4tech
Strategic thinking in sustainable energy

The Fuel Cell Industry Review 2015



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LIST OF ABBREVIATIONS

AC – Alternating Current	HyESS - Hybrid Energy Storage System
AFC – Alkaline Fuel Cell	HUS - Horizon Unmanned Systems
AFCC – Automotive Fuel Cell Cooperation	HySA – Hydrogen South Africa
APU – Auxiliary Power Unit	IE – Intelligent Energy
BC – British Columbia	IPO – Initial Public Offering
BEV – Battery Electric Vehicle	IP – Intellectual Property
BTI - Breakthrough Technologies Institute	kW – Kilowatt
CARB – California Air Resources Board	LGFCs – LG Fuel Cell Systems
CFCL – Ceramic Fuel Cells Limited	LoNo – Low or No Emission Vehicle Deployment Program
CHFCA – Canadian Hydrogen and Fuel Cell Association	mAh – milliampere-hour
CHIC – Clean Hydrogen In European Cities	MCFC – Molten Carbonate Fuel Cell
CHP – Combined Heat and Power	MoU – Memorandum of Understanding
COP – Conference of the Parties	MW – Megawatt
DC – Direct Current	NIP - National Innovation Programme for Hydrogen and Fuel Cell Technologies in Germany
°C – Degree Celsius / Degree Centigrade	OEM – Original Equipment Manufacturer
DMFC – Direct Methanol Fuel Cell	OLEV – UK Office of Low Emission Vehicles
DoD – US Department of Defense	PAFC – Phosphoric Acid Fuel Cell
DoE – US Department of Energy	PEM(FC) – Proton Exchange Membrane (Fuel Cell)
DoT – US Department of Transportation	PPA – Power Purchase Agreement
EPA – US Environmental Protection Agency	ppm – Part per million
EPS – Electro Power Systems	RD&D – Research, Development and Demonstration
EU – European Union	RoW – Rest of the World
EV – Electric Vehicle	SAFC – Solid Acid Fuel Cell
FCE – FuelCell Energy (USA)	SOFC – Solid Oxide Fuel Cell
FCEs – FuelCell Energy Solutions (Germany)	SMR - Steam Methane Reforming
FCEV – Fuel Cell Electric Vehicle	UAV – Unmanned Aerial Vehicle
FCH JU – Fuel Cells and Hydrogen Joint Undertaking (EU)	UK – United Kingdom
FCT – Fuel Cell Today	UPS – Uninterruptible Power Supply
FY – Fiscal Year	US – United States of America
HES - Horizon Energy Systems	VW – Volkswagen
HRS – Hydrogen Refuelling Station	W – Watt
HVAC – Heating, Ventilation and Air Conditioning	

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Executive Summary

More fuel cell units, more installed power. That's the simple headline for activity in the fuel cell industry in 2015. Behind that lies a struggle for commercial competitiveness, recognition, and even survival. One highlight of the year was of course the Toyota Mirai's roll-out and the joyful advertising campaign that accompanied it, followed by Honda's more restrained announcement of the 2016 Model Clarity Fuel Cell. On the stationary side, Doosan accelerated from modest shipments of its PAFC units to multiple MW of announcements and Bloom and FuelCell Energy continued their solid sales. Japan's Ene-Farm programme hit around 140,000 residential CHP units.

The industry lost some more well-known names, notably Ceramic Fuel Cells Ltd, whose European SOFC microCHP operation was picked up by the newly-formed SOLIDpower (SOFCpower as was), and BIC (Angstrom technology) who decided to call it a day in the consumer electronics segment and sold their IP to Intelligent Energy. But Electro Power Systems successfully entered the French stock market, and companies including Bloom, eZelleron, Ballard and Swiss Hydrogen raised money. Plug Power acquired the rest of HyPulsion in France, Ballard bought Protonex, and some heavy-weight competition entered the fuel cell

forklift space as NACCO (Hyster-Yale) acquired Nuvera's technology for its own vehicles.

At just over 70,000, units shipped in 2015 were only up slightly on 2014. However, we estimate that around 350 MW of fuel cells will have been deployed, not far from double 2014's figure. The apparent discrepancy is easily explained; fewer tiny fuel cell chargers and more large units were shipped. Roughly twice as many cars entered the market, and more than double again should go out of the door in 2016. Even so, waiting lists for the Mirai are said to be around 3 years, and demand in general is far from being met by supply.

Frenzied hydrogen infrastructure building is underway too; some 46 public stations are near completion in California, perhaps a couple of dozen in Europe, and 74 should be ready in Japan by early 2016. The complexity of matching car roll-out and that of infrastructure is not easily solved, and it will be many years before fuelling is a sustainable business. Because of that it is strongly government backed, although Toyota and Honda have also funded station-builders, and the German H2Mobility consortium is now a private joint venture company, able to take that farsighted view and invest now for future returns.



In stationary applications, unit numbers are dominated by Japan: the Ene-Farm programme continues to expand and increasing (though still small) numbers of residential SOFC CHP units are being sold in addition to PEM. The market for large-scale units still belongs to FuelCell Energy (MCFC), to Bloom Energy (SOFC) and somewhat to Doosan (PAFC), though AFC Energy provided a welcome – if small – return for their alkaline chemistry. Most of the large units are in Korea, where the support programme remains generous and in the US, which also has state and federal programmes. Aside from that, telecoms backup remains a solid and strongly competitive market and so, increasingly, are entirely autonomous systems with their own hydrogen generation and storage.

Europe remains a slight anomaly. With many strong firms and some solid support, especially in Germany, and with development and demonstration financing available from the European FCH JU, European deployment is nevertheless much lower than the regions mentioned above: only around 10% of shipments in both unit numbers and installed capacity. This reflects the low or absent commercial subsidy regimes in comparison with these other regions, but also uncertainty in European energy markets, turmoil in the energy utilities, and the impacts of austerity regimes more generally. The only exception is buses; more fuel cell buses are operating in Europe than anywhere else, though this may change within a year or two if sales in China are realised.

It looks like 2016 will be a mixed year. Encouragingly, a number of large and credible orders and intentions have been announced – both stationary and transport. Ballard is working on sizable orders for trams, trains and buses in China, Hydrogenics has a solid order book which includes commuter trains supplied to Alstom, while Doosan and FCE also have many units to build. Aspirations are equally large – South Africa has installed one PAFC from Fuji but hopes to have many MW more. A few hundred MW of stationary power

is easy to forecast, though some still depends on subsidy agreements.

Intelligent Energy now has nearly 40,000 telecom towers to manage, into which it would like to install fuel cells. Being your own customer requires knowledge of the actual operating business, but since the telecoms market is being targeted by many companies this may be a safer way to ensure participation than simply competing hard with everybody else.

We expect 2016 to bring even bigger fuel cell passenger car shipment numbers. 2,000 units of Toyota's Mirai alone are slated to be handed over to customers, while Hyundai – which has cut its prices – will continue steady sales and Honda will start to lease the first few Claritys to favoured customers. Buses, trucks, vans and smaller vehicles will also continue to be released into controlled markets. We remain cautious about the very small end of the market, though design award-winning chargers will be released into the world by MyFC and eZelleron, and the rest of the portable power segment is likely to continue expansion.

At the same time, several important subsidy programmes may come to an end. Japan's Ene-Farm subsidy is expected – but not guaranteed – to be renegotiated. The US investment tax credit is scheduled to run its course and while a major proposal for fuel cell support is in discussion enactment is far from certain.

Overall we remain cautiously positive. We think shipments will be significantly higher in 2016. We also fear a few more companies may start but not finish the year. What we can't say is how many – if any – companies might make a profit from selling fuel cells.



Reactions to the 2014 Fuel Cell Industry Review

We produced our first of these annual Industry Reviews a year ago, with the aim of providing a free, objective and, as far as possible, authoritative overview of the main developments in the fuel cell industry. We wanted to make the data sets as closely as possible comparable with previous Industry Reviews, so that trends could be easily charted.

We received great support from within the industry, with many organisations contributing time, data and photos to the publication. After publication we received positive comments both on the fact that we had picked up the baton from Fuel Cell Today, and also on the quality of the Review. Thousands of individuals downloaded it, and often sent it to colleagues. It has been referenced in analyst reports and company conference presentations, and the data tables have even been projected onto an IMAX screen – bigger than we dared dream!

Reassured by the favourable reaction, we have gone ahead and produced a 2015 edition, and we intend to continue to produce these Reviews annually as long as they remain of use. As the Industry continues to evolve, we will keep

track of corporate activity, government policies and investment trends in addition to reporting units shipped, while rigorously maintaining data confidentiality. We will also continue to offer thought pieces on aspects of the industry we feel worthy of commentary.

E4tech continues to lead this work, but both Bob Rose of Breakthrough Technologies Institute and Jonathan Lewis Consulting are an integral and essential part of the team; we are extremely grateful for their strong and continued support. This year we also have guest input on the Canadian picture from Matthew Klippenstein.

We are keen to continue to hear your views on what has been useful or what could be added next time. Several people have asked if we plan to widen the coverage and include other parts of the hydrogen industry, which may be possible in a future edition. Please do continue to make suggestions for improvement or expansion, offer data, correct errors, or contact us to discuss other aspects of the industry. If you'd like to explore ways in which we could help you more directly we'd of course be delighted to discuss this too.

About the Review

Applications

As in 2014, to allow year on year data comparisons with previous editions, we use the same categorisation of shipment data as FCT did. 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 MCFC AFC SOFC PAFC	PEMFC DMFC
Examples	<ul style="list-style-type: none">• 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)	<ul style="list-style-type: none">• Large stationary combined heat and power (CHP)• Small stationary micro-CHP• Uninterruptible power supplies (UPS)	<ul style="list-style-type: none">• Materials handling vehicles• Fuel cell electric vehicles (FCEV)• Trucks and buses

Portable fuel cells are 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.

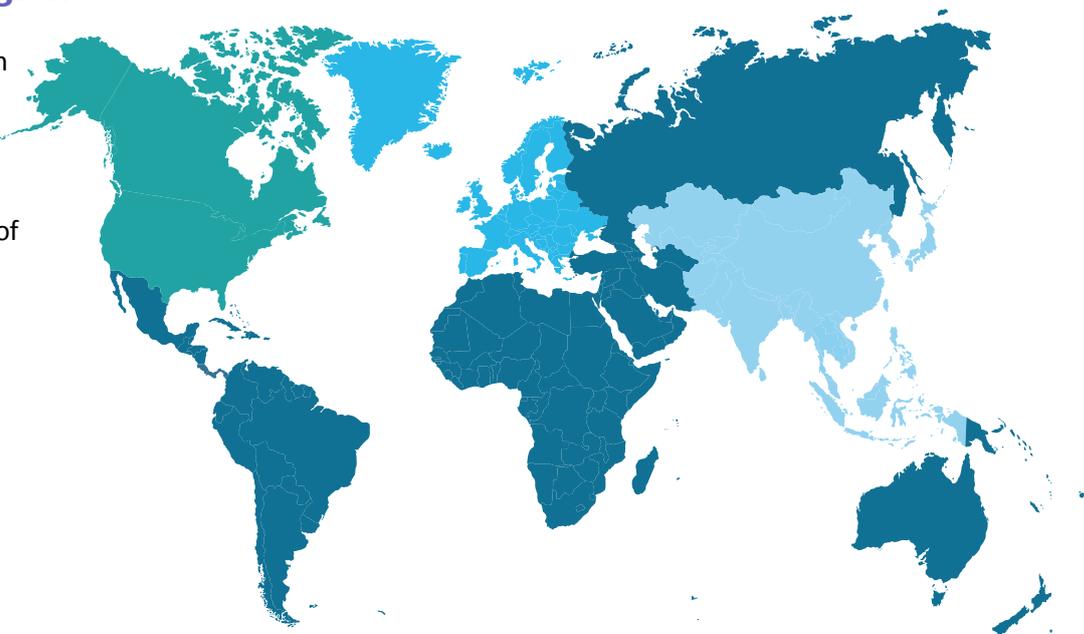
Explanations of these six main types of fuel cells can still be found on the FCT website:

<http://www.fuelcelltoday.com/technologies>

Geographic regions

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

- ROW
- Asia
- North America
- Europe



Reported shipment data

Tables of data can be found at the back of this Review, including historical information from FCT dating back to 2010. 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 2010 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 2015 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 very few declined to give us primary data. For those – and also for others – 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 currently count replacement stacks in existing applications, and where possible we also do not count inventory, only systems that are shipped to users.

We include an error bar for 2015, based on the quality of our data sources and our views on the uncertainty in the forecasts. We will revise data for 2015 in our 2016 edition as appropriate. We have slightly revised the figures for 2014 in this report.

How was 2015 for the fuel cell ‘industry’?

In the 2014 Review we cautiously suggested that 2015 could be ‘a watershed year’, talking in particular about the coming light duty vehicles. In terms of press coverage it certainly was, with many articles and blogs following the ups and downs. We are pleased – and relieved – to note that our expectation of increased shipments was borne out, though we were too optimistic about the smallest systems: the fuel cell chargers didn’t ship as claimed and do not in fact dominate our numbers.

The industry is far from stable yet, with CFCL and BIC’s fuel cell efforts and IP ending up with others. Protonex and HyPulsion were absorbed as going concerns rather than after the doors closed. Many companies continue to rely on raising finance to support themselves, unable to rely on commercial revenues alone, though the fact that they continue to be able to find investors is a good sign. But share prices have continued to suffer; at this writing many are trading at 50% off their 2015 highs, or worse. However, some new blood came in, like Swiss Hydrogen, and EPS launched itself on the French stock exchange. Companies continued to try and become their own customers, with Heliocentris building out more telecom support in Myanmar and Intelligent Energy acquiring more telecom towers to manage in India. Each of course plans to supply fuel cells into these sites when the time is ripe.

Ballard proudly announced delivery of its 3000th ElectraGen™ telecom backup fuel cell power system, Doosan breathed life back into what was once UTC’s PAFC technology, and Ene-Farm sales in Japan continued their (state-sponsored) success, though didn’t quite manage to hit aggressive government targets. Larger stationary systems accelerated their deployment. In general though, fuel cell customers tend to be repeat customers, with deep pocket companies such as BMW (forklifts), Walmart (power systems and forklifts) and

POSCO (power systems) building fuel cells into their routine operations, taking advantage of federal and state subsidies.

Apart from the headline vehicles – the Mirai, the Tucson iX35, the Clarity – plenty of smaller companies continued to deploy. Symbio FCell’s range-extended vans fit France’s cautious H2Mobility plans, Microcabs are in trial and scooters remain an intriguing option in Taiwan. The rhetoric around bus fleets continues to grow, and so do some of the fleets.

Hydrogen infrastructure roll-out is ‘nearly there’, but still has teething problems. While the roll-out is behind schedule, dozens of stations are in build and near completion in the early-market Japanese, Californian and European jurisdictions, and should be on line soon enough not only to take hundreds of vehicles but also to give the technical redundancy and physical proximity essential to make the first customers feel comfortable. At the time of writing there are of course only just ‘hundreds of vehicles’, and Toyota’s sustained series of advertisements around the Mirai, while lifting the spirits of the industry, has also raised expectations. These will need to be met for customers and governments to see benefit and continue their support.

Critics could argue that the most important milestones for the industry are being set by governments; certainly they would not have been achieved without government support. Japan’s 2015 fuel cell and hydrogen budget is about US\$500m. Japan’s government has pushed the private sector to deploy vehicle fuelling stations and intends to make the 2020 Tokyo Olympics a showpiece for its hydrogen energy strategy. Germany’s first round of station building firmed up in 2015, and the government is close to announcing a new support program for micro-CHP. In the US, power generation, forklifts, and – especially in California – fuelling station development,

are all heavily subsidised. Korea's leadership in power generation relies on supportive policies. In Europe, the EU's expanded fuel cell RD&D program made big new project awards. Countries such as

France and the UK stepped into the arena with new, or newly public, programs.

These support programmes, like those for solar, wind and even nuclear and coal, have a purpose. Companies in each of the fuel cell chemistries have used the opportunities to build on their foundations. PEM, SOFC and MCFC still dominate different areas of our charts, but PAFC has ticked up nicely and even AFC is registering a position – and much promise. Much of this was outside of Europe, where many things are happening but



deployment numbers are low. Uncertainty in energy markets and companies, coupled with the long drag of austerity measures is not helping. While the FCH JU continues to move its funding towards

deployment and away from R&D, absolute numbers remain low. Nevertheless, the residential scale demonstrations funded by FCH JU and Callux are likely essential to future market uptake, as even the companies with hardware 'ready to go' do not seem able to easily shift many units.

With inevitable exceptions, 2015 was a good year overall for fuel cells, with numbers up more or less across the board. Getting even more fuel cells for less government money, soon, is an essential next step.

Cars, cars, cars... and buses, trucks, forklifts...

Light duty passenger vehicles – the most talked-about, possibly most exciting, and certainly one of the most frustrating fuel cell applications -- are firmly back in the spotlight. The first commercially available Hyundai fuel cell vehicles rolled off the small production line early in 2013 and can be found in 15 countries. Toyota squeaked the launch of its Mirai into 2014, beginning deliveries in 2015. Honda showcased the 2016 Clarity Fuel Cell at the Tokyo Motor Show in 2015, though the first leases will only begin in Japan in March 2016. Vehicles from all three manufacturers are expected to be on offer in California by the end of 2016, and Hyundai has promised a redesign for 2018.

It's not the mass wave of launches that once was promised by companies including Daimler and GM. But it represents a very serious commitment by some of the world's largest companies, which are not only investing billions of dollars collectively on development, and in some cases on initial infrastructure, but also connecting the products firmly to their brand. Toyota has even gone so far as to engage in a public debate with the founder of Tesla, the luxury battery electric vehicle. Toyota uses a series of short films to make

fun of critics while proving points about the fuel cell pathway.

Other manufacturers are waiting in the wings. BMW showcased both an i8 and a 5-series fuel cell vehicle at one of its "Group Innovation Days" in 2015. VW – before the exposure of its defeat device software – presented Passat-, Golf- and Audi-based fuel cell vehicles at the 2014 LA auto show, and, in a presentation in 2015, allegedly hinted at a fuel cell Porsche. Daimler unveiled a bulbous autonomous concept vehicle in Tokyo in 2015, powered by fuel cells. Nissan, perhaps under pressure from its fellow Japanese companies, has mentioned commercialisation dates as early as 2017 or 2018, though its CEO speaks of 2020. General Motors has remained noncommittal on timing, although its fuel cell technology chief recently said GM was renewing its interest in fuel cell power generation applications.

A toe in the water

Manufacturers are being very cautious early in the production cycle. Since the vehicles are money losers and early roll-out entails risk, one way to minimise both is to build only a few, until



they really take hold. This also reduces the cost of building out early support. Toyota initially suggested only 350 Mirais would be built in 2015, but upped that to 700 based on very high demand; 2,000 more will be produced in 2016, 3,000 in 2017. The statement from the top is that they plan to have 30,000 cars in use worldwide by 2020, which implies tripling annual production capacity post-2017. And rumours suggest a fuel cell Lexus is in the pipeline; Toyota showed a concept Lexus fuel cell sport sedan, the LF-FC, at the Tokyo auto show in 2015.

Demand for the Mirai is high. The waiting list in Japan is rumoured to be 3 years, the result of Toyota's limited initial production. Europe is clamouring for vehicles, and 1,900 people in California had their names listed by autumn 2015. But at most 200-300 cars will be delivered outside of Japan this year, and they must be split among California and several European nations.

Honda has been very cautious about its figures, saying only that the initial customers will be mainly local governments and businesses who have already been working with the company in Japan, and that private Japanese customers, US and European roll-out will all come later. Sources suggest maybe 200 Claritys will be put on the road in 2016.

The cars on the road, like the majority of fuel cell cars previously, have been well received. More problematic, at least in some regions, is the infrastructure to supply them. Customers in California have been understandably vocal in their frustration with breakdowns at fuelling stations during 2015. The causes have varied, but technical problems need to be solved and backup options put in place if the initial roll-out is not to founder because nobody can fuel their car. As one owner pointed out "what value is free fuel if there isn't any to be found?" In fairness, many of the current stations are older trial units that supported fleet demonstrations. At time of writing only three fully commercial stations are open in California, though 46 more are on the way.

Technology progresses

The technology has advanced considerably. Both Toyota and Honda cite 'world-leading' power density of 3.1 kW/litre for their stacks and range for each vehicle is over 300 miles on US EPA tests. Compare this to the all-electric Nissan Leaf, which advertises EPA mileage of up to 107 miles per charge. Tesla models tested by EPA have tended to yield a range estimate of around 250 miles according to www.fueleconomy.gov. Hyundai says its 2018 redesign will achieve 80 mpg equivalent efficiency and a range – more than 500 miles – that favourably compares with the typical gasoline mid-size car.

Honda now has space for five passengers, not four. Both Honda and Toyota have chosen to offer emergency back-up power supply too: each has an EV-standard CHAdeMO socket in the boot of the car where an external inverter can be plugged in to take DC power from the fuel cell and supply up to 9 kW of AC power.

Reports suggest that both BMW's modified i8 and the 5-series FCEVs have a 'total system power' presumably including a battery, of 200 kW. Storage tank options are the increasingly standard 700 bar tank, or BMW's own cryo-compressed storage, the latter storing more hydrogen, at lower pressure, but at liquid hydrogen temperatures of approaching -253°C. Range with the former is just below 300 miles, with the latter claimed to be nearly 440. Intriguingly, the i8 was reportedly developed in 2012, before BMW's 2013 partnership with Toyota and access to its fuel cell technology.





A widening choice

The mainstream cars inevitably take the headlines. But as our analysis shows, they aren't the only vehicles being launched. Extending the range of BEVs has previously been the job of a small internal combustion engine, but fuel cells have been used by several companies for the same purpose. Intelligent Energy of the UK added its fuel cells to a battery Peugeot van some years back, and French company and Michelin investment SymbioFCell has been working with Renault-supplied Kangoo vans to deliver the electric Kangoo ZE-H2, with a 5 kW fuel cell feeding the batteries, into northern and central France. Swiss Hydrogen Power has a range-extended Fiat 500. And at the high power end we saw a Forza fuel cell race car developed by Delft Technical University setting records on the Nurburgring, and the considerably more powerful GreenGT H2 showcased at the Paul Ricard circuit in southern France. The latter is something of a thoroughbred: fully homologated, it uses only fuel cell power – no hybridisation of any sort – to achieve its 300 km/h top speed. This shaves weight and integration complexity from the system.

A competitive supply chain

While the mainstream automotive companies are focused on their in-house developments, they are of course trying to build a supportive supply chain. Some supply chain companies themselves develop fuel cell technology – in part to better understand the methods by which they

can be produced, but also with the intention of supplying other types of vehicles. Picking just a few examples, Elring Klinger has an in-house metal-plate stack with a power density of around 3 kW/litre, and Dana is an important partner in the FCH JU-supported AutostackCore project developing a similar specification unit within a consortium. Bosch has a pair of bespoke fuel cell Engine Control Units currently being deployed in prototype systems but ready for much wider use.

The transit industry – picking up

In 2015, fuel cells in transit applications came back to the foreground. China saw several deals, with Ballard the big beneficiary. They announced a “framework agreement” with Tangshan Railway Vehicle Company, Ltd., in June 2015 for development of a new fuel cell module, for tram or Ground Transport Vehicle applications, and later cemented it for a value of US\$3m. Ballard also signed a joint development agreement and a supply agreement to develop and commercialise a fuel cell for integration into low floor trams manufactured by CRRC Qingdao Sifang Company, Ltd., a Chinese rolling stock manufacturer. The deal includes delivery of systems for eight vehicles plus two spares. The initial value of the deal was put at US\$6m.

Ballard further announced a license and supply agreement with Guangdong Synergy Hydrogen Power Technology Co., Ltd., to support the planned deployment of approximately 300 fuel cell-powered buses in the cities of Foshan and Yunfu, China. Initial value was put at US\$17m. This follows an earlier agreement with Synergy and Nantong Zehe New



Energy Technology Co, Ltd., valued at US\$10m, for the delivery of FCvelocity®-HD7 90 kW net power modules for use in 33 fuel cell buses to be deployed in Yunfu, again, and Rugao, China.

History has taught us to be very cautious in interpreting announcements of this sort, but the partnerships look solid and the fact that there are four agreements is encouraging. If all the deals produce the numbers expected, China will soon become the leader in fuel cell bus deployments.

In Europe, Hydrogenics agreed to a 10 year deal to supply fuel cells for regional commuter trains for Alstom Transport. The agreement, valued at over €50m, includes the supply of at least 200 fuel cell systems plus service and maintenance. The first units are expected to be delivered in 2016 following prototype work slated for late 2015. Interestingly, also in 2015 the German government commissioned a study looking into infrastructure needs for hydrogen trains.

Further abroad, TIG/m, LLC announced delivery of its third hydrogen/hybrid heritage-style streetcar to Oranjestad, Aruba.

European bus plans

The end of 2014 and early 2015 saw growing support for an expansion of buses across Europe: in November 2014 five bus manufacturers, plus the cities of Hamburg and London, signed a Letter of Intent to commercialise hundreds of fuel cell buses in the coming years. By mid-2015 a further 30 European Local Authorities had stated their willingness to deploy fuel cell buses in the future. In preparation for these deployments the FCH JU is supporting a consortium of bus manufacturers, refuelling businesses, gas companies and users in a project looking at the engineering challenges and optimum modus operandi of depots with between 50 and 200 fuel cell buses. The aim is

to develop joint procurement strategies in multiple locations and hence bring down costs.

FCH JU projects dominate the European bus landscape. Early in 2015, Van Hool was awarded a grant for the 3Emotion project it leads, for 21 fuel cell buses to be deployed over the next few years to six European locations: London (UK), Rome (Italy), Cherbourg (France), Rotterdam and S Holland (both in the Netherlands), and Flanders (Belgium). The buses, including 18 metre articulated units, will all use Ballard's new FCVelocity-HD7 module, reported to be 35-40% cheaper than the precursor HD6 (v2) unit and thus a large contributor to the lower costs of these buses compared to previous versions. Including 3Emotion, Van Hool will have deployed 49 buses in Europe and the USA. The project joins three others: CHIC has 26 buses in five locations; HighV.LoCity has 14 buses in three locations and HyTransit six buses in Aberdeen. Together with other, nationally-funded projects 83 buses will be deployed in Europe, more than anywhere else at this stage.

Van Hool is not the only manufacturer involved – others include Evobus, Wrightbus and Solaris – and the projects also support a large number of hydrogen refuelling stations at the various locations. Hydrogen is supplied via electrolyser and tube trailer. Results from CHIC, the longest operating of the projects, show encouraging trends in bus availability, which has historically been an issue. This has risen to an average of 90% in some cities, although only 80% over all locations – a figure which must be increased to match the 95-98% achieved by diesel buses, for widespread adoption of the technology.



Other regions

In the US, by contrast, fewer than 20 fuel cell transit buses are operating, nearly all in California. Another dozen are under construction, including 10 financed by a new US Department of Transportation (DOT) Program called the Low or No Emission Vehicle Deployment Program (LoNo); awards were announced in February 2015. Transit agencies in Ohio and California will receive five buses each at a total cost of US\$18.7m, out of an overall LoNo program budget of US\$55m. DOT has made available another US\$22.5m in 2015 for low or no emission vehicles, suggesting funding for perhaps another five fuel cell buses. In California there is a further plan to deploy up to 40 fuel cell buses over the next two or three years, financed in large part by the sale of carbon reduction credits.

In Japan, Hino Motors has committed to commercialising its fuel cell bus in 2016, with the aim of deploying 100 in Japan in time for the Tokyo Olympics in 2020.

Forklifts and speciality vehicles

Forklift sales have been dominated for years by Plug Power, with some methanol-based systems from Oorja Protonics, and occasional units from companies such as Toyota and H2Logic – whose forklift business is now part of Taiwan's M-Field. Nuvera had early demonstrations also, but had left the field to others in recent times. However, its acquisition by NACCO Materials Handling Group (Hyster-Yale) late in 2014 has put its focus firmly back on forklifts, working on new product designs and planning to ship in 2016. While Plug Power has market traction and experience, Nuvera will be able to bring a fully-integrated solution based on in-house truck designs. Other speciality vehicle applications in development include refrigerated trucks.

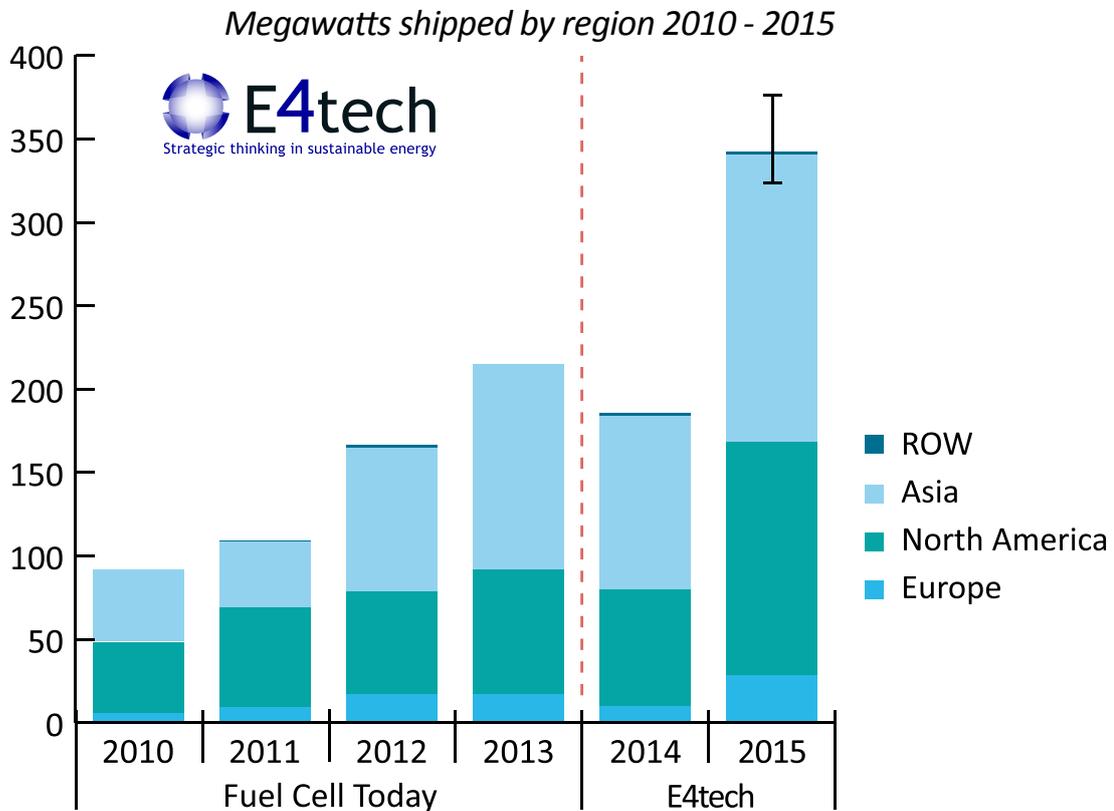
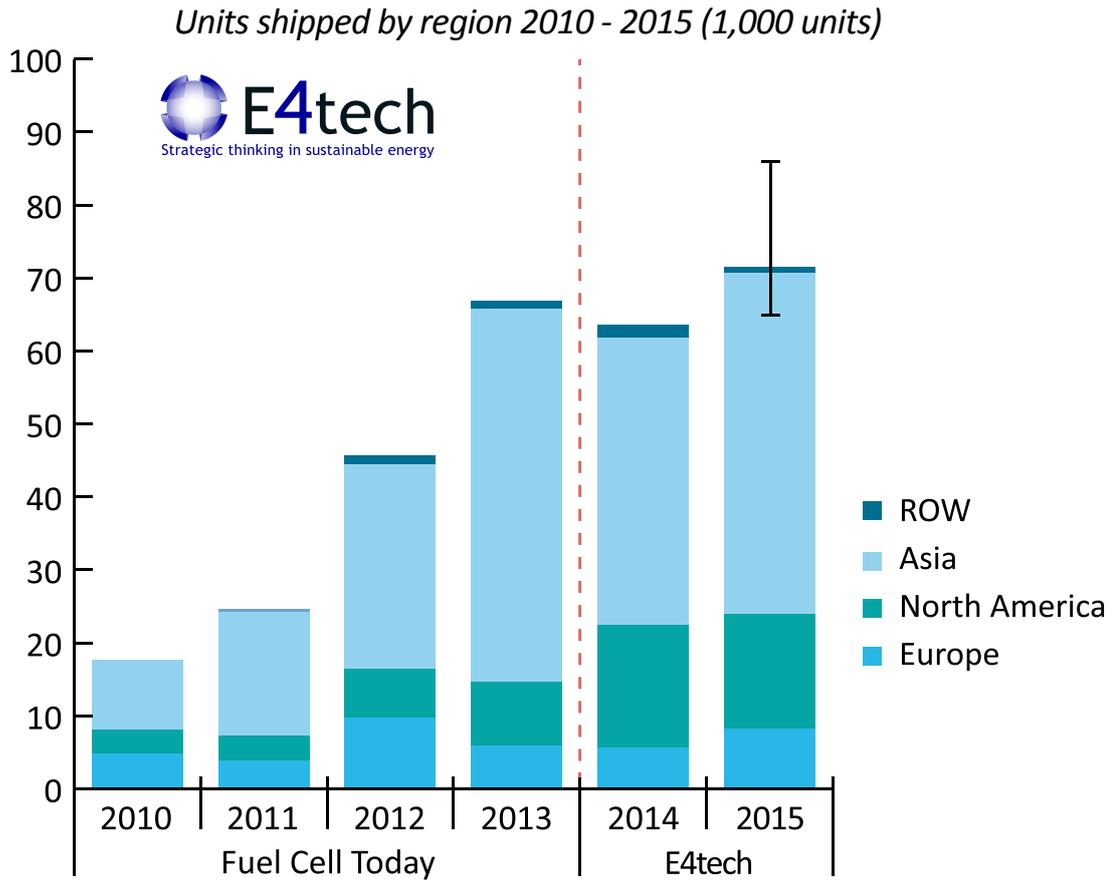
Plug Power began a forklift foray into Europe through Air Liquide and HyPulsion, and now owns 100% of the latter. Otherwise, developments in Europe have been slow, due to the thus far less compelling economic case for battery forklift replacements. Demonstration projects funded

by the FCH JU include HyLift and HAWL. HyLift is looking to deploy 200 vehicles in total, with 28 put in the field in France in September 2015, with Still as the forklift partner. HAWL includes Crown and Toyota Material Handling as the OEMs, and intends to roll out 84 lift trucks in France, of which ten were deployed by late 2015.

Enabling delivery of goods in noise- and pollution-regulated cities, fuel cells for trucks are increasingly relevant. Proton Motor has previously integrated their fuel cell range extenders into a 7.5 tonne duty delivery lorry from UK based Smith Electric Vehicles, which is now being tested by Hermes parcel delivery service. Symbio FCell has added range extenders to the Renault Maxity platform and Hydrogenics has launched a fully integrated fuel cell module for medium and heavy trucks, also available as a bundled solution including a Siemens hybrid drive system. Finally, the US Department of Energy is supporting demonstrations of a variety of speciality vehicles and systems, including a 100 kW barge mounted fuel cell power system for use in ports (with a total budget of US\$2.4m); 15 cargo tow tractors (US\$5.0m), used at Federal Express airport facilities; two auxiliary power systems for refrigerated trucks (US\$3.2m); a refuse truck, and a bucket truck. An award for fuel cell hybrid medium duty delivery vans is pending. Similar demonstrations have been made over the years in the US and Europe but reducing emissions and increasing efficiency in the movement of goods is a high priority in parts of the US.



Shipments by region



Footnote: Data from 2010-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2014 data are slightly corrected from our forecast in last year's Review. 2015 is our forecast for the full year. We include an error bar for 2015, based on the quality of our data sources and our views on the uncertainty in the forecasts to year-end.

Our estimates of full year 2015 fuel cell shipments show that all three of the primary economic regions, Asia, North America and Europe, have witnessed substantial growth in terms of power installed (MW). Global unit numbers and MW shipped in 2015 are at an all-time high. In fact, measured in megawatts, shipments almost doubled year on year from 185 MW to about 340 MW.

Asia stands out as installing almost two thirds of total fuel cell shipments and just under half of the MW shipped. As in 2014, this reflects the large numbers of micro-CHP units shipped in Japan under the Ene-Farm programme - which we estimate could be up on 2014 by as much as 10,000 units, depending on late-year sales - and on the numbers of larger stationary fuel cell units shipped to Korea. The introduction of the Toyota Mirai, with its maximum power output of 114 kW, into the Japanese markets had a measurable impact on Asian shipments in 2015, and the impact of automotive sales will be even larger beginning in 2016. Shipments to China and India, especially for telecoms back-up applications and increasingly for transport, as reported in the Transportation section, also increased the 2015 totals.

Fuel cell shipment unit numbers into or within **North America** have seen a slight downturn, with notably fewer portable units, but the total power of the units that have been shipped has just about doubled. This reflects the activities of Bloom Energy, FuelCell Energy, and now Doosan shipping larger stationary systems. In 2014 PAFC shipments were strongly down following the closure of the ClearEdge business, but Doosan has turned the situation

around, announcing significant order volume. In addition to these heavyweights, portable units and small stationary fuel cells – mainly for telecom back-up – are being delivered to clients in North America. Transport fuel cell systems, including the initial deliveries of Toyota’s Mirai and continued deployment of Hyundai’s Tucson, notably into California, has added further to the megawatt figure.

Europe’s experience in 2015 is starker than Asia or North America: a likely increase in overall unit numbers, depending on deliveries of portable chargers in late 2015, but an almost trebling of the MW value from its low base. Shipments of stationary fuel cells, micro-CHP, large scale CHP and back-up have all been partly responsible for this, with some further fuel cells for transport applications. Although this increase is welcome, shipments of fuel cells in and to Europe remain a fraction of those to Asia and North America.

The **Rest of the World** unit shipments are down on 2014, though up in terms of megawatts, but as a proportion of the global total these numbers are still insignificant. Shipments have been made to some areas of Africa, including South Africa, and to Mexico, amongst others. Ambitious deployment plans are reported for South Africa, which if realised would add significant stationary capacity in the coming years.

In terms of power rating, 2015 represents a step change from preceding years, and we expect to see another step change in 2016, though this depends in substantial part on the success of sales of fuel cell vehicles, and whether 2015’s added manufacturing capacity for large stationary fuel cells is put to work.

Selected country highlights

Canada's resilient industry

Canadian fuel cell companies are significant players in the global industry, with world-leading businesses in several sectors. Ballard Power Systems and Hydrogenics are leaders in PEM for transportation and stationary applications. Automotive technology developer AFCC (Automotive Fuel Cell Cooperation) is jointly owned by the global automotive concerns of Daimler-Benz and Ford Motor Company. Mercedes-Benz's PEM manufacturing facility is close by and Versa Power Systems, owned by FuelCell Energy Inc, is developing SOFC technology in Calgary, with funding from the US DoE. These and other businesses were estimated by the Canadian Hydrogen and Fuel Cell Association (CHFCA) to employ 1,550 people in 2013¹. 1,200 were located in British Columbia primarily in and around Burnaby, the home of Ballard Power Systems, AFCC and Mercedes-Benz's PEM production.

To get here, however, Canada's industry has gone through a series of ups and downs over more than two decades, matching the highs and lows of the fuel cell sector as a whole. Canada was doing fuel cells before the industry's rise in the early 2000s, when they were ranked alongside other innovative technologies as favoured investment targets, with Ballard – chosen by Daimler and Ford for early and significant investment – the poster child. In March 2000, Ballard Power Systems had a share price of CAD129, making it briefly one of the ten most valuable companies in Canada, based on market capitalisation. In 2002 Hydrogenics shares were trading at CAD200 each. In the same year, employment in the Canadian industry was estimated to stand at 2,860, an all-time high, whilst revenues were put at CAD134m.

The industry experienced a downturn in the mid-2000s following the bursting of the

technology stock bubble. The technology itself fell out of favour as commercialisation timescales continually slipped and then the financial crisis precipitated the shrinkage - and closure – of many fuel cell businesses globally. During this time and over several subsequent years Canadian fuel cell businesses were acquired or eventually closed: Angstrom Power (portable fuel cells) was acquired by French giant BIC, which in 2015 sold the intellectual property to UK's Intelligent Energy; Tekion worked on formic acid fuel cells with Motorola before going under; Polyfuel's novel hydrocarbon PEM and DMFC membranes were acquired by the University of North Florida; QuestAir (gas purification) merged with Xebec to focus on oil and gas; and General Hydrogen (a Geoffrey Ballard venture focusing on fuel cells for materials handling) was acquired by PlugPower to complement its acquisition of another Vancouver forklift company, Cellex. DDI Energy and Fuel Cell Technologies, both SOFC developers, went out of business.

More positively the wealth of fuel cell knowledge and expertise developed in Canada found its way into other businesses globally through the diaspora of employees. Ex-Ballard employees now populate fuel cell and other businesses around the globe and maintain a network that supports the industry in many ways. Canadian examples include Greenlight Innovation, which manufactures fuel cell, electrolyser and battery test stands, and recently branched out into manufacturing equipment. Non-core Ballard IP has been exploited by others: dPoint Technologies licensed early low-cost humidifier technology and supplies humidifiers for materials handling and automotive fuel cells. It also has a large market in the HVAC industry, supplying membranes for Energy Recovery Ventilators to preheat and humidify/dehumidify incoming air.

Over this same period Canada's leading fuel cell businesses evolved and developed their

activities. Ballard disposed of some parts of its business, notably AFCC, and acquired Dantherm and more recently IdaTech as a means to expand its product range and its global reach. It also re-entered the automotive sector in 2013 by signing a multi-year engineering services contract with Volkswagen, and then acquiring rights to a range of UTC's IPR before selling on the automotive-related patents to VW as part of a bigger deal in 2015. Also in 2013 AFCC's owners signed a three way agreement with Nissan Motor Company to develop the next generation of automotive fuel cell technology. Hydrogenics evolved and expanded, acquiring Stuart Energy and its electrolyser business (and Vandenborre's activity in Europe). At the other end of the scale start-ups developed in niche areas; PowerDisc – which designs flow fields to reduce mass transport losses and improve power density – and Terrella Energy, which offers flow field plate embossing expertise.

In employment and sales terms the period 2008 to 2013 (the latest figures available) shows the effects of the tougher economic climate and the continued challenges of commercialising fuel cell technology across the various markets. In 2008 Canadian fuel cell employment stood at 1,560 compared to 2,860 in 2002, and sales had fallen back to CAD88m from the CAD97m of 2005. Since then employment and sales have fluctuated, but 2013 found these figures at roughly the same levels as 2008.

Towards the end of 2015 the outlook for Canada's fuel cell businesses seems to be brightening. As noted in the transportation section, Ballard has signed deals to sell its heavy duty fuel cell modules to Chinese bus and tram manufacturers, the largest being 300 bus units for the cities of Fushan and Yunfu. If the deal is realised, moving from tens to hundreds of units would be a major milestone for the industry. Also in the mass transit field, Hydrogenics

signed a €50m deal with Alstom for 200 fuel cell engine systems for regional commuter trains in Germany, while Hydrogenics' Korean venture saw its first 1 MW power generation unit shipped and start operations in 2015.

Canadians unexpectedly elected a new Liberal Party government in October 2015. The Liberal Party campaign platform included public re-investment and increased support for clean energy. The latter may prove to be good for Canada's fuel cell industry – it promises increased Federal Government use of clean technologies in its buildings, procurement and energy use, making it into a 'test bed' for Canadian innovation. The party also proposed a CAD2bn green bond programme to provide affordable loan guarantees for clean energy projects; investing CAD100m more per year in technology incubators and other programmes to support the clean tech sector; and working to ensure that all provinces and territories put a price on carbon emissions. Clean technology businesses in Canada may now receive the support they have long requested, and product-ready fuel cell businesses could take advantage.

¹Estimate by the Canadian Hydrogen and Fuel Cell Association

South African opportunity

South Africa has been a strong supporter of fuel cells since 2007. With nearly 90% of the world's known platinum reserves, the South African government considers fuel cells a good opportunity to develop higher value-added offerings than just basic materials, from its wealth of natural resources.

Hydrogen South Africa (HySA), an alliance of government organisations and universities, was set up to build local knowledge and skills, and exploit local opportunities. With its long term goal to establish a South African hydrogen economy capable of competing on the international market – and capturing an ambitious 25% of catalyst demand in Hydrogen and Fuel Cell applications – HySA's second and current phase is focused on establishing supply chain capabilities and delivering the first products to market.

Applications include the mining industry – to power underground machines – telecom applications and remote power for off-grid villages. The deployment of larger-scale units started in 2015, with a 100 kW installation at the Chamber of Mines in Johannesburg. The Fuji Electric PAFC unit was supported by a ZAR7.5m (~US\$550,000) government

grant, but the project developers are hoping to demonstrate cost competitiveness against South Africa's relatively expensive and unreliable grid power. In fact power outages are sufficiently frequent that they affect the operation of businesses so fuel cells, as decentralised generation assets capable of delivering backup power, are seen as a possible remedy. While truck delivery is possible, hydrogen is not available everywhere – though there is one hydrogen pipeline, and hydrogen gained from the metal reduction process in mining operations – so many fuel cells will run on other fuels, such as methanol or natural gas.

In the country's first major deployment, Platinum producer Impala Platinum intends to install 1.8 MW of hydrogen fuel cell capacity at its platinum refinery in 2016. Later on, this could be boosted to 22 MW, enabling the site to become independent from the grid. Finally, a target of 1,000 MW of fuel cell capacity by 2020 was mentioned by the Minister of the Department of Trade and Industry at the launch of the Chamber of Mines installation, strongly underlining the country's ambitions.



Korean commitment

Korea sets its fuel cell ambitions in the context of its larger effort to deploy “New and Renewable Energy” technologies (fuel cells are among the “new”), with the goal of obtaining 11% of the nation’s primary energy supply from these sources by 2035. But it also values fuel cells for their economic development potential, projecting a US\$98bn Korean fuel cell industry employing 175,000 by 2040.

Spurred by the corporate commitment of Hyundai to fuel cell vehicles, and by a very attractive feed-in tariff subsidy for fuel cell power generation, Korea has emerged as a leader in several market segments. Hyundai was the first auto company to offer a vehicle for lease on commercial terms, beginning in 2013. Investments by Posco Power and others have made Korea the leader in large-scale fuel cell power generation, with more than 150 MW of capacity installed as of March 2015, and we expect up to 70 MW will be added by March 2016.

Posco’s huge Gyeonggi Green Power Plant is the largest fuel cell installation in the world at 58.8 MW. Posco’s joint venture with FuelCell Energy aims at Korean production of fuel cell units for Asian markets. Posco has ordered more than 270 MW of fuel cells from FCE over a number of years.

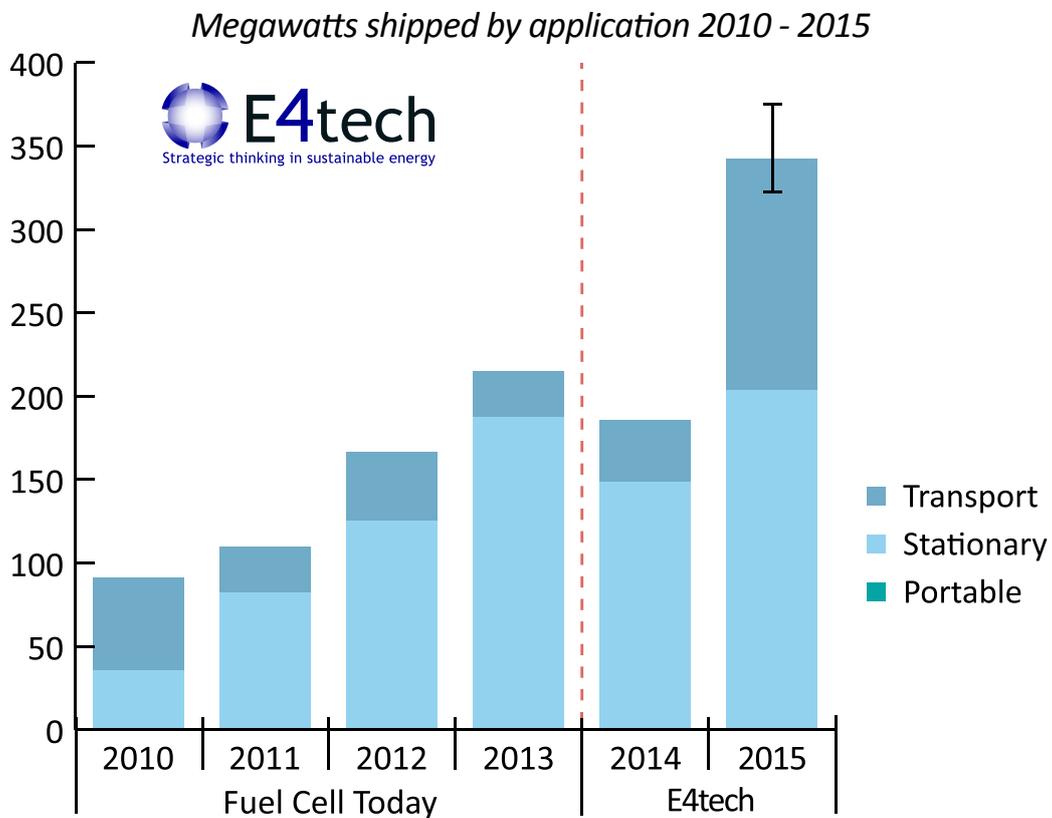
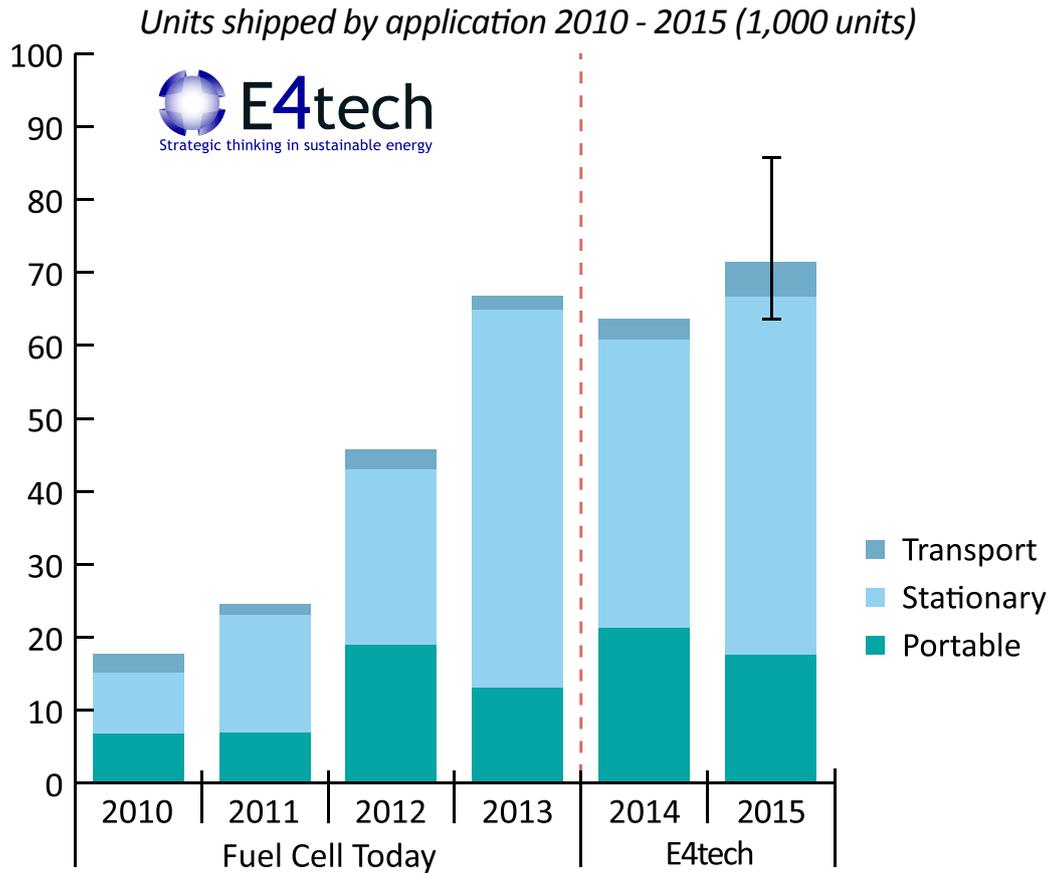
Not all of the investment is in deployment. Among the significant steps Hyundai/Kia took in 2015 was establishment of a “creative

economy innovation center” in Gwangju, with a focus on fuel cells and e-mobility technologies. The government’s goal is 17 such centres nationwide, all to help small and mid-size companies and start-ups to participate in cutting-edge economic expansion. Hyundai and other public and private contributors have pooled KRW177bn won (US\$164m) with KRW100bn won going to support existing auto industry companies and KRW50bn won set aside for start-ups. Hyundai also made 1,000 patents available.

Mindful of competition from Toyota and Honda, in 2015 Hyundai announced a 43% price cut on its Tucson (iX35) FCV, and brought forward the projected date for the next generation vehicle. The company promised that its next fuel-cell car will be lighter, faster and more fuel efficient, offered at “a very reasonable price,” and available in 2018. The company projects nearly 500-mile range and more than 80 miles per gallon equivalent, with a projected top speed above 110 mph.

Broader applications are also taking place: a community-wide demonstration called the Hydrogen Town is operating in Ulsan. The project uses by-product hydrogen delivered by pipeline. About 150 fuel cell units are deployed, including 140 1 kW residential units, nine 5 kW units at commercial sites and one 10 kW system for a commercial application.

Shipments by application



Footnote: Data from 2010-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2014 data are slightly corrected from our forecast in last year's Review. 2015 is our forecast for the full year. We include an error bar for 2015, based on the quality of our data sources and our views on the uncertainty in the forecasts to year-end.

Total shipments of fuel cell units by number and power have topped those of 2013 and 2014, but perhaps more interestingly, the composition of the total has begun to change. While portable shipments are estimated to be lower than 2014 and stationary fuel cell units higher, transport numbers have almost doubled. This change is revealed in even starker terms when expressed by MW: as always portable units barely register; the power capacity of stationary units is up on 2014; but transport, with more than 1,000 fuel cell cars hitting the road in 2015, has more than trebled.

We estimate about half of the fuel cell cars shipped in 2015 will be in Japan, and the remainder split more or less equally between Europe and California. We expect Toyota will lead this segment in 2015, ahead of Hyundai which maintains its solid annual performance started in late 2013. At the same time fuel cell range extenders for light goods vehicles, exemplified by the products of SymbioFCCell of France, have further added to the unit numbers and MW figures.

Mass transit applications of fuel cells are also increasing, as witnessed by Ballard's shipments of modules to China where dedicated support schemes

are now reported to be in place. Further growth can be expected in 2016, including the shipment of fuel cell units for Europe's next bus demonstration project 3Emotion, and for smaller US initiatives. Even though they do not figure in the 2015 total, this year's announcements of fuel cells for future trains and trams should further strengthen the mass transit application in the coming years.

Materials handling applications have dominated the transport sector for a number of years, and 2015 will be no different. Plug Power, using Ballard modules, has a target of deploying 3,300 material

handling vehicles for 2015, a 25% year-on-year increase. Other players are also apparent in this sector with vehicles being demonstrated at airports and other locations, and Hyster-Yale's Nuvera purchase suggests some interesting competition ahead.



The diversity of applications in the transport sector includes fuel cells for unmanned aerial vehicles (drones) and other unmanned military vehicles, which although sometimes high profile, we estimate are low in terms of numbers and power; some heavy duty trucks; and fuel cells for racing cars, notably from the Swiss company GreenGT.



Stationary fuel cell shipments fall mainly into the three well-worn categories evident in past years: back-up or off-grid power for telecoms equipment; fuel cells for micro-CHP and larger CHP; and power-only systems of hundreds of kW to MW electrical output.

Shipments of small systems - around the 5kW size - for back-up and off-grid applications continue to be the main deployments into the more exotic markets around the world, including India, South East Asia, China, the Middle East and Africa, but also in Europe and North America. Established fuel cell players in North America and Europe, as well as from Asia, are targeting these markets. However, this segment only accounts for a small amount of total MW.

Micro-CHP fuel cell shipments dominate unit numbers in the stationary sector. The Ene-Farm programme in Japan provides the market for Panasonic, Toshiba and Aisin, and together these three will dispatch more units than ever before, up to 20% growth in 2015 year-on-year. Elsewhere, numbers of micro-CHP units are much, much smaller, and most of those are in Europe where the Ene.Field programme benefits the likes of BDR Thermea, Vaillant, SolidPower, Bosch and Elcore. Collectively Europe's shipments in this field are up on 2014, despite CFCL's 2015 demise - though shipments of their BlueGen units are reported to be resuming following SOLIDpower's acquisition of certain CFCL assets.

Large scale stationary fuel cells of the 100 kW to MW scale, dominate the sector in terms of capacity shipped. FCE, shipping MCFC with its Korean partner POSCO Energy; Bloom Energy with its SOFC units, and Doosan's PAFC units; will collectively ship more this year than ever before. The primary destination of these fuel cells is Korea, and to a lesser extent the USA, still Bloom Energy's core market. Other players also benefit from the Korean appetite for stationary fuel cell systems, including Hydrogenics which completed a 1MW unit in summer of 2015. Europe's

presence in this part of the stationary sector is modest at best.

Shipments of portable units run into the thousands, but their total power output is small. Chargers of 5 W unsurprisingly contribute little to the MW total. Suppliers include Horizon, which has been working on the Brunton Hydrogen Reactor in the USA, and Intelligent Energy which has an agreement with Apple to distribute its Upp product in the UK. More significant are the 50 to 100 W auxiliary power units used for leisure purposes, and those for off-grid applications such as construction sites, for sensors in transport, and oil and gas infrastructures - seen as a growth area. Lastly there are military applications, including those with power outputs of 50 W to several hundreds of Watts.

We believe that final 2015 shipments will have been affected by a hiatus in activity for some businesses. MyFC, for example, has been focused on the commercialisation of its Jaq product for the end of 2015, after phasing out the PowerTrek line. Others have shipped fewer units than hoped, notably Intelligent Energy which encountered manufacturing issues with its Upp product. Finally a relatively new entrant, eZelleron, has plans to ship its Kraftwerk charger from 2016.



Stationary fuel cell installations - still in the majority

The pattern of progress in the deployment and development of stationary fuel cells in 2015 very much followed 2014: strong activity in Japan and South Korea, in small and large scale fuel cell systems respectively; continued growth in large scale fuel cell systems in North America; low, but growing numbers of micro-CHP fuel cell systems installed in Europe; and limited activity in the rest of the world, mainly in power for telecommunications and military applications.

Small fuel cells, big numbers

Japan's Ene-Farm programme, the umbrella term for the different micro-CHP fuel cell systems for residential applications across the country, continued its success in 2015 – though still with government backing. From its inception in 2009 to October 2015 the government programme has supported the installation of around 140,000 units. Total installations in calendar year 2015 are expected to be at least 40,000 and possibly even 50,000 (estimated to year end) – the largest annual deployment to date, though fewer than initially hoped. These units are primarily PEM units of 0.7-0.75 kW supplied by Panasonic and Toshiba, plus smaller numbers of Aisin Seiki's SOFC units. Routes to market are almost wholly through Japan's gas suppliers, e.g. Tokyo Gas and Osaka Gas, with Panasonic, for example, working with 17 of these entities. Aisin, using Kyocera cells, entered the SOFC market in earnest through Osaka Gas in 2014 and SOFC sales should account for around ten percent of the Ene-Farm shipments in 2015.

The Japanese Government maintains its publicly-stated targets of installing 1.4 million of these micro-CHP units by 2020 and 5.3 million by 2030. This is ambitious. Although the Ene-Farm programme has managed to increase its installations every year, 1.25 million units in the next five years will require a big step up. To help, the Government is maintaining its public

support beyond the initially suggested phase-out period, though the amount is tapering heavily – each PEM unit received ¥350,000 in 2015, with a total available of ¥22.2bn – enough for up to 65,000 units. SOFC units receive slightly higher subsidies – ¥430,000 each in 2015 – reflecting their comparative immaturity. Both Government and industry are keen to avoid the steep drop-off in sales that befell the ECOWILL gas engine CHP unit when subsidy was removed. Ene-Farm subsidies are scheduled to end this year, but further budget has been requested for 2016, perhaps with a different programme structure.

The progression of technology to improve performance and reduce costs has been a primary focus for the technology developers. Both Toshiba and Panasonic have improved their offerings on a regular basis since 2009. For example, in early 2015 Panasonic announced improvements to its PEM offering: reconfiguring the stack, simplifying the system and reducing the number of components by 15%, alongside 20% reductions in platinum usage and weight reduction from 90 kg to 77 kg, all whilst increasing durability from 60,000 to 70,000 hours and maintaining total efficiency at 95%. It also introduced a system with a 'black out' function able to generate 500 W for up to 96 hours. Both Panasonic and Toshiba are expanding their market offerings, including systems for use in apartments or condominiums.



Panasonic also announced a reduction in the recommended price of ¥300,000 from the 2013 model. Indeed since 2009 Panasonic has halved the price of its fuel cell systems through a determined technology simplification and improvement process. These improvements parallel those instituted in 2014 by Toshiba, which improved fuel efficiency (increasing carbon savings), reduced physical dimensions and reduced costs. The 2014 (third generation) product is 50% cheaper than the first generation. This price reduction is partly due to technical developments but also reflects a ramp-up in manufacturing: Toshiba's current daily production of 120-140 units equals its monthly capacity in 2009.

It is clear that only by lowering the cost of ownership to households can Japan's ambitious installation targets be met. Efficiency is already close to its theoretical maximum, so this means lowering capital cost through better and cheaper design and through more production. Broadening the market should lead to more demand and hence greater scope for mass manufacturing. Given their investment to date and their existing market access, it is not surprising that the Japanese developers have sought to extend their activities and technologies into other markets, most notably Europe and in particular Germany. Panasonic is partnered with Viessmann, Toshiba with BDR Thermea (under the Senertec brand) and Aisin with Bosch (Buderus and Junkers brands).

The Korean roll-out rolls on

Whilst Japan leads the way in micro-CHP fuel cell systems Korea continues to advance its ambitions in larger scale systems, notably MCFC to date, but with other technologies in the pipeline. The multi-MW MCFC fuel cell parks started or announced in 2014, notably Hwasung City's 59 MW park and others such as Pyeongtaek City, are on track. To support these local deployments POSCO, Korea's largest fuel cell system supplier, is due to begin operations

at its Pohang MCFC manufacturing facility in Autumn 2015, replacing some of its demand for importing systems from its long-time partner FCE in the US, with whom it continues to work – in fact FCE announced an additional 14 MW of sales to POSCO through to early Q4 2015.

Meanwhile, Doosan Fuelcell America, working with Samsung C&T Corp. and Korea Hydro and Nuclear Power, announced a deal to supply 70 of its PureCell 400 PAFC power plants for a 30.8 MW facility. This will provide power to a new residential complex in Busan, with the first shipments from Doosan at the end of 2015, the last scheduled for mid-2016, and full operation scheduled for 2017. The project follows a 2.6 MW project in Seoul that started operation in the first half of 2015. Doosan has followed through strongly on its promises to revive PAFC sales, also announcing an order by Korea South East Power Co. for 13 PureCell units for Bundang, to be switched on by the end of 2015. Summer 2015 also saw the delivery of Hydrogenics' 1 MW power module system to Kolon, Hydrogenics' Korean partner, with operation slated to start in the last quarter of 2015.

These projects are founded largely on the favourable support regimes South Korea has implemented over the past decade: tax incentives, capex support and feed-in-tariffs have been or are being used in addition to other instruments such as a renewable portfolio standard supporting 'clean energy' production. Korea will also start a Renewable Heat Obligation scheme in 2016, which will require any commercial property project of 10,000m² in floor space to have on-site new and/or renewable power generation. This is ideal for fuel cells operating in CHP mode. The scheme will be extended to properties of 5,000m² in 2020. These policies reflect to a large degree the desire by government to lessen its dependence on energy imports, and have led Korean businesses from across the spectrum to invest in fuel cell technology at home and abroad.

Major corporations in Korea are partnered with, or have bought into, European and North American based fuel cell technologies and businesses. POSCO led the way in its partnership with FCE Inc., and since then LG has bought into the Rolls-Royce Fuel Cell Systems business to form LGFCS, Doosan purchased the assets and rights to the PAFC technology of ClearEdge/UTC, and KD Navien has been working with Ceres Power. SK's agreement with Topsoe Fuel Cell, which closed down in 2014, does not seem to have been followed by any other initiative by the Korean corporation. However general demand has expanded further in 2015 as Samyoung Corp and Chan Sin Chemical have an MoU with the UK's AFC Energy, developer of alkaline fuel cells, to install 50 MW of AFC's 'Kore' fuel cell systems.

US momentum building

Larger scale stationary fuel cell installations in North America are dominated by three fuel cell developers: FuelCell Energy (FCE) Inc. using MCFC technology, Doosan Fuel Cell America with PAFC systems and Bloom Energy with its SOFC plants. Units from these developers range in size from 100 kW through to several MW. As in previous years, most installations of these units are in regions and states with supportive regulatory and financial regimes, with California and Connecticut being front runners.

FCE has continued to win orders for its DirectFuelCell MCFC technology. A 63 MW fuel cell park has been proposed for Beacon Falls, Connecticut, with FCE working alongside O&G Industry and CT Energy & Technology. Smaller follow-on orders include a 1.4 MW unit for the Pepperidge Farm company, which follows on from a unit installed several years ago. FCE sold 70 MW of units in FY2014 and at the end of Q3 2015 still had



a revenue backlog, units and service contracts, valued at US\$338m; as units are shipped so the service element of FCE's revenues grows. To meet these and future orders FCE has been engaged in expanding its state-supported manufacturing facility at Torrington, Connecticut – where just under half of FCE's 622 employees were located at the end of 2014 – to an annual capacity of 100 MW. This capacity is similar to the POSCO facility in Pohang, and both have the potential to double their annual output to 200 MW. Continued use of Power Purchase Agreements (PPA) has helped FCE to deliver units to customers without the upfront capital investment. For example, at the end of October it announced a 20 year PPA with Alameda County, California, to supply power and heat to the county jail using a 1.4 MW Direct FuelCell. The unit will be delivered in the latter half of 2016, replacing a smaller unit installed in 2006.

Hydrogenics appears to be successfully taking in new orders for their power products in addition to the ones mentioned for Korea, with a substantial order backlog. However, publicised orders have been scarce, with only a 100 kW fuel cell for Levenmouth's Community Energy Project in the UK getting a mention.

Doosan (which took over the orphaned PAFC technology located in South Windsor, Connecticut, in summer 2014) has spent the intervening period re-building the team, forecast to be 300 by the end of 2015, and winning new orders for the 400 kW PAFC PureCell product. In addition to the above-mentioned activity in Korea, Doosan has focused on the USA, with a Model 400 ordered for the CT Transit depot at Hamden,

Connecticut, similar to the unit installed at their Hartford depot. Meanwhile Fuji Electric has continued to sell its 100 kW PAFC offerings, operating on various fuels, into Asia, the US and Germany, as well as a unit to South Africa.

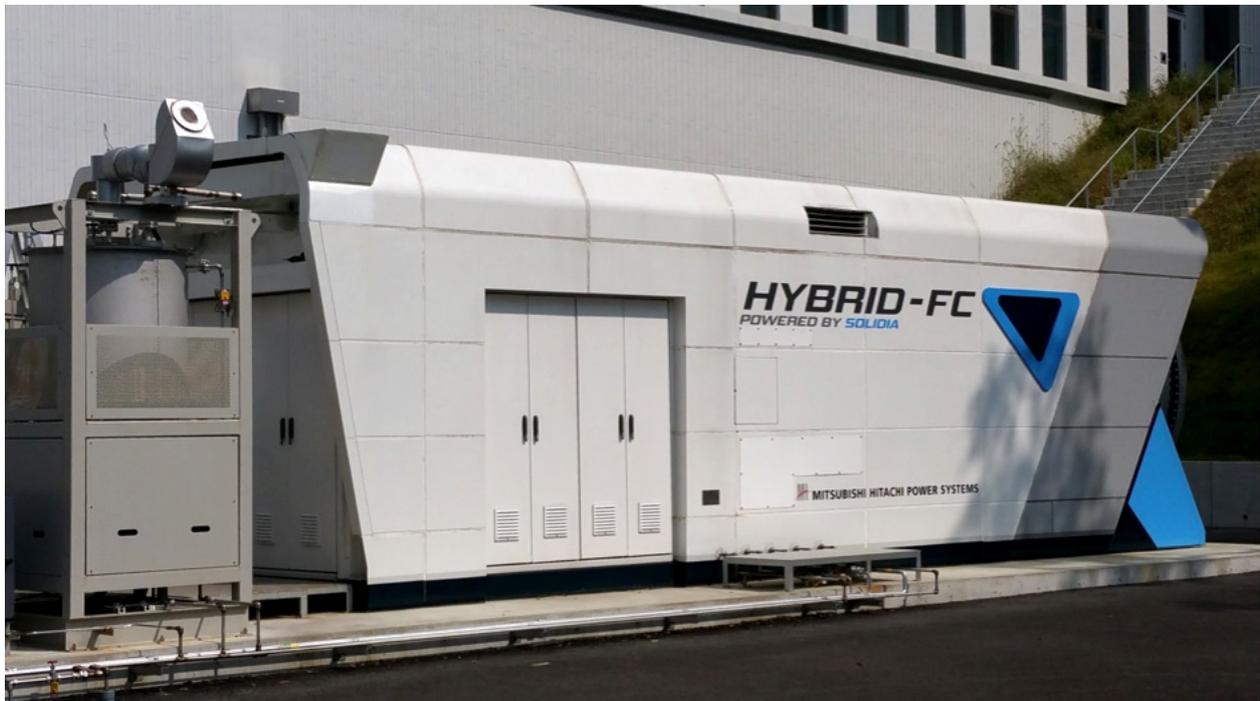


Bloom Energy remains coy about its engagements and its plans, occasionally announcing a major new customer or development and also continuing sales with loyal customers like Walmart. The SOFC Energy Server product received a major boost in summer 2015 when Constellation and Bloom agreed to supply 40 MW of units to customers across California, Connecticut, New Jersey and New York. Constellation will fund and own a majority interest in these units which will be sited at 170 customer locations. This follows a similar deal in 2014 with Exelon, parent of Constellation, to fund 21 MW of units. Bloom entered into another finance-based deal to support sales of units with the XL Group, which is to provide performance warranties for 6.1 MW of units and continues to make progress in the data centre field, including sales to CenturyLink and Equinix, both in California, and an agreement with Vapor IO to provide distributed ‘green’ power for data centres. These units are sold partly on green credentials, and partly on other attributes: distributed fuel cell units running on gas are able to provide the power reliability that these mission critical services require. The company has also taken advantage of some of the unused space in its modules, and now fits 500 kW in a unit similar to those that previously held 250.

Controversy continues to stalk the company, however, as an out-of-court settlement of a lawsuit in Delaware shows. Legislation which ‘discriminated against out-of-state businesses’ was repealed so that FCE, amongst others, could compete to supply renewable energy into Delaware’s programme. Bloom needs to employ 600 people in Delaware by the end of 2015 to adhere to an agreement that saw it build a subsidised factory in the State, but employment numbers were lagging the target at the end of 2014, with 208 out of a projected 300 people working at the plant. A report at the end of October 2015 puts the figure at 224, still far from the target of 600. Part of the support is funded through the addition of a controversial surcharge on the power bills of Delmarva (Delaware, Maryland and Virginia) customers. Local media reports suggest that a typical customer is paying over US\$4 extra per month.

Hybrid Fuel Cell Systems – back in the picture?

Hybrid SOFC systems for stationary applications have been under development for some time in Japan, USA and UK. The first systems were built more than a decade ago by Siemens-Westinghouse, and ran briefly, but cost and complexity worked against them. Nevertheless,



the concept of a very high efficiency hybrid unit remains enticing. LG Fuel Cell Systems, with operations in Ohio USA, Derby UK, and Korea, ran large scale pressurized SOFC-micro-turbine unit trials at the 200 kW scale, using an 'integrated string' of components. In 2016 the company is expected to move to a fully integrated 250 kW system test, and then towards commercial deployment. Mitsubishi Hitachi Power Systems has delivered a 250 kW unit to Kyushu University, complete with an integrated 80,000 rpm micro-turbine supplied by Toyota. The unit is operating in a pre-commercial verification programme at the Next Generation Fuel Cell Centre at Kyushu University's impressive Fukuoka campus.

And, after about a decade of absence, in mid-2014 GE Energy announced a return to the fuel cell arena with plans for a 50 kW hybrid SOFC system coupling a reciprocating gas engine and an SOFC unit made by additive manufacturing, which will 'dramatically reduce cost'. This method of hybridisation is a first of its kind, and the effort is supported by a 20,000 sqft facility in Malta, in New York State. Activity in 2015 appears to have focused on recruiting the team to support the development activity, which at the end of 2014 was targeting 30 employees.

Europe's Stepwise Progress

2015 has been a significant year for stationary fuel cells in Europe. It marks the last full year of operation of Germany's Callux programme demonstrating micro-CHP units from several, primarily German, developers. Over 500 units have been installed across the country. Germany also offers funding at the State level, with both North Rhine Westphalia and Baden-Wuerttemberg supporting fuel cell installations and new energy technologies generally. Market deployment support is still needed, however, and a Technology Implementation Programme for this is currently being determined (see text box), sponsored by the German Federal Ministry for Economic Affairs and Energy.

At the same time Europe's largest micro-CHP trial, the FCH JU-supported Ene.field programme, moved forward with installations towards its target of approximately 1,000 units. By September 2015 more than a third of these had been installed across eight European countries. With the project due to end in 2017, installation of the remainder will need to come soon for them to provide demonstration value – though a call for FCH JU proposals closed earlier in 2015 and included requests for a "Large scale demonstration of micro-CHP fuel cells". A more advanced project could thus build on Ene.field.

A German Ene-Farm copy on the horizon?

The German government has supported RD&D in micro-CHP fuel cells for many years, recognising the importance of this technology to improving energy efficiency; the Callux demonstration programme is significant amongst these actions. German boiler manufacturers, as well as pure fuel cell developers, have over recent years launched a range of products in expectation of wider market adoption. But a typical 0.7 kW system is still some eight to ten thousand Euros above a competitive cost to the buyer. For many years manufacturers – along with power and gas utilities – have articulated the need for a broader market introduction programme to enable higher production volumes and hence unit cost reductions. In May 2015 the Federal Ministry for Economic Affairs and Energy gave the long awaited green light for a dedicated fuel

cell CHP incentive programme. At the time of writing, details of the scheme have not been finalised, but the beginning of 2016 remains the planned start date. At this moment the level of funding per unit and the annual volume can only be speculated at, but from conversations with stakeholders, the scheme will in all likelihood enable the roll-out of thousands of micro-CHP units annually in Germany. However, even with a programme of the size and duration of Ene-Farm costs may not decline as dramatically as observed in Japan. The incentives in Germany will be shared by a larger pool of manufacturers and technologies, meaning lower volumes and less pronounced cost reduction effects for an individual player, though of course sales in other markets would contribute additional volume.

The FCH JU also funded a study of distributed energy generation technologies, focusing on fuel cells, led by Roland Berger in conjunction with a coalition of more than thirty businesses, public entities and associations. The study reinforced the need for reduced costs and improved performance, and emphasised public support for pre-commercial deployments of large numbers of units to gain experience and help bring costs down. Further European demonstration programmes putting micro-CHP fuel cell systems into residential applications may prove essential for success.

Activity in Europe has also been affected by events at the business unit level. In early 2015 the Australian micro-CHP developer CFCL went into voluntary administration. CFCL had been very active in Europe, installing around 600 BlueGen micro-CHP units in Germany, Netherlands and the UK and building a manufacturing facility at Heinsberg in Germany. In July 2015 the Italian/Swiss developer SOLIDpower (formerly SOFC Power) acquired Ceramic Fuel Cell GmbH's assets and employees, with a licence to use the Australian parent's technology. The parent

company IP is apparently now with a Chinese owner. SOLIDPower reportedly has plans to re-start the deployment of BlueGen units alongside their own EnGEN 2500, which they started to deploy in 2015 through Ene.field. Existing BlueGen units deployed in German and UK homes in 2014 under the European supported SOFC-PACT project have been decommissioned, however.

Viessmann, a 50% owner since 2012 in long term SOFC micro-CHP player Hexis, bought the remaining 50% of the business in mid-2015 to become the sole owner. It is not yet clear whether Viessmann, which also has a partnership with Panasonic enabling it to deploy PEMFC micro-CHP technology, will continue the Hexis brand though the technology, people and locations are expected to be maintained. Hexis continued to deploy units in 2015.

Elsewhere in the micro-CHP field Baxi, part of BDR Thermea, partnered with Toshiba, began shipments of its PEM units under their Senertec brand. Bosch (with Aisin SOFC technology), Vaillant, Elcore and others are successfully deploying numbers of units across Europe. At the same time Ceres Power, the developer of the



SOFC Steel Cell technology, announced output improvements of 40% with electrical efficiency rising to 47%. This technology has been trialled at KD Navien's facility in Seoul, Korea. Ceres Power is also working with IE CHP in the UK and signed an agreement in early 2015 for a Joint Development Agreement with a major Japanese power business.

In contrast to the relatively large number of micro-CHP fuel cell developers in Europe, developers of large scale commercial and industrial systems are limited. FuelCell Energy Solutions GmbH (FCES), part of the FCE Inc. business, imports modules from the USA which are then packaged with balance of plant in Germany. In July 2015 FCES announced an agreement with E.ON Connecting Energies and Friartec AG to deliver a 1.4 MW Direct Fuel Cell for heat and power for Friartec's manufacturing facility in Germany.

This unit may be joined by a further MW scale unit when Ballard supplies its ClearGen PEM technology to Hydrogène de France, as part of an FCH JU supported project to use hydrogen at AkzoNobel's sodium chlorate plant in Bordeaux. And large-scale PEM is also being put in place by Nedstack, the Dutch PEM developer, who announced an agreement to supply 2MW of stack for a facility in Yingkou, China, alongside AkzoNobel, MTSA Technopower and Ynnovate Sanzheng Fine Chemicals. Again supported by the FCH JU, this unit will also use waste hydrogen, this time from the chlor-alkali process, and provide on-site power.

AFC Energy of the UK, the only company developing alkaline fuel cell technology, also has big ambitions. 2015 saw it install the first part of its Stade power plant in Germany. Again financed to a large extent by the European FCH JU, the first 'tier' of the system went live in October, generating 40 kW of power. The intent is to have the full Kore system, with multiple tiers, able to produce 240 kW by December. The company has been busy commercially, with a series of agreements for installations in South Korea and

Thailand, with Bangkok Industrial Gas. Both are multi-MW facilities with 7 MW of installations apparently due by the end of 2016. From there it will require further rapid scale-up to achieve the 50 MW of systems hoped for in Korea, and potentially an enormous 300 MW of units in Dubai by 2020. Interestingly, these latter units are intended to produce for sale not only power but also water, improving the economics of the unit.

Telecoms in India

The use of fuel cells to provide either back-up power or primary off-grid power for telecoms equipment has been one of the few real markets for the world's fuel cell developers, and is now taking hold in India. With a growing user base and telecom infrastructure, India is reported to have 400,000 towers dependent upon diesel and/or batteries to back up unreliable grids.

Ballard has reported 50 orders for its direct hydrogen-fuelled ElectraGen product by the Aditya Birla Group for delivery in 2015, and up to 200 by the end of 2016. This order follows a period of tests and trials with Aditya from 2013. In addition 100 of the methanol fuelled ElectraGen units have been ordered by Reliance's Jio Infocomm business, and these are expected to be shipped through 2015. These orders represent welcome change from 2014, when shipments by Ballard were affected by delays in orders from telecoms companies and where the majority of units went to South East Asia and South Africa.

India is also a major focus for Intelligent Energy. The business announced a £1.2bn deal with GTL Limited to purchase the energy management



contracts of over 27,000 towers across India. This adds to the 10,000 or so towers already under contract through its subsidiary Essential Energy, which has plans to replace diesel-based power supplies by fuel cells for 70% of the towers over the term of their contracts. In January 2015 Intelligent Energy announced the successful operation of its latest generation fuel cell at an Indian telecom tower in Uttar Pradesh West. This approach is similar to that of Heliocentris, which for some time has managed energy solutions for telecoms applications. It also has tower operating services... but in Myanmar rather than in India.

Autonomous power

Other fuel cell developers have exploited other off-grid power applications, especially those at lower power. For example, SFC Energy has sold further of its 100+ W EFOY units into the oil and gas sectors, with its subsidiary Simark logging a CAD1.3m order in mid-2015. And in autumn SFC described the use of one of its 245 W EFOY products in a hybrid fuel cell and solar unit developed by a part of the Russian Gazprom business. The unit is completed by a battery, to meet the needs of the oil and gas sector for remote telemetry. Acumentrics is another supplier with a foot in oil and gas. And

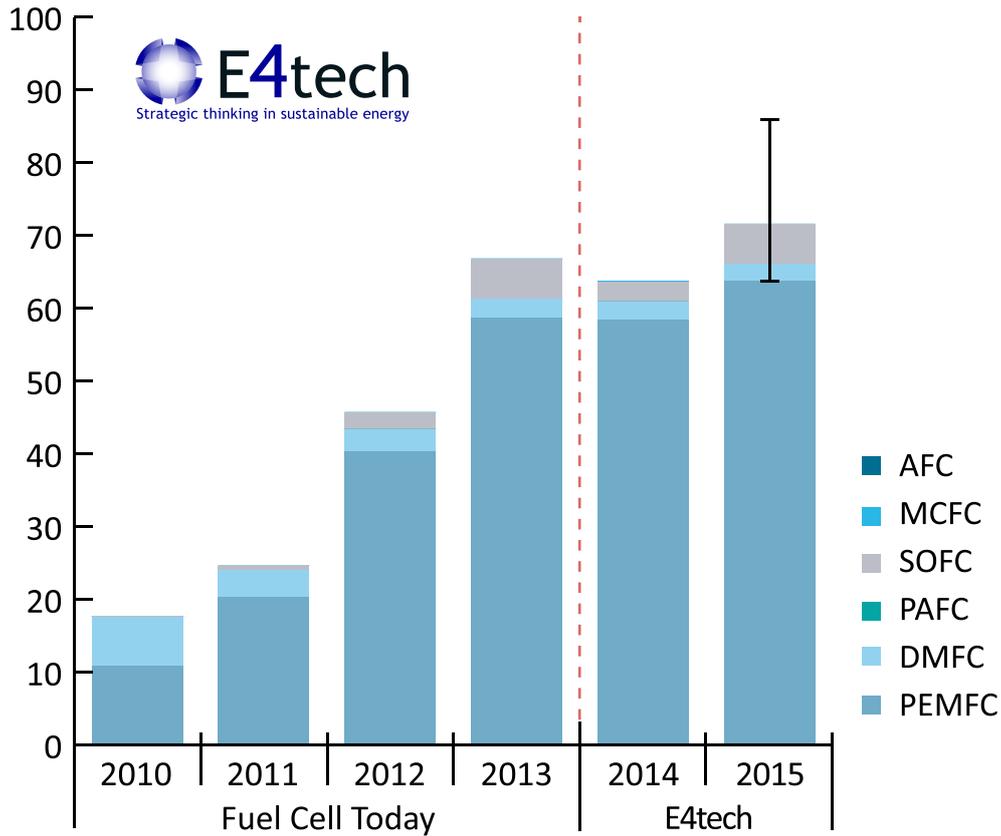
the integration of renewable energy with fuel cells has proved attractive to other fuel cell developers, including the Italian-based Electro Power Systems. Their Hybrid Energy Storage System (HyESS) combines a lithium battery and fuel cell for uninterruptible off-grid power. EPS has successfully installed close to 600 systems for off-grid applications and believes that the HyESS system has a further role to play. South African-based Bryanston Resources is working with EPS to develop off-grid markets in emerging countries where power demand outstrips the development of the power infrastructure. HyESS is currently undergoing component level testing, with system testing due in Q1 2016, and subsequent roll-out will be supported by a new production facility in Turin, Italy, with a monthly output capacity of 2 MW. Many others are active in this area.

In April 2015 Toshiba began operating their H2One product for Kawasaki City's port area. This system combines solar PV, batteries, an electrolyser, hydrogen and water storage and a fuel cell to provide emergency autonomous power, heat and water. The fuel cell element output is a maximum 3.5 kW and is combined with a 350 kWh battery storage and 30 kW of solar PV. In normal operation the system feeds power to the local grid.

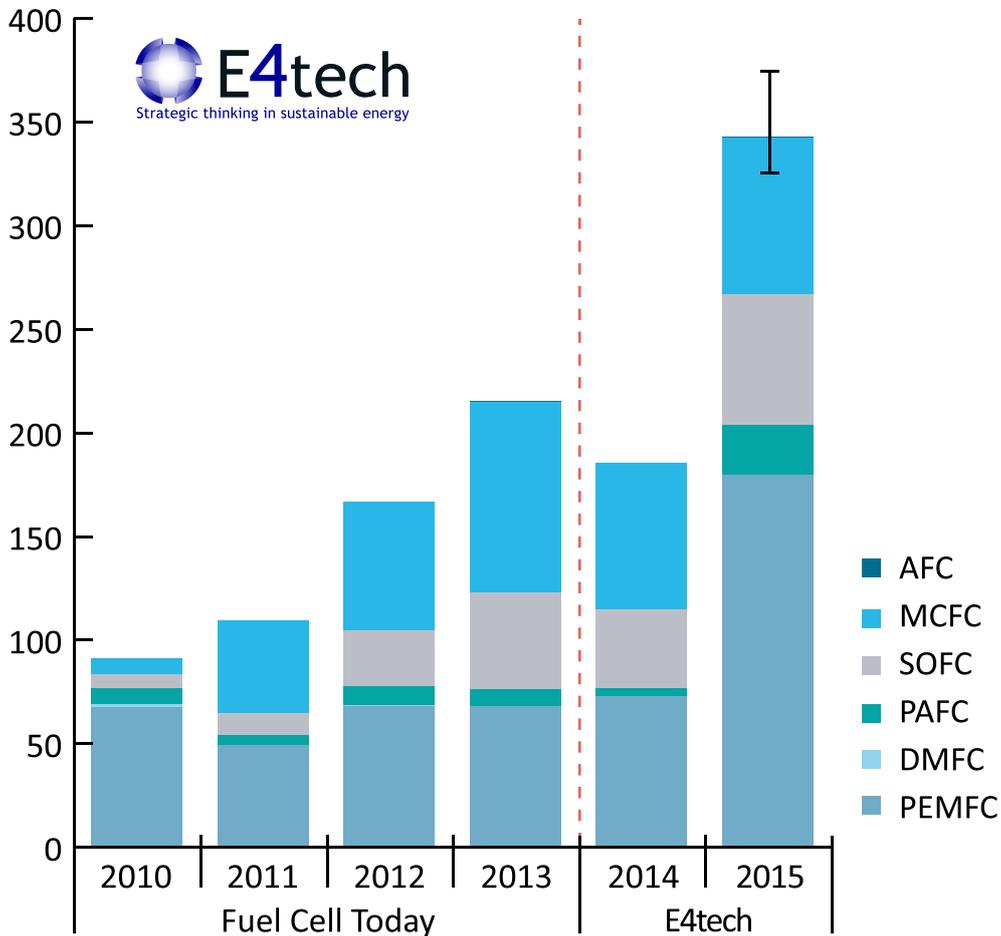


Shipments by fuel cell type

Units shipped by fuel cell type 2010 - 2015 (1,000 units)



Megawatts shipped by fuel cell type 2010 - 2015



Footnote: Data from 2010-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2014 data are slightly corrected from our forecast in last year's Review. 2015 is our forecast for the full year. We include an error bar for 2015, based on the quality of our data sources and our views on the uncertainty in the forecasts to year-end.

PEM technology continues to dominate the unit numbers of fuel cell shipments. This repeats the pattern of previous years and reflects the simple fact that the technology is very adaptable to a wide range of applications in the transport, stationary and portable fields. By contrast other fuel cell technologies are focused on specific applications, for example **MCFC** and **PAFC** for larger scale stationary uses, or **SOFC** for stationary and some portable applications. **DMFC**, a related PEM technology, is found in portable, occasionally small transport, and some small scale back-up or off-grid uses.

In MW shipped, however, 2015 sees a shift from previous years. Whereas PEM shipments were stable at 60 to 70 MW previously, 2015 has seen the number more than double. At 180 MW, the total of PEM shipments exceeds the sum of all other fuel cell technologies.

PEM shipments benefited in 2015 from the roll-out of fuel cell electric vehicles, notably Toyota and Hyundai cars. With a maximum power output of 114 and 100 kW respectively, the MW quickly add up. Add to these numbers PEM stacks for forklifts, buses and other transport applications, and it is easy to see why the uptick has occurred and why the growth trend should continue. Of course, the fact that a few hundred cars makes a material difference to global sales throws the size of the total fuel cell industry into sharp relief.

PEM shipments have also benefited from the continued expansion of the micro-CHP sector in Japan and to some extent in Europe, and continued use in back-up and off-grid applications. Japanese and Canadian companies are currently predominant, though the US has some players in, for example, Alteryg and ReliOn. Japanese PEM technology is also being used in Europe in the micro-CHP sector, through Viessmann, and Baxi/Senertec while Elcore uses its own patented high temperature PEM.

PAFC technology shipments represent the other major change from 2014 to 2015. This is largely due to the re-start of the PureCell stationary systems

production in Connecticut by Doosan following their acquisition of ClearEdge in 2014. Doosan's sale of PAFC units into Korea is a primary driver of shipments in 2015, and this can be expected to continue into 2016. Fuji Electric is also shipping PAFC technology, with plans for more in 2016.

SOFC technologies are well represented in the stationary sector and totals have benefited from growth in shipments by Bloom and also the smaller micro-CHP units from Japanese and European developers. Kyocera's SOFC technology is used by Aisin Seiki in Japan, which also supplies Bosch for their Buderus and Junkers brands in Europe. SOFC technology for micro-CHP continues to be a European strength though, with SOLIDpower, Sunfire, Hexis/Viessmann, Elcogen and Ceres all active, and work still feeding in to LGFCS from the Rolls-Royce facilities in the UK.

MCFC shipments are expected to be maintained in 2015 at a similar level to 2014. This is driven by FCE's Direct FuelCell products, in partnership with POSCO. With POSCO opening a 100 MW MCFC facility in Pohang in autumn 2015 and FCE's Torrington plant at a similar production capacity, MCFC shipments have the potential to grow in 2016 and beyond.



Other technologies remain minor in comparison to the total. Important nevertheless in 2015 is the shipment of alkaline fuel cells by AFC Energy of the UK to its flagship demonstration project in Stade, Germany. This technology appears in the figures for the first time since 2013.

Mobility progress in California

California's second annual report on the state of fuel cell vehicles and hydrogen fuelling stations was completed in 2015 and foresees more than 34,000 FCEVs on California roads by 2021. But the California Air Resources Board (CARB), author of the report, expressed concern that hydrogen fuelling capacity may fall short of demand.

CARB surveys automakers annually on their roll-out projections under a directive from California's Legislature. Aggregating deployment estimates from the different OEMs leads the 2015 report to a figure of 34,300 by the end of 2021. Direct comparison between the 2015 and 2014 reports is impossible, since they make estimates for 2021 and 2020 respectively, but overall the two reports suggest substantial and sustained growth in vehicle sales over the next six years, from a base of 179 FCEVs in mid-2015.

Three hydrogen fuelling stations are fully commercial at time of writing, with approved metering systems that allow fully transparent customer purchases. California is particularly proud of a recent 1,000-mile test drive involving five Daimler Benz B-Class F-CELL vehicles fuelled only at public stations. In one case, all five drivers fuelled at a single station within half an hour, paying for the fuel by credit card.

The number of stations in development seems to change weekly in California, and even apparently authoritative sources disagree. As of early November, 2015, the California Fuel Cell Partnership reports the three fully public stations,

another 46 in development and nine operating non-retail stations, including four that primarily or only serve bus demonstrations.

The state has pledged funding of US\$20m annually for stations and operating expenses until 100 stations are built. But CARB points out that demand for operating expenses at existing stations will reduce the money available for new ones, and thus expects only 86 to be on-line by 2021, enough of a shortfall for them to express concern. "After 2018, the number of vehicles expected to be on the road may need more fuel than can be provided by the number of hydrogen stations that can be built with currently available public funding, assuming funding levels and station capacity remain unchanged."

CARB did not advocate an increase in the state's subsidy program, reflecting the political realities in the state, where hydrogen station funding remains controversial. They suggested that "Addressing the expected gaps in hydrogen capacity and coverage may require exploring innovative actions to maximize the utility of public investment and rapidly accelerate industry momentum to expand the fueling network." Recent reports of problems at the existing stations may complicate matters further. "Station technical capabilities must continue to advance to satisfy customer expectations for a retail fueling experience, including meeting current fueling protocols and expanding capacity to fuel growing numbers of FCEVs," CARB concluded.

Corporate news

Corporate activity in 2015 has reflected the recent trend towards consolidation in the sector, with a number of closures and acquisitions, in addition to arrangements to work together. This is against the perennial backdrop of businesses seeking funds to continue or grow their fuel cell development activities. Although new companies are still forming, the rate seems to have slowed in comparison with some of the 'hype' periods of the past. And while some of those formed during the hype have subsequently gone to the wall, activity in recent years points to a more sophisticated industry, and more (although not always) sophisticated investors.

Accessing technology

Interest in fuel cell products to meet market need continues, with non-fuel cell corporations seeking access to technologies that they can scale up and take to market. Korean corporations have been exemplars of this approach, offering cash investment in return for access to technology. Doosan is perhaps the best example, buying both small scale PEM and larger scale PAFC power generation technology. In the US, Hyster-Yale (NACCO), well known in materials handling equipment, will compete directly with Plug Power through in-house ability gained by buying Nuvera's fuel cell and small scale natural gas reformer technology late in December 2014. Hyster-Yale announced plans to put US\$40m to US\$50m into development, perhaps the best sign yet that fuel cell forklifts have established a market presence.

In Europe, major European heating appliance manufacturers have teamed up with European and Japanese fuel cell developers. The most recent example is Viessmann's decision to buy all Hexis' shares; this now gives it full ownership of an SOFC technology. Viessmann also has an agreement with Panasonic which gives it access to Panasonic's small scale PEM capability. Fuel cell technology is hard – much harder than most

companies imagined when they started on their journeys – and so buying in is typically cheaper and simpler than starting from scratch.

In the automotive field, in early 2015 Ballard finally inked its Technology Solutions deal with Volkswagen to transfer certain automotive related fuel cell intellectual property; the two also signed a two year extension to an engineering services contract now to end in 2019, all for US\$80m. This provides VW with a springboard to technology which other car companies have largely developed in house. Intelligent Energy also announced a deal with a major Japanese car company for access to and application of IE's technology and know-how.

Routes to market and new blood

Outright acquisition of one fuel cell business by another, or by a business outside the sector, has also proved a popular way to access routes to market. The various Korean investments, some described in the stationary section, provide examples of this - especially in terms of 'catching up' with others in the field.

In autumn 2015 Ballard acquired the Protonex business for a mixture of cash and shares, securing access to Protonex's complementary product line and its valuable knowledge of and access to the important US military market for fuel cells. Intelligent Energy's acquisition of energy supply contracts from GTL Limited in India demonstrates another means of accessing markets for its products over a number of years, as it replaces diesel and batteries with fuel cell systems.

New entrants to the field continue. In mid-2015 Swiss Hydrogen SA was spun out of its previous home in the Swatch Group, where it was part of the Belenos structure – the brainchild of the late Nicolas G Hayek. Swiss utility Groupe E and an unnamed investor now own the company, which works in PEM fuel cells, electrolyzers and hydrogen refuelling. More dramatically, the previously low-key Dominovas Energy, based in

Atlanta, announced a 'commitment to financing' for US\$1.2bn to build 200 MW of SOFC systems for deployments targeted for Africa. Delphi and AVL are listed as partners, with the latter having conducted a manufacturing feasibility study. The scale of Dominovas' ambition is impressive, though details of the technology base, development status and any field trials remain absent.

Businesses in fuel cell technology have also moved to capture more of the value chain associated with fuel cell products. Intelligent Energy bought consumer electronics-related fuel cell system IP from BIC in the first half of 2015 for US\$13m, plus further sums for completion of transition services and a potential earn out. BIC's fuel cell cartridges will complement IE's consumer fuel cell products and help it meet the recurring fuel needs of the consumer and not just the 'one-off' base product.

2015 has also seen further evolution of the relationship between Plug Power and Air Liquide. Air Liquide's fuel cell-focused subsidiary Axane sold Plug Power its shares of Hypulsion – a Plug Power-Axane JV working on forklifts. Plug Power had 20%, but now wholly owns HyPulsion, and Air Liquide will continue to supply hydrogen to Hypulsion customers. Another French business, Symbio FCell, entered into an agreement with ITM Power, the UK electrolyser and hydrogen refueller developer, and Arcola, a specialist technology supplier and integrator. This will provide a 'one-stop shop' for operators of Symbio fuel cell range extender vans in the UK. ITM will provide hydrogen and Arcola education and training, plus maintenance and support for fleet users. These two examples highlight a notably more positive attitude to hydrogen and fuel cells in France than for some time.

Cash is king

The fuel cell sector is characterised by long development times and slow market uptake, and hence enormous reserves of cash and patience are needed to bring a fuel cell product to market, particularly in conservative sectors with strong incumbents such as transport or residential

heating. No amount of 'orders' or 'commitments to order' will replace cash in the bank. In spring 2015 the Australian SOFC micro-CHP developer CFCL went into voluntary administration following a failure to secure further funding from an investor. Although CFCL had been relatively successful in advancing its technology to the stage where hundreds of its units were deployed in Europe and further afield, it had not managed to create a sustainable revenue stream or secure further investment. The development investment was not wasted, however, as CFCL's assets in Germany were bought out by SOFCPower of Italy in summer 2015, and the company SOLIDpower was formed. Although public detail is hard to find, the Australian IP seems to have been bought by a Chinese company. The European assets provide SOLIDpower not only a German base from which to secure access to the German marketplace, but also – through a licensing agreement – access to CFCL SOFC technology which could be used to supplement its existing EnGEN equipment.

Securing investment

With insufficient sales revenue, fuel cell businesses have long relied on securing funds from investors, private and public, to fund their day-to-day activities. Fuel cell companies recently have started to come back to the investment marketplace. Intelligent Energy floated in 2014, and Electro Power Systems continued the trend in 2015, floating on the Paris based Euronext in April. EPS raised over €14m, which will be used to underpin its HyESS system development and commercialisation.

More established companies also continue to raise funds, with Ballard issuing over 9 million common shares in the USA for gross proceeds of about US\$15m, US\$13.6m after costs, following its Protonex acquisition. Ballard also sold US\$5 million of common stock to Nisshinbo of Japan, a long-time supplier of bipolar plates to Ballard and a collaborator on advanced technology. Likewise Bloom Energy raised US\$130m in early 2015 to support its programme, bringing its reported

investment to date up to the order of US\$1.3bn.

A more novel approach to fundraising was undertaken by the German fuel cell developer eZelleron. eZelleron used crowd funding to raise over US\$1.6m from 11,300 backers by early March 2015. The funds will be used to accelerate the development of eZelleron's portable power product, kraftwerk, for consumer applications.

Fuel cell order backlogs

One sign of improved market health is growth in the backlog of product orders. While it is customary to recognise income only when units are shipped, the backlog - evidence that sales are outstripping shipments - can be a comforting sign of high product demand. Where companies have the capacity to provide after sales service, backlogs promise additional high margin income for years to come.

Backlogs can also present challenges. The backlog may be too high, overwhelming a company's production capacity; the resulting long delivery times may drive customers elsewhere. Backlog orders may be rather easily delayed or cancelled and there are at least two high profile examples of where delays in orders or payments have had serious, even fatal, consequences. On the other hand, a declining backlog may represent nothing more than an increase in production capacity or efficiency, both good things.

Determining order backlogs in the fuel cell sector is difficult without access to reliable data on sales and shipments over a number of years. However, it is reasonable to assume that a number of fuel cell businesses have a backlog of some size. For example backlogs are likely in the stationary micro-CHP sector where programme such as Ene.Field and Ene.Farm have some sort of multi-year 'commitment'. Public companies often report their order backlogs and dollar value. And many multi-year sales are reported as "up to" a certain number of units over time, while actual shipments can fall well short. Examples of "up to" in 2015 include Intelligent Energy's long-term projection of the market potential of its recent acquisition

of an Indian telecoms utility, Ballard's China bus announcements, and a spectacularly large if sceptically received framework contract with the Republic of Congo for solid oxide power systems.

FCE Inc is the one business where financial information is available on a multi-year basis. As its business has grown, so the order backlog of product and services has expanded. By end October 2012, following successful sales, most notably in Asia, the FCE backlog was reported to stand at US\$367m, comprising US\$288m of product and US\$79m of service orders. As FCE expanded its annual production rate but did not quite managed to replace shipped products with new sales the product backlog had slipped to US\$310m at the end of October 2014 (excluding Advanced Technologies contracts). However, this backlog was constituted of US\$113m of product and US\$197m of service orders. At the end of July 2015 the overall number had risen to US\$338m, with US\$98m of product, equivalent to 70% of product sales, and US\$225m of service backlog. 2014 was a record year for production with 70 MW.

Although product backlog has continued to fall, the service backlog is increasing with more and more systems in the market. FCE reported that service agreements now average about 10 years duration, and represent a relatively stable future revenue stream, subject to cancellations. Product backlog will depend on the extent to which sales can be increased over the next few years in response to opportunities in the major markets of Asia and North America and the nascent European market.

Hydrogenics is one of the few other businesses which provides information on their backlog of both hydrogen generation and power systems products in quarterly earnings reports. The backlog value has been fairly consistent for a few years, ranging between US\$35m to US\$45m. This fell in March 2015 to US\$28.1m before jumping to US\$75.5m in June, a significant rise and presumably a reflection of contract wins the preceding quarter. Plug Power's backlog is estimated at US\$100m to US\$150m.

Where can I refuel my fuel cell car?

The global number of public stations available to fuel a passenger vehicle will approach 200 by the end of 2016, based on public data from North America, Europe and Asia. This does not include the substantial number of private stations supporting vehicle research or industrial vehicles such as forklifts.

If this is a race, Japan is in the lead. Several private sector teams, under pressure from the government, are building or operating 74 stations, a dramatic jump from the 45 stations operating or under construction at the end of 2014 – though short of the government’s initial goal of 100 by the end of 2015. By comparison, 58 stations in California are in some stage of development, with 3 already open, according to the California Fuel Cell Partnership, while Germany has about 50 stations operating or financed. Toyota has further pledged financial support for 10 to 12 stations in the Northeastern US, to expand the market options.

The Japanese government is now promising 100 stations “prior to market introduction,” which may charitably be interpreted to mean 2016 (Honda’s vehicles will come out first in March) or 2017 (Nissan’s soft target). Toyota is already selling its Mirai fuel cell vehicle in Japan. Meanwhile the three Japanese auto makers made a fresh commitment to support station deployment by subsidising operating expenses and supporting public education programs until about 2020.

In Korea, 13 stations were open and 10 more are planned by 2020. However not all of the existing stations are accessible to the public.

The “Hydrogen Mobility Europe” project announced in September 2015 should bring 29 operational stations in ten countries by 2019. The project is underpinned by the major European initiatives in the area: H2 Mobility Germany, Mobilité Hydrogène France, the Scandinavian Hydrogen Highway Partnership and UK H2Mobility, with funding from the FCH JU.



Deployment of some 200 cars and 125 range-extended vans is also part of the plan.

In October, H2Mobility Germany, a company formed as a joint venture consortium by six private European companies, separately announced a goal of 100 hydrogen stations in the country in the next four years, financed largely with private funds. Nineteen public stations are already open in Germany, with financing secured to bring the total to 50. Scandinavia has nine operating stations and one under construction, with a goal of 15 full service stations and as many as 30 satellite stations.

Five public stations are operating in the United Kingdom. The UK Government, with Department of Transport financing through the Office of Low Emission Vehicles (OLEV) announced funding in March 2015 to bring 12 sites into public use. This includes 2 entirely new stations, 2 mobile refuellers, and upgrades to a number of other stations to bring them to full compliance with customer requirements, including credit card payment capabilities. Stations are open in several other countries, including Switzerland, Austria, France, Spain and Italy.



A note of caution: the numbers presented above change almost daily as commitments are announced and stations come into or out of operation. There is disagreement on how mobile stations or bus fuelling stations should be counted (we exclude them unless specifically mentioned), and in some cases stations may be open to the public only by arrangement.

Nevertheless it is clear that the initial infrastructure is in place – or shortly will be – to support the first sales of fuel cell passenger cars. It is now up to the auto industry to provide enough cars to supply demand at these stations and avoid discouraging policy makers and potential customers alike.

Hydrogen refuelling station providers

Suppliers of hydrogen refuelling stations (HRS) can broadly be divided into three groups: Pure players with HRS as their core business, manufacturers of hydrogen production equipment and industrial gas companies; the latter two have strategic interest in this business. Some of the players are highlighted below.

Seeing opportunity for their onsite hydrogen generation products, electrolyser manufacturers such as Hydrogenics and ITM have offered and already been building refuelling stations for some time. In 2015, NEL of Norway, which has manufactured electrolysers for almost 90 years (initially as part of Norsk Hydro), acquired H2Logic to enter the HRS market. In 2015 H2Logic signed a technology licensing agreement with Mitsubishi Kakoki Kaisha for stations to be built in Japan. Recently NEL also bought RotoBoost H2, a start-up developing an electrolysis concept suited for compact hydrogen refuelling stations. Nuvera's onsite refuelling solutions based on steam methane reforming (SMR) complement the electrolyser companies. In many regions it will be some time before additional renewable power provides a grid electricity mix that will yield hydrogen of a lower carbon footprint than natural gas SMR. Other pure players include HTEC and Powertech, both of Canada.

Several industrial gas companies have developed their own technology for HRS, as a strategic opportunity that complements their traditional business. Linde Gas has started small series production of hydrogen refuelling stations, which includes a proprietary ionic compressor, developed in-house. Fifty to sixty stations

per year can be manufactured in a one-shift regime at their Vienna plant. Most of Linde's stations go to the US and Japan; they have a partnership with Iwatani in Japan. Iwatani together with JX Nippon Oil & Energy are the two main developers of hydrogen stations in Japan. Taiyo Nippon Sanso, a Japanese industrial gas company, provides hydrogen refuelling technology, including mobile solutions. Air Liquide has partnered with Toyota Tsusho for station deployment in Japan and as with Linde they are part of the H2Mobility joint venture that aims to bring 400 HRS to Germany by 2023, and others to the US. Air Products has an agreement to supply their technology to at least 19 HRS of First Element Fuel in California and is involved in further projects. Finnish gas company Voikoski in 2015 installed their first HRS outside Finland, in Sweden.

Irrespective of the hydrogen supply mode, HRS remain expensive and in Europe currently cost three to four times as much as a CNG station. Core equipment, including the dispenser, compressor and onsite storage add up to about €1m. Higher production volumes, standardisation and technology development are required to bring costs down and improve performance. Advanced compression techniques remain a focus of development, as do low-cost and rapid contaminant measurement techniques. One of the main providers' cost reduction scenarios shows €300,000 achievable in the mid-term, cutting cost by two thirds, assuming that station roll-out globally proceeds as planned and mass manufacturing can be implemented.

Portable Power

The use of portable fuel cells – those designed to be moved – extends over many different applications. These continue to attract the attention of fuel cell developers worldwide, be it for the consumer charger market with units of a few watts or so, the off-grid application and auxiliary power area of hundreds of watts power, or for the specialist military and UAV markets. Significant activity continued in all three areas in 2015, emphasizing the attractiveness of the opportunities, but also the challenges.

Consumer Chargers

The allure of the consumer device market may be founded on large numbers of potential consumers, but it remains one of the hardest to enter, and fuel cell history is littered with companies who tried and failed. Not only must fuel cell based chargers compete with one another, they must primarily take on increasingly reliable, low-cost batteries which are also improving in performance. This is also no simple ‘innovative technology’ play; fuel cell products must appeal to consumers’ pockets and aesthetics, as well as being simple to operate and easy to re-fill.

One business with some resilience in taking on the consumer challenge is Sweden’s MyFC. Early in 2015, MyFC unveiled its new consumer electronics product, Jaq. At 200g Jaq weighs less, and is smaller than, MyFC’s earlier PowerTrek, yet can provide more energy – an output of 1,800mAh per fuel cartridge. The fuel cartridge, or PowerCard, is reported to be easy to operate and, unlike some competitor fuel cell systems, is disposable. However, it only provides one charge for the average smart phone. Jaq is aimed squarely at the smart phone charger market.

Its notable feature is its design: small, sleek and



colourful, and it won a German design award in autumn 2015, recognising the importance of price and design as much as technology in the consumer market. Jaq will be launched in late 2015, and can be purchased for €4.90/month over 24 months (similar to the average term of many phone contracts), reducing the ‘sticker shock’ in comparison with a typical battery charger. MyFC is reported to be in the process of phasing out the previous PowerTrek product, and is seeking a buyer to support the current user base and further develop the opportunity.

German developer eZelleron has been busy developing its ‘kraftwerk’ product and crowdfunding itself (see the Corporate Activity section). Kraftwerk is a 10 W peak power device, capable of up to 11 smartphone charges per filling of ubiquitous lighter fuel. The three different design colours and names: ‘urban’, ‘outdoor’ and ‘glam’, again show marketing investment. It also has won a German Design award for Excellent Product Design – in Lifestyle and Fashion. It should be available mid-2016 for US\$299, while the crowd funders will receive their units from the beginning of 2016, and at lower prices. eZelleron is also working with partners on the integration of its fuel cells into other appliances, such as power tools.



Intelligent Energy, which launched its consumer product charger Upp in 2014, appears to have had mixed success. Initial statements mentioned 50,000 units towards the end of 2014 and into 2015. However, at the half year 2015 results it was announced that production had been limited to 30,000 units, due to manufacturing issues. Nonetheless Intelligent Energy has been busy developing marketing channels with cachet: both Apple and Doodle stores in the UK have joined the effort. In 2015 Intelligent

Energy agreed to purchase BIC's fuel cell charger and cartridge business, formerly developed by Angstrom. This is intended to allow IE to develop further products, and provides access to high volume manufacturing and production intellectual property.

Horizon continues to evolve. The original organisation in Shanghai remains, but has moved somewhat away from very small portable chargers – though the Minipak remains part of the portfolio, sold through Brunton as the Brunton Hydrogen Reactor in the US. HydrogenCore, the fuel cartridge, provides three iPhone charges with 4,500 mAh.

In the US, Neah Power Systems offers a BuzzBar Suite product with variously battery, solar, fuel cell and grid power capabilities; Neah reported they had shipped all orders received through their website and were focused on the next generation, Gen3, which they expect to ship later in 2015 subject to fundraising and an acquisition.

The competition is stiff: back-up battery chargers remain ubiquitous, with a wide variety of sizes, power ranges and add-ons – such as solar charging. Establishing a competitive fuel cell-based business remains a major challenge, with the primary advantage simply the ability to rapidly swap cartridges instead of needing to recharge the unit – but with a need to supply cartridges wherever they may be required by the customer. Moves by Intelligent Energy to integrate fuel cells into laptops – and even into smartphones – suggest future directions for a fuel cell sector that has yet to be really picked up by consumers.



Auxiliary Power Units

The market for fuel cell auxiliary power units is very broad, ranging from leisure activities such as caravanning or yachting, through emergency services requirements for off-grid power, to industrial users such as the oil and gas sector which has widespread off-grid power needs for sensors. Standard fuel cell products capable of producing 100 W to 500 W have been sold across all markets, but differentiation may be beginning – even if the predominant fuel remains methanol. Furthermore, the marketing and sales approach to each of these markets is very different. Customers range from inexperienced consumers to extremely capable procurement individuals in industry.

SFC Energy, the German portable fuel cell company, announced two new products in 2015. The first was the release of the EFOY12000 Pro Duo 500 W system for industrial customers. The largest SFC product to date, this represents a move into the generator markets for off-grid power. As such, the tie up with Toyota Tsusho as its channel partner in Japan is significant. The second product was the EFOY GO!, aimed at the leisure market and available through channel marketing partners and its own on-line EFOY GO! shop. As is typical of SFC, this is a hybrid product which combines a lithium battery along with the fuel cell.

It is also the case that these different markets have their own economic cycles. Prospects in the leisure market appear to be growing again, especially in the caravanning segment. UPS Systems, a UK based partner for SFC products, reports continued year-on-year sales growth. On the other hand, SFC also reported that the downturn in the oil and gas sector was depressing demand for the products marketed through its Simark subsidiary, although it has announced at least one order for products for this sector in 2015.

Japanese company Aquafairy started out with very small (2 W) chargers, but is now developing

a portfolio of APU-type products, and PowerCell in Sweden offers APUs for both stationary and transport applications, the latter capable of operating on diesel.

Military Applications

The application of fuel cells to the ever increasing small-scale (1 W – 100s of W) power needs of the world's militaries is an attractive and potentially lucrative market niche. Furthermore the military will often assist with the development of products it wants. This is especially so with the US Department of Defense (DoD), which has supported many projects and prototypes in many US-based businesses.

While this market can be understandably sensitive, companies selling products include amongst others Protonex, Acumentrics and UltraCell in the USA, and SFC in Germany. These businesses sell fuel cell chargers for soldier power battery packs, as well as prime power for smaller equipment such as communications and sensors. In 2015 Protonex was acquired by Ballard Power Systems, seeking to broaden its portfolio and gain access to the portable military market.

SFC announced several orders for its products from militaries over the summer: one to an unidentified customer for its Jenny 1200 product, with shipments due in 2016, and another for next generation fuel cells for another international defence force, valued at €1.2m. Also encouraging was a repeat order, valued at €1.3m, from the German Bundeswehr for its Emily series, following an order for a study of SFC's 500 W fuel cells for military applications. Acumentrics is partnering with the US military to deliver SOFC generators of up to 10 kW.

Fuel cells are often seen as ideal power solutions for unmanned aerial vehicles (UAVs, increasingly known as drones), with the ability to provide operating times significantly over and above those available with batteries. Horizon Energy Systems (HES) continues to develop UAV fuel cells in Singapore, with a new organisation, Horizon Unmanned Systems (HUS) integrating them into professional UAV products. Scottish business RaptorUAS uses HES's fuel cell module for the Raptor E1 UAV. In Autumn 2015 this was scheduled to be tested in a flight across the North Sea from the UK to Norway, a distance of 300 km and flight duration of ten hours plus. RaptorUAS is reported to be working with Northern Colorado Search and Rescue. The US Navy also is researching the capability of fuel cells to power torpedoes.

UltraCell, which has a development agreement with the US DoD to develop small scale portable systems, announced in early 2015 a small initial production run order for its methanol based XX55 from an international military customer, and has agreed to licence its knowledge in remote systems to SAFCell, with which it was testing solid acid fuel cell power solutions. Others with defence products include Ultra Electronics AMI with its SOFC based Roamio series of 245 W and 300 W for portable and UAV use.



The outlook for 2016... and a little beyond

2015 was an important year for fuel cells, with significantly increased sales in most markets. However, the industry's steady progress overall since 2010 is still a fragile thing. In nearly every significant market, sales are supported by financial and non-financial incentives, several of which are scheduled to expire by the end of 2016. Of course, this is true even in established industries; the International Monetary Fund estimates post-tax energy subsidies globally at 6.5% of global GDP in 2015 (US\$5.3 trn)¹.

Competing technologies are entrenched in major growth markets, including combined heat and power and telecom backup power. In some related markets, such as energy storage, hydrogen technology is unfamiliar to customers, and lacks a developed business case and commercial terms. Round-trip hydrogen-fuel cell systems are regarded as uneconomic.

Competition is also not standing still. Widespread use of battery technology, for example, already limits or is believed to limit fuel cell access to light duty vehicle and other mobile markets, energy storage markets, and backup power systems. Battery advocates argue that technology improvements soon will make fuel cells redundant – though in many applications fuel cells augment batteries and a hybridised system is an overall optimum, suggesting that co-operation is rather more valuable than confrontation.

Despite this difficult backdrop, our view is more optimistic. Fuel cell technology is not standing still, either. Bloom Energy's incredible shrinking power module now delivers 500 kW in the space that a 100 kW system required just a few years ago. Honda's new 2016 model year Clarity includes a module small enough to fit comfortably into the same volume as its four-cylinder combustion engine, and system efficiency is yielding a vehicle range of well over 300 miles. Another way to look at it is to be clear that in most cases, fuel cell products are in their first or at most second

generation, while batteries, combustion engines and gensets have a commercial development history of well over 100 years. As the actor Tommy Lee Jones said in *Men in Black*, "Imagine what we will know tomorrow."

Stepping back, what strikes us is just how many credible forward looking announcements about fuel cells have been made in 2015, suggesting a healthy if probably not revolutionary increase in commercial deliveries in 2016. Shipments in the light duty vehicle market, for example, approximately 1200 vehicles in 2015, likely will double in 2016. Total installed fuel cell generation in the United States, reliably estimated at less than 180 MW today by a private source, could also step up if the proposed MW FCE facility in Connecticut receives timely approval. Similar year-on-year increases in capacity are possible in Korea as well, with POSCO Energy being joined by several other power park developers. Fuel cell bus orders, if delivered as promised, would more than double the bus fleet.

Looking a little farther ahead, Tokyo City, the Government of Japan and a list of major corporations are on board a collective effort to make the 2020 Tokyo Olympics a showcase for hydrogen systems, products and energy service. This is accelerating other local plans and developments.

By 2020 the industry ought to be seeing significant production of cars from General Motors, Daimler and perhaps Nissan, BMW and VW, plus range-extender and niche vehicles from other manufacturers. Would-be mobility provider (not car seller) Riversimple promises a new vehicle unveiling in early 2016, designed by the former design head of the Fiat 500. Production is targeted for 2018. Meanwhile California's Air Resources Board projects more than 18,000 fuel cell vehicles in the state by 2020, with 6,500 by 2017. Even assuming half of all FCEVs will be sold in California, which is

¹How Large Are Global Energy Subsidies? Coady, Parry, Sears, Shang, International Monetary Fund (May 2015)

probably too high given Japan's position and Europe's desire, this implies a 2020 worldwide fleet of 35,000 vehicles carrying perhaps 4 GW of fuel cell power. Toyota's aspiration to sell 30,000 FCEVs per year, on its own, by 2020 suggests even greater things.

We urge readers, however, to continue to approach these projections with caution, as markets remain thin, government policies will be under review, and it is not uncommon for contract sales to fall short of announced projections. Additionally for vehicles, it is essential that the many hydrogen refuelling stations under development are actually finished, and operate reliably. Alienating the first customers would be a poor start to a promising roll-out period.

Critical policies will be under review in 2016. In Japan, the government's financial support for residential fuel cell installations is scheduled to decline to zero. Discussions on a follow-on program are under way. In the US, the 30% investment tax credit for purchases of fuel cell units expires at the end of 2016; a comprehensive proposal to extend and expand fuel cell support has been introduced but its future is highly uncertain. This incentive has been crucial to the success of both power generation and forklift sales. In the US States, support for fuel cell power generation and for hydrogen fuelling stations are typically reviewed annually and future funding at current levels is not guaranteed.

Few direct support programmes for fuel cells exist in Europe, though Germany's NIP is large and valuable. Also, many FCH JU projects of

significant size are under way, and are important to the development and increased profile of the sector. The FCH JU runs to 2020; projects will run for several years more, and while the current NIP finishes in 2016, funding is being continued. Other support mechanisms that can be exploited include the typical range of local feed-in tariffs, tax breaks for clean vehicles or subsidies for highly efficient equipment, but all are subject to local moods and whims.

Some confusion remains in the energy markets, however. Oil prices are lower than had been thought possible, squeezing margins for the big energy companies. Large utilities in Europe remain under pressure, as variable renewable energy capacity increases on the grid. In the UK, shutting down older power stations continues and the safety margin between likely demand and capacity is razor-thin. Quite what impact this will have on fuel cells is unclear, though distributed generation – and storage – have long been talked about as possible solutions.

The Paris climate change COP may have some impact. The world is already half way to achieving a 2°C rise over pre-industrial temperatures, and CO₂ in the atmosphere has hit 400ppm. Air quality is increasingly poor and increasingly important politically, and the fallout from the admissions of cheating at VW is also unclear. While there does not seem to have been a public rush away from diesel, at the very least governments are realising that the emissions reductions they thought they were getting are far from real. Stricter testing regimes and yet-to-emerge responses could push car companies faster into new vehicles. Whether those will be fuel cells remains to be seen.

Data Tables

Shipments by application						
1,000 Units	Fuel Cell Today				E4tech	
	2010	2011	2012	2013	2014	2015
Portable	6.8	6.9	18.9	13.0	21.2	17.6
Stationary	8.3	16.1	24.1	51.8	39.5	49.0
Transport	2.6	1.6	2.7	2.0	2.9	4.9
Total	17.7	24.6	45.7	66.8	63.6	71.5

Shipments by region						
1,000 Units	Fuel Cell Today				E4tech	
	2010	2011	2012	2013	2014	2015
Europe	4.8	3.9	9.7	6.0	5.6	8.3
North America	3.3	3.3	6.8	8.7	16.9	15.7
Asia	9.5	17.0	28.0	51.1	39.3	46.6
ROW	0.1	0.4	1.2	1.0	1.8	0.9
Total	17.7	24.6	45.7	66.8	63.6	71.5

Shipments by fuel cell type						
1,000 Units	Fuel Cell Today				E4tech	
	2010	2011	2012	2013	2014	2015
PEMFC	10.9	20.4	40.4	58.7	58.4	63.8
DMFC	6.7	3.6	3.0	2.6	2.5	2.2
PAFC	0.0	0.0	0.0	0.0	0.0	0.1
SOFC	0.1	0.6	2.3	5.5	2.7	5.4
MCFC	0.0	0.0	0.0	0.0	0.1	0.1
AFC	0.0	0.0	0.0	0.0	0.0	0.0
Total	17.7	24.6	45.7	66.8	63.6	71.5

Footnote: Data from 2010-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2014 data are slightly corrected from our forecast in last year's Review. 2015 is our forecast for the full year. We include an error bar for 2015, based on the quality of our data sources and our views on the uncertainty in the forecasts to year-end.

Megawatts by application						
Megawatts	Fuel Cell Today				E4tech	
	2010	2011	2012	2013	2014	2015
Portable	0.4	0.4	0.5	0.3	0.4	0.7
Stationary	35.0	81.4	124.9	186.9	147.8	203.2
Transport	55.8	27.6	41.3	28.1	37.2	138.7
Total	91.2	109.4	166.7	215.3	185.4	342.6

Megawatts by region						
Megawatts	Fuel Cell Today				E4tech	
	2010	2011	2012	2013	2014	2015
Europe	5.8	9.4	17.3	17.3	9.9	28.5
North America	42.5	59.6	61.5	74.7	69.8	139.7
Asia	42.5	39.6	86.1	122.9	104.5	172.2
ROW	0.4	0.8	1.8	0.4	1.2	2.2
Total	91.2	109.4	166.7	215.3	185.4	342.6

Megawatts by fuel cell type						
Megawatts	Fuel Cell Today				E4tech	
	2010	2011	2012	2013	2014	2015
PEMFC	67.7	49.2	68.3	68.0	72.7	179.6
DMFC	1.1	0.4	0.3	0.2	0.2	0.2
PAFC	7.9	4.6	9.2	7.9	3.8	24.0
SOFC	6.7	10.6	26.9	47.0	38.2	63.1
MCFC	7.7	44.5	62.0	91.9	70.5	75.6
AFC	0.1	0.1	0.0	0.3	0.0	0.2
Total	91.2	109.4	166.7	215.3	185.4	342.6

Footnote: Data from 2010-2013 are as published by Fuel Cell Today, including their forecasts for 2013; 2014 data are slightly corrected from our forecast in last year's Review. 2015 is our forecast for the full year. We include an error bar for 2015, based on the quality of our data sources and our views on the uncertainty in the forecasts to year-end.

Notes

- 2010-2013 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.
- Our 2015 figures are a forecast for the full year. Data for 2015 and 2014 were collected directly from fuel cell manufacturers where they were able to share it; also through interviews with industry experts; careful review of publicly available sources such as company statements, 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 types of fuel cells currently in an early stage, such as microbial fuel cells and solid acid fuel cells, are not included in the numbers shown.

About E4tech and the authors

Since 1997, E4tech has been helping clients to understand and grasp opportunities at the interface between technology, policy, and business. We focus mainly on innovative approaches to 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 corporates, financiers and governments worldwide. These projects range from market and competitor analysis through business strategy, technical and commercial due diligence, and support for policy development. See www.e4tech.com

Prof. David Hart is a Director of E4tech, responsible for the Fuel Cell and Hydrogen Practices. In 20 years in the sector he has consulted and carried out research for a wide range of organisations worldwide, including national governments, major industrial companies, financial organisations and NGOs. He is also a Visiting Professor at Imperial College London's Centre for Environmental Policy, chairs the Steering Committee of the Grove Fuel Cell Symposium, and has been an invited speaker at conferences on six continents.

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Robert Rose is Executive Director of the Breakthrough Technologies Institute, an independent non-profit advocate for technologies that carry environmental benefits to society; Rose'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, non-profit 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.

Jonathan Lewis is an independent consultant with over twenty years' experience in the business development arena, ranging from strategy and policy development through business plans to technology commercialisation activities. He has worked in the fuel cell and hydrogen area for more than 10 years, initially with Rolls-Royce Fuel Cell Systems Ltd, and more recently in an independent capacity working for the private and public sectors. He has extensive experience in Europe, serving on the Board of the FCH JU and the NEW-IG, and more recently working with the FCH JU in a variety of roles.

Our guest contributor, on Canada, is **Matthew Klippenstein**. Previously with Ballard and AFCC in Vancouver, he maintains a keen interest in the sector and blogs for GreenCarReports.

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. Our services include, *inter alia*, bespoke expert briefings, market and supply chain analysis, technology evaluation, business and investor support.

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- Electro Power Systems SA
- Toshiba Corporation
- AFC Energy PLC
- H2 Logic A/S
- ITM Power Plc
- myFC AB
- eZelleron GmbH
- Intelligent Energy Limited
- Horizon Energy Systems Pte. 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 2014 to 31st October 2015.

US\$1 = €0.8814	€1 = US\$1.1369	1£ = US\$1.5389	1¥ = US\$0.0083
US\$1 = £0.6500	€1 = £0.7385	1£ = €1.3558	1¥ = €0.0073
US\$1 = ¥120.32	€1 = ¥136.72	1£ = ¥185.17	1¥ = £0.0054

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Notes



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