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The Fuel Cell Industry Review 2019

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LIST OF ABBREVIATIONS

AFC – Alkaline Fuel Cell	kW – Kilowatt
APU – Auxiliary Power Unit	LGFCs – LG Fuel Cell Systems
BEV – Battery Electric Vehicle	LNG – Liquefied Natural Gas
BMVI – Bundesministerium für Verkehr und digitale Infrastruktur (German Federal Ministry of Transport and Digital Infrastructure)	MCFC – Molten Carbonate Fuel Cell
BMW – Bayerische Motoren Werke AG	MEA – Membrane Electrode Assembly
CARB – California Air Resources Board	MHPS – Mitsubishi Hitachi Power Systems
CHEM – Chung-Hsin Electric and Machinery Mfg Corp	MoU – Memorandum of Understanding
CHP – Combined Heat and Power	MW – Megawatt
CT – Connecticut, USA	NREL – National Renewable Energy Lab (Golden, Colorado)
DMFC – Direct Methanol Fuel Cell	OEM – Original Equipment Manufacturer
DoD – US Department of Defense	OLEV – Office for Low Emission Vehicles
DoE – US Department of Energy	PACE – Pathway to Competitive European FC mCHP market
EFOY – Energy For You (SFC Energy fuel cell products)	PAFC – Phosphoric Acid Fuel Cell
FC – Fuel Cell	PBI – Polybenzimidazole (HT membrane)
FCE – FuelCell Energy (USA)	PCB – Printed Circuit Board
FCEB – Fuel Cell Electric Bus	PEM(FC) – Polymer Electrolyte Membrane (Fuel Cell)
FCEV – Fuel Cell Electric Vehicle	POSCO – (formerly Pohang Iron and Steel Company), a South Korean steel-making company
FCH JU – Fuel Cells and Hydrogen Joint Undertaking (EU)	PPA – Power Purchasing Agreement
FCT – Fuel Cell Today	PSA – Peugeot S.A.
GE – General Electric	PV – Photovoltaic
GM – General Motors Company	R&D – Research and Development
GW – Gigawatt	RoW – Rest of the World
H2SS – Hybrid Energy Storage System	SBCTA – San Bernardino County Transportation Authority
HRS – Hydrogen Refuelling Station	SAIC – SAIC Motor Corporation
HyPER – Hydrogen-Paired Electric Racecar	SoCalGas – Southern California Gas Company
ICE – Internal Combustion Engine	SOFC – Solid Oxide Fuel Cell
IE – Intelligent Energy	SPC – Special Purpose Company
IPO – Initial Public Offering	STEP – Société du Taxi Électrique Parisien
IP – Intellectual Property	SUV – Sports Utility Vehicle
JIVE – Joint Initiative for hydrogen Vehicles across Europe	UAV – Unmanned Aerial Vehicle
JMC – Jiangling Motors Corporation Limited	UGV – Unmanned Ground Vehicle
JP-8 – kerosene (military grade)	UPS – Uninterruptible Power Supply
JV – Joint Venture	VDMA – German Mechanical Engineering Industry Association
KEPCO – Korea Electric Power Corporation	W – Watt
kfW 433 – Förderung für das Heizen mit Brennstoffzelle (German national mCHP programme)	ZANZEFF – Zero and Near-Zero Emissions Freight Facilities

December 2019

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The Year of the Gigawatt

2019 was a landmark year for fuel cells – in more ways than one. The fuel cell industry finally shipped more than a gigawatt of fuel cells – around 1.1 GW in fact – evidence of an increasingly capable supply chain. Major corporate players placed reasonably-sized bets on fuel cells being a part of the future energy mix. Some swallowed smaller pure-play entities whole, while others chose the route of multiple partners for the multiple applications and solutions.

In bare numbers, the total units shipped globally grew only marginally over 2018 and remains near 70,000 pieces. A more important indicator is the output in megawatts (MW) shipped. This correlates with the area of fuel cells produced and thus with the sales and manufacturing capacities in the industry – and with costs. More MW means lower costs ahead. And the MW grew by 40% from 800 MW in 2018 to more than 1,100 MW in our preliminary figures for 2019, which include a forecast for the final quarter.

Korea turned up the volume, pushing out a Hydrogen Roadmap, a lot of stationary power, and more cars than anyone else, plus setting ambitious targets for many other sectors. California still leads in cars on the road, though with fewer fuelling stations than either Japan or Germany. And Toyota has still produced more vehicles than anyone.

Amongst all the activity, we see a lot of the fundamentals settling into place. The supply chain is investing – Umicore's new factory in Korea to provide catalysts to Hyundai is a case in point. The various acquisitions and investments by Cummins, Bosch, CNH, and others also points towards a heavy-duty fuel cell world we started to see a year or two back. Two trains have already been running for a year, and dozens more are on order, meaning that more manufacturing capability will be added.

Buses moved ahead too. While we anticipated more on the roads in China by now, they should come soon, as infrastructure and vehicle

production start to align. But in Korea they are taking the roads, and Europe is following on from various programmes with H2Bus – a plan for 1,000 fuel cell buses at prices competitive with almost all other options.

The stationary sector also shows signs of development. A lot has been put into making larger-scale 'commercial' fuel cells of multiple kW, which can slot into a niche between the sub-kW Ene-farm systems and the hundreds of kW – and even MW – provided by the biggest players. These newish units should increasingly become available, in Asia and Europe at least.

The value of fuel cell technologies is starting to be noticed by politicians, who want to ensure jobs and economies are protected in the energy transition, and especially in the maelstrom of change that is the automotive industry. Financial investment is coming back. Costs are coming down, and will come down much further, if momentum is sustained.

It all sounds great. But...

Fully two-thirds of the MW shipped are from two companies – Toyota and Hyundai. Other manufacturers, with the honourable exception of Honda, and to some extent Daimler – are mainly talking about BEVs, cutting costs to pay for them, and cutting jobs. Trucks are an obviously appealing application because of the limitations of batteries – but few currently run. Developing solutions for an understandably conservative and cash-poor industry will require real proof of performance and reliability, or some very strong policy measures.

So we hope 2020 brings two things: more solidification of the supply chain through investment and large corporate engagement, and more units operating, consistently, across a swathe of applications. Then, by the end of 2020, we'll have a lot more evidence of what will work.



About the review

Applications

To allow year-on-year data comparisons, we base our categorisation of shipment data on that defined by FCT. For applications, these categories are Portable, Stationary and Transport, defined as follows:

Application type	Portable	Stationary	Transport
Definition	Units that are built into, or charge up, products that are designed to be moved, including small auxiliary power units (APU)	Units that provide electricity (and sometimes heat) but are not designed to be moved	Units that provide propulsive power or range extension to a vehicle
Typical power range	1 W to 20 kW	0.5 kW to 2 MW	1 kW to 300 kW
Typical technology	PEMFC DMFC SOFC	PEMFC MCFC AFC SOFC PAFC	PEMFC (DMFC) (SOFC)
Example	<ul style="list-style-type: none"> • Small 'movable' APUs (campervans, boats, lighting) • Military applications (portable soldier-borne power, skid-mounted generators) • Portable products (torches, battery chargers), small personal electronics (mp3 player, cameras) 	<ul style="list-style-type: none"> • Large stationary prime power and combined heat and power (CHP) • Small stationary micro-CHP • Uninterruptible power supplies (UPS) • Larger 'permanent' APUs (e.g. trucks and ships) 	<ul style="list-style-type: none"> • Materials handling vehicles • Fuel cell electric vehicles (FCEV) • Trucks and buses • Rail vehicles • Autonomous vehicles (air, land or water)

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

Fuel cell types

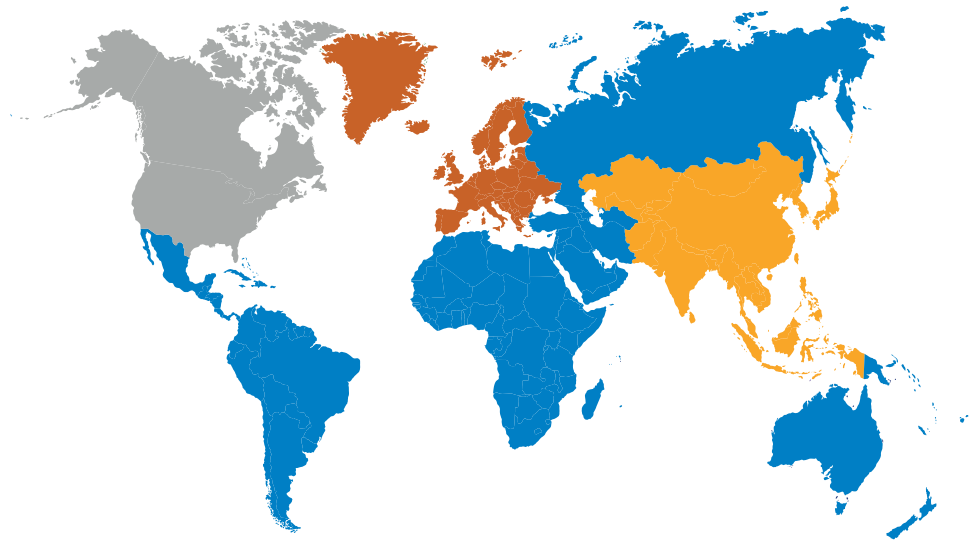
Shipments by fuel cell type refer to the six main electrolytes used in fuel cells: proton exchange membrane fuel cells (PEMFC), direct methanol fuel cells (DMFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and alkaline fuel cells (AFC). High temperature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

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

Geographic regions

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

- RoW
- Asia
- North America
- Europe



Reported shipment data

E4tech has been publishing this Review for six years now. Tables of data going back to 2015 can be found at the back of this Review. Editions of the review prior to 2018 included historical information from Fuel Cells Today dating back to 2012. Data are presented for each year in terms of annual system shipments and the sum total of those systems in megawatts, divided by application, region and fuel cell type as described in the section below.

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

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

Data sources and methodology

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

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

Our dataset is based on firm numbers for the period January to end of September 2019 and in a very few cases to October 2019. For the remaining period we use forecasts shared with us by individual companies or forecasts prepared by us in discussion with industry. We will revise data for 2019 in our 2020 edition as appropriate. We have revised the figures for 2018 in this report: Unit numbers were reduced by about 8% and megawatt numbers increased by 0.3% compared to our published 2018 forecast. The main change relates to lower Ene-farm micro-CHP numbers in Japan than initially forecasted, after final data for 2018 became available.

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

How was 2019 for you?

The fuel cell sector finally hit a gigawatt of shipments – in fact exceeded it by 10%. In some ways that's a small number, easily matched by a reasonably-sized nuclear powerplant, but psychologically it's a great achievement.

It also shows gathering momentum. It's up by 40% from 2018, and could have been even bigger, if China had delivered as anticipated and FuelCell Energy had not gone through a difficult period. That pent-up demand should show in 2020's figures.

The industry remains parochial though, with the usual suspects of Toyota and Hyundai dominating car sales, Plug Power materials handling, and Panasonic and Aisin the small-scale CHP. Bloom Energy, Doosan and – despite the pain – FuelCell Energy were responsible for the large-scale units. But the upstream part of the supply chain strengthened, and big names came into the frame. Cummins made several investments, including taking over one of the long-standing 'pure' players, Hydrogenics. Hyundai built partnerships in many areas and jurisdictions, and overtook Toyota in annual sales. Both companies are making great efforts to maximise the exploitation of their stacks and systems, supplying other companies for transport and even stationary uses.

The growth in interest in hydrogen continued worldwide. It is now a normal topic of discussion at the World Economic Forum, the World Energy Council, and amongst the G20 nations. While much of the discussion is not about fuel cells, the logic of using hydrogen in a fuel cell is nevertheless compelling. Companies like Doosan Fuel Cell and Ceres Power responded to that, joining Toshiba and Panasonic with pure hydrogen offerings, not only natural gas-fired ones. Bloom Energy is testing pure hydrogen too.

The climate driver remains important, but air quality is now extremely high on the agenda. With increasing evidence that pollution in cities kills many more people than previously thought, and significantly reduces the life quality of others, zero emissions zones are an easy political response. So the rise in bus fleets in Europe, where fuel cells buses are being ordered in dozens, is completely logical, and the launch of the ambitious H2Bus Europe project reinforced the belief. The rise in enthusiasm for fuel cell commercial vehicles, from range-extended battery vans to 44 t trucks can be explained this way too – batteries will definitely help clean up transport, but weight, cost and recharge time count against them as applications get bigger and distance longer. So the 800 lb gorillas in the sector now include Cummins, joining Weichai and IVECO. At the smaller and possibly more agile end are Nikola and Horizon (though the latter is dancing with a gorilla, in its partnership with Ford/JMC). Heavy duty still needs to be proven in action though – duty cycles are tougher than for passenger cars, and trucking companies can ill-afford downtime.

The rail and maritime sectors also advanced, though the bigger the scale the more time significant deployment is likely to take.

But cars are still only really produced by Toyota and Hyundai. Honda has a good vehicle but limited production, and Daimler remains part of the pack, but only just. Despite the rhetoric of the global executives, who say every year that fuel cells are very high on their agendas, the automotive industry is suffering. European sales are down, and tens of thousands of job losses will happen in Germany over the coming few years, brought about in part by a massive – and late – investment in battery cars, to meet CO₂ targets and avoid fines. There is neither money nor headspace to focus on fuel cells for now.

China retains its title of enigma. The wild exuberance of the market has calmed somewhat as government subsidies reduce and future policy remains unspoken. China's economy is also suffering, and it is taking longer to develop high quality fuel cell technology than many outside the industry realised. But as long as some supportive policy remains, the market may be able to stabilise and rationalise around the stronger players. Despite the uncertainty, China still managed to get more than a thousand vehicles on the road, and the biggest companies are globally competitive, and will go it alone if they see a future market.

The North American picture is mixed. Canadian policy is picking up, and California remains the biggest market for fuel cell cars – though Korea may overtake next year. Stationary units do continue to sell though, and Bloom, Doosan, FuelCell Energy are all moving product.

Like the mentions above, other company activity was broadly positive. FuelCell Energy was pulled from hard times by a US\$200m line of credit; Doosan spun off its Fuel Cell business to go it alone; Ceres announced a partnership with Miura, as well as with Doosan, and continues scaling up with Bosch. Intelligent Energy partnered with Changan, and Sinopec invested in Shanghai Re-Fire.

And finally, in addition to direct corporate spending, venture capital is back. AP Ventures, a specialist in the hydrogen and fuel cell space, announced investments from Mitsubishi Corporation and Plastic Omnium to add to its Anglo Platinum heritage.



Corporate developments

2019 was – broadly – a good year for fuel cell businesses globally. 1 GW of fuel cell shipments is a significant achievement. Investments and acquisitions were a major theme. Together with growing enthusiasm amongst policy and decision makers world-wide for hydrogen solutions, of which fuel cells are a part, the outlook is positive. Still, even amongst the success stories, some businesses struggled.

Corporate Highs and Lows

2019 saw a rare event – a fuel cell business stock market flotation – in Korea, with Doosan Fuel Cells. Fortunately, no high-profile company failed, though FuelCell Energy came perilously close.

Doosan Corporation's decision in early 2019 to spin off its fuel cell division, the stationary PAFC operation, continued the whirlwind journey of the erstwhile United Technologies technology. Handed to ClearEdge Power, Doosan bought the assets in 2014 and has invested heavily since, building both sales and a new production facility in Iksan, Korea. Doosan Fuel Cell Co Ltd was spun out in October and floated on the Korean stock exchange with a goal of sales of ₩1tn (US\$850m) by 2023. Doosan Corporation retains a proportion of the equity, but the fuel cell business should now have access to external funds for further business development. The fuel cell spin-offs shares were sought after, rising 30% in early trading, and a lot more soon after.

FCE's story is rather different. In Q1, faced with a capital crunch and impending debt repayments, a restructuring specialist was engaged to 'right-size the business'. In April, 135 employees were laid off and other cash cutting measures taken. Emergency cash was raised through further share sales, and a licence for carbon capture technology sold exclusively to Exxon for US\$10m, this has allowed maturing debt to be repaid.

The new loan facility of US\$200m from Orion Energy Partners, announced in November, is now enabling the business to fund its order backlog and rebuild capacity. One challenge facing FCE is the long-term PPA model that requires assets to be financed upfront whilst the revenue stream comes in over 20 years.

Other pure-play companies have reported better fortunes. Ceres Power, now on its second run at developing a sustainable business after a near-death experience early in the 2010s, seems to have found a better formula. Now using a licensing model and working with major partners such as Bosch, Weichai Power and Nissan, in 2019 it announced a CHP product with Miura of Japan and Doosan as a new partner. Others are doing it too: PowerCell came to an agreement with Bosch in spring of 2019.

OEM interest grows

More big players are sniffing around the sector, dipping a toe in the water, or making big bets. Some of the biggest are looking across technology and ensuring they have access to multiple platforms: Weichai's existing investments in Ballard on PEM and Ceres on SOFC are examples. One of Weichai's major competitors in China is Cummins, which itself dominates parts of the diesel engine industry, like trucking in North America. They have set up an electrification business division and acquired, in quick succession, GE's SOFC technology; Hydrogenics; a position in Loop Energy and an agreement with Hyundai.

And Bosch has adopted a similar approach, already having developed both PEM and SOFC relationships in several areas.

Other heavy-duty players are moving too, with IVECO, part of CNH, investing in Nikola and announcing an ongoing development partnership. They will invest US\$250m in cash and in in-kind support for engineering and scale-up. They join Bosch, interested mainly in powertrain elements and controls, and Hanwha, which will supply solar panels for Nikola's hydrogen production. And Michelin and Faurecia created a joint venture company, Symbio, crystallising their investments in the fuel cell company that originally span out of France's CEA. Initial investments of €140m (US\$157m) will help launch mass production.

Faced with tightening environmental legislation, global corporates dependent on ICE technology for revenue and profits have an imperative to seek out alternative technologies as part of longer term offensive and defensive plays. For the fuel cell players who have got this far, these OEMs bring considerable development resources, plus routes to market, sales know-how and a big seat at the negotiating table.

As global OEMs begin to 'pull' fuel cell technology from the sector, fuel cell business no longer need to try to do everything from 'soup to nuts' (not always successfully), but can now focus on what they do best, fuel cell technology development and production of cells, stacks and modules. The emergence of specialist systems integrators, for example Arcola and Fuel Cell systems in the UK and eCap Mobility in Germany, points to the move from a vertical to a more traditional tiered industrial structure.

On a tangential but interesting note Wrightbus of Northern Ireland, a bus manufacturer with some experience of integrating fuel cell technologies, went into receivership in Autumn 2019. The assets were bought by a special company set up by Jo Bamford to invest in hydrogen related technologies. Bamford is also heir to the UK's JCB, a worldwide supplier of off-road construction equipment, invariably powered by diesel.

Gloves coming off

As fuel cells and hydrogen get more mainstream, and money threatens to be made, the finance game becomes more intense – and more cutthroat. Ballard has already been chased by short sellers, though with limited effect. This year it was Bloom's turn, with a report in September making a raft of allegations about the company's debt, fuel cell performance, revenue and emissions. This prompted a riposte from Bloom directly addressing some of the allegations. It states that about 40% of its debt is non-recourse, and that its current cells have an average life of around 5 years, which should enable its future service revenue to rise above its service cost. In other words, the service business should become profitable – in addition to revenue from product upgrades.

Raising Funds

Unlike some years, relatively few fuel cell businesses have raised funds in the markets in 2019. An exception was PlugPower which this year placed stock worth US\$23m directly with Odey Asset Management, set up a US\$100m debt facility with Generate Capital, and in December began publicly offering 40 million shares of common stock. The funds will be used for business operations and expansion, including a plan announced in September, to grow revenues to US\$1bn by 2024. And venture capital is back too – AP Ventures announced investments from Mitsubishi Corporation and Plastic Omnium in its fuel cell- and hydrogen-sector focused funds.

In other news

Many companies made their own investments in scaling. Umicore, one of the few companies able to supply fuel cell catalysts to the automotive market, inaugurated a factory near Seoul, Korea, close to its technology development centre to complement its plant in Hanau, Germany. The location is strategic – a primary customer is Hyundai, also the most aggressive of the OEMs. Initial production ramp-up will be in 2020, and the facility is built to accommodate further expansion. The facility will support other automotive customers too. Integrator Arcola Energy is building a facility near Liverpool to assemble double-decker fuel cell buses for a local fleet.

And in a signal open to interpretation, both Hyundai and Toyota broadened their supply agreements. Toyota now supplies fuel cells to CaetanoBus in Portugal, as well as Higer and FAW, Beiqi Foton and SinoHytec in China, and has ties to Re-Fire who act as an integrator. Re-Fire themselves got investment from Chinese petroleum giant Sinopec. Hyundai also announced it would offer its stack and system to others, took a stake in performance car company Rimac, and linked with Cummins as mentioned above.

The message could be that both companies are now so secure in their position that they want to start to capture additional value in new applications and regions. Or maybe that they now finally see others coming to the party and wish to occupy as much white space as possible. Or perhaps that, having invested many billions to date, they feel it's time to make some returns. Whatever it is, they have more experience than most.

Cars

Fuel cell cars remain ‘better than batteries’ in the eyes of believers, but remain far from most manufacturers’ line-ups. They are now also rather taking second stage to heavy duty vehicles, despite good ongoing deployments of both the Toyota Mirai and Hyundai NEXO.

The two-horse race?

The NEXO has been well received. It is selling well too: 2019 shipments are even above the Mirai, though the latter has more cumulative deployment, having been available for longer. In September, the 10,000th Mirai left Toyota’s production line. And a new Mirai, a sleeker car than the original, with a coupé silhouette, longer range and a full five seats, is starting to grace global motor shows. It will be launched sometime late in 2020, presumably when Toyota increases its production capacity to 30,000 in line with previous announcements. Stacks will be built at the Honsha (headquarters) plant and hydrogen tanks at Shimoyama.

Shipments from other companies lag a long way behind Toyota and Hyundai. Honda comes in third, but has shipped few Clarity Fuel Cells, and has made little noise about its intentions, though seems to retain a development agreement with GM. No news has seeped out about the joint production facility, Fuel Cell System Manufacturing LLC, that was announced in 2017 for operation in 2020. And Daimler, the only other manufacturer with a commercial FCEV, also remains low-key and with very few vehicles on the road. In Europe at least, manufacturers are laser-focused on delivering battery vehicles to avoid costly fines when CO₂ emissions regulations tighten in 2021. Though the ‘Key trends’ analysis of KPMG’s annual survey of Automotive Executives puts batteries and fuel cells neck-and-neck on 56% – just behind connectivity and digitalisation.

Some other major companies are making noises, even if only faint ones. BMW teased with its iHydrogen NEXT concept car at the 2019 Frankfurt Motor Show, and says it might manage a small series of FC-powered X5s by 2022, but doesn’t expect commercialisation until 2025.

PSA, out of the fuel cell game for a decade or so confirmed it has longer-term plans to return to fuel cell production. And Audi will increase its investment in fuel cell technology, and plans on a limited-run pilot production FCEV by 2021. In a sign of how the supply chain might shape up, Audi has complemented its Ballard fuel cell engineering support with an agreement with Hyundai for fuel cell-related components, while BMW gets its stacks from Toyota as part of its global R&D tie-up. And both Toyota and Hyundai have announced much more open fuel cell supply intentions, even to competitors. Toyota will supply China’s FAW Group and Higer Bus, with Shanghai Re-Fire acting as system integrator. It has already been supplying Beiqi Foton and Beijing SinoHytec.

In China, SAIC has sold mainly Maxus vans. Development of its Roewe car is ongoing, as are cars programmes at several other manufacturers. The China picture is clouded by uncertainty about Government subsidy going forward, which we discuss in more detail in our China section. Luxury car company Grove launched in March, after what it says was a three-year process of hydrogen vehicle development. It claims fantastic performance for its cars, including 1,000 km range. 200 will apparently be on the road by the end of 2019 in a ride-sharing scheme, and mass production capability of 5,000 per year is forecast in 2020.



Quirky is good

Yamaha maintains its reputation for quirky fuel cell entries. There's no recent news of its DMFC scooter, but it is testing a small people-mover. Its 3-seat YG-M prototype FCEV is running on a city-centre course in Wajima City, Ishikawa Prefecture. Mysteriously, "Yamaha Motor developed the fuel-cell (FC) system of the vehicle in cooperation with another company."



And a few smaller companies fight on: Riversimple has crowd- and grant-funded its way to developing a fleet of 20 Rasa cars (17 new ones) to be tested by 200 users over a year near its Welsh base.

The need for speed

GreenGT, another small company, continues to develop its homologated race cars. Its LMPH2G lapped Le Mans before the official 2019 race start, clocked up a first by formally entering a race meeting, in Spa, and doubled down by completing the first hydrogen refuelling event at a race meeting. It's not quite alone though. The Forze VIII, a hydrogen-electric Le Mans style prototype, became the first-ever H₂-electric vehicle to beat petrol-powered cars in an official race. Designed, built, tested and raced by students from Delft University of Technology, the car finished second in the Supercar Challenge at the TT Circuit in Assen, the Netherlands.

And out of nowhere, Malaysian company Handal Energy Solutions announced an agreement to develop a hydrogen-powered electric race car in Malaysia. Handal will be system integrator for a prototype car called Hydrogen-Paired Electric Racecar ('HyPER'), using a so-called Hydrogen and Hybrid Energy Storage System (H2SS) from NanoMalaysia, the nanotechnology commercialisation agency. Wheelspin Motorsports is providing the race car platform. We await further news with interest.

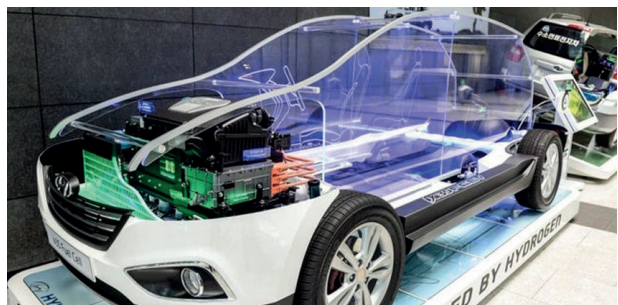
Cars on roads

California retains its crown as the global leader in car deployment – more than 7,500 are on public roads as of November, and with infrastructure still rolling out the signs are optimistic. However, an unusual separation of funding between vehicles and infrastructure means that more alignment is needed than in some places, to make sure both are getting the right attention. Since California shows strong signs of getting to critical mass quite soon (some fuelling stations are already struggling to cope with demand), a year or two more investment could start to really pay back.

California is also one of the regions where cars are being introduced through rentals and car sharing. Luxivair, at San Bernardino International Airport is partnering with StratosShare, an on-demand car rental company. Customers can rent a Mirai by the hour – or by the day. In Paris and London, fuel cell cars are used as taxis. Paris' Hype fleet was the first, and now boasts 100 Mirais. It wants to get to 600 in 2020, and increase refuelling stations from the current four. Helping it will be industrial investment company Kouros, which has taken a stake in the companies involved in Hype – STEP and HysetCo. The latter was established in February as a JV between Air Liquide, energy services company IDEX, STEP and Toyota.

More Mirais are on the road in Hamburg, Munich and Stuttgart, with 45 vehicles in the CleverShuttle fleet. The ride-sharing service bundles passengers with similar routes to keep fares down, using battery and fuel cell electric vehicles to keep emissions down too. Mitsui took a nearly 12% stake in the company in October, joining lead investor Deutsche Bahn.

In London, Green Tomato Cars added 25 more Mirais to its fleet of 27. The company has driven them for more than a million miles around the UK capital.



Asia is moving, but whither Europe?

As we noted in 2018, Korea is back in the forefront of the hydrogen and fuel cell race. The nation has aggressive targets for hydrogen and fuel cells in both stationary and transport applications, and Hyundai has been building capacity to try and keep up with the announcements. It claims a planned US\$6.7bn investment in the technology over the next decade, and is being pushed hard by the Korean Government to get over ten thousand (some say well over ten thousand) FCEVs on the road in Korea in 2020. The group has also invested €80m (US\$90m) in Croatian electric hypercar maker Rimac to develop a high-performance FCEV, and showed its Genesis GV80 Concept (first flaunted in 2017) in China in November. The leadership team remains convinced that batteries are not enough, and will continue to accelerate down the fuel cell road.

In Europe, the late switch to battery electric drivetrains, combined with a downturn in car sales is leading both OEMs and suppliers to shed jobs. Tens of thousands will go in Germany alone over the coming two years. This could be bad news for fuel cells, as car companies will have limited appetite – or funds – for another expensive and complex drivetrain. But hope glimmers: EU industrial policy was instrumental in supporting Europe's fight-back to localise battery supply chains. As analysis we led for the FCH JU¹ shows, fuel cells also create or maintain automotive industry value. Europe's politicians are already responding to this opportunity, so perhaps industrial policy will help support fuel cell technologies too.

The sustainability of battery vehicles is facing sterner scrutiny these days. Both the extraction of the materials used in the batteries and their end-of-life treatment are under the magnifying glass. Fuel cells may fare slightly better on a life

cycle basis, but limited work has been done and limited recycling capability exists. In anticipation, both Riversimple and Microcab use radically different concepts than conventional manufacturers. Microcab has followed a project examining remanufacturing with a proposal to extend the life of its eventually commercialised vehicles to 20 years, with planned interventions to remanufacture or replace components.



¹ <https://www.fch.europa.eu/page/FCH-value-chain>

Hydrogen infrastructure: small but growing

To make good use of the planned increases in Toyota and Hyundai's planned vehicle production volumes, the main jurisdictions will need the right number of reliable hydrogen fuelling stations (HRS). Happily, 2019 saw refuelling infrastructure grow in all the main early adopter regions, including Japan, Korea, California, China, Germany and other parts of Europe. But the pace of vehicle versus station roll-out is quite different in each one. In Germany, one HRS serves fewer than 10 cars on average. In the US and Korea the ratio is about 130 cars per HRS. Some stations in California are visited so frequently that they can run out of hydrogen, and need to be upgraded. Japanese stations service about 30 cars.

The equipment suppliers have worked on improved offerings, to allow quicker roll-out and add flexibility: Air Liquide will launch a skid-mounted hydrogen refuelling station in the US. Compact and intended to be mobile, it should suit temporary installations, small fleet usage, vehicle testing or location testing. Fuelling capacity is up to 200 kg per day and up to five fills per hour with the capability for 2-7 kg per fill (average tank capacity is 5 kg). Quebec City has taken delivery of Powertech's new "hydrogen station in a box" – a 28 ft containerised 700 bar HRS designed for rapid deployment with minimal site preparation. It can deliver four consecutive fills of a typical passenger car should fill around 20 vehicles per day. On the heavy duty side, McPhy launched its new "Augmented McFilling" flexible HRS architecture, in modular units of 2,000, 4,000 and 10,000 kg H₂/day.

According to H2 Mobility Germany, 78 HRS were operating in Germany by December. Nine more are in trials, 3 in the execution phase, 5 in approvals and 10 more in planning. Germany should reach its 100 stations goal by mid-2020. Frustratingly, only just over 600 FCEVs (of all kinds) are on the roads. Across other European countries, approximately 50 HRS have been added in 2019. By 2025, the national energy and climate plans target 750 HRS by 2025. This includes Germany's target of 400 HRS by 2025, given sufficient roll-out of vehicles.

California added relatively few stations between end 2018 and early December: open stations grew from 39 to 44. This is a slow-down of roll-out compared to the development projected by CARB in 2018, which was for 64 stations in 2020.

The next target, 200 in 2025 will also depend on the pace of vehicle deployment, though California remains the leader in deployed FCEV.

FirstElement Fuel, responsible for installing and operating 19 of California's HRS, has another 12 in development. It also secured US\$24m in funding (US\$12m each from Mitsui Group's US-based subsidiary Hy Solution, and from Air Liquide) to help fund its True Zero Hydrogen Network of retail stations. Mitsui will also collaborate in the development & maintenance of FirstElement's HRS in California and beyond.



Japan added approximately 30 HRS and now has 130, serving the more than 3,500 fuel cell cars on the road. The 2020 target of 160 stations looks within reach.

As we mentioned last year, Korea has gone big in hydrogen. In parallel to an accelerated roll-out of NEXOs, 2019 saw a doubling in HRS – from 14 to about 30. The government target is for 310 stations by 2022. Part of this goal is being delivered by the Hydrogen Energy Network (HyNet) Special Purpose Company (SPC) we reported on in 2018. The government also plans to select three 'hydrogen-powered cities' by the end of 2019, and the city of Ulsan announced it will build the first dedicated hydrogen pipeline system, to supply six hydrogen refuelling stations.

Limited HRS availability has hindered fuel cell mobility roll-out in China in recent years, with only 18 stations in place at the end of 2018. 2019 will have seen approximately 10 added, but the reported goal of 300 HRS by 2020 remains distant. Recent signs are positive though – November saw Sinopec, one of the two large national conventional fuel retailers, announced its commitment to hydrogen. It signed an MoU with Air Liquide to accelerate the deployment of hydrogen mobility in China. Earlier in the year, Air Liquide and Chengdu Huaqi Houpu Holding created a JV for the production and development of a HRS network in China. The snappily-titled Air Liquide Houpu Hydrogen Equipment Co combines Air Liquide's expertise in hydrogen mobility with Houpu's in the production and construction of natural gas refilling stations in the Chinese market.

Outside of the main jurisdictions, Saudi Aramco and Air Products inaugurated the first HRS in Saudi Arabia.

The infrastructure is not yet fully robust, however and all of the ongoing work in safety and standards remains essential. On 1st June an explosion occurred at an Air Products industrial gases plant in Santa Clara during the filling of a hydrogen distribution trailer. Fortunately, there were no injuries, but hydrogen distribution to many stations in Northern California was disrupted for several months, as hydrogen had to be trucked in from Southern California. To keep their customers happy, Toyota, Honda and Hyundai provided their affected fuel cell car customers with conventional vehicles.

Unrelated, but just days later, on June 10th, an HRS in Kjørbo, near Oslo, Norway, caught fire. Again there were no on-site injuries, but three people suffered minor injuries due to airbags deploying in their cars close to the site. This is thought to have been caused by the pressure wave from the hydrogen ignition. Nel ASA, the station supplier, engaged safety consultancy Gexcon to investigate. The root cause was identified as an assembly error of a specific plug in a hydrogen tank in the high-pressure storage unit. Nel communicated proactively and openly throughout the period, an important move, and one which meant little damage was done to the perception of hydrogen mobility internationally. However, for Norway the incident was a setback; as unaffected stations remained offline in early December.

These two incidents underscore the fact that any problems with hydrogen in the early years will draw substantial media attention, unlike incidents with conventional fuels such as gasoline. Hydrogen mobility is still in its infancy and isolated local events can have very wide ramifications.

Fuel cell buses – nearly a real business?

After years of concerted effort, fuel cell electric buses (FCEBs) are edging closer to commercial normality. 2019 was another good year. In short: more buses are being deployed, from a wider range of bus OEMs, in more places around the globe. It's not about technology demonstrations so much as deployment on commercial or near commercial terms.

A prime driver is the growing imperative for cities – and their public transport authorities – to radically reduce emissions in urban areas. Conventional buses make a high-profile contribution to pollution. So 2019 saw Chinese cities Shenzhen and Foshan join the growing list of cities worldwide committed to procure only zero emission buses in the future. At the same time, initiatives to subsidise the (dropping) capital and infrastructure costs of FCEBs have grown.

Cost is high but dropping fast. Time is still needed to implement refuelling infrastructure. Operation and maintenance activities need setting up. But FCEBs are an increasingly strong option.

Europe accelerates

Europe has been at the centre of FCEB development and deployment, and has clung on for another year in the face of growing Asian competition. Strong FCH JU support has catalysed additional public investment: in the UK, OLEV funds are supporting deployment in London, the Ile de France government funds buses in Versailles and Aalborg municipality in Denmark. The JIVE projects are an important driving force, targeting 290 buses across Europe, of which Groningen in the Netherlands ordered 20 out of a planned 50 Van Hool buses in July, and London ordered 20 Wright double-decker buses in May. In March Van Hool received Europe's largest single order to date, with RKV Koln and WSW Wuppertal ordering 40 of the 12 m A330 vehicles – powered by Ballard's FC Velocity HD85.

After JIVE comes the less-evocatively-named H2Bus Europe, formally launched in June. A consortium including Ballard Power, WrightBus and Nel is seeking to deploy 1,000 FCEBs – assisted by €40m (US\$47.4m) from the European Union's Connecting Europe Facility. The first 600 will be in the UK,

Denmark and Latvia, and of three types: a standard 12 m, a double decker and an 18 m articulated vehicle. The target cost for the 12 m vehicle will be less than €375,000 (US\$450,000), another step change from the JIVE projects, which were at €600,000+ (US\$711,000+). The buses will be part of a package, including HRS and hydrogen supply, with a target hydrogen price of €5-7/kg (US\$5.9-8.3/kg).

In another positive sign for buyers and markets, the long-established fuel cell module suppliers, like Ballard and Hydrogenics, will start to face competition. The fight should be a good one – in 2019 a Ballard FCveloCity-HD6 fuel cell hit 35,000 operating hours in service on a Wright bus in London. Though the buses have now been refurbished with new stacks, these lifetimes way exceed the lives expected when they were delivered. Now Ballard has its eighth generation FC module, the FCmove-HD, which is smaller and lighter and expected to be used in buses for JIVE and H2Bus Europe.

Amongst the explosion in interest from OEMs and fuel cell suppliers are: Skoda of the Czech Republic, which in March signed a letter of intent to use Proton's HyRange FC modules; CaetanoBus of Portugal, which will use Toyota's technology; Goldi Mobility of Hungary, which hopes to provide 12 m and 18 m vehicles using Horizon 100 kW fuel cell modules. OEMs new to the sector include SAFRA of France, using Michelin fuel cell modules; and VDL of the Netherlands which has developed a novel fuel cell 'back-pack' for its electric buses, due to be placed into service in Rotterdam.



Solaris bus of Poland has received orders for its Urbino buses, using Ballard fuel cell modules, from Poland, Italy and elsewhere in Europe. The UK's Arcola Energy is working with Alexander Dennis, establishing a new facility in Liverpool under a £6.4m (US\$7.6m) OLEV project. With the existing players Van Hool, Wright and Daimler in the European market, there are now reckoned to be 12 OEMs offering FCEBs.

California leads the USA

Some of the first FCEBs were in the USA. But despite two decades of operating experience, progress in commercialisation has been slow. At the end of 2018 the USA was reported to have 35 buses running, with another 39 planned. The majority of these were with the 'usual suspects': Sunline Transit, Orange County Transit and AC Transit in California, and Ohio's Stark Area Regional Transit Authority. The odd bus is in trial in other States, e.g. Illinois and Hawaii. 2019 saw a few additions to the fleet, mainly in California where 31 should be operating at the end of 2019. Another 21 are planned. Most are made by either EIDorado National or New Flyer. In 2019 both launched new models, their XCelsior and Axxess FCEBs respectively, with Ballard modules. The US's Altoona, PA, bus testing and research centre was used for pre-launch tests.

Why California? Policy, policy, policy. Its Clean Transit Regulation stipulates that 25% of buses procured from 2023 should be zero emission, and targets 100% by 2040, although the actual ambition is likely to aim for even earlier. California Air Resources Board and California Climate Investment Programme are providing financial support, such as the Hybrid and Zero Emission Truck and Bus Voucher Incentive Project. This

supports the 20 New Flyer XCelsior vehicles entering the Orange County and AC Transit FCEB fleets, and the installation of two new HRS, amongst other projects. California also has an FCEB Roadmap, produced in 2013 and updated in 2019. This posits a possible 100% zero emission bus procurement scenario in 2029, with target orders of 100 in 2020 and 300-400 in 2025.

The roadmap does also identify 'drags' on commercialisation: capital cost; parts supply and maintenance; cost of – and access to – hydrogen. Work is needed, but NREL's series of FCEB evaluations show a maturing technology, with fuel cell modules lifetimes now repeatedly meeting the US DoE target of 25,000 hours; five AC Transit buses had exceeded this even by the end of 2018.

Asia – China leads for now

Since Chinese interest started in the sector, FCEB activity in Asia has increased dramatically. In China it's also all about policy – with Government subsidy the reason for the sector to exist. Vehicles are smaller than those in Europe or the USA, and use smaller fuel cells as range extenders for battery dominant vehicles. More buses should be running in China than in Europe, and one source claims that 126 buses delivered by the end of Q3 2019, but it remains unclear how many are in active service. The registration process takes time, and hydrogen infrastructure is only now starting to catch up.

Nevertheless, a growing number of Chinese companies are offering or developing FCEBs. In 2019 Geely launched its F12 FCEB; Beiqi Foton exhibited its FCEB offer in November 2019, and is aiming to deploy 1000 units by the end of 2022;

Golden Dragon announced that it will deliver 100 FCEBs, comprising 8.5 and 12 m vehicles, for Zhejiang Province by the end 2020; and both Ronn Motor Group and Anhui Automobile stated intentions of developing lightweight FCEBs for China and for export markets.



Right now, the fuel cell technology is often from Ballard and Hydrogenics. Other non-Chinese fuel cell developers are entering too, like Toyota. And Weichai announced that it will put Ceres Power SteelCell SOFCs in bus trials, as 30 kW battery range extenders running on natural gas.

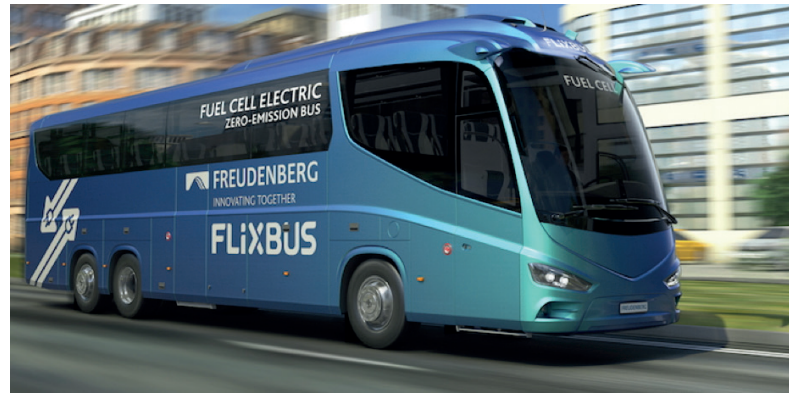
Both Japan and Korea are now developing more substantial FCEB activity, primarily driven by Toyota and Hyundai, and supported by government incentives. 37 buses were to be funded in Korea in 2019, adding to the seven from 2018, of the 2,000 buses planned for 2022. The subsidy is reported to be about US\$170,000 per vehicle. Buses come from Hyundai, which is also slated to replace 802 buses operated by the police force with FCEBs between 2021 and 2028, not least to reduce the emissions which often come from the buses idling in cities.



Japan plans to have 100 buses in service in 2020, for the Tokyo Olympics, and 1,200 running by 2030. At least 18 are already in service in and around Tokyo. All are Toyota's 10.5 m Sora, updated for 2019. Both Hyundai and Toyota use the same stacks as in their cars – the 95 kW NEXO stack for Hyundai and the 114 kW Mirai stack for Toyota, helping maximise supply chain benefit.

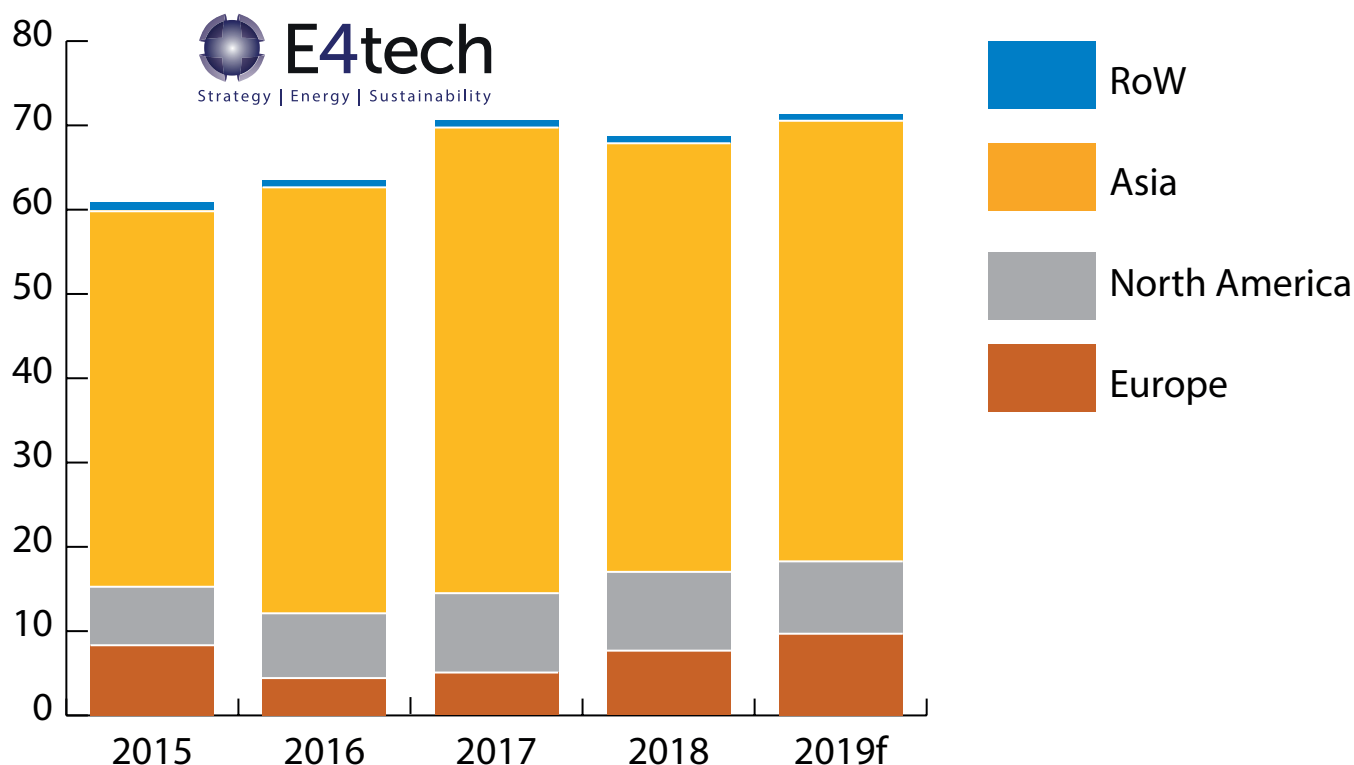
Malaysia has been trialling three FCEBs from Foshan Feichi Automobile in the Santibong National Park. And in India, following Tata's development of a fuel cell powered version of its Starbus Electric in 2018, the Ministry of New and Renewable Energy launched a procurement activity for four FCEBs for a five-year trial in New Delhi. Even New Zealand is entering the fray: Auckland Transport has ordered the first FCEB from local manufacturer Global Bus Ventures.

And finally, it's good to see longer-distance transport entering the mix. European coach operator FlixBus is working with Freudenberg on a coach that will go 500 km between refuels. It plans an initial fleet of 30 buses.

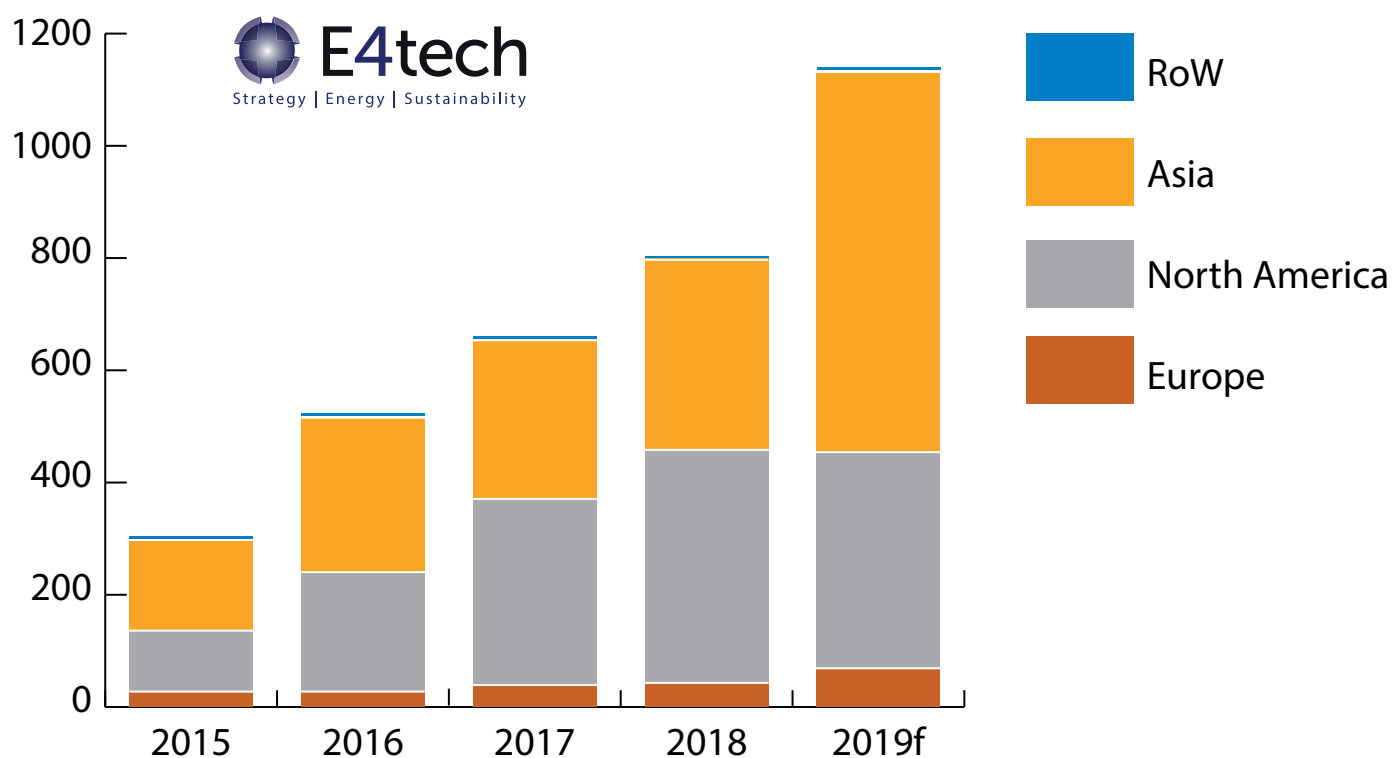


Shipments by region

Shipments by region of adoption 2015 - 2019 (1,000 units)



Megawatts by region of adoption 2015 - 2019



2019f is our forecast for the full year, based on firm data from January to September.

We have revised the figures for 2018 in this report. The main change relates to the final 2018 data for Ene-farm micro-CHP units in Japan being lower than initially forecast.

Shipments by region

Asia, as always, leads the world in the number of fuel cell systems shipped, and as always it is the Japanese who come in first, thanks to the Ene-farm programme. Of the total 70,000 fuel cell units shipped in 2019 – a few percent up on 2018 – 45,000 or so went into Japanese homes. Of the MW shipped, Asia retook the crown it gave to North America in 2017, almost exactly doubling shipments year-on-year to some 680 MW.

This growth has been driven almost exclusively by Hyundai NEXO sales into Korea. The Koreans overtook Toyota in 2019 and sold almost 4,000 NEXO fuel cell cars in the first ten months, more than 3,000 in Korea and the remainder in North America and Europe. This compares to a total of 2,200 Toyota Mirais in the same period, largely to California, then Japan, but with a few sales in many other regions. Fuel cell vehicles deployed in Asia in 2019, including also trucks and buses in China, constitute 50% of the total shipped fuel cell capacity worldwide.

Each country has its policy driver to push fuel cells, which suggests continued deployment. China is expected to continue to support fuel cells. Korea's Hydrogen Roadmap seeks to move swathes of the economy to hydrogen by 2040. And Japan's support is underpinned by its Basic Hydrogen Economy vision. Toyota will ramp up production capacity in 2020 to 30,000 cars per year.

Aside from Asia, the major regions for fuel cell shipments remain Europe and North America, similar in terms of unit shipments (with 14% and 12% of overall fuel cell numbers, respectively), but with North America seeing five times the yearly installed capacity by MW. Much of the 'megawatt capacity' going into North America derives from large shipments of Toyota Mirai, Hyundai NEXO and some Honda Clarity into the US.

In comparison, shipments to the rest of the world (regions outside Asia, Europe and North America) remain insignificant, and are mainly linked to back-up power systems.

Though still small, shipments of fuel cells overall have grown in Europe, from just over 8,600 units in 2018 to just over 9,700 units in 2019. Shipped capacity into Europe over the same period increased significantly, from 41 MW to 69 MW, largely driven – again – by increases in shipments of Hyundai NEXO, and to a lesser extent increases in PACE shipments and KfW 433 approvals.

Total numbers of fuel cells shipped to North America have barely changed, from 8,900 units in 2018 to 8,600 units in 2019. Shipped capacity dropped alongside, from 425 MW to 384 MW year on year. Stationary shipments by capacity were barely changed year on year (79 MW increasing to 93 MW), while MW of transport shipments into North America declined from 345 MW to 290 MW.



Increasingly commercial vehicles

With increasing pressure on both greenhouse gas and regulated emissions, and with batteries not always a suitable electrification strategy, the diesel-reliant commercial vehicle market is focusing harder on fuel cells. Many fleets have 'return to base' operation, which helps with fuelling, and fuel corridors can be envisaged for longer distance fleets. And while Tesla claims its Semi will offer 300–500 mile range for around US\$200,000, and be produced in 2020, the weight of the batteries and the recharging burden for trucks make the economics tough.

The long-haul market

The HGV market is brutally cost sensitive. Government support or intervention is limited, compared to buses for example. And truck OEMs don't always have the balance sheets of the major automotive OEMs, so can't afford to follow every new trend: CNG, LNG, LPG, DME, hybrids... and fuel cells. But as diesel trucks begin to be banned from major city centres, the cost-benefit case strengthens. Nevertheless, commercial duty cycles can be very tough, with fuel cell makers targeting 50,000 hrs of stack life, notably more than the 35,000 achieved so far by the best buses on the roads.

Despite the 'fleet benefit', fuelling trucks is not a trivial undertaking. Getting adequate range in a long-haul vehicle in a few minutes (10-15 is accepted as a reasonable target) requires hydrogen flow-rates 5-6 times higher than the SAE standard for cars – with the nozzle and cooling modifications that entails. Nikola Motors plans to build its own infrastructure (though will let rivals use it): 700 refuelling stations by 2028, with renewable hydrogen the focus. It is working with Air Liquide, Hyundai, NEL, Shell, and Toyota to test the pre-commercial 70 MPa high flow (H70HF) fuelling hardware for future Class 8 trucks.



Nikola, like Tesla, takes non-binding pre-orders for its trucks. Orders for at least 13,000 vehicles have been taken (including the 800 for Anheuser-Busch), featuring up to 1,000 horsepower (746 kW) and 2,000 ft-lbs (2,700 Nm) of torque, range 500-750 miles and 15-20 minute refuel times. Its partner Bosch has been joined by IVECO, though PowerCell is no longer directly involved. It seems the two companies could not agree on business terms. Still, Bosch has its own agreement with PowerCell, so is still able to provide stack and system support while Nikola develops its own.

But the IVECO partnership, through the main holding company CNH Industrial, allows IVECO to support Nikola in the US and vice-versa in Europe. Nikola's contribution includes fuel-cell expertise, on-board H₂ storage and power electronics, as well as potential access to a H₂ refuelling network. IVECO has invested cash in Nikola shares, but is also providing significant in-kind support to help the start-up company industrialise. Nikola will use IVECO's sales, service and warranty channels to accelerate access to the European market, and the European JV will cover both battery and fuel-cell electric vehicles launched by Q4 2022. Bosch & Hanwha also invested in Nikola during the Series D fundraising. Bosch is actively supporting FC system and battery development, while Hanwha's solar panel manufacturing capability allows it to be Nikola's exclusive PV panel provider, for making the renewable hydrogen.

PowerCell has plenty to do elsewhere, including in heavy duty. It is part of the EU-funded truck project, H2Haul, along with Air Liquide, Eoly, H2 Energy, Hydrogen Europe, IRU Projects, ThinkStep and WaterstofNet. Iveco and FPT Industrial (both part of CNH Industrial) and VDL ETS will develop and build three truck models of up to 44 t. ElringKlinger and Hydrogenics join Powercell as stack providers. Hydrogenics will install an MS-100 fuel cell system into a medium-duty truck for tests by the university RTWH Aachen, part of the LiVe project to develop cost-efficient electric drivetrains for medium-duty trucks.

A changing industry landscape?

In a further sign of the importance of the sector, bigger players are entering. Cummins purchased the remaining part of Hydrogenics that wasn't under Air Liquide, and entered into an MoU with Hyundai look at developing and commercialising electric & fuel cell powertrains. Hyundai's FC systems would be combined with Cummins' electric powertrain, battery & control technologies. The links back to the launch of Cummins Electrified Power business in 2018, making fully electric and hybrid powertrain systems to serve commercial markets as they adopt electrification. With Hyundai, initial focus is the North American commercial vehicle market, including working with OEMs to integrate the powertrains into their vehicles. Other steps include developing next-generation fuel cell systems, even stationary power generators for backup and remote sites. Also benefitting from Cummins' spending spree with a cash investment was Loop Energy, which has been developing fuel cell electric range extenders for medium- and heavy-duty transport applications, and will supply Cummins with systems for incorporation into demonstration trucks.

California again

Kenworth and Toyota are working together to develop 10 zero-emission Kenworth T680s using Toyota fuel cell powertrains, for use in a Southern Californian project funded partially by the State's environmental regulatory agency. The first trucks should be in service by early 2020. US\$41m has been provisionally granted for Zero and Near-Zero Emissions Freight Facilities (ZANZEFF) by the California Air Resources Board (CARB), with the Port of Los Angeles as the prime applicant. This is part of an US\$82m programme to put fuel cell electric tractors, hydrogen fuelling, and zero emissions cargo handling equipment into Long Beach and Los Angeles ports, and Los Angeles basin in 2020. And Nel has a US\$6m supply contract with EQUILON Enterprises (trading as Shell Oil Products US) for an H2Station® solution for heavy-duty vehicles in Los Angeles, serving trucks 'from a major vehicle OEM'.

Horizon, originally known for its remote-controlled model fuel cell cars, has been creeping up the size scale for years, and went big in 2019. It unveiled new 150 kW stacks for road-certified 42 tonne trucks made by Ford's joint venture JMC. Horizon, Jiening New Energy and partners this year also showcased the first 20 Class 8 fuel cell trucks of an aggressive plan to deploy at least 2,000 over the next few years. 500 km range is claimed, and 1,600 is the target for the next generation.

Horizon is focused on even larger fuel cell systems and also announced high-volume production of the world's highest power single stack PEMFC, 300 kW, for heavy vehicles, trains, ships, and port equipment. The first should be available in 2020.



Hyundai thinking big

Hyundai continues to extend its reach. Perhaps initially prompted by being pulled into the Swiss Co-op project in 2018, it has become considerably more expansionist in recent times. It will also be testing its hydrogen-fuelled trucks in Israel in 2020 in conjunction with Colmobil Group and Taavura Holdings. Colmobil imports Mercedes, Smart, Mitsubishi and Hyundai vehicles into Israel, including trucks and buses, while Taavura represents DAF Trucks. Its technical and logistical centre collects truck fleet data like stress, exertion, and wear, and Israel's varied climate, extreme road inclines in the Galilee and the Golan Heights, and long roads in the Arava make it a prime testing ground. Awkwardly, Israel currently has no hydrogen fuelling infrastructure, but a tender from the Ministry of Energy for a proof of concept should come soon.



Hyundai's bespoke fuel cell truck, the X2 Xcient was unveiled in September. Two 95 kW NEXO stacks in parallel give it 190 kW of power, and the 35 kg of hydrogen in seven tanks should allow 400 km range. The first 50 should be delivered to Switzerland in 2020, as well as the one to New Zealand. The Swiss fleet will be managed by H2Energy and fuelled by Hydros spider – a JV between them, Alpiq and Linde founded in early 2019. Truck financing will be 'pay-per-use', much as Nikola plans.

Hyundai's design team has clearly been working overtime, as they also unveiled an HDC-6 Neptune Concept truck, inspired by the 1930s Art Deco streamliner railway trains and with room for up to eight hydrogen tanks. However, Hyundai is having to develop new, more powerful stacks to enable it to pull the 80,000-pound beast long haul.



Fuel cells are not just for traction

For many years, fuel cells have been researched as Auxiliary Power Units (APUs) for HGVs, to power refrigeration units and other hotel loads. France's Malherbe is now in final tests of the 'world's first' refrigerated semi-trailer with fuel cell-powered cooling, built by Chereau as part of the €5.5m (US\$6.5m) ROAD project. The fuel cell system was provided by the CNRS FCLAB research consortium. And Christian Cavegn, a major Swiss refrigerated food transport company joined H2 Mobility Switzerland.

Mine trucks? Yes, really

Mining vehicles are colossal, require huge amounts of power, and are increasingly electrified to help provide torque. Though they operate in often brutal conditions, those characteristics lend themselves to possible fuel cell solutions. So, a consortium including Anglo American and ENGIE is working towards that. Anglo, also a Ballard investor, has ordered 9 x 100 kW fuel cell modules (one is a spare) to power a retrofitted ultraheavy-duty mining truck in a demonstration project at an Anglo mining operation in South Africa during 2020. If all goes well Anglo American expects to deploy further of these MW-class trucks at other operations around the world. Since the mine's existing Komatsu trucks feature an electric drive, modifications include replacing the diesel tank with hydrogen tanks and the engine with fuel cells and a battery pack. The hydrogen will come from solar generation at the mining site.

Light duty commercial begins to deliver

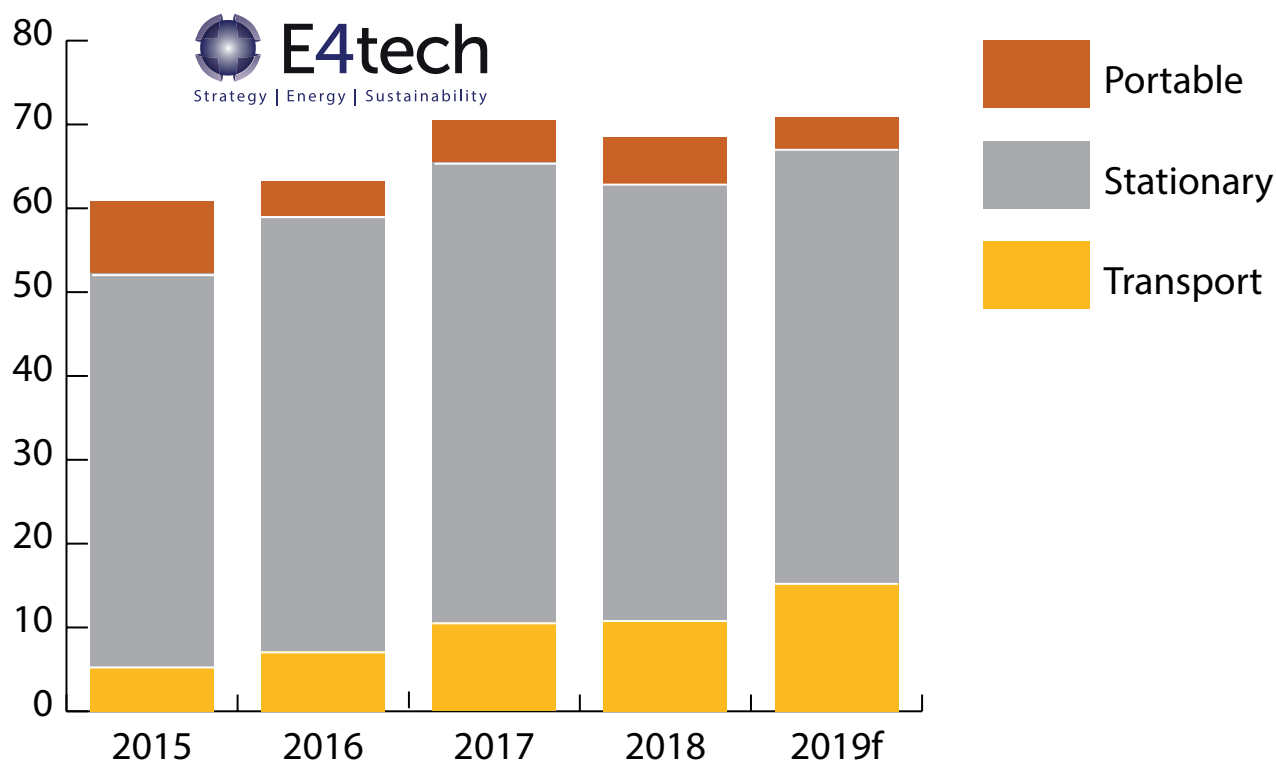
StreetScooter has spent some time searching for its fuel cell dance partner to power commercial delivery vans. Starting 2020 it plans to deploy 100 'H2 Panel Vans' in Germany, with Plug Power and DHL Express. They will be the first 4.25-tonne commercial fuel-cell range-extender vehicles with a range of up to 500 km, have 26 kW of fuel cells on board plus 40 kWh of battery, and 6 kg hydrogen. Payload is 800 kg, maximum speed 75 mph.

Plug Power has also been working with FedEx to demonstrate and test fuel cells in goods supply chains. A fuel cell delivery van is delivering packages in Albany, NY, and data from the trial could lead to expansion to a fleet of 20 trucks. And FedEx has also placed fleets of Plug's ProGen-powered cargo tugs at Albany airport, joining the ones that went into Memphis previously.

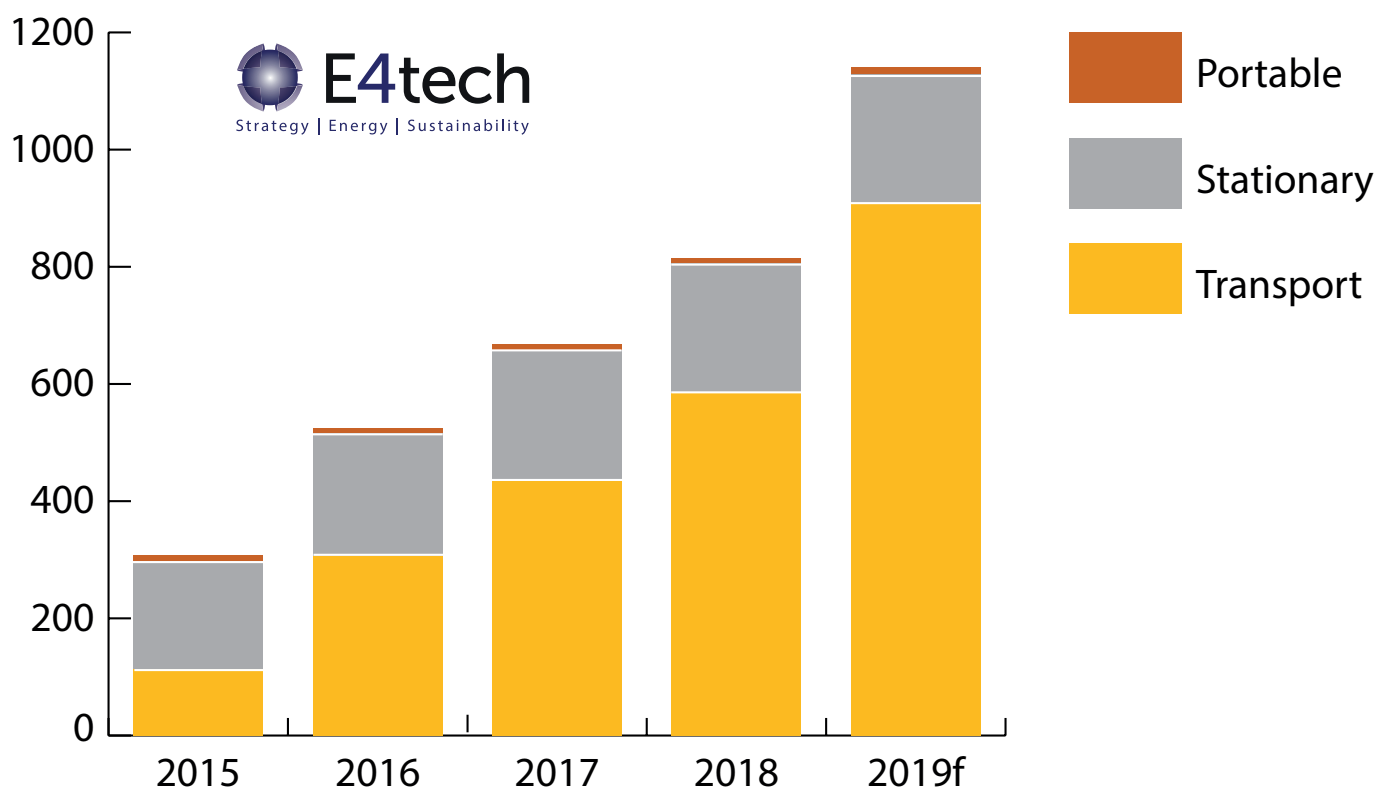
And Renault, essentially absent from the fuel cell field for many years, has formally introduced fuel cell range extenders to its electric light commercial vehicle range (the Kangoo ZE and Master ZE), by adding a 10 kW fuel cell to the 33 kW battery. The fuel cells come from Michelin's subsidiary, Symbio, which first put its fuel cells into Kangoos bought from Renault around 2014. The fuel cell variant costs €48,300 (US\$47,300).

Shipments by application

Shipments by application 2015 - 2019 (1,000 units)



Megawatts by application 2015 - 2019



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We have revised the figures for 2018 in this report. The main change relates to the final 2018 data for Ene-farm micro-CHP units in Japan being lower than initially forecast.

Shipments by application

Last year we suggested over 1 gigawatt of fuel cell system capacity would be shipped in 2019. Happily, that was conservative, and we now expect over 1.1 GW to have entered the market. Previous years' trends continue, with fuel cell vehicles increasingly dominant. From 2014 to 2019 their share increased from 20% to 80% of the MW shipped. Also in 2019 Hyundai took the lead from Toyota. It shipped a forecasted 4,750 or so vehicles to the end of 2019, or 450 MW. Toyota is closely behind though – nearly 2,700 vehicles are anticipated by year-end, representing a bit more than 300 MW. The two together account for two thirds of 2019's shipped fuel cell capacity.

Added to these figures are substantial truck and bus numbers in China. We estimate well over 1,500 units shipped. Honda and to a lesser extent Daimler add further to the transport numbers. Most fuel cell vehicles running in China are trucks and buses, though SAIC has sold a few hundred vans. Numbers in China were anticipated to be bigger this year, but the backlog will likely be rolled out early 2020. The average stack size will be bigger, responding to a change in subsidy, so each vehicle is likely to contribute 60-80 kW to the installed base, unlike the current 30-40.

A small but growing number of specialist fuel cell vehicles is coming too, from commercial vans (Renault, in partnership with Michelin/Symbio) to refuse trucks and even the odd big truck, such as the Toyota/Kenworths in Los Angeles or the recent Nikola 'beer run' for Anheuser Busch. In total, more than 15,000 vehicles of all types were shipped (or forecast), or over 900 MW of the 1.1 GW total. Having slowed briefly in 2018, materials handling shipments have been growing again, with more than 5,000 expected for 2019. These contribute about one third of the total vehicle numbers.

Still the most significant in unit numbers, though lower in capacity, the stationary sector saw over 51,000 units shipped and forecast, adding 220 MW or so to the mix. Combined heat and power (CHP) stays far in the lead by units, as always because of the Japanese Ene-farm programme – with some help from Europe in the form of the PACE project and more importantly the German KfW 433 support. The total CHP contribution also includes larger capacity units, though they are small in number.

The portable fuel cell segment hardly appears in the megawatt count. However, relatively small systems in the 25 W+ range generate significant sales, for example for military applications. Direct methanol fuel cells (DMFC) as well as small SOFC devices play an important role in this segment. 'Portable' fuel cells also go into remote applications, either as grid backup or as off-grid supplies, met by SFC Energy, Adaptive Energy and a few others. The year-on-year decline in unit sales is essentially because myFC, the last remaining supplier of FC-powered USB chargers, has also left this segment.



Trains

Fuel cells used in trains and trams are no longer regarded as an oddity. Alstom's fuel cell hybrid Coradia iLint has achieved more than 130,000 km in revenue service in Germany, with boringly high reliability for a new technology, of 95%. Two Coradia iLints have been in service for Eisenbahnen Verkehrsbetriebe Elbe-Weser (EVE) in Lower Saxony since 2018. Reliability will nevertheless need to improve as the technology matures, and progress will be assessed before 14 more units are delivered in 2021.

Other rail operators across Europe are nevertheless interested. Rhein-Main Transport in Germany ordered 27 units in May 2019, for lines north of Frankfurt currently operated by diesels. The Federal Government is picking up 40% of the additional costs. Alstom has teamed up with Infrserv GmbH to deliver the units, accompanied by a 25-year maintenance and hydrogen supply agreement. Delivery is expected by the end of 2022.

Much as the UK announced an ambition in 2018 to phase out all diesel trains by 2040, the French operator SNCF plans to replace all its current diesel units by 2035. The process appears to have started, with SNCF ordering the first Alstom hydrogen Multiple Units for lines in the Auxerre and Auvergne-Rhone-Alps regions in France. The concept is designed for French regional transport, has 50% more power than the iLint at 300+ kW and referred to as Régiolis by SNCF. Romania has also shown interest, ostensibly for the line from Bucharest Otopeni airport to the city, and a two-week test of the iLint will take place in Groningen in early 2020.



The benefits of fuel cell trains are being touted more broadly. A study on using fuel cells and hydrogen in the rail environment, funded by Europe's FCH JU and Shift2Rail JU, suggested that 20% of newly purchased trains could be hydrogen-fuelled by 2030. Both Alstom and its competitor Siemens could benefit – the latter is developing a fuel cell powered version of its Mireo units using 200 kW fuel cells from Ballard. The intended merger between Alstom and Siemens, which might have killed this competition, was quashed by the European Commission on broader market dominance concerns.

In the UK the immediate emphasis is on refurbishing older trains rather than purchasing new. Train leasing businesses Porterbrook and Eversholt own older 1980s electric units that have been superseded by newer models. They want to refit the older units with fuel cells so they can operate on the nearly 60% of UK lines that are not electrified. Porterbrook and the University of Birmingham have begun testing of a HydroFlexClass 319 unit fitted with Ballard fuel cells and a 200 kW battery, while Eversholt is working with Alstom on the Breeze project, aiming to fit a Class 321 unit with fuel cells.



Also in the UK, VivaRail is working with systems integrator Arcola to design and build a fuel cell-battery hybrid, based on their existing class 230 battery module. A concept train to demonstrate performance is likely in early 2020.

Finally, Abellio is set to trail hydrogen trains on its Midland Mainline franchise, one of the few mainlines in the UK without plans for electrification.

Despite Japan Rail's efforts some years back, Asia lags Europe on fuel cell powered trains. But 2019 announcements suggest that units may be demonstrated soon. Japan's Railway Technology Institute has developed a hybrid train with two 90 kW fuel cells and a 540 kW Li-ion battery. JR East is planning to test fuel cell trains in Fiscal Year 2021, with possible commercialisation in 2024. These trains can travel at 100 km/hour with a limited range – about 140 km.

Korea's push for all things hydrogen includes rail too. The Railroad institute is working with Woorin Industrial systems on a ₩25bn (US\$21.5bn) programme to develop a fuel cell battery hybrid train with 1.2 MW of power. This should do speeds up to 110 km/hour over 600 km, and could be in test in 2022. Hyundai's train builder Rotem is also reported to be interested in developing a fuel cell train using Hyundai's automotive fuel cell stacks. These could substitute for the 131 diesel powered commuter trains in Korea estimated to need replacing in the next decade or so.

After a few headlines in 2017, China's efforts in the sector have calmed. China Railway Rolling Stock Corporation's light rail hybrids, using Ballard fuel cells, were trialled in Foshan City, but no further developments have been announced. However, Indian Railways should be commissioning a fuel cell shunter locomotive following a 2018 agreement with SMR University. It will work on moving rolling stock in an Indian Railways facility in Chennai, supplanting an older diesel locomotive with high emissions. This shunter profile is common worldwide, and the emissions are exacerbated by the considerable time spent idling awaiting work.

North America experimented with fuel cell locomotives for shunting way back in 2010, with an example developed for Burlington Northern Santa Fe railroad in California. It has taken until now for the next major development, an announcement by San Bernardino County Transportation Authority (SBCTA) to buy a hydrogen-powered train from Swiss company Stadler Rail, with an option for four more. The charmingly-named FLIRT, a two-car train, should enter passenger service in 2024 as part of the Redlands Passenger Rail Project, a nine-mile connector between Redlands and San Bernardino's Metrolink station.

Otherwise, only Ontario's MetroLinx service in the Greater Toronto region has examined fuel cell trains in depth, as electrification of the service is planned. While initial analysis was positive about the economics, no decision appears to have been taken on whether to go with fuel cells or with overhead electric lines.

Light rail has not had so much attention recently. However, local municipal agency Gorelektrotans has launched a test fuel cell-powered tram in St Petersburg, for its fuel cell operation to be compared with its electrified line equivalent.



Material handling and forklift trucks

Materials handling continues to be a major fuel cell sector. Over 30,000 fuel cell forklifts are now in daily operation in the US, chosen for economic reasons above all. Most were made by Plug Power, but Hyster-Yale and others are now edging into the market. Hyster-Yale's offering is larger than Plug's current sweet spot, with Nuvera, its fuel cell division, now shipping 45 kW modules to partners in Europe and China for integration into commercial medium- and heavy-duty applications. Nuvera also delivers internally to Hyster-Yale.

Horizon's agreement with US company Off Grid Logistics to establish Horizon Material Handling LLC is intended to lead in the near-term towards Class II and III forklift systems. Longer-term ambitions include large lift trucks and even port equipment.

Plug continues to consolidate its position, including production of its next generation GenDrive systems for Class 1 industrial forklifts. Lipari Foods has joined its client list for its Michigan site. In July, French company FM Logistic became Plug's first GenKey customer in Europe, with Fiat Chrysler following on and ordering more than 240 units in November.

Every other region trails. Only around 500 materials handling vehicles are running in Europe, mainly small forklifts. Things are gradually moving though: Intelligent Energy has teamed with German-based Fahrzeug Entwicklung Sachsen to offer fuel cell products for Class 3 electric hand trucks, starting in 2020. European Class 3 trucks have apparently been a problem in the past, with small width batteries hard to replace by fuel cells, unlike the larger US applications.

And Powercell has made its MS-100 FC system 30% more compact, with materials handling in mind. The UK's Auriga Energy trialled its AurigaGen FL prototype fuel cell powered unit on a Bristol Forklifts pallet truck, and Linde expanded its range of forklifts with a fuel cell 'Roadster'. Meanwhile, the German Federal Ministry of Transport and Digital Infrastructure (BMVI) is supporting FC materials handling through funding of up to €4.2m (US\$5.0m).

In Japan, Toyota installed its SimpleFuel™ refuelling station at its Motomachi Plant in Toyota City. This HRS provides enough hydrogen to fuel up to eight FC forklifts, supplied by subsidiary Toyota Industries Corporation, who has also supplied 160 FC forklifts to airports, seaports and factories, predominately in Japan. They plan 500 units in 2020, and up to 10,000 per annum by 2030. And of course Korea has a hydrogen forklift plan too, with Jeonbuk province subsidising the replacement of ten forklift batteries with fuel cells in the first instance, for ₩66m (US\$56,800) each. The initiative is part of a bigger strategy to foster the hydrogen construction machinery sector.



Ships and boats

With smaller vessels already proven, a race is on to get 'metal in water' for different fuel cell ferry projects worldwide. The Scots, the Norwegians and the Californians all have plans. In Scotland, the HySeas III project is preparing the drivetrain test phase of a hybrid passenger ferry powered by Ballard HD100 100 kW PEMFC and Leclanché batteries. Plans are to run the Kirkwall – Shapinsay route in Orkney in 2021. Orkney already has a lot of hydrogen-based activity. Ferguson Marine, the shipbuilder for the project, has just emerged from a near-death experience by being taken into public ownership following insolvency.

Norway is making solid progress too, having stipulated that only zero emission boats can enter its UNESCO-protected fjords by 2026. Hyon (the JV between Nel, Hexagon and PowerCell) is working on two fuel cell-powered vessels with the help of partners from the NCE Maritime CleanTech cluster: Norled, Selfa Arctic, LMG Marin and Servogear. The first, a hybrid fast ferry, got NOK 10.5m (US\$1.2m) in December 2018 from Norway's PILOT-E innovation support programme, and is aiming at launch in 2020. Its hydrofoils will allow it to carry 100-300 passengers at speeds between 25 and 45 knots. The second, a coastal freighter with autonomous cargo handling for up to 200 containers, powered by diesel or gas electric propulsion, batteries and hydrogen, got NOK 6m (US\$0.7m). Both boats will use the Hyon group's technologies.



Havyard Group was awarded NOK 104m (US\$11.9m) to develop a long-range ROPAX (roll-on, roll-off, passenger) vessel using hydrogen, for Havila Kyststruten. Supported by Sintef Ocean, Norwegian Electric Systems and Protech, this long-range FC-battery hybrid should be in operation in 2022.

Maritime developments are still emerging and so are heavily project-dependant. With €5m (US\$6m) from Horizon 2020, Flagships also aims to develop a passenger and car ferry for Norway, to be operated by Norled in Stavanger and able to hold 199 passengers plus 60 cars or 6 trucks.

A smaller hydrogen fuel cell utility vessel is also planned for Lyon, France. Power for the ferry will come from ABB and Ballard to enable the 260 km and 19 operating hours per day from 460 kg of hydrogen, stored in a 600 kg capacity tank at 250 bar. Ballard plans on shipping the 2 x 200 kW PEMFC in 2020, for operating tests in 2021. And finally, Brødrene AA – a maker of high-end and low energy consumption carbon fibre fast ferries – has presented its new hydrogen-fuelled AERO. The production-ready design was arrived at with industry partners Westcon, Boreal and Ocean Hyway Cluster, for the Norwegian fjords.

France is also looking at inland waterways. Helion Hydrogen Power will integrate a fuel cell into a river barge, working with Shipowner The Crew and with Orion Naval Solutions. The HyBarge project will start with system validation in 2020.

At larger scale, Bloom Energy and Samsung Heavy Industries have teamed up to build SOFC powered ships. Bloom brings its expertise in stationary FC systems, while Samsung Heavy Industry builds ships. The certification agencies are already engaging: this project has received approval in principle from DNV-GL. Meanwhile Hyundai has signed an MoU with Gangwon Province to put fuel cells into 5 t fishing boats. The long-term plan is for a marine-ready stack module by 2022, and application to larger vessels by 2030.

GE Power Conversion is also eyeing bigger vessels: it is partnering with Nedstack to develop hydrogen FC systems for cruise vessels. Nedstack provides the MW scale fuel cell technology, starting with 2 MW fuel cell powerplant concepts, and GE brings the expertise in power and propulsion systems.

Very involved in fuel cell applications for the maritime sector, Ballard established a Centre of Excellence in Hobro, Denmark, to design and manufacture heavy duty fuel cell modules for the marine industry. The centre is expected to be finished by the end of 2019, and can output 15 MW of fuel cell modules per year.

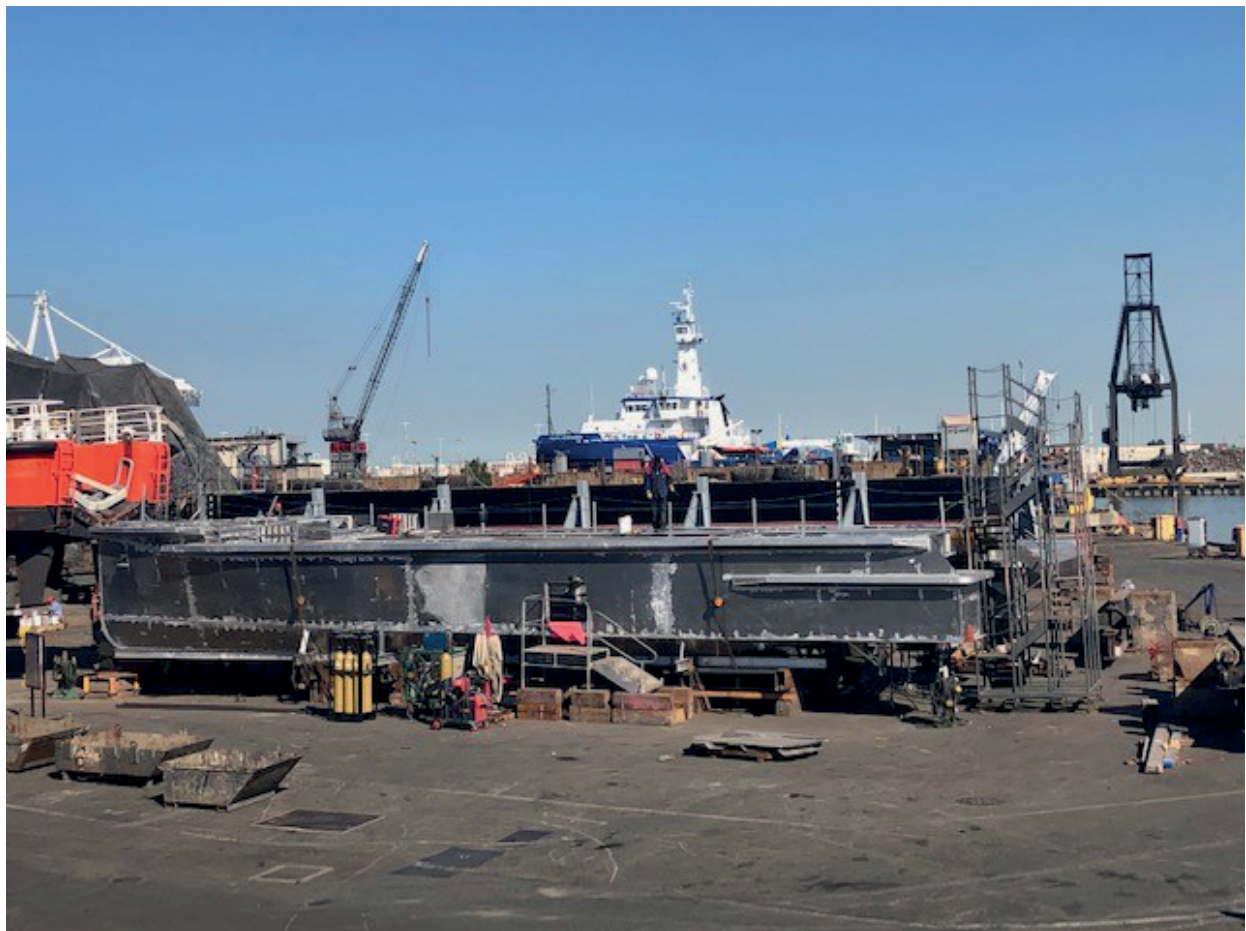
Nedstack will also provide fuel cell systems for a 65 t bollard pull harbour tug, with the help of OSD IMT. Hydrogen in 20 ft ISO containers will allow 2 to 4 days autonomy. 45-50 t and 75-80 t concepts are in design. The Netherlands is also examining the hydrogen concept: Nouryon, NPRC and Lenten Scheepvaart want to transport salt from Delfzijl to Rotterdam, but are only in the analysis phase.

At the luxury end of the market, American firm Daedalus Yachts has designed the Daedalus 80, claimed to be the first luxury sailboat equipped from new with an electrolyser, fuel cell and battery system. The 24 m catamaran carries an electric tender, and deionised sea water is intended to provide the feed for the electrolyser, with power coming renewably from sailing (up to 60 kW/hr), wind (4 kW/hr) and solar (4 kW/hr, for 10-16 hours a day – if the sun is shining). Fincantieri, another shipbuilder, also has plans, with a 38 kW fuel cell on order from Proton Power Systems. It could end up in a vessel, should an initial feasibility study show promise.

Prize for most ambitious design was easily taken by the fuel cell-powered concept superyacht from Dutch company Sinot, with a six-foot model of a 367 foot vessel named Aqua. Twin 28 t liquid hydrogen tanks and 4 MW of PEMFC would allow a top speed of 17 knots, and a 3,750 nautical mile range. Pricing and delivery dates were not revealed, though it's safe to suggest that if you need to ask, you can't afford it...

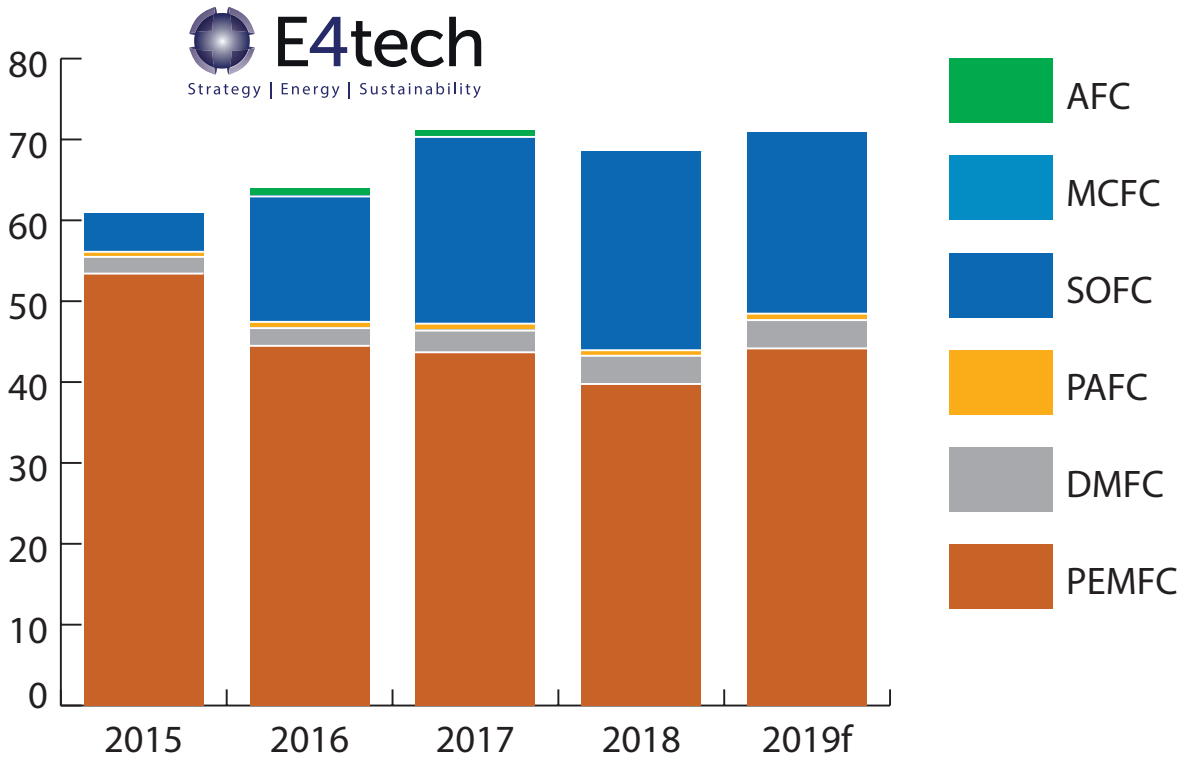
In Japan, Toyota fuel cells could power fishing boats. Boat design has started and a 19-ton prototype is expected for the start of 2020. Ocean testing is planned for 2022, and initial implementation at a tuna farm on Goto island, Nagasaki prefecture. And 'e5 tag', an electric harbour tugboat powered by fuel cells and batteries, will be developed by Tokyo Kisen and e5 Lab Co. With two 1,500 kW azimuth thrusters, the boat will have 50 t towing power and a service speed of 14 knots. Launch is planned for the Yokohama and Kawasaki ports in 2022.

The Water-go-round ferry that might have been launched in 2019 is still in build, but could still win the race to get hull in water. Construction is proceeding apace.

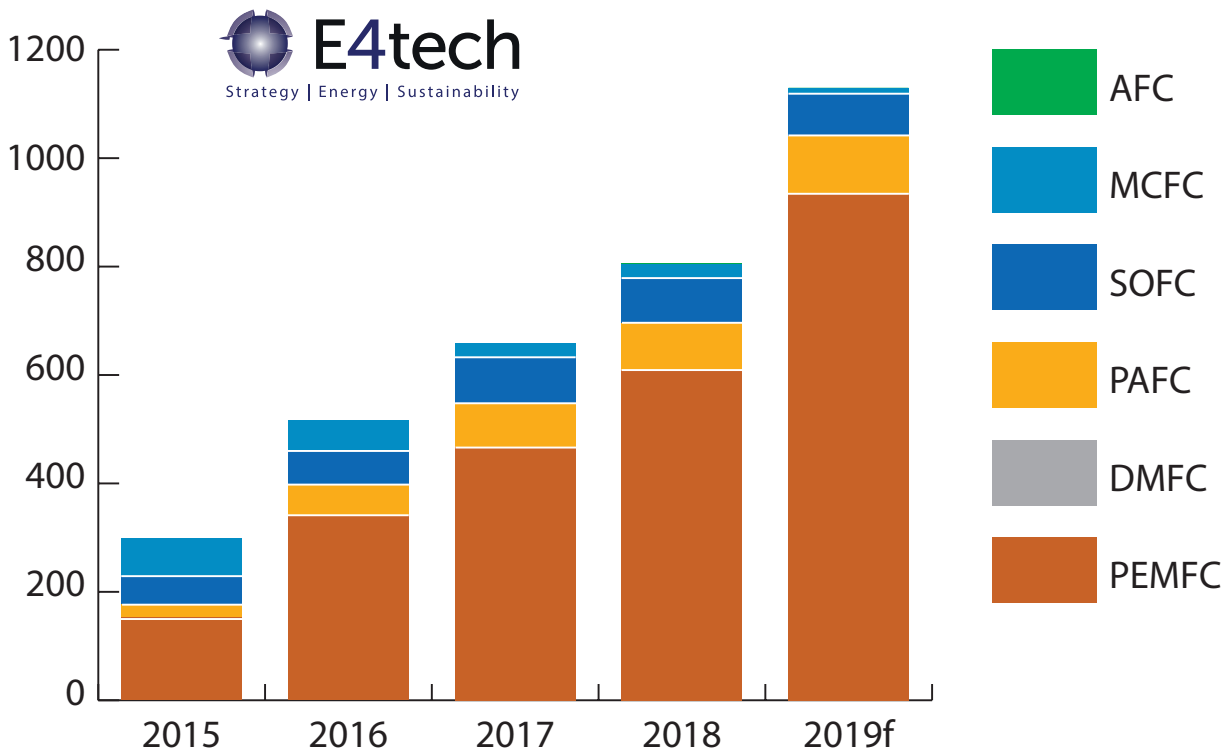


Shipments by fuel cell type

Shipments by fuel cell type 2015 - 2019 (1,000 units)



Megawatts by fuel cell type 2015 - 2019



2019f is our forecast for the full year, based on firm data from January to September.

We have revised the figures for 2018 in this report. The main change relates to the final 2018 data for Ene-farm micro-CHP units in Japan being lower than initially forecast.

Shipments by fuel cell type

As has been the case since 2014, **PEMFC** dominates shipments by fuel cell type, both in numbers (now at over 44,000 units annually) and in capacity (now at more than 900 MW). Much of the former is from Ene-Farm, and much of the latter from transportation, notably the fuel cell passenger cars of Hyundai and Toyota. The anticipated increase in shipments in the transport sector suggests we can expect further PEMFC growth ahead.

SOFC is second in terms of unit numbers, with over 22,800 shipped, mainly for stationary power and particularly domestic CHP. Much is from Aisin in Japan and SOLIDpower in Europe. The bulk of the nearly 80 MW of SOFC capacity comes from Bloom Energy in the US.

SOFC is well suited to CHP and prime power, but the agreements to incorporate SOFC stacks in vehicle applications, such as Weichai's use of Ceres Power's technology could see some future diversification.

PAFC are behind SOFC in numbers, but ahead in capacity, led by Doosan Fuel Cell shipments and followed by Fuji Electric. Altogether, we estimate over 100 MW of PAFC shipped in 2019, a 25% increase over 2018.

MCFC shipments suffered with their only supplier, FuelCell Energy. An estimated 10 MW was added in 2019, but the production lines are now ramping up again.

DMFC is expected to contribute a similar unit number in 2019 as in 2018 – around 3,700, aggregating to less than a megawatt in capacity. DMFC is used for portable charging (mainly camping, with some defence applications) and for remote small power output supplies. The sole volume supplier is now SFC Energy, though a few companies continue to explore the technology.

PBI-based solutions, which we count under PEM, continue to be developed and sold by Serenergy (focusing on stationary) and Blue World Technologies (transport), and Palcan operating from China. Current shipment numbers and capacity of the PBI-based stacks are small, even with contributions from niche suppliers such as UltraCell.

While several positive announcements were made about **AFC**, which continues to be offered by AFC Energy and GenCell, very limited shipments went ahead.



Stationary fuel cell systems

The stationary fuel cell market remains patchy. Ene-farm in Japan has more or less maintained its annual sales, and both Bloom Energy and Doosan continue to find customers. FuelCell Energy had a difficult year though, and is only at the end of 2019 picking up on back orders, having received a funding lifeline. Most sales remain dependent on government support in some form. The trend – if one can be discerned – is towards ‘commercial’ scale fuel cells. EneFarm has always been 1 kW or below, while the other companies above specialise in several hundred kW and above. Units of around 5-10 kW are now coming to the fore.

Japan remains out front

Both Government and industry in Japan have retained an extraordinary long-term commitment to fuel cells and hydrogen. Although subsidies for PEMFC systems have now run out, and are only a maximum of ¥80,000 (US\$730) for SOFC, annual installations remain close to the 45,000 mark. We count total shipments since the programme started of the order of 350,000, though according to METI only 295,000 units had requested subsidies by September 2019. The programme has been running for some time; it is not impossible that for some the small amount of government funding is not claimed.

Although the Japanese fleet of residential fuel cell systems is the world’s largest, the 2020 installation target will not be met. It would have taken an extraordinary uptick in sales to meet the originally-announced 1.4 million units. The 2030 target of 5.3 million units also seems aggressive, especially since only Panasonic and Aisin Seiki remain in the game. Panasonic is the only survivor of the original Ene-farm companies, and has probably built and sold more fuel cells than any other company on earth – something over 160,000. On an annual basis though, it is now neck-and-neck with Aisin, as SOFC systems match PEMFC in popularity. New competition may be emerging though, as Dainichi Kogyo (a Japanese manufacturing business), Kyocera and Tokyo Gas released the Ene-farm Mini in October. Sales of the SOFC CHP unit, with 400 W of power and an integral hot water tank, were due to start towards the end of the year

Panasonic’s 700 W PEM based CHP system is its fifth generation, with the PEM module now warranted for an impressive 90,000 hours life.

Aisin Seiki’s 700 W SOFC system has had fewer iterations, and is still counted as immature for the purposes of the subsidy. Both companies work directly with Japan’s main regional gas companies, who have also developed the small-scale reformer units to convert natural gas into hydrogen. Most units are sold through the gas companies. Tokyo Gas and Osaka Gas – the two largest – have sold over 100,000 systems each.

The sheer scale of the programme, coupled with never-ceasing improvements to reduce part-count and streamline manufacturing, have enabled the PEM systems to reach the target price of ¥800,000 (US\$7,350) per unit – the reason why subsidies have ceased. SOFC systems still qualify for modest subsidy as they have yet to reach the target price of ¥1,230,000 (US\$11,300). In addition, much smaller additional subsidies are available from local and regional governments.



Moving to commercial scale?

Years of development may be coming to fruition in the commercial scale sector, though installations to date remain in single figures. But with Miura’s announcement of a 4.2 kW SOFC system in October, and Kyocera’s 3 kW system coming too, 2020 may see some changes. Miura broke cover as one of Ceres Power’s Japanese OEM partners, and has been working with the UK company for several years to put its SteelCell into a system. The FC-5B system has 50% net AC and 90% overall CHP efficiencies.

Miura is Japan's largest boiler manufacturer, and is using SOFC CHP technology in developing lower emissions products. Both Denso and Hitachi Zosen have developments, but no significant announcements, and Fuji Electric continues to work on SOFC development, reported to be in the scale of tens of kW. In the meantime it has kept up some sales of its FP-100i PAFC unit.

Hydrogen rising?

As interest in hydrogen rises globally, so does the number of stationary fuel cells designed to run on pure hydrogen – particularly in Japan. At the end of 2018 Panasonic unveiled its PEM-based Hydrogen Fuel Cell Generator, a 5 kW system with a claimed 57% electrical efficiency. The first demonstration units should be in the HARUMI FLAG urban redevelopment project in Tokyo, with a system commercialisation target of 2021. Panasonic joins Toshiba and Brother in the space. Toshiba has offered its H2Rex range of systems – from 700 watts through 3.5 kW to 100 kW (using multiple 3.5 kW modules) for a few years now, for use in smaller commercial applications such as retail stores and hotels. Brother Industries has collaborated with Seiryu Power Energy and Morimatsu Industries to demonstrate a 4.4 kW pure hydrogen CHP system, the G-Force, again aimed at the commercial market.

Korea powers on

Where Japan holds the small-scale crown, Korea is a king of large-scale systems, thanks to the government's ever-tightening ratchet on the power market, which forces ever-greater amounts of renewables – and fuel cells – to be deployed. Korea's installations are already around 300 MW, with the world's largest fuel cell park operated by Gyeonggi Green Energy, with 59 MW of FuelCell Energy/POSCO MCFC systems. Scaling up further, an MoU for a 200 MW plant at Gangdong industrial complex was signed in March between Korea West Power, Korea Nuclear and Hydro, Gangdong Energy and Gyeongju City.

Growth in recent years has ramped up. And it needs to: Korea's Hydrogen Roadmap shows the Government is seeking to treble installations by 2022. And 8 GW is planned for 2040, which will require another step change in rollout, and a concerted effort by Government, industry and the energy sector to achieve.

Until 2017 the leading supplier of stationary fuel cells was POSCO, through an agreement with FuelCell Energy. However, stack life for the POSCO-supplied systems was reportedly unusually short.

The resulting costs of earlier than planned stack replacements under service agreements left POSCO nursing accumulated losses/deficit reported to be anything up to ₩1tn (US\$859m). POSCO has been trying to withdraw from the sector since 2017, and in July was reported to have finally come to an agreement with FCE to allow it do so. POSCO continues to service the installed fleet and in August renegotiated a long-term service agreement with Gyeonggi, which will set the benchmark for renewal of agreements POSCO has elsewhere.

With POSCO's withdrawal the sales of MCFC in Korea have declined, with none reported for 2019. But Doosan Fuel Cells has compensated well, with a backlog of orders for its PAFC PureCell units, and Bloom Energy's SOFC-based Energy Servers are also entering the market.

The hydrogen trend is apparent in Korea too: Doosan already has a pure-hydrogen variant of the PureCell, historically natural gas-only. And in August work started on the world's largest hydrogen-fuelled fuel cell plant, the 50 MW Seosan installation being developed by Korea East-West, Hanwha Energy and Doosan. It will use by-product hydrogen from the adjacent chemical processing plant. Other Doosan orders in 2019 include 22 MW for Korea Western Power and 5 MW from Korea Midland Power, adding to the installed capacity of ~160 MW and pipeline of 235 MW estimated in early 2019. Total sales in 2019 should top US\$400m. This could have allowed the business to post a profit, but in October it was spun off from Doosan Corporation and the new financials have not yet settled. Doosan's Global PureCell fleet in October 2019 was 306 units or 175 MW in operation, and another 554 units – 226 MW – in the pipeline.

Korean interest in hydrogen fuelled fuel cells received a further boost in October, when Hyundai and Doosan signed an MoU with Ulsan TechnoPark to establish a hydrogen micro-grid demonstration using both hydrogen fuelled PEM and PAFC fuel cell systems.

Bloom's inroads have come through agreements with Korean partners, notably Korea's SK Engineering and Construction company, where Bloom extended its cooperation through an agreement with SK D&D, the real estate and energy business. Three contracts have been reported in 2019: 6 MW for Korean Midland Power, to be located in Seoul, and two 900 kW installations for KT Corporation, Korea's largest telecoms business.

In a further deepening of its relationship, SK Engineering and Construction announced a Korean based JV with Bloom 'to develop and produce fuel cells targeting domestic and foreign customers'. Bloom gets 51% of the JV to SK's 49%.

Other Korean businesses are active too, though at a different scale. Hyundai continues its strategy to use the NEXO automotive PEM module for as many applications as possible, and in February five NEXO units were installed to generate 450 kW of stationary power for a building in Chungju, whilst in April a 1 MW system was announced for Ulsan due for completion by the end of 2019. Also new in stationary systems are companies like Hygen Power, which should start shipping residential units in 2020, and has plans for bigger systems too, and PEM units from Doosan, S-Fuelcell and HnPower.

Mixed fortunes in the USA

The USA has the most installed stationary fuel cell power in the world, primarily industrial- scale 100 kW+ units supplied by one of three US-based businesses: Bloom Energy of California and Delaware; and Doosan Fuel Cells America and Fuel Cell Energy, both located in Connecticut.

But these are installed in only a proportion of the 50 States: California, with a significant chunk, and some of the North-East States including New York, Connecticut, Pennsylvania, Delaware and Massachusetts. Each has some form of supportive regulation: strict emissions requirements, strong renewable portfolio standards and/or favourable subsidies, complementing a system of federal tax credits. In 2019 for example California's South Coast Air Quality Management District Board announced funding support for three projects: a Bloom Energy Server for the College of the Canyons in Los Angeles, a 1.32 MW system for the aquarium in Long Beach and a residential fuel cell project with SoCalGas.

Doosan Fuel Cells America is part of the newly spun-out Doosan Fuel Cell business. Along with its more recent sister plant in Iksan, Korea, the South Windsor facility also manufactures the PureCell. Estimates from earlier in 2019 suggest that Doosan had an installed base of 45 MW in the USA, including 18 MW in Connecticut, and a reported pipeline in Connecticut of 30 MW. The State has a supportive framework for procurement of environmentally friendly energy. This pipeline includes 20 MW PureCell units due to be installed as part of the new data centre at New Britain, CT announced last year. The 44 units are expected to be running in 2020.

Doosan has continued to pick up new orders this year from other Connecticut end users, including a unit for the City of Bristol wastewater facility, due to operate from late 2019 under a 20-year PPA, and potentially units for UConn and Connecticut State Colleges and Universities.



Following its flotation last year and the re-introduction of the Federal Investment Tax Credit, Bloom Energy has shipped steadily through 2019, notably from the data centre and health sectors. Bloom has end users in 11 of the 50 States in the USA, the top three being California, New York and Pennsylvania. Many are repeat customers, with Home Depot for example fielding 202 Energy Servers across the USA. Notable deals in 2019 include 37 MW of units for Duke Energy One, potentially worth US\$250m.

Duke is reported to have identified 30 sites across its customer base which could receive units over the next 18 months. Extreme Networks in Silicon Valley has also ordered units, 3.5 MW will go into Illumina's HQ in San Diego, and 2.5 MW to electronics manufacturer II-VI in New Jersey. Agilent needs 3.5 MW for facilities in California and Delaware, while Fordham University, NY and LA's Alhambra Development have signed up for 250 kW and 1 MW respectively. Bloom is now also 'upgrading' older Energy Servers, including the 30 MW with Delmarva financially supported by Southern Company. Pure hydrogen is again in the picture, with Bloom saying in June it could use it as a fuel.

Trials are also ongoing on biogas, with a 50 kW demonstration unit. Fuel from waste is a feature of a proposed deal with California Bioenergy, to use dairy cattle waste to fuel the Energy Servers.

Beyond the USA and Korea, Bloom is making small inroads into India. 4 MW of units are lined up for Energy Power of India at Shirala in Maharashtra, also to be fuelled by bio-waste.

1 MW of Energy Servers are planned for the Whitefield Tower development in Bangalore, using natural gas, which will join 3.5 MW of Bloom units at Intel in the same city.

At the end of 2019 FuelCell Energy is emerging from a dark period. It limped through the early part of the year, laying off 135 employees in April, a third of its workforce in Danbury and Torrington. But light appeared in November in the form of Orion Energy Partners, a New York-based firm specialised in providing creative debt solutions. Orion has extended FCE an 8-year, US\$200m lifeline and has warrants to buy up to 20m FCE shares. US\$80m of the loan was drawn down immediately, to support project execution. The remaining US\$120m will be available over the coming 18 months for working capital and strategic growth investments. FCE has a big backlog, with reportedly 84.5 MW of ongoing projects, and is ramping mothballed production back up to deliver them.

FCE's pipeline is wholly provided under 20-year PPAs, such as for Long Island Power Authority, and Derby and Hartford in Connecticut. Significant capital is required to fund this business model, and FCE recorded no product sales revenues over three quarters. But the loan, coupled with a 2-year joint development agreement with ExxonMobil valued at US\$60m, has changed the picture. The latter is for carbon capture technology, using the MCFC stack as a concentrator.

FCE has announced a few successes in 2019: San Bernadino has signed up to a 20-year PPA for a SureSource 1500 operating on anaerobic digester gas; in May FCE acquired Dominion Energy's 14.9 MW MCFC Bridgeport Fuel Cell Park – originally supplied and commissioned in 2013 by FCE; in April it started a two 200 kW scale advanced SOFC system demonstration supported by the US DoE Office of Fossil Energy. FCE reported 26 MW of generating assets valued at US\$156m in its Q3 results.

Europe speeds up... slowly

Deployment of stationary fuel cell systems in Europe remains slower than in Korea, Japan or the USA. Although support overall is strong, support of large-scale rollout is not yet there. So financial incentives for deployment of domestic fuel cell CHP systems tends to be for thousands not ten-thousands of units, and little exists to promote larger scale commercial and industrial systems. The most important programmes come under the European Union's public-private partnership, FCH2 JU (Fuel Cell and Hydrogen

Joint Undertaking 2) and the German KfW 433 initiative.

The FCH2 JU is funding the five-year €90m (US\$107m) PACE project, with five of Europe's domestic fuel cell CHP systems suppliers. The project is focused on stimulating the market: BDR Thermea, Bosch, SOLIDpower, Sunfire and Viessmann are collectively seeking to install 2,800 units across ten countries by 2021. Increasing unit numbers help lower costs, gain operating and maintenance experience and raise awareness. Now in its third year, PACE numbers are respectable, if not in Japan's league. About 800 units are reported installed in the 10 member countries, with a high of nearly 400 units in Belgium. Several hundred more have been ordered, and the ultimate target is for 2,800 units to be installed.

The same suppliers also benefit from the German KfW 433 programme, ongoing since 2016. End users of fuel cell systems between 250 W and 5 kWe get support of up to €28,200 (US\$33,400) in a mix of grant and output related subsidy. From the start in 2016 to the end of September 2019 almost 9,000 units had been supported. 3,403 applications were approved in the first nine months of 2019 alone. Installations trail approvals by some months.

Viessmann's next generation 750 W Vitovalor PT2 system incorporates an additional boiler and hot water cylinder, and uses a PEM module from Panasonic. Viessmann reported over 4,500 units installed across Europe, as of in June 2019, with 710 units sold under the PACE project. A SOFC based system also of 750 W will also be part of the Viessmann offer.



Sunfire offers its SunfireHome 750 W SOFC system and more than 250 are reported to have been installed, with the PACE target set at about 500. It incorporates technology from Vaillant as well as Sunfire's own SOFC stacks. These also power Sunfire's PowerPlus commercial scale systems and the smaller SunfireRemote products.



Sunfire's Neubrandenburg site, acquired with NewEnergyday in Autumn 2018, was announced as its new fuel cell centre of competence earlier this year.

SOLIDpower also introduced a next generation product, the SOFC-based BlueGEN BG15, earlier in 2019. This 1.5 kW CHP system claims 55%+ electrical efficiency and comes with a ten-year comprehensive maintenance agreement. 1,400 BlueGen units are reported worldwide. SOLIDpower should complete its Italian 25 MW production plant (50 MW with two shifts) by the end of the year, complementing its German Heinsberg facility. BDR Thermea and Bosch each offer PEM-based domestic CHP systems, and Bosch is developing an SOFC product with Ceres. Under PACE, BDR's Senertec Dachs Innogen 700 W PEM system is targeting 500 units and Bosch 650. As is increasingly the case, SOLIDpower has also announced that it will sell SOFC modules to OEM businesses and system integrators, in addition to its existing business of complete microCHP and other stationary units.

Like in Japan, commercial stationary fuel cells are just starting to get attention in Europe. The FCH JU-funded COMSOS project will field 23-25 commercial scale SOFC units of between 10-60 kW. SOLIDpower will deliver 15 x 12 kW SOFC systems, Convion two of its 60 kW C50 system and Sunfire its 20 kW system. SOLIDpower is scaling up its products and this year delivered a 25 kW SOFC system to an academic partner in Germany, joining several other SOLIDpower commercial scale units in Korea and the USA. Convion will also deliver two C50 systems to the Finnish LEMENE project, with SOFC stacks from Estonia's Elcogen. Convion is an

integrator, and has previously used IKTS/Plansee stacks, in systems delivered to the DEMOSOFC project in Italy.

The lack of commercial traction in Europe means Convion is pursuing opportunities in Asia, Korea, Japan and most recently China, markets where SOLIDpower and Sunfire already have activity. Sunfire reports two 25 kW units installed in China.

AFC Energy, quiet since its 250 kW alkaline stack went into Hamburg as part of the FCH JU-supported POWER-UP project, made a string of announcements over 2019. In April it raised £813,000 (US\$1m) in preparation for commercial deployment and secured a £4m (US\$5m) convertible bond facility, and in June raised a further £1m (US\$1.25m) as working capital. Working with De Nora, its stacks have now shown 12 months' continuous operation, targeting electrode longevity greater than 4 years. These stacks are branded as the HydroX-Cell(L) and configured in 10 kW modules for large scale industrial applications. AFC also has a new solid electrolyte-based stack, the higher power density HydroX-Cell(S), intended for both mobile and stationary applications. Both stack designs can use 'low' grade hydrogen, an advantage over PEM if not SOFC, though CO₂ must still be scrubbed out.

AFC has also developed an integrated ammonia cracker to allow fuel to be delivered to remote applications such as telecoms backup. Like one or two others, the company has started pushing a system to support electric vehicle charging. The 'H-Power' is hydrogen based. In November they raised £520,000 (US\$663,000) through a share subscription to help fund orders of the device, scheduled to launch in December in conjunction with EV charger company Rolec.

Ceres Power's licencing model has seen it add further to its OEM partnerships in 2019. In July it signed an £8m (US\$10.2) collaboration and licencing agreement with Doosan for the Korean market, where the SteelCell technology will be used in commercial scale applications in the 5 to 20 kW range.

Doosan joins Bosch, which signed a similar technology agreement with Ceres in 2019, Miura of Japan (for CHP) and Cummins of the USA. Meanwhile Ceres is commissioning its new stack manufacturing facility at Redhill in the UK, scheduled to be ready for 2020. This 2 MW capacity pilot plant will prove out production for its OEM partners, prior to building much larger plants outside the UK. Bosch is already building its own analogous unit to allow for rapid technology and know-how transfer. Ceres, too, is interested in hydrogen. To counter policy fears of obsolescence, should a move be made from natural gas to hydrogen for home heating for example, Ceres has demonstrated units running on pure hydrogen. They will also take natural gas, or mixtures of the two with no adverse effects.

European deployment of industrial sized stationary fuel cell systems, 100 kW plus, are few and far between. The FCH JU supported Electrou project has been struggling to find 1 MW+ of stationary fuel cells for the 67-acre redevelopment project at King's Cross in London. FuelCell Energy withdrew from the project, Doosan was reported to have been interested, but the search continues. This despite FCE's July announcement that it was to relaunch the sub-MW class of SureSource MCFC systems, the 250 and 400 models, which will be assembled in Germany using stacks from the USA. This was followed in October by an agreement with EOn Business Solutions, the German energy business, to work together to sell FCE's SureSource units into the European market, so now the company has adequate funding we may see significant activity in Europe into the future.

Hybrids

While over the years several companies have seen merit in developing hybrid stationary fuel cell systems – designed for industrial scale and with 60%+ efficiencies – only one remains. In principle, combining a fuel cell, usually SOFC, with a turbine generating power from the fuel cell exhaust makes great use of the energy in the fuel. In practice it is expensive and complicated to make it work. Siemens Westinghouse tried in the early 2000s, but no longer plays in the fuel cell space; GE planned an SOFC with a reciprocating engine and then spent several years trying to sell the technology and IP before finally succeeding – to Cummins – in July; and at the very end of 2018 LGFCS, the venture between Korea's LG Electronics and Rolls-Royce, terminated its own SOFC hybrid development.

Ironically so, as it had finally made enough progress to run a 5,000 hour test on a 250 kW pressurised hybrid SOFC system, supported by the US DoE. When the axe fell, the unit had run for over 1,800 hours achieving net AC of 55% and feeding power into the Ohio grid. But over 70 fuel cell jobs were cut in Canton, Ohio and Derby, UK, as both LG Electronics and Rolls-Royce 'focused on their core businesses'. So MHPS of Japan is the last entity standing. Ironically, Rolls-Royce Power Systems and Lab1886, a unit within the Mercedes-Benz group, are partnering on a pilot project using fuel cells for on-site power at data centres. Rolls-Royce, under its MTU brand name, will develop gensets using vehicle fuel cells made by Mercedes-Benz Fuel Cell GmbH, and test them in Rolls-Royce's data centre in Friedrichshafen, Germany.

MHPS' 250 kW SOFC turbine hybrid system, the MEGAMIE, has now been installed in the Marunouchi Building in Tokyo. A further order came in the spring from the Hazam Ando Corp for its Technology Research Institute in Ibaraki, with delivery in mid-2019. These join six demonstration units already in operation across Japan at various members of the MHPS development partnership, e.g., Toyota and NGK Spark Plug. The Solida fuel cells in the MEGAMIE come from a partnership between MHPS and NGK Spark Plug dating back to 2014. In July, NGK and MHPS agreed to form a JV to manufacture and sell SOFC stacks in the wider marketplace, presumably to generate additional sales. MHPS plans to grow the unit to 1 MW, and eventually to integrate it with gas and steam turbines to create utility scale power generation plants capable of electrical efficiencies of 70%+.

Staying off-grid

While fuel cells are in principle attractive for applications beyond the reach of the grid, uptake has not been as easy as once anticipated. Telecoms companies need high proven reliability, and incumbents have fought back with low prices. But some of the more resilient players remain. Chung-Hsin Electric and Machinery Manufacturing Corp (CHEM) of Taiwan acquired technology from H2PT and Ballard, and is reported to have over 3,000 system operating worldwide, primarily in Asia.

They announced a move from the original technology in April: the ME2Power methanol-fuelled systems (with reformer) will switch from Ballard technology to PlugPower's ProGen module. In September came plans for a manufacturing facility in South Africa to supply G5 ME2Power systems. VodaCom is said to have deployed 300 systems for its in-country telecoms network since 2011. CHEM is also involved in South Africa's Rural Electrification Project, to demonstrate small stationary fuel cell systems for off-grid villages. Local company HyPlat is said to be developing MEAs for these systems.

Another player is GenCell of Israel, whose alkaline based G5 and A5 4-5 kW systems are starting to sell into the telecoms and other remote markets. The company had targeted an IPO in 2019, but that has since been paused. Meanwhile in February GenCell came to an agreement with Flex Ltd which should allow production capacity to be raised from 100s of units a year to 5,000. Alteryg has a long history in the space, selling its 5 kW Freedom Power system into California, Florida and New York with over 700 units in service; Ballard has its H2PM system Hydrogenics offers the HyPM-X. PlugPower sells its GenSure E series, ranging from 200 W to 4.4 kW into the same markets. PlugPower has a reported 4,500 units in service.

The Ballard FCgen-H2PM comes in 1.7 and 5 kW variants. Reported sales are very modest, but steady revenues from these units come from Europe and Japan. And in February Ballard signed framework agreements with two Danish network operators, Eniig and Fibia, for 30 x 5 kW FCgen-H2PM units complete with hydrogen storage. These will join 125 systems currently used by the companies in Denmark. The initial 30-unit order is worth US\$1.2m, and 40-70 more are possible in 2019.

SFC Energy, which acquired hydrogen fuel cell assets and IP last year, got a framework contract from its cooperation partner adKor GmbH for the delivery of hydrogen fuel cells for radio towers in several states in Germany in October. The contract, worth up to €5.3m (US\$5.9m) runs to 2021 and will be fulfilled with 2.5 kW Jupiter systems.

Also in October, German-based Sunfire GmbH announced it is partnering with Ensol Systems, a Canadian manufacturer and supplier of off-grid power solutions, for the integration, distribution and service of Sunfire solid oxide fuel cells for the North American market, so we can expect to see an increasing share by SOFCs into the future.

Finally, Proton Power Systems, a division of Proton Motor, announced a letter of intent with Germany's APEX Energy Teterow GmbH to provide ten fuel-cell containers, with up to 150 kW of fuel cells from 2020-22. Licensing agreements allowing licensees to produce containers with up to 500 kW systems were also mentioned. Proton typically makes these container-based systems for critical systems UPS, such as rail infrastructure.



Remote, portable and military options

In principle fuel cells can outperform batteries in many off-grid applications. In practice, high costs and complex system engineering, coupled with significant increases in battery performance, have reduced the accessible market for portable fuel cells and led to company and product failures over the years. 2019 saw the end of the small 'consumer electronics' fuel cells as MyFC pulled out of the market.

Remote and portable

SFC Energy though, one of the earliest fuel cell companies, is still standing proud. It has sold over 41,000 DMFC-based systems, originally with products to trickle charge batteries for camping autonomy. The Simark subsidiary allowed it to sell into the Canadian oil & gas industry and now contributes 38% of sales. In November, Simark signed a partnership agreement with Axsera Inc. of Montreal for EFOY Pro fuel cell solutions for telecommunication applications across North America. SFC's other subsidiary PBF Group sells specialist equipment to the electronics industry. SFC successfully raised capital of €27m (US\$30m) in 2019, to accelerate organic growth in core markets, introduce newly-developed hydrogen fuel cells (the Jupiter series, with adKor) and finance further potential strategic acquisitions and investments. Full year revenue for SFC energy is expected to be around €60m (US\$71m).

Few others are chasing portable power

Other companies in the portable space include UK-based Adelan (pioneer of the microtubular SOFC design); Adaptive Energy (formerly USSI, and before that AMI, with a range of SOFC products for ground-based and UAV systems); and Upstart Power (formerly Protonex, with its developmental SOFC). In 2019, Ballard sold the erstwhile Protonex power manager business to Revision Military. SAFCell continues to make progress, working alongside UltraCell, and Imperial/UCL spin-out Bramble Energy is aiming to sell its PCB-based PEM stack design into portable and perhaps other markets, as it matures.

Adelan has been through difficult periods, but has expanded team and premises. It has developed a small generator system trialled with UK clients and has two projects in China, one an SOFC-powered UAV. Adaptive Energy has sold hundreds of lightweight SOFCs for ported remote power supplies and UAVs. SAFCell is looking for US\$10m to scale up and launch its 50 W system to 1 kW, allowing access to oil and gas and telecoms markets) and to continue its development of military JP-8 fuelled systems. Bramble Energy should launch its first commercial 20 W product with BOC in H1 2020 and is looking for A Round capital, to scale up their stacks.



Re-packaging, the way ahead?

Outside the military space (where fuel cells are now used for missions exceeding 12 hours), the path is strewn with companies and products that tried and failed to compete with batteries. So companies like MyFC (with its latest LAMINA-MAX) are now seeking to license their designs to produce large automotive fuel cells. And quite small portable fuel cells can be repackaged for remote/off-grid use (often in an environmental enclosure). The EcoCabinet is such an example, for SIQENS' methanol-fuelled Ecoport 800. In January, Autobahndirektion Nordbayern, the motorway maintenance agency, purchased one to power video cameras. Similar repackaging is used by Adaptive Energy and by SFC. BOC has never sought to repackage, instead using small fuel cells and long-lasting hydrogen canisters to target off-grid customers needing long run-times, low noise, or low emissions. Like Taylor Construction Plant, which supplied a TH200 lighting tower for use in Essex Highways' Heybridge storage depot.

UAVs, the new forklifts?

Forklifts were one of the earliest commercial markets for fuel cells, which really did outperform batteries. UAVs offer similar characteristics. As the UAV or drone market grows, with new uses on an almost daily basis, fuel cells are increasingly used as their power sources. They can deliver longer runtimes, save recharging time and reduce the required fleet of vehicles for a given area. Dam and pipeline monitoring, mapping, and watching for forest fires or wildlife poachers are all drone-friendly tasks.

The fuel cells being sold into this market are now an integral part of the UAV rather than a bolt-on. This degree of integration is championed by Doosan Mobility (retained by its Doosan parent when the PAFC business was spun off) and Horizon Energy Systems.

Doosan flew a UAV for 2 hours in February (the battery version lasts 30 minutes); it is now being used by power company KEPCO to inspect transmission lines. In the first quarter of 2019, Intelligent Energy demonstrated a micro-UAV carrying a 5 kg payload (including a 6-litre compressed hydrogen tank) for 70 minutes. Weight is critical; a liquid hydrogen storage tank (more hydrogen per weight of tank) from MetaVista of Korea yielded over 10 hours of uninterrupted flight time. IE has also launched its Power Path Module, to allow 800 W stacks to be linked together for larger UAVs.

In April, a 4.8 kW drone using an AMS Composite Cylinder delivered 2-hours' flight time. In July, BM Power of South Africa demonstrated 3.5 hours flight time for a 2.1 kW UAV.



The larger players are also involved. In April, Ballard Unmanned Systems, a subsidiary of Ballard, launched its FCair™ product line: comprising liquid-cooled stacks rated at 600 and 1200 W, a lightweight 420 bar tanks and regulators, and built-in hybrid battery control and charging.

In June, Plug Power acquired Canada-based EnergyOr, with its lightweight fuel cell platform for UAVs and UGVs, which will open new markets for Plug as well as opening a door for integration of the stacks into Plug Power's ProGen fuel cell engines.

Companies like Alaka'l Technologies (with its Skai) and ZeroAvia, working with Intelligent Energy, are now seeking to apply fuel cells to small passenger-carrying aircraft, an altogether more difficult challenge.

Military applications

Fuel cells are slowly diffusing into military uses, as charging platforms, for missions requiring silent watch, and for missions of long duration where pure batteries are impractically heavy. Fuel cells have high fuel energy density and can continually recharge at small scale.

SFC Energy remains dominant on land, with products well-enough regarded to be assigned a NATO stock number. About 15% of SFC Energy's revenues now comes from its defence sales, two-thirds outside Germany. February 2019 saw an order of €1m (US\$1.2m) for JENNY fuel cells, from an Asia-based defence procurement agency, and another of €1.4m (US\$1.7m) for a mix of JENNY, EMILY and power managers in May.

A further target application is tactical generators of 1 kW or more, where high efficiency fuel cells could require less fuel. Precision Combustion continues to develop JP-8 fuelled SOFC generators of 1-10 kW with US DoD support.

Atrex also demonstrated a 1.5 kW SOFC system on JP-8 in 2019. SAFCell, targeting 1 kW JP-8 fuelled generators, relies on its inherent high stack temperatures for higher tolerance to CO and hence more fuel flexibility.

Finally, in October 2019, naval ship builder thyssenkrupp Marine Systems (TKMS) unveiled its 4th Generation Fuel Cell (FC4G) for submarines in Kiel, after completing an extensive test programme with more than 70,000 operating hours in the real-world environment, a testament to the durability of fuel cells. The proposition here is silent running for extended periods, without the cost and safety implications of nuclear propulsion.

Remote working?

Difficult environments suit fuel cells more than batteries. The biosphere recording assembly at Prins Karl Forland islet off Svalbard is SFC fuel cell-powered, and needs a single replenishment of methanol fuel a year. Oil and gas pipeline monitoring in cold and remote areas is done by fuel cells. In January, SAFCell completed an eight-month field trial of their remote methanol-fuelled power system at a Shell Canada well site in Rocky Mountain House, Alberta.

Telecoms fuel cells are commonly for remote backup power, but near Dettelbach, Germany, bio-methanol fuel and a high temperature PEM fuel cell system from HYREF provides 9-months' continuous runtime from a 3,000 litre fuel tank.



Understanding China?

A lot is going on China. Exactly what is happening, how fast, where and with what result is harder to divine. The anticipated roll-out of hundreds of buses and trucks in many cities and regions remains behind schedule, but should still happen. But the Government has confirmed that the currently generous subsidy scheme will diminish, along a previously-announced trajectory. The first step was a 20% reduction for all vehicles, and the rumour-mill suggests that support will be redirected from the vehicle manufacturers to component suppliers and end-users.

Are fuel cells different?

One concern about the current system seems to be the large amount of money spent, for apparently limited impact. A ministry website suggested 'addiction' to subsidies amongst some manufacturers, making it difficult for the companies to compete globally. In this, the fuel cell sector probably suffers in comparison with previous Chinese Government technology push. Solar PV, wind power and even batteries were considerably more mature industries before China decided to adopt them. Development needs were mainly in manufacturing scale-up. Fuel cells, however, are still a maturing technology. Every technology generation is significantly different from the last, and different manufacturers adopt quite different strategies. The supply chain is evolving, and know-how remains as important as patents in the production cycle. In addition, the sector suffers from a lack of human capital. China has been scouring the world to attract experienced overseas fuel cell talent – with some success – but there is just not enough experience to go round.

This means that China has not been able to pick up an established industry and advance it. The money that flooded into the system has encouraged dozens of speculative start-up enterprises to join the established and powerful players. Some are well-funded and impressive; others a severe distraction. Which suggests that some of the support so far really has missed its target. Frustratingly though, China has succeeded in developing some good engineering skills and is starting to develop indigenous technology – it's just not on the roads and so not very visible. Companies like Dongyue and Weichai are globally significant and very well placed. SAIC and Great Wall Motors have good internal capabilities. And many other parts of the supply chain are strongly represented too.

But the refocusing of subsidies may help in weeding out the less strong – in many instances Chinese technology has not performed well, and rebadging of overseas technology is not unknown.

Two companies have successfully claimed subsidies for vehicles on the road: Re-Fire and SAIC. The process is not for the faint-hearted: only vehicles that have completed 20,000 km on the road are eligible, and Re-Fire received its cash in October 2019 for a claim submitted 12 months earlier, and following onsite verification by officials. The Re-Fire payout was for 114 trucks linked to Dongfeng, and SAIC received cash for 20. That's of course far fewer than there are vehicles on the road: SAIC alone claimed to have sold a cumulative 305 Maxus vans from January to September.

Roadmaps and White Papers continue to be published and updated, though specific numbers remain absent from national government policy. 1m vehicles on the road by 2030 has been repeated enough times to sound like de-facto policy however. In its white paper, The China Hydrogen Alliance suggested 1.3m vehicles by 2035 and 5m by 2050, which remains small in the grand scheme of China's vehicle parc.



The regions compete

The overheated growth phase may be slowing, but regional competition remains important. Jiangsu, Hebei and Tianjin provinces have released or updated plans, as have cities like Ningbo, Chengdu, Guangzhou, Fuzhou and Jiaxing. Some cities continue to provide generous support, such as Zhangjiagang in Hebei, where companies are given a handout to locate in the city. It may be that cities and regions are positioning themselves should another rumour come true – that fuel cell and hydrogen development may be limited by decree to only a few areas.

That might stop the free-for-all, reduce dilution of investment, and enable enough focus to get the industry off the ground.

Industry remains an important driver

Nothing happens in China without National Government approval, tacit or overt. But China has both giant corporations and agile entrepreneurs to build industries. Of the former, Sinopec is becoming more active – building some fuelling stations (including ones where hydrogen and conventional fuels are dispensed side-by-side), signing an MoU with Air Liquide on accelerating hydrogen mobility, and investing in Re-Fire. Weichai is building an ‘industrialisation plant’ for CNY 10.6bn (US\$1.5bn), while Great Wall is locating its hydrogen HQ in Shanghai (Jiading). Meijin Energy Group has increased its investment in SinoHyKey to 51%, pumping in an additional CNY 100m (US\$14.5m); and now owns 10% of SinoSynergy. It also owns 51% of Feichi – a bus maker which delivered 190 buses to Foshan and 3 to Kuching in Sarawak, Malaysia; the first Chinese fuel cell vehicle export that we know of. Vision Group acquired nearly 6% of bipolar plate supplier Shanghai Hongfeng, and Dalian Institute of Chemical Physics, one of the founding owners of Sunrise Power, sold its nearly 18% stake to an automotive supplier. Once one of the leaders in China, Sunrise has gone through a difficult period with staff and IP becoming part of Shanghai Hydrogen Propulsion Technology through another owner, SAIC.



Horizon made some big announcements, claiming a novel high power density bipolar plate design, a 370 kW fuel cell designed specifically for heavy-duty, and “the world’s largest fuel cell heavy truck rollout”. At least 2,000 x 42 t trucks

should be deployed over the next few years, in partnership with Jiening New Energy and built by Ford JV JMC. Twenty of those are on the way. Meanwhile, Wuhan Tiger is developing 80 kW systems for 18 t trucks with Jiangling Motor, and has agreements with Lifan Group, Hengtian LingRui and Chongqing Guoneng for vehicles including buses. Grove, operating rather under the radar until recently, laid its claims for a 5,000 vehicle-capacity plant to come and Aaways’ link to Denmark’s Blue World continues, with the latter announcing a Shanghai subsidiary.

Take your partners...

Many Chinese and overseas companies are pairing up. Toyota is now supplying fuel cell stacks and components to companies and collaborations including Re-Fire, Suzhou King Long, Higer and FAW, and has an agreement with GAC Group in Guangzhou. Powercell is setting up a Shanghai office. Horizon is not only linked to Ford via JMC, but announced a material handling company in the US back in February, in partnership with Dallas company Off Grid Logistics. Changan has teamed up with the UK’s Intelligent Energy, which will integrate its fuel cells into Changan SUVs. IE also has a three-way agreement with Hynertech and the Hubei-based Tri-Ring Group. BASF, which has continued to work on its high temperature PBI membranes, is linked with BLEST and PBI-specialist start-up Kun Ai. Weifu High Technology now owns 66% of Denmark’s IRD Fuel Cells, bought from FCCTApS – a special purpose vehicle of Troowin – for just over €7m (US\$8.3m). UK-based air compressor maker Aeristech agreed a technology transfer with Easyland Group, who will build a CNY 100m (US\$14.5m) plant to supply automotive industry players. Targets include SAIC, FAW, BYD, Lifan and others.

Chinese components

Chinese component manufacturers are racing to build out capacity too: WUT New Energy scaled its MEA line up to 20,000 m² per year, while Hydrogine claimed the first production of direct-coated roll-to-roll MEAs. SinoHyKey commissioned its own MEA line. AMT said it had started supply of metal bipolar plates to stack makers, and some movement is afoot in on-board storage too, with 70 MPa cylinders starting to be integrated into vehicles. Silinda Anke will produce high pressure composite cylinders for SAIC. And other stack developers include Foresight, which released its 76 kW stack and gained a CNY 45m (US\$6.5m) order from companies related to its parent Weichai; Troowin, developing a 120 kW metal-plate stack; Innoreagen, which is working on stacks from 1-80 kW; and Vision Group’s 87 kW system.

Looking forward: 2020

The trends from 2019 will be stronger in 2020. Global drivers for hydrogen are increasingly reinforced by big corporate engagement, and 2020 should see well over this year's capacity shipped, and possibly even double. Considering the China backlog and other transport OEMS – car, bus and truck – and PEM shipments will almost certainly hit this year's magic number for the whole industry. In an aggressive scenario, Hyundai alone might manage 1 GW.

Stationary shipments are likely to be up on 2019, with FuelCell Energy, in particular, looking to get their production capability back up to capacity. Smaller-scale systems will also be on the increase, as recent Korean government regulations in buildings start to bite, with – potentially – hundreds of related installations anticipated.

At the same time, cluster development is in vogue. On top of the FCH JU's funding for a Netherlands 'Hydrogen Valley', NOW in Germany has announced three in Germany. A 'Valley' is a mix of different hydrogen and fuel cell applications built together as a regional cluster, all co-ordinated to maximise system benefit. This will not trigger large shipments in 2020, but will lay groundwork for future years: building infrastructure, ensuring the safety case is made, and raising public awareness. In the US, fuelling infrastructure and cars will start to populate some North-East States.

Little of scale is expected from automotive companies aside from Toyota and Hyundai, as they will remain heavily focused on getting sufficient BEVs on the road to meet 2021 EU targets. Expect more scrutiny of resource extraction, recycling and charging infrastructure business models.

A wild card is the GM/Honda plan to start their manufacturing plant in the USA. But fortunately, buses will keep coming along, especially in Europe and Asia, along with tens of heavy trucks and a ferry or two. All of this, supported by the increasing engagement of bigger companies all along the supply chain, suggests that the capability to deliver robust and mass-market fuel cell systems will be noticeably reinforced.

In turn, this investment by supply chain companies will reinforce the value creation narrative starting to be laid out: how fuel cells and hydrogen can support jobs and local, regional or national economies. At the same time we anticipate more focused market entry strategies by a wider range of companies, including those only just hearing about the sector.

This emphasis on supply chains from both companies and politicians will influence the funding mechanisms available. In China, signals are being sent that component suppliers may be supported rather than end users. In Europe, the discussion around the successor to the FCH JU is already cast in terms of value creation and environmental improvement. The climate imperative taken up by the incoming Commission will have positive knock-on effects in the sector. The eventual follow-on to the FCH JU is likely to have more of the same programmes, with the emphasis shifted towards hydrogen production and roll-out of bigger projects.

Tokyo's 'hydrogen Olympics' will be an important global showcase, but otherwise it seems likely that the flow of projects, products and information will start to overwhelm. That's good news of course, and we'll do our best to stay on top of it!

On the corporate side, more merger, acquisition and investment activity is likely. And even financial investors are getting back in the frame, for both established and start-up organisations.

Will shipments next year really hit 2 GW? Maybe. But even if not all things go to plan, the trajectory will be firmly and strongly upwards.



Data tables

Shipments by application					
1,000 Units	2015	2016	2017	2018	2019f
Portable	8.7	4.2	5.0	5.7	3.9
Stationary	47.0	51.8	54.9	51.9	51.7
Transport	5.2	7.2	10.6	10.9	15.3
Total	60.9	63.2	70.5	68.5	70.9

Shipments by region of adoption					
1,000 Units	2015	2016	2017	2018	2019f
Europe	8.4	4.4	5.1	7.7	9.7
North America	6.9	7.7	9.4	9.3	8.6
Asia	44.6	50.6	55.3	50.9	52.3
RoW	1.0	0.5	0.8	0.6	0.3
Total	60.9	63.2	70.5	68.5	70.9

Shipments by fuel cell type					
1,000 Units	2015	2016	2017	2018	2019f
PEMFC	53.5	44.5	43.7	39.7	44.1
DMFC	2.1	2.3	2.8	3.7	3.7
PAFC	0.1	0.1	0.2	0.2	0.3
SOFC	5.2	16.2	23.7	24.9	22.8
MCFC	0.0	0.0	0.0	0.0	0.0
AFC	0.0	0.1	0.1	0.0	0.0
Total	60.9	63.2	70.5	68.5	70.9

2019f is our forecast for the full year, based on firm data from January to September.

We have revised the figures for 2018 in this report. The main change relates to the final 2018 data for Ene-farm micro-CHP units in Japan being lower than initially forecast.

Data tables

Megawatts by application					
Megawatts	2015	2016	2017	2018	2019f
Portable	0.9	0.3	0.6	0.7	0.6
Stationary	183.6	209.0	222.3	220.6	221.2
Transport	113.6	307.2	435.7	584.5	907.8
Total	298.1	516.5	658.6	805.8	1,129.6

Megawatts by region of adoption					
Megawatts	2015	2016	2017	2018	2019f
Europe	27.7	27.4	38.9	41.2	68.6
North America	108.4	213.6	331.8	425.3	384.1
Asia	159.7	273.8	285.8	337.9	676.7
RoW	2.3	1.7	2.1	1.2	0.2
Total	298.1	516.5	658.6	805.8	1,129.6

Megawatts by fuel cell type					
Megawatts	2015	2016	2017	2018	2019f
PEMFC	151.8	341.0	466.7	609.0	934.2
DMFC	0.2	0.2	0.3	0.4	0.4
PAFC	24.0	56.2	81.0	86.3	106.7
SOFC	53.3	62.9	85.2	84.1	78.1
MCFC	68.6	55.7	24.7	25.8	10.2
AFC	0.2	0.5	0.6	0.1	0.0
Total	298.1	516.5	658.6	805.8	1,129.6

2019f is our forecast for the full year, based on firm data from January to September.

We have revised the figures for 2018 in this report. The main change relates to the final 2018 data for Ene-farm micro-CHP units in Japan being lower than initially forecast.

Notes

- Data for 2014 to 2019 have been collected directly from fuel cell manufacturers and integrators where they were able to share it. For those who were not able to share primary data, and to sense-check our numbers, we have collected and cross-referenced data from publicly available sources such as company statements and statutory reports, press releases, and demonstration and roll-out programmes, in addition to discussions with other parties in the supply chain.
- Our 2019 figures are a forecast for the full year. The dataset contains firm numbers for the period January to September 2019 (and in a very few cases to October 2019), and for the remaining period we use companies' own forecasts, shared with us, or ones we prepare in discussion with industry.
- We will revise data for 2019 in our 2020 edition as appropriate. We have slightly revised the figures for 2018 in this report: Unit numbers were reduced by about 8% and megawatt numbers increased by 0.3% compared to our published 2018 forecast. Unit numbers are rounded to the nearest 100 units. An entry of zero indicates that fewer than 50 systems were shipped in that year.
- Megawatt numbers are rounded to the nearest 0.1 MW. An entry of zero indicates that less than 50 kW was shipped in that year.
- The reported figures refer to fuel cell system shipments by the final manufacturer, usually the system integrator. In transport we count the vehicle when shipped from the factory.
- We do not count replacement stacks in existing applications, and where possible we also do not count inventory, only systems that are shipped to users.
- Portable fuel cells refer to fuel cells designed to be moved. They include small auxiliary power units (APU), and consumer electronics (e.g. phone chargers). Toys and educational kits are not reported.
- Stationary fuel cells refer to fuel cell units designed to provide power at a 'fixed' location. They include small and large stationary prime power, backup and uninterruptable power supplies, combined heat and power (CHP) and combined cooling and power. On-board APUs 'fixed' to larger vehicles such as trucks and ships are also included.
- Transport fuel cells refer to fuel cell units that provide propulsive power or range extender function to vehicles, including UAVs, cars, buses and material handling vehicles.
- Our geographical regions are broken down into Asia, Europe, North America and the Rest of the World (RoW), including Russia.

Shipments by fuel cell type refer to the electrolyte. Six main electrolyte types are included here. High temperature PEMFC and conventional PEMFC are shown together as PEMFC. Other types of fuel cells currently in an early stage, such as microbial fuel cells and solid acid fuel cells, are not included in the numbers shown.

About E4tech and the authors

Since 1997, E4tech has helped clients to understand and profit from opportunities in sustainable energy, with deep expertise and long experience in many sectors, and in the energy transition. Fuel cells and hydrogen are particular areas of strength, and we have carried out hundreds of projects for early stage companies, SMEs, large companies, financiers and governments worldwide. These projects include:

- market forecasting and competitor analysis
- business plan development and strategy
- technical and commercial due diligence
- support for policy development. See www.e4tech.com.

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



Prof David Hart is a Director of E4tech, responsible for the Fuel Cell and Hydrogen Practices. In 25 years in the sector he has been an expert adviser, consulted and carried out research for national governments, major industrial companies, start-ups, financial organisations and NGOs. He has been an invited keynote speaker at conferences on six continents.



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

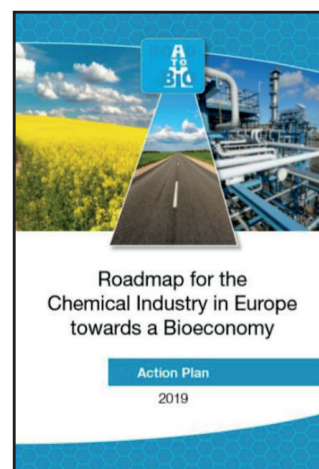
Dr. Stuart Jones is E4tech's Energy Technology Knowledge Manager. He has extensive industry experience with fuel cells, hydrogen and battery technologies.



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



E4tech has conducted numerous influential analyses in the fuel cells and hydrogen energy space, in addition to renewable and bio-based fuels and chemicals; batteries and other energy storage; low carbon transport, innovation policy and support and sustainability more broadly. Examples of our public work can be found at www.e4tech.com. Selected examples are below:

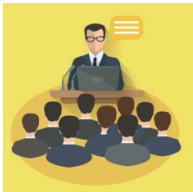


We would also like to acknowledge the helpful support of the Working Group Fuel Cells of the German VDMA (Verband Deutscher Maschinen-und Anlagenbau, or German Mechanical Engineering Industry Association). The VDMA carries out a survey on the German fuel cell industry and is kindly assisting us in liaising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

Can we help?

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

Our services include:



Bespoke Expert Briefings

– Would you like a focused discussion on the detail of the **fuel cell sector** or the whole breadth of **hydrogen energy** for your **team** or your **Board**?

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

Market and Supply Chain Analyses

– Are you looking for something better than the generic **fuel cell market forecasts** typically available? We can build **bespoke forecasts** for **regions, applications** and **components**

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

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



Commercial and Technical Due Diligence Evaluations

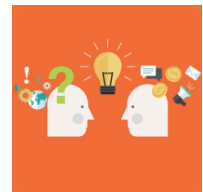
– Are you thinking of **investing** in or **acquiring** a technology or company?

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

Business and Strategy Support

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

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



Objective Review and Expert Resource

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

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

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

Picture Credits

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12	Yamaha YG-M FC prototype personal mobility FCEV	Yamaha Motor Co., Ltd.
12	Handal HyPER fuel cell concept race car	Handal Energy Solutions SDN BHD
13	Hyundai NEXO in Vancouver	David Hart
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18	Geely F12 fuel cell bus (Yuang Cheng brand)	Zhejiang Geely Holding Group Co., Ltd.
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21	Nikola Two fuel cell truck	Nikola Corp.
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28	Linde hydrogen fuel cell forklift	Linde Material Handling
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30	Water go-round ferry in build	Dr. Tim Lipman
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35	PureCell Model 400 PAFC system	Doosan Fuel Cell Co., Ltd.
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37	Zero emission H-Power BEV charger system	AFC Energy plc
39	FCgen-H2PM stationary PEM system	Ballard Power Systems
40	H2O 20 W portable power unit	Bramble Energy Ltd.
41	BFD H2-6 multi-rotor UAV, with FCair-1200 fuel cell	Ballard Power Systems
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43	Grove fuel cell passenger car	Grove Hydrogen Automotive Co., Ltd.
44	Foshan Feichi FCEB in Sarawak, Malaysia	Foshan Feichi Automobile Manufacturing Co., Ltd.
45	Toyota Mirai sedan FCEV concept	Toyota Motor Corporation

Note on currencies:

The following exchange rates can be used as guidance to convert currencies mentioned in this report. These are the average mid-point exchange rates from 30th November 2018 to 30th November 2019.

US\$1 = € 0.8917	€1 = US\$ 1.2716	1£ = US\$ 1.2727	1¥ = US\$ 0.0092
US\$1 = £ 0.7862	€1 = £ 0.8817	1£ = € 1.1347	1¥ = € 0.0082
US\$1 = ¥ 119.24	€1 = ¥ 122.53	1£ = ¥ 139.06	1¥ = £ 0.0072



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