Strategy | Energy | Sustainability

The Fuel Cell Industry Review 2020

ACKNOWLEDGEMENTS

We gratefully acknowledge the contribution of many individuals and companies within the fuel cell industry in providing information for and assistance with the compilation of the Fuel Cell Industry Review 2020. The Fuel Cell Industry Review 2020 is based on shipment information between October and December and news items up to December.

LIST OF ABBREVIATIONS

AFC – Alkaline Fuel Cell
APU – Auxiliary Power Unit
BEV – Battery Electric Vehicle
BOC – British Oxygen Company (Linde subsidiary)
BOS/BOSNet – TETRA based digital radio system in Germany
BMW – Bayerische Motoren Werke AG
Capex – Capital Expenditure
CARB – California Air Resources Board
CEA – French Alternative Energies and Atomic Energy Commission
CHEM – Chung-Hsin Electric and Machinery Mfg Corp
CHP – Combined Heat and Power
CNG – Compressed Natural Gas
COVID/COIVD-19 – Coronavirus 2019 (SARS-CoV-2)
DKTI – German Climate Technology Initiative
DMFC – Direct Methanol Fuel Cell
DMI – Doosan Mobility Innovation
EFOY – Energy For You (SFC Energy fuel cell products)
EMU – Electric Multiple Unit (train)
ENOVA – Norwegian government enterprise responsible for promotion of environmentally-friendly production and consumption of energy
EVs – Electric Vehicles
FC – Fuel Cell
FCE – FuelCell Energy (USA)
FCEB – Fuel Cell Electric Bus
FCEV – Fuel Cell Electric Vehicle
FCH JU – Fuel Cells and Hydrogen Joint Undertaking (EU)
FCT – Fuel Cell Today
GE – General Electric
GM – General Motors Company
GW – Gigawatt
HDV – Heavy Duty Vehicle (trucks, sometimes also applied to buses)
HRS – Hydrogen Refuelling Station
ICE – Internal Combustion Engine
IE – Intelligent Energy
IP – Intellectual Property
IPO – Initial Public Offering
ISO – International Organization for Standardization
JIVE – Joint Initiative for hydrogen Vehicles across Europe
JLR – Jaguar Land Rover
JV – Joint Venture
kFW 433 – Förderung für das Heizen mit Brennstoffzelle (German national mCHP programme)
kW – Kilowatt
LH2 – Liquid Hydrogen
LNG – Liquefied Natural Gas
LPG – Liquefied Petroleum Gas
M&A – Mergers & Acquisitions
MCFC – Molten Carbonate Fuel Cell
METI – Ministry of Economy, Trade and Industry (Japan)
MoU – Memorandum of Understanding
MW – Megawatt
NASA – National Aeronautics and Space Administration (US)
NEV – New Energy Vehicle (authorized battery and fuel cell vehicles in China)
OEM – Original Equipment Manufacturer
Opex – Operational Expenditure
PACE – Pathway to Competitive European FC mCHP market
PAFC – Phosphoric Acid Fuel Cell
PEM(FC) – Polymer Electrolyte Membrane (Fuel Cell)
PILOT-E – Norwegian funding scheme for clean energy innovation
POSCO – (formerly Pohang Iron and Steel Company), a South Korean steel-making company
PPA – Power Purchasing Agreement
PSA – Peugeot S.A.
PV – Photovoltaic
R&D – Research and Development
Ro-Ro – Roll-on/Roll-off (ferry)
RoW – Rest of the World
RVK – Regionalverkehr Köln public transport agency (Germany)
SK – Saskatchewan
SOFC – Solid Oxide Fuel Cell
SPAC – Special-Purpose Acquisition Company
SUV – Sports Utility Vehicle
TESS – Toshiba Energy Systems & Solutions Corp.
UAV – Unmanned Aerial Vehicle
UGV – Unmanned Ground Vehicle
UPS – Uninterruptible Power Supply
US – United States
UTC – United Technologies Corp.
UTR – Utility Tractor Rig
VTOL – Vertical Take-off and Landing (aerial vehicle)
W – Watt

March 2021

Table of contents

An industry chasing the Zeitgeist

Despite the title of this publication, we've said before that the fuel cell 'industry' is not a single industry at all. As those inside it know, it is divided by different materials, stages of maturity, applications and regions – all contributors to the fact it has taken time to get going. But it does seem to be getting traction. Part of that is down to decades of hard work and investment in R&D, technology improvement, and demonstrations. Thankfully, part of it is also down to changes in external conditions. Improving air quality is increasingly non-negotiable. Reducing greenhouse gas emissions likewise. And all while maintaining economic development and opportunity.

The growth spurt of the battery industry, allied with some of the drivers above, has catalysed thinking in where and how fuel cells can fit. Countries and regions which did not support batteries early on are scrambling to catch up and wish not to risk a repeat of their errors with fuel cells. So, support is being targeted at industrial development and competitiveness as well as solving societal problems. Which in turn is helping industry to decide on and take investment steps: Weichai's 20,000 unit per annum PEM factory in China; Daimler and Volvo setting up their fuel cell truck JV; CHEM Energy building a factory for remote systems in S Africa.

There have been missteps, some of them major. Nikola's well-publicised descent from high-valued upstart did not help the company, though ironically it may have helped the industry, by reinforcing the need for caution and deep due diligence by investors. It hasn't stopped the big deals from going ahead though – Plug Power moving to become an end-to-end 'hydrogen economy' player through acquiring Giner electrolysers and United Hydrogen; Michelin and Faurecia's tie-up with Symbio producing the fuel cells for PSA commercial vehicles; Bloom's tie-up with SK E&C pushing towards renewable hydrogen as well as fuel cell power, by returning to Bloom's electrolyser roots. The teaming up of unexpected bedfellows like Trafigura and H_2 Energy in Switzerland further illustrates the zeitgeist – lower carbon, cleaner air, sustainable hydrogen.

The other major shaper of 2020 has been COVID, of course. Numbers of fuel cells shipped would potentially have been much higher had it not been for the drag effects of the pandemic: slowing supply chains and production at one end, and of course curtailing demand at the other.

Nevertheless, most of the year's numbers were up over 2019: nearly 82,500 units were shipped, or about 10,000 more than the year before. MW were up by about 100 to 1,300 MW. Over 50,000 fuel cell micro-CHP units went to Japan and Germany, and Korea looks set to deploy more. Hyundai shifted about 8,500 NEXO cars; Toyota paused while the new Mirai was prepared and finally launched at year end. Materials handling was up too, with Plug Power announcing shipments up from around 6,000 to more like 10,000 units year-on-year.

Conversely, China slowed down. Our estimate for 2019 turned out to be low, and 2,700 units were shipped by year-end, which nearly halved in 2020 – we think only 1,400 or so were delivered. This is easily explained though – Chinese policy has changed. Most of 2020 saw a limbo where – although strong signals of the changes had been sent – nothing was set in stone until very late. Now that support for supply chain end selected regions is confirmed there will be much more to come, with 50,000 vehicles intended to be on Chinese roads by 2025. That will help keep Weichai's production line busy, but also less well-known players such as Unilia – the merger between Vancouver's OverDrive and Shanghai Cosmic Chemical Technologies.

Heavy-duty remains a sector where fuel cells can help. Buses remain the trailblazer, with hundreds in Europe and hundreds more to come. Optare in the UK partnered with Arcola Energy to develop a double-decker, and Bamford continued to push its Wrightbus investment. Caetano in Portugal is using its Toyota supply partnership to deliver buses into different fleets. China continues to lead though, and in an interesting twist Nanjing announced, in April 2020, a plan to replace all of its battery buses with range-extender fuel cells.

Most of the global truck manufacturers have also adopted some form of fuel cell strategy, from Daimler and Volvo through CNH, Hyundai, Hino and North American providers like Navistar. As CNH points out, large long-haul units are a disproportionate contributor to CO_2 emissions from trucking, and a solution there, with a limited number of strategically placed refuelling stations, could cover a lot of Europe's needs. Hyzon Motors, a new name based on Horizon Fuel Cells expertise, arrived on the scene too, aiming at trucks and buses globally, at high-power single stacks of 370 kW, and with an initial production agreement with Dutch systems integrator Holthausen.

Scale up further and fuel cells may play in off-road vehicles in construction and mining, though here the competition changes – not batteries but hydrogen ICEs are aiming for the same markets. Non-traditional specialists are helping the incumbents here, such as Williams Advanced Engineering (yes, the people who started in Formula One) working with Anglo American and Fortescue Group. Weichai has also developed a vehicle in partnership with China's CHN Energy Group and CRRC Yongji.

Marine developments continue too, though most remain at the project stage, rather than early commercial fleets. Still, PEM players such as Ballard, Nedstack, Powercell and Proton Power have all taken maritime orders, Hyundai of course has its own ship company, and Toyota's partnership with the Energy Observer round-the-world educational yacht has evolved into a solutions company called Energy Observer Developments. Ballard has even set up a dedicated marine centre in Denmark.

Fuel cell shipments are ever more dominated by PEM and SOFC, though Doosan is keeping the PAFC flame well and truly alive and has backlog to keep its factories full for the next year or so. SFC Energy is doing much the same for DMFC, with consistent markets in remote areas, military and recreation. FuelCell Energy is still recovering from a painful 2019 and although it has order backlog it has not been able to produce and ship much equipment. AFCs show signs of scaling though – GenCell got an IPO off the ground in 2020 and AFC Energy has had scale-up investment. We expect the mix of options to continue for a while, at least.

What do we expect in 2021? We hope that vaccinations will help the world get back on its feet, and that the belated realisation that climate resilience is essential will continue to drive clean energy. That should help to keep capital mobilising, and policy supportive. Korea and China certainly should see continued ramp-up of production and deployment. Other regions may follow, as post-COVID stimulus packages combine with investor enthusiasm. The new Mirai should help re-enthuse the car sector, and 2020's record number of hydrogen refuelling stations augurs well for vehicles generally. And the delineation between batteries and fuel cells may become clearer: JLR is pushing ahead with a fuel cell SUV prototype, as is BMW. Batteries are very likely to dominate at the smaller vehicle end, but may not make as much technical or commercial sense at the larger.

The continued involvement of major players is vital and will help the 'industry' mature and compete – whether that be in specialist supply of components and stacks, or of end-to-end solutions.

About the review

Applications

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

Application type	Portable	Stationary	Transport
Definition	Units that are built into, or charge up, products that are designed to be moved, including small auxiliary power units (APU)	Units that provide electricity (and sometimes heat) but are not designed to be moved	Units that provide propulsive power or range extension to a vehicle
Typical power range	1 W to 20 kW	0.5 kW to 2 MW	1 kW to 300 kW
Typical technology	PEMFC DMFC SOFC	PEMFC MCFC AFC SOFC PAFC	PEMFC DMFC
Example	• 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)	• 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)	• 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 seven years now. Tables of data can be found at the back of this Review going back to 2015. 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, both 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 50 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 the end of September 2020 and in a few cases as late as December 2020. Where we do not have full year data we use forecasts shared with us by individual companies or forecasts prepared by us in discussion with industry. We will revise data for 2020 in our 2021 edition as appropriate. We have revised the figures for 2019 in this report: Unit numbers were increased by 2.5% and megawatt numbers increased by about 6% compared to our published 2019 forecast. The main changes relate to a higher number of fuel cell vehicles (trucks and buses) in China than initially forecast, and a higher shipment of large stationary fuel cells to Korea than forecast, after final data for 2019 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.

Looking back on 2020

Well, that did not go to plan!

As our 2019 report went to press, COVID-19 was just a few people with flu-like symptoms in China. Major fuel cell and hydrogen initiatives were in planning, with multiple high-level conferences worldwide. Factories were ramping up and local and regional governments supportive. We were convinced we'd see another major uptick in shipments, 'perhaps even double'!

But by the time of Tokyo's FCExpo in February, it was clear that 'normal' had been suspended. Despite the organisers' best efforts, the event was a ghost trade show, and lockdowns subsequently hit every major region. Promised fuel cell orders could not be fulfilled, as supply chains were disrupted. Even the factories that were open had to find ways to work with suitable personnel distancing, slowing production further. Illnesses and sadly, deaths, hit the industry like every other.

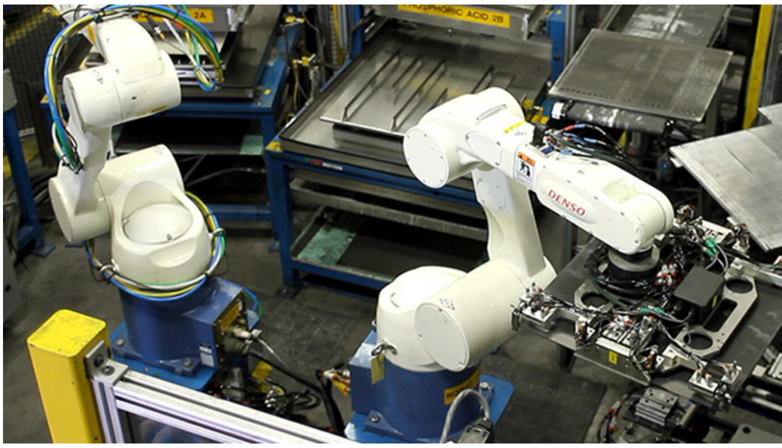
Despite all of that, more fuel cell units and more power were shipped – up 10% or so on 2019. Companies found ways to make and ship product, and the industry, as part of the 'green wave' fared much better than legacy industries like oil and gas. Government money continued to flow into the sector, which began to be seen as a more important and nearer-term part of a sustainable future than ever before.

The realisation that businesses and humanity needed 'pandemic resilience' was followed by a rapid appreciation that climate change is a much worse shock to the system, and climate resilience was needed even more urgently. So external investors piled into fuel cell and hydrogen stocks; major corporations continued M&A or other partnering activities; technology developers and scientists scented a good time to launch start-ups. And shareholders and boards started valuing companies with a climate plan – and indeed a hydrogen/fuel cell plan – rather than discounting them. Yet more organisations joined the Hydrogen Council, and esoteric conversations about 'net zero' carbon emissions started to concretise. Fuel cells also became a more concrete part of decarbonisation solutions, and of economic development plans.

The supply chains are still wobbly, and deliveries are still delayed. But the enthusiasm of existing governments for green solutions has set the industry back on a strong path. As the US rejoins the Paris Agreement, things there could become more positive too, perhaps with Federal initiatives to bring together the various State solutions.

2020 was brutal, but the fuel cell industry seems to have survived it. Japan and Korea maintained strong programmes, and others joined. Headhunting continued apace, always a sign of more work than people, even if those hired often have yet to meet their colleagues! As a consulting business we had more, bigger and more varied projects to work on in every aspect of the fuel cell space, including a real upswing in due diligence – reinforcing the investment trend.

None of us will have been sorry to bid farewell to 2020. We can only hope that vaccines, coupled with coherent and competent national and international plans, will allow all of us back to work, to visit our loved ones, and to deliver on the promise of cleaner energy and transport, so that we can face the climate challenge as we faced the COVID challenge.



Cars

Toyota and Hyundai: keeping the faith

Despite the pandemic's impact on the global automotive industry, 2020 saw more fuel cell cars shipped than ever before, with more than 8,000 sold worldwide. Deployments of the Hyundai NEXO increased by more than a third over 2019, though shipments of the Toyota Mirai decreased, almost halving outside of Japan. The pandemic was partly to blame, but also the much-anticipated launch of the next-generation Mirai.

More NEXOs are now on the road than Mirais, though the December 2020 launch of the new version puts the pressure back on Hyundai. The new Mirai 'drives like a Mustang' according to one owner, with a 20% smaller and 50% lighter – but, at 128 kW, higher power – fuel cell stack under the bonnet. The relocation of the stack and adoption of a rear-wheel-drive platform allow for a five-seat cabin and a third hydrogen fuel tank, leading to 30% longer range. Toyota targets a 10-fold increase in global Mirai sales, in line with previous announcements of boosting its production capacity to 30,000 units a year.

And then there's everybody else

Shipments from other manufacturers remain far behind Hyundai and Toyota. Honda has deployed limited numbers of Clarity Fuel Cell vehicles and continues to co-develop next-gen fuel cell systems with GM. Still no concrete news on the Fuel Cell System Manufacturing joint venture, set to operate within GM's existing battery pack manufacturing facility in Michigan, originally slated to start activities in 2020. Daimler has given up on fuel cell cars for now, consolidating its fuel cell activities into the newly-constituted Daimler Truck Fuel Cell GmbH & Co. KG, a subsidiary of Daimler Truck AG. Volvo Group will acquire 50% of the partnership interests in this subsidiary, establishing a joint venture to develop, produce and commercialise fuel cell systems for heavy duty applications.

Some fresh sparks?

After a long period of fuel cell dormancy, Groupe PSA announced a fleet of fuel cell vans in 2021. The first 100 vehicles – the Peugeot Expert, Citroen Jumpy and Opel Vivaro models – will be retrofitted with fuel cell range extenders provided by Symbio, presumably as was done with the Renault Kangoo ZE Hydrogen vans. In parallel, subsidiary Opel plans to road test a fuel cell version of its Zafira Life van.

BMW Group maintains its plans for a few X5s to have fuel cell powertrains by 2022 as pilots for its iHydrogen NEXT, building on its development collaboration with Toyota, but commercialisation remains for 'the second half of the decade'. And while Audi intends to release a small-series luxury fuel cell SUV by 2023, the VW Group is still keeping its fuel cell activities very quiet, with no production fuel cell vehicle likely anytime soon.

Things are moving in China though, with SAIC Motor presenting its hydrogen strategy plan, aiming for 10 FCEV models, 30,000 shipments and 10% market share by 2025. Its Maxus EUNIQ 7, claimed to be the world's first fuel cell multi-purpose vehicle, joins the existing Roewe car and the Maxus FCV80 van.

New players

With the enthusiasm behind hydrogen in general, and an increasingly mature fuel cell supply chain, new players are arriving. H2X aims to introduce a series of zero emission vehicles to Australian roads, with its Snowy SUV (60 kW fuel cell system, ultracapacitor and optional plug-in battery charge), which could hit the market as early as 2022. Ronn Motor Group is targeting the same date for roll-out of its Myst luxury SUV and Q-Series, comprising sedan and multi-purpose vehicle designs, focusing on the US and China markets. But fellow Arizona-based Nikola's plans for its much-publicised Badger pick-up truck were thrown into turmoil by the short-seller report we discuss elsewhere, and now their non-binding MoU with GM only covers the provision of GM's fuel cell system for Nikola's Class 7/8 trucks, and not for the Badger.

I feel the need for fuel cell speed!

Gumpert Aiways, a joint venture between German sports car brand Roland Gumpert and Chinese electric mobility player Aiways, announced the start of production of Nathalie, its methanol-powered fuel cell sports coupé. Denmark's Blue World Technologies supplies the 15 kW reformed methanol fuel cell system range extender, based on high temperature PEM technology. The 'first edition' series has a 65-litre tank, resulting in a range of about 850 km.

And California start-up Hyperion Motors unveiled its XP-1 hydrogen fuel cell supercar concept, which it claims will offer 1,000 miles range. Capitalising on advanced aerospace technology, some derived by NASA, the company is aiming at an ultra-lightweight design with state-of-the-art hydrogen storage solutions, potentially applicable beyond the automotive industry.

Car racing is also in the news, with the MissionH24 programme now backed by Michelin and its joint venture Symbio as an opportunity to boost their work on fuel cell and hydrogen technologies. Developed by the Automobile Club de l'Ouest – organiser of the Le Mans 24 Hours event – and by GreenGT, the programme aspires to an electric-hydrogen category in the 2024 race. And the Hyraze League is scheduled to launch in 2023, planning to be a new environmentally-friendly motorsport competition with 800 HP (597 kW) fuel cell race cars. It is supported by partners including motorsports engineering experts HWA AG, which expect to develop the concept and key components of the vehicles.

Asia takes the lead

South Korea has become the global leader in fuel cell car deployment, surpassing California, with more than 10,000 Hyundai NEXOs on the road. Domestic shipments increased by 38% in 2020 and, driven by public policy, should keep increasing. South Korea's New Green Deal aims for 200,000 fuel cell vehicles on the road by 2025. A lot of them will be Hyundais…

And while Toyota sold more Mirais in Japan than in 2019, shipments to the rest of the world decreased. Domestic sales picked up in December, presumably partly because of the new Mirai. Curiously, the Japanese roadmap also envisages 200,000 fuel cell vehicles by 2025.

Downturn in California

Fewer than 1,000 fuel cell cars were sold in California in 2020, the lowest number since 2015. California has been hard-hit by COVID, which certainly takes some of the blame. Still, San Bernardino county signed an agreement with shared-vehicle programme StratosShare to make five Mirais available to county departments. At federal level, Hyundai agreed to provide five NEXOs to the Department of Energy, part of a collaboration to assess the status of hydrogen and fuel cell technologies and address challenges.

What about the rest of the world?

German ride-sharing service CleverShuttle added 25 Hyundai NEXOs to its fleet, claimed to be the largest in the country. Its current fleet of 45 Mirais has reportedly achieved a combined total of 5 million kilometres with few problems. Airport Taxi Zürich fielded 10 NEXOs, and 500 Mirais are expected to complete the Hype hydrogen taxi fleet in Paris.

Firms and fleets are testing the fuel cell water too. Dutch engineering and construction firm Jos Scholman took delivery of 11 NEXOs and is planning on developing a hydrogen refuelling station close to its facilities in Nieuwegein, while British gas operator Cadent North London started a commitment to 1,000 zero emissions vehicles across its networks by 2026 by deploying 5 NEXOs. The Berlin fire brigade added 4 Mirais to its fleet, and local police departments in Germany, Switzerland and Italy now have fuel cell patrol cars. As part of the EU project LIFEalps, South Tirol in Italy purchased 10 Hyundai NEXOs for long-term renters, the South Tyrolean government, and public and private project partners. Down Under, the Australian Capital Territory landed an Australia-first fleet of 20 NEXOs, though they will not hit the road until a dedicated hydrogen refuelling station opens in Canberra.

Hydrogen refuelling stations

As 2020 started, it looked like the strong growth rate for hydrogen refuelling infrastructure deployment evident in recent years would be continued. But COVID has hit the supply chain hard, delaying construction and deployment and reducing the rate at which new stations have come onstream in the year. How quickly these delays are recovered from will vary by region, but faster deployments are expected in the coming year as existing projects are fulfilled and hydrogen momentum continues. The pace at which new HRS have been announced has certainly continued unabated.

2020 saw equipment suppliers developing solutions with both increased station capacity and new refuelling capabilities, including technical innovations. Air Liquide announced an enhancement to its HRS design, upping capacity and including dual filling to meet the increasing demand of the US market. The new high-capacity stations can fill vehicles simultaneously at 700 bar, dispensing up to 1,000 kg/day (enough for up to 250 passenger cars), and at around 25 m^2 are more compact than before. A similar large-capacity station was unveiled in France to refuel heavy-duty trucks.

The California Energy Commission announced its largest investment in hydrogen infrastructure since 2015, funding 110 new stations over the next five years. FirstElement deployed the first passenger car HRS in California to have four fuelling positions and the largest capacity to date (1,200 kg). Haskel Hydrogen Group launched two new compact 'plug and play' portable hydrogen stations, the Nano and Nano-Pro, aimed at small fleet customers.

On the industry side, new alliances are being forged and corporate investments and consolidations are emerging. Mitsui & Co., Ltd invested US$25m into FirstElement Fuel, California's biggest developer and operator of hydrogen stations. As lead investor, Mitsui will collaborate with FirstElement and look to use their experience to expand into new business areas and regions. Chesterfield Special Cylinders announced a five-year framework agreement for hydrogen storage cylinders to support Shell's HRS roll out plans in Europe. Poland took its first steps in hydrogen infrastructure with Nel Hydrogen Fueling receiving an order from ZE PAK, a Polish energy company, for an H2Station™ for both cars and buses, and Toyota Motor Poland and the Polish Oil and Gas Company (PGNIG) announced a cooperation to advance H_2 in the country. Czechia also announced its first three public hydrogen stations, to be rolled out by Unipetrol Group and Bonett Group.

Hympulsion, deploying the largest mobility project in France, has installed the first of 20 stations in the Zero Emission Valley, and Nel ASA signed an MoU with Everfuel A/S where the latter a majority stake in H2 Fuel Norway AS. And the first two of six green hydrogen refuelling stations covering the route between Lake Constance and Lake Geneva have opened, supporting the deployment of Hyundai's first 50 Xcient commercial fuel cell trucks. In China, Linde and the Dalian Bingshan Group have agreed a new joint venture company to manufacture hydrogen refuelling stations in Dalian, China, tripling Linde's production capacity in the next few years. And Valmax Corp. will cooperate with HnPower Co., Ltd. (a technical partner of Osaka Gas) to localise core components and help building HRS. In Canada, HTC Extraction Systems (Regina, SK) looks set to acquire up to 20% equity in the US-based company, PowerTap Hydrogen Fueling Corp. for C$6.5m (US$4.9m). Its small footprint hydrogen production system steam reforms renewable natural gas (biomethane) and is claimed to offer a carbon capture ability. Down under, Fortescue Metals Group and ATCO Australia have agreed to explore hydrogen vehicle refuelling infrastructure in Western Australia and green H_2 specialist Infinite Blue Energy has teamed with New Volt Infrastructure for green H_2 for road transport in Australia, to be supplied through 17 EV fast-chargers and green HRS at key locations on major roads. The Infrastructure Reference Group has provisionally approved NZ$20m (US$13m) to establish New Zealand's first nationwide HRS network from Hiringa Energy, involving the installation of 8 HRS for heavy duty vehicles with a gross budget of NZ$69m (US$45m).

Supply chain delays are evident in the slowing down of new stations deployed globally. H2 Mobility Germany said that 81 HRS were operating in Germany in early December, with 8 more in trial, 6 in approval and 4 in planning. Germany's 2020 goal of 100 Stations with 700 bar capability, the basis of a national network, will now be fulfilled in early 2021. Though other European countries are some way behind, with only 78 operational HRS between them, over half in France, the UK and Norway.

In California the story is the same. In early December, 42 stations were open, 15 in development – while 64 had been targeted by CARB by 2020. Still, the target of 200 stations by 2025, intended to enable economies of scale and growth without further state incentives, is still within reach. In September, Shell was awarded US$40m in grants to build 48 stations in California.

Japan leads the pack, with 133 stations operational (including mobile stations), though again this is a slowdown compared with 2019, and short of the 2020 target of 160 stations. Ongoing regulatory reforms, capex and opex reduction targets have been set out to accelerate deployment of HRS toward Japan's 2025 target of around 320 stations. And despite the Tokyo Olympics delay, Japan intends to maintain the promotion of the event as a platform to showcase the country's commitment to hydrogen.

Korea is providing subsidies and reducing regulations to encourage the construction of new refuelling stations to facilitate planned expansion, but deployment numbers are as yet far from its ambitious roadmap, which calls for an expansion from the current 43 stations to 310 in 2022.

37 refuelling stations were in operation in China in December 2020, far from their goal of 100. Recent signals are promising though, with Shell China announcing a JV with Zhangjiakou City to deploy hydrogen refuelling stations in the city to support 1,000 trucks and buses used for logistics for the Beijing Winter Olympics in 2022. The initiative includes a 20 MW electrolyser. In December 2020, Air Liquide China also signed an agreement with Sichuan China National Nuclear Guoxing Technology Co., Ltd. in Chengdu, to further develop the hydrogen energy industry chain in Southwest China, including collaborating in their hydrogen refuelling station rollout plan.

Buses

After two decades of development and demonstration the Fuel Cell Electric Bus (FCEB) revolution is underway. Driving and refuelling experiences compare to diesels/diesel-hybrid buses, and operational characteristics can even be better. Cost remains higher, though is dropping fast. At the same time, public transport authorities have an imperative to eliminate health-damaging emissions, whilst continuing to offer transport to the public, so more and more authorities are committing to zero emission bus fleets. In 2020, the New Zealand Government committed to phase out diesel buses by 2035, as did Sunline Transit in California. With very few long-term zero emission vehicle options, FCEBs are firmly under consideration in almost every part of the world.

All of that said, 2020 was a difficult year for public transport, with COVID restrictions reducing ridership dramatically in many areas. Intended bus developments did not always go ahead, and the sector may have gone through fundamental change.

European FCEBs multiply

Despite headwinds, Europe's FCEB ambitions remain strong. The end of 2020 saw an estimated 115 FECBs in operation, and 350 are planned for 2021. National Climate Energy Plans suggest the fleet could expand to 8,000–17,000 vehicles by 2030. As ever, major FCH JU projects are an important driving force. The €57m supporting JIVE and JIVE2, plus national and regional funds, is delivering deployment across Europe. Birmingham in the UK has 20 Wrightbuses on order supported by JIVE, UK Government Office for Low Emission Vehicles and City Council Funds.

The European H2Bus consortium, with HRS and hydrogen suppliers plus fuel cell developer Ballard, plans to deploy 1,000 FCEBs and their supporting infrastructure. In September it announced that it was joining with Wrightbus to offer a range of vehicle types, with a 12 m bus available for €375,000 (US$424,000) after funding, using Ballard's FCMove modules announced in 2019. Hydrogen will sell for Euro 5-7/kg and maintenance will cost €0.25 to €0.35/km. The first 600 vehicles are due for deployment in Denmark, Latvia and the UK, supported by Connecting Europe funds. Funded in part through JIVE, Regionalverkehr Köln (RVK) public transport agency in Germany now operates Europe's largest FCEB fleet, 35, and four HRS. RVK started back in 2011, operating a mix of Van Hool A330 and other vehicles in the area. 15 more FCEBs are due in 2021, these will be Solaris' Urbino 12 bus, powered by Ballard's modules. RVK has plans to field 230 FCEBs out of a fleet of 300 vehicles (the other 70 being CNG units) and build six more HRS, the initially-high costs of which fall off rapidly per vehicle as the fleet increases. In nearby Wuppertal, WSW Mobil GmbH started operating ten Van Hool A330 in 2020, part of Europe's largest vehicle order in 2019 of 40 vehicles across Wuppertal and Köln.

London has also been a long-term operator of FCEBs. In 2020 it announced the phase-out of its original fleet of Wrightbuses from 2010, and that a fleet of 20 Wrightbuses (Wright is now owned by Bamford Bus) would come in from 2021. These double decker vehicles have Ballard FC-veloCity fuel cell modules, and the buses are said to cost £545,000 each (US$698,000). Another UK pioneer, Aberdeen in Scotland, took delivery of its first double decker FECB in October, the first of a 15-vehicle order worth £8.3m. These vehicles will join the existing fleet of ten Van Hool buses.

Across Europe the story is similar. Bielefeld in Germany ordered four Caetano 12 m City Gold buses, partly funded by the North Rhine-Westphalia Government, which is also supporting Duren's purchase of five FCEBs. Südwestdeutsche Landesverkehr wants to be amongst the first to trial the Mercedes eCitaro REX (range extender), supported by State and Federal grants. Hamburg Hochbahn has launched a tender for up to 50 FCEBs for delivery between 2021 to 2025, and

Frankfurt wants 20. Emmen in the Netherlands has ten FCEBs on order, plus a Shell built HRS. In Denmark, Aalborg finally received three Van Hool A330 buses under another FCH JU project, 3Emotion. The same project saw eight Van Hool 18 m articulated Febus, using Ballard FCveloCity modules, enter service in Pau, France. And four of the unusual VDL 12 m Citea bus are now operating in South Holland, again part of 3Emotion.

These buses are modified electric vehicles fitted with a trailer 'back-pack' with Ballard FC modules. Ten trolleybuses, with fuel cell modules fitted to double their range, are operating with Rigas-Satiksme, in Riga, Latvia. A Solaris Urbino 12 is being trialled with Viennese bus operator Wiener Vienna. And Ireland has plans to trial a Caetano City Gold bus through Hydrogen Mobility Ireland.

European OEMs are responding by developing further models and looking to ramp up production. Wrightbus plans to deliver 3,000 zero emission buses, including FCEBs, by 2024.

The UK's Optare, part of the Indian conglomerate that also owns Ashok-Leyland, will introduce its MetroDecker in 2021. Developed with Arcola Energy, Ballard fuel cells figure once again. Hungarian developer Goldi Mobility has been working with Hy-Hybrid Energy of Scotland to develop its GOLDiON 12 m and 18 m buses; Solaris reported 57 orders for its Urbino 12 bus launched in 2019, and Caetano is taking orders for its H2.City Gold bus, launched at the same time. Barcelona has ordered eight Caetano buses, along with an HRS.

While Ballard fuel cell modules have figured strongly in buses, 2020 saw an agreement with Audi AG for Ballard to use the jointly developed Ballard FCgen-HPS (High Performance Stack) in all applications. This will have a maximum output of 140 kW, and a higher power density than existing Ballard modules. A relative newcomer to the sector is ElringKlinger, the German fuel cell developer, which has a relationship with VDL. Portuguese Caetano has an agreement to use Toyota's 60 kW fuel cell modules in its City Gold buses. French bus manufacturer Saffra is using a 30 kW Symbio (Michelin) fuel cell as a range extender with a 132 kWh battery for the Businova product, five of which have been ordered by the Auxerrois Community in France.

With buses starting to move more smoothly, efforts are underway to expand the offering, including FCH JU plans to support development of long-distance fuel cell coaches.

North America, speeding up?

The FCEB fleet in the USA is also growing, though more slowly, and there are positive signs both there and in Canada. At the end of 2020 64 FCEBs should have been active, with another 30 planned for 2021 and beyond. Many are in California, driven by the challenge of emissions and air quality and supported through various state incentives. Three transit authorities account for 47 vehicles: Orange County, AC transit (Alameda-Contra Costa) and Sunline of Thousand Palms. Orange County introduced ten New Flyer Xcelsior Charge vehicles in February. Current and future orders are also led by Californian customers: Golden Empire Transit of Bakersfield will get five, and Foothill Transit of West Covina has authority to buy twenty. The move is towards zero emission bus fleets, with Orange County already committed to do this by 2040.

In the other 49 States, Stark Area Regional Transit in Ohio has a fleet of 12 vehicles, and Hawaii is commissioning three Eldorado National units. All of Hawaii's counties have pledged to have zero emission bus fleets by 2035. Further afield, Champaign-Urbana Transit of Illinois has ordered two New Flyer Xcelsior Charge vehicles, and Las Vegas has a Federal Low-No grant for two more.

Most of these FECBs are produced by New Flyer and ElDorado National. Fuel cells come from Ballard and US Hybrid, integrated by either BAE Systems or Siemens. Both OEMs introduced new 40 ft (12 m) models in 2019, the New Flyer Xcelsior and ElDorado Axess. In Canada, FCEBs look set to make a comeback. While the ten-vehicle FCEB fleet in Whistler was the world's largest, providing public transit during the 2010 Winter Olympics, it was axed in 2014. The absence of FCEBs in Canada since then has been a source of frustration to many, not least Ballard and Hydrogenics, who have powered buses in many other regions of the world. This looks set to change, with the start of the grandly-titled Pan-Canadian Hydrogen Fuel cell Electric Bus Demonstration and Integration Trial, which will include transit authorities MiWay of Mississauga and Winnipeg Transit, and industry including Ballard, Hydrogenics, ABB and New Flyer.

Asia: China Races Ahead

China has the world's largest bus and coach market, so it should not be surprising that it also has the world's largest FCEB fleet. Even with our access, accurate counts are hard, but around 3,600 buses have been delivered. Foton Bus alone reports delivery of 600 vehicles to 2020, and a range of Chinese OEMs offer models: in 2020 alone the Ministry of Industry and Information Technology Catalogue of New Energy Vehicles mentioned eight new FCEB models. Often, more FCEBs enter service in one month in China than in one year in other markets; 79 started operations in October 2020, and deliveries are in tens of units. Changshu received 20 Suzhou Jinlong FCEBs in January 2020, whilst Zhengzhou replaced 30 buses with FCEBs in one go.

Orders by local and regional governments can number in the hundreds: in April Nanjing announced an intent to replace its entire electric battery bus fleet with range-extender FCEBs, a total of 7,000 vehicles, with a leading Chinese bus manufacturer placing a 3-year US$15m order with Canada's Loop Energy to support the switch. This activity is down to a generous subsidy regime, reported to be as much as CNY0.7m (US$100,000) per vehicle, from the Chinese Government and local and regional authorities. The regime is changing, and Chinese cities are now vying for Model City status, which will unlock further FCEB funds.

Chinese FCEBs tend to be smaller than their European and US counterparts. As battery-dominant hybrids; the fuel cell operates as a range extender, with fuel cell modules in the 40 kW to 60 kW range – though subsidy changes will likely see larger units in future. Automotive groups large and small are in the fray, including Zhontong, Foton, Foshan Feichi, Golden Dragon and Geely. However, these businesses and others are currently largely dependent upon imported fuel cell technology. Ballard, Hydrogenics, Hyundai and Toyota all have relationships and supply fuel cell modules either from their home countries or factories in China, usually as joint ventures. Toyota has an agreement with Re-Fire of Shanghai, which itself supplies OEMs such as Foton. And other established fuel cell businesses are joining in: 2020 saw Nuvera's E-60 PEM module get certification from Chinese authorities, joining its E45 model, currently in 10.5 m FCEBs. Loop Energy's 50 kW PEM modules are being integrated into Skywell's 10.5 m FCEBs.

Korea

Korea's FCEB activity is smaller than China's, but ambitious by world standards. The national roadmap includes 2,000 FCEBs by 2022 and 40,000 by 2040, with Hyundai leading the charge, using its NEXO fuel cell module in the Elec City hybrid bus. Two modules totalling 180 kW, plus a 78.4 kWh battery and a 180 kW central motor, drive the 11 m long vehicle, the first of which entered service in 2019. Five of the Elec City FCEBs delivered to Busan in 2019 were joined by a further 15 in 2020. The city intends to field 100 by 2022, and is developing the supporting infrastructure, with two HRS due to open in 2021. The Elec City is also being introduced into service with the Korean National Police Agency, with two vehicles running from the end of 2020. About 800 diesel buses will be replaced by 2028. Incheon Airport also has activity, with Air Liquide installing an HRS to refuel Hyundai FCEBs which will replace the current diesel fleet. Seven vehicles were planned by the end of 2020. And Hyundai's first export of FCEBs saw two Elec City vehicles delivered to Saudi Aramco in Saudi Arabia.

Japan

Japan's FCEB bus activities are, like Korea, dominated by one company: Toyota. The Sora FCEB runs on two 114 kW Mirai fuel cell modules integrated with a nickel metal hydride battery. Despite Japan's long history in hydrogen, its bus ambitions are modest, with only 1,200 FCEBs expected on the roads by 2030. The end of 2020 saw 91 FCEBs in service with various public transport and private operators, the largest single one being the Tokyo Metropolitan Government, with a target of 70 units for the end of 2020. The initial driver behind this was the ill-fated 2020 Tokyo Olympics. These and other FCEBs are partly supported by the Ministry of the Environment.

India

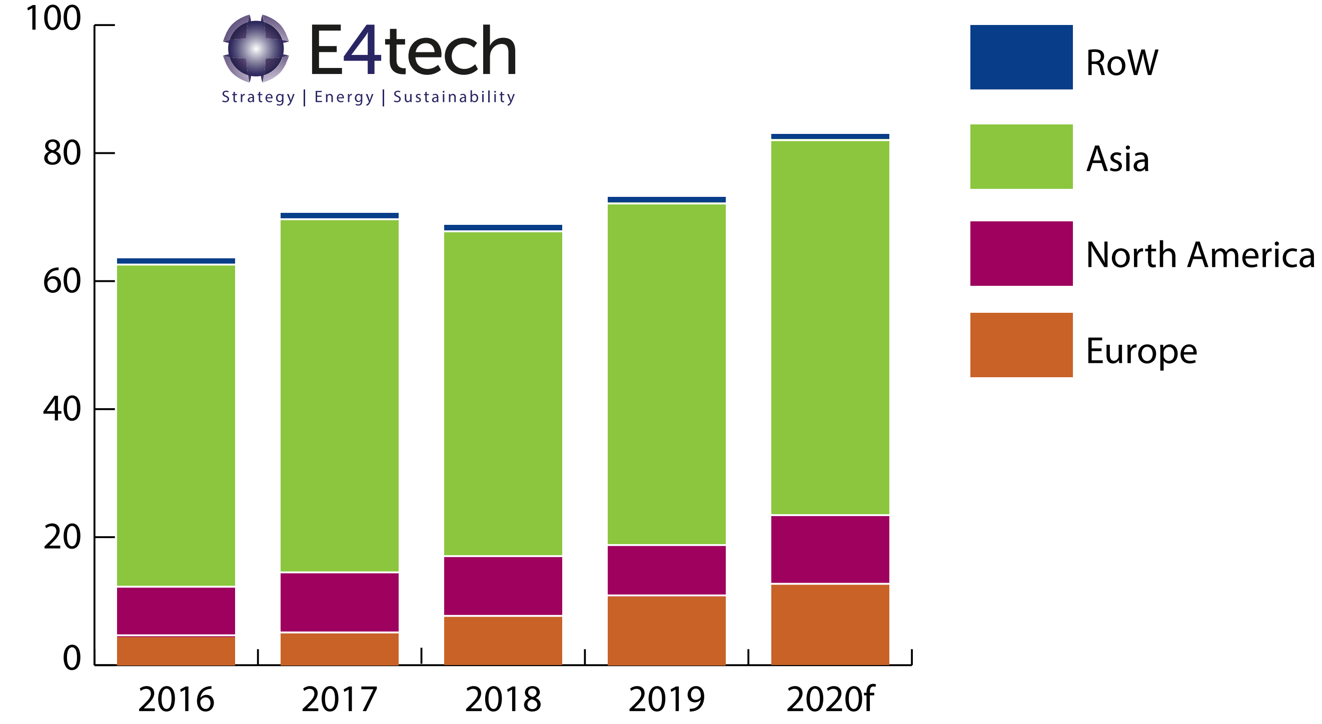
India's FCEB journey has been sedate. Technology has been under development for the last decade, culminating in Tata Motors' StarBus in 2018, reportedly under test for the past two years. Up to ten FCEBs are said to be on India's roads, though this might double in the near future. The Ministry of New and Renewable Energy and the National Thermal Power Corporation put out a call for the supply of ten FCEBs and fuel cell cars to operate in Leh, Ladakh and Dehli. The StarBus may be a contender, as may Ashok-Leyland's subsidiary Optare.

Other regions

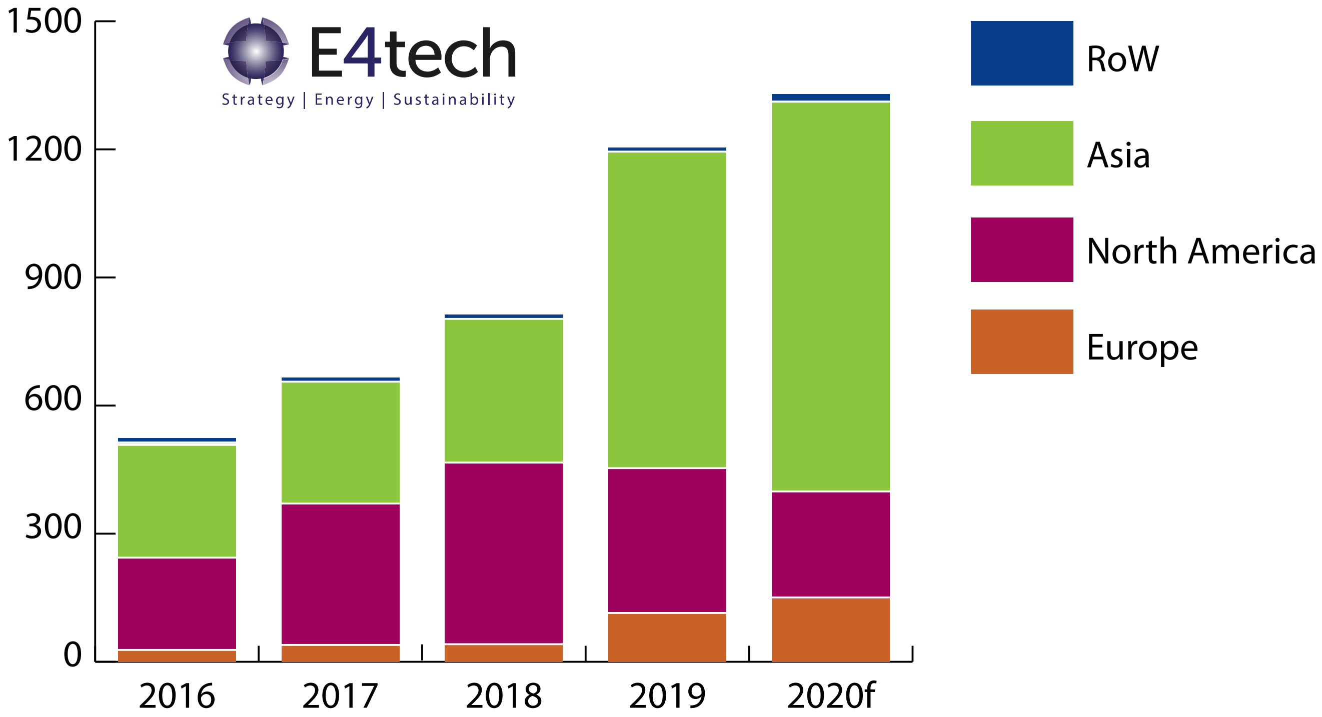
FCEB activity elsewhere has been limited. Sarawak in Malaysia officially launched its first FCEB service in June 2020, with three Foshan Feichi Automobile FCEBs operating the route. Foton, part of the Beijing Automotive Group, plans to develop activities in both Australia and New Zealand and will import a 12 m FCEB, powered by Toyota fuel cell modules, into Australia in March 2021 as a demonstrator for the local diesel bus operators. More significantly in Australia, May 2020 saw the H2OzBus consortium launched, with an initial target for 100 FCEBs operating across ten hubs. ITM Power and BOC will supply the hydrogen and the HRS, and Ballard the fuel cell modules. The FCEB manufacturers have yet to be announced. Australia's Fortescue Metals also got hydrogen religion, announcing that it would deploy ten fuel cell coaches from US developer Hyzon at its Christmas Creek mine in Western Australia from 2021, part of an effort to reduce the carbon emissions from its vehicle fleet.

Shipments by region

Shipments by region of adoption 2016 - 2020 (1,000 units)



Megawatts by region of adoption 2016 - 2020



2020f is our forecast for the full year, based on firm data from January to September, and in some cases to as late as December.
We have revised the figures for 2019 in this report, now with firm full year data where previously a final quarter forecast was required.

Shipments by region

At nearly 82,500 units, 2020's fuel cell shipments are up significantly on 2019's 72,600. In megawatts shipped they increased from 1,192 MW to 1,319 MW in 2020. The 2020 numbers were inevitably reduced because of the slowdown from COVID. Asia continues to lead the shipments, with Ene-Farm as usual topping the unit numbers, while Hyundai again shipped most MW.

Asia's lead results largely from strong policy instruments: Chinese NEV support, Korea's Hydrogen Economy Roadmap and Renewables Portfolio Standard, and the triennially revised Basic Energy Plan and the Strategic Roadmap for Hydrogen and Fuel Cells of Japan. Similar policy instruments may emerge in Europe, but Asia is likely to stay well in the lead for fuel cell shipments globally.

For policy reasons, Hyundai has focused NEXO deployment on Korea, where they contribute hugely to the MW shipped. With around 6,000 local units in 2020, the NEXO shipments represent 576 MW of power, or close to 50% of global fuel cell shipments by megawatts of all kinds.

Europe's annual shipments grew by 17% year-on-year in MW terms (again mainly NEXOs), from 113 MW to nearly 132 MW. They also grew in number, led by micro-CHP units for the German KfW 433 initiative, from just over 10,500 units in 2019 to just over 12,500 units in 2020. As with other regions, fewer Mirais were shipped to Europe as Toyota prepared for the global release of the new model Mirai in December 2020.

Unit shipments to North America rose from just over 8,000 units in 2019 to over 10,500 units in 2020, led largely by Plug Power for materials handling. The megawatts shipped during 2020 declined, from 339 MW in 2019 (less than our forecast of 384 MW in that year) to 253 MW in 2020.

The adjustment to megawatts shipped for 2019 is attributable to lower numbers than forecast of NEXOs and Mirais to the US. At the same time, more NEXOs were shipped to Europe and fewer to North America.

2020 did see continued growth in stationary fuel cells in North America though, led by Bloom Energy. Bloom now also ships one third of its output to Korea, in its partnership with SK E&C. We saw annual stationary fuel cell shipments in North America grow from 104 MW in 2019 to 115 MW in 2020. But this gain is offset by a big fall in Mirais shipped to the US, from nearly 1,500 units in 2019 to fewer than 500 in 2020. That's a 120 MW drop in Mirai shipments, which contributes to a net 84 MW fall in capacity shipped to North America.

Vehicle fuel cells are typically in the tens of kW (at the low end for range extenders, higher in some trucks), and so the large but fluctuating numbers of fuel cell vehicles now fielded in China contribute to significant volatility in industry numbers. 2019 was a bumper year, with our initial forecast of 1,673 units for China some way under the final total of 2,737 units (~100 MW), mainly buses, trucks and then vans. We expected continued growth into 2020, but changes to subsidy policy, and subsequently to eligibility, resulted in a subdued output, down to just over 1,400 units (~87 MW) for 2020. With policy now becoming clear, we expect a return to growth in 2021.

Overall, increased Ene-Farm micro-CHP shipments, increased larger CHP and prime power shipments (chiefly from Doosan Fuel Cell and Bloom Energy), and higher numbers of NEXOs drove annual Asian shipments from ~744 MW in 2019 to ~912 MW in 2020. This represents 69% of the global MW shipped.

While we expect new support policies to drive uptake in Europe too, we think Asia will stay comfortably in the lead in 2021.

Commercial vehicles

Trucks again

Just like in 2019, heavy duty was an important sector for fuel cells in 2020. And there were global headlines aplenty, some less welcome than others…

Nikola followed the current trend and reversed into a SPAC to IPO mid-year, and its value rocketed on news about a tie-up with GM for its Badger pick-up truck. Then came a damning research report from short-seller Hindenburg Research, previously targeters of Ballard and Bloom, suggesting that Nikola had little or no technology and was pulling a lot of wool over a lot of eyes. The shares crashed, founder Trevor Milton resigned, and GM hastily drew back from a nascent agreement to take an 11% stake. The truth, as usual, seems to rest between Nikola and Hindenburg's stories, but it does seem that Nikola was claiming more than it could deliver. Still, Nikola maintains strong partnerships with Bosch, CNH Industrial and Nel Hydrogen, and has signed a purchase agreement of US$30m for 85 MW of alkaline electrolysers to help it create its fuelling network. IVECO will work with FPT Industrial, both CNH companies, to produce Nikola's Tre in Europe, and GM will now supply FC powertrains for Nikola's North American heavy-duty trucks.

Hyundai Motor shipped the first ten units of its Xcient fuel cell heavy-duty truck, the world's first to come off a production line, to logistics operators in Switzerland. 1,600 units are planned to be shipped by 2025. Powered by two 95 kW NEXO stacks, the Xcient can travel up to 400 km on a single fill of gaseous hydrogen. And Scania has supplied Norwegian wholesaler ASKO with four hydrogen powered trucks, to be piloted in daily use. The 26 t trucks each have a 90 kW PEMFC, and 33 kg hydrogen at 350 bar gives them a range of 500 km.

Refuse collection vehicles are also starting to be fuel cell adopters. Breda, in the Netherlands, is operating FC refuse trucks under the REVIVE project and Hydrogenics, now owned by Cummins, has supplied fuel cells as range extenders for FAUN's refuse trucks. The 3x30 kW FCs allow a range of up to 560 km.

2020 not only saw truck deployments, but also agreements amongst players in the sector. Daimler and Volvo signed a binding agreement to produce and commercialize fuel cell systems for HDV applications and other uses, and a new entity, Daimler Truck Fuel Cell, consolidates the company's current fuel cell activities under the joint venture. Plug Power announced an MoU for the demonstration of its ProGen engine in Class 6 and 8 trucks, to be used by Linde. The fleet is expected to be fielded in early 2021. Other partnerships include Honda Motor with Isuzu Motors to develop H_2-powered trucks, Total Group's stake in Hyzon Motors, TRATON and Hino who plan to develop BEV and FCEV trucks together, Toyota and Fujian Snowman cooperating on hydrogen fuel cells, and Ballard's deal with Audi for use of the FCgen-HPS modular 140 kW stacks.

The future is also becoming clearer. Hyundai's roadmap and vision sets out a ramp to a 2,000 trucks/year production capacity by 2021 and to deploy 25,000 trucks in Europe by 2030. Hyundai also has plans for North America with its HDC-6 Neptune, hoping to achieve hundreds of trucks by 2022 and 12,000 by 2030; and for China, targeting 27,000 units by 2030, based on three different models. Two letters of intent have been signed already with Chinese companies for the supply of 4,000 trucks by 2025.

The Daimler Trucks strategy diverges from others, with an emphasis on liquid hydrogen for its 40 t GenH2 fuel cell truck. Customer trials are planned for 2023, and series production in the second half of the decade. Mitsubishi Fuso Truck and Bus Corporation, part of the Daimler truck group, intends to make all new vehicles for Japan CO_2-neutral by 2039, with series production of fuel-cell trucks by the late 2020s.

The Nikola Tre is slated for manufacture in Ulm, Germany, at the IVECO facility, with production of the initial BEV units apparently expected within the first quarter of 2021 and the first deliveries to customers in the same year. Fuel cell electric versions, built on the same platform, will be tested during 2021, with an expected market launch in 2023. Nikola has also unveiled plans for its manufacturing facility for the Nikola Two in Coolidge, USA, with a planned production capacity of 35,000 trucks annually. Construction is scheduled for completion in late 2021.

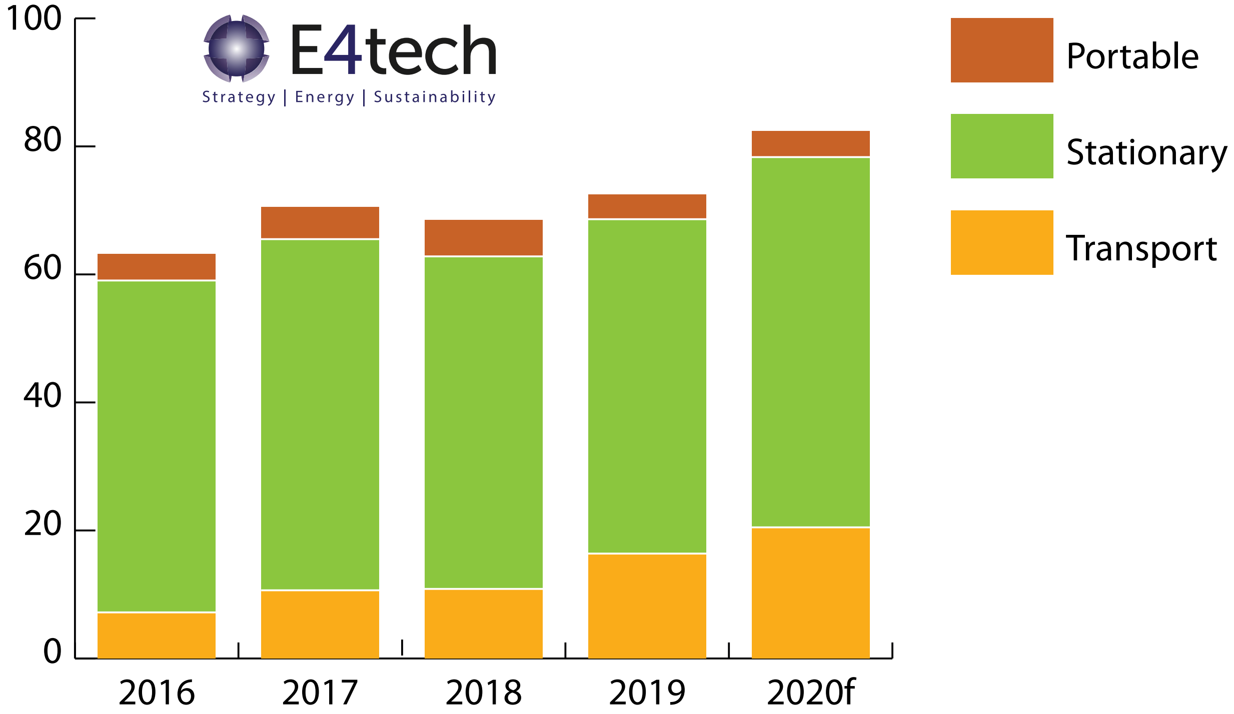
The other fast mover in the sector is Hyzon Motors, offspring of Chinese-Singaporean fuel cell company Horizon, which has acquired the former GM fuel cell facility in Honeoye Falls, New York. The facility will be used to manufacture FC systems and support integration into US class 8 (over 33,000 lb, ~15 t) heavy trucks. The company also launched Hyzon Motors Europe BV, its new European HQ and manufacturing centre based in Groningen, the Netherlands, in partnership with local company Holthausen. Hyzon, building on the know-how gained in China through shipping buses and trucks there, expects to ship hundreds of fuel cell heavy vehicles by the end of 2021. And ensuring it has a footprint in both hemispheres, it is also setting up a division in Australia, targeting FC truck assembly by 2022, and is planning to deploy 1,500 trucks in New Zealand by 2026.

Other players planning to supply trucks include Toyota and its subsidiary Hino for both the Japanese and North American markets, Cummins and Navistar, MAN under its brand TRATON, Freudenberg Sealing Technologies and Quantron, and Foton and Feichi in China. And Swiss company GreenGT, better known for its Le Mans fuel cell developments, continues to integrate its technology onto the Kamaz truck chassis.

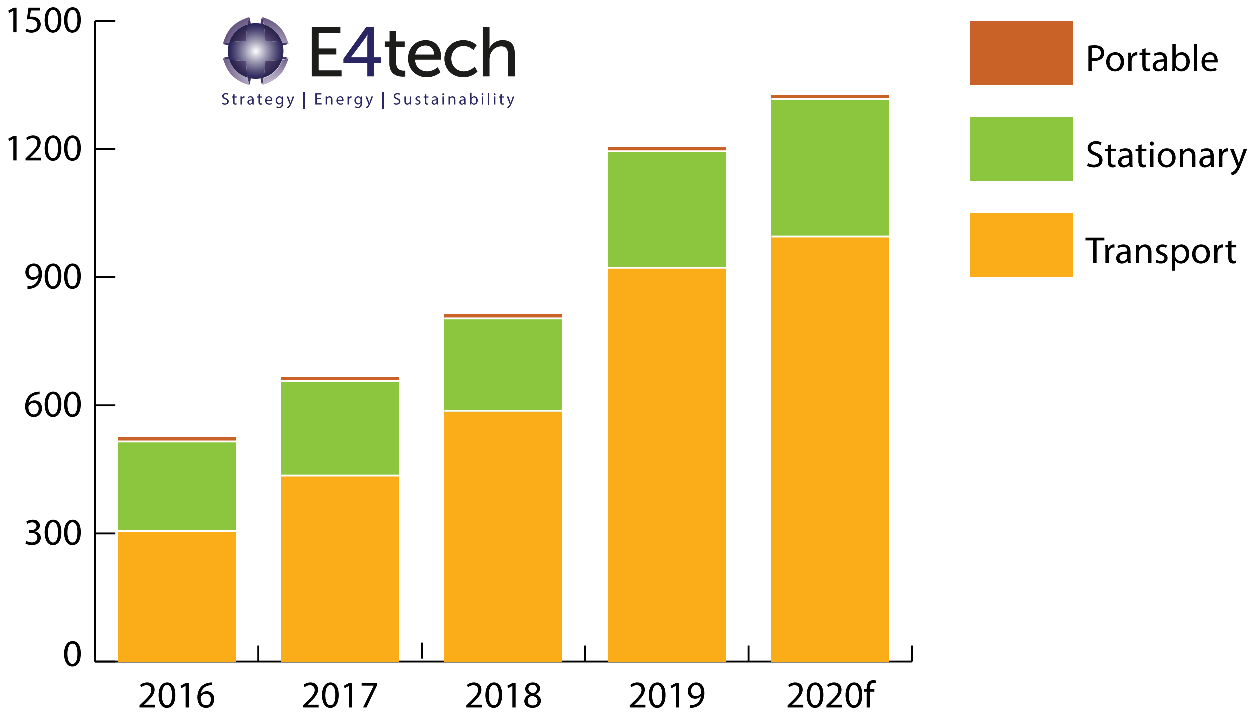
Illustrating the importance and the ambition, a coalition of vehicle manufacturers, technology and infrastructure providers and more signed a statement in March with targets of 5-10,000 hydrogen trucks on Europe's roads by 2025, and at least 100 fuelling stations. The ambition is for 100,000 trucks by 2030 and 1,500 HRS. While non-binding, this clearly shows a cross-industry acceptance that fuel cells will play an essential role in cleaning up heavy duty vehicles.

Shipments by application

Shipments by application 2016 - 2020 (1,000 units)



Megawatts by application 2016 - 2020



2020f is our forecast for the full year, based on firm data from January to September, and in some cases to as late as December.
We have revised the figures for 2019 in this report, now with firm full year data where previously a final quarter forecast was required.

Shipments by application

Although one effect of COVID-19 has been to slow the increase in fuel cell shipments over 2020, they are still growing. The leading applications remain passenger cars, CHP, and prime power.

In unit numbers, micro-CHP dominates, with over 47,000 units forecast for Ene-Farm in Japan and over 5,000 units to the KfW 433 initiative in Germany. Approaching 1,000 more units went to the pan-European PACE programme.

The growth in 2020 is some testament to the resilience of the markets. Japan no longer subsidises PEM micro-CHP installations (SOFCs get a small contribution) yet shipments remain relatively stable. And many of Europe's micro-CHP units are built around Panasonic technology, licenced and developed for the European market by Viessmann, enabled through the improvements engendered by Ene-Farm.

Vehicles, particularly the passenger cars of Toyota and Hyundai, also contribute hugely to overall numbers, with over 8,500 cars shipped in 2020. But car unit numbers are dwarfed by their capacity, around 859 MW globally, nearly two thirds of the shipped capacity for all applications.

Buses and trucks account for further shipments, though modest outside China. Excluding China, global fuel cell bus and truck shipments in 2020 were about 300 units, equating to 22 MW. Inside China, buses, trucks and vans (led by SAIC's Maxus FCV80) reached over 1,400 units shipped in 2020, a combined 87 MW capacity for the year. This significant decline from 2019 was caused partly by policy uncertainty, as manufacturers paused efforts until they knew funding could be available. As the picture clears, more stringent criteria for funding will be applied: focusing on building up supply chain capability in cluster cities, the local policy and institutional environment, and reducing costs and creating economies of scale. Simply making the vehicle and running it will no longer be enough. This is logical, as China's market becomes increasingly sophisticated and specialised, and points to the longer-term policy goal of developing indigenous capability to enable a targeted 50,000 cumulative vehicles to be fielded by 2025.

The materials handling application is not only strong but getting stronger. In 2019, market leader Plug Power's annual report indicated over 6,000 units shipped. 2020's first three quarter reports suggest numbers closer to 10,000 units over the year – a huge achievement given COVID. Other materials handling providers, like Hyster-Yale's Nuvera business, continue to develop their markets. Much larger materials handling facilities are now employing fuel cells as demonstrators, for example at shipping ports.

Large CHP and prime power above 100 kW together contributed over 270 MW new capacity in 2020, and around 400 units globally (up from roughly 230 MW in 2019). Smaller fuel cells for grid support and off-grid power seem to number about 2,200 units, contributing around 8 MW of capacity.

As in 2019, around 4,000 portable fuel cell units were reported as having shipped in 2020. Many of these are from SFC Energy and include a mix of recreational battery extenders, remote monitoring and remote power units, some for military uses.

While UAVs seem an excellent opportunity for fuel cells, in 2020 numbers grew slowly, with offerings from Plug Power (former Energy OR), Intelligent Energy, Doosan Mobility Innovation and others accounting for multiples of tens of units.

Trains

Alstom's move to put fuel cells in trains a few years back seems to have finally given the sector momentum. Although others had worked on hydrogen trains – 'hydrail' – none had a fully engineered commercial vehicle. But 2020 saw further growth.

Like others, European rail operators have zero emissions requirements to look forward to. For many, this means upgrading parts of their networks still serviced by diesel technology, often dating back thirty or more years. Non-electrified lines are still a large part of the European rail network: 28% in the Netherlands, 41% in Germany and 62% in the UK. A 2020 study by the German Aerospace Centre, DLR, concluded that by 2038 up to 2,500 hybrid trains, including fuel cell battery hybrid multiple units, could be required for 130 of the local German rail networks either wholly or partly without overhead lines.

In spring 2020 two units of the Coradia iLint finished their 18-month passenger service trial, completing 180,000 km of service and 95% reliability on the Eisenbahnen Verkehrsbetrieb Elbe-Weser line in Lower Saxony. 14 Coradia iLints will begin commercial service in 2021/22, replacing the current diesel units. The Coradia units will be refuelled by the world's first rail-dedicated HRS at Bremervoerde station. Linde will build the HRS, using UK's ITM electrolysers, with some funding from Germany's National Innovation Programme for Hydrogen and Fuel Cell technology.

The successful lower Saxony trial has further cemented interest across Europe. May saw Alstom get a €500m (US$565m) order for 27 iLints for lines around Frankfurt, due in 2022 and including hydrogen supplied by Infraserv. Another iLint was tested on the line from Julich to Obermaubach, with the local transport authority expected to order two units, and in the Netherlands one completed testing over the 65 km between Groningen and Leeuwarden. In Austria the Federal Railways tested a unit for three months on rail lines around Vienna. Italian rail operator Ferrovie Nord Milano has ordered six Alstom Coradia Stream trains, using the same fuel cell technology as the iLint, for service beginning in 2023. Snam, the Italian gas utility and infrastructure provider, will work with Alstom on providing hydrogen.

All this has led to orders for at least 41 train units, produced in Salzgitter, Germany. And since these trains require fuel cells, Cummins, which acquired Hydrogenics and hence this fuel cell business line, will open a factory in Herten, Germany to manufacture the PEM power modules and systems.

Although Alstom has been the pioneer, other European businesses have plans. The Siemens Mireo Plus H incorporates Ballard fuel cells into its Mireo regional train platform to provide 600 km of range at up to 160 km/hour (99 mph). Early in 2020 Siemens and Deutsche Bahn signed the 'H2goesRail' partnership, to test the train over lines in the Tübingen area of Germany from 2024, using hydrogen from renewable power. Spanish rolling stock manufacturer CAF plans to develop a fuel cell version of its Civia three-car regional platform, using Toyota PEM modules hybridised with batteries as part of an FCH JU funded project; and Talgo, another Spanish player, has announced tests of its Talgo Vittal One in 2021. In France, national rail operator SNCF is working with regional authorities to introduce the Alstom Regiolis fuel cell hybrid train to the regional TER services, 50% of which run on diesels today. The Regiolis should start operations in 2021 in the regions of Grand Est, Occitanie, and Nouvelle Acquitaine. SNCF aims to eliminate all diesel trains by 2035.

The UK has similar aspirations, but with more non-electrified lines and some 2,500 diesels that need replacing in the near future. The start point is to convert existing older electric trains. In summer 2020, train leasing business Porterbrook's HydroFlex fuel cell train ran on a UK mainline. A converted Class 319 with a Ballard fuel cell, developed in conjunction with the University of Birmingham, the train retains overhead and third rail capability. The objective is to extend the lives of older EMUs in its fleet by replacing diesel units. Another train leasing business, Eversholt, and Alstom are investing £1m in the UK to develop the Breeze fuel cell train. This is another conversion of an existing older EMU class, the 321, of which there is a fleet of 177. The Breeze, also to replace diesels units, will become the 600 series and be converted at Alstom's Widnes Transport Technology Centre.

In Scotland, Arcola Energy has worked with Brodie Engineering on adapting a redundant ScotRail class 314 unit to operate on fuel cells, to demonstrate the feasibility of operations over Scotland's non-electrified lines. The Scottish Government wants to eliminate diesel services within 15 years, five years before the rest of the UK rail network.

Whilst the focus in Europe is on passenger trains, moves are afoot to undertake a pilot project in northern Sweden to convert diesel freight locomotives to hydrogen. Polish train manufacturer Pesa Bydgoszcz also has its eyes on a fuel cell freight locomotive and is cooperating with refiner PKN Orlen on the project to deliver a demonstrator in 'three to four' years.

Asia

Fuel cell train developments have been underway in Japan since the 2000s, but progress has been slow. East Japan Railways has long had plans to demonstrate the technology and signed an agreement in 2020 with Hitachi and Toyota to develop the two-car fuel cell Hybari. Toyota will supply four 60 kW modules, based on Mirai technology, and Hitachi the hybrid powertrain, including two 120 kWh lithium ion batteries, for testing from 2022.

In contrast, Korea's ambitions for fuel cell trains are relatively new. The Korean Railroad Research institute has announced that it will use 400 kW of Horizon PEM modules for a train demonstrator and start a three/four-year test programme in 2021. It is not clear whether this development is in place of or additional to work with other organisations, including Woojin Industrial Systems, on a design incorporating a 1.2 MW fuel cell. Rolling stock manufacturer Hyundai Rotem has agreed with Hyundai automotive to use 95 kW of PEM modules for a fuel cell tram, top speed 70 km/hour (43 mph), range 150 km, for testing in 2021. Hyundai Rotem also signed an agreement with Ulsan city to assist the development of a proposed 48 km tram network due to open in 2027.

Tram development is also active in China. Rolling stock business CRRC already delivered fuel cell trams for Qingdao and Tangshan in 2016 and 2017, and 2020 saw the service start on the first phase of the 17 km Gaoming line, with eight trams supplied by CRRC Qingdao Sifang powered by Ballard fuel cell modules.

India, like Korea, is a relative newcomer. Nevertheless, Indian Railways has announced ambitious plans to electrify its entire network by 2024, and for only clean power to be used by 2030. Fuel cell trains are part of the mix. A four-car unit will be converted by the Diesel Loco Modernisation Works in Patiala to operate with 300 kW of fuel cell modules and batteries and be capable of 140 km/hour (87 mph).

USA

Like Japan, the USA has seen fuel cell train developments over the years, but no real deployment. This will change in 2024, when the San Bernardino County Transport Authority will start operations with a two-car hydrogen FLIRT train, with technology from Stadler Rail of Switzerland.

Material handling and forklift trucks

2020 saw more growth for materials handling vehicles, still mostly in North America. Plug Power maintains its domination, with nearly 10,000 systems shipped. System sizes are growing too: Nuvera added a 60 kW engine for heavier applications, and a wider range of applications is being demonstrated, from larger container handling equipment at air and seaports, to tractors in China, and niche applications like snow groomers in Europe.

Hyundai also entered the sector (to complement its car, bus, truck, train and ship offerings), signing an MoU between Hyundai Mobis, Hyundai Motor Company and its engineering and construction unit early in 2020. Seven months later, a first forklift with a 5 t carrying capacity was showcased, built around the NEXO engine. This is the first medium-sized H_2 forklift and it will be trialled at ports and distribution centres. More forklifts and medium to large excavators are slated for commercialisation in 2023. In the meantime, July saw UK construction vehicle OEM, JCB, announce the world's first fuel cell excavator. The 20 t 220X excavator successfully completed 12 months of trials. JCB has ambitions to be a world leader in hydrogen powered construction equipment (and now also buses), complementing its battery electric offerings.

Despite COVID, Plug managed to nearly double its shipments year-on-year, including moving towards fulfilment of a US$172m 2019 order for H_2 forklift deployments including GenDrives, the GenFuel H_2 fuel, storage and dispensing gear, and GenCare aftermarket service and support. Other GenKey deployments include a six-month trial for UK supermarket ASDA's chilled distribution centre, with a view to more widespread adoption.

Gaussin, an engineering company for transport and logistics products, intends to use Plug's ProGen range for logistics vehicles for seaports, airports and distribution hubs in 2021 for European, US and other global markets. Green hydrogen will fuel the zero-emissions vehicles and help its uptake in logistics clusters. Plug Power targets 50% of its hydrogen to be green in 2024.

Also in Europe, French retail giant Carrefour is using 137 forklift trucks from STILL, a KION Group company, in a large scale pilot – again using Plug systems. Linde, also under the parent KION, demonstrated its Plug-powered FC30 fuel cell forklift in Switzerland. The two brands are pooling their experience into KION's New Energy Systems unit. Linde's demonstration followed an announcement of an MoU with Plug Power for its larger systems for on-road Class 6 and Class 8 trucks, to be used by Linde for product deliveries as early as 2021.

Nuvera has added more than just a 60 kW unit: two 45 kW, E-45 fuel cell engines are integrated into the Hyster container handling, top-pick and reach stackers for the ports of Los Angeles, US and Valencia, Spain, and the 60 kW E-60 itself can be expanded for on-road applications up to 120 kW.

Not to be outdone, Toyota fielded the first hydrogen fuel cell utility tractor rig (UTR) with Fenix Marine Services at Pier 300 in the Port of Los Angeles. Based on the Mirai fuel cell, the aim is to test its use in the real world which could see it support the movement of 1 million containers per year. And not far behind Toyota was the trial of a yard tractor from Terberg in the United Waalhaven Terminals in Rotterdam.

Fuel cells are also being demonstrated on the ski slopes of Austria, in a snow groomer, and in Chinese fields in a fuel cell electric tractor. The old and wise amongst you will recall that the very first fuel cell vehicle, in 1959, was an Allis Chalmers tractor. Plus ça change…

Maritime

Cleaner shipping is high priority, and while much of the focus is on long-term large-scale use of cleaner fuels, 2020 did see more fuel cell activity. More marinized fuel cell offerings have emerged, with a better range for smaller vessels. Shipyards are trialling cold ironing and ports are great cluster locations for hydrogen, including land-side applications like materials handling and port drayage. Ballard, CMR Prototech, Nedstack, PowerCell and Proton Power have all received stack orders for hydrogen-based shipping applications for 2021, and Freudenberg has approval in principle by DNV GL for its methanol-fuelled fuel cell, which will be installed on an AidaNova cruise ship in 2021 for the 'Pa-X-ell 2' project. Toyota has developed a fuel cell system for marine markets, with trials now taking place on the Energy Observer green catamaran. An associated company, EODev (Energy Observer Developments), now offers portable fuel cells, range extenders to 1 MW and a floating platform for H_2 supply in marinas.

2020 saw Ballard's Marine Centre at Hobro, Denmark, launch (ha ha) the industry's first module designed for primary propulsion power in ships. The 200 kW FCwave, claimed to last more than 30,000 hours, can be scaled to multi-MW power levels. ABB extended its MoU with Ballard to build PEM systems for ocean-going ships, with stacks to be assembled at HDF Energy's facility in Bordeaux. Other projects in build include the ELEKTRA hydrogen push boat, with operation on the Elbe planned from 2021; the HySEAS III ferry, now expected to come into service with Caledonian McBrayne in 2022; and Compagnie Fluvial de Transport's Rhône push boat, part of the FCH JU FLAGSHIPS project, is expected to start operations in 2021.

Norway – a hive of activity

Norway's drive for zero emissions fjords is pushing hydrogen in shipping, including design company LMG MARIN and ferry operator Norled. Another FLAGSHIPS ship is a retrofitted biodiesel-fuelled ferry, MF Hilde, with fuel cells and hydrogen, for operation on the Norwegian west coast Judaberg-Helgøy route in 2022. LMG Marin is fitting two further ferries, Hydra and Nesvik, with two 200 kW FCwave modules and 80 m^3 liquid H_2 storage, for the Hjelmeland-Nesvik route. LH2 is planned to come from a new facility in Mongstad, Greater Bergen, involving BKK, Equinor and Air Liquide. The same LH2 should supply the Topeka Ro-Ro ferry, developed by Wilhelmsen as a member of the 14-partner HyShip project, that will transport goods between Kristiansund and Stavanger as well as distribute containerized LH2 from Mongstad to bunkering hubs. And while Viking announced back in 2017 that it would develop a 900 passenger, 500 crew cruise ship using the LH2 bunkering, more recent reports suggest LH2 is being considered for cold ironing of the cruise ship.

'FreeCO2ast', an ENOVA (PILOT-E) funded project focused on large ships, has Havyard Group leading with Norwegian Electric Systems delivering the design, Linde the LH2 tanks and PowerCell the fuel cell modules. Four ships are contracted, the first should start operating in 2021. Multiple marinized 200 kW modules deliver a total power of 3.2 MW, the largest yet deployed on a ship. Another ENOVA-funded project, the 'Hellesylt Hydrogen Hub' will be a H_2 supply facility to ships in the Geirangerfjord, 200 km NE of Bergen, one of two World Heritage Fjords in Norway. Ferry operation should begin by 2022, with H_2 from surplus hydropower at Hellesylt by 2023. Edda Wind has signed long-term charters with MHI Vestas and Ocean Breeze Energy, for two of four offshore wind service vessels to be powered by H_2 fuel cells, ordered from Spanish yards. The hybrid electric newbuilds, also ENOVA-funded, will be operated by Østensjø Rederi AS from 2022, servicing the BARD farm, 100 km offshore.

Other parts of Europe are not standing still

Initiatives are multiplying elsewhere too: ShippingLab, the consortium to realize the Danish Blue Hydrogen initiative, plans a large (Ballard) fuel cell dredger with H_2 from wind at the Port of Hvide Sande; the Waddenfonds Green Shipping initiative will start with a mobile H_2 (Nedstack) fuel cell generator in ports; and E.ON, Port of Rotterdam Authority and DeltaPort Niederrheinhäfen are to create an inland infrastructure for goods transport by 2050, starting with a pilot on the German inland DeltaPort location in Voerde & Wesel. The Port of

Den Helder, ENGIE and Damen Shipyards plan to develop HRS facilities for maritime and road transport in the Den Helder region, with €1.4m from the German finance fund DKTI. The 2.6 MW solar park, electrolyser, HRS facility and a H_2 fuel cell ship should be operational in 2021.

Nedstack is now developing 200 and 500 kW stacks for marine markets, and is a partner in the FELMAR-consortium. In the WEVA project, the 135 m vessel Antonie van Lenten will be fuelled by green H_2 from the Nouryon salt factory in Delfzijl and run to the Botlek in Rotterdam. Two more ships are already in development. The Ulstein SX190 Zero Emission hybrid support vessel has a total installed power of 7.5 MW, with a 2 MW PEM from Nedstack, the balance diesel electric. Sea trials of the ship are expected from 2022.

AVL is supporting TECO 2030 ASA in the development of its TECO Marine Fuel Cell, designed for heavy-duty marine use. The systems should be deployed on tugboats in the Blue Danube hydrogen and similar projects. Proton Motor Power Systems won a second order for a 144 kW fuel cell for Fincantieri's 25 m long floating lab, 'ZEUS' (Zero Emission Ultimate Ship), while PowerCell delivered an MS-30 system. In September, Kontakt-Elektro showcased its commercially-available fuel cell motor cruiser in Hungary. The 6.2 m boat can transport 8 people at up to 12 knots (22 km/hour), at this speed for 37 NM (66 km).

It's not just PEM fuel cells

MSC Cruises project PACBOAT will integrate a CEA Liten 50 kW SOFC onboard the LNG-powered Europa cruise ship due to go into service from 2022, and the American Bureau of Shipping and Daewoo Shipbuilding & Marine Engineering have a joint development project to use SOFC technology to replace at least one of three diesel generators typically on-board a Very Large Crude Carrier. Meanwhile, Wärtsilä is developing ammonia storage and supply systems for use on Eidesvik Offshore's supply vessel Viking Energy within the EU project ShipFC. Wärtsilä already designs LPG cargo handling systems, also used to transport ammonia. The ship will field a 2 MW ammonia fuelled fuel cell by 2023.

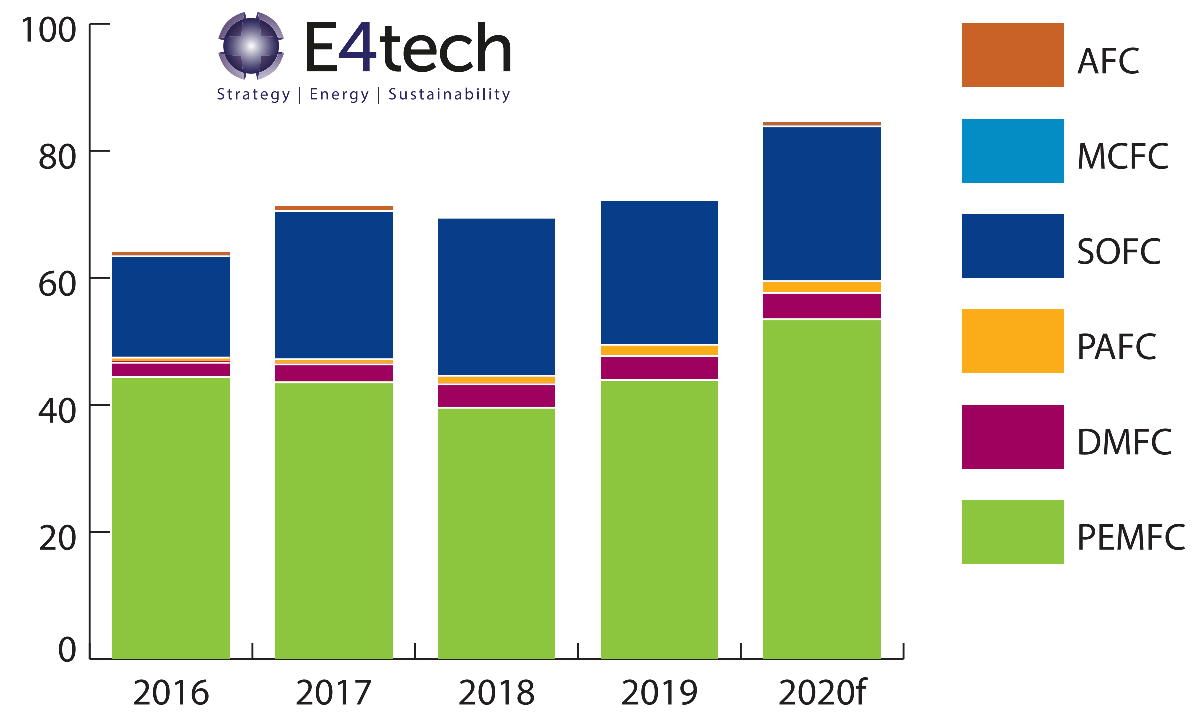
Asia is following fast

In the 'Commercialization of Hydrogen Fuel Ships' project, Vinssen HL (with Hyundai as an investor) will put H_2 fuel cell vessels in the Ulsan Metropolitan City's Hydrogen Green Mobility Regulatory Free Zone, for small vessels operating on the Taehwa River from 2021. Hyundai Mipo Dockyard is to build a ship propelled by fuel cells, with either diesel or LNG fuel, by 2022, to carry up to 375 passengers. Bloom Energy and Samsung Heavy Industries (SHI) will collaborate in the design and development of fuel cells for shipping. SHI plans to replace all existing main engines and generators with SOFCs, aiming to present a design to customers in 2022.

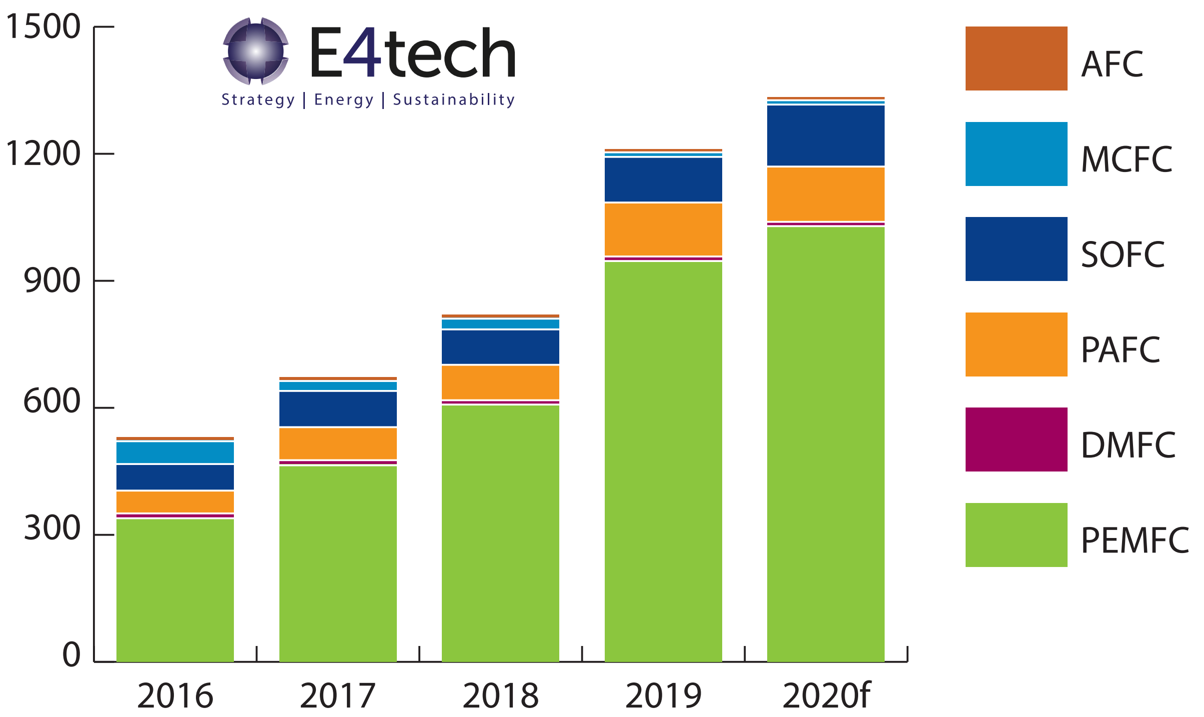
Yanmar signed an MoU with Toyota to develop fuel cells for maritime applications, based on Mirai systems. Field tests are planned for early 2021. And NYK Line, Toshiba Energy Systems & Solutions, Kawasaki Heavy Industries and ENEOS are looking at powering a medium-sized tourist ship with TESS H_2 fuel cells: design 2021, construction 2023, demonstration 2024. Meanwhile Mitsui OSK Lines and e5 Lab, Tokyo, are studying a car carrier with a hybrid fuel cell drive for inshore zero emissions operation. Offshore, the ship would use an LNG-fuelled generator and large-capacity batteries.

Shipments by fuel cell type

Shipments by fuel cell type 2016 - 2020 (1,000 units)



Megawatts by fuel cell type 2016 - 2020



2020f is our forecast for the full year, based on firm data from January to September, and in some cases to as late as December.
We have revised the figures for 2019 in this report, now with firm full year data where previously a final quarter forecast was required.

Shipments by fuel cell type

Led by passenger cars and micro-CHP shipments, **PEM** fuel cells continue to dominate, both in number and in capacity. Over 53,600 units were shipped in 2020, or ~1,030 MW. The range is extensive: from direct hydrogen units used in vehicles to reformer-based fuel cells in micro-CHP, fuelled by natural gas and LPG. This number is up from the just over 45,700 units (948 MW) shipped in 2019.

SOFCs remain second in terms of unit numbers. The nearly 25,000 units equated to 148 MW capacity shipped in 2020, up from nearly 22,000 units and 107 MW capacity in 2019. This growth in SOFC units comes largely from an overall rise in Ene-Farm shipments, enhanced by a slight shift from PEM-based units towards SOFC, favoured by their higher efficiency and slowly reducing system costs. In capacity terms, Bloom Energy servers continue to be deployed, now also in significant volume in South Korea through SK E&C. Future opportunity exists in data centres, with units expected from Bloom, from Bosch, using Ceres' SteelCell technology, and from others such as SOLIDpower – though significant volume will take time.

The next largest fuel cell type shipped, by capacity, is the **PAFC**, led by Doosan Fuel Cell and with smaller stacks also from Fuji Electric. Doosan's reported shipments remain well over 100 MW, and their Q4 report suggests sales of PAFCs in Korea may quadruple by 2024, buoyed by a near tripling of manufacturing capacity to 260 MW/year in 2021.

MCFC remains the exclusive domain of FuelCell Energy, though the company also has SOFCs in development. Production suffered further in 2020, and stands at less than 10 MW pa, with only one new shipment reported.

AFCs remain the Cinderella of the fuel cell world. In both number and capacity, these hardly figure in the count. GenCell Energy's investor website discloses just 18 installations since its formation in 2011. But AFC is an intrinsically low-cost technology and the position may change. With ABB, AFC Energy plans to bring a DC Fast Charging system for EVs to the market in Europe and US in the second half of 2021. Bosch plans to bring a similar (SOFC) offering to market in conjunction with Ceres.

DMFCs remain the mainstay of portable systems below 100 W, where the high stack costs are offset by the ease of refuelling and long runtimes. These continue to ship in the low thousands (nearly 4,000 in 2020). As the required power approaches 1 kW or more, PEMFCs are favoured on cost grounds, exemplified by SFC Energy's use of adKor PEM technology in delivering power supplies for BOS digital radio towers in Germany.

We count **PBI** fuel cells as a PEM variant. Danish company SerEnergy continues to ship product for backup power, while Blue World Technologies has begun limited production of units for Gumpert Aiways' high end Nathalie passenger car, though numbers could increase as it plans to put in place 5,000 units or 50 MW of capacity.

Stationary fuel cell systems

The deployment of stationary fuel cell systems in 2020 followed the steady but unspectacular growth trend of the past few years. While the effect of COVID has slowed things in Europe and the USA, Asia has steamed ahead. The sector remains heterogeneous, with every fuel cell technology represented across the size spectrum from kW to MW, reflecting differences in operating performance, power densities and fuels.

Japan still leads the numbers game

Deployment in Japan reflects the longstanding commitment of both Government and industry to Japan's Hydrogen Society ambition. 2020 saw new stationary fuel cell developments and products announced – which should build the commercial proposition and enable faster deployment to come.

Japan is home to by far the world's largest fleet of micro-CHP fuel cells. Deployment of these Ene-Farm units since 2011 has been about getting the volume required to drive the technology along the learning curve and generate substantial economies of mass production. Though others have come and gone along the way, Ene-Farm units are now PEM technology from Panasonic and SOFC from Aisin Seiki. The flagship products are both rated at 700 W, operate on natural gas or LPG, and are supplied via Japan's gas companies, notably Tokyo Gas and Osaka Gas. Official figures suggested 313,000 Ene-Farm units in total had been deployed by March 2020, 43,000 more than a year earlier. Our figures suggest a full calendar year increase close to 47,000 units over 2020. While this leaves installations some way short of the aspirational 2020 target of 1.4 million units announced at the start of the programme, the market is now close to self-sustaining, and a 2030 target of 5.3 million remains.

Industry continues to invest: in February Aisin Seiki, working with Kyocera and Toyota Motor, released a new model Type S (SOFC) system, with increased electrical efficiency of 55%, up from 53%, and an overall efficiency of 87%. Service life is up from 10 to 12 years. Panasonic's new PEM micro-CHP system for apartments came out in June 2020, and can handle 200-700 W electrical outputs and operate in blackout mode, with an electrical efficiency now up to 40% and overall efficiency claimed at 97%. Like Aisin's unit, it is lighter and smaller than previously. While PEM is considered mature and has received no subsidy since 2019, SOFC support remains. The retail price for the Aisin Seiki unit is ¥1.68m, about US$16,300, above the target price of ¥1.23m set by Government, and will still get a small subsidy.

Interestingly, in mid-2020 METI announced projects with four utilities to build virtual power plans using customer-side assets. Osaka Gas intends to use 1,500 Ene-Farm units, with Internet of Things capability, as a source of additional power when required by the grid. The value proposition of micro-CHP systems should be enhanced if such virtual power plants become mainstream.

(Not yet) commercial units?

Bigger, so-called 'commercial scale' fuel cell systems of ~5 kW to 100 kW have lagged the smaller units. More expensive to develop, they came later to the market and have not been supported by policy in the same way. Published Japanese data suggest fewer than ten SOFC systems operating in early 2020, including Miura's FC-5B 4.2 kW SOFC system using Ceres SOFC technology. Miura and Ceres have announced a joint specialist maintenance team for these systems in Japan's metropolitan areas, which tends to suggest a higher number of fielded ~5 kW units than published. And Kyocera's 3 kW system is also available, but the status of SOFC developments reported in the past by Denso, Hitachi Zosen and Fuji Electric remain unclear. Fuji still manufactures PAFC based FP-100i systems of 100 kW, but sales have been slow.

From natural gas to hydrogen?

In contrast to the SOFC and PAFC systems, interest in hydrogen-fuelled commercial scale PEM is more bullish. Using pure hydrogen as a fuel eliminates the expensive natural gas reforming system and substantially raises the electrical efficiency, to more than 50%. For now, the challenge is a reliable and sufficient supply of hydrogen, which at present mostly comes from 'brown' sources – natural gas using steam methane reforming. But with a global drive for green hydrogen, change is expected.

Toshiba Energy Systems and Solutions has been a pioneer in the commercial deployment of hydrogen fuelled PEM systems for stationary power and heat. Its H2Rex system has been deployed at 120 sites across Japan, at power ranging from 700 W through 3.5 kW to 100 kW. Hotels, stores and markets are customers. The system boasts 50-55% electrical efficiency, and 90%+ total efficiency in the power and heat mode. Renewable hydrogen is entering the mix, with 2020 seeing an H2Rex system deployed at Michinoeki-Namie in Fukushima, using hydrogen from the Fukushima Hydrogen Energy Research Field, an electrolyser plant powered by 10 MW Solar PV. Toshiba, having abandoned its smaller Ene-Farm units, is relocating its H_2 energy production facility, from Yokohama City to the Ukishima area, upscaling production ten-fold to meet demand. Toshiba even announced a 1 MW PEM system, comprising ten of its standard 100 kW modules.

Toyota's interest in broadening uptake of its Mirai PEM automotive units continues. Following installation of a 100 kW PEM system at its Honshu plant in 2019, 2020 saw verification tests of a 50 kW stationary system in Shunan, working with the chemical business Tokuyama, using by-product hydrogen. And Panasonic is working on the deployment of hydrogen fuelled PEM systems at the 18 hectare Harumi Flag property development in Tokyo for 2021, despite the postponement of the Tokyo Olympics. The hydrogen-fuelled 5 kW systems will achieve 57% electrical efficiency. Brother Industries' BFC4-5000 unit, with a 4.4 kW power output, is also targeted at the commercial market.

Fuel Cell Hybrids

Mitsubishi Power, the new name for Mitsubishi Hitachi Power Systems, is the world's only developer of a pressurised SOFC hybrid system still standing. The 250 kW MEGAMIE system, an SOFC stack with a turbine driven by the high temperature exhaust from the SOFC, is still in early commercial deployment though. April 2020 saw a second 'commercial' system start operations at the Hazama Ando Technical Research Institute at Tsukuba in Ibaraki Prefecture. The SOFC stack comes from CECYLLS, the JV established in February by Mitsubishi and NGK Spark Plug, whilst the micro-turbine is supplied by Toyota.

Korea has the power

Korea remains the leader in the deployment of stationary fuel cell systems at the industrial/grid scale. The world's largest fuel cell park, 59 MW of Fuel Cell Energy/POSCO MCFC systems, is in Gyeonggi, and 2020 saw it joined by the world's largest 50 MW facility fuelled purely by hydrogen, in Daesan. 114 of Doosan's 440 kW PureCell PAFC systems use by-product hydrogen from Hanwha's nearby petrochemical works to supply power and heat to the local grid.

Korea's fuel cell ambitions are very much part of a plan. Government sees hydrogen and fuel cells as an enabler of emissions reductions, energy diversification and both domestic and export-led economic growth. 8 GW of large-scale stationary fuel cell systems is planned for 2040, with another 7 GW exported. 2.1 GW more will provide power and heat for buildings. That translates to annual deployment in the range of 350 MW-400 MW. Up to now, deployment has been driven by a Renewable Portfolio Standard which includes fuel cells, and which ratchets up annually. It looks like 2022 will also see a Hydrogen Portfolio Standard, separating hydrogen and fuel cells from typical renewables like solar and wind. This should further boost demand.

These stationary fuel cell technologies have primarily been acquired from overseas. Doosan, POSCO and SK Engineering and Construction (SKE&C) have either bought foreign technology or partnered with non-Korea technology suppliers. POSCO Energy pioneered the approach, working with Fuel Cell Energy. Doosan acquired the erstwhile UTC PAFC technology, and SK E&C has partnered with Bloom Energy and their SOFC systems. SK E&C's parent, SK Group, entered into a JV with Plug Power very early in 2021, though not for stationary systems.

Doosan Fuel Cell has been installing its PureCell PAFC units as fast as it can manufacture them. At the end of 2019, 318 units (140 MW) were under construction, supplied by factories in Iksan, Korea and South Windsor, Connecticut, USA. The 2020 target across South Korea is 142 MW. The Incheon Fuel Cell development, supported by Korea Hydro and Nuclear Power, ordered 39.6 MW. Doosan has its sights set high – the 2023 global sales target has been raised to 300 MW – up from 184 MW in 2019. The Iksan plant capacity will increase to 260 MW per annum. And ambitions go beyond its current PAFC technology: it wants to be "Hydrogen Energy Global No. 1 Player", adding both PEM and SOFC technology to its portfolio. The SOFC roadmap, built around a technology agreement with the UK's Ceres, includes a 50 MW manufacturing plant, breaking ground in 2021. Solid oxide electrolyser development is also part of the mix.

Bloom Energy, for a long-time firmly US-focused, and its Korean partner SK E&C are working on a factory in Gumi to manufacture 50 MW of Bloom's SOFC systems under their JV. 2020 saw two Bloom-powered facilities start operation in Gyeonggi: 19.8 MW at Hwasung and 8.1 MW at Paju. Korea Midland Power has ordered 6 MW and another 900 kW will go to KT Corporation, the telecoms business. Korea now features strongly in Bloom's longer term technology strategy with hydrogen-fuelled SOFC systems to be fielded in 2021 in partnership with SK E&C, as well as electrolysers. One home for the hydrogen-powered units will be the Changwon RE100 Project, which will take 1.8 MW. Solid Oxide electrolyser systems will be added from 2022.

POSCO Energy and Fuel CellEnergy remained locked in stasis, with FCE terminating its marketing agreement with POSCO in summer 2020. But elsewhere in Korea, stationary fuel cell systems are part of Hyundai's plans. Like Toyota, it is applying its NEXO automotive PEM technology to the market, and in September 2020 it shipped systems to Switzerland's GRZ Technologies as part of power supply systems for buildings. Indigenous S-Fuel Cell started exporting fuel cell units to China, also for buildings, and another Korean business, Bumhan, was reported to be sourcing PowerCell PEM systems for applications in Korea.

North America remains subdued

The USA has pretty much all of the stationary deployments in North America, using mainly home-grown technology: Doosan's systems were originally developed by UTC in Connecticut; FuelCell Energy's too; and Bloom Energy is in California and Delaware. Deployment has been – and continues to be – driven by a mix of Federal and State regulations, capital subsidies, tariffs and tax breaks. End user interest in green, self-energy generation is growing though; attractive to the USA's larger corporations with declared environmental policies and targets. In States with weaker or congested grids on-site self-generation is also tempting.

But deployment of stationary systems in North America in 2020 was down, maybe linked to political uncertainty, perhaps also to the impact of coronavirus on general US economic activity and investment decisions. While Bloom had already reported 92 MW of new acceptances by Q3, 28 MW of those were headed for Korea. New US orders or intentions included retail chain Stop & Shop, planning to convert 40 of its stores to Bloom's AlwaysON microgrid system. Systems were also delivered as COVID response units to Vallejo and Sacramento medical facilities in California, and to two Southern California Gas facilities in Los Angeles, plus the Gillette Stadium in Massachusetts. An AlwaysON system was also reported to be operating in Yokohama City Hall, Japan.

FuelCell Energy still seems to be rebuilding after its existential crisis in 2019, focusing on restructuring its finances as well as adopting its new 'PowerHouse' Strategy, built around Power Purchasing Agreements. Although it booked few new product sales in 2020, the order backlog in terms of PPAs remains substantial. But developments did continue: 7.4 MW of SureSource 4000 units for the US Navy Base at Groton, CT; the smaller San Bernardino, CA 1.4 MW SureSource 1500 which will operate on biofuels; and a SureSource 4000 at the Danbury, CT Triangle Street development. FCE's Torrington facility, shut in March due to the Coronavirus crisis, resumed production in June. The only new orders announced were for four SureSource 3000 (2.8 MW) units for four sites across Connecticut, under the Shared Clean Energy Facility sponsored by the State, and will be operated under 20 year PPAs providing power to EverSource and United Illuminating utilities.

Doosan Fuel Cell America now operates in the shadow of its Korean sister plant Iksan in terms of numbers, but retains a healthy backlog and is producing at or close to capacity. New units included those for the New Britain development in Connecticut, and a proposed tri-generation unit for Toyota Long Beach, CA remains on plan.

Three other major developers can serve stationary markets, although their attention to date has been on mobility. The first two are Canadian: Hydrogenics offers its Hy-PM XR units from kW to MW scale, but its focus in recent years has been almost exclusively mobility. Cummins, owners of Hydrogenics for a year now, may be focusing its stationary ambitions on the SOFC technology it acquired from GE. Ballard has largely scaled back its stationary activity to its smaller FCgen-H2PM systems for back-up and remote applications, including telecoms, though it does have a 1 MW PEM stationary system using by-product hydrogen at a refinery in Martinique in the West Indies. Ballard also has a Product Development Agreement with Hydrogène de France to develop and manufacture PEM systems as part of HDF Energy's Renewstable power generation system which integrates the fuel cell with electrolysers, hydrogen storage and renewable power. Plug Power of the USA has had some interest in smaller size system for telecoms applications, and now has its new GenSure High Power Platform for stationary power applications of between 500 kW and 1.5 MW for high power end users, such as data centres. These will use 125 kW ProGen Systems packaged in standard ISO containers.

Europe is big on ambition but small on numbers

Far fewer stationary fuel cells systems have been deployed across Europe than in North America, Korea or Japan. The market is more fragmented, grids are typically stronger and more reliable, and subsidy regimes and regulations less favourable. But European businesses continue to develop and invest in a range of stationary power technologies.

Deployment to date has hinged on European Union initiatives led by the Fuel Cell and Hydrogen Joint Undertaking 2 (FCH 2 JU), or country level-support, the most important of which is Germany's Federal KfW 433 grant. The FCH 2 JU's PACE programme is a five year, €90m initiative supporting 2,800 micro-CHP fuel cell systems across ten countries and involving five of Europe's leading domestic micro-CHP developers: BDR Thermea, Bosch, SolidPower, Sunfire and Viessmann. KfW 433 will support systems of between 250 W and 5 kW electrical with up to €28,800. Not surprisingly, most fuel cell deployments in Europe have been in Germany, though Belgium has seen substantive deployment in Flanders, where both PACE and some smaller regional Government support is available. Other countries receiving PACE units include Italy, Netherlands and the UK. But PACE is due to end in 2022 and some suppliers have nearly met their commitments. No plan for a successor has yet emerged, though KfW 433 will be continued, possibly even with slightly higher support, and Italy has a little-known programme which, under certain circumstances, promises to offer 110% of the capital cost of a system.

Between them, the five developers above field both PEM and SOFC micro-CHP units, and introduced new products for 2020. BDR Thermea's latest SenerTec Dachs PEM system has 750 W power, 38% electrical efficiency and 92% overall. Stack life is an impressive 12 years. The BDR Thermea Group's Dutch subsidiary Remeha's eLecta 300 also uses a PEM stack. As with most domestic systems, the waste heat is supplemented by a burner, often for much more thermal power – 5.2 to 21.8 kW in this case. The Remeha subsidiary also began public trials of a pure hydrogen boiler system (no stack present) in Rozenburg in June, with plans for a larger trial in the UK to follow.

Sunfire has a variant of its Sunfire Home SOFC system using LPG, with outputs of 750 W power and 1.25 kW heat, at an advertised electrical efficiency close to 40% and overall efficiency at 89%. The SOFC stack, the PowerCore, is also used in the Sunfire-Remote system available at 400 W to 1.2 kW, and optionally to 3. 6kW operating on propane/natural gas. These are targeted for remote locations such as sensors on oil and gas pipelines, and railway infrastructure, including that of Deutsche Bahn.

Viessmann's offering is a new 750 W VitoValor PT2 System, still based on Panasonic's PEM module and incorporating a boiler and hot water tank to boost the thermal capability. Electrical efficiency is 37%, overall efficiency 92% and the stack life also 12 years. Bucking what is a trend towards SOFC in some places, June 2020 saw Viessmann sell its Hexis SOFC business to mPower GmbH, a subsidiary of India's h2e Power Systems business. Viessmann retains a right to use Hexis SOFC technology, however, in its stated role as a system integrator, a useful route to market for mPower, which also has accesss to IKTS SOFC technology developed in Dresden.

Italian business SOLIDpower has been focused on improving and developing the BlueGEN technology it acquired when Australia's CFCL went bankrupt and merging the best of that with the best of its own in-house technology. The BlueGEN units are produced in Heinsberg, Germany, whilst SOFC cells and stacks come from the 25 MW capacity factory in Mezzolombardo in Italy, opened in August 2020. The BlueGEN technology is also used in Bosch's Buderus brand SOFC micro-CHP system, replacing the Japanese Aisin Seiki unit formerly used. Electrical efficiencies of up to 60% are advertised for units of 5 to 11 kW.

SOLIDpower is reported to be working on two further commercial scale systems: a 6 kW BlueGEN (BG-60) system with 60% efficiency for 2022, and a 180 kW system incorporating 30x 6 kW stacks. The market focus for this will include data centres and other power-hungry applications in grid congested locations. SOLIDpower has also been working on a 25 kW Solid Oxide electrolyser.

The complicated web of fuel cell relationships includes another Bosch agreement, this time with Ceres, another of Europe's SOFC developers. Bosch increased its equity stake in Ceres from 4% to 18% in 2020, for £38m (US$49m). The technology is destined for commercial scale applications, and Bosch has started manufacturing Ceres cells and stacks at a pilot facility in Germany. 10 kW SOFC systems are going into five sites in Germany. Ceres has other relationships too. Its business model is different from most other developers, as it is based on licencing agreements with OEMs, usually systems integrators. Significant partners include Miura and Honda in Japan, Weichai of China and Korea's Doosan. The agreement with Doosan for Ceres' SteelCell technology, for commercial scale units of 5 kW to 20 kW, was extended in October 2020 for £43m plus licence fees. And in the UK Ceres opened its new Redhill pilot cell and stack plant, already earmarked for a capacity upgrade from 2 MW to 3 MW per annum.

Elcogen, in Estonia, manufactures SOFC cells and stacks in Tallinn for system integrators, including Finland's Convion. 2020 saw an agreement with Magnex, a Japanese SOFC stack and system developer, and with Korean companies E&KOA, an SOFC stack manufacturer, and P&P Energytech, a system integrator. Elcogen plans to expand its European cell manufacturing capacity to 2 MW by 2021/22. The agreement with Convion is for 50 kW C50 fuel cell systems, the first of which was to be installed at the LEMENE project in Finland as part of a microgrid. Convion, spun out of Wartsila, is unusual in that its aspirations are solely towards the commercial 5 kW to 100 kW market segment. The FCH 2 JU's COMSOS project is focused on developing and demonstrating products for this market, and brings together Convion, Sunfire and SOLIDpower to field commercial scale SOFC systems with electrical efficiencies of 50% to 60% and overall CHP efficiencies of 80% to 90%. Convion will deploy two of its C50 units, Sunfire its 20 kW system and SOLIDpower a 12 kW SOFC unit.

German PEM developer Proton Motor, which works across both stationary and mobile applications, was reported to have an order for a 36 kW PEM system for a residential property developer in Bochum, Germany. Proton Motor offers stacks and systems in two sizes, up to 8 kW and up to 25 kW.

The Energy Observer yacht was intended to showcase integrated hydrogen fuel cell systems globally. Its development spin-off, EODev, has signed an agreement with the Eneria subsidiary of the Monnoyeur Group for the industrialization of EODev's GEH2 generator. The GEH2 offers 100 kVA at 230/400 V and 50 Hz, using Toyota's Mirai H_2 stack. 4 units can be stacked in 20 ft containers to deliver 2 MVA ensembles. EODev also raised a first full round of funding in September, securing €20m investment.

Off-grid

Another long-time and generally slow-moving (there have been occasional annual volumes in the low 100s, mostly for remote telecoms) market for stationary fuel cells is off grid. CHEM has remained in the game, and its ME2 Power G3 PEM RMFC uses 225 L of methanol fuel for up to 100 hours' run time at 2 kW, though it can hit 5 kW. This has proven popular with telecoms tower operators worldwide, including Vodacom in South Africa, Vodafone in India and Docomo in Japan, and over 3,000 units have been sold in 33 countries over six continents. In September 2020 CHEM opened a factory in South Africa's Dube Trade Port Special Economic Zone. This will manufacture G3 system for the South African and other regional markets.

Israel's GenCell, one of only two alkaline fuel cell players, floated on the Israeli Stock Exchange in November. Its A5 and G5 systems play in telecom and power back-up markets, but sales have yet to ramp up. The A5 is fuelled by anhydrous ammonia, which can be much lower cost than diesel, and should run for a full year on a 12 ton tank. The G5 UPS is fuelled by a set of six hydrogen cylinders, delivering 15 hours' backup power at 5 kW output.

Altergy is another survivor, with its 5 kW Freedom Power System sold sporadically into various US states; Ballard has its H2PM system and Hydrogenics (now Cummins) its HyPM-X; and Plug Power's GenSure E series of systems has outputs from 200 W to 4.4 kW. These North American suppliers are likely to see some benefit from the decision by the California Public Utilities Commission to make a 72-hour power back-up mandatory for telecom towers in the State, following extreme weather events and the fire season in 2019, which apparently caused some counties to lose up to 60% of their tower coverage at any one time.

A similar back-up capability applies also to Germany. In January this year Ballard announced Equipment Sales Agreements with adKor GmbH and SFC Energy for 500 FCGen-1020ACS (2.9 kW) stacks to be used in Jupiter systems to support BOSNet digital radio towers across the country in meeting the Federal 72 hour back-up power requirement. Initially, 200 sites are being converted, with a potential for 650 sites in total. Between one and three stacks are required for each tower. Previously, adKor, together with their system partners, had won tenders for emergency backup power equipment for over 400 radio tower sites.

Portable

SFC Energy remains top of the portable fuel cell tree, having sold over 45,000 units in its 20 years. It is the sole volume producer of DMFC systems, though its licensing arrangement with adKor means it also provides PEMFC for needs above about 1 kW, currently for digital telecoms systems. March 2020 saw the deployment of its 1,000th EFOY Pro DMFC, as an off-grid power supply for Singapore, and the EFOY 80 and 150 leisure range have been restyled, made smaller and lighter, and now come with complementing lithium-ion battery options of 70 and 105 Ah capacity. Coupling them with solar means complete hotel load solutions for small boats – and other markets, like the AuroraHut floating panoramic cabins on Finnish lakes.

Also in March, UK-based Bramble Energy unveiled a 1 kW H_2 fuel cell named the K1000 or 'Big Kahuna'. Designed as a diesel generator replacement, the first prototype is in testing and design iteration.

In August, Bramble raised £5m in a Series A round, aiming to launch of its portable power range in 2021. First out will be a 20 W unit (the BD20), shortly followed by 60 W and 100 W versions. These look well suited to BOC's HYMERA CCTV, process monitoring and control, and lighting tower applications. Higher power density, liquid-cooled systems are in the pipeline.

'Portable' fuel cells can also be ported and dropped, often left for long periods of time, or integrated into trailers or cabinets. Recreational boating is increasingly targeted, for example by WATT Fuel Cell's Imperium LPG-fuelled SOFCs of up to 1,000 W. Like SFC, WATT also targets the oil and gas industry, with its Nemesis range. TCP in the UK packages HYMERA fuel cells in lighting and CCTV towers, but also the Intelligent Energy 801 module in the 1.2 kW Eco-GH2 product. Intelligent Energy is also marketing packaged 1.2–4 kW modules as the IE-Lift series, including a battery box replacement for forklifts.

The UK's Adelan has packaged a small LPG-fuelled SOFC as a demonstrator, targeting applications such as welfare cabins for construction sites. And Adaptive Energy (once Adaptive Materials, previously owned by Ultra Electronics) now package most of its small SOFCs in remote stationary applications. UltraCell continues to focus on military applications with its PBI-based RMFC systems.

Estonian company PowerUP now provides portable fuel cell systems with outputs between 200 and 6,000 W. Its UP200 targets smaller uses such as lights, and the top-end UP6K is aimed at cabins, yachts and RVs, and backup power for telecom towers. They claim corrosion-resistance, operability in marine conditions and in all climates. The UP400 targets yachts, to power the essentials of GPS, radio, bilge pump and lights for €8,500 (US$10,300). They run on compressed hydrogen, meaning lightweight Type III cylinders are required.

The longer a portable unit is left in one place, the more like a stationary unit it becomes, such as Adaptive Energy's Performer P250i, packaged by channel partner RedHawk Energy, LLC, to address railway power outages. More fuel cells are being used as critical backup systems, attesting their reliability.

In May, the South African government deployed seven H_2 fuel cell units to a military hospital in Pretoria to assist with the response to COVID-19. Bambili Energy, a microenterprise focused on commercialising IP from the HySA programme, is working with Horizon and Element One to incorporate HySA IP into their products, including

5 of the 7 systems to be deployed. Powercell is the partner for the other 2. Bambili plans local manufacturing of the stationary fuel cell systems by March 2021.

In June, Intelligent Energy supplied a single FCM801 and a single FCM802 module to MBR Global, for a Malaysian microgrid supplying back-up power to individual homes. MBR's existing deployments include Asia's first H_2-based off-grid community, with Enapter supplying its modular AEM-based EL 2.1 electrolyser. The fuel cell modules will be integrated into its H-RES system, which uses H_2 electrolysed from rainwater using PV power.

Vehicle-based power supply platforms remains an option, like Denyo and Toyota's system for disaster relief – and for outdoor events such as concerts. A 7.3 t Toyota 'Dyna' light-duty truck with a Mirai engine and 65 kg H_2 in 27 tanks (total volume 1,626 litre), can both travel long distances and, when static, generate power for long periods of time. The 8.5 kW single and three phase output stack can run for around 72 hours. Toyota and Honda are working together on 'Moving e', a Toyota fuel cell bus that doubles as a mobile power platform for disaster response. The hybrid export power system has a maximum output of 18 kW and a 454 kWh capacity.

Military

Military fuel cell developments remain either very secretive or very limited. SFC Energy remains well positioned, with UltraCell's 50 W XX25 and XX55 systems now joined by the Blade range of ruggedized systems up to 165 W. Adaptive Energy continues to package its SOFC systems for both UAVs and UGVs. Both SFC and UltraCell now provide buried systems for covert watch, fitted with snorkels for air breathing.

Military procurement contracts can be uncertain and patchy. SFC's Q3 report noted sales to the military segment were particularly hit by procurement delays associated with COVID, nearly 70% lower than the comparable period in 2019.

UAVs

More unmanned aerial vehicles, both civil and military, are seeing their batteries augmented with fuel cells. Doosan Mobility Innovation (DMI), Adaptive Energy, Intelligent Energy, Horizon and Plug Power remain very active. Honeywell acquired the assets of Ballard Unmanned Systems in October 2020, one of the former Protonex businesses. Elbit is working with Honeywell to develop a VTOL fuel cell drone with longer endurance. DMI launched its DS30 drone and DP30 powerpack at the 2020 Consumer Electronics Show, claiming a world first in mass producing H_2-powered drones for commercial use. In April 2020, DMI used its drone to distribute 15,000 protective masks to 490 residents of Korea's Gapa, Mara, and Biyang Islands. Hanyang will use the drone to do remote checks of Haenam Solar City, Korea's largest (98 MW) photovoltaic plant. DMI now plans to go bigger, with a 5-15 kg fuel cell package powering drone gross weights of 100-200 kg, covering distances between 100-400 km.

Intelligent Energy has also been busy, signing a distributor deal in April with Japanese UAV company RoboDEX Inc, based around its 2.4 kW module. June saw a similar agreement with Korea's Hogreen. A retrofit of the module into a M600 Pro frame with a 9 litre, 300 bar cylinder delivers 80 min flight time against 20 minutes with battery alone. In July, US-based Parry Lab was signed up for new and retrofit designs. US company Zephyr is now retrofitting pairs of 800 W IE modules into a custom-built VTOL drone for the US Army, targeting 14 hours' flight time.

August 2020 saw Plug Power announce a new 1 kW ProGen fuel cell for small scale robotics, automatic guided vehicles and UAVs. With compressed hydrogen, a UAV with the 1 kW module delivers 3-4 times the endurance of a battery, and up to 9 times with liquid hydrogen.

It's not just DMI going bigger – Horizon is working with GOLDI Mobility of Hungary to deliver enhanced ISR (Inspection, Surveillance, Reconnaissance) capability to Europe, and Intelligent Energy's 2.4 kW module has been integrated into ISS Aerospace's new heavy-lift drone: flight time 100 minutes with 8 kg payload.

Manned aerial vehicles?

It's not just UAVs. Fuel cells are back in vogue for larger aircraft, both fixed wing and rotor driven, capable of carrying people. September 2020 saw ZeroAvia fly a Piper M class six-seater plane for 20 minutes with power from a 100 kW Powercell stack. Also partnered with Intelligent Energy, ZeroAvia's next goal is a 250 mile flight from an airfield in Orkney, and the ultimately aim is 500-mile regional flights in 10- to 20-seat fixed wing aircraft. Avions Mauboussin, supported by France's Burgundy Franche-Comté region, intends to develop similar capability, starting with a 2-seater Alérion M1h and then a 6-seater Alcyon M3c. Plug Power has teamed up with Universal Hydrogen for regional aircraft, with a 2 MW H_2-electric powertrain aimed at mid-sized regional turboprop aircraft, such as the Dash 8 or ATR42/72 families, for flights up to 1,000 km (540 nautical miles). This range would cover 90% of existing routes, far more than possible with battery power alone. Mind you, some seats will be replaced by H_2 storage capsules, reducing capacity from 50 to 40 people for the Dash 8-400. The work will start with a so-called 'iron bird' ground-based prototype, with actual fight tests expected from 2024.

And for rotor-driven planes, Urban Aeronautics signed an agreement in June with HT-PEM developer HyPoint Inc. (formerly BMPower) to bring H_2 fuel cells into its 4-passenger CityHawk eVTOL design. Bigger actors are also in the (air) frame. DLR has signed an MoU with MTU Aero Engines to equip and test a Dornier 228 aircraft with a H_2-powered fuel cell and a single-sided electric propeller drive of 500 kW power. They want to develop a complete aviation-compatible drivetrain, with cooling, for a maiden flight around 2026. Airbus has revealed three concepts for zero-emission commercial aircraft larger than 'Group I' (15 m+ wingspan) that could enter service by 2035. These explore H_2 for primary power – with heat engines rather than fuel cells – though Airbus is now teamed with ElringKlinger for fuel cell activities, in a strategic partnership deal in the 'low to mid-double-digit million Euro range'.

Fuel cells for ground support equipment are also popular again, from bus and car fleets at airports, to the tugs at Hamburg, Memphis and Albany, NY, with Plug Power 10 kW GenDrive stacks. Cummins is working on a similar tow-tractor demonstration for Hamburg airport.

2021: slowing down or speeding up?

2021 did not dawn bright. Lockdowns persisted in many regions, and growth continued to stutter. The automotive industry, and many parts of the energy industry, suffered extreme losses.

But for hydrogen-related industries things looked very different. Multiple countries made or reiterated their net zero carbon commitments, including China. The US welcomed a new administration, which promptly rejoined the Paris Climate agreement, and officials were once again allowed to utter the words 'climate change'. Hydrogen strategies and roadmaps continued to emerge, and while fuel cells are not always explicitly included, most often they are. Mergers and acquisitions – almost unaffected by 2020 conditions – carried on in early 2021. Investors either started or carried on paying attention to the sector, and stock prices surged. Plug Power announced a mammoth US$1.6bn investment from SK Group to build a hydrogen and fuel cell economy in Asia, while new fuel cell truck and bus entrant Hyzon Motors, carrying out an IPO by reversing into a SPAC, was valued at US$2.6bn.

While some of the valuations in the industry suggest froth – or at least too much money chasing too few opportunities – the fundamentals remain strong. Simply put:

- Decarbonisation – and fast – is essential
- Hydrogen will help us decarbonise
- Money can be made with fuel cells and hydrogen while decarbonising

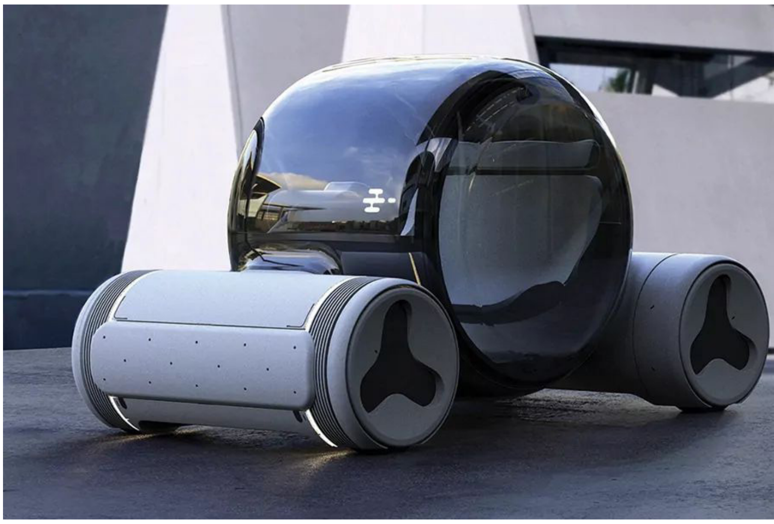
If nothing else, some of the enforced slowdown in 2020 enabled industries to take stock and plan. Plug Power's deal includes a planned fuel cell and electrolyser Gigafactory, and others are looming. Fuel cell projects and products are scaling too. And China, having taken stock itself, will be back in growth mode in 2021 as their new fuel cell support mechanisms make themselves felt. Korea should also continue to support the sector, so Asia is likely to remain a focal point for scale-up and roll-out.

That said, Europe remains strong on the supply side, and country strategies are increasingly influencing company ones. We expect some important fuel cell manufacturing announcements, and continued deployment in heavy duty vehicles of all types. Those deployments will make inroads into proving business models, start to pay off the investment in manufacturing, and nucleate clusters around which other applications can grow.

The white heat of the sector will burn a few companies – we have seen and are seeing more 'technology-light' attempts to enter, just to benefit from available funds looking for a home. Thankfully, investors are increasingly savvy, and most of the more speculative companies get little funding or traction. In fact, the vast majority of players are already well-established, with track records and scar tissue from previous investment cycles. Others are founded by people who bring that same experience from previous roles. Either way, we believe that most of them know what they are doing, and how to make the most of the current enthusiasm.

As we've said before, what is most needed is proof. Proof that it's not only forklifts and drones that have a business case. Proof that scale can be achieved, and competitive cost, and growth sustained. We think the chances of 2021 demonstrating more of those proof points are good.

We learned our lesson about predictions in 2019, and won't be saying anything about numbers this year. But the signs do suggest a positive outlook for 2021...



Data tables

Shipments by application					
1,000 Units	**2016**	**2017**	**2018**	**2019**	**2020f**
Portable	4.2	5.0	5.7	3.9	4.1
Stationary	51.8	54.9	51.9	52.2	57.8
Transport	7.2	10.6	10.9	16.4	20.5
Total	**63.2**	**70.5**	**68.5**	**72.5**	**82.4**

Shipments by region of adoption					
1,000 Units	**2016**	**2017**	**2018**	**2019**	**2020f**
Europe	4.4	5.1	7.7	10.7	12.7
North America	7.7	9.4	9.3	8.1	10.7
Asia	50.6	55.3	50.9	53.5	58.8
RoW	0.5	0.8	0.6	0.2	0.2
Total	**63.2**	**70.5**	**68.5**	**72.5**	**82.4**

Shipments by fuel cell type					
1,000 Units	**2016**	**2017**	**2018**	**2019**	**2020f**
PEMFC	44.5	43.7	39.7	45.7	53.6
DMFC	2.3	2.8	3.7	3.7	3.8
PAFC	0.1	0.2	0.2	0.3	0.3
SOFC	16.2	23.7	24.9	22.8	24.7
MCFC	0.0	0.0	0.0	0.0	0.0
AFC	0.1	0.1	0.0	0.0	0.0
Total	**63.2**	**70.5**	**68.5**	**72.5**	**82.4**

2020f is our forecast for the full year, based on firm data from January to September, and in some cases to as late as December.
We have revised the figures for 2019 in this report, now with firm full year data where previously a final quarter forecast was required.

Data tables

Megawatts by application					
Megawatts	**2016**	**2017**	**2018**	**2019**	**2020f**
Portable	0.3	0.6	0.7	0.4	0.4
Stationary	209.0	222.3	220.6	274.8	324.8
Transport	307.2	435.7	584.5	921.1	993.5
Total	**516.5**	**658.6**	**805.8**	**1,196.3**	**1,318.7**

Megawatts by region of adoption					
Megawatts	**2016**	**2017**	**2018**	**2019**	**2020f**
Europe	27.4	38.9	41.2	113.0	148.6
North America	213.6	331.8	425.3	339.2	252.7
Asia	273.8	285.8	337.9	743.9	912.4
RoW	1.7	2.1	1.2	0.2	5.0
Total	**516.5**	**658.6**	**805.8**	**1,196.3**	**1,318.7**

Megawatts by fuel cell type					
Megawatts	**2016**	**2017**	**2018**	**2019**	**2020f**
PEMFC	341.0	466.7	609.0	948.0	1,029.7
DMFC	0.2	0.3	0.4	0.4	0.4
PAFC	56.2	81.0	86.3	130.9	132.2
SOFC	62.9	85.2	84.1	106.8	147.5
MCFC	55.7	24.7	25.8	10.2	8.8
AFC	0.5	0.6	0.1	0.0	0.1
Total	**516.5**	**658.6**	**805.8**	**1,196.3**	**1,318.7**

2020f is our forecast for the full year, based on firm data from January to September, and in some cases to as late as December.
We have revised the figures for 2019 in this report, now with firm full year data where previously a final quarter forecast was required.

Notes

- Data for 2014 to 2020 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 2020 figures are a forecast for the full year. The dataset contains firm numbers for the period January to September 2020 (and in a few cases as late as December 2020). For any remaining period of the year we use companies' own forecasts, shared with us, or ones we prepare in discussion with industry.
- We will revise data for 2020 in our 2021 edition as appropriate. We have slightly revised the figures for 2019 in this report: Unit numbers were increased by 2.5% and megawatt numbers increased by about 6% compared to our published 2019 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.

Please see **www.e4tech.com** for details and our email address for enquiries.

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.

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. Much of our work is client confidential. Examples of our public work can be found at www.e4tech.com.

Please Donate – but not to us

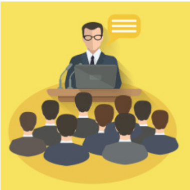
In a very difficult year globally, E4tech has been fortunate. Our work can be conducted remotely and we are in a sector which has received – and is receiving – exceptional interest.

If you found this Review useful in any way, please consider donating to a cause – any cause – that benefits those less fortunate. Food banks, mental health charities, aid organisations and many others would welcome your support. Thank you.

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 23 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

The pictures in the Fuel Cell Industry Review come from various sources. They are credited below. We thank all of the organisations involved.

PAGE	IMAGE	IMAGE CREDIT
5	Night and Day – 50 MW PAFC facility at Daesan	Doosan Fuel Cell Co., Ltd
8	PAFC manufacturing	Doosan Fuel Cell America
9	Toyota Mirai in California	Dr Tim Lipman
10	Hyperion XP-1 supercar	Hyperion Motors
12	ENEOS-JERA hydrogen refuelling station	ENEOS Corporation
13	Wrightbus double-decker for NX West Midlands	Wrightbus
14	Optare MetroDecker double-decker bus	Arcola Energy and Optare
15	Line-up of Golden Dragon fuel cell buses	Xiamen Golden Dragon Bus Co., Ltd
16	Hyundai Elec City bus for Saudi Arabia	Hyundai Motor Corporation
19	Hyundai Xcient in Switzerland	H2 Energy AG
20	Hyzon fuel cell truck prototype	Hyzon Motors/Holthausen
22	STILL fuel cell forklifts	STILL GmbH
23	HydroFLEX fuel cell-powered train	Birmingham University
24	Stadler FLIRT train for San Bernardino	Stadler Rail and the San Bernardino County Transit Authority
25	Allis Chalmers fuel cell tractor, 1959	National Museum of American History, Behring Center
27	HySEAS III ferry planned for 2022	Caledonian MacBrayne
29	Modular hybrid power unit	AFC Energy
31	H2Rex pure hydrogen fuel cell system	Toshiba Energy Systems & Solutions
34	Convion C60 ensemble (EU DEMOSOFC project)	Convion
35	2.5 kW Jupiter series fuel cell used by SFC Energy	AdKor
36	Bramble Energy K1000 prototype	Bramble Energy
36	WATT Imperium ported SOFC	WATT Energy
37	Mole (buried fuel cell system for covert watch)	UltraCell
37	Drone featuring 2-4 kW IE-Soar fuel cells	Intelligent Energy
38	First FC powered manned aircraft takes flight	ZeroAvia
39	Future Center Europe FC concept car	Nikita Konopatov

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 2019 to 30th November 2020.

US$1 = € 0.8855	€1 = US$ 1.1306	£1 = US$ 1.2814	¥1 = US$ 0.0093
US$1 = £ 0.7810	€1 = £ 0.8826	£1 = € 1.1340	¥1 = € 0.0082
US$1 = ¥ 107.34	€1 = ¥ 121.31	£1 = ¥ 137.57	¥1 = £ 0.0073

E4tech

Strategy | Energy | Sustainability