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Fuel cells development: Present and Future

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Intelligence Report

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1. INTRODUCTION AND TECH COMPARISON

Fuel cells are devices that generate electricity through an electrochemical reaction in which oxygen and a fuel, such as hydrogen gas, mix to form water as a byproduct. Fuel cells can be used in every type of transportation, in material handling, and for stationary, portable and emergency backup power applications. They can operate at higher efficiencies than combustion engines.

This type of battery-like device is expected to play a vital role in the decarbonisation of various industries because it can run on hydrogen produced from renewable energy sources. Analysts believe that the 2020s will mark the rapid commercialisation of fuel cells and the build out of related infrastructure.

Presently, there are a number of fuel cell technologies. The more widely adopted among the larger sector players are polymer electrolyte membrane (pem) and solid oxide (sofc). More details about each technology are available below in a table prepared by the us government's office of energy efficiency & renewable energy.

Fuel cell type	Common electrolyte	Operating tempera-ture	Typical stack size	Electrical efficiency (lhv)	Applica-tions	Advantages	Challenges
Polymer electrolyte membrane (pem)	Perfluorosul-fonic acid	<120°c	<1 kw–100 kw	60% direct h2 40% re-formed fuel	Backup power Portable power Distributed generation Transporta-tion Specialty vehicles	Solid electrolyte reduces cor-rosion and electrolyte management problems Low temper-ature Quick start-up and load following	Expensive catalysts Sensitive to fuel impu-rities
Alkaline (afc)	Aqueous potassium hydroxide soaked in a porous ma-trix, or alka-line polymer membrane	<100°c	1–100 kw	60%	Military Space Backup power Transporta-tion	Wider range of stable ma-terials allows lower cost components Low temper-ature Quick start-up	Sensitive to co2 in fuel and air Electrolyte management (aqueous) Electrolyte conductivity (polymer)

Fuel cell type	Common electrolyte	Operating temperature	Typical stack size	Electrical efficiency (lhv)	Applications	Advantages	Challenges
Phosphoric acid (pafc)	Phosphoric acid soaked in a porous matrix or imbibed in a polymer membrane	150°–200°c	5–400 kw, 100 kw module (liquid pafc)	40%	Distributed generation	Suitable for chp Increased tolerance to fuel impurities	Expensive catalysts Long start-up time Sulfur sensitivity
Molten carbonate (mcfc)	Molten lithium, sodium, and/or potassium carbonates, soaked in a porous matrix	600°–700°c	300 kw–3 mw, 300 kw module	50%	Electric utility Distributed generation	High efficiency Fuel flexibility Suitable for chp Hybrid/gas turbine cycle	High temperature corrosion and breakdown of cell components Long start-up time Low power density
Solid oxide (sofc)	Yttria stabilised zirconia	500°–1,000°c	1 kw–2 mw	60%	Auxiliary power Electric utility Distributed generation	High efficiency Fuel flexibility Solid electrolyte Suitable for chp Hybrid/gas turbine cycle	High temperature corrosion and breakdown of cell components Long start-up time Limited number of shutdowns

In addition to the five technologies mentioned above, also noteworthy are zinc air fuel cells (zafc) and direct methanol fuel cells (dmfc).

Zafcs feature a gas diffusion electrode, a zinc anode separated by electrolyte and a mechanical separator. In these fuel cells oxygen is reduced to hydroxide, which combines with oxidized zinc and generates electrons in the process.

As per dmfcs, they are similar to pems except that rather than using gaseous hydrogen as the fuel, they utilise liquid methanol. Their operating temperatures range from 60 to 130 degrees celsius.

2. LEADING PLAYERS IN THE MARKET

The table below includes five of the larger publicly-traded players in the field of fuel cell technology, ranked based on their market capitalisation on february 23, 2021. Some of these companies are fuel cell suppliers, while others offer complete solutions for various sectors.

Country	Name	Ticker	Market cap (in usd)	Technology
Usa	Plug power inc	(nasdaq:plug)	24.42bn	Pem
Canada	Ballard power systems inc	(nasdaq:plug)	8.55bn	Pem
Usa	Fuelcell energy inc	(nasdaq:fcel)	5.76bn	Solid oxide
Usa	Bloom energy corp	(nyse:be)	4.76bn	Solid oxide
Uk	Ceres power holdings plc	(lon:cwr)	3.07bn	Solid oxide

Plug power

The company with significantly higher capitalisation than the other four is plug power, which hit the headlines at the start of 2021 by signing a major investment deal with a south korean industrial conglomerate.

Plug power is a fuel cell developer and supplier that focuses on green hydrogen opportunities around the world. The company's offerings include: progen fuel cell engines for use in transportation and stationary power products; gendrive fuel cells for existing electric class-1, class-2 and class-3 material handling electric truck fleets; and gensure hydrogen fuel cell backup power solutions for markets with both low-power and high-power requirements.

South korea's sk group agreed in early january to invest usd 1.5 billion in the hydrogen fuel cell provider as part of a new strategic partnership between the two, in exchange for a roughly 9.9% stake in the us company. The pair said their alliance aims at accelerating hydrogen as an alternative energy source in asian markets, where, particularly in korea, they plan to offer hydrogen fuel cell systems, hydrogen fuelling stations and electrolysers. A joint venture targeting the korean market is also being planned.

In the weeks after the partnership announcement, the company launched an upsized public offering of common stock through which it raised more than usd 2 billion in net proceeds for working capital and other general corporate purposes. The company noted that that was the largest bought deal in the clean tech sector. When also taking into consideration the final closing of the partnership with sk group, plug power's total cash balance is exceeding usd 5 billion, it said at the time.

The company's key focus areas for 2021 include stepping up its expansion in the green hydrogen generation business and successfully launching jvs with both sk group and carmaker groupe renault to create a global footprint. In mid-february 2021, plug power also announced the signing of a memorandum of understanding (mou) to set up an equally-owned green hydrogen jv in madrid with sustainable infrastructure company acciona sa to serve customers in spain and portugal. Plug power will serve as the preferred supplier of electrolyser technology.

About a month before announcing its financial results for 2020, plug power said it had exceeded its annual gross billings target and raised its 2021 guidance to usd 475 million from usd 450 million. Moreover, it increased its 2024 gross billings target by over 40% to usd 1.7 billion.

The actual 2020 figure was later reported at usd 337.4 million, which is a 42.5% year-on-year jump, marking a record for the company. Still, it continued to post annual net losses, with a negative 2020 bottom line of usd 561.7 million largely due to huge costs related to non-cash charges for certain customer warrants.

Ballard

Ballard is a provider of zero-emission pem fuel cells for use in the electrification of mobility. The company's offerings include:

- Motive modules with net power ranging from 30 kw to 100 kw for buses, trucks, light rail and other heavy duty vehicles;
- The fcwave module that provides zero-emission power to marine vessels;
- Both air-cooled and liquid-cooled pem fuel cell stacks for mobility and stationary applications;
- And hydrogen-fueled stationary systems that provide backup power to critical infrastructure.

With corporate headquarters in vancouver, ballard has operations in canada, the us, europe and china. The company's core activities of membrane electrode assemblies production, integration and testing of fuel cell stacks, and assembly and testing of motive modules, are carried out at its canadian facilities.

Similar to plug power, ballard recently closed a bought deal offering of common stock, raising usd 550.2 million gross. It could secure a further usd 82.5 million if the underwriters exercise the over-allotment option in full. Ballard said it will use the net proceeds to further bolster its balance sheet. This will provide it with additional flexibility to finance its growth strategy, which covers product innovation, investments in production capacity expansion and localisation, future acquisitions and strategic partnerships and investments.

For the nine months through september 2020, ballard reported a top line of usd 75.3 million, up from usd 64 million, while for the full 2019 it posted revenues of usd 106.3 million. The bottom line for the first nine months of 2020 was a loss of usd 36.7 million, growing from usd 28.8 million a year earlier. The annual net loss for 2019 was usd 39 million.

The company plans to announce its 2020 financial results on march 11, 2021.

Fuelcell energy

Connecticut-based fuelcell energy offers fuel cell solutions under the suresource product line, delivering distributed power generation through plants that emit only trace levels of nitrogen oxide (nox), sulfur oxide (sox) or particulate matter. The products are available in different sizes and configurations to address customer needs such as natural gas letdown station energy recovery, fuel cell carbon capture and distributed hydrogen.

In december, the company concluded an underwritten public offering of shares and raised usd 162.5 million in gross proceeds for its own use, not including usd 95.5 million received by selling stockholders. Fuelcell energy later said it had used the funds to extinguish senior secured debt and pay amounts owed to enbridge inc under certain preferred shares issued previously by a fuelcell energy subsidiary. This left usd 47.5 million of net proceeds from the offering to be used to speed up the development and commercialisation of the company's solid oxide platform and for project development and financing, as well as for working capital support and general corporate purposes.

In the full fiscal year through october 2020, fuelcell energy generated usd 70.9 million in total revenues, up 17%, and ended the 12-month period with a total backlog of usd 1.29 billion, down 2.5% on the year. Its net loss for the fiscal year widened to usd 89.1 million from usd 77.6 million.

Bloom energy

San jose, california-based bloom energy has developed a distributed, on-site electric power solution, called the energy server platform, that uses solid oxide fuel cells to convert fuel to electricity, without combustion. The bloom energy server can run on natural gas or biogas and is a modular solution that can be delivered with capacities ranging from 100 kw to 10s mw.

This stationary power generation platform delivers uninterrupted, clean electricity that, the company says, is ideal for microgrid applications. Bloom energy has customers in manufacturing, data centres, healthcare, retail, higher education, utilities and other industries.

Because the company offers a complete solution for power generation , bloom energy's business generates significantly more revenues than the aforementioned sector players offering mainly fuel cells. The company reported a top line of usd 794.2 million for 2020, up 1.1%, with 1,326 "acceptances" representing 132.6 mw, which is an 11.1% year-on-year increase. It made a forecast for 2021 revenues in the range of usd 950 million to usd 1 billion and expects to approach a positive cash flow from operations this year.

"the biden administration is embracing proactive climate change policies and continuing a low-interest environment while focusing on critical infrastructure investments that fit well with our strategic approach. And, beyond the united states, there is significant momentum in asia and opportunities to grow in other markets around the world," said kr sridhar, founder, chairman and ceo of the company.

In 2020, bloom energy's annual net loss was reduced to usd 157.6 million from usd 306.9 million.

Ceres power

Ceres power is the developer of the steelcell solid oxide fuel cell technology, which can generate power from both conventional fuels such as natural gas and sustainable ones like biogas, ethanol or hydrogen. The company is looking to embed its technology in mass-market energy products for the commercial, residential and transportation markets. The solution is modular and can be installed in 1-kw systems for residential use through to hundreds of kilowatts for car charging or grid reinforcement.

In december 2020, ceres power announced the continuation of its existing relationship with the bosch group to move from prototyping fuel cell stacks to preparing for mass production of fuel cell systems based on ceres' technology. The plan is to establish multiple sites in germany to achieve an initial manufacturing capacity of 200 mw in 2024. The systems will be used in the stationary power market, initially for decentralised power plants in cities, factories, data centres and electric vehicle (ev) charging infrastructure. Bosch is already a minority shareholder in ceres, with a 17.6% interest.

Ceres noted that in time it could seek an expansion at the german facilities to not only meet demand for bosch fuel cell systems but also that for steelcell-based stacks in multiple third-party systems.

The uk firm also has a partnership with doosan fuel cell co ltd. The latter plans to build an initial 50-mw mass manufacturing facility to produce under licence ceres' fuel cell stacks in south korea. Doosan also intends to jointly develop a ceres-based fuel cell system for marine propulsion and power generation with singaporean shipping company navig8.

In 2020, ceres changed its fiscal year end to december 31 from june 30 and reported revenue of gbp 18.9 million for the 12 months through june 2020 versus gbp 15.3 million for the financial year ended june 30, 2019. Its loss expanded to gbp 7.3 million from gbp 4.8 million.

For the 18-month period to december 31, 2020, the company expects its revenue to range from gbp 32 million to gbp 33 million, putting it above market expectations.

The company said in february 2021 that its current focus remains on assisting its manufacturing partners in achieving mass market launches in 2024. This, in turn, will trigger royalty payments to ceres.

Other notable players

There are a number of both listed and non-publicly-traded companies that are heavily involved in the field of fuel cells development, as well as some conglomerates that have dedicated fuel cell divisions. The listed ones include us diversified groups air products & chemicals inc and cummins inc, elringklinger ag of germany, uk-based proton motor power systems plc and israel's gencell ltd. Among the non-publicly-traded players we can find the above-mentioned doosan and bosch, as well as toshiba energy systems & solutions corp, altergy systems, powercell sweden ab, intelligent energy ltd and blue world technologies aps.

There is also advent technologies, which got listed on the nasdaq stock market during the preparation of this report by completing a merger with the publicly listed special purpose acquisition company (spac) called amci acquisition corp. Advent technologies develops high temperature pem fuel cells for passenger, commercial vehicle, drone and lightweight aviation (evtol), and other stationary and portable power applications. The company says it intends to commercialise its technology through partnerships with tier1s, original equipment manufacturers (oems) and system integrators.

3. TRENDS IN FUEL CELL DEVELOPMENT

Sector players most often rely on government grants and business partnerships in a drive to commercialise their fuel cell offerings.

Usa

In the us, the department of energy (doe) has a dedicated hydrogen and fuel cell technologies office (hfto) that regularly offers grants and funding opportunities for research and development (r&d) activities in the field. The doe points at factors like **cost, performance** and **durability** as the key challenges in the fuel cell industry. The energy department explains that with platinum being one of the largest **cost** components of a fuel cell, a big chunk of the r&d work falls on identifying ways to boost activity and utilisation of current platinum group metal (pgm) and pgm-alloy catalysts, as well as on non-pgm catalyst approaches for long-term applications.

When it comes to **performance**, r&d focuses on the development of ion-exchange membrane electrolytes with enhanced efficiency and durability at lower cost, improving membrane electrode assemblies (meas), developing transport models, identifying and mitigating degradation mechanisms, and maintaining core activities on components and sub-systems.

As per a key performance factor such as **durability,** doe has set respective durability targets of 40,000 hours and 5,000 hours for stationary and transportation fuel cells, under realistic operating conditions, and is developing materials and strategies to mitigate fuel cell degradation mechanisms.

Every year, the doe publishes an annual progress report for its hydrogen and fuel cells programme that includes a section supporting the r&d of fuel cell technologies for transportation, stationary and cross-cutting applications. The particular sub-programme sets objectives such as:

- Develop a 68% peak-efficient (ultimate 72%), direct hydrogen fuel cell power system for heavy-duty trucks that can achieve 25,000-hour durability (ultimate 30,000 hours) and be mass produced at a cost of usd 80 per kw by 2030 (ultimate usd 60/kw).
- Develop a 65% peak-efficient, automotive direct hydrogen fuel cell power system that can achieve 5,000-hour durability (ultimate 8,000 hours) and be mass produced at a cost of usd 40/kw by 2025 (ultimate usd 30/kw).

- Develop medium-scale chp systems (100 kw–3 mw) by 2025 that achieve 50% electrical efficiency, 90% chp efficiency, and 80,000-hour durability at a cost of usd 1,500/kw for operation on natural gas and usd 2,100/kw when configured for operation on biogas.

The results of r&d activities towards these goals, as of end-2019, can be found in the latest report. The 2020 annual progress report is yet to be published on the government website.

An example for doe financial support is a usd-33-million funding opportunity announced in december 2020, targeting innovative hydrogen and fuel cell r&d, infrastructure supply chain development and validation, and cost analysis activities. Topics covered by the funding opportunity include r&d in fuel cells for heavy-duty trucks, hydrogen production through high-temperature (high-t) water splitting (electrolysis) and biological processes that use waste, and domestic manufacturing of high-t electrolysers and related components. Full applications are due on march 8, 2021.

Also in the us, backup power solutions provider cummins has won a usd-2.6-million doe grant to build a 20-kw small-scale sofc power system at the university of connecticut, fuelled by natural gas but able to use multiple fuels. The durability of the system will be tested in a 5,000-hour run. Cummins hopes to develop a system that would be available at a price point below usd 1,000/kw. Testing is planned to begin in 2021.

The company has also won a usd-2-million doe grant for a second project focused on the cost, performance and reliability of a reversible fuel cell (r-sofc).

Also in the us and strictly targeting the automotive sector, advent technologies reached an agreement in the autumn of 2020 to collaborate with los alamos national labs, the university of texas at austin (ut austin), rensselaer polytechnic institute (rpi), the university of new mexico and toyota motor north america r&d (tmna r&d) to continue development of the high-temperature pem fuel cell technology under a programme funded by an advanced research projects agency–energy (arpa-e) open award.

The development programme will focus on using ht-pem technology operating at 80 degrees celsius to 150 degrees celsius to increase the system efficiency from 60% to 70%, achieve a fast start-up time and superior heat management, improve performance with platinum and non-platinum catalysts to increase lifetime, and address the hydrogen infrastructure challenge.

Europe

Meanwhile in europe, an interesting alliance has been formed between swedish and danish parties, namely alfa laval ab, dtu energy, haldor topsoe, svitzer and the mærsk mc-kinney møller center for zero carbon shipping, aimed at speeding up the development of the sofc technology and its adoption by the maritime industry. The project, called sofc4maritime, revolves around the use of sofcs for power production on marine vessels.

Again in scandinavia, and denmark in particular, a methanol fuel cell start-up called blue world technologies aps was founded in october 2018 and began pursuing large-scale production with the ultimate goal of retiring combustion engine technologies, but met challenges on the way. It finally initiated a limited methanol fuel cell production in the autumn of 2020, which, co-founder and cco mads friis jensen explained, enables the start-up to progress with development and trial projects with customers in a first step towards commercialising its technology.

A couple of months later, the firm closed an investment round of eur 6.4 million with both large and smaller investors, and announced the signing of a leasing agreement that allowed it to set foot in a building at the port of aalborg to house a 50-mw facility able to produce up to 5,000 units per year.

Since then, blue world technologies also bought out ht-pem material research company danish power systems, announced a partnership with california-based luxury electric vehicles (evs) maker karma automotive for the development of a fuel cell propulsion system, and the takeover of a larger production building at the port in view of its large order book with a double-digit million euro amount.

Blue world technologies expects to start pre-series production at the new site in mid-2021 and hopes to reach a full-scale commercial production capacity of 50,000 units within three years.

4. FUTURE TRENDS AND EXPECTATIONS

According to the global fuel cells industry report released in july 2020, the global market for fuel cells is seen to reach usd 14.6 billion by 2027 as fuel cells and other sustainable energy technologies are expected to benefit from economic stimulus packages following the covid-19 pandemic.

Looking specifically at the fuel cell electric vehicle (fcev) market, it has been flourishing over the past few years, according to statistics prepared by the international energy agency (iae), last updated in june 2020. The top destinations in this regard are the us, china, japan and korea, while the netherlands and france stand out in europe.

Iea stats show that the global fcev stock nearly doubled to 25,210 units at the end of 2019, with 12,350 new vehicles sold, which is more than double the 5,800 purchased in 2018. Around the world, there were 23,354 fcevs in 2019, including 8,039 in the us, which continues to be the world leader in fcev stock, as one in three fcevs run on us roads. It is followed by china, japan and korea.

This decade is expected to also see a sharp increase in fuel cell system use beyond consumer vehicles, with projects studying diverse applications in heavy-duty, air and rail transport, and stationary applications, including to power data centres, telecommunications and emergency systems.

2020 was a big year for green hydrogen plans and strategies, especially in europe and asia, and these will surely further boost demand for fuel cell solutions in these markets.

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