VERTIV WHITE PAPER

Evaluating the Potential of Fuel Cells for Backup and Primary Data Center Power

Executive Summary

Fuel Cells and the Carbon-Neutral Data Center

Capacity growth has become a constant challenge for the data center industry. Despite the massive investments in new capacity that have been made over the last five years, more capacity is required to support the continued digitalization of business and society. The Dell'Oro Group projects investments in hyperscale data centers to double in the next five years.

That growth threatens to drive up the greenhouse gas emissions that can be attributed to data centers. Despite the efficiency of today's facilities, they are inherently energy intensive. The International Energy Agency estimates that data centers consumed between 200 and 250 terawatt hours (TWh) of energy in 2020. Much of that electricity is generated from carbon-based fuels, which contribute to Scope 2 emissions for data center operators.

In addition, large data centers rely on diesel generators that add to a facility's carbon footprint through Scope 1 emissions. Monthly diesel generator checks contribute 9.2 kilograms (kg) per kilowatt hour (kWh) of carbon dioxide (CO2) into the atmosphere, assuming 2 liters of diesel is consumed.

This has led many operators to take steps to reduce greenhouse gas emissions, doing their part to protect the environment and demonstrate their commitment to customers, associates and stakeholders. Several hyperscale operators have set goals of becoming carbon neutral or carbon negative by the end of this decade, and colocation operators are offering carbon-neutral environments to their customers.

There is opportunity within many facilities to reduce emissions by increasing data center efficiency and equipment utilization. While an essential step, it does not get data centers to their carbon-neutral goals. To offset their dependence on carbon-based fuels, operators are currently relying on power purchase agreements (PPAs) and renewable energy credits (RECs). In 2021, clean energy PPAs grew 24% from 2020 to reach a new high of 37.1 gigawatts (GW).

Hyperscalers Amazon, Microsoft, and Meta were the largest purchasers of these agreements across all industries. But there are also signs that operators are looking to wean themselves off PPAs. Google, which invested more than any other organization in PPAs in 2020, reduced its investment in 2021 as it seeks sources of carbon-free power through other methods.

The long-term solution many operators are seeking is to power data centers directly with clean energy. However, with the utility grids in most regions unlikely to be able to provide 100% renewable power to all customers for the foreseeable future, the onus is on operators to work with their partners to develop solutions that enable carbon-free operation.

Local energy generation using renewable solar or wind power isn't practical at many data center sites, and the intermittency of renewable energy creates challenges for always-on data centers. However, hydrogen produced using renewable energy does represent a viable solution for on-site energy generation at a wide range of sites.

This white paper examines recent advances in fuel cell technology that have improved performance and reduced costs such as hydrogen-powered fuel cells that are emerging as a solution to displace diesel generators for backup power. It also addresses why fuel cells represent a promising solution for zero-carbon primary data center power in the longer term.

Understanding Fuel Cells

Fuel cells aren't energy storage devices like batteries. They generate electrical energy from chemical reactions created by a fuel source and oxygen. The most common fuel sources for fuel cells are hydrogen and natural gas. When hydrogen is used as a fuel source, the only byproducts are water and heat.

Natural Gas Versus Hydrogen Fuel Cells

Natural gas-powered fuel cells benefit from robust and mature production and distribution infrastructure that makes a continuous supply of natural gas available in many areas. Natural gas-powered fuel cells are relatively clean but do generate some greenhouse gas emissions. Some manufacturers of fuel cells that use natural gas are currently adapting their designs to increase fuel flexibility for multiple applications.

Hydrogen has more limited production capacity and lacks a robust distribution network, but efforts are underway to rectify these limitations. Hydrogen fuel cells can support true carbon-neutral operation, depending on how the hydrogen is produced.

Most hydrogen today is produced from fossil fuels by steam reforming of natural gas, partial oxidation of heavier hydrocarbons, or coal gasification. Hydrogen produced through these methods is commonly referred to as "gray hydrogen" due to its reliance on fossil fuels. The emissions produced during the process should be factored into the environmental footprint of the fuel cell application. Hydrogen can also be produced from renewable energy through the electrolysis of water — referred to as "green hydrogen" because it does not generate greenhouse gas emissions during the production process. Since hydrogen fuel cells do not generate emissions, using green hydrogen to power fuel cells enables zero-carbon on-site energy generation.

Due to the lack of a hydrogen distribution network, hydrogen used to power fuel cells in stationary power applications will likely need to be transported by truck from where it is produced to where it is being used and stored. This makes use of hydrogen fuel cells for primary data center power impractical today. It is, however, feasible for backup power, as enough hydrogen to support 48 hours of continuous operation for large data centers can be stored on site.

Types of Fuel Cells for Data Center Power

As with batteries, there are multiple types of fuel cells available that are classified mainly by the electrolyte used, which in turn determines the fuel characteristics, operating temperatures, transient conditions, and ultimately, the electrical performance of the system. For data center applications, two types of fuel cells have the required characteristics: proton-exchange membrane (PEM) and solid oxide fuel cells (SOFCs).

PEM fuel cells use hydrogen as their fuel source and feature a solid polymer electrolyte that delivers high power density that enables a smaller footprint than other fuel cells. They require only hydrogen and oxygen from the air to generate electricity and operate at relatively low temperatures (up to 80 degrees Celsius/176 degrees Fahrenheit). Because they don't have to heat up to the high temperatures required with other types of fuel cells, they can start quickly, making them suitable for backup power applications. PEM fuel cells do require a noble-metal catalyst such as platinum to separate the hydrogen's electrons and protons, which calls for special safety protections because it is hazardous to humans.

SOFCs use a ceramic compound as the electrolyte. They operate at much higher temperatures (800-900 C/1,472-1,652 F) than PEM fuel cells, which eliminates the need for a precious-metal catalyst, but it increases startup and shutdown times and makes them better suited for continuous duty applications. They are also more flexible in the input fuel, mainly using natural gas with some designs able to process pure hydrogen. SOFCs have a high operating efficiency that can be further increased by capturing and reusing heat generated during operation. Their high operating temperature requires significant thermal shielding to retain heat and protect personnel. This can limit the number of on/off cycles in the life of a system due to the thermal stress suffered by cell material.

The Fuel Cell Powered Data Center

Based on the current state of fuel cell technology, as well as other evolutions in data center critical power technology, it's possible to envision a future state in which fuel cells provide clean primary and secondary power to the data center. Today PEM fuel cells would provide backup power and SOFCs would be used for primary power. However, there is the potential for PEM fuel cells to provide primary power in the event not all SOFCs can be reconditioned to work with pure hydrogen.

Vertiv has done extensive research into the application of fuel cells in data centers and is involved in multiple pilot projects focused on ensuring fuel cells can meet data center requirements for reliability and performance.

Using Fuel Cells for Data Center Backup Power

Diesel generators are a significant source of Scope 1 emissions in today's data centers, and some operators are actively seeking solutions to reduce their dependence on these systems. One potential solution is to extend battery runtimes to enable the battery system to support longer outages. This could work for operators that require 30 minutes or less of outage protection. Due to the size of the battery system that would be required, it will not be practical for data centers that need to stay online for outages of 24 or 48 hours to meet service level agreements or user expectations. There are also some interesting technologies being developed, such as linear generators, which may provide viable solutions at some point in the future.

Fuel cells represent a more proven and established solution, having already been used in transportation, military, marine, and other applications. In addition, fuel cell costs have dropped significantly in the last five years, and that trend is expected to continue in the future. But while fuel cells are being used in multiple applications as of this writing, they have not been applied in large stationary power applications such as those that exist in data centers, and these applications do present some technical challenges.

Specifically, fuel cells are relatively slow to respond to load changes, creating transients, and therefore, they need a way to dissipate the excess energy. This can be accomplished through uninterruptible power supply (UPS) systems. By configuring the fuel cells and the UPS system's lithium-ion batteries in parallel, the fuel cells can dissipate excess energy resulting from load changes by storing energy in the battery system.

With this configuration, the system does not even have to transfer the load to the backup power source. Instead, the system transfers the load to the batteries when an outage occurs, and the batteries are continuously charged by the fuel cells until stored hydrogen is depleted. UPS energy management capabilities will also be used to increase fuel cell value by enabling peak shaving and other grid services. Here are the key components of a data center backup power solution capable of displacing a diesel generator:

- **Hydrogen storage:** Enough hydrogen to support desired backup times is stored on site in trailers. Approximately four trailers of hydrogen are required to provide 48 hours of backup power for a 1 megawatt (MW) facility.

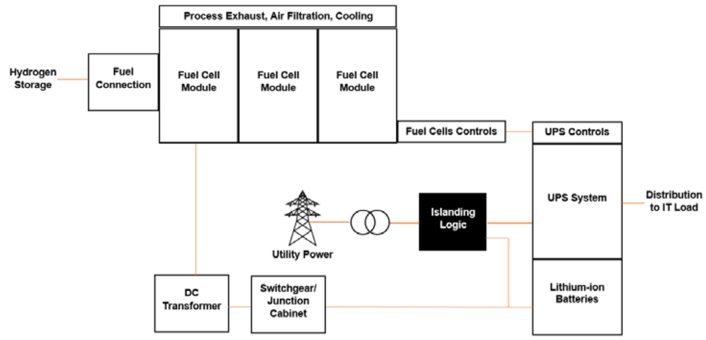
- **Fully contained PEM fuel cell system:** PEM fuel cell modules can be housed in an external enclosure with integrated thermal management, air filtration, and DC output to the UPS and lithium-ion batteries. Most fuel cells are also certified to work indoors, which could eliminate the cost of an external container. Depending on application requirements, the fuel cells can be idle when not operating, which will result in a startup time of about one minute, or can be kept in standby mode to provide instantaneous startup with full power within a few seconds.

- **UPS with lithium-ion batteries:** The UPS should have the capability to control the fuel cells and feature an integrated DC-to-DC converter able to work continuously for several hours. Extra battery capacity is typically required to absorb energy dissipated from the fuel cells when the batteries are fully charged.

Using Fuel Cells for Primary Data Center Power

The path to using fuel cells as a source of primary, zero-carbon data center power is longer than that of backup power applications, due largely to the current limitations of hydrogen distribution. But progress is being made on this front, and natural gas-powered fuel cells can be used as a bridge solution that reduces emissions and delivers other benefits while hydrogen distribution is being expanded.

Vertiv is part of a project funded by the Fuel Cells and Hydrogen 2 Joint Undertaking with support from European Union's Horizon 2020 research and innovation program, Hydrogen Europe, and Hydrogen Europe Research. This undertaking is piloting the use of natural gas-powered SOFCs as the primary source of power for hyperlocal edge data centers to reduce the environmental impact of these sites and advance an authoritative open standard for fuel cell applications in data centers.



In this application, the SOFCs serve as the main source of power with the grid providing backup power in conjunction with lithium-ion batteries. As with backup power applications, the UPS will eventually control the interface between the batteries and fuel cells, managing fuel cell set points and excess power from transients. In the future, the UPS could act an energy manager by coordinating multiple power sources, including utility, fuel cells, and a backup generator, if one exists; continually selecting the best source based on cost, reliability, and other factors; and managing transitions between sources.

While this undertaking is focused on hyperlocal data centers, its learnings are expected to advance progress related to using natural gas-powered SOFCs as a primary power source for large data centers. As hydrogen drops in cost and becomes more available, SOFCs can be transitioned to hydrogen power, enabling carbon-neutral operation.

Evaluating the Feasibility of Fuel Cells for Data Center Backup Power

From a technical perspective, fuel cells that are properly managed by an intelligent UPS system have the performance characteristics required to provide clean, reliable backup power for data centers. Based on current pilot projects, it isn't unreasonable to expect commercialization of PEM fuel cell solutions for data center backup power in the next several years.

However, these solutions will also need to demonstrate they can be cost-effective in order to achieve widespread support in the industry. That doesn't necessarily mean they have to be less expensive than diesel generators, as there is real value in their potential to reduce Scope 1 emissions and that value may increase in the future if the cost of carbon increases. In addition, new capabilities enabled by fuel cells, such as peak shaving, also add value.

It is difficult to project lifetime costs for a commercialized PEM fuel cell solution today, as costs for the fuel cell modules and the hydrogen fuel are dynamic and expected to drop in the coming years.

There is a significant effort by the United States government to drive down hydrogen costs through the U.S. Department of Energy (DOE) Earthshot Initiative. Launched in June 2021, this initiative seeks to reduce the cost of clean hydrogen to \$1/kg by the end of this decade. Following are the key economic factors that could influence adoption of fuel cells as a backup power source in data centers:

- **Capital expense:** Today, PEM fuel cells require a larger capital investment than a comparative capacity diesel generator. Our research shows PEM fuel cells to range from \$1,800-\$2,000/kW compared to about \$450/kW for a diesel generator. This gap is expected to close as fuel cell costs drop, but it may not reach parity when commercial solutions are first available.

- **Fuel costs:** Fuel costs are variable based on demand and region. Hydrogen fuel costs currently range from \$4.84 to \$6.68/kg. In the U.S., the average cost for a gallon of diesel, which provides slightly more energy than a kilogram of hydrogen, is \$3.29. If the DOE's Earthshot Initiative comes even close to its target, hydrogen will be less expensive than diesel over the life of a system.

- **Efficiency:** Compared to diesel generators, both types of fuel cells are showing higher efficiency, especially SOFCs. Moreover, diesel generators operate using alternating current (AC) that is subject to switching, which can diminish efficiency. Alternatively, fuel cells that use direct current (DC) to the UPS improve the overall system efficiency. By eliminating this use of AC power, operators are likely to see cost and sustainability benefits.

- **Maintenance:** The electro-chemical processes used in fuel cells require less maintenance than the mechanical processes used in generators.

- **Operating flexibility:** Because PEM fuel cells can be controlled by the UPS, they enable new energy management capabilities that aren't available with diesel generators, creating savings on energy costs.

- **Regulatory environment:** Some localities have created regulations that restrict or ban the use of internal combustion engines for power generation. Operators seeking to expand into these areas will need to find alternate approaches to maintaining continuity during outages, and fuel cell solutions should compare favorably to the alternatives.

Initial application of fuel cells to displace or supplement diesel generators is likely to be driven by hyperscale operators who have taken a leading position on carbon reduction. However, as they advance, fuel cells will become a more attractive solution for a range of data center types and sizes.

Conclusion

To enable continued growth while simultaneously reducing environmental impact, data center operators are exploring alternatives to carbon-based grid power and diesel generators.

Fuel cells are among the most promising solutions for enabling operators to achieve their carbon-neutral goals. Using clean hydrogen, PEM fuel cells can eliminate CO2 emissions from monthly generator checks and operation during outages. PEM fuel cells are being piloted today in this application and could be available in commercial solutions in the next several years.

Natural gas-powered fuel cells are being piloted as a primary source of power for edge data centers, and learnings from this pilot will help advance use of this technology in large data centers. As hydrogen producers and governments invest more in hydrogen production and distribution, these fuel cells can be converted to hydrogen to enable carbon-free operation.

Efforts to implement fuel cells today are being driven by organizations that place a premium on reducing carbon emissions. From a cost perspective, fuel cells are not currently competitive with diesel generators or grid power. But costs of key components and hydrogen fuel are expected to decline in the coming years, closing the gap and making fuel cells a viable and economically feasible data center power solution.

Vertiv is taking a leading role in advancing the use of fuel cells in data center applications by delivering critical infrastructure solutions that enable the effective use of fuel cells and support additional functionality, such as peak shaving, use of renewables, and grid services.

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