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An Assessment of Fuel Cell Applications in Data Centres for Greenhouse Gas Abatement Benefits

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Executive Summary

This white paper provides a high level assessment of the benefits to data centre greenhouse gas abatement which can be obtained through the application of different fuel cell types. Fuel cells utilising hydrogen-based fuel (natural gas) are shown to be suitable for data centre applications such as for back-up or primary power generation. In their favour, and depending upon the energy mix of the local utility and its dependence on fossil fuels such as coal and oil, fuel cells present an opportunity to reduce marginal emissions of CO_2 and NOx gases, as well as the use of water. The deployment of fuel cells fits very well with existing electrical designs using, e.g., diesel standby generators, however there are scale capital cost implications which must be considered.

Contents

1. Introduction

This paper focuses solely on fuel cells which are suitable for data centre application, though not necessarily implemented in commercial data centres, and their potential contribution to greenhouse gas abatement.

A fuel cell is an electrochemical device that converts chemical energy from a source fuel directly into electrical energy. It achieves this through an electrochemical reaction between hydrogen-based gaseous fuel and oxygen or another oxidizing agent without combustion. See Figure 1.

Figure 1: Energy Schematic of a Fuel Cell

In a typical fuel cell illustrated in Figure 2 below, fuel is fed to the anode while an oxidant (oxygen from the air) is fed to the cathode. Electrochemical reactions take place at the electrodes to produce the electric current.

Various hydrocarbon-based gaseous fuels can be used including:

- Natural Gas
- BioGas
- Town/City Gas or LPG
- Hydrogen

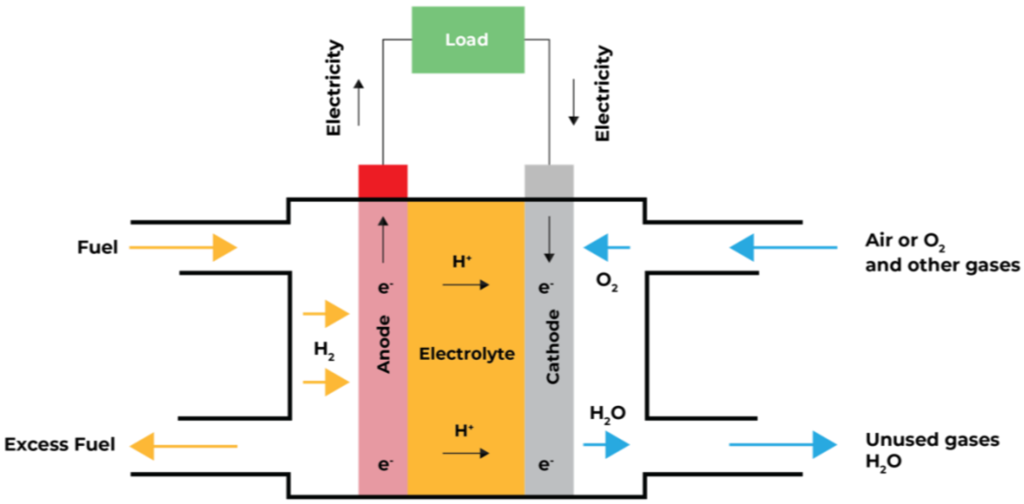


Figure 2: Schematic of a Typical Fuel Cell

Individual fuel cells are typically compact in size, with relatively low electrical potential and generating relatively low power. For example, Bloom Energy's fuel cell is illustrated in Figure 3 below, is only 100ɥm thick and generates 25W of electrical power. However, these elemental fuel cells can be stacked and connected both in series and in parallel to produce a higher power fuel cell system according to the actual application.

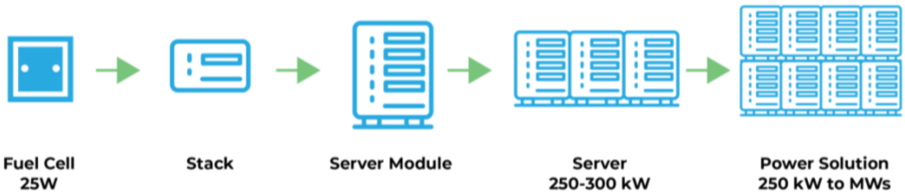


Figure 3: Graphic Illustration of typical Stacking of Fuel Cells to Application Modules [Source: Bloom Energy] [1]

Today, fuel cells are used in a wide range of applications and can be grouped in three broad application types, namely:

a. Portable
b. Stationary
c. Transportation

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 (camper-vans, 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)

Figure 4: Categorization of Fuel Cells by Application Types
[Source: www.FuelCellIndustryReview.com - E4tech – The Fuel Cell Industry Review 2020] [2]

Fuel cells which can be applied in data centre applications are categorized as Stationary, i.e., those that remain in a single fixed location to generate power.

Total fuel cells shipped globally for Stationary applications had been steady at around 200MW from 2016 to 2018 However, this increased during 2019 and had been projected to reach over 324MW for 2020. Refer to Figure 5 below: Global MW of Fuel Cell shipped by Application.

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**

Figure 5: Global MW of Fuel Cell shipped by Application
[Source: www.FuelCellIndustryReview.com - E4tech – The Fuel Cell Industry Review 2020] [2]
[2020f is the data at end of 2020 using the forecasted numbers for the last quarter]

Fuel cells are commonly categorized according to their electrolyte. The types which today can be commercially used for data centres include:

- Alkaline Fuel Cell (AFC)
- Direct Methanol Fuel Cell (DMFC)
- Molten Carbonate Fuel Cell (MCFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Proton Exchange Membrane Fuel Cell (PEMFC)
- Solid Oxide Fuel Cell (SOFC)

Although hydrocarbon-based gaseous fuels, including green hydrogen, are key to the operation of fuel cells, the production, supply, delivery, and safe storage, e.g., natural gas and hydrogen etc., are the subject of a future paper by the GHG Abatement Group.

2. Application of Fuel Cells for Data Centres

As a power generation system, fuel cells can be applied to data centres in two main areas: Back-Up Power Supply and Primary Power Supply.

Back-Up Power

In this application, fuel cells are used to provide the emergency back-up power during electrical utility grid failure, replacing emergency diesel or gas generators typically utilised by data centres. Static UPS, chemical batteries or ultracapacitors would be required to provide the short-term back-up during electrical utility grid failure, prior to the start-up and voltage stabilization of the fuel cells.

Figure 6 illustrates a possible schematic using fuel cells as back-up power source for a typical 2N power configuration for power supply to the IT equipment.

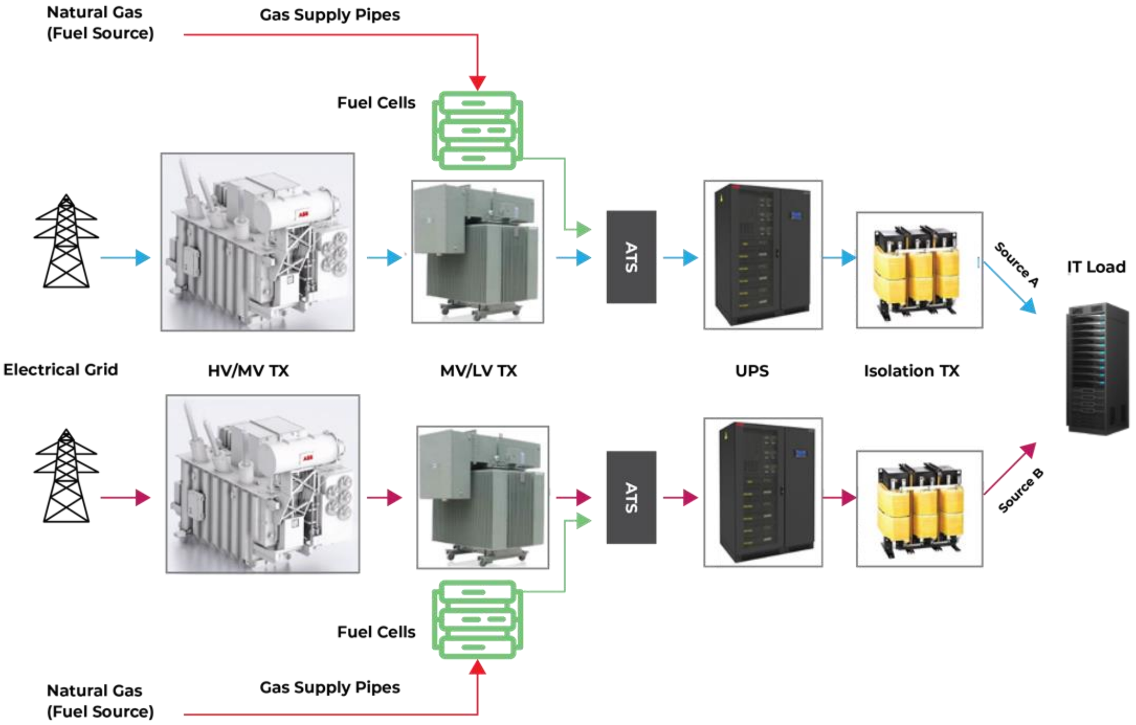


Figure 6: Schematic of Fuel Cell Application as Back-Up Power Source for IT Loads in Data Centres

During normal operation, the IT equipment load is fed by A & B power feed from the Electrical Utility Grid, protected by a static UPS together with back-up power supplied by gas-powered fuel cells.

In the event of an electrical utility grid failure, the static UPS immediately switches to Battery mode to provide short-term uninterrupted power back-up to the downstream IT Loads. At the same time, the fuel cells are activated powered by natural gas fuel. When the output of the fuel cells has stabilized, the power inputs of the UPS will be switched over to the fuel cell supply to provide long-term power back-up.

Fuel cells used for such back-up power applications must be able to start generating steady power within a short duration, similar to the typical emergency diesel or gas back-up generators. For fuel cells providing power back-up to IT equipment loads, the fuel cell's power would have to reach steady state within the UPS Battery back-up time. Since 5 to 10 minute UPS battery runtimes are typical, this is easily achievable by the appropriate fuel cells.

For back-up power to air-conditioning systems where there is a need to maintain continuous cooling, fuel cells would be required to reach steady state power within a time equivalent to that of typical emergency diesel generators, i.e., 10 to 15 seconds, to support a rapid re-start of the air-conditioning equipment.

Manufacturers of fuel cells currently used for Back-Up Power Supply include:

- AFC Energy – AFC
- Ballard – PEMFC
- Daimler – AFC
- Plug Power – PEMFC

Typically, these fuel cells are used today in remote sites to support telecommunication equipment.

Primary Power

In this application, the fuel cell provides the primary power supply to the data centre while the electrical utility grid acts as a back-up. For such an application, the fuel cell could feasibly replace both the generator and UPS in the data centre.

Figure 7 illustrates a possible schematic to implement fuel cells as the primary power source using the electricity utility grid as a back-up power supply.

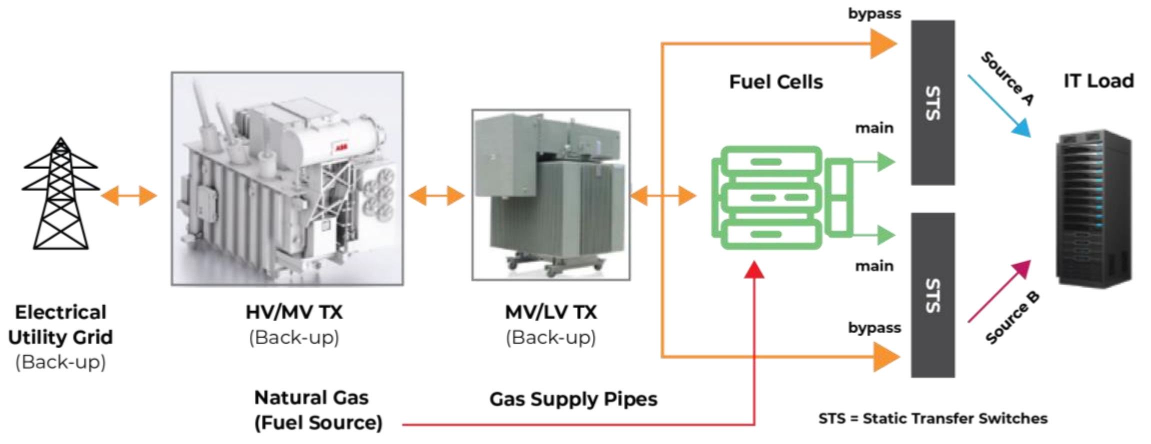


Figure 7: Schematic of Fuel Cell Application as Primary Power Source for Data Centres

During normal operation, the gas-powered fuel cells operate as the primary power source, to provide no-break A & B power feeds to the IT equipment load via Static Transfer Switches (STS). The STS are configured with the fuel cell power supply as the primary power source and electrical utility grid as the secondary power source.

In the event of an electrical utility grid failure, the power supply to the IT equipment load is not affected as the primary power source from the fuel cells are unaffected by the electrical utility grid.

Should the fuel cells fail, the STS sense that the failure at its primary power source input and automatically transfer power to the secondary source from the electrical utility grid.

This configuration provides true dual redundancy of power sources with the gas fuel as the primary source and electrical utility grid as the secondary source. As the gas fuel and electrical utility are supplied via two different independent infrastructures, failure of either one of the infrastructure or source will not impact the availability of the other source.

The resiliency of the primary power source fuel cells can be enhanced by configuring at least N + 1 redundancy for the fuel cells, in a similar way to that of an N + 1 modular UPS with N + 1 generators configuration.

Manufacturers of fuel cells used for Primary Power Supply include:

- Bloom Energy - SOFC
- Doosan - PAFC
- FuelCell Energy – MCFC

Public information as of April 2022 from Bloom Energy's [3] and Doosan's (previously Clear Edge Power) [4] show the track record of their fuel cells deployment in data centres. Public information as of April 2022 from FuelCell Energy's [5] and Plug Power's [6] websites does not directly show the track record of their Fuel Cell deployment in Data Centre.

The Sustainability Case for the Application of Fuel Cells in Data Centres

Power generation using fuel cells is more efficient than conventional combustion or turbine power generators in terms of electrical energy generated per fuel energy consumed. The more efficient process of electrical energy generation by fuel cells reduces emissions of carbon dioxide (CO_2) for each MWh of electricity produced.

Fuel cells generate power via an electrochemical process which is cleaner than the conventional combustion-based process. The emission rates (kg/MWh) of Sulphur Oxides (SOx) and Nitrogen Oxides (NOx) of typical fuel cells are significantly lower than those of conventional combustion power generators used in electrical utility grids. SOx and NOx are harmful air pollutants linked to severe respiratory diseases and poor air quality worldwide.

Generating power using fuel cells' electrochemical process without combustion also results in significantly lower noise compared with the raw noise of combustion power generators, which therefore must be either situated away from noise sensitive areas or fitted with acoustic attenuators to meet local environmental requirements.

As the fuel cells can generate electrical power on-site in close proximity to the point of power consumption, they offer increased electrical reliability and improved energy security being unaffected by environmental or human impact upon electrical transmission infrastructure.

For example, electricity in the US is generally transmitted from the power generating plant to the data centre via overhead high voltage power lines, which can be impacted by hurricanes and high winds, winter storms or other extreme weather conditions. Underground electrical grid transmission could be impacted by human error during road works, construction or excavation.

Efficiency losses due to grid transmissions are also avoided through on-site power generation. The Environment Protection Agency (EPA) estimates that during 2020 the average Grid Gross Loss (GGL) in the US was around 5.3% of the electricity distributed, as illustrated in Figure 8 below.

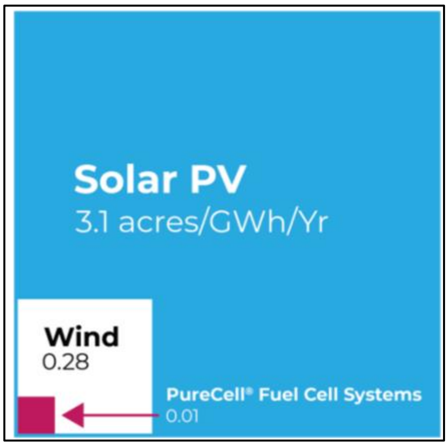
eGRID2020 Grid Gross Loss (%)	
Power Grid	**Grid Gross Loss (%)**
Eastern	**5.3%**
Western	**5.3%**
ERCOT	**5.2%**
Alaska	**5.5%**
Hawaii	**5.6%**
U.S.	**5.3%**

Figure 8: US EPA eGrid2020 Grid Gross Loss
[Source: US EPA eGrid2020] [7]

A potentially useful by-product of the electrochemical process used by fuel cells to generate power is waste heat. There is, therefore, potential to further enhance the fuel-energy efficiency and hence improve the CO_2 emission factor (CO_2 kg/kWh) of fuel cells by recovering the generated heat.

a. To drive steam turbines (CHP - Combined Heat and Power); or
b. To power absorption chillers to produce cooling (CCP – Combined Cooling and Power).

By virtue of their compact size, fuel cell systems also take up significantly less space in proportion to other clean energy technologies. See Figures 9 and 10 below.



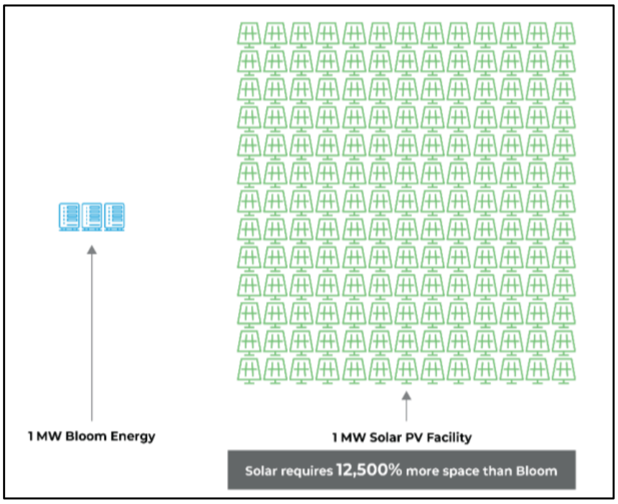


Figure 9 and 10: Illustration of the Space Requirement of Fuel Cells vs equivalent Renewable Energy Sources
[Source: Doosan, Bloom Energy] [8] [1]

The required space is compared with respect to the electrical energy production (GWh/year). Solar PV cells require more space and only generate electricity during daylight hours. Solar photovoltaic cells require 31,000% more space and Wind turbines requires 2,800% more space than, for example, Doosan's PureCell Fuel Cells to generate the same amount of electrical energy.

Power generation using fuel cells consumes zero or minimal water compared with combined cycle gas turbine power plants where a large amount of water, about 780 litres/MWh [9], is required to produce steam, cool the equipment, and serve other functions.

Sustainability Performance Indicators

Figure 11 below shows the comparison of the Sustainability Performance Indicators of some Fuel Cells against Gas Turbines and Combined Cycle Gas Turbines (CCGT), using Natural Gas as the fuel.

	Gas Turbines [1]	CCGT[2]	Bloom Energy Energy Server 5 ES5-YA8AAN	Doosan [4] PureCell 400	FuelCell Energy [5] SureSource 3000
Electrolyte	N.A.	N.A	Solid Oxide	Phosphoric Acid	Molten Carbonate
Power Output	1,000 kW	1,000 MW	300 kW	440 kW	2,800 kW
Operating Temperature °C	900 to 1,400 °C	900 to 1,400 °C	500 to 1000 °C	< 200 °C	400 °C
Fuel	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Fuel Consumption (m³/MWh)	310	N/A	188	233	220
Electrical Efficiency (LHV)	30%	N/A	65%-53%	43%	45%
Electrical Efficency with Heat Recovery	N/A	65%-50%	75%	90% peak	No Specifc Data
CO_2 (kg/MWh)	756	N/A	308 to 378	454	445
CO_2 with Heat Recovery (kg/MWh)	N/A	430	No Specific Data	220 to 371	236 to 308
NOx (kg/MWh)	0.5940	0.2360	0.0008	0.0091	0.0045
SOx (kg/MWh)	N/A	No Data	Negligible	Negligible	0.000045
CO (kg/MWh)	0.7300	0.2400	0.0154	0.0045	No Data
VOC (kg/MWh)	0.0400	0.0300	0.0072	0.0045	No Data
PM10 (kg/MWh)	N/A	No Data	No Data	N/A	0.0000091
Water Consumption (m³/MWh)	N/A	0.78	None during normal ops	N/A	0.73
Noise (dBA)	115 **	123 **	< 70 @ 1.83m	< 65 @ 10m	72 @ 3m

Figure 11: Comparison of Sustainability Performance Indicators between Gas Turbines, CCGT and Various Fuel Cells
(Sources: Gas Turbine Data Source: Bloom Energy's comparison slides [10], CCGT Data Source: Bloom Energy's comparison slides [11], Bloom Energy's Energy Server 5 ES5-YA8AAN Product Catalogue [12], Doosan's PureCell Model 400 Product Catalogue [13], Source: FuelCell Energy's SureSource 3000 Product Catalogue [14])

Annual GHG Abatement of a 10MW IT Data Centre using Fuel Cells

Based on the Sustainability Performance parameters above, the estimated annual greenhouse gas and water abatement of the IT power consumption of a 10MW IT Power data centre, using fuel cells powered by Natural Gas as its primary power supply is tabulated in Figure 12 below:

Power Generator	CO_2 (kg)	NOx (kg)	CO (kg)	Water (m³)
CCGT	37,668,000	20,665	21,024	68,328[1]
Fuel Cells[2]	33,112,800	70	1,349	None during normal ops
Annual Abatement	4,555,200	20,595	19,675	68,328

Figure 12: Annual Abatement Comparison between Fuel Cells and CCGT
(Source: Wartsilla website [9], Bloom Energy Energy Server 5 ES5-YA8AAN Product Catalogue [11])

3. Challenges

While there are many clear sustainability advantages of using fuel cells for data centres, their actual adoption is still low due to the following challenges:

Reliability and Availability

Reliability and availability of power systems are key to a data centre's main business – that of enabling data and IT services to be continuously available.

Redundancy is provided as a norm to enhance the power system's reliability and availability. The data centre industry is invariably apprehensive about new technologies and configuration schemes. In addition to their acceptance by those responsible for designing and operating data centres, the adoption of fuel cell technology and its application in colocation data centres would also require endorsement from all prospective customers, creating further uncertainty for the business.

More publicity surrounding successful fuel cell operation in data centres would help garner the approval of the data centre industry as well as end user customers, evidencing the reliability and availability of fuel cells.

Cost of ownership

The data centre business today is highly commercialized and competitive. Conventional grid energy offers relatively low and predictable cost of ownership. This proves to be a major roadblock to the adoption of fuel cells as the primary data centre power supply as the technology is significantly more expensive except in markets where the cost of electricity is highest.

Fuel supply

For fuel cells to operate as the primary power source, the data centre needs to be sited near gas pipelines to ensure a stable and reliable stream of fuel supply. In addition, in some cases, fuel storage would be required to be provided on site. Due to the lower energy density of natural gas vs diesel oil, the fuel storage space requirement would be higher for fuel cells. Piping and storage of natural gas fuel would also need to overcome the safety and permitting requirements of the local AHJ.

4. Development and Roadmap

Industry Inertia

Despite the conservative and risk-averse nature of the data centre industry and its apprehensiveness towards new technologies, it had been expected that fuel cells would gain acceptance for use as backup power in data centres since the electrical infrastructure and configuration would generally remain similar to diesel generator backup power.

The fuel supply and storage for backup applications would also be manageable due to the low consumption rate. However, typically the amount of annual reduction in greenhouse gas (GHG) emissions together with associated energy savings do not justify the significantly higher cost of adopting fuel cells as backup power. The case for using fuel cells for backup power would is considerably strengthened should AHJs start to restrict use of diesel generators because of environmental concerns.

To aide cost recovery, fuel cells as backup power could also be setup to provide ancillary services to the grid, including peak shaving, frequency regulation and demand response management.

Cost Reductions

Fuel cells are projected to achieve cost parity for adoption in data centres partly driven by higher adoption of fuel cells for transportation applications, which helps educate regarding fuel cell technology, drives improvements, and the reduced costs of key components and manufacture associated with higher volumes. McKinsey & Company, in their publication of "Road Map to a U.S. Hydrogen Economy", estimate that fuel cells could achieve cost parity with diesel generators in data centres in three to five years [15].

Natural Gas to Hydrogen as fuel

Although emissions of carbon and other GHGs by blended natural gas-powered fuel cells are lower than conventional combined cycle gas turbine plants, manufacturers are further enhancing their fuel cell products to utilise hydrogen gas as fuel, further reducing the emissions of carbon and other GHGs.

Fuel Cell manufacturers who have already developed pure hydrogen fuel cells include:

- Ballard
- Bloom Energy
- Doosan
- Plug Power

Due to the cost and availability of hydrogen, early adoption of pure hydrogen fuel cells is for use in remote sites, where they replace generators and diesel fuel supplies.

Distributed Primary Power

Research into the application of fuel cells as primary power has also considered the possible adoption of distributed primary power supplies. The University of California, Irvine (UCI) and Microsoft have published a white paper entitled, “Fuel Cells for Data Centres: Power Generation Inches from the Server” [16], studying the use of PEMFC and SOFC technologies in distributed power configuration and highlighting some promising results.

5. Conclusion

Natural gas powered fuel cells can be successfully applied as backup power and primary power sources in data centres, the engineering case for the latter is perhaps stronger than the former. Currently, in the ICT sector fuel cells are predominantly used to provide backup power to telecommunications facilities in remote locations.

Used onsite, fuel cells can improve the reliability of the supply by eliminating the need for power cables to and from the data centre location which can be exposed to risk from extreme weather (in the case of overhead cabling) and human interactions such as construction (in the case of underground cabling).

Depending on the local energy mix, the application of fuel cells in data centres can result in significant abatement of greenhouse gas emissions, however more work is needed to help foster wider adoption of the technology including improving understanding and acceptance of the technology through the publication of successful case studies, a reduction in total cost of ownership and improvements to fuel management.

Because of the combustion-less process by which power is delivered by fuel cells, they may be usefully applied in, e.g., residential and other areas where noise levels are subject to bye-laws. Additionally, regulators taking firmer action regarding the use of fossil fuels including diesel for standby generation may increase the appeal of fuel cells due to their lower emissions profile.

6. References

[1] Bloom Energy's presentation dated 13 Aug 2021

[2] The Fuel Cell Industry Review 2020 by E4Tech http://www.FuelCellIndustryReview.com

[3] Bloom Energy's website https://www.bloomenergy.com

[4] Doosan's website https://www.doosanfuelcell.com/en

[5] FuelCell Energy's website https://www.fuelcellenergy.com

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[7] US EPA eGrid2020 Technical Guide - The Emissions & Generation Resource Integrated Database

[8] Doosan's Presentation Slides at ADB 2019

[9] https://www.wartsila.com/energy/learn-more/technical-comparisons/combustion-engine-vs-gas-turbine-water-consumption

[10] Bloom Energy's Comparison between Bloom Energy's Energy Saver and Gas Turbines

[11] Bloom Energy's Comparison between Bloom Energy's Energy Saver and Combined Cycle Gas Turbine Plant

[12] Bloom Energy's Energy Saver ES5-YA8AAN 300kW Data Sheet

[13] Doosan's PureCell Model 400 Data Sheet

[14] FuelCell Energy's SureSource 3000 Data Sheet

[15] McKinsey – Road Map to a US Hydrogen Economy

[16] University of California, Irvine (UCI) and Microsoft: "Fuel Cells for Data Centres: Power Generation Inches from the Server

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Seng Wee leads the day-to-day management of APAC business at i3 Solutions Group. With nearly 25 years' experience in mission-critical industries, Seng Wee's areas of expertise include data centre design, electrical engineering, data centre infrastructure management systems and business continuity management.

He is a registered Professional Engineer (Electrical) in Singapore and a Licensed 22kV Electrical Engineer registered with Energy Market Authority.

Seng Wee was part of the Technical Committee on Mains Failure Standby Generating System, which was responsible for Singapore Standard SS 535 : 2007 Code of Practice for Standby Generators (formerly CP31 : 1996).

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