Infrastructure Sustainability Options and Revenue Opportunities for Data Centres

Whitepaper 1

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Executive Summary

The purpose of this paper is to provide the reader with an overview of the main factors associated with the many low-carbon technology options available and the confluence of features that influence decision-making associated with a particular technology.

Reduced Greenhouse Gas (GHG) emissions and revenue-generating opportunities can coincide when low-carbon technologies combine with demand-side response.

The falling costs of low-carbon distributed energy systems provide data centre operators with opportunities to satisfy the requirements of hyperscale end-users with ambitions for a Zero Carbon Solution.

The drivers for change incorporate a wide range of commercial, operational, and environmental elements, with end-users demanding reduced costs and carbon neutrality.

Content

i. Introduction
ii. Demand-Side Response and Sustainable Energy Trading
iii. Data Centres as Bidirectional and Unidirectional Microgrids
iv. System Selection Criteria
v. Future Papers by the i_3 EYP GHG Abatement Group
vi. Glossary

1. Introduction

Government regulation is driving data centre owners to consider the impact of their business on climate change. Globally, large economies have declared their intention to decarbonise grid generation using low-carbon energy sources such as nuclear and hydro, and adding renewable sources, primarily wind, solar and tidal power.

The energy sector appears to be responding. Figures released in February 2021 by the IEA (International Energy Agency) revealed that "Global emissions from the electricity sector dropped by 450 million tonnes in 2020. This resulted partly from lower electricity demand but also from increases in electricity generation by solar PV and wind."

However, overall the IEA figures showed a carbon bounce due to rebounding economic activity at the end of 2020. The IEA said: Emissions in China for the whole of 2020 increased by 0.8%, or 75 million tonnes, from 2019 levels driven by China's economic recovery over the course of the year. Emissions in the United States fell by 10% in 2020. But on a monthly basis, after hitting their lowest levels in the spring, they started to bounce back with December 2020 emissions matching those of the previous year.

Dr Fatih Birol, the IEA Executive Director, said: "In March 2020, the IEA urged governments to put clean energy at the heart of their economic stimulus plans to ensure a sustainable recovery. But our numbers show we are returning to carbon-intensive business-as-usual… these latest numbers are a sharp reminder of the immense challenge we face in rapidly transforming the global energy system."

Renewable energy brings enormous benefits. However, the energy output from solar and wind is intermittent, and tidal energy is periodic. Furthermore, renewables could de-stabilize the grid if large blocks of power are added or removed.

Paradoxically, this presents both challenges to the utility providers as well as new revenue opportunities to data centre owners. Data centres with low-carbon generation sources and sufficient energy storage can assist in backfill grid capacity shortfalls by interacting with the grid. Embedded generation grid integration is well established amongst existing distributed generation companies.

Historically almost all data centres have used UPS to condition utility power and provide 5 – 10 minutes of IT power together with diesel generators to supply 24 to 72 hours of standby power during a utility power failure. In countries with reliable grids, diesel generators usually operate just a few hours each year. Diesel engines have high emission factors and therefore are unsuitable as a sustainable energy source for grid support.

Substituting diesel engines with low-carbon alternatives such as gas reciprocating engines or turbines in conjunction with sustainable energy storage devices will enable many data centre owners to reduce their carbon footprint, and gain additional income derived from the various grid support schemes discussed in Section 2.

Gas-driven generators have low NO_x and SO_x emissions, so they are generally permitted for unlimited use. Conversely, standby diesel generators operate are generally required to operate for only a few hours a year, so their overall carbon contribution is rather insignificant. The high emissions associated with diesel generators is the reason they are only permitted to run for few hours.

Each country has a different grid generation fuel mix. Each type of generation has an associated emission factor, typically referred to as equivalent carbon footprint which includes the effect of all GHG emissions including CO_2, SO_x, NO_x and F-gases.

Figure 1 illustrates the 2019 GEF (Grid Emission Factor) data for some countries.

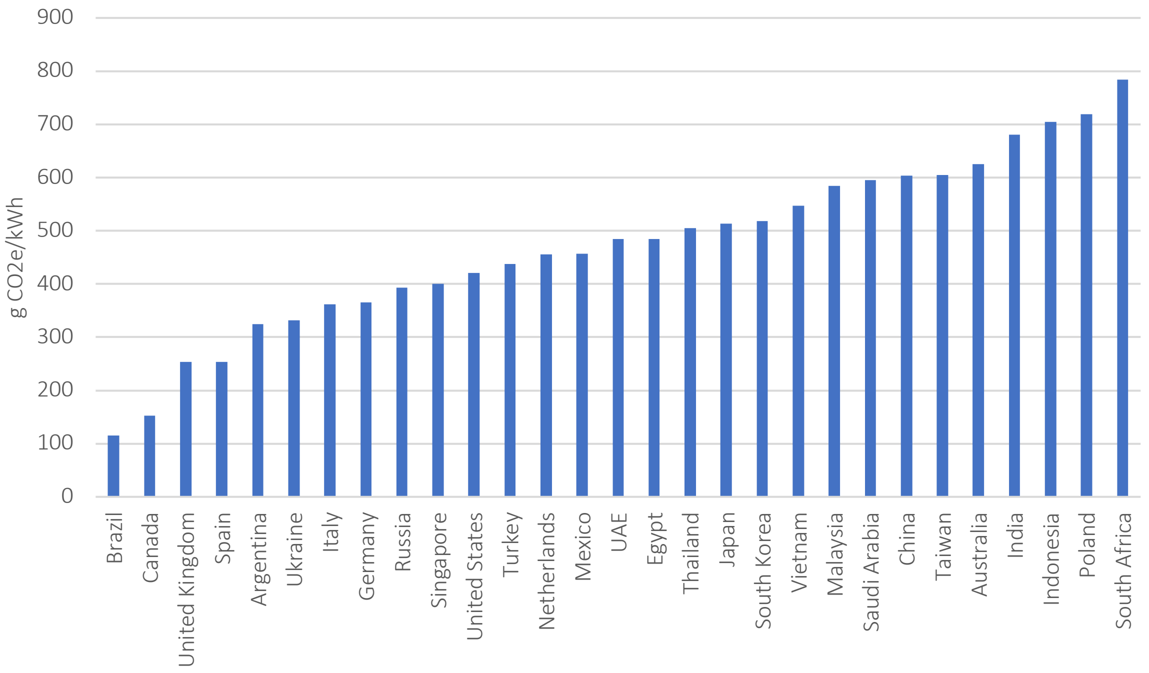

Figure 1

Sample Country GEF in 2019

The fuel mix is the ratio of the CO_{2e} emission factors associated with each type of generation source expressed as the overall grid emission factor (GEF) stated in g CO_{2e}/kWh.

Some companies are seeking to reduce their carbon footprint by buying renewable energy from utility power companies. This supply chain behaviour is typically underpinned by specific customer expectation or as part of active marketing.

In large countries with multiple grids, this approach merely pushes fossil fuel off the local grid but does not reduce GHGs nationally. For most countries with a single grid, where all generated energy sources feed the same grid, there is also no reduction in national grid GHG emissions.

In other words, a company buying renewables from a private utility company does not improve sustainability unless it results in a higher ratio of additional renewable energy and a reduction in national GEF.

To meaningfully reduce a country's carbon footprint, a different approach is required, wherein on-site data centre energy generation and storage decreases the GEF by exporting low-carbon energy into the grid.

2. Demand-Side Response (DSR) and Sustainable Energy Trading

Demand response helps power utility service providers manage fluctuations in supply and demand to maintain the most appropriate generation levels. Maintaining constant voltage and frequency is fundamentally changing as grids decarbonise using more renewable grid generation, particularly from wind and solar. The challenge to the grid is primarily due to the unpredictable nature of these renewable energy sources. Such fluctuations can be countered by Demand-Side Response (DSR). Generally, financial returns are improved by the ability to trade flexibly, in particular via fast balancing services.

Data centre owners have an opportunity to take advantage of DSR energy trading premium prices by operating as bi-directional smart grids, which enable energy export, import and running in 'island mode' to assist the demand-side balancing market – Figure 2 refers.

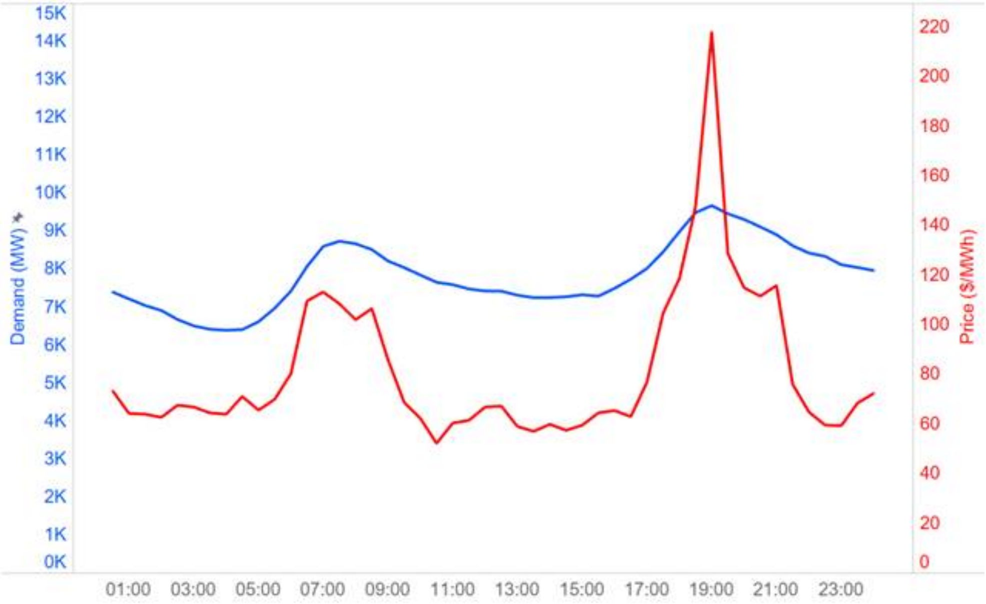

Figure 2

Wholesale Spot Power Price 24 Hour Fluctuation ($/MWh)
Source: AEMC, NSW Australia, 00:00 17.09.18 to 00:00 18.0.18

Integration of the data centre with the grid does present some technical and bureaucratic hurdles. However, none are insurmountable in jurisdictions that permit integration of private generation for demand-side response.

There are several areas where data centre owners could participate in energy trading. The rationale for energy trading is to provide additional power to the grid arising from intermittent generating sources, e.g., low wind levels resulting in the reduction of wind energy input, overall grid utilisation and grid-related events such as frequency deviation and voltage sags.

Frequency Response

Dynamic frequency response (DFR) and static frequency response (SFR) require embedded stored energy and generation sources to be made available to the grid to prevent unacceptable deviations in system frequency.

DFR is the management of system frequency under normal operation. In contrast, SFR is concerned with maintaining system frequency within set limits in the event of a fault and is triggered at a defined frequency. SFR is typically activated within milliseconds. An example of a DFR application may be battery energy storage systems (BESS) with a bi-directional UPS rectifier. The BESS system is required to be always available and the utility pays for this service irrespective of whether it is used or not.

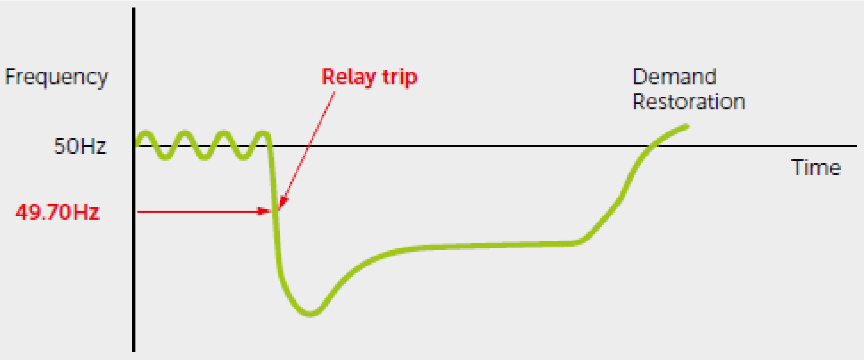

Figure 3

Frequency Control by Demand Management
Source: Major Energy Users' Council in association with National Grid

For example, in the UK, frequency data from National Grid suggests providers are expected to be called upon roughly ten times a year at the pre-set frequency deviation of 49.7Hz. This means they will provide a frequency demand response service when the system frequency drops below 49.7Hz as shown in Figure 3.

Short Term Operating Reserve

Short term operating reserve (STOR) is export of power to the grid derived from distributed generation systems during certain times. STOR provides additional power to the grid when demand is greater than forecast, or there are unforeseen grid-level generation shortfalls.

Data centre owners can financially benefit from STOR and simultaneously reduce GHGs. On the proviso that on-site generation has a lower emission factor than the GEF , excess or redundant capacity can be delivered to the grid via low-carbon generation, e.g., gas generators, turbines and fuel cells.

Typically, the utility instructs STOR power via a centralised time of use platform. The data centre would then need export power within two hours of instruction.

Demand-Side Balancing Reserve

Demand-side balancing reserve (DSBR) involves either disconnecting the entire data centre load from the utility or reducing the data centre load connected to the grid, usually for several hours. Usually, the utility is required to give a few hours' notice prior to disconnection or load reduction. An example DSBR application suited to data centres could be to run the facility on its standby gas engines.

3. Data Centres as Bidirectional and Unidirectional Microgrids

Practically all data centres have some excess capacity. Data centre owners should consider whether it is possible to increase the utilisation of standby and redundant generation and energy storage assets for DSR or, indeed, configuring low-carbon generation assets to be the primary source of power to the data centre.

Generation

Data centre power generation falls broadly into two categories - mechanical generators and fuel cells (see figure 4).

Mechanical generators are either (diesel or gas) reciprocating engines or gas turbines. Gas reciprocating engines and gas turbines can be run on natural gas (methane), biogas, hydrogen or a blend of natural gas and hydrogen. Diesel generators are generally considered unsuitable in the context of next-generation data centres since the associated emission factor will not meet environment permitting requirements.

Fuel cells are either hot (Solid Oxide, Molten Carbonate, Phosphoric acid) or cold (Proton Exchange Membrane (PEM)). Solid Oxide fuel cells can run on natural gas, biogas or hydrogen.

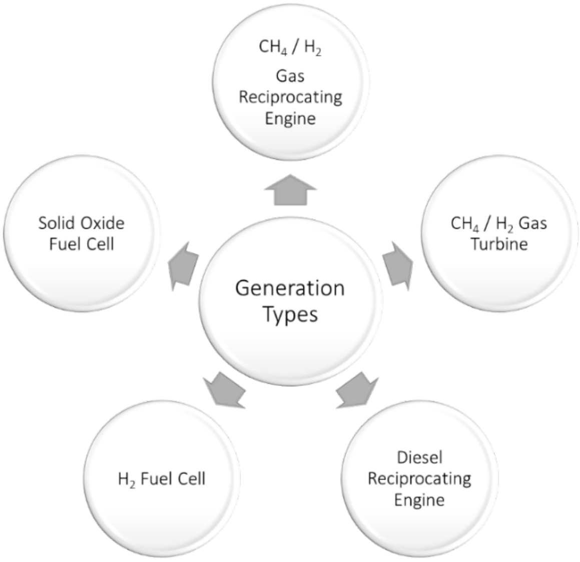

Figure 4

Data Centre Embedded Generation Sources

Examples of mechanical generation and fuel cell generation are shown in Figures 5 and 6, respectively.

Figure 5 is a high-level illustration showing hydrogen-fuelled gas reciprocating engines powered from 'green' hydrogen. When there is no call for DSR from the grid, the data centre is served directly by utility power and creates hydrogen via a PEM electrolyser. Grid energy also used to compress and store hydrogen.

When there is a DSBR call from the grid or a utility failure, the reciprocating engines start and load up to feed the data centre.

A problem with this approach is that the energy used to create hydrogen is significantly more than the hydrogen engine's output. From a sustainability perspective, hydrogen should be produced using excess renewable energy that the grid control systems would otherwise curtail.

Provided this condition is satisfied, the major benefit of this type of system is it has a near-zero carbon footprint.

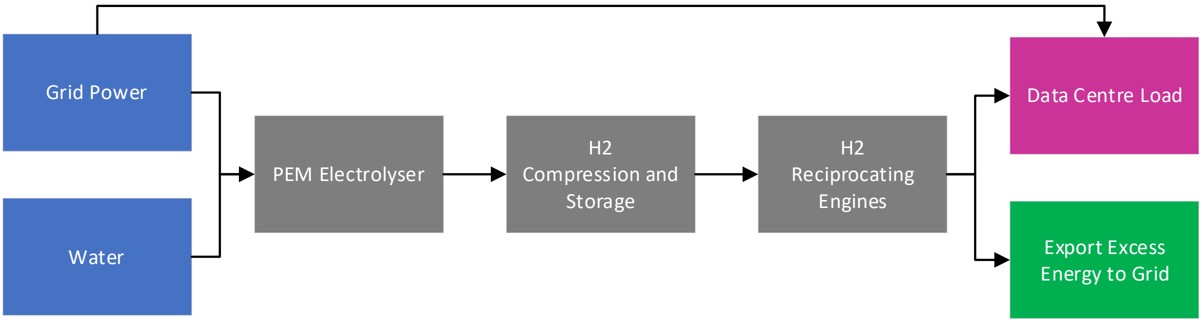

Figure 5

Grid Energy for H_2 production with Energy Export

Figure 6 shows a Solid Oxide fuel cell (SOFC) system which provides the primary power source to the data centre. In this example, the SOFC is fuelled by natural gas. Generally, gas utility supplies are meshed networks and are more reliable than utility power. Any excess power generated by the SOFC is exported to the grid.

SOFCs require water for start-up and are typically configured with N+1 stack redundancy. However, in the event of catastrophic SOFC failure or utility outage, standby generators could be used to support the data centre load. SOFCs do not react well to high rates of change in load; therefore, a grid connection is required.

The advantages of this type of system include its relatively low operating cost, reduced emissions (subject to the GEF) and offset energy costs due to the grid export component.

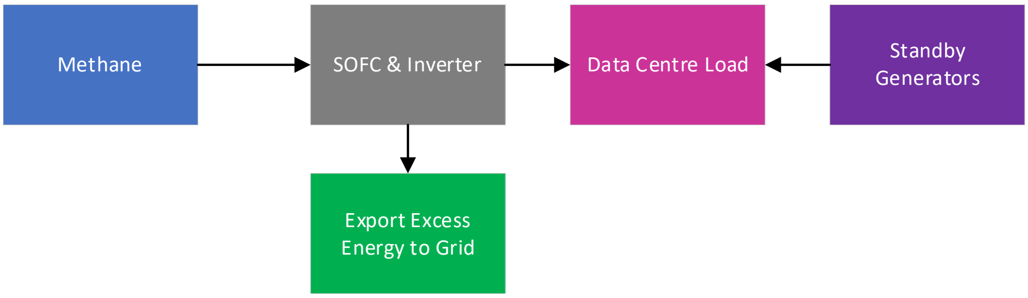

Figure 6

Solid Oxide Fuel Cell Application with Energy Export

Energy Storage

Energy storage has seven categories.

- Battery (chemical)
- Kinetic
- Compressed gas
- Pumped Hydro
- High Temperature Energy Storage (HTES)
- Gravity storage
- Nanotechnology

Batteries have eight main categories as shown in Figure 7. However, other promising battery technologies include flow batteries, liquid metal, lithium or sodium glass.

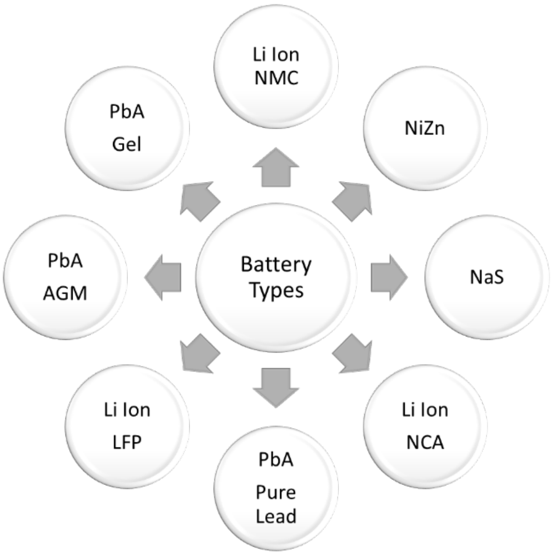

Figure 7

Battery Technologies

Compressed methane, hydrogen and biogas are fuel sources for the mechanical generator. Whereas kinetic energy is usually best suited to providing short term ride-through power between utility failure and engine load up.

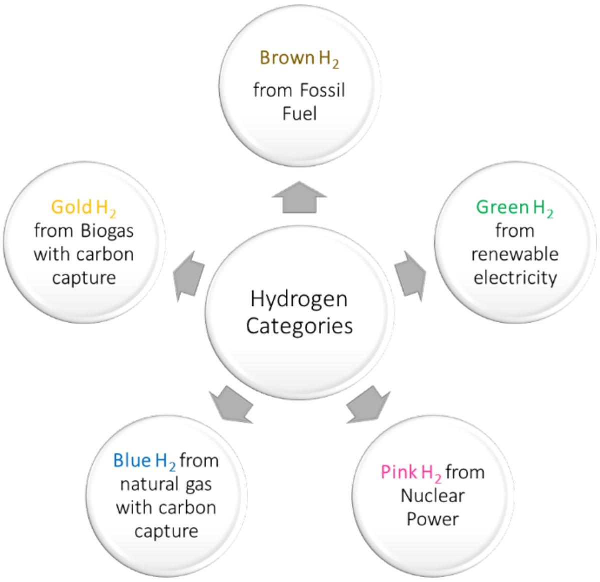

Figure 8

Hydrogen Categories

Traditionally, lead acid batteries have been used to provide ride-through power to drive the UPS inverter stage after a utility outage and whilst the generators load up. Lead acid batteries have to some extent been overtaken by lithium-ion batteries, both at UPS level and extensively at rack level. Lithium-ion batteries are perhaps less sustainable than first believed and more recently nickel zinc batteries have started to challenge both lead acid and lithium-ion.

4. System Selection Criteria

Many interacting factors need to be considered when selecting the appropriate low-carbon energy storage and generation systems. Principally, this includes the type of application, sustainability performance indicators, investment and revenue return, technical performance and location constraints.

Sustainability Performance Indices (SPIs)

In terms of sustainability, there are at least nine main metrics to be considered at component level. These include product carbon footprint, water use, volatile organic compounds, carbon payback, embodied energy, recycling, source material environmental impact, electrical and thermal system efficiency. Each are essential topics in their own right and will be subject to subsequent publications as part of the i_3 EYP MCF GHG Abatement Group initiative.

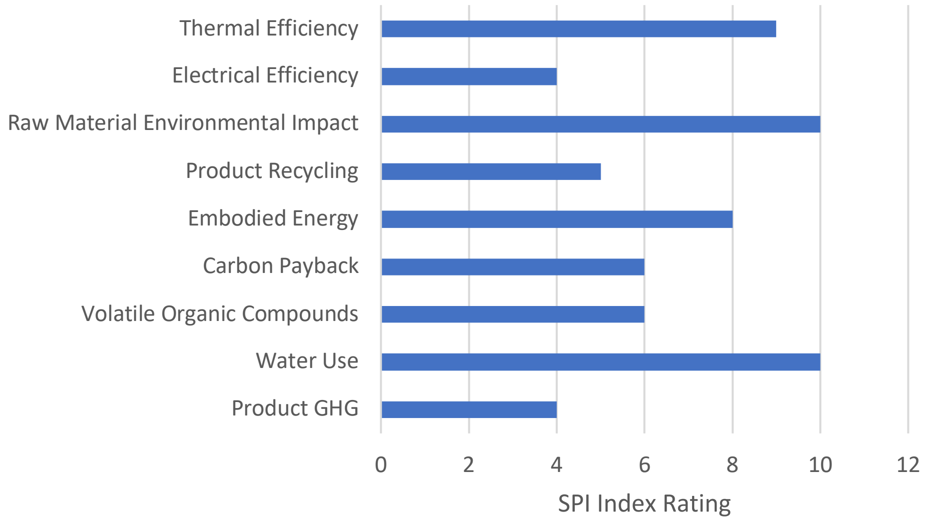

Figure 9

Product Type Comparison - Sustainability Performance Indices

Technical Considerations

The numerous different technologies and technical considerations will also be analysed in future work by the i_3 EYP MCF GHG Abatement Group. However, in summary, the primary technical considerations include the following:

- Type of application: primary source or standby,
- DSR type
- Fuel reserve – types and autonomy
- Energy storage: type and capacity, efficiency, life expectancy, operating temperature, safety
- Service levels - system reliability and availability
- Load acceptance, dynamic response, fault clearance
- Power and energy density
- Charge and discharge rate
- Grid Integration
- Maintenance and serviceability
- Product maturity
- IT load capacity and ramp-up
- Size and weight

Location Factors

It is important to note that location and specific national and state-related conditions will substantially affect the selection of an appropriate low-carbon technology. This is mainly due to local variations in resource availability, legislation and geography.

From a sustainability perspective, the local GEF will influence decision-making. This is because the carbon footprint of the selected generation or energy storage technologies must contribute to a net reduction in GHGs based on the individual country or state carbon footprint and all other SPIs.

Developed countries tend to have a substantial stock of legacy data centres or buildings predisposed to conversion to a data centre. Such countries should, in the first instance, assess the sustainability benefit of reduced embodied energy arising from building reuse when compared to constructing a new building.

Other location factors include:

- Space utilization
- Availability of water
- Proportion of curtailed energy due to renewables
- Speed to market of utility gas connection
- Utility power availability and stability
- Availability of natural gas, biogas and hydrogen
- Regulatory requirements – local demand-side response rules
- Thermal environment
- Tax implications, benefit zones
- Seismic, acoustic, zoning, traffic, EMF
- Sub-surface cavities

Financial Benefits

DSR and sustainability can combine using low-carbon technologies to provide data centre owners a significant new income stream to offset TCO costs and simultaneously reduce overall GHG emissions. Each technology should be considered on its sustainability, technical, location and financial merits.

In terms of cost, CAPEX and OPEX investment are of course key metrics. However, a new dimension of energy trading income should be considered in the context of the regulatory environment and wholesale market grid component generation trends.

Typical financial considerations include initial and staged capital cost (CAPEX), operating cost (OPEX), firm frequency response revenue (FFR), short-term operating reserve (STOR), continuous energy export (CEE), energy return on investment (EROI) and energy stored on investment (ESOI).

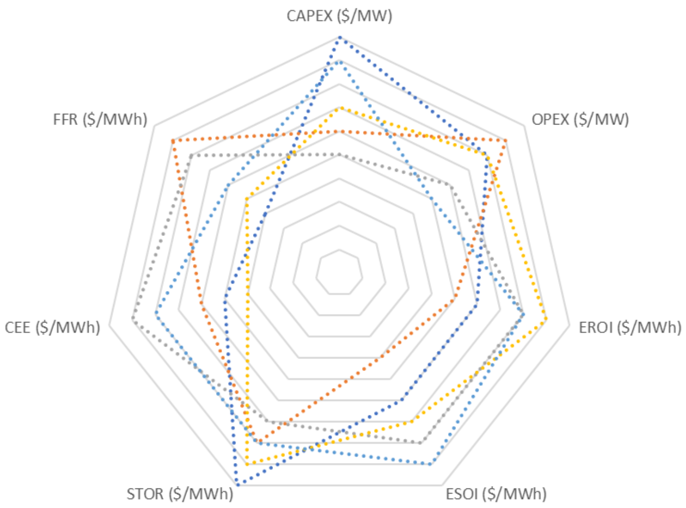

Figure 9
Product Type Comparison - Cost and Revenue Factors

5. Future Papers by the i$_3$ EYP MCF GHG Abatement Group

In subsequent papers, the i$_3$ EYP MCF GHG Abatement Group will address the issues raised in this paper and objectively analyse the application and performance of these technologies in data centre.

Future work will assess the technical, sustainability and financial considerations associated with the following topics.

- Assessment and Application of BESS to data centres
- Assessment and application of gas reciprocating engines and turbines
- Assessment and application of fuel cells to data centres
- Low GHG energy trading opportunities for large scale data centres
- Demand response opportunities for data centre embedded generation and storage systems
- GHG reduction with blended hydrogen and natural gas generation
- Reliability implications of embedded generation and energy storage systems
- Building reuse and embodied energy benefits for data centres
- Energy storage – kinetic, compressed air, liquid air, hydrogen and chemical
- Heat reuse using cogeneration and tri-generation
- Production and application of hydrogen to data centres
- Carbon Reduction Roadmap

About the author

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Considered a pioneer of the data centre mission critical industry, Ed Ansett has in-depth expertise in critical facility design, risk and root-cause failure analysis. Ed has published numerous technical papers on critical facilities design and power reliability. His specialist expertise means he is a sought-out keynote speaker and facilitator at data centre industry events around the world. Ed is the recipient of a DatacenterDynamics Award for Outstanding Contribution to the Industry, and is also a founder of DCiRN (the Data Centre Incident Reporting Network), a not-for-profit enterprise which aims to help eliminate downtime and ensure safe and resilient data centre operations.

Glossary

BESS	Battery Energy Storage System
CAPEX	Capital Cost
CCS	Carbon Capture and Storage
DFR	Dynamic Frequency Response
DSBR	Demand Side Balancing Reserve
DSR	Demand Side Response
EROI	Energy Return on Investment
ESOI	Energy Stored on Investment
FFR	Firm Frequency Response
GHG	Greenhouse Gases comprising CO_2, NO_x, SO_x and F-Gases
GEF	Grid Emission Factor
HTES	High temperature energy storage
OPEX	Operating Cost
PEM	Polymer Electrolyte Membrane
SFR	Static Frequency Response
SOFC	Solid Oxide Fuel Cell
SPI	Sustainability Performance Index
STOR	Short Term Operating Reserve
TCO	Total Cost of Ownership

Contact Us

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