VERTIV WHITE PAPER

Wired for change: Data centers' dynamic shift to hybrid power solutions

Executive summary

Over the past two decades, we witnessed the evolution of the data center power architecture and operating philosophy: from highly robust 2N architectures to reserve architectures. We have seen the shift in focus from high resiliency to high utilization and high efficiency.

Now, data centers are simultaneously facing multiple disruptors in their power architecture and operations:

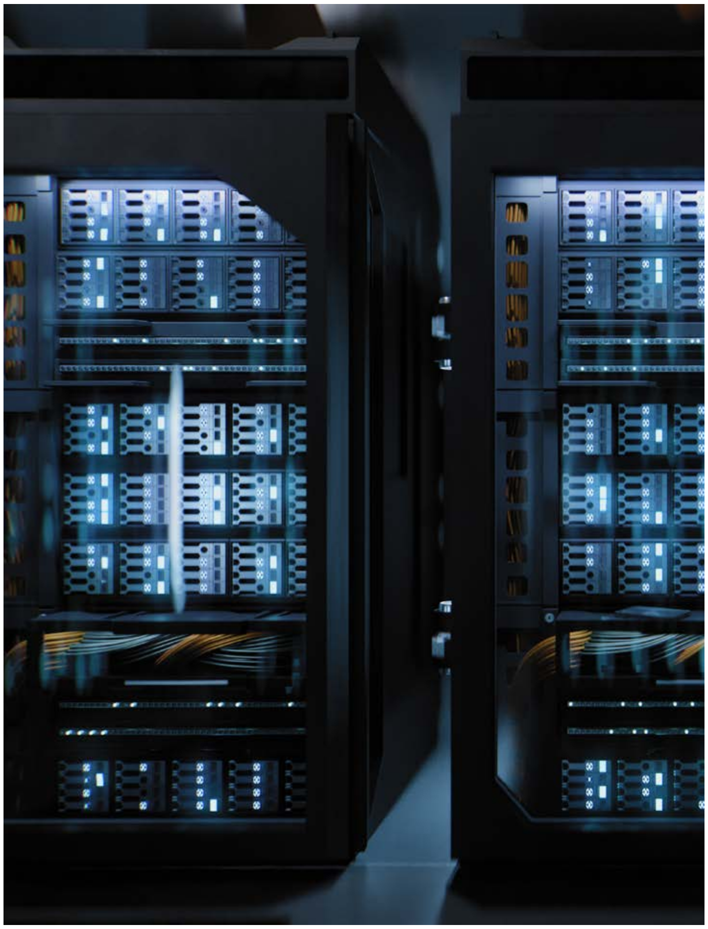
- First, in the past few years, there has been a move towards reducing carbon emissions driven by corporate sustainability mandates. Efficiency and utilization are now taking a back seat to decarbonization, but they are still important to data center designers and operators.
- Second, data centers are being stressed by increasing power demands due to the overall surge in online services and the explosive growth of AI.
- Third, this is all occurring when the grid is limited by generation, transmission, and distribution capacity and with demands to reduce the use of coal and fossil fuels. In some areas, more utility power capacity is not expected until 2030.

Compounding these issues is the reluctance of local and state governments to permit more diesel generator installations due to noise and emission levels. What can data centers do when faced with a lack of utility power and no ability to add backup diesel generators?

The solution is "Bring Your Own Power." Data centers must shift their focus to energy independence. They cannot wait for the utility to increase capacity sometime in the future and at likely higher rates. They need to take control of their energy future now.

Data center operators are currently investigating the idea of achieving energy independence with a mix of caution and optimism. They are striving to gain a comprehensive understanding of the challenges faced by critical infrastructure, which will allow them to take bold steps toward energy independence and smoothly integrate systems for a more autonomous operation.

This paper emphasizes the significant impact the shift towards energy independence has on the data center industry. As the industry moves towards cleaner energy sources, the existing challenges in power supply accelerate this trend. This transition marks a crucial step towards achieving sustainable operations within the data center sector, highlighting a pivotal moment in its evolution towards environmental responsibility.



Industry leaders and regulatory challenges

Major players in the tech industry, including Microsoft, Google, Amazon, and Meta, have set aggressive targets to reduce their carbon emissions, spearheading a movement towards sustainability. In addition, local governments and utilities in the US, Europe, and Asia have or are starting to implement regulations limiting generator permit issuance and restricting noise and pollutant levels. This poses further challenges for data centers as it is likely that these regulations will become even more stringent in the future.

A focus on reducing generator usage

One of the main goals in data center operations is to reduce generator usage, as this significantly impacts carbon footprints. Although these challenges can be disruptive, data center operators can view them as opportunities to advance their business, environmental, and financial goals by working towards achieving utility independence.

The changing power landscape

Traditional power sources are increasingly falling short due to limited grid capacity and reliability issues caused by weather, human errors, and old equipment. Furthermore, growing regulations and infrastructure limits restrict data centers' ability to expand, raising the risk of power interruptions from grid instability.[1][2][3][4]

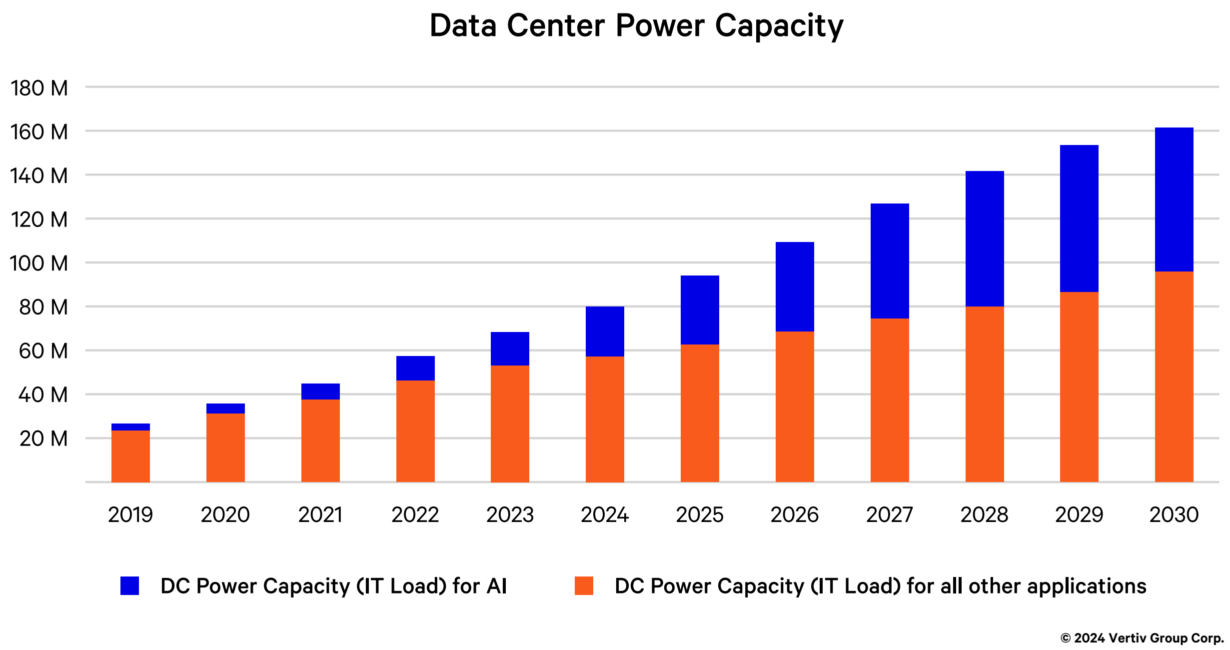


Figure 1. *Data center power capacity by IT workloads from 2019 to 2030 studies and forecast. Source: Omdia*

Erratic capacity and reliability

With the rise of digitalization and technologies like AI becoming mainstream, there's a higher electricity demand. Utilities are working to meet everyone's energy needs despite this increased demand, which the current power grid struggles to support. This situation could lead to temporary power outages or reduced power supply, as the grid can't always handle the load from more power-hungry technologies and computing.

Increasing workloads with widely varying load profiles

Historically, data centers were built assuming steady power needs. But now, power usage varies significantly because of changing workloads, including activities that heavily use CPUs and GPUs. This leads to different patterns of power consumption.[5]

The mismatch between energy supply and demand can lead to significant problems, such as increased costs, equipment damage, and more frequent downtime. Additionally, utilities using more peaking capacity can further strain the supply. Even if more data centers were built to help manage demand, the global issues of limited space in urban areas and power rationing would still increase operational costs without guaranteeing a reliable energy supply.

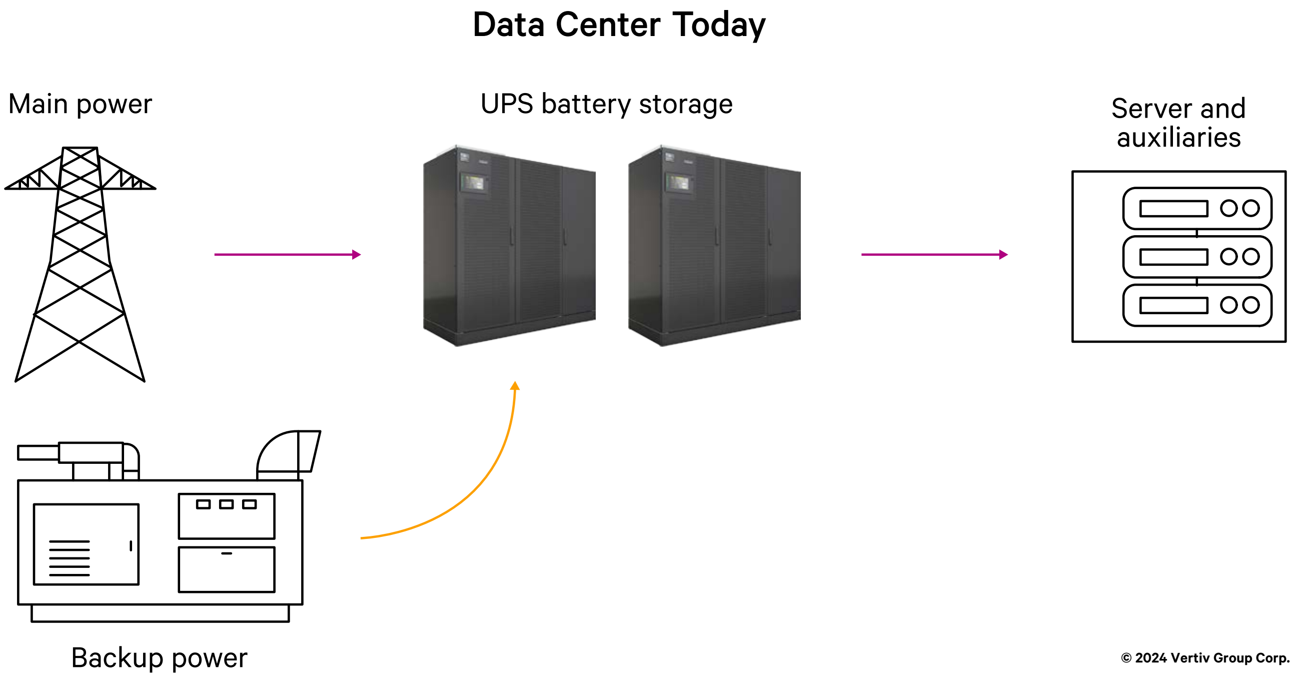


Figure 2. *The current data center*

Traditional backup power methods

During grid power failures, diesel generators provide needed reserves. However, they present significant challenges:

- High operational costs.
- The noise, heat, and Scope 1 emissions produced by gensets simultaneously turning on and running.
- Reliance and losses on fluctuating fossil fuel prices.

Understanding power requirements in data centers

In data centers, setups vary based on the facility's power needs to ensure the continuity of critical IT operations. Regardless of these demands, relying on diesel generators during grid failures hinders decarbonization efforts, while relying on UPS battery systems with short runtimes isn't sufficient to support a full load of numerous data center systems during grid failures lasting an hour or more.

Transitioning to modern power solutions

Traditional power infrastructure in data centers uses UPS systems with batteries to ensure continuity of power during grid outages, facilitating a smooth transition to backup sources like generators. Stored energy in UPS units acts as a bridge to diesel generators, providing electricity to all systems for 30 minutes to over 2 hours until grid power is restored.

Operators can use new solutions by leveraging the latest research and technologies in phases, such as battery energy storage systems (BESS), polymer electrolyte membrane (PEM) fuel cells, and linear generators, to provide backup power rather than run diesel generators. This allows for planning, transitioning, and aligning technology requirements.

Enhancing Data Center Energy Autonomy: Quick Strategies

Adopting these measures boosts data center energy autonomy and resilience, ensuring consistent operation despite grid challenges.

1. Integrate Energy Storage: Add durable batteries or BESS to microgrids for increased reliability, creating a robust microgrid system.
2. Localized Power Generation: Use three-phase UPS systems with extended backup batteries for smooth operations during grid failures.
3. Provision Management: Manage fluctuating compute workloads by expanding energy storage with BESS or fuel cells in the UPS system, stabilizing demand spikes.
4. Increase Voltage Levels: Raise energy storage voltage to prolong battery operation during outages, significantly extending backup times.
5. Explore DC to AC Conversion: Investigate DC to AC conversion technologies, like Vertiv's lightning inverters, for efficient and lasting backup power.

Bring Your Own Power (BYOP)

BYOP microgrids, consisting of distributed energy resources (DERs) and battery storage systems, offer a versatile solution.[6,7] They allow local control over power generation and consumption, improving reliability and reducing transmission losses. These microgrids can function both connected to or independently from the main electricity grid, enhancing energy security through islanding. Hybrid systems that merge renewable energy with battery storage provide an always-on, dependable, pollution-free power source, avoiding the downsides of traditional generators.

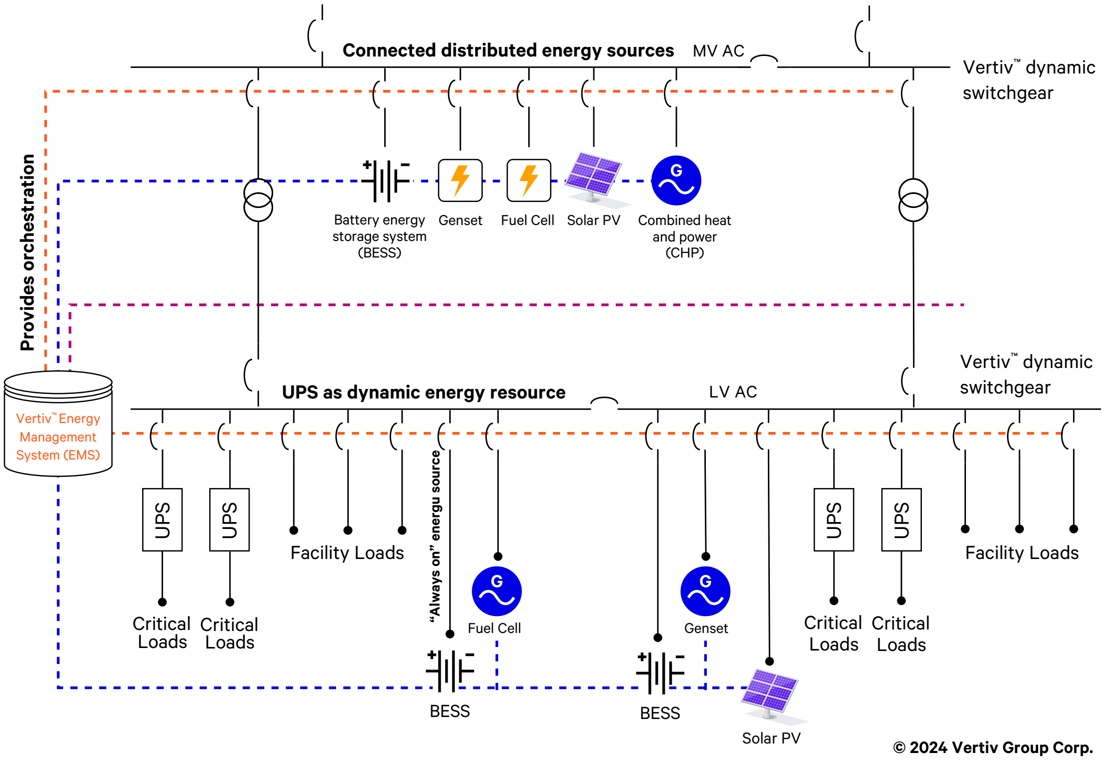


Figure 3. A dynamic or hybrid power energy ecosystem can reduce a data center's vulnerability to an unstable grid by combining multiple energy sources and streamlining storage, distribution, and contingency mechanisms.

Managed hybrid energy solutions revolutionize power management for businesses seeking to develop mission-critical infrastructure amidst rising power demands and complexity. BYOP microgrids significantly reduce diesel generator use and grid outage vulnerabilities, fostering a hybrid energy ecosystem within the facility. This ecosystem integrates sustainable PEM and solid oxide (SOFC) fuel cells, enhancing energy resilience and sustainability.[8] [9]

Incorporating BYOP practices as such enables data centers to have an always-on energy source, mitigating grid instability risks and enhancing their capacity to manage more power resources effectively. BYOP hardens the infrastructure against external power issues as it leverages multiple renewable energy sources to stabilize and align the systems involved for power storage, distribution, and contingency.

Power transitions: Current technologies and infrastructure future-proofing

Data center operators and companies can look to start their road to energy independence in phases. Considering the challenges companies experience with grid power insufficiencies, planning for future-proofing mission-critical infrastructure ensures energy resilience in the immediate term and business protection in the long run.

Start today

- Solid-oxide fuel cells (SOFCs) or turbines for prime power using natural gas (NG).
- Add battery energy storage systems (BESS) on the AC bus to reduce diesel generators' starts for every outage.

Near future

- Add BESS as a long-duration DC source to the UPS when high-voltage batteries are supported.

Long-term future

- Add proton-exchange membrane (PEM) fuel cells as a diesel generator replacement when hydrogen supply is sufficient.
- Retrofit NG SOFC to hydrogen fuel when supply is sufficient.

How BYOP helps stabilize the grid

An always-on BYOP microgrid enables operators to turn batteries on and off at their discretion, not only during emergencies. This approach reduces inefficiencies like voltage fluctuation losses and line losses during transit from the grid. Additionally, it allows for better demand management, benefiting both the data center and the grid by reducing grid power use during peak demand times and utilizing reserves from the microgrid's BESS and UPS systems.

In addition to business continuity, energy independence leads to better management of unpredictable and spiky loads.
In reinforcing the data center's power and backup reserves, an operator can include a select number of BESS blocks to handle the spiky loads instead of spreading the unstable loads to all the blocks. Sized accordingly, these single-ended substations of N+1 BESS systems can be assigned to manage the identified load profiles' demands.

Moreover, managing unstable loads gives the operator an overview of the bus's stability vis-à-vis future energy goals. For instance, the operator can turn their discontinuous battery or hydrogen fuel cell into an always-on bi-directional power source. This can power the mission-critical infrastructure and energize and manage short—and long-duration configurations.

Roadmap to energy independence

As part of a dynamic ecosystem, the UPS becomes bidirectional. It can be seen as an additional DER that contributes to energy management, powers systems during blackouts, and delays the use of gensets for as long as possible. Moreover, the ability to control the storage and distribution of energy to the rest of the systems means that data center operators can determine the applicable deployment modes for efficient energy operations and usage savings.

Modern hybrid energy ecosystems enable operators to switch to more efficient modes for their respective microgrids. For instance, the Vertiv™ interactive grid UPS technology makes microgrids more efficient and compatible with renewable energy generation, storage, and distribution. [10] It supports grid balancing services such as fast frequency response and peak shaving.

To date, most systems overlap and operate independently. High-voltage BESS and utility generation sources are tied to the grid in front of the meter, along with other DERs such as solar arrays and wind power. Behind the meter, other sources like low-voltage generators are connected along with the UPS and can operate unidirectionally. These independent pieces result in function duplications and higher CapEx and OpEx costs.

The core difference centers on transforming backup power solutions into reliable, always-on power generators. This approach necessitates designing an integrated system that ensures a smooth transition between power sources. Key considerations for achieving this include:

- **Interaction with fuel cells:** Determining the most effective method for integrating fuel cells. Options include using a standalone converter with DC-to-AC capabilities or connecting the UPS directly to the fuel cell as a DC source. The choice depends on the specific performance requirements and how best to meet them.
- **Connection points:** To ensure efficiency and reliability, identify the optimal connection points for integrating BESS and fuel cells with the existing infrastructure.
- **Technology evaluation:** Assessing various technologies such as UPS, switchgear, control breakers, and energy storage for their ability to:
  - Facilitate dynamic usage.
  - Allow operators to control power paths and integrate functions seamlessly.
  - Improve total cost of ownership (TCO) in both short and long term.
- **Current vs. intended storage location:** Analyzing the impact of relocating fuel cells on latency, especially concerning the targeted service locations. Considerations include:
  - Power availability in the new location.
  - Potential power loss during transmission.
  - Accessibility to other Distributed Energy Resources (DERs) when needed.

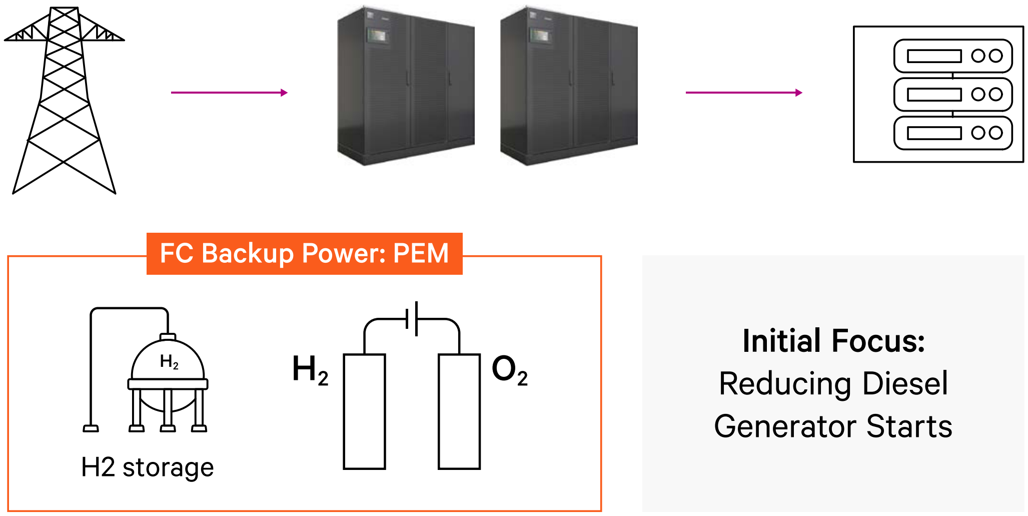
This structured approach highlights the strategic considerations necessary for effectively integrating backup and prime power solutions.

Fuel cells as prime power and backup power

Where utility power is limited or non-existent, the transition to energy independence has few choices today. Data center operators must now rely on natural gas to provide power. While not a carbon-free solution, natural gas power generation is much lower in emissions and relatively high in efficiency in today's turbines and SOFCs. While turbines are an excellent choice for prime power, they do not offer an easy path to carbon-free operations like a SOFC. Operators can begin with natural gas for their fuel cells and later transition to hydrogen as it becomes more viable and mass-produced.

As illustrated below, some companies can eliminate diesel generators first and replace them with a backup PEM fuel cell (Phase 2). Others might jump straight to Phase 3: deploying fuel cells outright as prime power. The grid may become a backup if available.

Data Center with PEM FC as Backup Power



Data Center with SOFC Prime Power

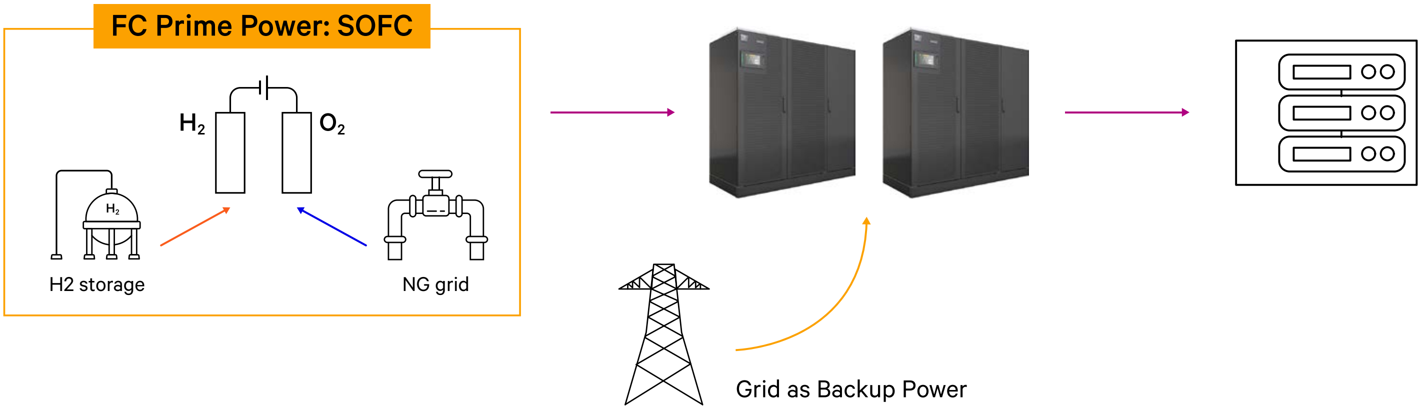


Figure 4. *Phases 2 and 3 are short- to medium-term goals for data centers' energy independence: reducing diesel generators' starts from the microgrid facility and replacing them with PEM and SOFC fuel cells as backup and prime power sources, respectively.*

Myths on fuel cells

Myths	Fact
Fuel cells burn hydrogen.	Fuel cells electrochemically convert hydrogen and oxygen in the air to energy using a fuel cell membrane. In the process of energy provision and conversion, the byproduct is water. [11]
Fuel cells explode, are poisonous and flammable, and are hard to get permits for.	Hydrogen is a non-toxic gas. Modern fuel cells have advanced safety standards for storage and safe utilization. Leak detection, ventilation, and safety implements like air recirculation and flame detectors are added for additional safety. Once these measures are in place, permitting can be straightforward. [12]
Fuel cells are expensive.	Platinum and iridium are expensive catalysts in fuel cells due to their scarcity. Only government agencies such as NASA could afford to use them in the 60s and 80s because of their high cost. [13] [14] New technologies have driven down prices for alternative materials. Fuel production and distribution infrastructure, especially for hydrogen, is rapidly expanding worldwide. SOFCs can run on various fuels, including biogas and natural gas, which are widely available.

The zero-carbon data center

Ultimately, operators want to get to the configuration below: complete energy independence. They may initially derive prime power from natural gas, but the transition to green hydrogen should occur once there's enough supply to sustain large operations indefinitely. Operators can use excess power from wind and solar to hydrolyze water into hydrogen and charge a BESS. The UPS now acts as a power center which functions as an Energy Management Controller, automatically selecting the optimal power source and managing the charging and discharging of battery resources as needed.

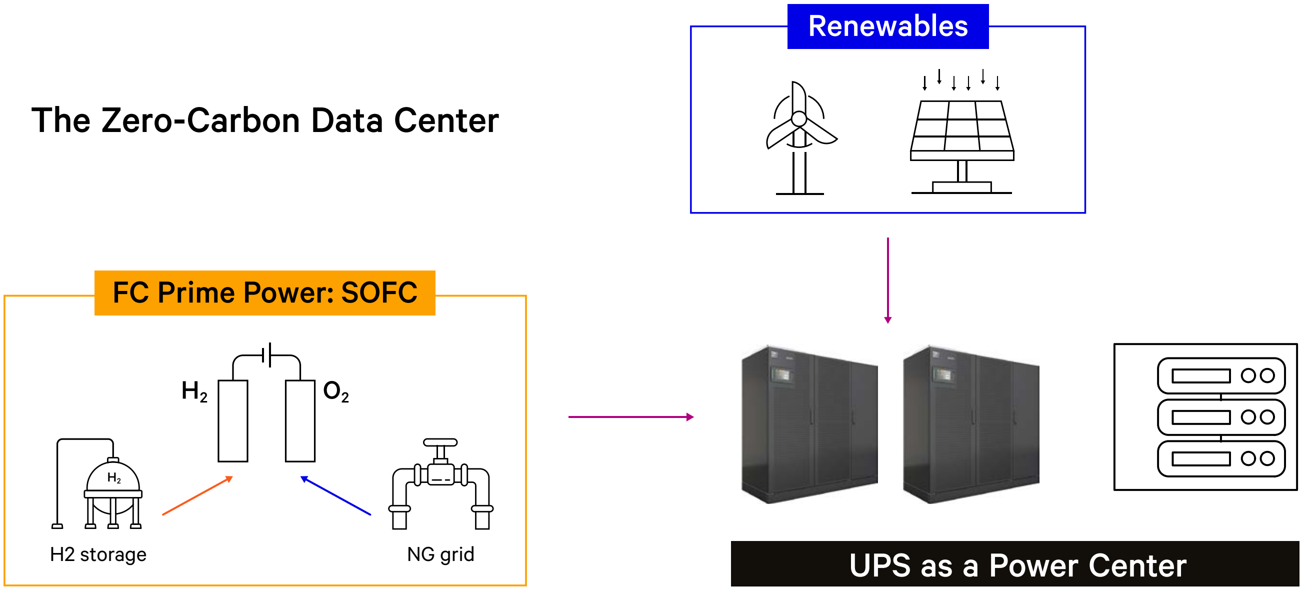


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Figure 5. Reimagining resilience: Implementing and deploying for the future, ensuring business continuity after a disruption, and managing unstable load spikes drive the urgency of the timeline for energy independence.

Current market suppliers: A fragmented approach

Despite operators asking for comprehensive solutions for their needs, vendors refrain from discussing solutions because most cannot find suppliers with standardized, globally sustainable, and cost-effective expertise. When designing an independent power system, here's what operators need to consider:

- Where to source the power?
- How much will be derived from the grid and the local sources onsite?
- How much is used for their premises' functions compared to external electricity?
- When should power from the grid be used vs. from local DERs?
- How to use DC energy sources alternately, and so on.

Working toward energy independence with a capable technology partner offers customers a comprehensive approach, tackling problems and delivering solutions from start to finish. This process encompasses planning, design, understanding the local landscape, implementation, integration, deployment, training, and services, after-sales support, and ensuring global availability. Through partnerships and facilities worldwide, feasibility research and studies on necessary components and systems are carried out to stay ahead of companies' and communities' evolving needs.

Facilitating integrated transitions while managing growth

The primary driver of energy independence is the increasing demand for business and customer services. Issues such as latency and power outages can quickly lead to customer dissatisfaction, posing challenges for their future plans in this critical space. For example, as cooling systems require more power and strain the IT-critical bus, using BESS blocks to manage load spikes can help address these issues.

Microgrid technologies will continue to develop, especially for broader and better production and distribution. However, considering their current technological capabilities, BESS and fuel cells can address various energy concerns through integration and management.

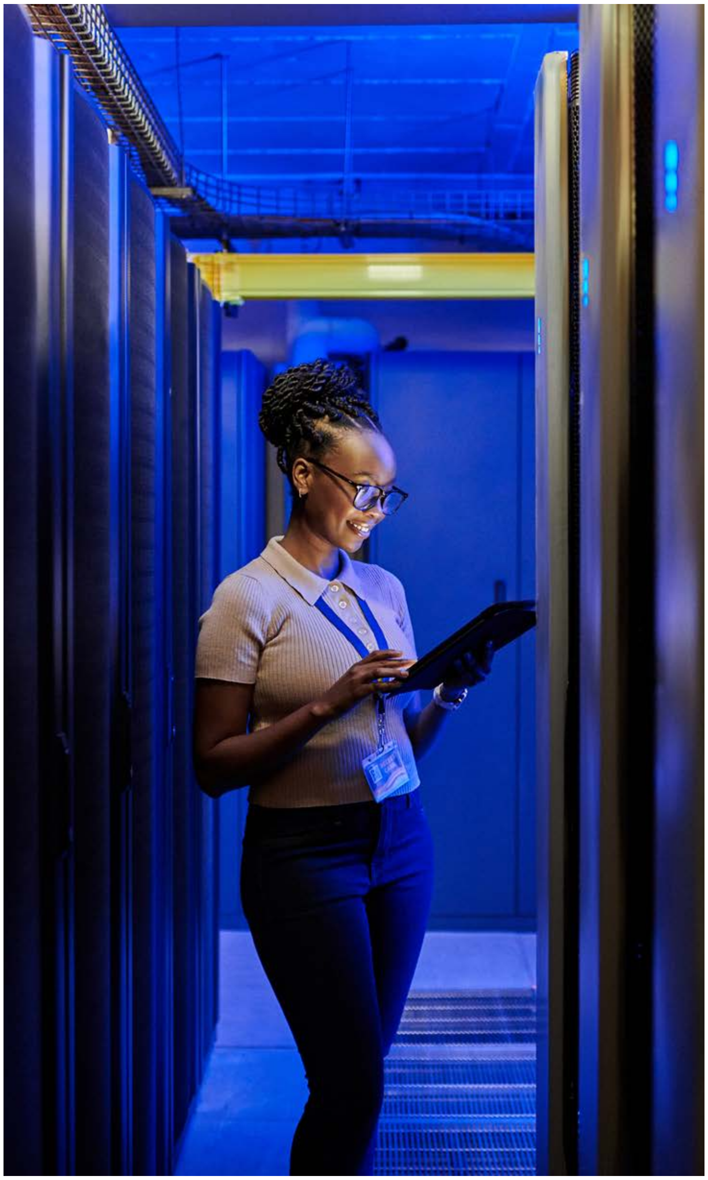
Conclusion

Insights: Being a good grid citizen and putting a strategic advantage to the forefront

Data centers are the backbone of enterprise operations, cloud services, and the global internet infrastructure. The role of always-on power is critical as it supports the high availability and reliability that are critical for data processing, storage solutions, and accessing online services which are essential for businesses, governments, and society at large.

Fuel cell technology is set to become even more critical. Advancements and research promise to increase energy density, reduce costs, and expand the types of fuels that can be used, further enhancing their sustainability credentials. In the future, data centers will likely adopt fuel cell systems and generate surplus energy to power other campus facilities, thereby supporting the broader community by generating their own supply and promoting renewable energy sources.

By adopting the bring-your-own-power (BYOP) model and integrating cutting-edge renewable energy technologies, data centers can achieve grid independence, reduce carbon footprint, and act as responsible grid citizens. This move not only answers the challenge of power reliability but also supports broader sustainability goals, reinforcing the role of data centers in fostering a resilient, efficient, and sustainable digital future.



Glossary

"Always-on" power: The continuous provision of uninterrupted power supply sourced from multiple energy resources to keep mission-critical systems and infrastructure operational, ensuring that critical components — servers, networking equipment, cooling systems, and security devices — remain fully functional. Even during low utilization or idle states, essential functions remain powered even when systems are not actively processing data.

Bring-your-own-power (BYOP): Modern and robust power systems that include alternative always-on energy solutions within a localized area to compensate for traditional grid power.

Distributed energy resources (DERs): Hybrid energy sources that serve as alternative energy assets and are integrated into one locale, such as solar panels, wind turbines, natural gas, and hydrogen fuel cells.

Islanding: Is the capability of a backup power source reserve, such as hybrid microgrids, to continuously power a specified area during electric grid outages and emergencies independent from the grid.

Grid forming: Is the ability of an energy source in interconnected systems to provide voltage and frequency support and operate independently or in coordination with other sources.

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