Mission Critical Microgrids

Securing a Better Energy Future through the Power of Choice

A Technical Paper prepared for SCTE by

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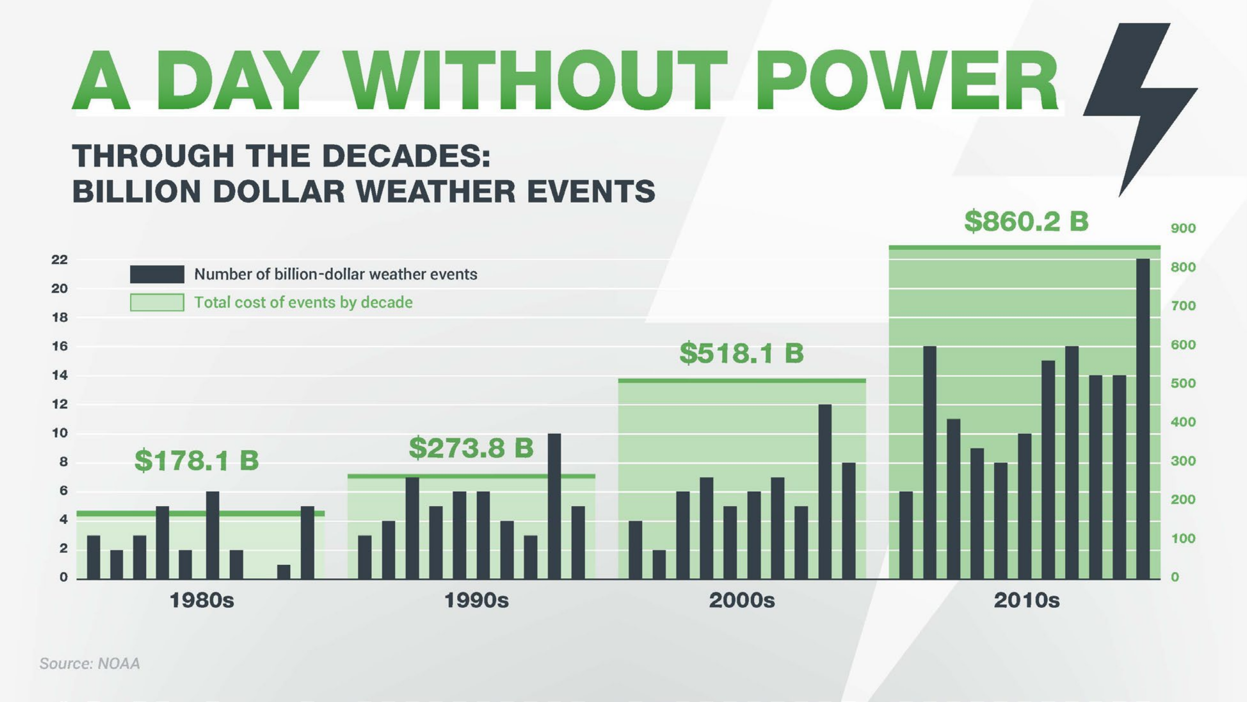
1. Introduction

A day without power is hard to imagine. Electricity has become a basic necessity, powering everything from our homes, to our businesses, to our transportation systems. But in a post-climate change world, extreme weather events are happening more frequently and becoming increasingly severe, threatening our access to the 24 x 7 power so integral to our everyday lives. This has caused a shift in thinking from, "the cost of power" to "the cost of not having power."

Demands of our digital economy coupled with the escalating consequences of our changing climate have created an unprecedented risk landscape. Energy challenges are on the rise and pressure is mounting for our electric system to get cleaner, faster. The sheer financial cost of climate impact is nearly outpacing the billions of dollars utilities are spending to improve the electric delivery system.



Source: NOAA

During 2020, there were 22 separate billion-dollar weather and climate disaster events across the United States, breaking the previous annual record of 16 events that occurred in 2017 and 2011.

This is the risk landscape for all of us, but without proper safeguards in place, the consequences of those risks are higher for those whose power choices are directly tied and vital to the functioning of their organizations. Mitigation requires a highly strategic approach to energy management.

Fortunately, we are now in a time where there are multiple options for sourcing and delivering electricity. Distributed generation has completely shifted the energy paradigm, providing a clear path forward for those seeking to gain more control of their electricity supply.

This paper explores this crucial paradigm shift. Its objective is to educate and mobilize individuals, businesses, communities, and policymakers around the importance of resilient power – the challenges we face, the risks we can mitigate, and how leaders can gain control of their energy future through distributed generation and microgrid solutions.

2. Centralized Present, Distributed Future

Over the course of the 20th century, the U.S. electric grid was built as a one-way value chain from fuel supply to end-user consumption. Such infrastructure design created cascading vulnerabilities whereby a failure of any one component can result in disruption of service to end users. Grid hardening programs are underway in every region, but upgrading such a complex system is expensive, and takes years to properly execute.

Some might say it's too little too late – that these complexities have left society too heavily reliant on an electric delivery system that has simply not kept pace with the evolution of its surrounding environment. This aging centralized power grid that is inherently prone to failure, now faces heightened demands of digitization, a rising frequency and intensity of natural disasters and a dangerous cyber-threat landscape.

As a result, companies with mission critical facility requirements must invest heavily in back-up and conditioning devices to ensure a constantly available, high-quality energy stream to power their equipment. However, the few traditional solutions available are prone to their own failures.

But consider the implications of developments in the energy space that have come from the rapid digital transformation over the last few decades. The conventional way of delivering electricity is experiencing a fundamental and promising shift – we are moving away from our centralized present towards a distributed future.

3. Energy as a Keystone Metric

Depending on the industry, energy can be a large component of a company's cost structure and a complicated operational issue. It touches every piece of a business' value chain.

Companies are increasingly opening the aperture on their energy strategies to meet their corporate objectives, with each company's approach reflecting critical business needs. These critical business needs may be substantially different depending on industry and facility requirements.

Retailers face different challenges than data centers or manufacturers. In some cases, business needs primarily reflect rising energy costs and their impact on other operating margins. In other cases, business needs may be more closely tied to reliability of critical infrastructure and ensuring that the business can continue to operate effectively during a prolonged grid outage.

The critical challenge for businesses in building a cohesive energy strategy is identifying their full scope of electricity-related risk factors. Recognizing risk is one thing. Having a strategy to mitigate it is another. Doing so requires a deeper understanding of the issues and how to address them from the top down.

4. The Reliability Spectrum

Every building has a distinct energy "fingerprint" based on the needs and requirements of its routine operations. When drilling down to the facility level, understanding the difference between demand and consumption is key to defining its energy characteristics. Fluctuation of demand and the usage that results from that demand make up one's load profile.

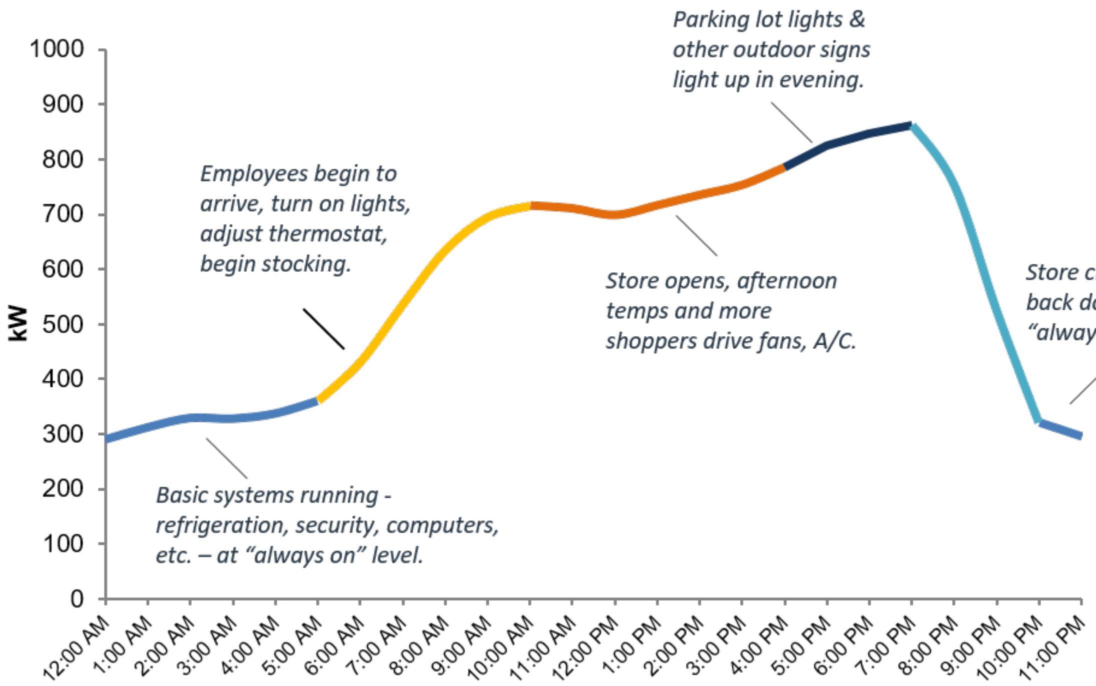


Figure 2: Snapshot representation of energy use for a typical day of business

A 'critical load' is a portion of electricity supply that powers infrastructure directly related to an organization's ability to operate. Infrastructure that warrants this status must either be kept running when main power supply fails or be powered down in an orderly manner to prevent system crashes, data loss or corruption, and life shortening hardware damage.

The term 'mission critical' is defined as something that is vital to the functioning of an organization. Operating under these conditions necessitates stronger emphasis on criteria that ties directly into the structural elements of a building's design.

OPERATING A MISSION CRITICAL FACILITY

1 REDUNDANCY
Secondary system or extra components that become instantly operational, so any failure in primary system doesn't result in mission failure.

2 FLEXIBILITY
Capacity to scale up or down to support evolving business needs without operational interruption or signification change in physical footprint.

3 MAINTAINABILITY
Ability to perform routine operation and maintenance on any component without affecting mission or processes of vital business functions.

4 HARDENING
Protection from physical forces and natural disasters where the electrical grid is unlikely to stand up to a disaster that could cause a power failure.

5 SECURITY
Built-in safeguarding from security breaches and man-made threats and the serious risks they pose to critical equipment and business processes.

MISSION CRITICAL KEY CONSIDERATIONS
There are several influencing factors that are key to mission critical infrastructure design.

Figure 3: Key considerations when operating a mission critical facility

Special focus must be placed on meeting minimum requirements across several key energy components – utility power supply, back-up generation, uninterruptible power systems (UPS), and cooling systems – which can come at great cost. Emerging technologies and business models represent a key opportunity to manage costs and mitigate risks. However, they also present an optimization challenge in terms of structuring those options to maximize the economic, reliability, and sustainability benefits.

5. The Resiliency Challenge: Eliminating Tradeoffs

As businesses look to address their critical resiliency needs, growing ambitions of a clean energy future and impacts of rising energy costs have elevated the importance of choice when it comes to power.

Most distributed energy resources (DER) are self-sufficient, but they are not one-size-fits all. Resiliency is just one benefit among many that microgrids provide, but resiliency decisions should not be made at the expense of environmental concerns and sustainability decisions should not ignore the importance of reliable energy supply. Diesel generators have been the status quo solution for power disruptions for decades. However, they are monolithic machines without inherent redundancy and they produce over 40 toxic air contaminants, including a variety of carcinogenic compounds during operation. What's more, since they are idle assets, they needlessly consume fuel while testing to ensure they can be available when needed. Further, the availability of diesel fuel during an extended outage and the reliability of diesel engines to operate continuously for long periods of time are both risks to the traditional design.

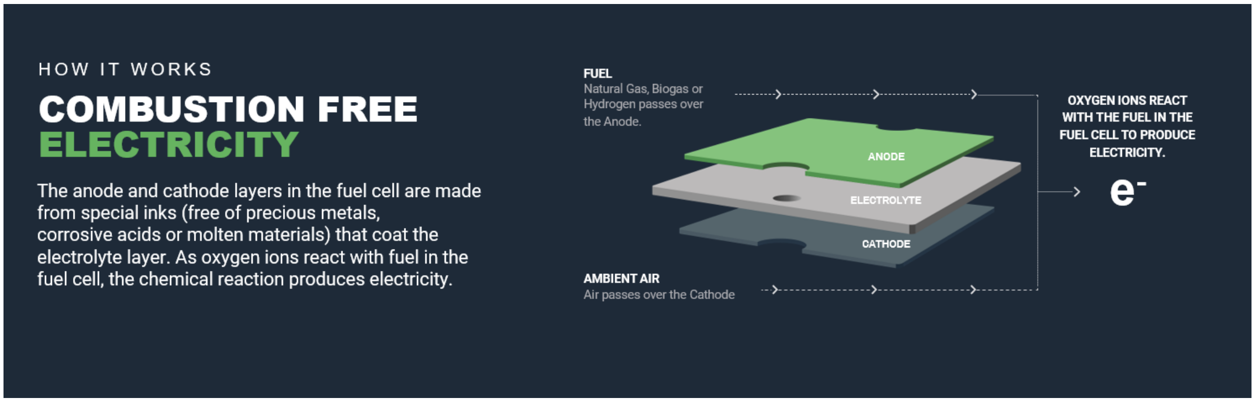
Technologies like solar and wind are great for their renewable profile but due to their inherent intermittency, cannot practically solve resiliency challenges. Their very nature requires some sort of energy storage and today's technology does not cost effectively support the massive load shifts from day to night, and certainly not from summer to winter. Further, the majority of solar (66%) and wind (~100%) are utility scale projects, meaning they still rely on the vulnerable, above ground, transmission and distribution system.

Fuel cell distributed generation projects are uniquely positioned to help eliminate tradeoffs and solve these compounding challenges. A fuel cell microgrid provides a distributed solution that is onsite and always on. It is not a UPS or generator sitting idle waiting for an outage event – it's an active asset that produces clean, highly reliable power 24 x 7 without particulate emissions.

6. Fuel Cell Building Blocks

Fuel cells provide a critical foundation for microgrids of varying complexity and can provide significant benefits to the communities, businesses, and utilities they are part of. This type of technology targets a customer's 24 x 7 energy usage whereas technologies like solar or battery storage are intermittent. Fuel cells were invented over a century ago and have been used in practically every NASA mission since the 1960's, but until now, they have not gained widespread adoption because of their inherently high costs – a challenge that once plagued a developing solar industry decades earlier.

There is a range of fuel cell technologies that exist today, however solid oxide fuel cells (SOFCs) are the market's most efficient and practical form. SOFC's provide an electrochemical pathway to convert fuel directly to electricity without combustion. The cell itself consists of three parts: an electrolyte, an anode (-), and a cathode (+). The electrolyte itself is a solid ceramic material and the anode and cathode are made from special inks that coat the electrolyte. As oxygen ions interact with fuel in the cell, the resulting electrochemical reaction is able to produce electricity without combustion. Because of its extremely high conversion efficiencies, they are able to produce twice as much electricity as conventional combustion generators using the same amount of fuel.



The anode and cathode layers in the fuel cell are made from special inks (free of precious metals, corrosive acids or molten materials) that coat the electrolyte layer. As oxygen ions react with fuel in the fuel cell, the chemical reaction produces electricity.

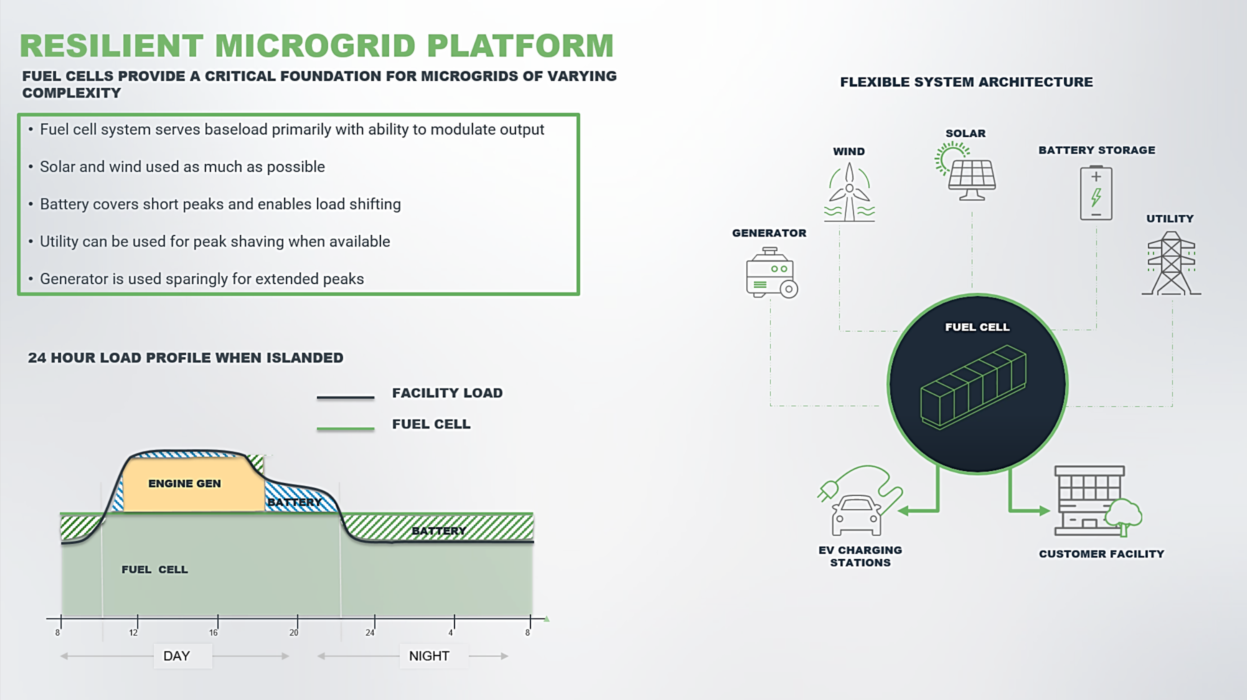
Figure 4: How a solid oxide fuel cell works

7. Microgrid System Architecture

Fuel cells are extremely versatile when comprised within a larger system. The process starts with a single cell which produces 25W, roughly enough to power a light bulb. The cells are then stacked within the system and assembled into 50 kW power modules – modules that can function independently from each other. This modular flexible architecture design allows for any number of modules to be clustered together, in various configurations, to form solutions from hundreds of kilowatts to many tens of megawatts.

The standard system architecture design interconnects with your facility in a grid parallel configuration. This means the system leverages a current mode inverter replicating the frequency and voltage of the grid and will not impact site power quality. Load changes by the site will similarly not impact output; the site will essentially have two utility feeds and anything needed above the fuel cell output will be supplied by the electric grid. A grid parallel interconnection is subject to IEEE-1547, similar to solar, such that when the grid is unavailable or out of IEEE-1547 specifications, the system is required by code to stop exporting power until the grid returns.

A mission critical design topology allows the fuel cell system to continue operating during an electric grid outage. The design requires a segmented load to be wired directly into a second set of voltage mode inverters that will be added to the system's architecture.


RESILIENT MICROGRID PLATFORM

FUEL CELLS PROVIDE A CRITICAL FOUNDATION FOR MICROGRIDS OF VARYING COMPLEXITY

- Fuel cell system serves baseload primarily with ability to modulate output
- Solar and wind used as much as possible
- Battery covers short peaks and enables load shifting
- Utility can be used for peak shaving when available
- Generator is used sparingly for extended peaks

Figure 5: Illustrative view of fuel cell microgrid system architecture

8. Key Differentiators for Mission Critical Support

Power Quality

The power quality delivered by SOFC systems is comparable to best-in-class UPS systems deployed in data centers and other mission critical facilities. They are able to utilize state-of-the-art PWM (pulse-width modulation) inverter technology for conversion of fuel cell DC power to 480V AC power. The waveform of the current supplied to the customer is generated by a sophisticated multi-level current-source inverter control scheme. The high inverter switching frequency supplemented by a high-performance filter in each inverter module means that harmonics are virtually eliminated.

These systems are designed to meet or exceed power quality requirements of standards relevant to distributed power generation and distribution such as:

- UL-1741
- IEEE-1547
- IEEE-519
- Other utility grid interconnection requirements in the USA and other countries around the world.

Density

Fuel cells provide significant power generation in a small footprint which makes it an ideal power solution for smarter space utilization. Unlike large, multi-megawatt generating combustion engines, SOFC systems can be deployed in increments as small as 200 kW, enabling power sources to be distributed and land to be used for critical business applications. Due to this minimal onsite footprint compared to other generation technologies, facilities can utilize available land for higher value uses – such as data centers expanding their facility to accommodate more server racks, or a hospital adding a new wing to accommodate more patients.

Redundancy

The modular, redundant architecture makes it such that a solid oxide fuel cell system can continue powering facilities while operation and maintenance activities occur on individual modules. Each power module independently connects and feeds power to a DC bus. When a power module needs maintenance, that module will be safely ramped down and shut off while the remaining modules continue producing consistent electrical output. The power module will then be repaired or replaced, and then ramped up to full power, ensuring consistent output from the fuel cells without disruption to a customer's business operations.

Reliability

SOFC systems deliver 24 x 7 x 365 baseload power, with mission critical reliability and grid independent capabilities. They can be easily configured to eliminate the need for traditional backup power equipment such as diesel generators, batteries and uninterruptible power systems.

What's more, by generating power at the point of consumption, the system is able to avoid the vulnerabilities and line losses of conventional transmission and distribution. It draws from two continuously operating independent sources – existing gas infrastructure, which is a redundant underground mesh network, and the utility grid. The probability of both failing simultaneously is extremely low. Modularity and combined with this fault-tolerant design means that SOFC systems are able to reliably operate at very high availability around the clock.

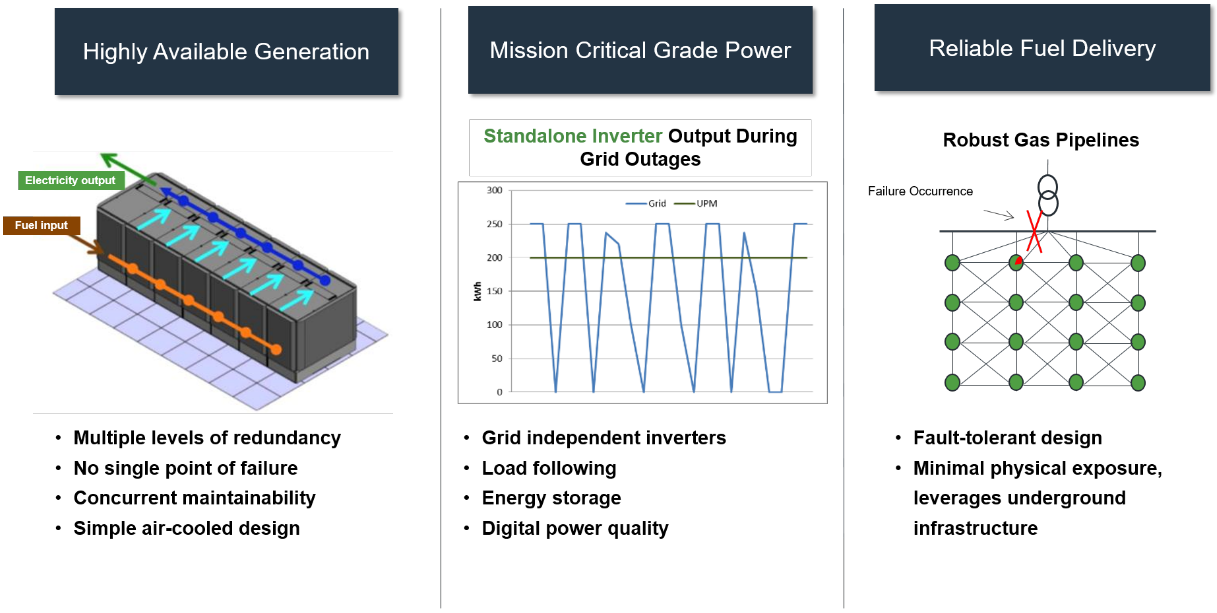


Figure 6: Key differentiators of SOFC for mission critical support

Resiliency

Fuel cell microgrids can provide critical resilience from power instability, driven increasingly by climate-related extreme weather events. The following case study highlights a technology manufacturing company who deployed Bloom Energy's AlwaysON solution to secure their operations and mitigate the negative impacts associated with escalating climate risks.

Case Study: Spotlight Save

A large technology company manufactures electronic test and measurement equipment and software that supports the larger digital ecosystem of e-mobility, network monitoring, 5G, LTE, and IOT. Their business needs are closely tied to the reliability of critical systems in operation at their HQ campus, located in a high-risk wildfire zone in Northern California.

The numerous unplanned outages they were experiencing throughout the year were costly and damaging to highly sensitive manufacturing equipment. With backup infrastructure reaching the end of its useful life, they were seeking new solution with mission critical capability that could power the whole campus independent of the grid.

In the wake of a growing number of outages and elevated risk to its operations, the company implemented an AlwaysON Microgrid, which enabled 2.8 MW of mission critical systems to operate independently when disruption to the electric grid occurs.

In the summer of 2019, California utilities began implementing transmission-level Public Safety Power Shutoffs (PSPS) to mitigate wildfire risk. Faced with one instance that left millions of customers without grid power for multiple days, Bloom's AlwaysON microgrid kept their campus online and operational throughout, reinforcing the technology's proven resiliency in the field.

9. Conclusion

In the last two decades, diverse groups across the energy sector has been working hard to create and commercialize innovative alternatives to centralized energy generation and delivery. Widespread decarbonization is occurring quickly through policy changes, technology innovation, and the willingness to adapt. However, it's becoming increasingly clear that alongside decarbonization sits an equally critical resiliency challenge. Hardening of our modern energy system will be a major focus for utilities going forward but businesses can support these efforts by helping break off smaller challenges through with distributed generation.

Fuel cell microgrids have changed the way businesses look at their critical power infrastructure, serving as a viable alternative source of primary power. The versatility of solid oxide technology operating at the core of a microgrid creates distinct advantages that will enable applications across the entire energy value chain for years to come. Its core efficiency advantages and ability to scale within a rapidly evolving energy landscape makes it the ideal distributed generation solution – one that delivers the greatest value now and provides the clear path needed to propel us all towards a better energy future.

Abbreviations

DER	Distributed Energy Resource
IEEE	Institute of Electrical and Electronics Engineers
IEEE-1547	IEEE standard for interconnecting distributed resources with electric power systems - provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.
IEEE-519	IEEE recommended practice and requirements for harmonic control in electric power systems
PSPS	Public Safety Power Shutoffs
PWM	Pulse-width modulation
SOFC	Solid oxide fuel cell
UL-1741	UL safety standard for inverters, converters, controllers and interconnection system equipment for use with distributed energy resources
UPM	Uninterruptible Power Module *(inherent to fuel cell system mission critical architecture)*
UPS	Uninterruptible Power System