

Hydrogen



 **FUEL CELLS**

Resilient & Sustainable Power

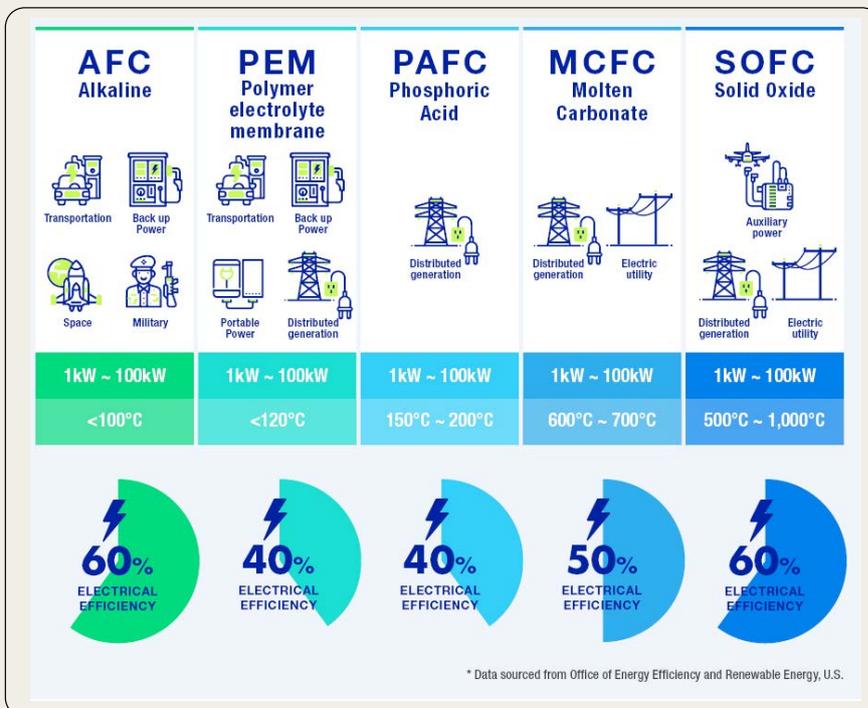
# Contents

INTRODUCTION.....	3
MAIN CHALLENGES TO THE POWER SECTOR .....	5
WHAT IS A FUEL CELL?.....	11
TYPES OF FUEL CELLS .....	13
FUELING THE FUEL CELLS - HYDROGEN .....	19
HYDROGEN & FUEL CELLS: MEETING THE RISING NEED FOR BACKUP POWER.....	26
GENCELL INC. AND HYDROGEN2POWER .....	32
CONCLUSION .....	33

# INTRODUCTION

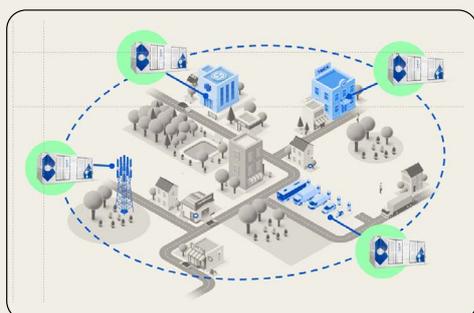
As the world aims to move toward decarbonization without reducing power consumption, the transition to electrification and uptake of diverse renewable energy resources - including fuel cell technologies – have a key role in achieving this challenging goal. Since they are weather-resistant and climate-resilient, highly efficient, produce no emissions, and can support a wide range of use cases that are challenging for other power sources, fuel cells are gaining traction as a significant component of a more sustainable energy future.

Driven largely by demand for zero-emission transportation and for backup power, **the global fuel cell market, valued at US\$4.53 billion in 2025, is projected to grow rapidly between 2025 -2032 at a CAGR of 20.5%, forecast to reach an estimated US\$16.73 billion by 2032. In the United States, the fuel cell market is projected to grow significantly, reaching an estimated value of USD 9.77 billion by 2032.** This growth is being fueled by public and private initiatives, including economic and stimulus packages designed to promote green energy production. Many of these initiatives feature hydrogen-powered fuel cells, which are particularly instrumental in reducing greenhouse gas emissions and air pollutants, aligning with stringent environmental policies and sustainability objectives.



**Figure 1**  
Fuel cells will drive a clean future  
Source: <https://news.samsungcnt.com/en/features/trading-investment/2021-10-fuel-cells-will-drive-clean-future/>

Hydrogen hubs and fuel cells figured prominently in the U.S. energy transition and renewable energy programs that received strong support in recent years but now have been largely reversed by President Trump. However, while the current administration is making significant changes to federal energy policies to cut back support on many renewable energy projects, a strong focus on energy security and independence as well as renewed support for natural gas all figure in **reinforcing the role of hydrogen and fuel cells**, both in supplementing grid power along with lowering emissions of gas-powered operations by incorporating hydrogen to the gas mix.



**Figure 2** Fuel cell DERs in microgrid

The rise of fuel cells aligns with another new trend in the energy market – decentralized energy production. **Virtual Power Plants (VPPs)** and local microgrids integrating renewable sources like solar, wind, and batteries as Distributed Energy Resources (DERs) aim to reduce the dependence on traditional centralized power plants alone. In decentralized energy systems, fuel cells complement intermittent renewables and energy storage with continuous steady on-site power generation. An illustration of this

decentralized shift is the growth in deployment of microgrids, particularly in regions with aging grid infrastructure and/or frequent natural disasters.

**The United States microgrid market was valued at USD 7.9 billion in 2024 and projected to attain USD 24.4 billion by 2033, demonstrating a compound annual growth rate (CAGR) of 13.3% from 2025 to 2033.** As the US rapidly embraces clean energy, power outages loom larger and costlier. Microgrids emerge as a game-changer, providing vital resilience where utilities fall short. According to Wood Mackenzie, **as demand grows, technology improves and new business models emerge, the US microgrid market has been growing rapidly, with operational microgrid capacity expanding at an annual growth rate of 32%, reaching 8.6 gigawatts (GW) by the end of 2023.** Fuel cells play a pivotal role in these ecosystems, offering scalable solutions for both grid-connected and off-grid systems.

A key pillar of this technological revolution is hydrogen, often hailed as the "fuel of the future." Hydrogen's versatility extends across applications, from powering mass transit and mission-critical infrastructure to supporting off-grid energy systems in remote regions. The ongoing establishment of hydrogen refueling networks and advancements in hydrogen production technologies are further unlocking the potential of hydrogen as a sustainable energy carrier.

# MAIN CHALLENGES TO THE POWER SECTOR

The power sector is undergoing significant transformation, but this progress is accompanied by several pressing challenges that threaten its stability, sustainability, and capacity to meet future energy needs.

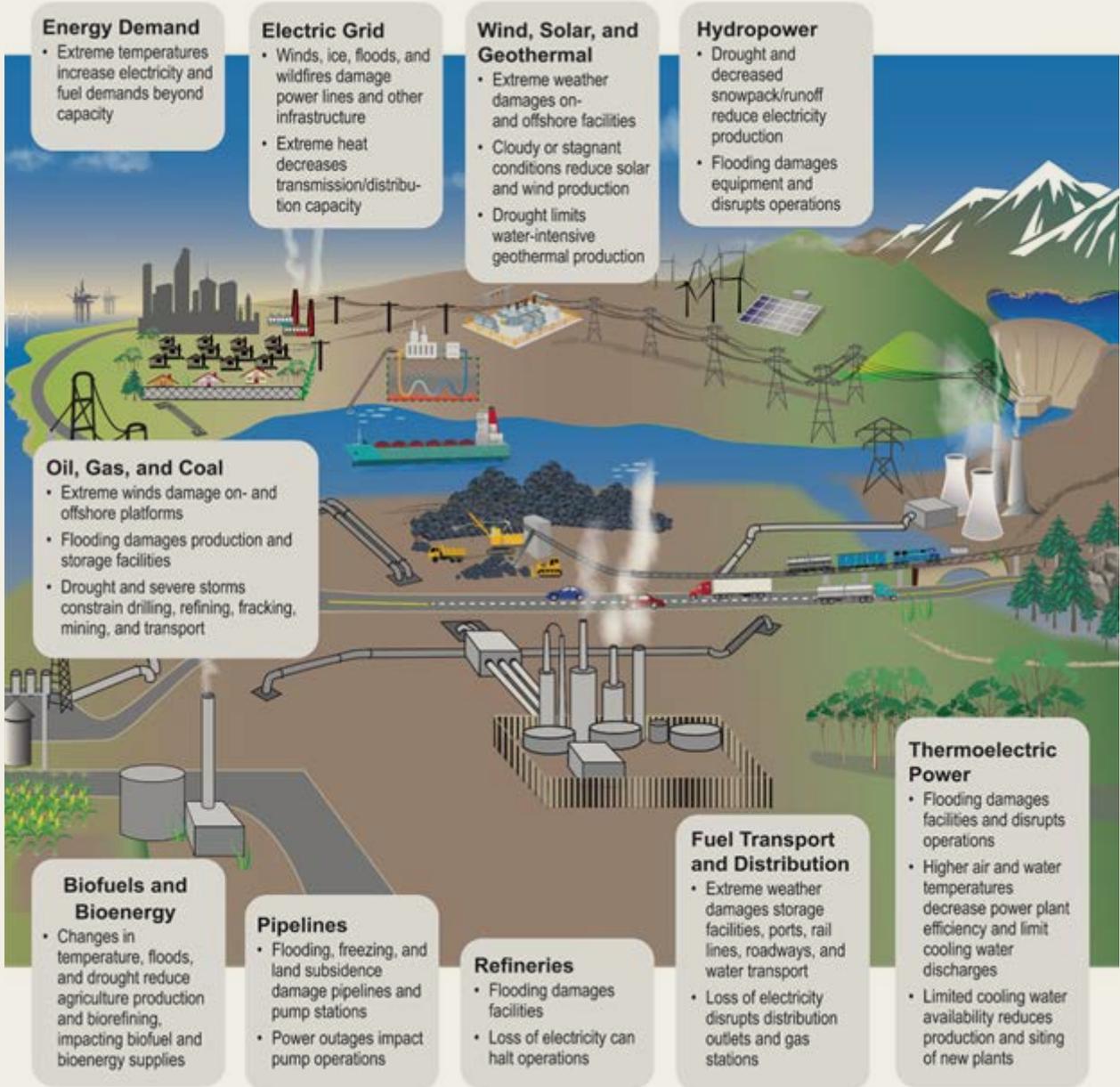
## Climate Challenges and Their Impact on Energy Systems

Renewable energy sources like wind and solar, though pivotal in mitigating emissions, face variability issues as extreme weather alters patterns of wind speed, solar radiation, and precipitation, making energy supply less predictable.

Climate change poses a dual threat to power systems: increased extreme weather events and rising global temperatures. Natural disasters such as hurricanes, floods, and wildfires disrupt power generation, transmission, and distribution infrastructure, leading to outages and costly repairs. For example, heatwaves place strain on power grids as energy demand surges for cooling, while water scarcity reduces the efficiency of thermal and hydropower plants reliant on water for cooling or generation. [Renewable energy sources like wind and solar, though pivotal in mitigating emissions, face variability issues as extreme weather alters patterns of wind speed, solar radiation, and precipitation, making energy supply less predictable.](#) This is where fuel cell technologies can bring complementary benefit.

Weather and climate-related events can lead to both performance issues, such as reduced efficiency of thermal plants or decreased transmission line capacity during extreme heat, and complete asset failures, like transformers being damaged by flooding. [These impacts vary in scale, from localized disruptions affecting only a few components with minimal customer impact to system-wide issues that can trigger cascading failures and widespread outages. Changes in individual climate factors, such as higher temperatures or specific events like heatwaves, can simultaneously affect multiple assets, increasing the likelihood of common-mode failures.](#) Moreover, the combined effects of multiple climate variables, such as heat and drought, can amplify the strain on power system performance and operations, exacerbating vulnerabilities across the network.

## Climate Change Impacts on the Energy System



**Figure 3** Climate Change Impacts on the Energy System: Driving Demand for Resilient Technologies  
 Source: U.S. Global Change Research Program Fourth National Climate Assessment

# Aging Power Grid Infrastructure

Many power grids across the U.S. and worldwide are decades old and ill-equipped to handle modern energy demands or the integration of intermittent renewable energy. Ageing infrastructure leads to inefficiencies, increased maintenance costs, and reliability issues. The power grid is increasingly grappling with reliability and resilience challenges, which have worsened since the mid-2010s, largely due to aging infrastructure. By 2023, around 70% of the grid's power lines and transformers were over 25 years old, nearing the end of their functional lifespan.

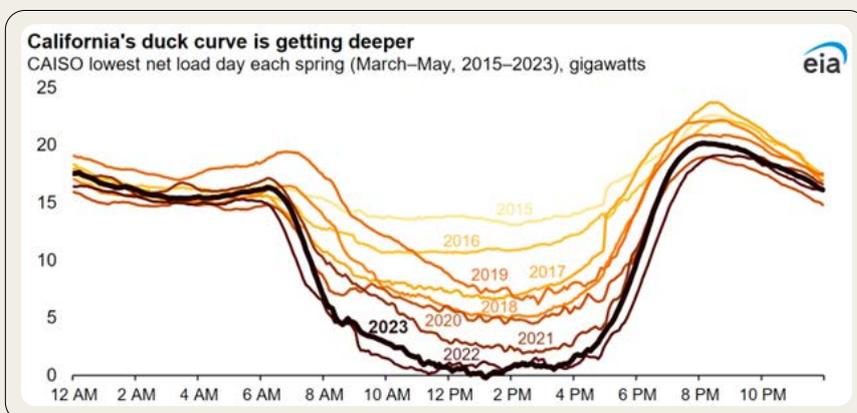
**Much of the U.S. electric grid, built between the 1960s and 1970s, is now approaching its 50- to 80-year life cycle limit. These aging systems are further strained by the growing frequency and severity of extreme weather events, exacerbated by climate change. Events like storms, heatwaves, and floods can trigger infrastructure failures, such as sagging or broken power lines, malfunctioning transformers, compromised substations, and overloaded generators.** The challenges are intensifying as extreme weather becomes more frequent, with 2023 setting a record for billion-dollar weather-related disasters in the United States. The combination of outdated infrastructure and climate-driven stresses highlights the urgent need to modernize the grid to ensure its resilience and reliability in the face of evolving threats.

Grids were also initially designed for centralized, one-way power flow from fossil fuel plants; however, the rise of decentralized energy systems, such as rooftop solar panels and battery storage, requires bi-directional flow and grid flexibility. Modernizing these systems to accommodate new technologies while ensuring reliability creates opportunity for varied technologies.

# Adoption of Renewable Energy: Intermittency and Volatility

While renewable energy sources, such as solar and wind, are vital for decarbonizing power generation, they introduce operational challenges due to their intermittent nature. Solar power generation, for instance, ceases at night and reduces on cloudy days, while wind energy is dependent on fluctuating wind patterns. [This intermittency creates volatility in supply, demanding innovative solutions for energy storage and grid balancing to ensure continuous power availability.](#) Storage technologies, like batteries and hydrogen fuel cells, play an emerging role in addressing these gaps. The variability in renewable energy generation causes supply imbalances, leading to grid instability and occasional price spikes during peak demand periods.

Regions with high renewable energy penetration face these challenges acutely. For instance, In the United States, California offers a clear example. The state generates a significant portion of its [electricity from solar—over 22% as of May 2025.](#) However, this has created operational challenges, such as the "duck curve" effect, where midday solar oversupply is followed by steep demand peaks in the evening, driving demand for energy storage.



**Figure 4** California's Duck Curve Over the Years  
Source: [Energy Information Administration](#)

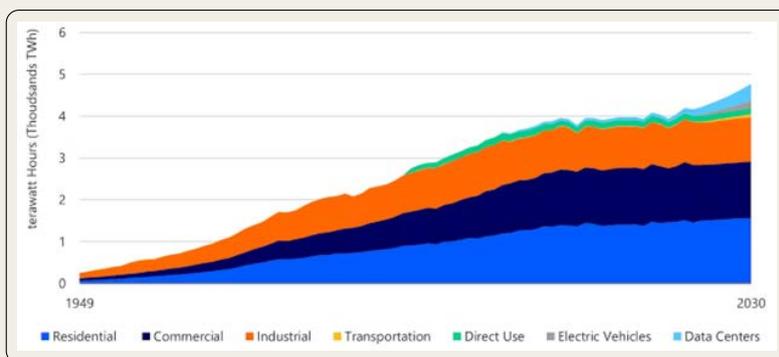
[During the August 2020 heatwave, this mismatch contributed to rolling blackouts affecting hundreds of thousands.](#) Thus, California has experienced negative electricity pricing, particularly in the spring, when solar generation outpaces demand. To mitigate these challenges, the state frequently issues Flex Alerts, asking residents to conserve electricity during peak hours to avoid overloading the grid. Integrating fluctuating renewable energy requires smarter, more flexible grid systems to balance supply and demand in real time. Without such upgrades, grid instability and power disruptions become more likely, especially in regions heavily dependent on renewables.

# High Power Demand Driven by 6G Technologies, Electrification of Transportation, Data Centers and AI

The push for decarbonization and electrification across sectors like heavy industry, transportation, and data centers has drastically increased power demand. For instance, adopting electric vehicles (EVs) add pressure on grids to meet peak charging loads and distributed power needs. Planned U.S. grid power generation capacity doesn't support these surges in demand.

[A new report from the IEA indicates that artificial intelligence has the potential to revolutionize the energy sector in the next decade](#), resulting in a significant increase in electricity demand from data centres worldwide and unlocking significant opportunities to reduce emissions. Data centers are projected to use nearly half of the increase in electricity demand between now and 2030 in the United States. The US economy will require more electricity in 2030 to process data than to manufacture aluminium, steel, cement, and chemicals due to AI use.

[By 2030, the national electricity demand in the United States could increase by 100TWh to 185TWh due to the accelerated adoption of electric vehicles \(EVs\)](#). This represents a range of 2.5% to 4.6% of the anticipated total consumption. By 2030, the national electricity demand in the United States could increase by 100TWh to 185TWh due to the accelerated adoption of electric vehicles (EVs). This represents a range of 2.5% to 4.6% of the anticipated total consumption.



**Figure 5**

Source: US Energy Information Administration (EIA), BloombergNEF (BNEF), Electric Power Research Institute (EPRI), RaboResearch 2024

Additionally, the digitization of economies further compounds this challenge. Data centers, the backbone of digital infrastructure, consume vast amounts of power, which will only grow with the integration of the more energy-intensive 6G technologies. [While 6G promises speed, connectivity, and data integration advancements, it also poses a significant challenge: high power consumption. It also presents several technical limitations. These include incompatibility issues with older infrastructure, higher energy consumption, and greater operating costs.](#)

# Resilient and Sustainable Hydrogen Fuel Cells Contribute to Resolving Power Sector Challenges and Transitioning to a Zero-Emission Energy Future

The totality of these challenges underscores the urgency of adopting innovative energy technologies and power sources that are both resilient and sustainable. Fuel cells offer a promising solution by providing a clean, efficient, and continuous energy supply, regardless of weather conditions or grid limitations. They can complement renewable systems by bridging supply gaps and offering backup power solutions, ensuring reliability even as the energy landscape evolves. Fuel cells are applicable across several sectors: In the transportation sector, from EVs to buses, trucks, trains, ships and even aircraft – including spacecraft - fuel cells offer more rapid refueling and a more extended driving range than batteries. Stationary fuel cells are used to power CHP (combined heat and power) systems as well as remote sites. And increasingly hydrogen fuel cells are powering mobile machinery and hard-to-decarbonize industrial applications.

Fuel cells offer a promising solution by providing a clean, efficient, and continuous energy supply, regardless of weather conditions or grid limitations. They can complement renewable systems by bridging supply gaps and offering backup power solutions, ensuring reliability even as the energy landscape evolves.

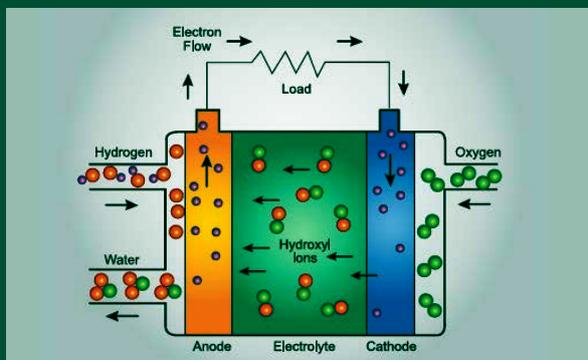
---

Source: <https://uppcsmagazine.com/hydrogen-fuel-cells-the-future-of-clean-and-sustainable-energy>

# WHAT IS A FUEL CELL?

A **hydrogen fuel cell** is an electrochemical device that converts the chemical energy of hydrogen and oxygen directly into electricity, with water and heat as the only byproducts. Fuel cells generate electricity without burning fuel and causing harmful emissions as do conventional combustion engines. Like batteries, fuel cells convert chemical energy into electrical energy, with heat as a by-product. However, unlike batteries—**which store chemical energy and operate for limited durations before needing to be discarded or recharged—fuel cells can continuously generate electricity as long as they are supplied with fuel (hydrogen) and an oxidant.**

Fuel cells operate using a chemical process called oxidation, where hydrogen atoms react with oxygen atoms to form water while releasing electrons, generating electricity. This non-combustion process makes fuel cells more efficient than traditional power generation technologies. Unlike turbogenerators or generator sets (diesel engine-electric generator combinations), fuel cells avoid the significant energy losses associated with combustion, where roughly 33% of energy is lost to friction and heat dissipation.



**Figure 6** The alkaline fuel cell electrochemical process.

Fuel cells offer numerous advantages over the conventional combustion-based technologies that are presently employed in numerous power plants and vehicles. **Fuel cells are capable of converting the chemical energy in the fuel directly to electrical energy, with efficiencies that can exceed 60%, and can operate at higher efficiencies than combustion engines. In contrast to combustion engines, fuel cells emit negligible or**

**no emissions.** Hydrogen fuel cells emit only heat and water, contributing to resolution of climate challenges as they do not produce carbon dioxide emissions. Furthermore, there are no air pollutants that generate smog and induce health complications at the site of operation. Fuel cells operate quietly due to their minimal number of moving components.

# The Evolution of Fuel Cell Technology

Fuel cells have undergone an extraordinary evolution since their invention by Sir William Grove in 1838.

Fuel cells have undergone an extraordinary evolution since their invention by Sir William Grove in 1838. Grove's pioneering work laid the foundation for Francis Thomas Bacon's hydrogen-oxygen fuel cell in 1932, which became the first commercially viable design. The alkaline fuel cell (AFC), also known as the Bacon fuel cell, gained fame in the mid-1960s when NASA adopted it to power satellites and space capsules, demonstrating its reliability in critical, high-stakes applications.

This innovation paved the way for broader adoption across a range of applications. By the 1980s, NASA had already integrated fuel cells into submarines, showcasing their potential for use in confined and remote environments. In 1981, alkaline fuel cells powered NASA's first space shuttle flight, and by 1988, the Soviet space agency utilized AFCs in its Buran space shuttle program. The 1990s marked a turning point as large stationary fuel cells were developed for commercial and industrial power generation. This era also saw the emergence of fuel cells in auxiliary power units (APUs) and backup power systems by 2007. Residential fuel cell micro-CHP systems became commercially available in Japan by 2009, making the technology accessible for household energy needs. The transportation sector embraced fuel cells with groundbreaking innovations. Honda introduced the FCX Clarity in 2008, demonstrating the viability of fuel cell electric vehicles (FCEVs). In 2014, Toyota unveiled the Mirai, a hydrogen-powered car designed for the mass market, signaling a shift toward sustainable transportation.

As mentioned above, beyond buildings and vehicles, fuel cells now power a diverse range of applications, including forklifts, buses, trains, motorcycles, and submarines. Their versatility, efficiency, and clean byproducts — electricity, heat, and water—have made them indispensable for both primary and backup power in remote and inaccessible locations. The journey of fuel cells from Sir William Grove's laboratory to their integration into modern life reflects an incredible trajectory of innovation, resilience, and adaptability, revolutionizing how we think about clean and sustainable energy.

# TYPES of FUEL CELLS

Fuel cells are characterized by the type of electrolytes used to separate the fuel cell electrodes. Since different materials are electrolytic at various temperature levels, fuel cells are classified as low, medium, and high temperatures. Each type of fuel cell has its inherent strengths and weaknesses that make it more suitable for specific markets and applications.

## There are seven primary types of fuel cells:

1. Proton Exchange Membrane Fuel Cells (low temperature)
2. Alkaline Fuel Cells (low temperature)
3. Phosphoric Acid Fuel Cells (medium temperature)
4. Molten Carbonate Fuel Cells (high temperature)
5. Solid Oxide Fuel Cells (high temperature)
6. Reversible fuel cells
7. Direct Methanol Fuel Cell (low temperature)

Each type of fuel cell has its own inherent strengths and weaknesses that make them more suitable for specific markets and applications.

### AFCs

Alkaline Fuel Cells  
(low temperature)

### PEMFC

Proton Exchange Membrane Fuel Cells  
(low temperature)

### $H_3PO_4$

Phosphoric Acid Fuel Cells  
(medium temperature)

### MCFCs

Molten Carbonate Fuel Cells  
(high temperature)

### SOFC

Solid Oxide Fuel Cells  
(high temperature)

# Proton Exchange Membrane Fuel Cells

The proton exchange membrane fuel cell (PEMFC or PEM fuel cell) uses a polymer membrane as an electrolyte. The membrane can be either water-based or mineral-acid-based, with platinum group-based electrodes. **The water-based PEM fuel cell operates at 80-100 degrees C, while the mineral-acid-based PEM, known as high-temperature PEM (or HTPEM), operates at up to 200 degrees C. PEM fuel cells consist of two electrodes (an anode and a cathode) with a thin platinum layer of catalyst bonded to either side of a proton exchange membrane.** Hydrogen and air are supplied to the electrodes, and hydrogen flows to the anode, where the platinum catalyst promotes its separation into protons and electrons.

On the opposite side, air flows to the cathode, where oxygen in the air attracts the hydrogen protons. The electrons are captured as useful electricity through an external circuit and combine with the protons and oxygen to produce water vapor on the cathode side. PEM fuel cells are relatively small and lightweight and are therefore the leading fuel cell technology used in material handling applications such as forklifts and transportation applications. Their acidic nature requires the use of a platinum catalyst. Also, **the low operating temperature offers key advantages: it enables rapid startup with minimal warm-up time and reduces strain on system components.** These features contribute to enhanced durability and reliability, making PEM fuel cells well-suited for applications requiring efficiency and frequent on-off cycles.



**Picture 7** Fuel Cell Hydrogen Truck Engine



**Picture 8** GenCell developed platinum-free AFC electrodes by applying carbon onto a nickel mesh.

## Alkaline Fuel Cells

**AFCs are among the most efficient types of fuel cells, reaching up to 60% efficiency**

Alkaline fuel cells (AFCs) were developed in 1959 by Francis Thomas Bacon. Using an alkaline electrolyte such as potassium hydroxide (KOH) in water and cathodes usually made with platinum, **AFCs are among the most efficient types of fuel cells, reaching up to 60% efficiency (up to 87% combined heat and power). Alkaline fuel cells also offer virtually** instant operation without preheating, even at sub-zero temperatures. AFCs were used by the NASA and MIR space programs to produce electricity and drinking water.

The alkaline fuel cell is comprised of a pair of porous electrodes—a positively charged cathode and a negatively charged anode—separated by an alkaline electrolyte or membrane electrolyte. Air, containing oxygen, is fed to the cathode gas chamber, where it reacts with water to produce four  $\text{OH}^-$  ions and four positive charges. The  $\text{OH}^-$  ions, attracted by the anode, pass from the cathode through the KOH electrolyte. Hydrogen, fed to the anode, reacts with  $\text{OH}^-$  ions to form molecules of water and negative charges. The electrons are attracted by the positive charge on the cathode and are forced through an external circuit as an electric current. The reaction produces usable heat and water as a byproduct.

# Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells (PAFCs) use phosphoric acid as an electrolyte and an anode and cathode made of a finely dispersed platinum catalyst on a carbon and silicon carbide structure. The PAFC is one of the most mature types of fuel cells and the first type to be commercially used. It has been typically used for stationary power generation in buildings, hotels, hospitals, and electric utilities in the USA, Europe, and Asia. The units have been technically successful and very reliable, with 40% plus efficiency levels and tens of thousands of operating hours. Water management in these fuel cells is easier than in PEMs, and they are more tolerant of impurities in hydrogen. However, the emission of phosphoric acid vapor is problematic, and adequate ventilation is mandatory.

[PAFCs are less powerful than other fuel cells for the same weight and volume and require much more platinum than other fuel cells, which raises their cost. PAFCs are frequently found in environments with significant energy requirements, like manufacturing and processing facilities, schools, and hospitals.](#)

# Molten Carbonate Fuel Cells

Molten Carbonate Fuel Cells (MCFCs) use a molten carbonate electrolyte and operate at 650 degrees C, which allows them to operate on unreformed fuels. The very high temperature eliminates the need for expensive and complicated reforming that is necessary with other types of fuel cells. Natural gas, methanol, ethanol, biogas, and coal gas are all usable fuels with MCFCs. In addition, the absence of a catalyst made from noble metal (i.e., from a metal like gold, silver, or platinum that does not corrode) allows MCFCs to be more cost-competitive with more traditional sources of power. [MCFCs also offer efficiency levels of close to 50%, which can be increased up to 80% when high-quality waste heat is reused. Although they do not require precious metals as catalysts,](#) MCFCs require a large number of stainless steel and nickel parts that increase the materials' cost and that may require specialized manufacturing techniques. Molten carbonate is also inherently corrosive. Since the operating temperature is so high, MCFCs require significant time to reach operating temperature and are slow to respond to sudden changes in electricity demand. As such, they are best suited for the provision of constant power in large utility applications.

# Solid Oxide Fuel Cells

Solid Oxide Fuel Cells (SOFCs) use a hard, non-porous ceramic compound as an electrolyte and operate at nearly 1,000 degrees C. The high operating temperature of SOFCs allows them to tolerate relatively impure fuels obtained from the gasification of coal but requires more expensive ceramic construction to provide stability and reliability. Since the operating temperature is so high, SOFCs require significant time to reach operating temperature and are slow to respond to changes in electricity demand. As such, they are best suited for large applications. Smaller applications have, however, operated at relatively lower output levels in laboratory settings.

One of the standout features of SOFCs is their resistance to sulfur and tolerance of carbon monoxide, which can even serve as a fuel. This resilience makes SOFCs versatile and effective in environments where other fuel cells might struggle. Rather, high-temperature operation comes with challenges. It leads to slower startup times and necessitates robust thermal shielding to retain heat and protect users, making SOFCs more suitable for stationary utility applications rather than transportation. Furthermore, the intense heat places significant durability demands on system materials. Addressing this requires the development of affordable, durable materials capable of withstanding harsh operating conditions, which remains a central technical challenge for this technology.



**Picture 9** 400 kWh solid oxide fuel cell

# Direct Methanol Fuel Cell (DMFC)

Similar to Proton Exchange Membrane Fuel Cells (PEMFCs), Direct Methanol Fuel Cells (DMFCs) use a polymer membrane as their electrolyte and often rely on a platinum catalyst. Though, unlike PEMFCs, DMFCs derive hydrogen from liquid methanol instead of using pure hydrogen gas. These cells operate at relatively low temperatures, typically between 125°F and 250°F. DMFCs are versatile, with applications ranging from small devices like battery chargers and laptops to larger uses, such as providing stationary power for telecommunications backup systems. [Direct methanol fuel cells avoid many of the fuel storage challenges faced by other fuel cell systems because methanol has a higher energy density than hydrogen, although it is less energy dense than gasoline or diesel.](#) As a liquid, methanol is easier to transport and distribute using existing infrastructure, similar to gasoline. DMFCs are commonly used for portable applications, such as powering cell phones and laptop computers.

# Reversible Fuel Cells

Reversible fuel cells are integrated with solid oxide fuel cell (SOFC) systems to enhance energy efficiency by leveraging renewable energy sources like solar or wind. These cells utilize the energy from these sources to produce hydrogen gas, which is subsequently compressed and stored in tanks. [The stored hydrogen then serves as a fuel for the SOFC system, generating electricity on demand. Currently, SOFC systems in fuel cell mode deliver an output of approximately 50 kW within a compact 20-foot container. However, advancements are expected to boost this power output to between 200 kW and 250 kW in the future.](#) As a relatively recent innovation spearheaded by NASA and similar research institutions, reversible fuel cells not only produce electricity, heat, and water by combining hydrogen and oxygen but also operate in reverse. Through electrolysis, they use excess electricity from renewable sources to split water into hydrogen and oxygen, effectively storing energy. [This dual functionality makes reversible fuel cells a pivotal technology for managing fluctuations in renewable energy production, enabling efficient storage of surplus energy during periods of high generation, such as strong winds, for future use.](#) This capability positions them as a crucial component in supporting intermittent renewable energy solutions.



**Figure 6** Hydrogen is the most abundant element in the universe.

# FUELING the FUEL CELLS - HYDROGEN

Hydrogen is the lightest and most abundant element in the universe and one of the most environmentally friendly fuels. Various methods such as steam reformation of natural gas, electrolysis processes, and biogas fermentation are used to produce nearly 65 million metric tons of hydrogen annually worldwide. Although its production costs are lower than gasoline or methane, the current distribution cost makes hydrogen more expensive than gasoline or methane for commercial usage. When used in fuel cells, hydrogen produces only water as a by-product, making it a zero-emission energy carrier. Hydrogen can be produced from diverse sources, such as natural gas, nuclear power, biomass, and renewable sources like solar and wind energy. These characteristics enable hydrogen to play a pivotal role in transportation, electricity generation, heating, and industrial processes. Hydrogen is most commonly supplied in cylinders, although it can be stored in tanks, salt mines and numerous other storage methods, as well as in a variety of chemical compounds including metal hydrides or carbon-based fuels such as natural gas (CH<sub>4</sub>), ammonia (NH<sub>3</sub>), gasoline, and diesel from which it can be extracted.

Hydrogen has emerged as a promising element in the pursuit of clean energy solutions, garnering increasing attention from policymakers worldwide. Many nations have now adopted national hydrogen strategies or roadmaps, and a significant portion of COVID-19 recovery funds were allocated to accelerating hydrogen development. [Global collaboration around clean hydrogen technologies, as shown via the COP conferences, underscores their role in the sustainable energy transition.](#)

With increased emphasis on sustainable energy and increased hydrogen demand, new distribution systems are already being deployed in Japan, California, and other US states and are expected to make hydrogen increasingly economical. People commonly refer to hydrogen as "the fuel of the future", particularly to replace the ICE vehicles for private and public transportation that are major sources of pollution. As supporting infrastructure is expanding, Toyota, Honda, Hyundai, Mercedes-Benz, General Motors and other automotive OEMs are focusing efforts on the development and sale of hydrogen fuel cell cars. The wide variety of production methods and the potential of the newer eco-friendly methods make hydrogen an extremely promising energy carrier. As the industry invests in innovations to overcome and reduce costs of hydrogen transport and storage limitations, the role of hydrogen in our energy future expands.

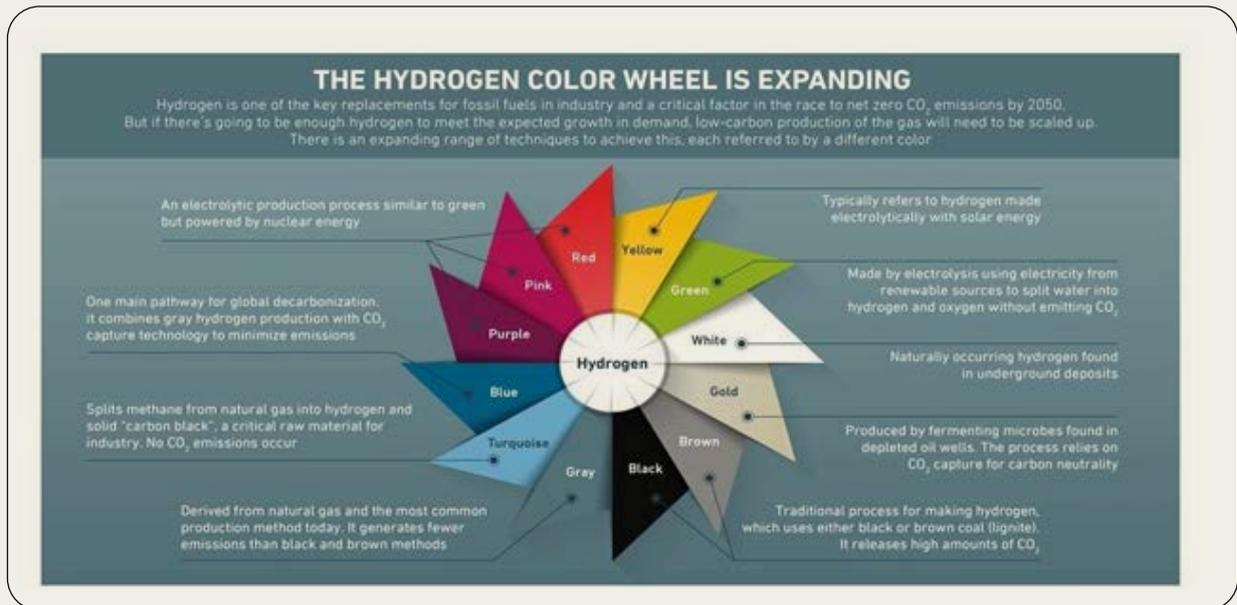
**Hydrogen is the lightest and most abundant element in the universe and one of the most environmentally friendly fuels**

**Picture 11** Hydrogen Molecules



# Hydrogen as a Fuel Source

Currently, hydrogen fuel can be produced through several techniques. These production processes of hydrogen result in different types of hydrogen, often categorized by colors such as grey, blue, green, or brown, based on the energy source and environmental impact involved in their creation.



**Figure 12** The Color Wheel of Hydrogen

Source: <https://spectra.mhi.com/the-colors-of-hydrogen-expanding-ways-of-decarbonization>

## The Color Wheel of Hydrogen

Hydrogen can be produced through:

### 1. Steam Methane Reforming (Grey Hydrogen)

Grey hydrogen is the most common form of hydrogen and is produced through steam methane reforming (SMR) or auto-thermal reforming (ATR), processes that separate hydrogen from natural gas while releasing carbon dioxide into the atmosphere. This method generates significant carbon emissions, contributing to global environmental concerns.

**[Hydrogen production through reforming and gasification accounts for emissions comparable in volume to the annual emissions of major nations. Only a small fraction of global hydrogen is produced using cleaner methods such as electrolysis. These methods, responsible for 95% of today's hydrogen supply, generate significant CO<sub>2</sub> emissions, making them incompatible with net-zero emission goals.](#)**

## 2. Gasification from Coal or Lignite (Black and Brown Hydrogen)

Black and brown hydrogen are derived from the traditional method of hydrogen production from black coal and lignite. These methods result in significant carbon emissions, making them the most environmentally damaging forms of hydrogen production. These terms are often used interchangeably for any hydrogen generated from fossil fuels. This process emits significant amounts of CO<sub>2</sub> and carbon monoxide into the air. [According to the International Energy Agency \(IEA\), approximately 20% of hydrogen was still produced using coal in 2020.](#)

## 3. Gasification with Carbon Capture (Blue Hydrogen)

[Blue hydrogen is produced using methods similar to grey hydrogen, such as SMR or gasification from fossil fuels, but incorporates carbon capture and storage \(CCS\) to reduce emissions and to trap and store the resulting carbon dioxide, capturing up to 90% of the CO<sub>2</sub> produced during the process.](#) As a result, blue hydrogen is viewed as a more sustainable alternative for industries reliant on fossil fuels, including heavy industry and power generation. While this approach can extend the use of existing infrastructure, its effectiveness depends on minimizing methane leaks which often occur during the SMR process. Emissions must remain below 0.2% with near-total carbon capture to achieve low greenhouse gas outputs. Challenges such as methane leakage risks, reliance on volatile fossil fuel prices, and added costs for CO<sub>2</sub> transport and storage limit blue hydrogen's scalability. Despite these drawbacks, blue hydrogen could provide short-to-medium-term flexibility, helping scale production while supporting infrastructure development.

## 4. Pyrolysis (Turquoise Hydrogen)

Similar to blue hydrogen, turquoise hydrogen is generated through [methane pyrolysis, which separates methane into hydrogen and solid carbon.](#) This method has the potential to be low-emission, particularly if renewable energy powers the heating process and the carbon byproduct is permanently stored or utilized.

## 5. Electrolysis from Nuclear Energy (Pink Hydrogen)

Pink hydrogen, sometimes referred to as purple or crimson hydrogen, is produced using nuclear energy to power the electrolysis process. [Nuclear reactors can also provide steam for efficient electrolysis or methane reforming. This method does not emit CO<sub>2</sub> during operation, aligning it closely with the environmental benefits of green hydrogen.](#)

## 6. White Hydrogen

White hydrogen refers to naturally occurring hydrogen found in subsurface geological deposits. While it exists naturally, commercial plans to extract and utilize this hydrogen are still quite premature. Recent research has revealed that these deposits are more abundant than initially believed and can often be accessed through relatively straightforward drilling techniques. For example, a well in Mali has been actively producing hydrogen since 2012, demonstrating the potential of this resource. Producing white hydrogen may be more cost-effective than gray hydrogen, with production costs potentially falling below \$1 per kilogram. As a carbon-free fuel, white hydrogen represents an environmentally friendly energy source; however, the potential ecological impacts of its extraction processes must be carefully assessed to ensure sustainability.

## 7. Fermentation (Gold Hydrogen)

Gold hydrogen refers to hydrogen that occurs naturally or is produced by fermenting microbes within depleted oil wells. This innovative approach provides a cost-effective method for hydrogen production while also repurposing abandoned oil fields, effectively extending their utility rather than allowing them to become stranded assets. However, for gold hydrogen to achieve carbon neutrality, its production and extraction processes require the integration of carbon capture technologies.

## 8. Electrolysis (Green Hydrogen)

Green hydrogen is most commonly produced via electrolysis, a process that splits water into hydrogen and oxygen using renewable energy sources such as wind or solar power.

Despite its environmental benefits, the high cost of renewable energy and electrolysis remains a challenge to widespread adoption. Green hydrogen can also serve as a solution for long-duration seasonal energy storage as well as a potential alternative to batteries for short-term energy storage. Green hydrogen, while fully sustainable and highly adaptable, remains costly to produce primarily due to the high expense of renewable energy required for its generation through electrolysis. Among the various hydrogen types, producing green hydrogen is particularly energy-intensive. As the world seeks to achieve zero-emission targets, the demand for green hydrogen is high and growing; efforts to discover new innovative technologies to synthesize green hydrogen with higher efficiency and lower energy and financial resources.

# Hydrogen Safety

Hydrogen, a fuel used extensively for decades in industrial applications and space exploration, presents unique safety considerations compared to conventional fuels like gasoline or natural gas. While hydrogen is no more or less inherently dangerous, its properties require distinct handling methods and safety measures. One notable characteristic of hydrogen is its rapid diffusivity, which is nearly four times faster than natural gas. As the lightest element, hydrogen rises quickly, dispersing at speeds of nearly 45 mph in open air. This rapid diffusion reduces the likelihood of lingering flammable concentrations, making it challenging to confine hydrogen in a manner that could create a fire hazard. Structures utilizing hydrogen are designed to allow the gas to escape safely upward, mitigating risks during accidental releases. Hydrogen's volatile and flammable nature necessitates rigorous safety protocols to mitigate the risks of leaks or explosions. These challenges also complicate its storage and transportation, requiring advanced containment systems to ensure safety and efficiency.

Unlike natural gas, which is made detectable with odorants like mercaptan, hydrogen is odorless, colorless, and tasteless. This makes human detection of leaks difficult. Instead, hydrogen safety relies on advanced sensors that have maintained a strong safety record over decades of use. Researchers are exploring alternatives for hydrogen leak detection, including tracers and innovative odorant technologies compatible with fuel cell applications. Hydrogen flames exhibit low radiant heat due to the absence of carbon and the heat-absorbing water vapor produced during combustion. This reduces the risk of secondary fires compared to hydrocarbon flames. Yet, while the flames burn as hot as other fuels, their low heat emission near the source poses fewer dangers to rescue workers and surrounding areas.

Hydrogen is a flammable fuel but has been proven to be as safe or even safer than gasoline or natural gas (methane). understanding its unique behavior and adhering to established safety protocols, hydrogen can be used as a safe, efficient, and clean energy carrier.

Despite its wide flammability range (4-74% in air) and low ignition energy (0.02 mJ), [hydrogen's buoyancy and diffusivity make it challenging to create conditions conducive to combustion](#). It is more difficult to ignite hydrogen near its lower flammability limit compared to gasoline or natural gas. In open environments, hydrogen's rapid rise further reduces explosion risks, unlike heavier fuels like propane, which remain near the ground. Hydrogen is non-toxic and does not pollute air or water, nor does it produce harmful fumes. Regardless, as a cryogenic liquid, it can cause severe freeze burns upon contact. [Modern liquid hydrogen storage systems incorporate robust safety features, including double-walled, vacuum-insulated containers designed to safely vent gaseous hydrogen if a breach occurs](#).



**Picture 13** Hydrogen car fire vs. gasoline car fire.

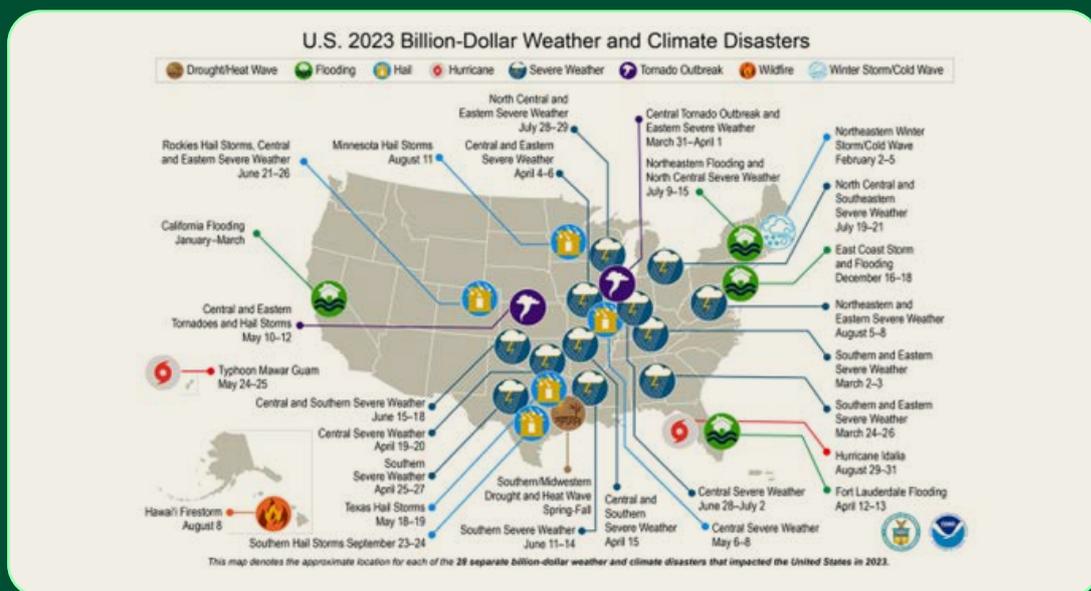
Today, [stringent safety codes and standards guide the safe production, storage, and utilization of hydrogen](#), ensuring its viability as a fuel for a sustainable energy future. Education and awareness of hydrogen's properties are also critical to its widespread adoption. By understanding its unique behavior and adhering to established safety protocols, hydrogen can be used as a safe, efficient, and clean energy carrier.

# HYDROGEN & FUEL CELLS: MEETING THE RISING NEED FOR BACKUP POWER

Backup power is a necessity in an economy and society increasingly reliant on continuous connectivity and technology.

In the United States, when climate change is becoming more unpredictable and energy needs are rising, strong backup power systems have never been more important than they are now. The country's electric grid has been put under a lot of stress by hurricanes, wildfires, and winter storms, among other extreme weather events. Frequent and long-lasting power outages affect daily life, the economy, and essential services. A reliable backup power infrastructure is vital not only for emergency preparedness, but also for supporting critical facilities like hospitals, data centers, telecommunications networks, and industrial operations. These systems provide energy security and energy independence, ensuring that power remains uninterrupted during grid failures—a necessity in an economy and society increasingly reliant on continuous connectivity and technology.

Trends of climate crisis and severe weather continue: [The National Oceanic and Atmospheric Administration reported that 2023 had already broken records for billion-dollar weather and climate disasters and experienced 28 weather and climate disasters, exceeding the previous record of 22 set in 2020.](#)



**Figure 14** Billion-Dollar Weather and Climate Disaster  
Source: NOAA

These events collectively incurred a minimum cost of \$92.9 billion. Catastrophic events like the deadly firestorm in Maui, severe flooding in California and New England, Hurricane Idalia's category four winds hitting the Gulf Coast, and destructive hailstorms and tornadoes in the central U.S. highlight the growing challenges a changing climate poses to the reliability of the electric grid, which is vital to the nation's economy, security, and the well-being of its communities.

To illustrate the issue, the inhabitants of Texas vividly remember Winter Storm Uri, the significant meteorological occurrence of February 2021.



**Picture 15** The Great Texas Freeze: February 11-20,2021  
Source: <https://www.ncei.noaa.gov/news/great-texas-freeze-february-2021>

**A combination of extreme cold, high energy demand, and unprepared grid infrastructure led to the collapse of electricity systems across the state.** The freezing temperatures left over 4.5 million homes and businesses without power for several days. This crisis resulted in the tragic loss of life and billions in economic damages. The disaster revealed the vulnerability of the Texas grid, which struggled with both a lack of winterized infrastructure and insufficient backup power solutions. The incident emphasized the need for robust backup power to maintain essential services and protect communities during emergencies.



**Figure 16** A Map Showing Winter Storm Warning before the The Great Texas Freeze  
 Source: <https://www.ncei.noaa.gov/news/great-texas-freeze-february-2021>

Building on the urgent need to address the growing challenges of extreme weather, the **[Biden-Harris Administration advanced its Investing in America agenda in 2023 by prioritizing the modernization of the nation’s electric grid.](#)** In fiscal year 2024 the U.S. Department of Energy (DOE) allocated \$473.6 million for Grid Resilience State and Tribal Formula Grants. This funding was distributed to 49 states, 5 territories, 254 Tribal Nations, and the District of Columbia to strengthen the grid against wildfires, severe storms, and other climate-driven disasters. Supported by the Bipartisan Infrastructure Law, the program targeted the reduction of the impacts of extreme weather while enhancing the reliability and sustainability of the power sector.

Regionally, the U.S. backup power systems market shows notable differences in terms of market size, demand, and adoption rates. **[Regions that are frequently hit by natural disasters and extreme weather, such as the Gulf Coast, West Coast, and areas prone to tornadoes, show a higher demand for backup power systems. States like California and Texas, which lead in renewable energy adoption, also present significant opportunities for integrating these advanced technologies into backup power systems.](#)** As the U.S. continues to deal with extreme weather events and shifting energy needs, backup power systems are playing an increasingly critical role in ensuring grid reliability and resilience.

According to a report published in 2023, the United States witnessed significant developments in its backup power systems market, reflecting the nation's growing energy needs amid these challenges. **The market was valued at an estimated USD 3.49 billion in 2024 and was projected to reach USD 4.47 billion by 2029, with a compound annual growth rate (CAGR) of 5.10% over the forecast period. Key drivers include the rapid expansion of infrastructure for data centers, fueled by rising connectivity demands and robust growth in the commercial sector. While the difficulties of accelerating integration of renewable energy sources and distributed technologies into the grid slow the advancement of backup power solutions, nevertheless the market is seeing growth both in the commercial and industrial as well as in residential energy sectors.**

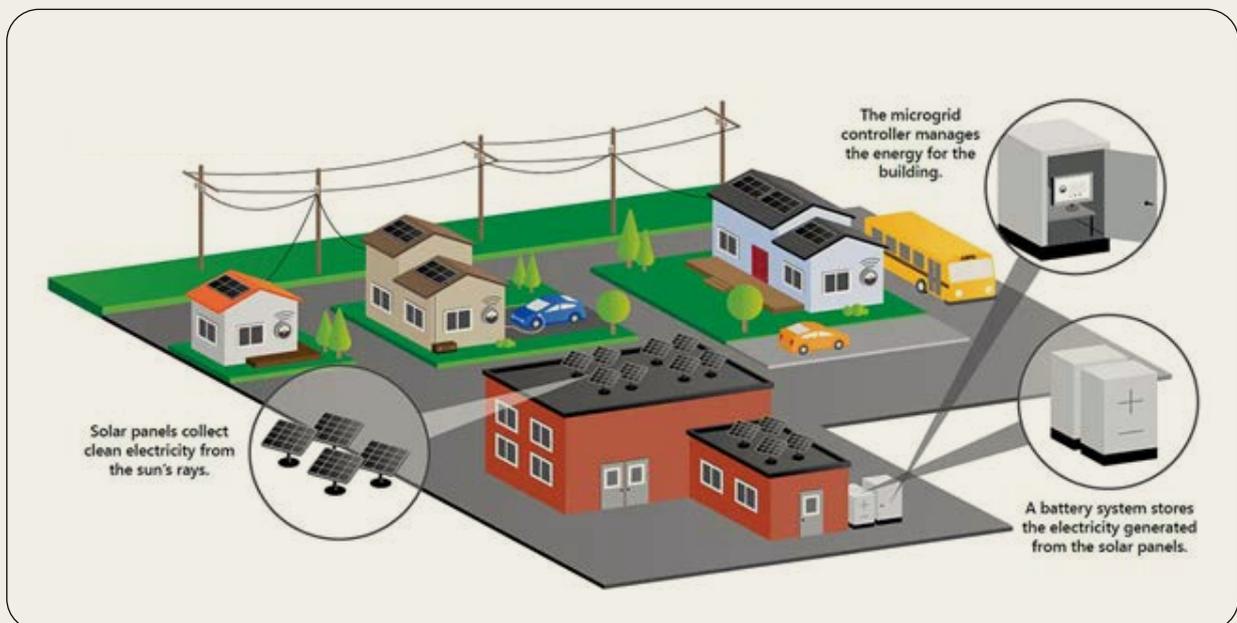
**According to a 2022 survey from the Uptime Institute, power-related problems accounted for 43% of significant outages at data centers.**

Several dynamic factors shape the U.S. backup power systems market and influence its growth. Technological advancements, regulatory policies, economic conditions, and consumer preferences all contribute to this development. The market is expanding due to innovations in energy storage and the integration of renewable energy sources like solar and wind, which are becoming increasingly popular and combining with backup power systems to create hybrid solutions. For instance, Tesla's Powerwall and Powerpack systems complement solar energy with battery storage to offer seamless power backup.

**According to a 2022 survey from the Uptime Institute, power-related problems accounted for 43% of significant outages at data centers (outages that caused downtime and financial loss).** Although data center owners have made progress in reducing power outages, they are still a major pain point. While fossil fuel generators are the go-to backup power solution, future-forward consumers are on the lookout for cleaner alternatives. Hydrogen fuel cells are a key component in the optimal power solution for data centers - hybrid solutions combining UPS devices to deliver immediate power for critical loads with BESS for energy storage and fuel cells for long-term backup power. These solutions allow data centers to generate clean, dispatchable power as a potential revenue stream via demand-side management in locations experiencing power gaps due to grid limitations and high proportion of intermittent renewables in the energy mix. In such circumstances, hydrogen fuel cells can generate stable, continuous power to balance renewables and enable grid stabilization. During times of peak demand that drive electricity prices up, data centers

can execute load shedding by easily switching to islanded backup power. The exponential growth of the data center market with its voracious power consumption requirements will continue to drive the demand for backup power and more specifically for hydrogen fuel cells.

The growing market for distributed, local microgrid solutions also drives opportunities for hydrogen fuel cells to provide backup power. **Microgrids integrating renewable energy sources, such as solar panels and wind turbines, allow for cleaner, more sustainable energy during power outages.** These systems integrate backup power technologies to provide localized energy solutions, increasing reliability and sustainability.



**Figure 12** What is a microgrid system and how does it work?

Source: <https://www.franklinwh.com/au/blog/microgrid-energy-system-introduction>

Advances in battery technology, particularly with lithium-ion batteries when combined with hydrogen fuel cells, together optimally balance intermittent renewables, ensuring more efficient and reliable backup power systems. **And incorporating backup power systems with smart grid technologies enhances their efficiency, enabling better monitoring, control, and utilization, which in turn improves grid resilience.**

In recent years, carbon pricing mechanisms, such as carbon taxes and cap-and-trade programs, have driven the move to replace fossil fuel-based backup power systems with cleaner alternatives. Carbon taxes, which set a fixed price on greenhouse gas emissions, are designed to increase the cost of emitting carbon, thereby encouraging businesses and consumers to reduce fossil fuel use and transition to sustainable energy sources. Programs like the Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade system demonstrate how pricing carbon can effectively reduce emissions across sectors.

Currently, 12 states, including California, Washington, and the RGGI states in the Northeast, have implemented carbon pricing initiatives, collectively covering over a quarter of the U.S. population and a third of the national GDP.

These programs not only curb emissions but also incentivize innovation in clean energy technologies, making them more accessible and cost-effective. The Trump administration's aim to support fossil fuels has made the future of carbon pricing mechanisms in the U.S. uncertain. Already well-established around the globe, these measures are likely to continue to drive transition to clean energy technologies in the long-term.

Utilizing hydrogen fuel cells in backup power solutions not only enhances resilience against climate and severe weather challenges, stabilizes the grid in circumstances of high penetration of intermittent renewables and enables flexible response to congestion and peak demands, but most significantly accelerates the transition to a zero-emission energy future without compromising on the availability or quality of power to meet the nation's ever-growing demand for power.

**Advances in battery technology, particularly with lithium-ion batteries when combined with hydrogen fuel cells, together optimally balance intermittent renewables, ensuring more efficient and reliable backup power systems.**

# GENCELL INC. AND HYDROGEN2POWER

## Hydrogen2Power™



GenCell Inc. develops and markets dispatchable, grid-optional hybrid power generation and storage solutions incorporating innovative Hydrogen2Power™ fuel cell technology to supplement or circumvent the grid with reliable, resilient, sustainable power wherever, whenever and for as long as needed. Founded in 2022 as

the customer-facing arm and U.S. subsidiary of hydrogen fuel cell provider GenCell Ltd., the mission of GenCell Inc. is to resolve the acute grid power gap that is posing a barrier to EV fleet DC fast charging, port operations and the efficient electrification of industrial equipment at sites where power needs have outstripped both grid and behind the meter infrastructure.

GenCell is poised to leverage the company's over 10+ years of field experience deploying fuel cells and its lessons learned while negotiating the many challenges facing the evolving fuel cell market to back up mission-critical operations with uninterrupted weather-resilient power. This optimally positions GenCell Inc. to bring to market GenCell EVOX® rapidly deployable containerized solutions integrating optimal, innovative fuel cell and BESS power technologies with proprietary GenCell GEMSTM EMS software to ensure efficient, dependable behind-the-meter grid-optional power wherever needed to ensure efficient continuous operations.

# CONCLUSION

Fuel cells and hydrogen technologies hold immense potential to revolutionize energy systems by providing clean, efficient, and versatile solutions. They enable zero-emission power generation for various applications, including transportation, stationary power, and portable devices. Hydrogen, as a renewable energy carrier, can be produced from diverse sources, offering a pathway to decarbonizing industries and integrating intermittent renewable energy into the grid.

The future of fuel cell technology is promising, driven by advancements in efficiency, cost reduction, and global support for green energy. Hydrogen-powered fuel cells are expected to play a critical role in achieving low-carbon and net-zero targets by replacing fossil fuels in sectors such as heavy transport, manufacturing, and power storage. Hydrogen constitutes a kind of bridge technology, both augmenting intermittent renewable and battery storage solutions on the one side, while enabling natural gas, methanol and other fossil fuel sectors to reduce emissions by integrating hydrogen into the fuel mix and fuel cells as power generation alternatives. State and local governments and public and private entities worldwide are investing in hydrogen infrastructure, indicating its growing importance in sustainable energy transitions. Shifting from fossil fuel generators to sustainable AND resilient hydrogen-fueled solutions to supplement and backup the grid is crucial to meeting the ever-rising demand for power while stabilizing the grid against the influx of intermittent renewables and at the same time ensuring a zero-emission energy future.

# ABOUT GENCELL



**GenCell Inc.** a wholly owned U.S.-based subsidiary of GenCell Ltd., leverages GenCell's legacy Hydrogen2Power™ technologies, proprietary EMS software and field experience to further develop the hydrogen-fueled, containerized GenCell EVOX® grid-optional DER and backup solution to power EV fleets and diverse electrified equipment to overcome the growing power gap. Founded in 2011 to adapt revolutionary space fuel cell technologies to serve critical power applications on Earth, the company is dedicated to transforming the energy landscape by providing reliable, sustainable and climate-resilient power solutions that address the growing demand for energy security and independence. With rapidly deployable solutions and the introduction of advanced software such as GenCell GEMS™, GenCell Inc. is well-positioned to drive growth and expand its presence in key markets across North America and beyond.

---

↳ **CONTACT  
US**

**GENCELLENERGY.COM**

TEAM@GENCELLENERGY.COM

