

The Big Deal With **FUEL CELLS**





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INTRODUCTION

The third industrial revolution, according to American economic and social theorist Jeremy Rifkin, will create a prosperous economy powered by clean energy and the Internet of Things. Hydrogen will be leveraged as one of the critical sources for generating power, fueling mass transit, powering hospitals, telecom towers, mission-critical systems, and more. Whether on-grid in urban areas or off-grid in remote areas, the world will be a more connected place. And not just people. Things from toasters and refrigerators to cars and factories will also be connected. All of this connectivity will place an even greater reliance on 24x7 electricity and communications. The need for sustainable backup power and off-grid power solutions will take even greater importance.

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Hydrogen is increasingly seen as a fuel of the future. Globally, more than 65,000 fuel cells, totaling over 300 MW, were shipped worldwide in 2016¹. Stationary fuel cells are using hydrogen to generate power at leading companies such as Apple, Verizon and Coca-Cola. Hydrogen fuel cell vehicles from Toyota, Honda and Hyundai are coming to market, metropolitan areas are beginning to migrate to hydrogen-fuel buses. Hydrogen refilling stations in California and other states are overcoming the challenges of hydrogen distribution for consumers. Indeed, the US Department of Energy notes that hydrogen and fuel cells are on the verge of a "tipping point".²

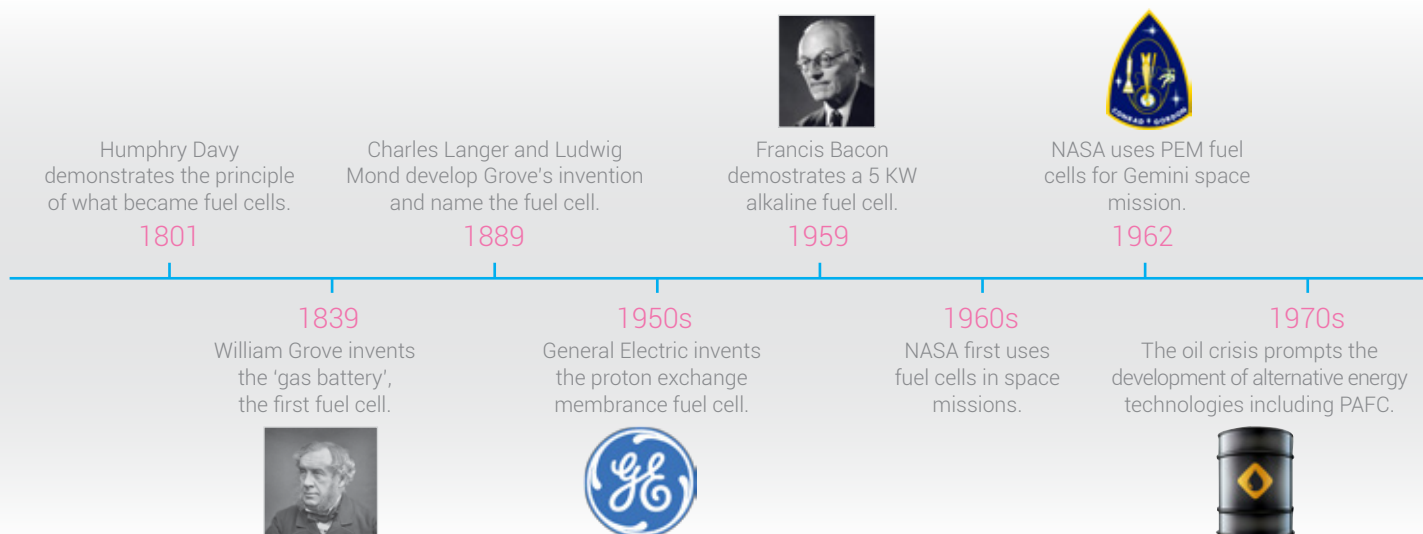


Figure 1: The evolution of fuel cell usage. (adapted from www.fuelcellstoday.com)

¹ E4tech. "The Fuel Cell Industry Review 2016." <https://goo.gl/R2PFXi>

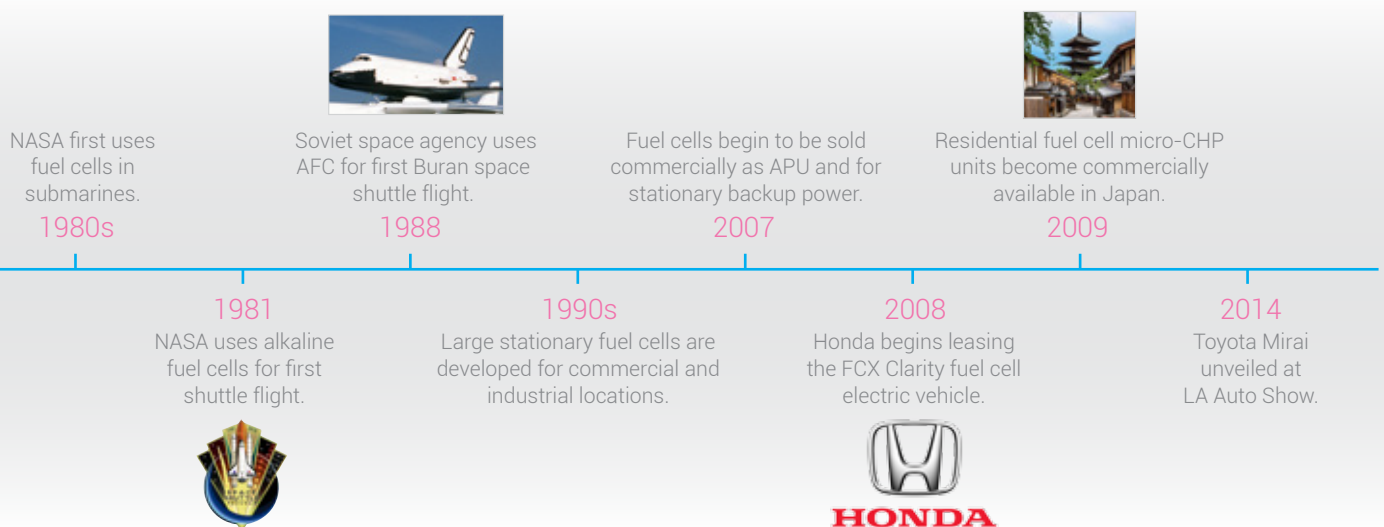
² US Dept. of Energy. "On the Verge of a Hydrogen Tipping Point?" (Oct. 12, 2016) <https://goo.gl/6R5HjI>

WHAT IS A FUEL CELL?

First invented in 1839 by William Grove, a fuel cell is an electrochemical energy conversion device that produces electricity by combining hydrogen and oxygen into water. Like batteries, fuel cells convert potential chemical energy into electrical energy and generate heat as a by-product. However, the chemical energy is stored inside batteries—rather than generated—they can only operate for a limited duration until they need to be discarded or recharged. Fuel cells, on the other hand, can continuously generate electricity as long as they are supplied with fuel (hydrogen) and an oxidant.

Fuel cells rely on a chemical process called oxidation in which hydrogen atoms react with oxygen atoms to form water and release electrons (i.e., electricity). Unlike other electric power sources such as turbogenerators or gensets (combined diesel engines and electric generators), they do not rely on the combustion of fuel and are much more efficient—lacking the 33% energy loss typical of combustion engines due to friction.³

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³ Nature. "Opportunities and challenges for a sustainable energy future." (Aug. 26, 2012) <https://goo.gl/U7K1gh>

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 different temperature levels, fuel cells are classified as low temperature, medium temperature and high temperature.

There are five primary types of fuel cells:

- Alkaline Fuel Cells (low temperature)
- Proton Exchange Membrane Fuel Cells (low temperature)
- Phosphoric Acid Fuel Cells (medium temperature)
- Molten Carbonate Fuel Cells (high temperature)
- Solid Oxide Fuel Cells (high temperature)

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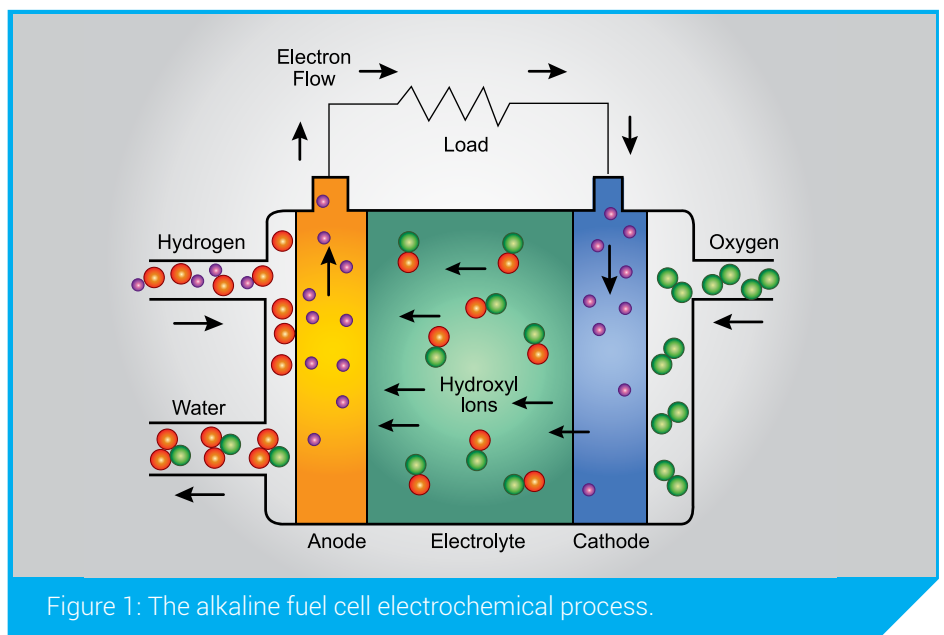


Figure 1: The alkaline fuel cell electrochemical process.

Alkaline Fuel Cells

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, AFC are among the most efficient type of fuel cells, reaching up to 60% efficiency (up to 87% combined heat and power). Alkaline fuel cells also offer virtually instant operation without pre-heating, even at sub-zero temperatures. AFC 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 OH⁻ ions and four positive charges. The OH⁻ ions, attracted by the anode, pass from the cathode through the KOH electrolyte. Hydrogen, fed to the anode, reacts with 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 useable heat and water as a byproduct.

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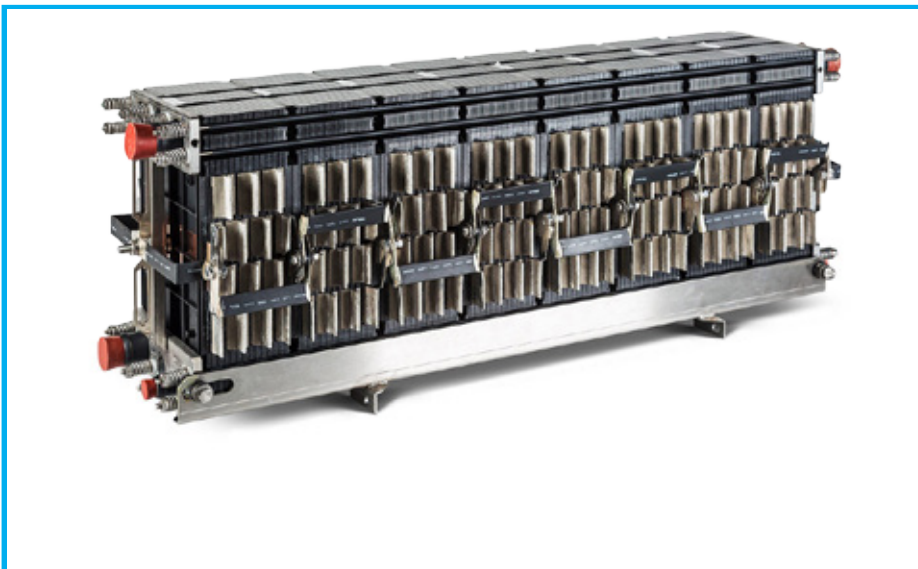


Figure 2: A GenCell 5 kW fuel cell stack.

Proton Exchange Membrane Fuel Cells

The proton exchange membrane fuel cell (PEMFC or PEM fuel cells) 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 light-weight and are therefore the leading fuel cell technology used in material handling applications such as forklifts and for transportation applications. Their acidic nature requires the use of a platinum catalyst.⁴

PEM fuel cells require precise humidity conditions to operate and their acidic nature requires the use of a platinum catalyst.



Figure 3: GenCell creates platinum-free electrodes by applying carbon onto a nickel mesh.

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 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 good 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.

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.

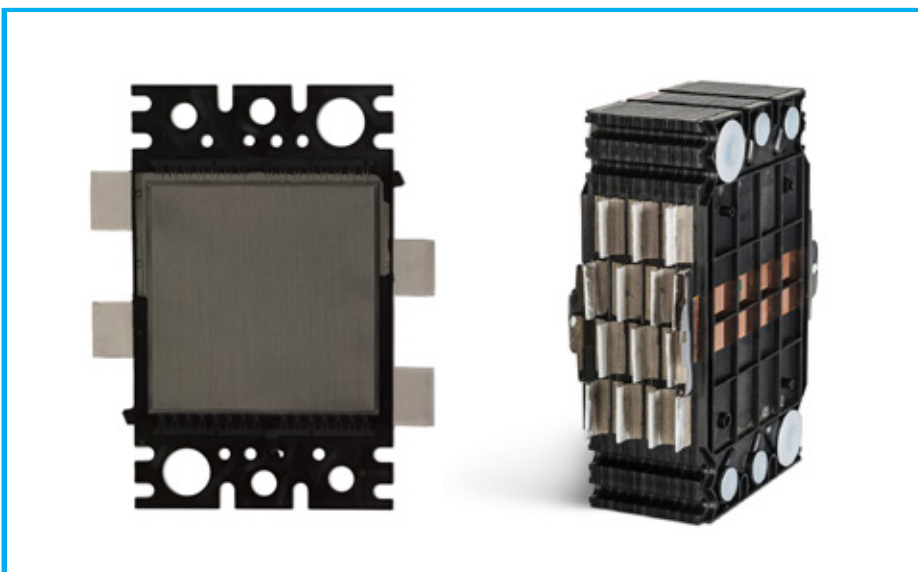


Figure 4: Fuel cells are created by pairing electrodes for use as anodes and cathodes.

MFCs require significant time to reach operating temperature and are slow to respond to sudden changes in electricity demand.

Molten Carbonate Fuel Cells

Molten Carbonate Fuel Cells (MFCs) 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 MFCs. 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 MFCs to be more cost competitive with more traditional sources of power. MFCs 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, MFCs 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 in nature. Since the operating temperature is so high, MFCs 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.⁵

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 lets it tolerate relatively impure fuels obtained from the gasification of coal but require more expensive ceramic construction to provide stability and reliability. The high operating temperature of SOFCs lets it tolerate relatively impure fuels obtained from the gasification of coal but require 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.

FUELING THE FUEL CELLS

Hydrogen

Hydrogen is the lightest and most abundant element in the universe and is considered the most environmentally friendly fuel. Nearly 65 million metric tons of hydrogen are produced every year worldwide using a variety of methods, including the steam reformation of natural gas, an electrolysis process and/or the fermentation of biogas.

Although its production costs are lower than gasoline or methane, the current cost of distribution makes hydrogen more expensive than gasoline or methane for commercial usage. 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 will make hydrogen increasingly economical.

Hydrogen is most commonly supplied in cylinders, although it can be stored and extracted from a variety of substances. These include a variety of chemical compounds or metal hydrides. In addition, hydrogen can be reformed from carbon-based fuels such as natural gas (CH₄), ammonia (NH₃), gasoline and diesel.

Hydrogen is the lightest and most abundant element in the universe and is considered the most environmentally friendly fuel.



Figure 5: Hydrogen is the most abundant element in the universe.

Additional methods of production use wind, solar, geothermal and hydroelectric power to split water.

Today, hydrogen is commonly referred to as “the fuel of the future”, especially for private and public transportation, which are significant sources of pollution. Toyota, Honda, Hyundai, Mercedes-Benz and General Motors and others are all focusing their efforts on the development and sale of hydrogen fuel cell cars as the supporting infrastructure is being deployed.

Additional methods of production use wind, solar, geothermal and hydroelectric power to split water. The wide variety of production methods and the potential of the newer eco-friendly methods makes hydrogen an extremely promising energy carrier.



Figure 6: Hydrogen cylinders.

Hydrogen Safety

Hydrogen is a flammable fuel but has been proven to be as safe or even safer than gasoline or natural gas (methane). For more than 50 years, hydrogen has been safely produced, stored, transported and used in substantial amounts by many industries using established best practices.

Hydrogen is lighter than air, gasoline and natural gas vapors. Hydrogen is 57 times lighter than gasoline vapor and 14 times lighter than air. This means that in the event of a leak, hydrogen rapidly rises into the atmosphere at a speed of 45 mph (20m/s) or 2,100 cubic feet per minute (60,000 l/min). Rather than pooling to cause an explosion, it quickly dissipates and/or burns.

A 2001 study by the University of Miami demonstrated the relative safety of hydrogen-fueled cars compared to gasoline-fuel cars. In the study, a gasoline-fed car fire consumed the vehicle leaving it a smoldering heap of charred steel and melted glass while the hydrogen-fed car fire was over in less than two minutes and the car was virtually undamaged.⁶

Hydrogen is a flammable fuel but has been proven to be as safe or even safer than gasoline or natural gas (methane).



Figure 7: Hydrogen car fire vs. gasoline car fire.

⁶ Swain, Dr. Michael R. "Fuel Leak Simulation." University of Miami (2001). <http://ewworld.com/library/Swainh2vgasVideo.pdf>

THE NEED FOR BACKUP POWER

Some parts of the US grid predate the 20th century while most of the transmission and infrastructure lines were constructed in the 1950s and 1960s with a 50-year life span.

In the 2017 Infrastructure Report Card, the American Society of Civil Engineers assigned a “D+” to the US energy infrastructure. The delivery of electricity in the US relies on an aging and complex patchwork of systems with various ownership and stakeholders. Some parts of the US grid predate the 20th century while most of the transmission and infrastructure lines were constructed in the 1950s and 1960s with a 50-year life span. The existing systems were neither designed to support the capacity required by today’s connected world nor the recurring severe weather. And with the power grid at full capacity, maintenance is an acute challenge as taking one section offline typically overloads others.⁷

In Japan, customers lose power for an average 4 minutes per year while customers in the American upper Midwest lose power for an average 92 minutes per year, and customers in the upper Northwest lose power for an average 214 minutes per year.⁸



Figure 8: Parts of the US grid were constructed in the 1950s and 1960s with a 50-year life span.

In 2015, Americans experienced a reported 3,571 total outages, with an average duration of 49 minutes. Momentary blackouts cost the US economy 60 billion USD while sustained blackouts cost 50 billion USD billion. 95% of these costs were borne by 13% of the customers in the commercial and industrial sectors.⁹

Just a few weeks after the 2017 Infrastructure Report Card was released in March, Los Angeles, New York and San Francisco were hit by major power outages on the same day. Mass transit was in chaos as platforms were packed with commuters and the electrical outages caused the failure of signals, escalators, communications and station lights. People were stranded in elevators and operating rooms were shut down. In San Francisco where 88,000 customers lost power, 58,000 had power restored by 2 PM while the rest had their power restored by 5 PM, nearly 8 hours after losing power.¹⁰

Momentary blackouts cost the US economy 60 billion USD while sustained blackouts cost 50 billion USD.



Figure 9: Momentary blackouts cost the US economy USD 60 billion while sustained blackouts cost USD 50 billion.

⁹ IEEE, The National Cost of Power Interruptions to Electricity Customers. <https://goo.gl/TejTrH>

¹⁰ <http://newyork.cbslocal.com/2017/04/21/nyc-sf-outages-infrastructure/>

THE GENCELL SOLUTION

With grid electricity forecasted to be increasingly precarious, a long duration backup solution is increasingly a necessity for business continuity. GenCell fuel-cell-based power solutions produce 5kW of electricity and overcome the significant weaknesses of legacy power solutions: the limited duration of batteries, the smell, noise and startup time of diesel generators, and the weather/daylight limitations of solar energy systems.

GenCell has succeeded in developing a number of patents to reduce the CAPEX and OPEX of their fuel-cell power solution, including the use of a non-platinum catalyst.

In addition, GenCell has succeeded in developing a number of patents to reduce the CAPEX and OPEX of its fuel-cell power solution, including the use of a non-platinum catalyst, as well as mechanisms for using regular, ambient air as an oxidizer and lower-cost industrial-grade hydrogen as a fuel.

GenCell currently offers two solutions that produce 5kW of auxiliary power:

- **GenCell G5 long-duration UPS** (uninterruptible power supply) for telecom, homeland security, healthcare and niche industrial markets. Designed to be extremely reliable, the GenCell solution has minimal moving parts, redundant internal systems and is highly resilient to extreme temperatures, humidity and air salinity.
- **GenCell G5rx utility backup power solution** for substations during power outages of any duration. Designed to operate as a direct source of backup power or to supplement the limited duration of legacy auxiliary battery systems, the GenCell G5rx solution offers an immediate injection of power and keeps circuit breaker “auto reclosers” operational until the grid recovers.



Figure 10: GenCell G5 long-duration UPS.

Both GenCell solutions are comprised of the following components: an electrochemical generator (i.e., the fuel cell), an energy bridge, a heat utilization unit and a hydrogen fuel supply. The GenCell G5rx also includes a shelter that is resistant to high-voltage interference, earthquakes and EMPs. An optional Network Operations Center (NOC) offers remote manage and maintenance of all GenCell solutions from a control room, web browser or mobile device.

Cleaner and More Reliable Than Diesel

When the grid fails, the GenCell solution delivers an immediate injection of power without the noise or smell of diesel generators. Zero emissions and no noise mean that GenCell is suitable for rooftops, urban areas, and even indoors. And with no moving parts, it is always ready to provide power, without frequent oil changes or time-consuming servicing and maintenance schedules.

Better Than Batteries

Battery-based solutions usually provide from minutes up to 6-8 hours of electricity although many power failures last longer, especially during extreme weather. The GenCell power solution can provide power as long as hydrogen fuel is available. With just six cylinders, the GenCell solution will deliver more than 15 hours of 5 kW backup power.

All-Weather Clean Energy

GenCell power solutions are all-weather sources of clean energy. Unlike solar or wind systems, rainy days, long nights or calm, windless days are not a challenge.

GenCell delivers an immediate injection of power without the noise or smell of diesel generators. Zero emissions and no noise make it suitable for rooftops, urban areas, and even indoors.



Figures 11: GenCell G5rx backup power solution.

GenCell's alkaline fuel cell technology overcomes the obstacles that have historically prevented the commercialization of fuel cells.

Fuel Cells for the Mainstream

With higher energy efficiency, extreme weather operation and low operating costs, GenCell's alkaline fuel cell technology overcomes the obstacles that have historically prevented the commercialization of fuel cells.

	Diesel Generators	Batteries	PEM FC Systems	GenCell (AFC System)
Applications	<ul style="list-style-type: none"> • Backup • Stationary • Mobile 	<ul style="list-style-type: none"> • Backup • Transportation • Mobile 	<ul style="list-style-type: none"> • Backup • Transportation • Mobile 	<ul style="list-style-type: none"> • Backup • Stationary • Space
Energy Efficiency	20-30%	>80%	50-60% direct hydrogen 35% reformed fuel	60% direct hydrogen
Reliability	Medium-high	Very high	High	High
Temperature Resistance	-40°C to +45°C	Narrow optimal temperature range	-20°C to +40°C	-25°C to +45°C
Humidity Resistance	High	High	High	Very High
Catalyst	n/a	n/a	Platinum-based	Platinum-free
Maintenance	Frequent oil changes & tune-ups	Depends on battery type	Annual	Annual
Lifespan	10 years	Up to 10 years	15 years	15 years
Startup Time	Immediate with battery bank	Immediate	Immediate with energy bridge	Immediate with energy bridge
Sustainability / Eco-Friendliness	Low (Emissions + noise)	Medium-high	Medium-high water vapor emission with hydrogen (+CO2 emissions with hydrocarbon reformer)	High water vapor emissions with hydrogen (+ N2 emission with ammonia cracker)
Fuel Type (gas)	n/a	n/a	High-purity hydrogen (99.99%)	Industrial-grade hydrogen (99.95%)
Fuel Type (liquid)	Diesel	n/a	Methanol-water mixture (Undetectable & highly toxic)	Ammonia (Detectable & may be harmful)
Run-Time Duration	Unlimited as long as fuel is supplied	Limited by battery bank capacity	Unlimited as long as fuel is supplied	Unlimited as long as fuel is supplied
Fuel Theft Risk	High	n/a	<ul style="list-style-type: none"> • Very low (hydrogen) • Medium (methanol) 	<ul style="list-style-type: none"> • Very low (hydrogen) • Very low (ammonia)

ABOUT GENCELL

GenCell manufactures, sells and services fuel-cell-based power solutions that provide a reliable, scalable source of 5kW electricity. Fueled by hydrogen, the clean energy of the future, the GenCell G5 long-duration UPS (uninterruptible power supply) provides backup power for telecom, homeland security, healthcare and niche industrial markets.

The GenCell G5rx utility backup power solution operates as a direct source of backup power or to supplement legacy backup battery systems that provide only 6-8 hours of power and includes a shelter that is resistant to EMPs and high voltage. Headquartered in Israel, GenCell has a regional presence and a distribution and support network in North America, Latin America and Europe.

GenCell manufactures, sells and services fuel-cell-based power solutions that provide a reliable, scalable source of 5kW electricity



Figures 12: Exterior view of the GenCell G5rx utility backup power solution.

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