

> What is a fuel cell?

It's a better way to more efficient, cleaner energy.

Here's how:

A fuel cell is a device that efficiently generates electricity from hydrogen rich fuels, through a clean electrochemical reaction rather than dirty combustion.

A fuel cell is similar to a battery in that it provides continuous DC electricity from a chemical reaction. Like a battery, it has an anode, a cathode, and an electrolyte. Unlike batteries, fuel cells cannot store electrical energy, do not 'run flat', or require electricity to charge them. Fuel cells can continuously generate electricity as long as they have a supply of fuel and air.

How are fuel cells different from other electricity generators?

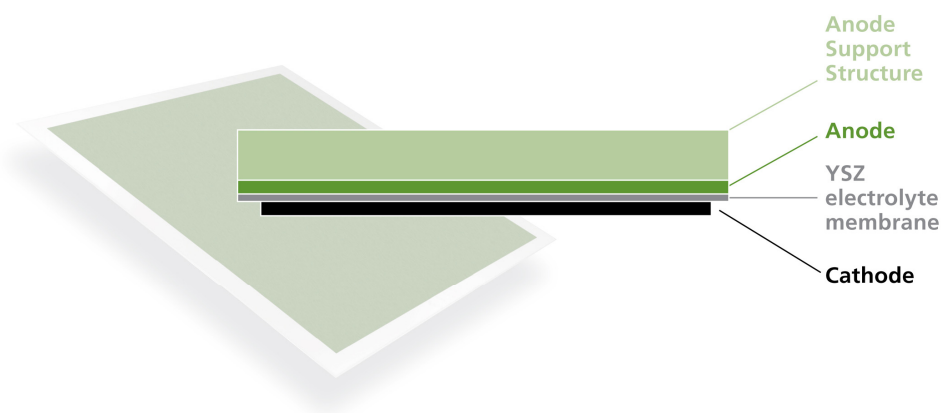
Unlike internal combustion engines or coal/gas powered turbines, fuel cells do not burn fuel. This means there are no noisy high-pressure rotors or loud exhaust noise and vibration. Fuel cells produce electricity through a silent electrochemical reaction. They also convert the chemical energy in the fuel directly into electricity, heat, and water.

How efficient are fuel cells in generating energy?

Very. And because fuel cells don't burn the fuel through combustion, they don't produce large quantities of greenhouse gases such as carbon dioxide (CO₂), methane (CH₄) and nitrogen oxide (NO_x). Fuel cell emissions amount to water in the form of steam and low levels of carbon dioxide - or no CO₂ at all, if the cell uses pure hydrogen as a fuel.

How is Ceramic Fuel Cells optimising these benefits?

A fuel cell needs sophisticated operating systems to function properly. Ceramic Fuel Cells designs and manufactures fuel cells as well as complete fuel cell systems. Ceramic Fuel Cells products have the potential to generate electricity much more efficiently and more cleanly than traditional fossil fuel-based combustion technologies.



> How does a fuel cell work?

Through a silent, efficient electrochemical process.

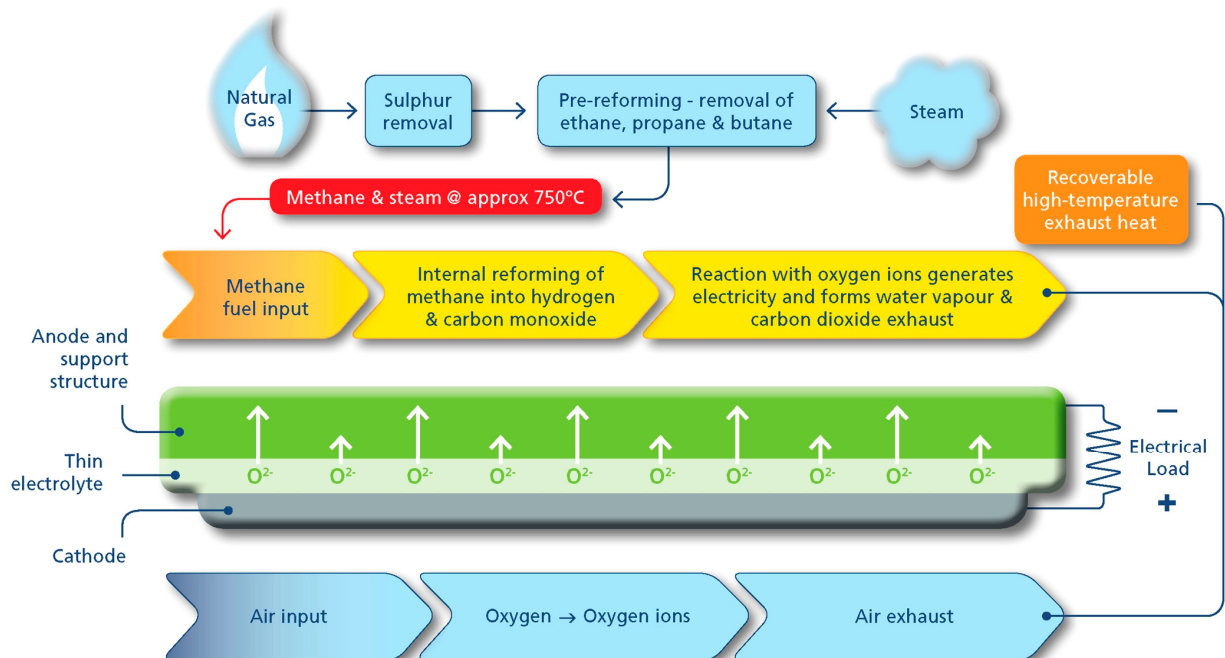
Here's a quick chemistry lesson:

All fuel cells produce electricity and heat through an electrochemical process using an electrolyte, a cathode and an anode. In the case of Ceramic Fuel Cells' products, electrical energy is produced at high temperatures from oxygen ions leaving the oxygen-rich cathode, passing through the electrolyte and then joining the hydrogen rich anode side.

Ceramic Fuel Cells manufactures Solid Oxide Fuel Cells (SOFC). These use natural gas as a fuel. The natural gas is treated to remove sulphur, then combined with steam to pre-reform other gases, leaving a methane-rich gas. The fuel passes over the anode side, which 'reforms' the methane gas under high temperature, into hydrogen. SOFCs can technically also use other fuels such as LPG and ethanol but unlike other fuel cells, SOFCs do not need pure hydrogen.

On the cathode side, high-temperature oxygen is blown across the cathode. The oxygen ions then travel through the electrolyte membrane and combine with hydrogen on the anode side and create an electric current, water and heat.

When a load (i.e. a light globe) is connected between the anode and cathode, the circuit is completed, allowing the electrons to flow from the anode back to the cathode. This produces electricity, much the same as connecting a light globe to a battery. Most individual fuel cells produce less than one volt of electricity, so they are assembled in layers called 'stacks' to provide a useful voltage. Today, Ceramic Fuel Cells can produce clean, efficient electricity from widely available natural gas - silently.



> Different types of fuel cells

Different electrolytes for different applications

What's the difference between high temperature and low temperature fuel cells?

Low temperature fuel cells need a relatively pure supply of hydrogen as a fuel. This often means that a fuel processor is required to convert or 'reform' the primary fuel (such as natural gas) into pure hydrogen. This process consumes additional energy and requires specialised equipment. High temperature fuel cells don't need this additional process because they can 'internally reform' the fuel at elevated temperatures, so it's not necessary to invest money in hydrogen infrastructure.

The main groups are:

Description	Operating Temperature	Electrical Efficiency	Fuel Source
Polymer Electrolyte Fuel Cell (PEFC) or Proton Exchange Membrane Fuel Cell (PEMFC) Electrolyte: Polymer ion exchange membrane. Very good at conducting protons often combined with an expensive platinum catalyst. Best suited to: Fast start up and shut down situations such as automotive and portable applications.	~ 80°C	~ 30 to 35 %	Pure Hydrogen
Phosphoric Acid Fuel Cells (PAFC) Electrolyte: Concentrated phosphoric acid. Best suited to: The design and power outputs make them ideal for buses and large stationary applications.	~ 100 – 220°C	~ 35 to 40 %	Pure Hydrogen
Alkaline Fuel Cells (AFC) Electrolyte: Potassium hydroxide solution. Best suited to: Expensive mission critical applications, such as the USA space program.	~ 150 – 200°C	~ 40 %	Pure Hydrogen
Molten Carbonate Fuel Cells (MCFC) Electrolyte: A combination of high temperature alkali carbonates (sodium or potassium). Best suited to: Large stationary power applications.	~ 550 – 700°C	~ 50 to <70 %	Most hydrocarbons
Solid Oxide Fuel Cells (SOFC) Electrolyte: A solid, non-porous ceramic based metal oxide, often Yttria doped Zirconia material. Because SOFCs operate at high temperature, they offer fuel flexibility without having to specially pre-treat the fuel.	~ 450 – 1,000°C	~ 45 to <70 %	Most hydrocarbons

SOFC are best suited to constant power for stationary applications. Ceramic Fuel Cells is developing SOFC systems for homes and businesses using today's existing fuel sources and infrastructure.

> Why solid oxide fuel cells?

Because they generate efficient, low-emission electricity

Fuel Cells: The solution for co-generation

Co-generation products, as their name implies, produce heat for space heating and hot water, as well as electricity that can be used on-site and fed back into the electricity grid. Distributed generation sources include photovoltaic cells (solar) and micro-wind turbines. These technologies are highly visible and well known; however they depend on weather conditions and cannot provide stable electricity all year round.

There are also several types of co-generation products being developed, based on a range of technologies including Stirling engines and internal combustion engines. These technologies often have low electrical efficiencies and are constrained by the large amount of heat they produce.

Ceramic Fuel Cells' products are a dependable source for generating efficient, low-emission electricity for small-scale co-generation applications. Using widely available natural gas and renewable fuels, these fuel cells generate residential scale electricity, utilising high efficiencies, and an appropriate amount of heat for small scale applications. They can be used in many different markets, from domestic electricity generation, to remote area power supplies, as well as auxiliary power units.

The issues with low temperature fuel cells

- > Lower electrical efficiencies (up to 40%) when using natural gas as a primary fuel.
- > Often use expensive precious metals (such as platinum) to improve performance.
- > Need a relatively pure supply of hydrogen as a fuel, which adds complexity and cost.
- > Can be rapidly thermally cycled, making them better suited for stop/start applications.

As an alternative, Solid Oxide Fuel Cells offer the following benefits:

- > Operate at a higher temperature, eliminating the need for precious metals.
- > Operate on a number of different hydrocarbon fuels, chiefly natural gas.
- > Better suited for continuous operation.
- > Produce the highest electrical efficiency (up to 60%).
- > Can use heat recovery technologies for a total system efficiency of up to 85 per cent.
- > Near zero emissions and quiet operation, with low maintenance requirements compared to existing generation technologies.

Most importantly...

Ceramic Fuel Cells' products deliver the most efficient source of electricity for small scale co-generation applications with a focus on maximising electrical output.

With SOFC powered co-generation units, the heat generated from the fuel cells can be integrated with heat exchangers to preheat water and maximise the overall system efficiency.

Because Ceramic Fuel Cells' products can be connected to a regular natural gas network, the fuel cells do not need a separate hydrogen infrastructure for operation. This includes equipment to create hydrogen gas and deliver this pure hydrogen to the customer.

> History of fuel cells

It all started back in the 1800s...

First discovered in 1838

The first positive identification of the fuel cell effect was by Christian Friedrich Schoenbein, a Swiss scientist. His friend Sir William Robert Grove, a Welsh judge, invented and refined the first fuel cell device from 1839 to 1845. Grove's apparatus took in hydrogen and oxygen and produced small amounts of electricity as well as water. A platinum electrode was immersed in nitric acid and a zinc electrode in zinc sulphate. This generated a current of about 12 Amperes at about 1.8 Volts. In 1896, William Jacques, developed the first fuel cell for household use.

At the turn of the century

Walther Nernst was the first to use zirconia as a solid electrolyte. In 1921, Emil Baur constructed the first molten carbonate fuel cell.

By the late 1930s

Francis Thomas Bacon had begun work on alkaline electrolyte fuel cells, and by 1939, had built a cell using nickel gauze electrodes operating under high pressure (3,000 psi). During World War II, Bacon worked on fuel cells for British Royal Navy submarines and in 1958, demonstrated an alkaline cell using a stack of 10-inch diameter electrodes.

Into space in the 1950s-60s

One of the most high profile applications for fuel cells arose from the USA National Aeronautics and Space Administration's (NASA) need for electrical energy in extended missions into space. The NASA alkaline fuel cell uses hydrogen and oxygen as fuel, combining the two chemicals in an electrochemical reaction. This produces three useful by-products in spaceflight: i) electricity to power the spacecraft, ii) water for drinking and cooling equipment and, iii) heat to keep the astronauts from freezing.

In 1962, as research into solid oxide technology began to accelerate in the US and Netherlands, the Allis-Chalmers Manufacturing Company demonstrated a 20-horsepower fuel-cell-powered tractor.

Cleaner energy options arise in the 1980s

As the industrialised world experienced major oil shortages, countries became more concerned about air pollution and sought cleaner electricity generation options. Governments, institutions and commercial organisations began focusing on developing a range of fuel cells for different industrial and domestic applications.

Ceramic Fuel Cells Ltd. was founded in 1992

Today, Ceramic Fuel Cells is continuing to develop Solid Oxide Fuel Cells (SOFC) into the 21st century. It's an exciting time for us, with a number of significant patents and innovative technologies covering the materials, processes, and production of SOFC systems. This includes BlueGen® – offering the world's highest electrical efficiency of any small scale generating technology.

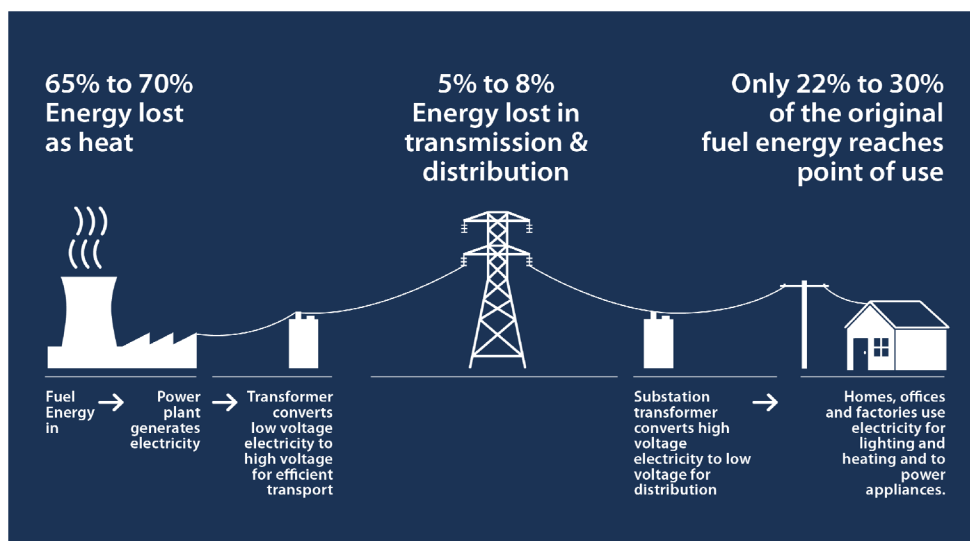
> Where are fuel cells used?

On-site - generating clean, highly efficient power.

Ceramic Fuel Cells is developing fuel cells for residential and light commercial electricity co-generation products - also known as micro-Combined Heat & Power units (m-CHP). These modular generator units are part of a Distributed Generation (DG) network. Rather than a large centralised power plant, there are many smaller 'generators'.

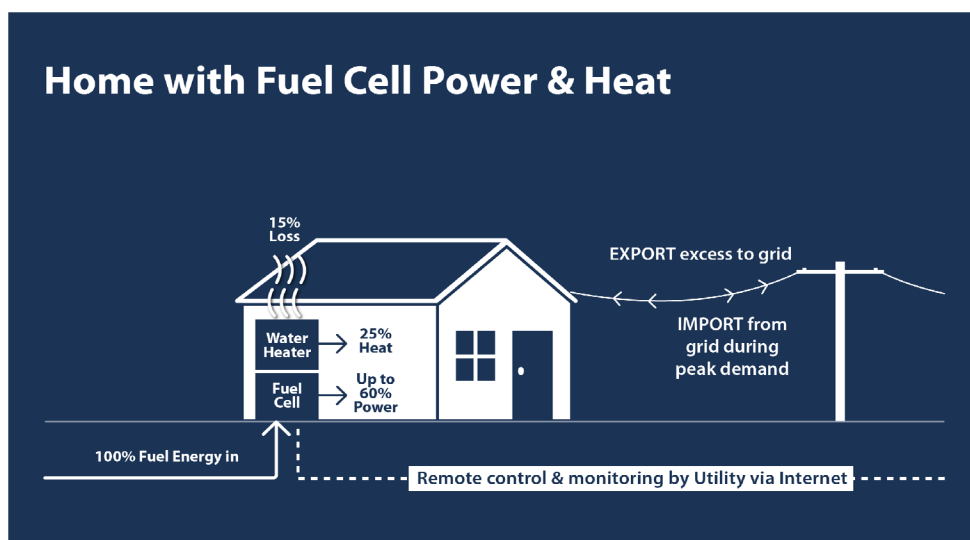
How efficient is energy delivered via a coal fired power station?

Efficiency losses from electricity generated by coal fired power station and delivered to the home through today's traditional networks are large. The efficiency losses from centralised generation include: losses from the power plant, high-voltage and low voltage transmission as well as distribution losses.



How does this compare with Ceramic Fuel Cells technology?

Using Ceramic Fuel Cells' technology, electricity is generated at up to 60 per cent electrical efficiency at the point of use. The household can also use the heat from the fuel cell for domestic hot water and/or space heating, which increases the total efficiency from the fuel energy.



> Different generation technologies

Big efficiency solution for small-scale distributed generation.

Here's how:

According to the International Energy Agency, in 2008 over 20 trillion kilowatt-hours (kWh) of electrical energy was generated worldwide. Approximately 68 per cent of this energy was produced using conventional thermal power generation sources.

What makes up thermal power generation?

Generally, the core technology of thermal power generation is a mechanical turbine or engine that transforms rotational (kinetic) energy into electricity, through electromagnetic induction in a generator. A source of energy is required to provide this rotational force. Often, this energy involves a process of combusting fuel to provide rotational propulsion, which in turn, drives the generator. Essentially, the chemical energy stored in the fuel is converted to kinetic energy, which is then converted to electricity.

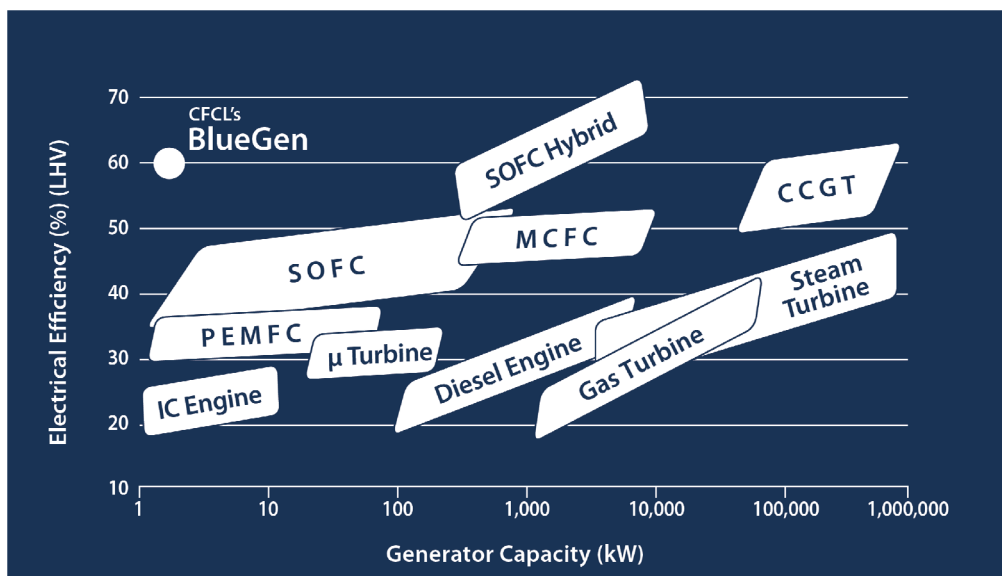
Electric generators can vary immensely, due to several factors:

- > Capacity – from less than a kilowatt to hundreds of megawatts
- > Propulsion mechanism – internal combustion engines to large steam or gas driven turbines
- > Fuel source – petrol, diesel, natural gas, coal and others
- > Operating mode – continuous (base-load), variable (peaking), on-demand (back-up)

Generally, larger thermal power generation plants have higher efficiencies than smaller plants. The exception is modern Combined Cycle Gas Turbine (CCGT) power plants fuelled by natural gas.

Here's the challenge for Distributed Generation technologies...

They must be small, yet efficient in order to compete effectively against large, centralised thermal power plants. As the diagram displays, Ceramic Fuel Cells technology provides outstanding efficiency (the same as a CCGT plant) from a small capacity.



Ceramic Fuel Cells' technology is a clear choice to maximise electrical efficiency for Distributed Generation applications.