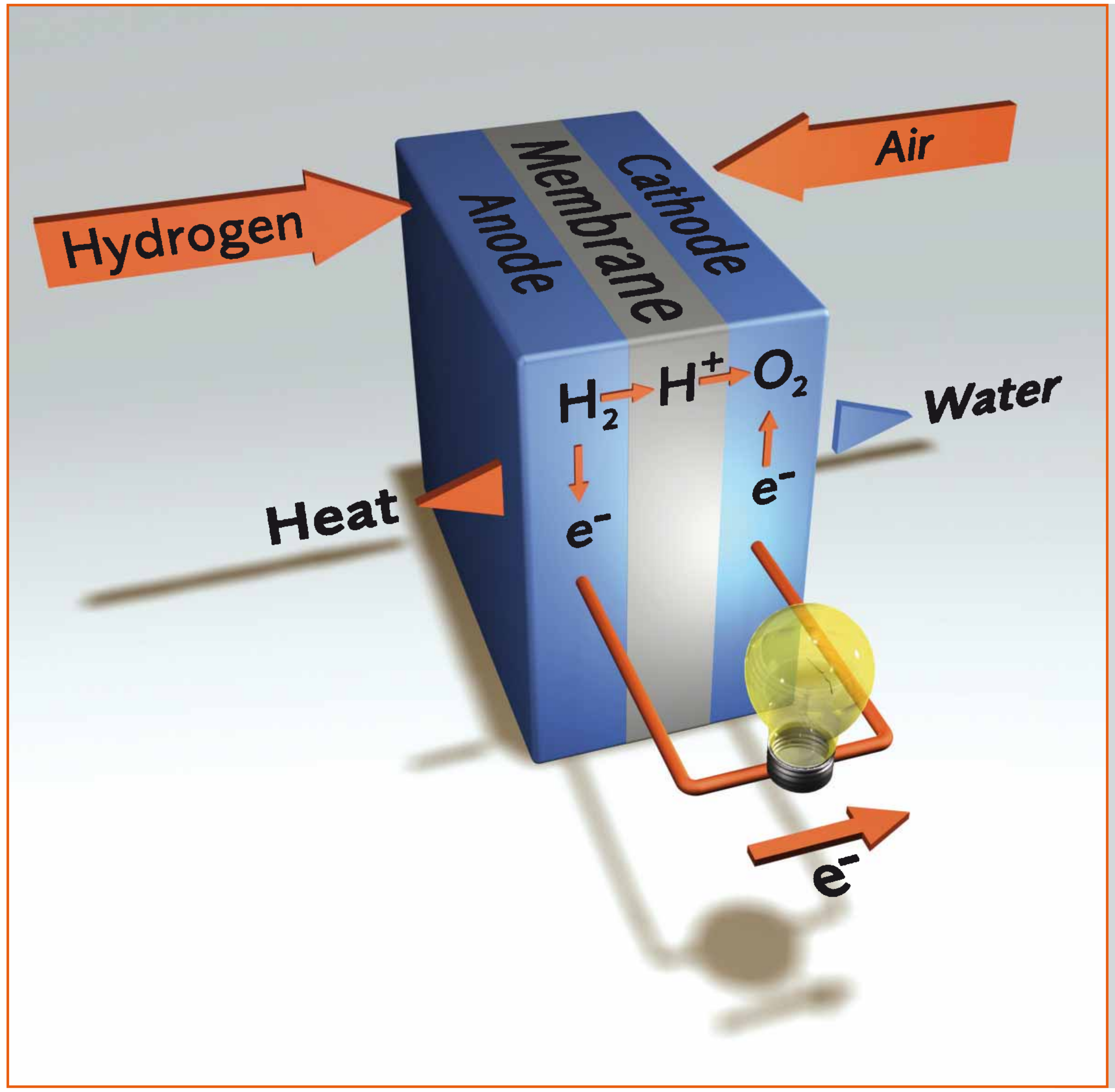


Simplified diagram showing the principle of fuel cell operation. Hydrogen and oxygen produce not only electricity, but also water and heat

Fuel cells for the aircraft industry

O_2 and H_2 for power and water

The temperature is a pleasant 21 degrees Celsius at an altitude of 39,000 feet. Many passengers are watching blockbusters on their video screens, while others are listening to music. A hot meal is about to be served. Modern passenger aircraft are very comfortable. The downside, however, is that a large amount of fuel is used up to generate electric power. For energy-hungry modern airliners, fuel cells could be the answer.

Experimental fuel cell stack: the detailed view shows how closely together the individual cells are packed

Countless systems consume electricity on a commercial aircraft: the cabin lighting, the in-flight entertainment system, the galley, the air-conditioning, the avionics and instruments in the cockpit, and not least of all the hydraulic pumps and actuators that move the control surfaces and flaps as well as extending and retracting the landing gear.

One of the hungriest power consumers on board is the de-icing system for the wings and the tail. Should the engineers' vision of an 'all-electric' aircraft ever become reality, it will require up to one megawatt of constant electric power.

Substitute for generators

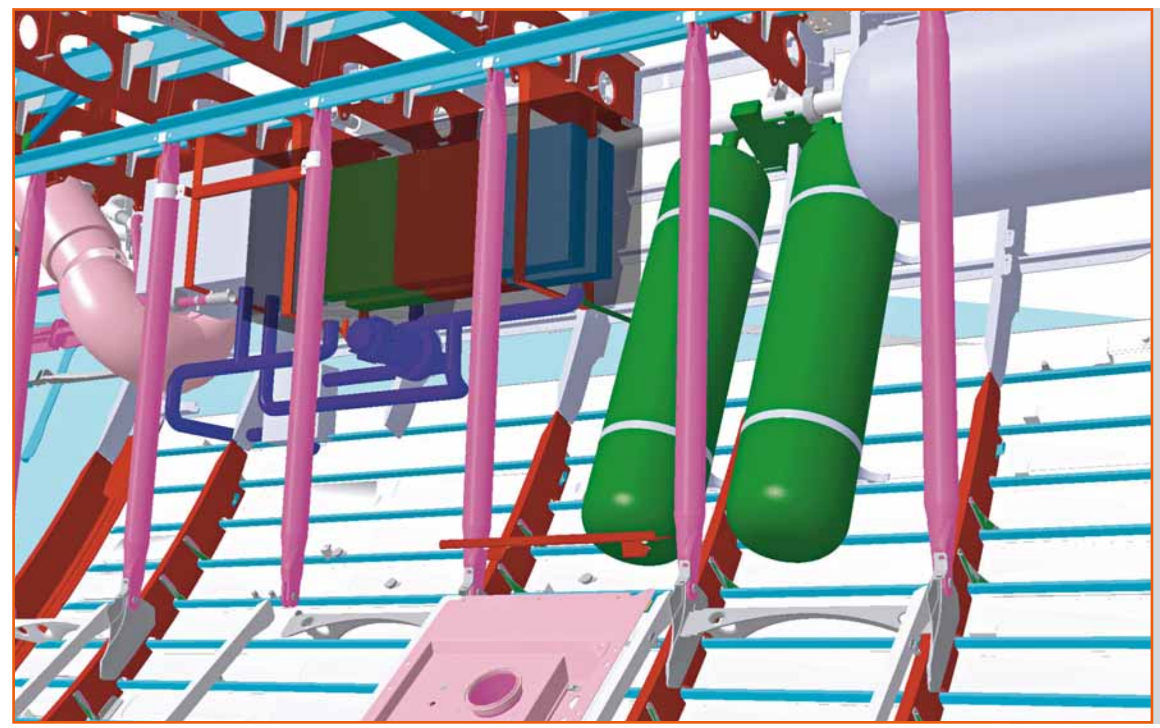
On a modern aircraft, the generators are driven by the main engines to produce electricity. Just as a cyclist has to pedal harder when the dynamo is engaged, the turbines use part of the power they generate – and hence also part of the fuel – to supply pow-

Fuel cell — How does it work?

The fuel cell was invented and first demonstrated by a Welshman, Sir William Grove, in 1839. Fuel cells generate electricity through a simple and silent electrochemical reaction in which hydrogen and oxygen combine to form water. There are several different types of fuel cell, each using different chemical elements, but they are all based on a common design consisting of two electrodes: the negative anode and the positive cathode. These are separated by a solid or liquid electrolyte that carries electrically charged particles between the two electrodes. The difference in electrical charge causes the oxygen and hydrogen molecules to be attracted to one another, the shortest path being directly through the membrane. However, only the protons can travel through the membrane, causing the negatively charged hydrogen electrons to collect at the anode, while a positive charge builds up at the oxygen (cathode) side.

A catalyst such as platinum is often used to speed up the reactions at the electrodes. Fuel cells are classified according to the nature of the electrolyte. Each type requires particular materials and fuels and is suitable for different applications. To produce the desired output, several cells are combined to form a stack.

rk



Layout diagram of a fuel-cell-powered emergency power unit that could be installed in the cargo bay of an aircraft. The fuel cell module is shown as a three-coloured block at the centre. Green: the oxygen bottles. Top right: the water tank. Blue: cooling pump and fuel lines. The hydrogen bottles are installed separately behind the lower fuselage fairing (not shown), which is not pressurised

Research | Partial dehydration

An operational kerosene reforming system on board aircraft will be a decisive factor for the success of the overall fuel cell system. The chemical process of 'partial dehydration' appears to be a viable alternative to existing reforming methods because it only needs kerosene and a catalyst that reacts under relatively low temperature and pressure conditions.

Only two process steps are involved: extracting hydrogen from the kerosene jet fuel and subsequently separating it. There are good chances that commercially available catalysts (palladium or platinum) can be used for the process and that desulphurization can be avoided upstream and hydrogen purification avoided downstream of the process. The gaseous hydrogen is fed to the fuel cell and the residual liquid hydrocarbons can be used directly for combustion or returned to the kerosene tank.

Partial dehydration is well known in the chemical industry but has never been applied to kerosene before. Consequently, as a first step, intensive chemical laboratory investigations need to be carried out with kerosene to fully understand the process and to establish a database for all relevant parameters. The scope of the present work also includes devising overall system concepts, as well as aircraft integration aspects such as interfacing with the tank system, the heat source for the reaction, the intake and exhaust characteristics, and materials requirements.

In parallel with the work on partial dehydration, the EADS Corporate Research Centre fuel cell specialists support EADS subsidiary Airbus in the areas of system simulation as well as system specification, development and testing.

As a member of the transportation core group, the CRC represents the aeronautics industry in the European Hydrogen and Fuel Cell Technology Platform, an establishment facilitated by the European Commission that focuses on accelerating the development and deployment of these key technologies in the European Union.

rk

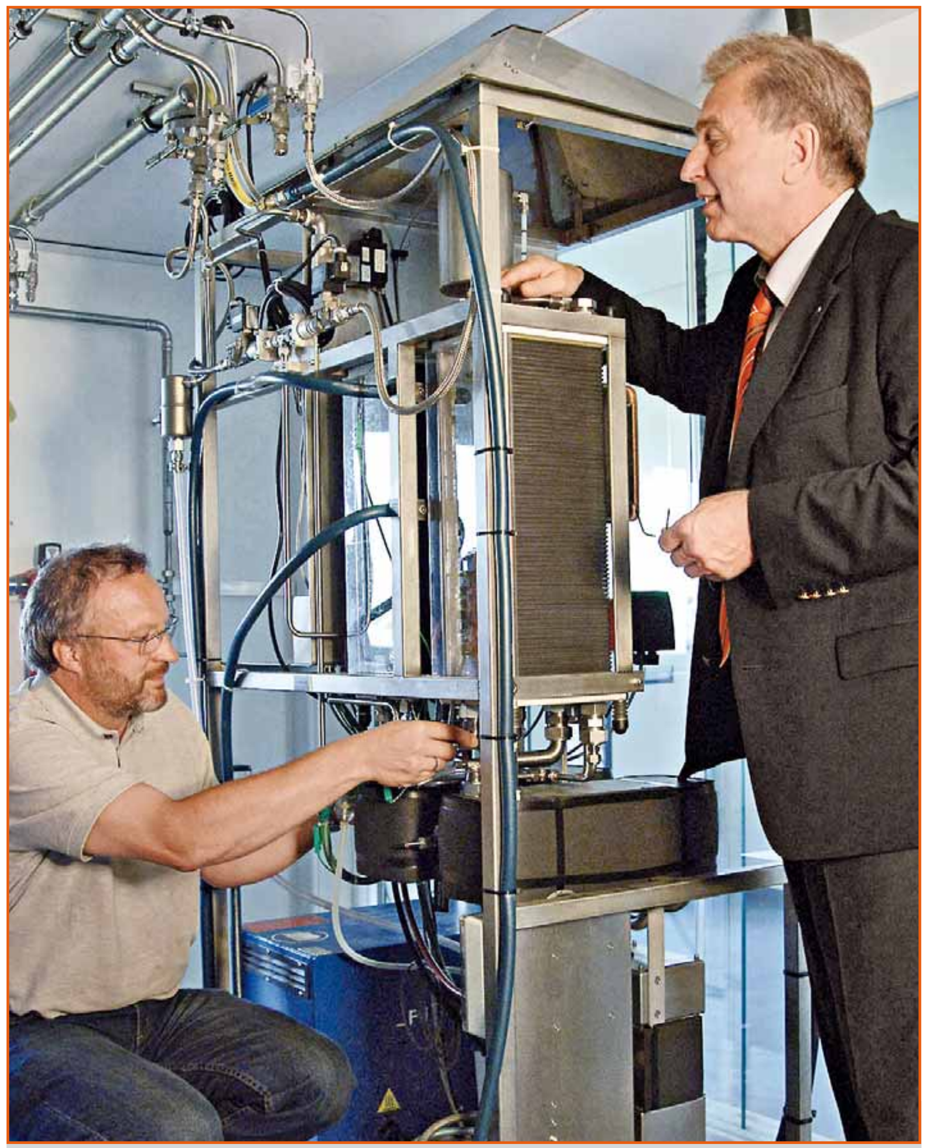
er to the aircraft's systems. On a typical long-haul flight, an Airbus A330 uses about 5000 litres of kerosene simply to produce electricity, compressed air and hydraulic power.

▶ Power from chemistry

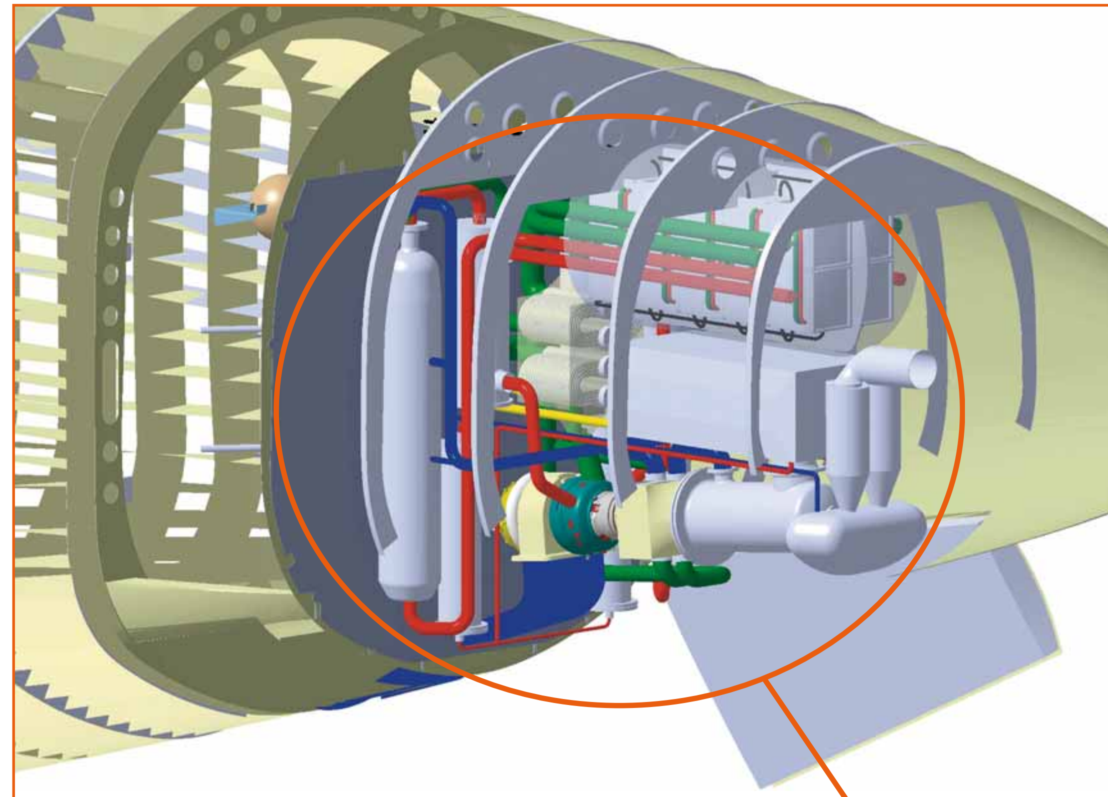
Rising fuel prices, dwindling resources and environmental considerations have motivated researchers and engineers at Airbus and EADS to work on an alternative source of on-board electricity: fuel cell systems. Their higher efficiency in converting fuel into electrical energy has the potential to considerably reduce fuel consumption. A fuel cell based power supply system, which would not only replace today's auxiliary power units (APUs) but continuously produce electricity while the aircraft is operating on the ground or in the air, would save airlines millions of dollars a year and cut exhaust and noise emission as well. However, many technical and operational issues will have to be resolved before fuel cell systems can go into service on airliners.

A fuel cell is a mini power-station that produces direct-current electricity through an electro-chemical process – with water as a 'waste' product (see Box 1). Rather like a battery, a fuel cell converts chemical energy into electricity – the difference being that a fuel cell never needs recharging and keeps on working as long as it continues to be supplied with fuel.

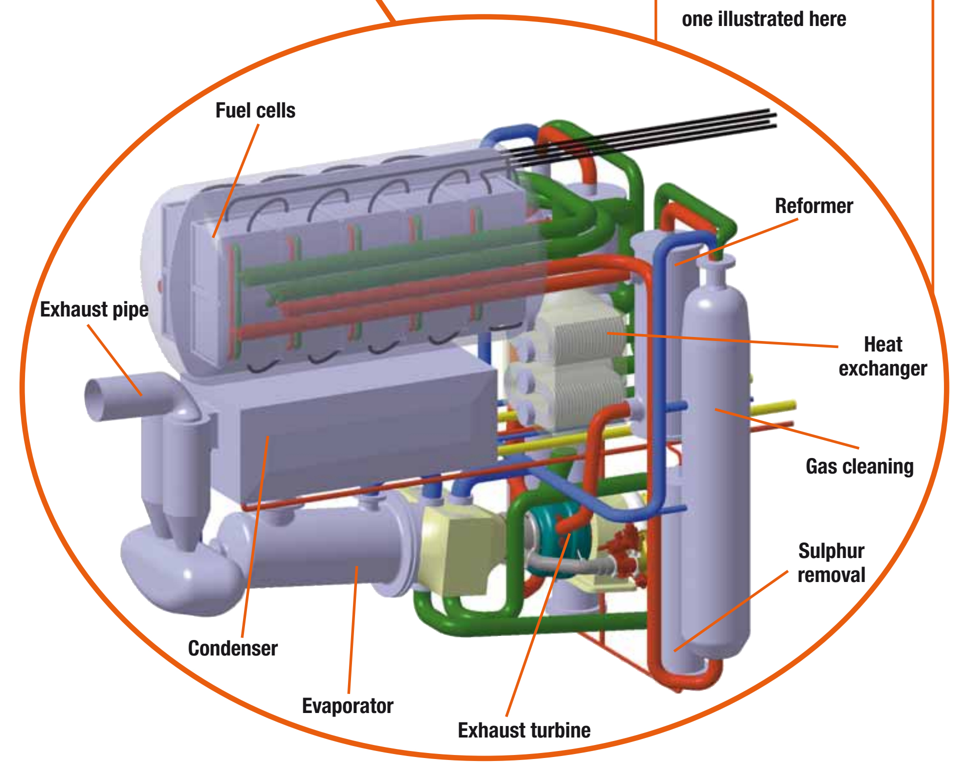
While a fuel cell's basic electro-chemical process is relatively simple, achieving practical applications proved to be too difficult for many years. Fuel cell technology received a major development boost through numerous re-search programmes for NASA's Apollo and



Airbus specialists examine the operating parameters of fuel cells on a test-rig under controlled laboratory conditions



A fuel-cell generator designed to replace the auxiliary power unit (APU) at the rear of a commercial airliner. However, much research and development work needs to be done before a fuel-cell generator with the same power output as a modern APU can be made as small as the one illustrated here



Space Shuttle programmes (see Box 2). In recent years, the automotive industry has also been advancing the development of cars, buses and trucks powered by fuel cells.

▶ The ideal APU

What space and automotive applications have in common is that their fuel cells are fed with pure hydrogen from an on-board tank. This, however, is not an option for continuous operation on commercial airliners. While flight tests have shown that jet engines are indeed capable also of using hydrogen as a fuel, an adequate hydrogen supply infrastructure is not expected to be available in the foreseeable future. Moreover, the need to incorporate voluminous on-board hydrogen tanks makes it highly improbable that an airliner's main engines will ever be able to run on hydrogen.

Instead, researchers plan to use the hydrogen contained in the normal jet fuel – kerosene – to produce electricity from fuel cells. This requires that the hydrogen be first extracted from the kerosene by a 'reformer', or by partial dehydration (see Box 3). While stationary fuel cell power stations with a re-former are commercially available today, their high cost as well as their large size and weight make them unsuitable for use on aircraft.

Before fuel cell system technology can become operational on commercial aircraft, much research and development work therefore needs to be done by the fuel cell and aircraft manufacturers. Nevertheless, Airbus researchers are not exactly 're-inventing the wheel' for fuel cells, or trying to improve them in terms of their power output to weight and volume ratios. They are cooperating with specialised companies to solve the multitude of issues associated with the integration of this technology on an air-craft. Stringent requirements with re-spect to low weight, small volume, flight safety regulations and reliability in operation have to be met. And an aircraft's operating conditions, such as the low temperatures at high altitudes and the shocks and vibration during take-off and landing are also big challenges for fuel cell integration specialists at the Airbus facility in Hamburg.

▶ Gradual increase in output

Rather than attempting to achieve the megawatt range in one go, they are cautiously moving stepwise from smaller to larger units. Airbus engineers will initially flight-test a fuel cell demonstrator that will not supply the aircraft's electrical system but will be used to gather data during operation in flight. Their next goal is to substitute a fuel cell for the air-craft's ram-air turbine. This emergency system with a small propeller and connected generator is caused to rotate by the airstream, acting as an emergency power source that will supply electricity in the extremely unlikely event that all other power sources should fail in flight. While it is practically never used, the ram-air turbine is a costly maintenance item. A small fuel cell system, which can be run on hydrogen and oxygen and produce about 20 kilowatts for one hour when needed, would not only be cheaper but also much more reliable than the conventional mechanical device. This application would also be an ideal point of entry from which to gain experience with fuel cells on board airliners.

More reliable than a ram-air turbine

A kerosene-based fuel cell system with a power output of about 400 kilowatts designed to eliminate the current auxiliary power units is expected to be available in about ten years' time. A key challenge will be the processing of the aircraft fuel to obtain hydrogen. This involves removing the sulphur contained in kerosene, reforming and – depending on the fuel cell type – cleaning the resulting hydrogen-rich gas because impurities in certain fuel cell elements would degrade their performance to unacceptable levels. Such a system must also be compact, light and efficient while requiring little maintenance or preferably none at all.

On a contract by Airbus, the EADS Corporate Research Centre is research-ing fuel processing by dehydration – a promising technology to produce pure hydrogen through a system with less complexity, bulk and weight (see Box 3).

Airbus engineers are counting on a positive side effect of electricity production with fuel cells: the water resulting as a 'waste' product. It could be used for flushing the toilets, or even as drinking water – following a thorough purification and re-mineralisation, needless to say. After all, astronauts have been doing it for decades. Ideally, it would no longer be necessary to take water on board at all. This would make an Airbus A380 several tons lighter on take-off. The aircraft would benefit from such 'dieting' by offering longer range or larger payloads.

Richard Kleebaur

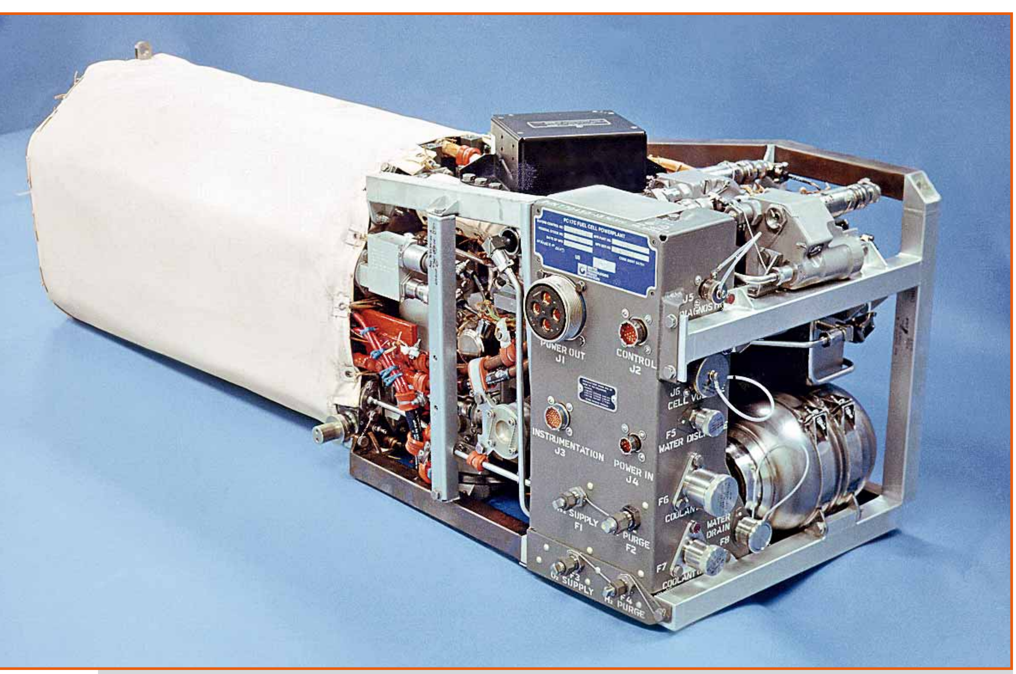
Fuel cells in space

In the late 1950s, NASA needed a compact way to generate electricity for space missions. Nuclear energy was considered too dangerous, batteries were too heavy and solar power was too cumbersome.

The answer was fuel cells. NASA went on to fund 200 research contracts to develop this technology, and since the 1960s fuel cells have been used to provide power on NASA spaceships, beginning with the Gemini V mission in 1965. Fuel cells produced power and water for all the manned Apollo missions. The Pratt & Whitney fuel cells on board the Apollo spaceships produced up to 2.2 kilowatts of electricity. Today's space shuttles carry three fuel cells (manufactured by the U.S. company UTC Power), each weighing about 120 kilograms.

Located under the payload bay area in the forward portion of the mid-fuselage, the cells are fuelled by cryogenic hydrogen and oxygen. Together they generate a maximum of 21 kilowatts to power the shuttle orbiter but can reach up to 36 kilowatts in short 15-minute bursts if needed. Some of the water produced as a by-product is used by the astronauts as drinking-water.

rk



Images: EADS

One of the fuel cells developed by UTC Power for the space shuttle, comprising a power generating unit plus a control and monitoring system. The powerplant, which converts hydrogen and oxygen into electricity, water and heat, consists of 96 cells producing a total output of 28 volts