The Taming of the Fuel Cell

© Gerry Goodstein. The Shakespeare Theatre of New Jersey

In Shakespeare's comedy "The Taming of the Shrew", a headstrong beauty resists the advances of a man: Katharina (played here by Ruth Eglsaer), refuses to give in to Petruchio (played by Gregory Derelian).

Fuel cells reveal their charms only to those who really understand them

Dr.-Ing. Josef Kallo

When the fuel-cell-powered electric car "Necar 1" was demonstrated on the streets of Germany in 1993, 400 years had passed since William Shakespeare wrote his comedy "The Taming of the Shrew". Electric car technology powered by fuel cells – it seemed – was a beast that had finally been tamed, following numerous attempts to develop fuel cells that were controllable, safe, efficient and cheap. Already invented a hundred years earlier, the fuel cell had even made it into space – as was so aptly demonstrated in the movie "Apollo 13", where the survival of the crew relies on the activation of a frozen fuel cell. Despite all the coaxing and technological innovation, however, the commercial prospects remained dim. Until December 1993, that is, when a surge of excitement spread through the research community. Students felt like pioneers of a new era when they submitted their dissertations, and everything seemed within reach. Combined with the prospect of cheap hydrogen storage through "nano tubes" – which promised environmentally-friendly fuel for up to 10,000 kilometres per filling – fuel-cell technology was expected to become the next big thing in the new millennium.

F-Cell Power Pack – this fuel-cell system delivers 400 watts of power and is an interesting option for recreational use and DIY activities

As we soon found out, this euphoria was not entirely realistic. Still, the foundations for a feasible technology had been laid. Fifteen years later – following many visions, disappointments, hopes and billions of euros in investment – we now have a technological and scientific framework that is actually compatible with a clean-and-green energy converter. The fuel cell, it would seem, really has been tamed this time. Two major factors contributed to this. Firstly, the materials used in fuel cells have become much more sophisticated. Secondly, there were some very brave and costly research decisions, right from the outset, to test the new materials not only in lab environments but also under real-world conditions.

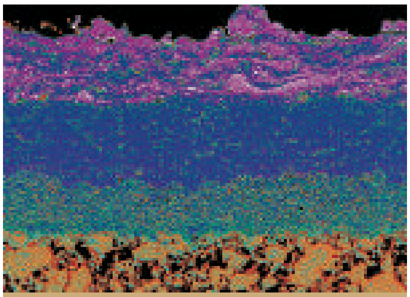
The combination of these two factors produced an unprecedented pace in the development of a real-world fuel cell. Unlike Shakespeare's Katharina, however, the fuel cell is not prepared to submit just yet.

Demanding…

The fuel cell is a peculiar and moody creature. If it is treated badly, it simply refuses to work. An attentive operating environment is required to ensure that all the conditions stay ideal, that the conversion is as efficient as it should be, and that the cell's operating life is adequate. Alkaline fuel cells (AFCs), for example, always have to have their cathode immersed in CO_2-free gas so that they don't clog up – quite a challenge, considering the presence of CO_2 in the air. Low-temperature polymer electrolyte fuel cells (PEFCs), on the other hand, need to be fuelled by CO-free hydrogen if they are to operate efficiently; unfortunately, the conductivity of the polymer electrolyte relies on water. All these factors place very high demands on the supply and cooling system, which has to be able to handle a wide range of loads – even in mobile applications.

The lifespan of fuel cells can be extended through coupling them with other energy storage systems, such as condensers or accumulators. If, however, such a hybrid approach makes it uneconomical to use the fuel cell as a power source, a system

DLR's hydrogen-powered glider with a fuel cell motor – based on the Antares 20E from Lange Aviation



An electron microscope image reveals the functional layers of a fuel cell. At the bottom is the substrate carrier with the anode, electrolyte and cathode layered on top

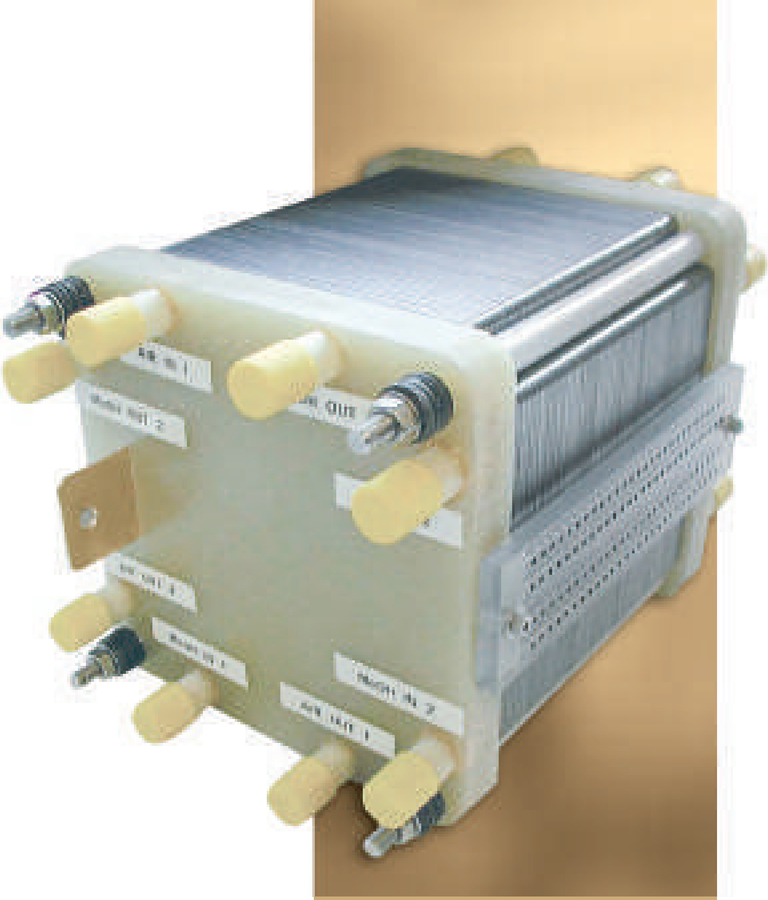
is needed that can utilise all the advantages – and by-products – of the fuel cell. In aviation, for example, the product water that is formed during the electrochemical reaction is quite valuable, because it means that less water needs to be carried during take-off. Another example is the exhaust from the cathode, which consists of oxygen-depleted air. This is ideal for decreasing the flammability of the kerosene-air mixture in the fuel tank (kerosene tank inertisation), contributing to overall safety.

In order to take advantage of such positive effects, the system needs to be able to cope with all the requirements of each flight or landing stage. Further uses of the fuel cell's power include operation of the air-conditioning system, emission-free propulsion at the airport (using the nose wheel), or even emergency control of the aircraft. In aviation, then, the functional versatility of the fuel cell is more important than the efficiency level.

Durable…

In stationary systems, the opposite is true. Here, the crucial factors are fuel efficiency and longevity. Systems are currently being developed for high-temperature fuel cells based on molten carbonate (MCFC) and solid oxide (SOFC) that can provide an ideal operating environment with very little load variation – and tens of thousands of operating hours. The start-and-stop procedures are also crucial, considering the ceramics used in the components and the operating temperatures. MCFCs operate at 650 degrees Celsius, SOFCs at up to 950 °C. If these temperatures are consistently maintained, the electrical yield from the fuel is more than 50 percent. Some systems have even been operated for 30,000 hours and longer. With major system upgrades, such as a gas turbine or a combined heat and power (CHP) unit, efficiency ratings in excess of 60 percent can be expected.

DLR's research activities are at the cutting edge of development. DLR is the leading developer of polymer electrolyte fuel cell systems for aviation. In the area of mobile applications, DLR has already built its own fuel-cell-driven vehicle, and in the business area of mini-systems, DLR



Fuel-cell stack with a membrane electrode assembly (MEA) developed at DLR

and its partners hold the world record for power density in hydrogen-air systems. DLR is also part of the "Hybrid Power Plant" virtual institute, which is investigating the stationary combination of an SOFC with a gas turbine. Thanks to its advanced laboratories and development environments and its excellent knowledge base, DLR is at the forefront of fuel cell research and development.

Made-to-measure…

Special mention should be made of the direct methanol fuel cell (DMFC, up to 70 °C) and the high-temperature polymer electrolyte membrane fuel cell (HT-PEM, up to 180 °C). In the case of the DMFC, the fuel supply and fuelling process are very simple because the liquid methanol is injected directly into the cell. However, the permeation of methanol from the anode to the cathode needs to be kept low, as too much fuel is wasted otherwise. In the case of the HT-PEM fuel cell, the system needs to provide very accurate water and gas management during the start and stop stages. And the operating temperature needs to be pushed above 140 °C very quickly and efficiently, as otherwise the cell's internal conductivity fails.

System design is of paramount importance for all types of fuel cells. Every application and every requirement necessitate a made-to-measure system; this is the only way to guarantee the fuel cell's success as an energy source. This shrew shall be tamed yet! But unlike in Shakespeare's play, the taming will require a lot of attention, sensitivity and understanding.

Author:

Dr.-Ing. Josef Kallo supervises Electrochemical Systems at the DLR Institute of Technical Thermodynamics.

DLR's "Hylite", an experimental fuel-cell-powered car