M0RE ELECTRICITY FROM FUEL CELLS

In Winterthur, work has been underway for almost 30 years on the development of fuel cells that convert natural gas into electricity and heat. With a new generation of fuel cells, HEXIS AG now wants to significantly increase the electrical efficiency to about 50%. Since the beginning of June 2018, a system with 1.5 kW of electrical power has been demonstrating the functionality of the concept. Field trials are now to be conducted to gain experience before the new unit is offered on the market.

The HEXIS engineers Dr. Andreas Mai (left) and Thomas Zähringer with the demonstration model of the fuel cell unit 'DaVinci'. In the middle of the unit is a round steel boiler with a fuel cell stack, directly below the steam reformer, which is supplied with desulfurized natural gas/methane via a line from the desulfurizer (bottle bottom left). The upper part of the steel cabinet provides space for later installation of an additional gas burner, which will support heat production on cold days. Photo: B. Vogel

A technical report about the results of a pilot and demonstration project in the field of fuel cells, which is financially supported by the Swiss Federal Office of Energy. The report has been published in 'Spektrum Gebäudetechnik' (October 2018).

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Modern large power plants convert natural gas into electricity and heat on a huge scale. Efficient combined heat and power plants are also in use in Switzerland, for example for the reclamation of biogas from agriculture and industrial waste. However, gas can also be converted into electricity and heat on a small scale. Fuel cell technology is preferred for this purpose. There are about one hundred fuel cell units in operation in Switzerland and several thousand in Germany, where the technology is subsidized by the state with up to 12,000 Euros per appliance. These figures are still modest compared to Japan, where around 200,000 fuel cell units have already been sold, more than half from the Japanese manufacturer Panasonic.

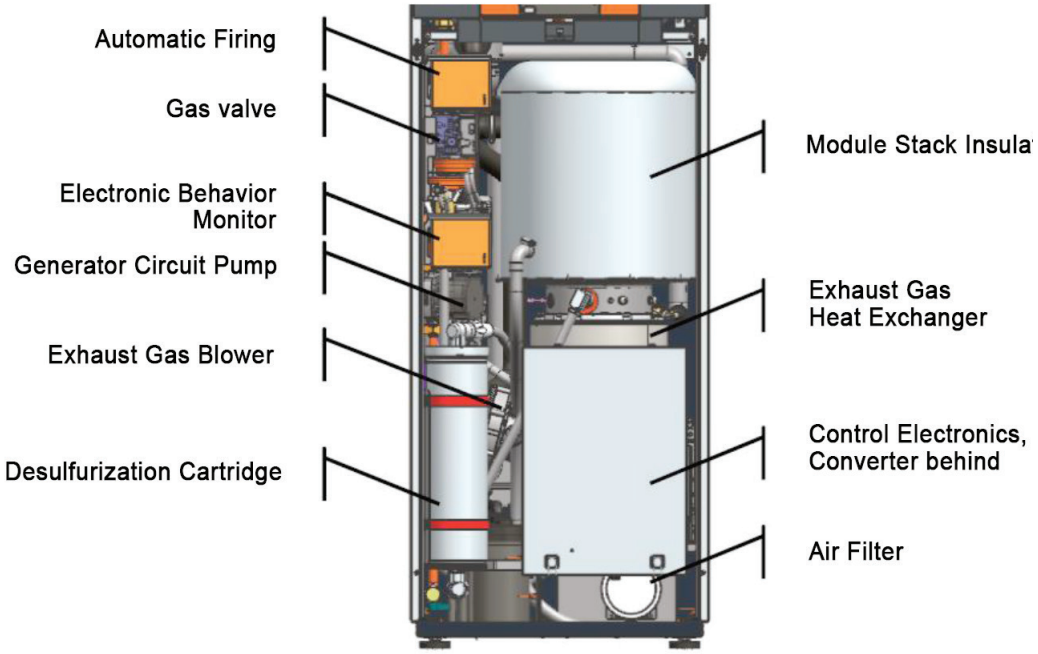
SOFC VERSUS PEMFC

Fuel cells exist in different types. They can be classified according to electrolyte, fuel and power. Solid oxide fuel cells (SOFCs) and polymer electrolyte fuel cells (PEMFCs) are the main types used to generate energy in buildings. Both fuel cells use a solid electrolyte—in the case of SOFC it is an oxide ceramic electrolyte, in the case of PEMFC a polymer membrane. The SOFC operates at high operating temperatures of 650 to 850 °C, the PEMFC at lower temperatures of 40 to 160 °C. PEMFCs are operated with hydrogen, SOFCs with natural gas. Fuel cell units generate heat and electricity with an overall efficiency of 85 to over 90%. BV

From Galileo to "DaVinci"

In Switzerland, one of fuel cell technology's traditional homes is in Winterthur. Since 1989, Sulzer AG's laboratories in Winter- thur have been developing ceramic fuel cells (solid oxide fuel cell or SOFC) that operate at high temperatures of 850 °C (in contrast to Panasonic›s low-temperature fuel cells, for example; see text box 'SOFC versus PEMFC' on the right). In 2006, Sulzer's fuel cell division became independent in a newly founded company named HEXIS AG. In 2012, Viessmann, the German manufacturer of heating and cooling systems, took over half of HEXIS; three years later in 2015, Viessmann took over all of HEXIS. At the end of 2013, HEXIS launched 'Galileo,' its first commercial fuel cell unit on the market, of which 300 had been built by last year.

HEXIS is currently working on a new generation of unit named Vitovalor (internal working mane 'Leonardo'), which will be introduced to the market in 2019. Later, with further increased performance data, a unit with the working title 'DaVinci' will follow. In contrast to 'Galileo,' the parent company Viessmann will be exclusively responsible for marketing this unit. The central innovation of the new generation unit lies in its electrical efficiency, which is to be increased from 35% ('Galileo') to 50% ('DaVinci'). "The production of electricity is constantly gaining in importance and makes a significant contribution to the economic efficiency of our units," says Dr Andreas Mai, Head of Research & Development at HEXIS, referring to the advantage of a higher electrical efficiency of

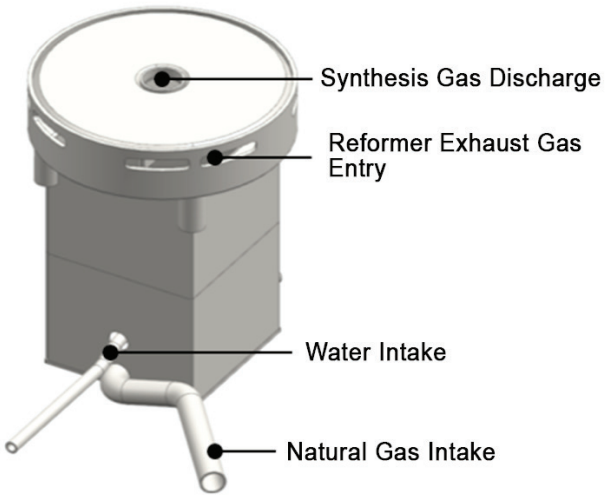


The main components of the fuel cell system 'DaVinci.' Graphic: HEXIS

the latest fuel cell units. Other manufacturers also rely on the advantages of high electrical efficiency.

Steam instead of Oxygen

'DaVinci' uses the same fuel cell technology as 'Galileo' to convert the fuel gas into electricity and heat in an electrochemical reaction without combustion. The expected service life of the stack of fuel cell elements for 'DaVinci' is 60,000 to 80,000 hours, so that the stack will only be replaced once over the planned service life of the entire unit of ten to 15 years. In order to achieve the high electrical efficiency, 'DaVinci' uses a different process for producing hydrogen than 'Galileo': where oxygen would be added to the (desulfurized) natural gas in 'Galileo,' 'DaVinci' now uses water vapor. This results in the 'DaVinci' fuel cell producing more electricity and less heat than its predecessor generation (see text box 'More Electricity, Less Heat' at the bottom).



The steam reformer that will be used in the 'DaVinci' fuel cell unit in the future. The Zurich University of Applied Sciences (ZHAW) supported HEXIS with the simulations and the design of the reformer. Illustration: HEXIS

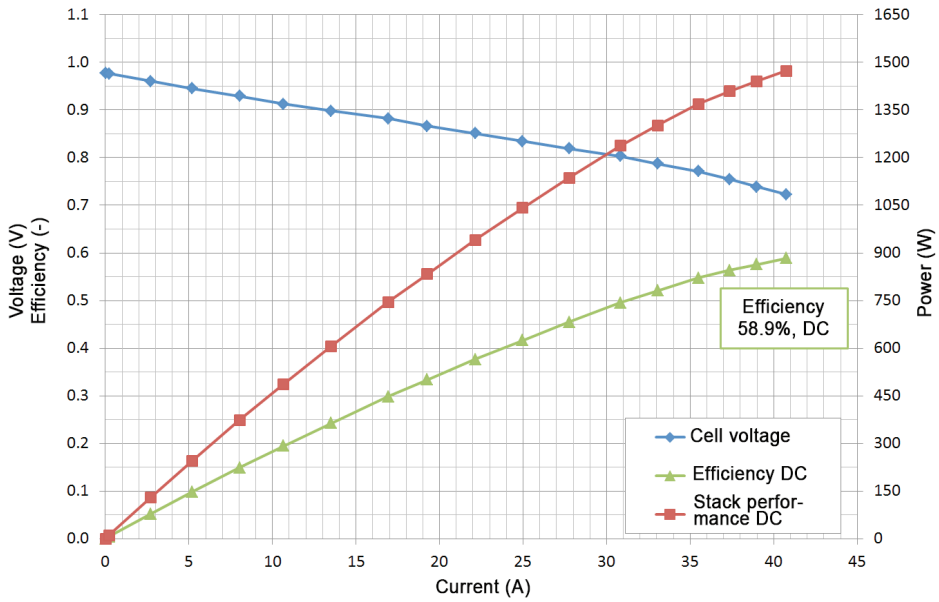
To further transform 'Galileo' into 'DaVinci,' the developers had to master two major challenges. The first was to develop a steam reformer with an associated catalyst in which the methane-water vapor mixture is converted into hydrogen and carbon monoxide. Together with a supplier from the automotive industry, a compact reformer was developed that is adapted to the limited space available and yet provides sufficient space for heat transfer. Thanks to its compact design, this component can be thermally well insulated, which is crucial for the efficiency of the overall system at an opera-

MORE ELECTRICITY, LESS HEAT

The SOFC fuel cells from HEXIS use hydrogen to generate electricity and heat. The hydrogen is produced from natural gas fuel, which mainly consists of methane. In 'Galileo,' the older HEXIS unit, oxygen (O_2) is added to the methane (CH_4); a chemical reaction (catalytic partial oxidation/CPO) produces carbon monoxide and hydrogen ($CH_4 + 1/2\ O_2 => CO + 2\ H_2$). 'DaVinci' adds water vapor to the methane and produces carbon monoxide and hydrogen ($CH_4 + H_2O => CO + 3\ H_2$) via a chemical reaction (steam reforming/STR). The advantage of steam reforming is that 50% more hydrogen can be produced with the same amount of methane - the electricity yield in the fuel cell is correspondingly higher. Since part of the heat produced is used to set the steam reforming reaction in motion, the net result is a relatively large amount of electricity. This means that the electrical efficiency can be increased from 35% to 50% compared to 'Galileo' (while the thermal efficiency decreases accordingly from 55 to 40%).

Steam reforming is an industrial process that has been tried and tested for a long time and the fuel cell engineers in Winterthur had already employed this process in earlier years. At that time, however, the process did not work reliably, was relatively complex and there were high costs associated with the provision of steam (specifically: purification of water to remove calcium and magnesium among other impurities). For this reason, HEXIS dropped steam reforming in favor of partial oxidation.

Now the technology is experiencing a renaissance with 'DaVinci': water is no longer piped in from the water supply, but is obtained by condensation from the moisture contained in the exhaust gas. This makes cleaning easier than using fresh water. The new unit works with a closed water circuit and therefore has another advantage –it does not need to be connected to a water pipe. BV

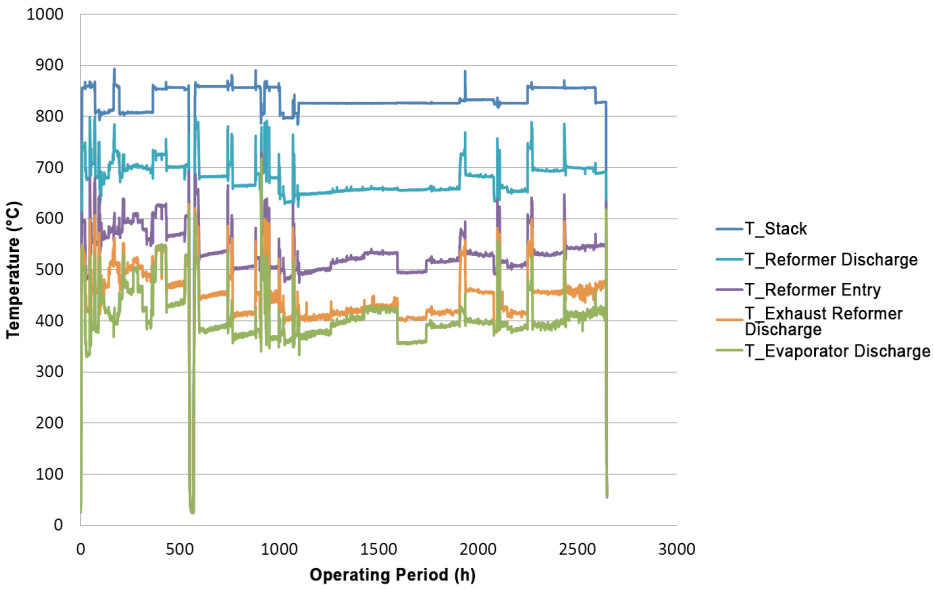


With an output of 1.5 kW (direct current/DC) from the fuel cell stack, 'DaVinci' achieves an electrical efficiency of 58.9%, according to the peak value previously measured by HEXIS. A part of the electricity obtained from the methane is lost during the conversion from direct to alternating current and to the operation of the fuel cell unit itself (electronics, fan, pump). The net efficiency is up to 50.5%. Graphic: HEXIS

ting temperature of 850 °C. The second challenge was the procurement of a reliable, cost-effective water pump, which consistently delivers a low volume flow of just 6 to 8 ml/minute over an expected operating life of the entire unit of up to 15 years.

Resistant to Ageing and Suitable for Partial Loads

Experience to date with the test bench, which incorporates five fuel cells instead of 50, gives reason for optimism. According to previous findings, steam reforming does not lead to faster ageing (degradation) of the fuel cells, which is important for the service life of the overall system. In addition, the electrical efficiency is consistently high even in partial load operation. This is important because the new heating system will not solely operate from September to May like 'Galileo,' but throughout the year. Since in summer only hot water must be heated, the fuel cell unit is not fully utilized and will therefore operate at (heat-guided) partial load. Like 'Galileo,' 'DaVinci' will also be equipped with an auxiliary heat generator (20 kW gas burner), which will ensure sufficient heat production in winter. "If a lot of heat is needed, we also produce a lot of electricity. This is also the time when little photovoltaic power is available," says HEXIS development engineer Thomas Zähringer. He therefore sees fuel cells as an ideal complement to photovoltaic and wind power plants.



HEXIS has subjected the steam reformer to a test run of more than 2500 hours. The measurement graph shows that various temperature parameters were practically constant over this period. This is a prerequisite for a stable operation system. Graphic: HEXIS

During the next phase, HEXIS developers want to further improve the reformer. Starting in 2019, the fuel cell unit is to be field-tested by test customers for at least a year before industrialization, certification and finally series production are started. A major challenge for the fuel cell industry is to reduce manufacturing costs. In the longer term, HEXIS is planning system prices for end customers in the range of CHF 15,000 to CHF 20,000 (fully installed and ready for operation incl. VAT). This price enables economic operation without subsidies and is thus accepted by the customers, according to the persons responsible. In terms of sales, they see the fuel cell unit as an alternative to solar thermal energy plus gas boilers, for example, or to the installation of an electrically operated heat pump. "Due to their high electrical and overall efficiency, fuel cell systems can make a very important contribution to a decentralized and environmentally friendly power supply," says HEXIS Managing Director Dr Alexander Schuler.

↗ For **information** on the project, please contact Dr. Yasmine Calisesi (yasmine.calisesi[at]bfe.admin.ch), responsible for the SFOE P+D programme, and Dr. Stefan Oberholzer (stefan.oberholzer[at]bfe.admin.ch), Head of the SFOE Fuel Cell Research Program.

↗ Further **technical papers** on research, pilot, demonstration and flagship projects in the field of fuel cells can be found at www.bfe.admin.ch/CT/H2.

PILOT, DEMONSTRATION AND FLAGSHIP PROJECTS OF SFOE

The development of the 'DaVinci' fuel cell heating system by HEXIS AG (Winterthur) is one of the pilot and demonstration projects with which the Swiss Federal Office of Energy (SFOE) is promoting the development of economical and rational energy technologies and the use of renewable energies. The SFOE supports pilot, demonstration and flagship projects with 40% of the non-amortizable, chargeable costs. Applications can be submitted at any time.

↗ **Information**:
www.bfe.admin.ch/pilotdemonstration
www.bfe.admin.ch/leuchtturmprogramm

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