Sulzer is developing SOFC systems (SULZER HEXIS SOFC) for small scale cogeneration in the electrical power range of 1 to 200 kW [1]. After several successful thermally self sustaining 1 kW lab system tests Sulzer has started a field test phase with units for the residential application. End of 1996 a first field test system started operation at the city utility of Winterthur (Switzerland) and a second one is planned mid of 1997 in a common project with the city utility of Dortmund (Germany). Prior to these demonstrations, Sulzer has successfully operated cell stacks using natural gas as fuel. A thermally integrated steam prereformer has been successfully operated during several thousand hours. From 1998 to 2000 Sulzer plans to install an additional small series of approximately ten field test units with several partners.

THE SULZER HEXIS STACK CONCEPT AND TEST RESULTS

Figure 1 shows the HEXIS stack concept in a three dimensional cross section. The concept is especially designed for small CHP systems. The key component of the HEXIS SOFC system is the ceramic/metal hybrid stack with circular planar SOFC elements (HEXIS means: Heat EXchanger Integrated Stack). Every stack repeat element consists of a PEN-element and a metallic interconnect (MIC), which serves as heat exchanger and current collector (PEN means a ceramic three layer membrane consisting of a Positive electrode, an Electrolyte in the middle and a Negative electrode). Figure 2 shows the improvements in performance of HEXIS single cell stacks using PENs manufactured by SOFCo (Salt Lake City, USA) and a metallic current collector manufactured by Plansee (Reutte, Austria). Sulzer HEXIS is focusing on current collector coatings and stack manufacturing. The curves show that the degradation has been reduced drastically during the last three years. The thermal spray coatings necessary for that performance have been qualified in stack tests up to 3000 hours and in component tests up to more than 10'000 hours at 1000 degrees Celsius without showing any degradation [2].
PERFORMANCE OF HEXIS 1 KW LAB SYSTEMS

After successful stack tests, which typically consist of one to five d=120 or 200 mm repeat elements (PENs & MICs) in electrically heated furnaces, a series of 1 kW lab system tests were carried out. These systems run thermally self sustaining after electrical heat up. This means that the stack is held on temperature only with the heat from the cells and from the afterburner, which is located directly on the outer rim of the stack. Figure 3 shows a photograph of the one 1 kW system environment. End of 1996, after three successful lab system tests using Plansee MICs and SOFCo PENs, a first system was built and tested using PENs manufactured by ECN (Netherlands Research Foundation, Petten). 46 repeat elements were connected in series. All components were of 120 mm diameter and had an electrochemical active area of 100 cm². Figure 4 shows the performance of that system. The maximum power was 600 W (0.130 W/cm²). For the first time such a system was grid connected via an inverter. Exactly the same specific cell performance was observed in corresponding stack tests using the same components.

DEVELOPMENT AND QUALIFICATION OF SYSTEM COMPONENTS

On the way to first field test, several integrated subsystems had to be developed and qualified. Field test units run thermally self sustaining and are heated up from ambient to operating temperature by a built in natural gas burner. A critical subsystem is the fuel processing system. Sulzer is using steam reforming. The necessary catalysts are from Haldor Topsoe (Lyngby, Denmark).

In a common project with the DEW (Dortmunder Energie und Wasser, Germany) and the University of Dortmund (faculty of electrical power generation) the behavior of SOFC stacks under real field conditions with natural gas was investigated. The German partners are supported by the ministerium of Nordrhein Westfalen. Figure 5 shows an electrically heated five cell stack test stand with an integrated steam prereformer. The test stand can be operated fully automatically via telephone from Switzerland. Figure 6 shows the performance of a five cell stack using natural gas from the low pressure grid without a gas pressure booster.

STATUS AND PLANNING OF THE HEXIS FIELD TEST PROGRAM

In addition to the technical work, detailed measurements of heat and electrical power consumption in different types of households (single family and multi family appartments) were carried out. This data was then used to
generate a detailed systems specification based on an analysis of the economics of small scale CHP systems. The calculations show that a system in the low kW range can be cost competitive based on current costs for gas and electricity in Dortmund. Similar investigations are now carried out in different European countries. Based on these technically and commercially encouraging results, Sulzer HEXIS is preparing the field test phase which starts with a first test end of 1996 (with the city utility of Winterthur in Switzerland) a second test mid of 1997 (with the city utility of Dortmund in Germany) and a third one end of 1997 (location not yet defined). From 1998 on Sulzer is planning a field test phase with 10 to 15 additional field test units operated at the sites of different partners in Europe, the USA and Japan. Figure 7 shows the layout of the system designed for the city utility of Winterthur. The cell stack consists of 70 repeat elements of 120 mm diameter. With the current power densities, this stack will ultimately have an electrical output of 1.4 kW with the current cell technology. According to previous stack tests the electrical efficiency will be approx. 35 % (LHV). The fuel cell module is combined with a conventional burner and a boiler to account for the variable heat requirements of the users.

PRODUCT DEVELOPMENT FOR RESIDENTIAL APPLICATION

In parallel to the field tests with systems as shown in the photograph in Figure 8, Sulzer HEXIS will, together with partners from the heating equipment industry, design compact micro-CHP-units. For small systems, Sulzer HEXIS is cooperating with the German company Vaillant. It is planned to start the market entry on a large scale in the year 2001.

STATUS OF THE HEXIS 50-200 KW CHP SYSTEM DEVELOPMENT

Figure 9 shows the photograph of a 7-15 kWe system module. The stack repeat elements have a diameter of 200 mm. The fuel cell stack consists of 100 repeat elements. In 1996 the system was successfully tested with a thermal dummy stack. The goal of these tests was to optimize the thermal part of the system, especially the thermally integrated natural gas prereformer and the start-up burner. The upscaling of the PENs remains a challenge. A cell technology with a very promising upscale potential is Medicoats (Mägenwil, Switzerland) VPS (Vacuum Plasma Spray) technology. This technology is applied in a substrate type stack repeat element, where the PEN is deposited on the surface of a Nickel felt as substrate which is bonded to a box-like interconnect/heat exchanger. Figure 10 shows the performance of a three cell stack of 200 mm diameter. For 1997, Sulzer HEXIS plans to build a first electrochemical test with this lab.
prototype module. In 1998 a similar test is planned at a field site and in 1999 a first system of the 50 kWe class is planned [3].

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BEW (Swiss Federal Office of Energy): Materials development such as current collector coatings and stack optimizations.

NEFF (Swiss National Energy Foundation): Lab-systems development such as the 1 kW lab system and the 7 kW lab prototype system module for 50 kWe CHP systems.

FOGA (Research Fund of the Swiss Gas Industry): Stack test stand and development of the first HEXIS field test unit.

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Figure 1: The HEXIS SOFC stack concept

Figure 2: Improvement of performance of HEXIS Plansee/SOFCo stacks

- Temperature: 920 °C
- Air massflow: 200 g/h
- Hydrogen massflow: 2.5 g/h
- Area=100 cm²

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Figure 3: Thermally self sustaining HEXIS 1 kW lab system

Figure 4: Performance of a HEXIS Plansee/ECN 1 kW lab system
Figure 5: HEXIS natural gas stack tests stand in Dortmund

Figure 6: Performance of a HEXIS Plansee/SOFCo stack using natural gas

- Thermal cycle down to ambient temperatures
- Prereformer tests (H₂O/N₂)
- Temperature: 950°C
- Massflows:
  - Air: 1 kg/h
  - NG: 25 g/h
  - Water: 2.0 ml/min
- HTAS catalysts
- Area=5*100 cm²
Figure 7: Layout of the first HEXIS FOA field test unit

Figure 8: Assembly of a HEXIS 70 cell stack (on top of prereformer) into the system (SOFC stack enclosure not shown on photo)
Figure 9: HEXIS 7-15 kWe CHP system module

Figure 10: Performance of a HEXIS Haynes230/Medicoat d=200 mm three cell stack

Stack Voltage at 45 Ampères and 900 °C
Stack Voltage at 30 Ampères and 850 °C
Air massflow: 2.2 kg/h
Hydrogen massflow: 22.5 g/h
Area=3*300 cm²