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BioCellus

Biomass Fuel Cell Utility System

STREP

Sustainable Energy Systems

D810 Project summary

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Project co-ordinator organisation name: Technische Universität München

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1. Project Execution

1.1 Project Objectives

Commercial biomass is considered as a promising energy source as it is nearly CO₂-free and well-distributed all over the world (see Figure 1). However, the concepts developed so far for its use in small-scale decentralized power plants achieve too low efficiencies to be economically feasible. Power could on the contrary be generated efficiently in fuel cells. This of course requires the gasification of the biomass.

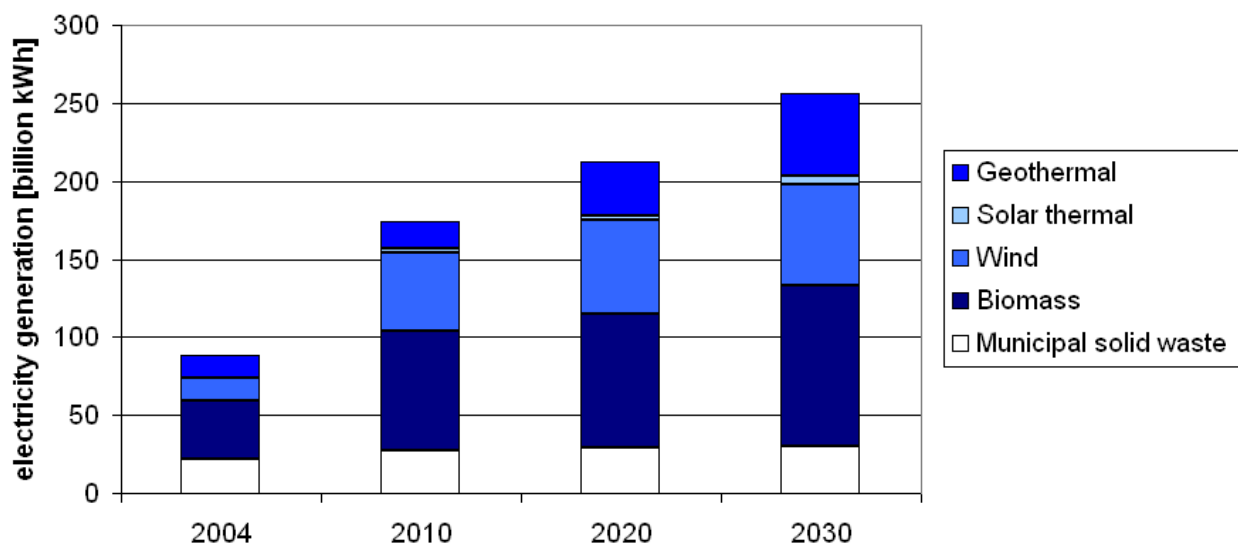


Figure 1: Nonhydroelectric renewable electricity generation by energy source in the USA [1]

High temperature fuel cells, among them SOFCs, are the most appropriate fuel cells for withstanding operation with wood gas: they accept not only hydrogen as fuel but also carbon monoxide and hydrocarbons, which are present in the product gas from a biomass gasifier. Due to the high operating temperature of SOFCs, the fuel processing and the thermal integration are simplified. Residual heat, available at a high temperature level, can be used in a combined heat and power plant.

Biomass gasifier-SOFC systems will still have to face at least two outstanding challenges: withstanding high levels of impurities in the gas and reaching high electrical efficiencies.

The gas cleaning device and/or the SOFC itself will have to handle very high concentrations of pollutants such as particles, sulphur compounds, chlorine compounds, alkali, and heavy metals, contained in the wood gas. The influence of higher hydrocarbons, so-called tars, on the behaviour of SOFCs is not known with precision, but tar reforming may be needed to avoid a destructive carbon deposition on the anode of the

cells. Special attention has to be spent on the development of advanced gas cleaning technologies.

The biomass gasifier, the gas cleaning system and the SOFC should be integrated in such a way that even small-scale applications under 100 kW_{el} can reach high electrical efficiencies. This is necessary for the plant to be profitable even without adequate heat consumer, as it is the case in Southern European countries for example.

The BioCellus project addresses these two challenges. First, the gas quality necessary for a safe operation of SOFCs should be determined by testing different membranes with real wood gas. Once the fuel cell requirements are known, an appropriate gas cleaning unit can be specified and constructed. The second part of the project concentrates on the integration of the biomass gasifier with the SOFC. A new concept, the so-called TopCycle, has been developed for thermal integration. It has been evaluated thermodynamically and economically and first steps towards its technical realization have been made.

1.2 Contractors involved

The consortium is composed of 17 partners from all over Europe, including major actors in the fields of fuel cell technology and biomass gasification. The participants are listed in Table 1. Both university and industry are represented in the consortium.

Table 1: List of participants

No	Participant name	Short name	Country
1	Institute for Energy Systems, Technische Universität München	TUM	Germany
2	National Technical University of Athens	NTUA	Greece
3	MAB Anlagenbau	MAB	Austria
4	Technical University of Delft	TUD	Netherlands
5	Energy Research Centre of the Netherlands	ECN	Netherlands
6	HTM Reetz GmbH	HTMR	Germany
7	Prototech	PRO	Norway
8	Institut für Kernenergetik und Energiesysteme, Universität Stuttgart	IKE	Germany
9	Institut für Wärmetechnik, Technische Universität Graz	TUG	Austria
10	Siemens	SIE	Germany
11	Faculty of Chemistry and Chemical Technology, University Ljubljana	UL	Slovenia

12	DM2 GmbH	DM2	Germany
13	COWI	COWI	Denmark
14	Technical University of Denmark	DTU	Denmark
15	iT consult	ITC	Germany
16	Aristotle University of Thessaloniki	AUTH	Greece
17	Paul Scherrer Institut	PSI	Switzerland

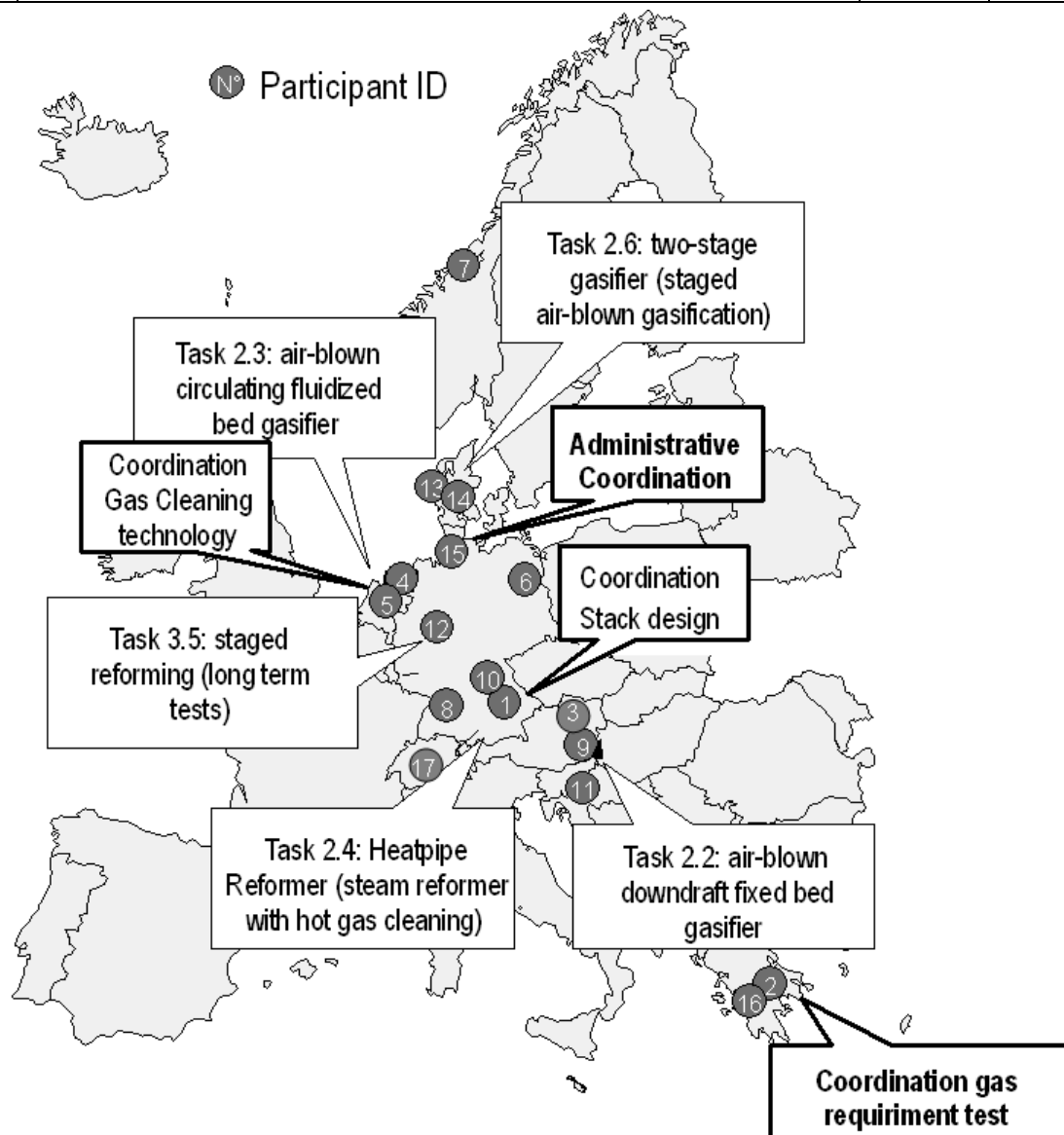


Figure 2: Locations of the participants with indication of main tasks

1.3 Work performed and end results

The approach followed in this project is to test fuel cells directly with real wood gas and to observe the degradation caused by the different pollutants. The first step to achieve this goal was therefore the construction of mobile test-rigs which can be transported to the different gasification sites.

1.3.1 Assembly and testing of mobile test-rigs

Two mobile SOFC test-rigs have been designed and constructed. Each test-rig is equipped with measurement, control, and data acquisition systems. Humidifiers and gas preheating equipment are also present.

The first test-rig is designed for planar fuel cells and has been made by ECN (see Figure 3). A particularity of the cell mounting is that the cathode and anode compartments are not sealed: the fuel and the oxidant meet directly at the outside of the cell. This sealless design ensures good electrical contacting with the current collecting meshes but also implies that the gases have to be supplied with slight overpressure.



Figure 3: Front panel of the test-rig developed by ECN for planar cells (left); heating elements and housing for planar cells (right)

The second test-rig has been developed by the Technical University of Munich to accept

tubular fuel cells and is equipped with a split tube furnace from HTM Reetz. The test-rig can be seen in Figure 4.

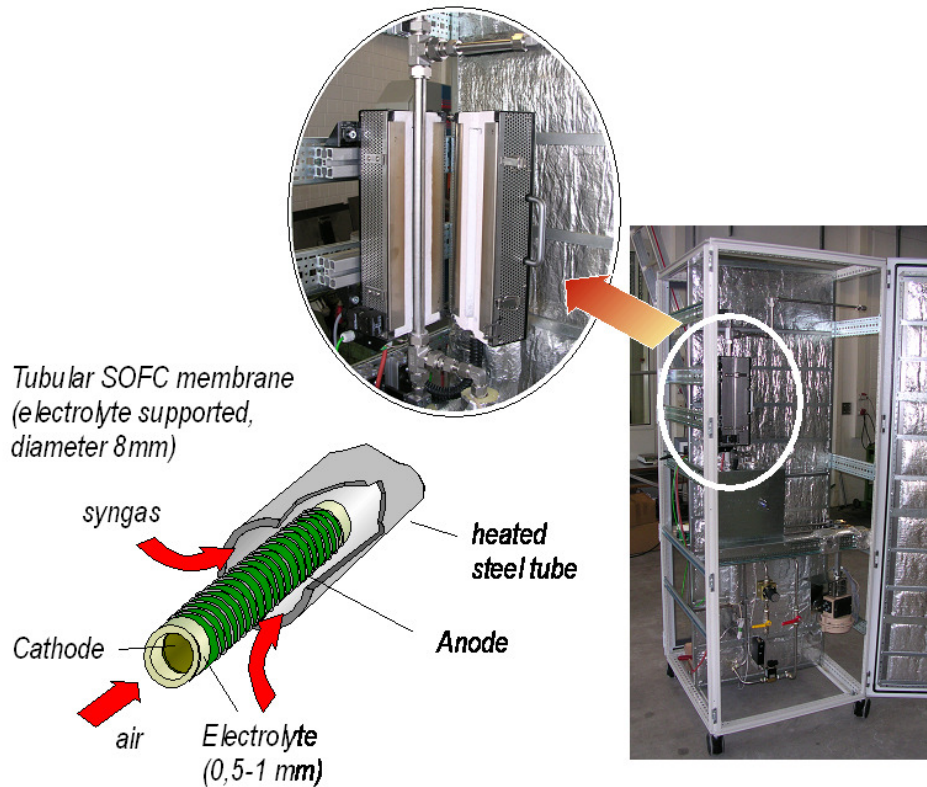


Figure 4: TU Munich test-rig for tubular fuel cells

The TU Graz has developed and tested a mobile hot gas conditioning unit, which accomplishes the following tasks at temperatures above 350 °C:

- Particle removal with cyclone and sinter metal filter
- Gas delivery – pumping with steam injector
- Chlorine removal through promoted alumina
- Sulphur removal with zinc oxide and copper oxide
- Tar prereforming with dolomite and nickel, which can be bypassed
- Trace heating between 350 and 600 °C
- Automation and control of temperatures and flows
- Constant flow control for fuel cells
- Humidification
- Online gas analysis and measurement of the water content

The gas cleaning unit is shown in Figure 5.

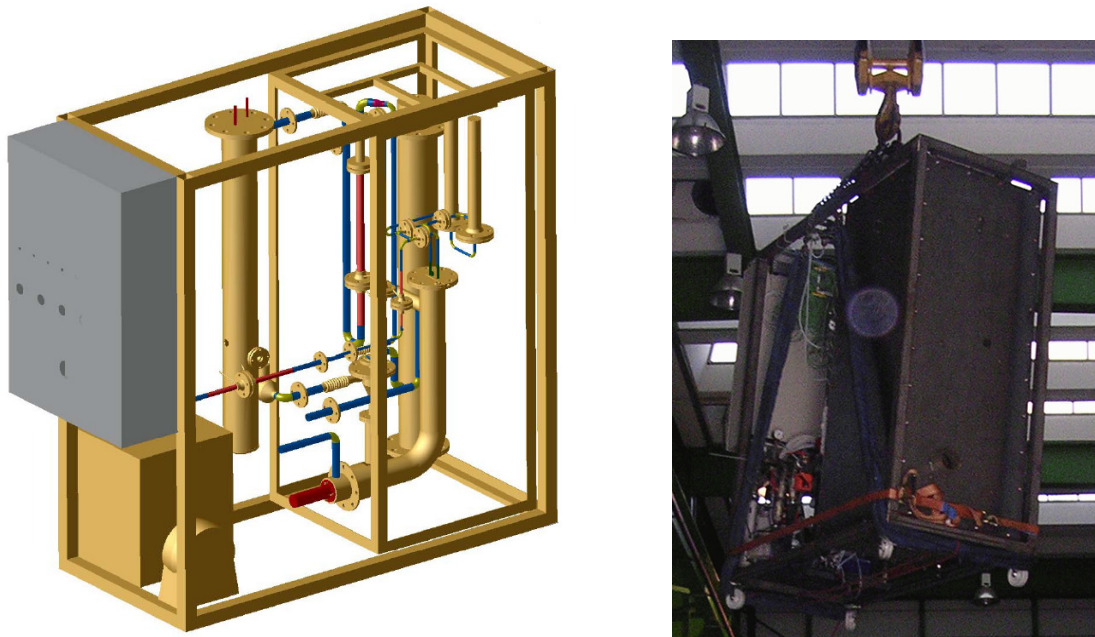


Figure 5: Mobile hot gas conditioning unit

Before being tested onsite with real wood gas, the operation of the different test-rigs has been checked with synthetic wood gas in the laboratory. For the planar cells, no deactivation took place during operation with synthetic wood gas mixtures and the anode microstructure after testing was normal. Higher tars were shown to have a negative impact on the cell performance: they inhibit the reforming of methane. Lower tar components are converted. The tubular fuel cells manufactured at the Technical University of Munich reacted to different gas flow rates, temperatures and gas compositions as expected. However, cell power was lower than expected.

1.3.2 Investigation of the syngas impact on the fuel cell performance

All three mobile test-rigs have been transported to different gasifiers in Europe. The gasifiers visited are significantly different and produce gas with diverse quality, principally concerning the tar content. The expected result from this onsite tests is the maximal tar level tolerable for the SOFC and therefore the determination of the requirements for the prereforming unit of the gas cleaning unit.

Four gasification sites were visited:

- autothermal fixed-bed downdraft gasifier of Graz University of Technology (TUG)
- allothermal bubbling fluidized bed reformer (biomass heat pipe reformer BioHPR) of Technical University of Munich (TUM)

- autothermal 2-stage fixed-bed downdraft Viking gasifier of Technical University of Denmark (DTU)
- circulating fluidized bed gasifier of Technical University of Delft (TUD)

All gasifiers were fed with woody biomass (wood chips or wood pellets) and were operated at their optimal operation conditions. The tests on wood gas operation were limited in duration (from 2 to 160 hours) in order to measure degradation rates with respect to certain wood gas contaminants.

Almost all tests resulted in stable cell voltage output for tar contents ranging from ~0 to more than 10 g/Nm³ cumulative tar load. Steam content for the tests at TUG, TUM and TUD was high, ranging from 40 vol-% to 70 vol-%, either due to gasifier operation or to additional steam injection by the gas cleaning unit in order to overcome the pressure drops in the system. Current/voltage curves on a synthetic reference gas mixture before and after each wood gas operation proved the unaffected fuel cell operation. The microstructure of the anode functional layer was intact after testing, as shown by post experimental microscopic analyses. Furthermore, no detectable carbon deposits were observed.

One longer test (more than 150 hours) at the Viking gasifier of DTU was conducted successfully with stable performance, resulting in the longest up-to-date reported test of a SOFC with biomass derived product gas. The performance can be seen in Figure 6.

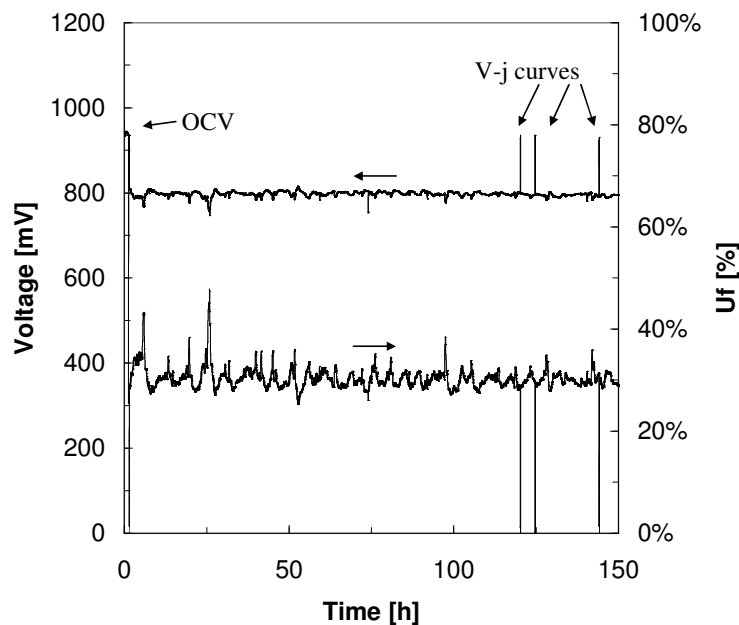


Figure 6: Long-term test of planar fuel cell with Viking gasifier

Operation at high fuel utilization of 70% to 85% resulted in partial anode oxidation due to high steam partial pressure and fluctuating wood gas composition and flow supply and

thus voltage degradation.

Char and fly ash particles reached the anode during operation, which resulted in anode contamination and formation of secondary carbon within the anode functional layer (in form of tubular shaped carbon, see Figure 7).

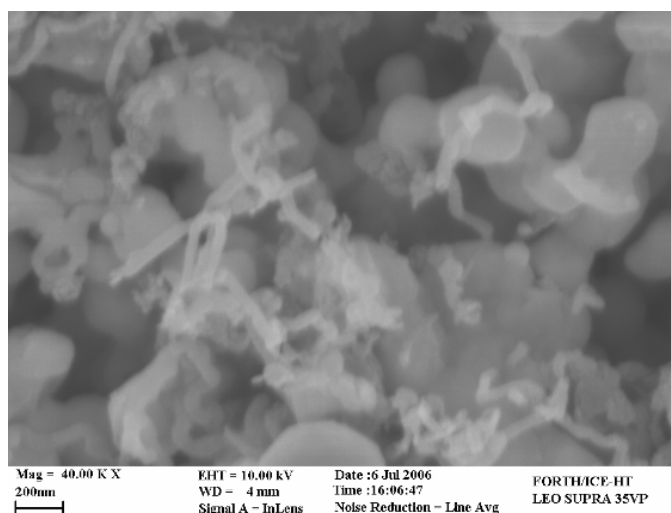


Figure 7: SEM analysis showing tubular shaped carbon.

The results of the tests suggest that the planar electrolyte supported SOFC with a Ni-GDC anode formulation could operate on and cope with the tar laden wood gas (from ~0 to > 10.000 mg/Nm³) without degradation due to carbon formation or other product gas impurity traces. Tubular fuel cells showed some degradation probably due to unsolved leakage problems and to handmade manufacturing.

1.3.3 Hot gas cleaning system and long-term testing of a single membrane

In order to achieve high efficiencies in a process integrating a biomass gasifier and a SOFC, hot gas cleaning is necessary. Hot gas cleaning is here defined as cleaning the gas at temperature above 600 °C.

The suggested cleaning system involves a ceramic filter, dolomite based tar cracker, sodium carbonate based HCl removal, activated alumina as an alkali getter, reduced ceria based H₂S cleaning and a final ceramic dust filter. The system is expected to be capable of cleaning tars to a few hundred ppm levels if dolomite is used as a catalyst for tar cracking and to a few ppmv levels if nickel based sorbents are used. Particulates are expected to be cleaned to approximately 1 ppm (weight). HCl emission is expected to be around 1-2 ppmv. KCl and H₂S are expected to be at sub ppm or few ppm levels in the cleaned gas.

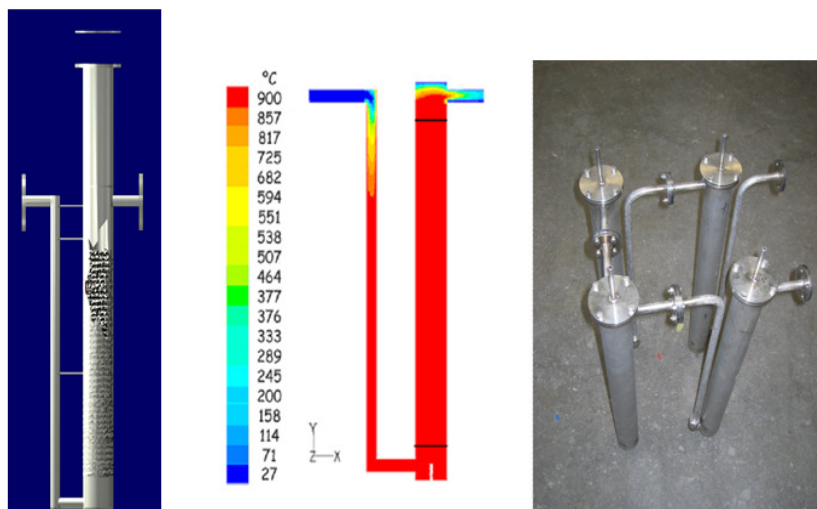


Figure 8: Reactors included in the high temperature gas cleaning system



Figure 9: High temperature gas cleaning system

In order to assess the feasibility of the TopCycle concept, it is necessary to study the performance of a commercial SOFC with simulated cleaned wood gas. To this purpose, tubular SOFCs of Siemens, manufactured like the cells for the demonstration plants, were slightly modified to allow electrochemical impedance analysis. An adapted single cell

housing was constructed and integrated into a new test equipment. The simulated wood gas was a mixture from the “dry” components (50% N₂, 20% H₂, 20% CO₂ , 5% CO, 5% CH₄) plus 60 % steam and 1 ppm of H₂S.

The goal to operate a cell on this gas mixture for 1000 h required 4 attempts due to several failures of the test equipment. Each one of these independent tests was performed with a new cell. Ten cells had been fabricated to this purpose.

Because the measured current density with a defined hydrogen mixture was lower than for the other commercial cells, it was concluded that the fuel supply was insufficient due to a partial bypass of gas by leaks in the applied cell housing.

With the addition of 1 ppm H₂S to the main wood gas components, two different types of voltage degradation were observed:

- a fast decay of voltage (6 %) within 25 h. This decay is due to a decreased electrocatalytic activity of the anode only.
- a very slow voltage decline (1% / 1000 h). This decay is originating from an increased inhibition of the electrocatalytic anode reaction and an increase of the ohmic resistance.



Figure 10: Siemens SOFC test-rig for long-term tests

1.3.4 Design of a SOFC with internal heatpipe cooling

In order to achieve high system performance, it was shown that the introduction of heatpipes in the fuel cell design is necessary. It is also very important to develop anode materials which are resistant to carbon deposition.

Different anode materials have been manufactured by the sol-gel, combustion synthesis, and Pechini methods. Ni/YSZ anode materials were modified by the addition of dopants such as platinum, palladium, and copper. Some other compositions of anode materials, produced by ECN and Siemens, have also been evaluated.

The carbon deposition on the materials has been tested via gas phase analysis by mass spectrometry and gas chromatography. Information on the amount of carbon deposited, on the reactivity of the deposit, and on the kinetics of the deposition was gained.

The testing of the anode materials is divided into three steps, as can be seen in Figure 11:

- temperature programmed and isothermal reduction of nickel oxide in Ni/YSZ composite,
- temperature programmed or isothermal deposition because of the thermal dissociation of methane,
- and temperature programmed oxidation.

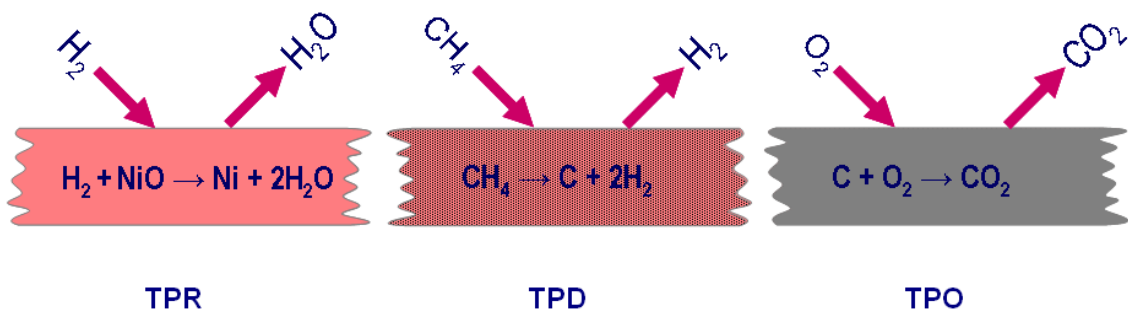


Figure 11: testing procedure of anode materials: temperature programmed reduction (TPR), temperature programmed deposition (TPD), and temperature programmed oxidation (TPO)

Results of the temperature programmed and isothermal deposition of carbon are that:

- the tested anode material samples differ in the onset temperature and in the amplitude of the hydrogen release, which corresponds to the amount of deposited carbon.
- the oxidation temperature of the deposited carbon varies significantly and is a measure of its reactivity.

After the fuel cell itself, the most important element of the stack design with internal cooling is the heatpipe. The Institut für Kernenergetik und Energiesysteme (Universität Stuttgart) is manufacturing and testing heatpipes.

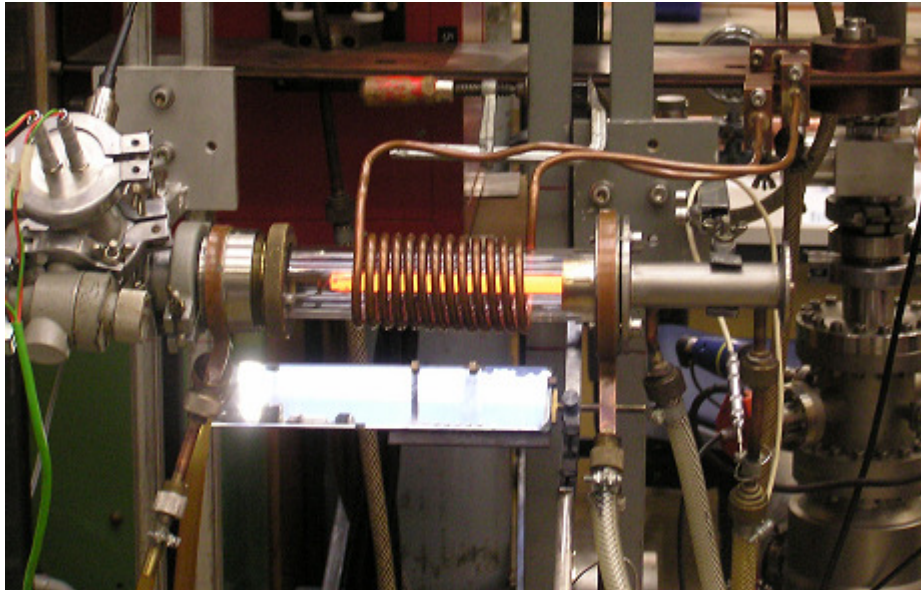


Figure 12: test-rig for heatpipes

A test-rig has been built in order to test the produced heatpipes (see Figure 12). The heatpipes perform well: the measured heat transport capabilities exceed the required heat load for cooling of fuel cell stacks, and the temperature drops along heatpipes are tested to be less than 10°C. The start-up behaviour of the heatpipes has been observed. Furthermore, the capillary structure has been checked and the fuel cell heating has been simulated.

Parallel to the development of anode materials and appropriate heatpipes, two stack designs have been conceived. In the planar stack design of Prototech, layers of fuel cells alternate with layers of heatpipes. The usual horizontal temperature gradients observed in planar fuel cell stacks are transformed in vertical temperature gradients by the use of heatpipes. Simulations have been carried out to determine the vertical temperature gradients in the stack depending on the heatpipe diameters. Possible interconnect materials have been identified.

The tubular cell and stack design for internal cooling has been developed by Technical University of Munich. For the fuel cells, a new configuration with perovskite filling has been chosen in order to ensure a good contact between two cells connected in series.

Both tubular and planar stack concepts were tested in a short version by Prototech and the Technical University of Munich. They can be seen in Figures 6 and 7. A planar stack with 1 kW electrical output will be constructed by Prototech and tested with real wood gas at the Biomass Heatpipe Reformer from TU Munich.

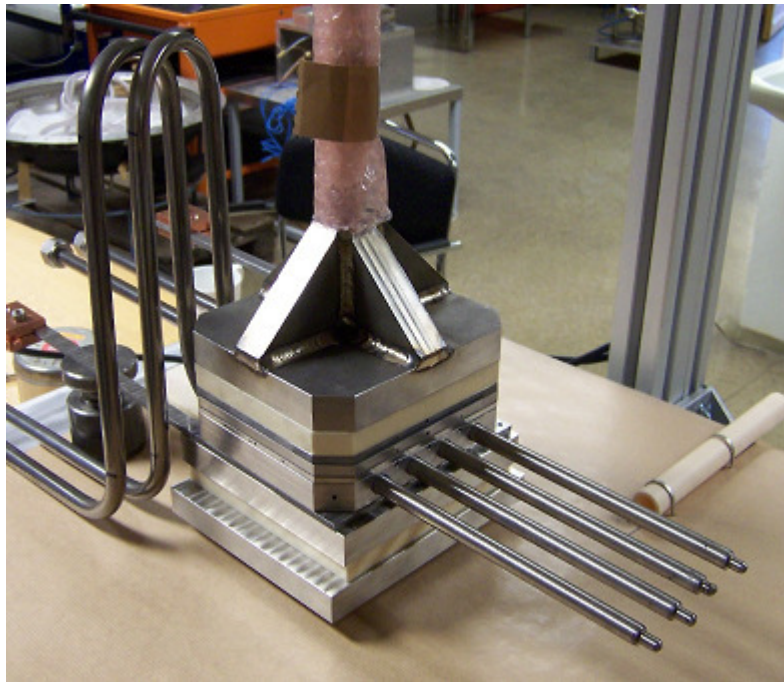


Figure 13: Short planar stack from Prototech

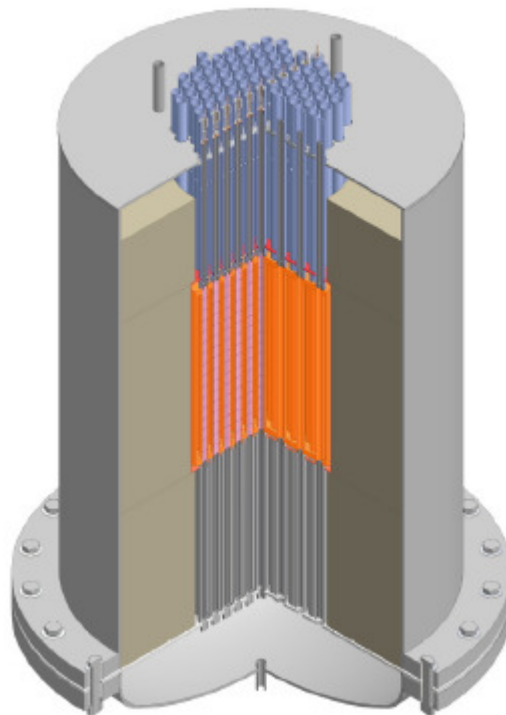


Figure 14: Tubular stack from TU Munich: short stack (left) and 1 kW stack concept (right)

1.3.5 Testing of the new SOFC concept

TU Delft constructed a new medium temperature gas cleaning unit based on the design of the one from TU Graz, but able to deliver higher flow rates which are convenient for fuel cell stacks. A planar stack, able to produce 1 kW power output, was constructed by Prototech. The short tubular stack constructed by TU Munich as preliminary unit was tested in parallel, as well as single planar fuel cells with improved anode configurations.

All 4 test-rigs were installed at the Biomass Heatpipe Reformer from TU Munich. It was possible to deliver real wood gas to all the test-rigs.

The planar stack was operated during approximately 7 hours on wood gas and had a very stable performance. The average power out was 300 W, the maximum power output, reached while increasing the wood gas flow to the stack, was 700 W. It should also be noted here that no experiment with stack and biomass gasifier of this kind with such high power output was reported in literature.

The vertical temperature gradient measured through the planar stack was higher than predicted by the model, but still lower than in stacks without heatpipes.

The excess air ratio could be reduced to 2, which is a significant improvement compared to usual systems where excess air ratios of 5-10 are used in order to remove the excess heat produced by the fuel cell. The heatpipes were responsible for about 80% of the cooling of the stack and therefore fulfil their task very good.

It was not possible to operate the tubular stack properly because of leakage problems between the fuel cells.

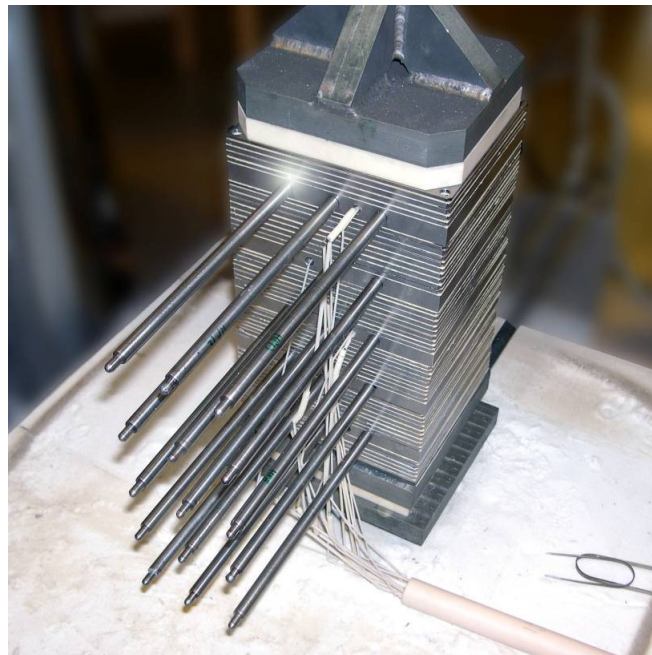


Figure 15: 1 kW planar stack from Prototech

1.3.6 Economic evaluation and environmental impact

In order to reach high electrical efficiencies, it is important to know how the biomass gasifier and the fuel cell are best combined. Four possible combinations of an allothermal gasifier and SOFC stack have been simulated with the software IPSEpro under the same realistic assumptions. The simulated plants belong to the small-scale class. The interdependency of the processes is growing, starting from the simplest configuration to the so called TopCycle. In the TopCycle, the heat produced by the fuel cell is directly transferred to the gasifier by means of liquid metal heatpipes. The comparison of the four processes shows the net superiority of the TopCycle: the net electrical efficiency is increasing from 28,0% for the simple configuration to 43,1% for the TopCycle (see Figure 17). The efficiency of the TopCycle could even be improved by 10%-points if both systems were operating under a pressure of 2,5 bar and if the exhaust gas were expanded in a microturbine. A pressurized operation is probably feasible: both the BioHPR and the Siemens fuel cells were already tested under such conditions.

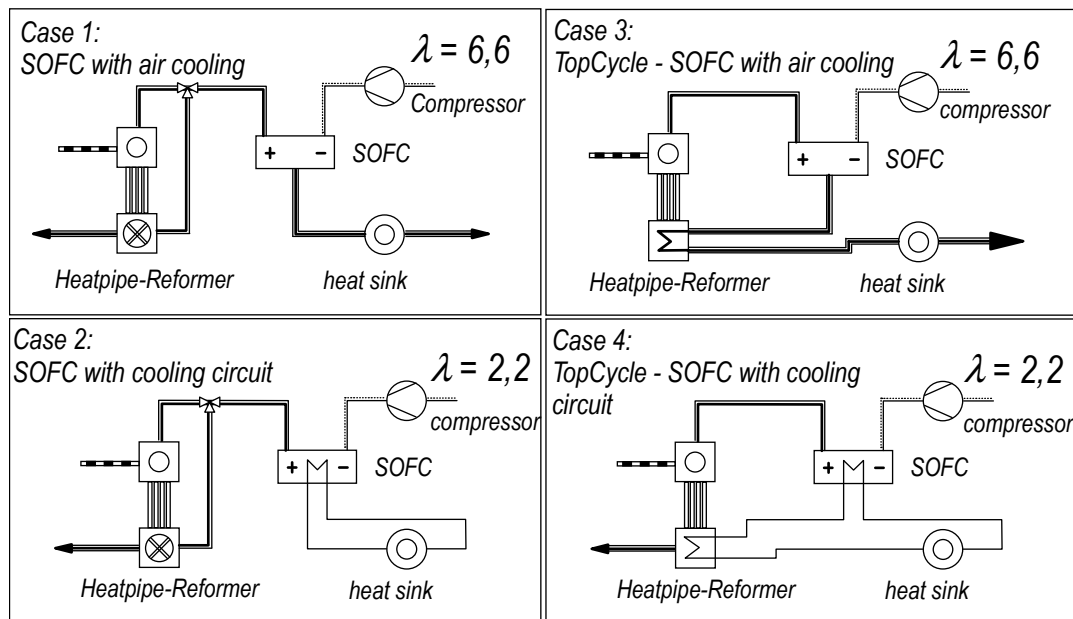


Figure 16: Cycle layouts with solid oxide fuel cells and integrated gasification of biomass

A parameter variation for the TopCycle further demonstrates that the excess air ratio, the fuel utilization in the fuel cell, and the excess steam ratio in the gasifier have a determinant influence on the cycle efficiency.

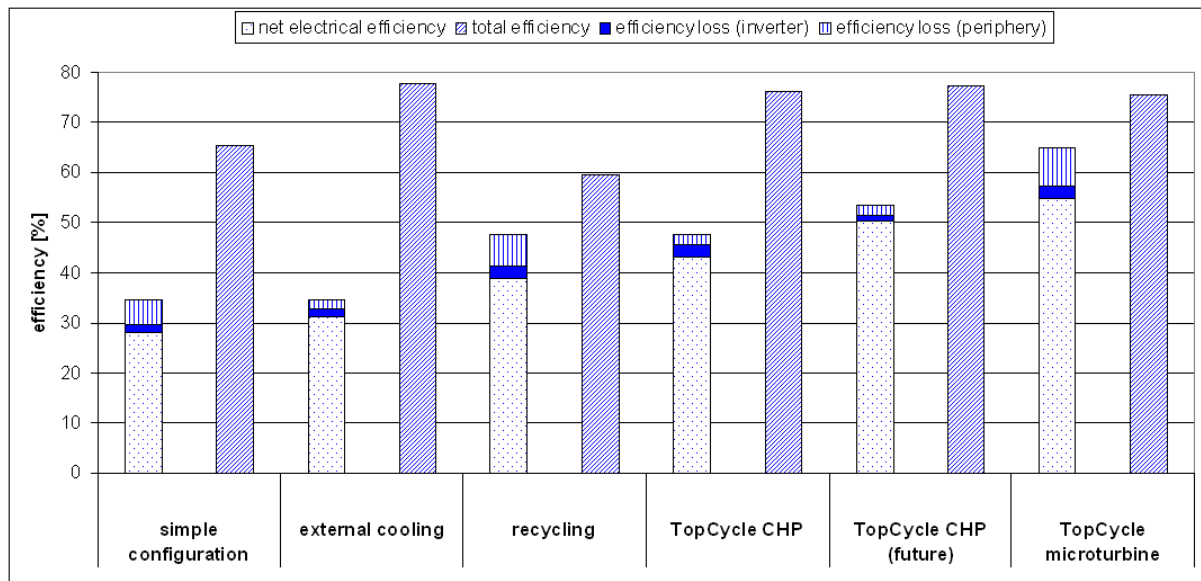


Figure 17: Comparison of the net electrical and the total efficiencies of the different configurations including BioHPR and SOFC

An estimate of the investment costs for a TopCycle system as combined heat and power plant has been carried out. As usual for a novel concept in this early phase of development, the cost calculation is made with a high uncertainty. All calculations are however based on existing cost estimation from other projects and reports. The economic evaluation reveals that the expected specific costs for a single TopCycle unit of 500 kWth will be about 12000 €/kWel. However, due to the principle of economy of scale, the 69th produced unit would already have specific costs lower than the 2600 €/kWel limit.

The investigation for the most appropriate feedstock concluded that, when focusing on Eastern and Mediterranean Europe, organic waste appears to be more abundant and convenient in use. Olive pit will be in particular very interesting.

Since there are no real data from TopCycle unit operations, the environmental impact considerations, that need to be taken care of in TopCycle applications, are reported here as speculations based on the sub-components outlet streams. These include:

- ash (disposed with current practices)
- unconverted char (disposed with current practices)
- spent trap catalysts for H₂S, and HCl (need recycling or special disposal)
- spent Ni or Ca based catalysts for tar reduction (need recycling or special disposal)
- typical gaseous emissions (based on gas cleaning of the fuel to allowable tolerance levels for SOFCs, emissions are expected to be magnitudes lower than legislative limits, with a possible exception of NO_x)
- reduced CO₂ emitted compared to coal.

1.3.7 Dissemination activities

A patent research was carried out in order to identify possible conflicts between innovative development during the BioCellus project and already existing patents. Different topics were studied: cell materials, cell design, stack design, system design, manufacturing processes and reforming concepts. The main constraints are expected from 2 patents, where the coupling of SOFC systems to gasifiers through heat recovery inside the fuel cells has been declared as their intellectual property.

Even if the TopCycle has been proven to be economic with enough unit production, niche market applications have to be found in order to allow the market entrance of the TopCycle. Olive residues are an appropriate fuel for such an application. The first TopCycle units have to be applied to the agricultural industry producing the fuel. In this way, fuel is available with zero cost and the available heat from the CHP is used for the heat requirements of the hosting agricultural industry. The typical olive centrifugal extractions units exhibit a very similar capacity to that of the present status of the Topcycle small scale system. In the proposed scheme part of the CHP's heat is used to partly evaporate and thus minimise the toxic and presently unsolved problem of the wastewater stream of centrifugal olive oil unit. The steam produced can be used as gasification agent thus minimising fresh water requirements of the system.

The concept of large-scale biomass TopCycle plants is evaluated by thermodynamic and economic terms. Excess heat of high quality is in addition utilized in a steam power cycle to produce steam for the gasification process and electric power. This system is modelled in Hysys simulation software and major equipment sizes and capacities are found. The model shows that this TopCycle configuration has electric net efficiency of more than 60% of plant sizes from 30 MW and up. A pilot scale demo plant should be built to demonstrate the thermal integration between the fuel cells and the gasifier. Equipment cost is estimated from simulation results and the cost break down show that non commercial technologies are 81% of total equipment cost.

The net present value analysis has shown that the system is highly feasible economically. Sensitivity to cost of biomass is low compared to the sales value of electricity. Governmental incentives in the form of for instance subsidiaries for biomass based power generation, would further reduce the investment risk.

A follow-up proposal was elaborated for funding in the 7th framework programme of the European Union.

2. Dissemination and use

2.1 Exploitable knowledge and its use

There are two main achievements from the BioCellus project. First, the tolerance of SOFCs towards tars was much higher than expected (actually, according to the round robin tests, unlimited). Even if the cells should be tested for longer periods on wood gas,

the very high tolerance, which means that tar cleaning might be superfluous, gives a serious advantage towards other power systems functioning with wood gas like gas turbines or gas motors.

The second major achievement is the successful operation of the planar fuel cell stack on wood gas with a decreased excess air ratio. This shows that the use of heatpipes to cool the fuel cell can significantly improve the efficiency of the system, because of the reduced consumption of the air compressor.

2.2 Dissemination of knowledge

2.2.1 Web page

The project web page was regularly actualized, the public part as well as the private part. The main results are accessible to the public. In the private part, all documents concerning the project (contracts, minutes, deliverables, presentations held at meetings) can be downloaded.

2.2.2 Newsletters

One newsletter has already been published. It was distributed at the 15th European Biomass Conference and Exhibition and is accessible on the web page. This newsletter presents the motivation for the project, the structure of the consortium and the first results obtained with the mobile test-rigs at the different gasification sites. A second newsletter will be published, presenting the complete results of the round robin test, the results from the stack testing and the results of the 1000 h testing.

2.2.3 Workshops

Two workshops have been organised during the project.

The first one was a meeting with the European project GreenFuelCell, whose research field is very close to the one of BioCellus (low tar gasification, inorganic hot gas cleaning system, mechanisms of tar destruction with char beds, behaviour of volatile inorganics with respect to SOFC materials). The meeting took place at CIRAD in Montpellier from the 14th to the 15th of June 2006. The objectives were to exchange information on common topics (gasification process, hot gas cleaning from tars and inorganics, impact of pollutants).

The second one was the BioCellus Summer School. It was held from the 4th to the 08th of September 2007 in Seggau Castle, near Graz in Austria. 37 persons participated, coming from all over Europe (Austria, Denmark, Finland, Germany, Greece, Netherlands, Poland, Slovenia, and Switzerland) and from Brazil. University and research centres were mainly represented. Specific information about biomass gasification, gas cleaning technologies, and fuel cell systems was given, current projects were presented. 4 different discussion workshops took place:

- carbon formation and innovative materials
- gasification and system integration
- gas analysis and cleaning technologies

- modelling of SOFCs

An excursion to the successful Güssing gasifier was organized.



Figure 18: Participants of the BioCellus Summer School

2.3 Publishable results

Results available for a wide public are available on the web page of the project: www.biocellus.com. Other more detailed results have been presented at different conferences or have been published in journals. The actual list is available on the web page and is inserted below:

Authors	Title	Publisher
Mathilde Saule, Regina Deschermeier, Nadine Frank, Jürgen Karl	EFC2007-39064 Carbon deposition during SOFC operation with biogenous gases	Proceedings of the Second European Fuel Cell Technology and Applications Conference, Rome
Marjan Marinšek, Jana Padežnik Gomilšek, Iztok Arcon, Miran Ceh, Alojz Kodre, Jadran Macek	Structure Development of NiO-YSZ Oxide Mixtures in Simulated Citrate-Nitrate Combustion Synthesis	Journal of the American Ceramic Society 90 (10), 3274–3281, 2007
Nadine Frank, Mathilde Saule, Sotirios Karellas, Jürgen Karl	Poster presentation: P1005-180: Degradation of Solid Oxide Fuel Cells with Wood Gases	Lucerne FUEL CELL FORUM 2006 (SOFC)
N. Frank, M. Saule, J. Karl	Degradation of solid oxide fuel cells with wood	WHEC 16 – Lyon France
N. Frank, M. Saule, J. Karl, A. Schweiger, U. Hohenwarter, P. Hoffmann, J. P. Ouweltjes, I. Waemhus	Results of the Biocellus Project: Gas Cleaning Technology. SOFC Operation on Wood Gas and Technical Implementation of the TopCycle	15th European Biomass Conference & Exhibition ICC International Congress Center Berlin, Germany
Ph. Hofmann, A. Schweiger, L. Fryda, K.D. Panopoulos, U. Hohenwarter, J.P. Ouweltjes, J. Karl, E. Kakaras	Results from Planar SOFCs Operated on Hot Cleaned Gas Derived from Two Experimental Gasification Facilities	15th European Biomass Conference and Exhibition, 7-11 May, Berlin 2007
N. Frank, M. Saule, J. Karl, A. Schweiger, U. Hohenwarter	Performance of Tubular SOFCs on Syngas from Wood Gasification	15th European Biomass Conference & Exhibition ICC International Congress Center Berlin, Germany
J. Karl, M. Saule, U. Hohenwarter, A. Schweiger	Benchmark Study of Power Cycles Integrating Biomass Gasifier and Solid Oxide Fuel Cell	15th European Biomass Conference & Exhibition ICC International Congress Center Berlin, Germany
Ph. Hofmann, A. Schweiger, L.	High temperature electrolyte	Journal of Power Sources, In Press, Corrected Proof,

Fryda, K.D. Panopoulos, U. Hohenwarter, J.D. Bentzen, J.P. Ouweltjes, J. Ahrenfeldt, U. Henriksen and E. Kakaras	supported Ni-GDC/YSZ/LSM SOFC operation on two-stage Viking gasifier product gas	Available online 5 May 2007, doi:10.1016/j.jpowsour.2007.04.073.
MARINŠEK, Marjan, PEJOVNIK, Stane, MACEK, Jadran	Modelling of electrical properties of Ni-YSZ composites	J. Eur. Ceram. Soc.. [Print ed.], 2007, vol. 27, no. 2/3, str. 959-964, graf. prikazi. [COBISS.SI-ID 28415237]
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3. Conclusion

The project achieved several valuable and promising results:

- The short term tests of single SOFCs together with a gas cleaning system at different gasification sites showed that SOFC operation on real wood gas is in principle a possible option. The gas cleaning system proved to be able to clean the biogenous gas to gas qualities required by a SOFC. The SOFC proved to be functional with cleaned biogenous gas and – most promising result – to even tolerate tar levels up to 10g/Nm³.
- Two stack designs realizing the TopCycle have been developed. Both designs – tubular and planar – have been successfully tested in small scale. The planar design has also been tested in a 1kW version and the cooling concept with heatpipes showed its superiority.
- Both stack designs have also been tested with real wood gas. While the sealless sealing concept of the tubular concept could not cope with the gas fluctuations in the biogenous gas, the planar stack had a high power output. No degradation due

to the operation on biogenous gas could be detected. A total power output of 660W could be measured – which is the highest power output of a SOFC system on wood gas reported in open literature.

- The long term testing was delayed due to problems at the blue tower of DM2. PSI took over as a new partner and installed the Siemens testing facilities at its gasifier in Switzerland. The testing is very successful and still ongoing. So far, very low degradation due to woody gas has been detected.
- The socio-economical studies such as a thermodynamical study, a market study and a cost analysis all showed the feasibility of such system. The TopCycle system is indeed a very promising system which should be pursued in future.
- Last but not least: dissemination activities have accompanied the whole project. The summer school was a great success and will hopefully be continued!

4. References

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