REDUCTION OF GREENHOUSE GAS EMISSIONS THROUGH FUEL CELL COMBINED HEAT AND POWER APPLICATIONS

U. Birnbaum[1], M. Haines[2], J.-Fr. Hake[1], J. Linssen[1]

[1] Forschungszentrum Juelich GmbH
Institute of Energy Research Systems Analysis and Technology Evaluation
52525 Juelich, Germany
jfh@fz-juelich.de

[2] IEA Greenhouse Gas R&D Programme;
Stoke Orchard; Cheltenham; Glos. GL52 7RZ; UK

INTRODUCTION

Global energy availability and sustainable development is a big challenge and efforts have to be undertaken in all energy consumption sectors.

Heat and electricity generation are one of the most important energy consuming categories, which still have a large potential for improvement of efficiency. This advancement would help to reduce carbon dioxide emissions.

It is expected, that combined heat and power production can deliver a substantial contribution to CO_2 emission reduction. Fuel Cell systems are able to produce combined power and heat in an efficient way. Because of the electrochemical reaction principle of fuel cells, the fuel cell is characterised by particularly high electrical efficiencies and low emissions. The technical realisation and application of these systems could be an essential contribution towards a sustainable and resource saving energy supply system.

The report analyses the possibilities of fuel cells entering into the stationary market by analysing the conditions and requirements. The goal is to find out if the application in the residential sector can cause a significant reduction of carbon dioxide emissions.

Fuel cells for distributed generation of heat and power represent a technology for decentralised energy supply in the residential and services sector. To come into the market they have to overcome the competition from other technologies.

COMBINED HEAT AND POWER SYSTEMS

Combined heat and power (CHP) means the simultaneous generation of thermal and electrical power in one system. In comparison to the separate generation of heat in a domestic heating system and electricity supply from the public grid, CHP-systems have the potential to save primary energy. The main reason for this saving potential is the use of the waste heat which is normally unused by thermal energy conversion systems. For small decentralized CHP-systems, avoiding network losses is an additional positive aspect. Figure 1 compares the typical fuel input needed to produce 30 units of electricity and 60 units of heat using conventional separate heat and power generation on the left side and CHP technology on the right side.

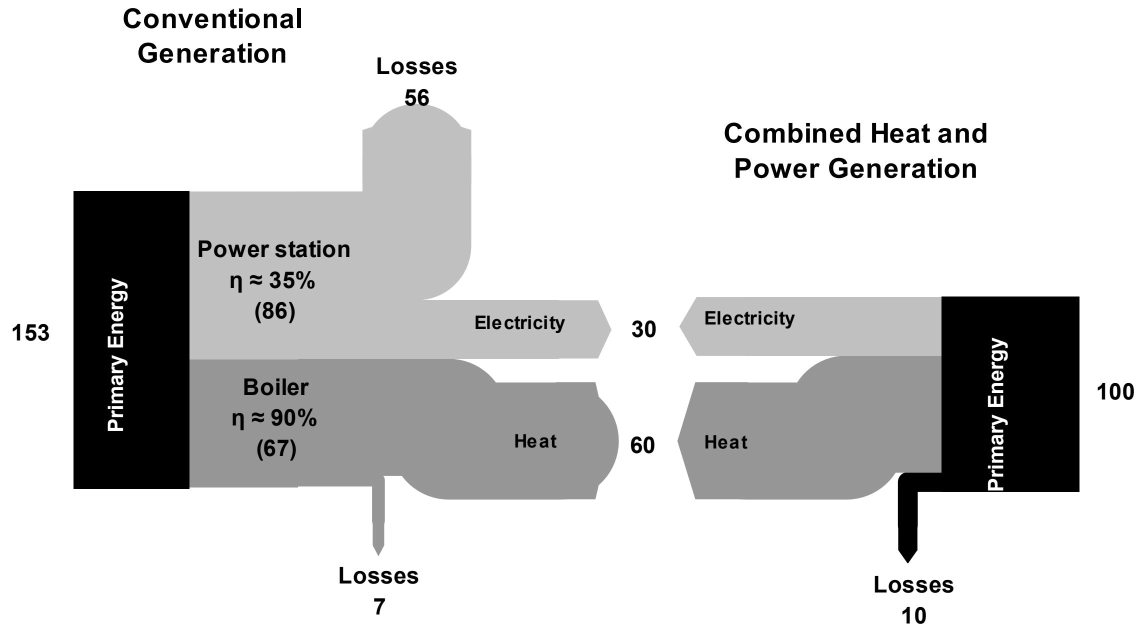

Figure 1: Separate vs. Combined Heat Power production

Because of the simultaneous generation and the very limited and expensive possibilities to store electricity immediate utilisation of the generated electrical power is needed.

CHP systems can follow either the heat or the electrical power demand. Micro-CHP-systems which were treated in this study generally run as heating appliances, providing space heating and warm water in residential, suburban, rural or commercial buildings. Any electricity not consumed is fed into the public grid.

DIFFERENT MICRO-CHP-SYSTEMS

For micro-CHP-systems several technologies have been developed:

Internal combustion engines: Conventional combustion engines coupled with a generator and heat exchangers to recover the heat of the exhaust gas and the cooling cycle.

Stirling engines: Thermal engines by which the heat is generated in a separate combustion chamber (external combustion engines). They are also equipped with a generator and heat exchangers.

Micro gas turbines: Small gas turbines belonging to the group of turbo machines up to an electric power output of 300 kW_{el}. In order to raise the electrical output micro gas turbines are equipped with a recuperator (heat/heat exchanger). They are also equipped with a regular heat exchanger in order to use the waste heat from the exhaust gases.

ORC: The Organic Rankine Cycle (ORC) is similar to the cycle of a conventional steam turbine, except for the fluid that drives the turbine, which is a high molecular weight organic fluid. The selected working fluids allow low temperature heat sources to be exploited efficiently to produce electricity in a wide range of power outputs (from few kW up to 3 MW electrical power per unit).

Fuel Cell Systems: With regard to the requirements and possibilities in the residential market, two fuel cell types are investigated, developed and tested in-depth. These are the Proton Exchange Membrane Fuel Cell (PEMFC) and the Solid Oxide Fuel Cell (SOFC).

Various other technologies, such as steam engines, thermoelectric devices, etc. are still under development. While reciprocating units are already commercially available, Stirling engines, ORC, micro-gas turbines and Fuel Cells are at field-testing or demonstration stage.

When considering new heating systems, which fulfil the requirements of the users and of a sustainable energy supply, fuel cell technology has come into play. It has a relatively high electrical efficiency, based on electrochemical reactions. That principle guarantees a very low emission level of the fuel cell itself. Only auxiliary systems like reformer or after burner produce emissions at a low level, like CO_2, CO, NO_X or others. A further advantage is the fact, that fuel cells are constructed as modules (cells and stacks) which opens the possibility to vary the capacity by combining less or more modules.

SCENARIO CALCULATIONS

With regard to international R&D activities in fuel cell systems, it can be said, that one focus is the application in the residential sector. This sector is responsible for nearly 8 % of the today's world carbon dioxide emissions [UNFCCC 2008].

In the Annex I countries of the United Nations Framework Convention on Climate Change (UNFCCC) room heating and hot water preparation are main sources for carbon dioxide emissions and it is seen as essential to introduce highly efficient generation systems which can deliver a noticeable contribution to GHG emission reduction.

Fuel cells are seen as such energy conversion systems and worldwide many companies are developing small fuel cell house heating systems. So far this part of the analysis concerns the application of fuel cell systems as house energy generation units. A typical capacity range for house heating fuel cells is 1-3 kW_{el} and 4-8 kW_{th}. The system is completed by an integrated condensing gas burner which ensures the supply of the household heat demand at peak load.

First step of the scenario calculation was the gathering of heat consumption data for different single and multi family houses and the status quo of heating systems in the OECD regions. That market segment seems to be predestined for the deployment of fuel cell systems for electricity and heat supply. Therefore data on the sales of house heating systems from the market report of Bosch Thermotechnik GmbH (BBT 2006) are used. With the data of this report it was also possible to identify future market developments.

The report estimates the 2006 world market volume of thermo technical appliances as space heating systems, water heating systems and technologies using renewables as 24.4 billion Euro. The classic heating systems have a share of 49% of this. The share of the renewable systems like heat pump and others is not yet spectacular, but their growth rate is is. Currently these systems have double-digit growth rates, and a further increase is expected by the manufacturers.

Within the category "Classic Heating Systems", the demand for house heating systems containing gas/ oil fired boilers is world-wide still the strongest. They have a volume of ~5 billion Euro (= 43% at the total sales of 11.9 billion Euro).

The condensing boilers currently have double-digit growth rates partly triggered by governmental obligations (for example in Great Britain) and a continuation of this trend is expected. The main market for this technology is Europe where ~90% of the systems are sold.

The Building Services Research and Information Association (BSRIA), UK, did publish in 2006 the study "World Market for Heating (2005)" (BSIRA 2006). BSRIA sees a rising volume of the world domestic boiler market, which has a volume of ~10 million units in 2005. For 2010 they expect nearly 12 million units sold. The non-condensing boilers represent still ~50% of the total market in volume, whereby a decline is expected for the future, as by the BTT market report. Actually the sales of condensing boilers are growing at a rate of over 15% per year so that this technology is expected to reach a share of 27% by 2010.

With our considerations for the market introduction and spreading of fuel cell heating systems we assumed a successful development of marketable and competitive systems within the next 6 to 7 years, which can be operated reliably at home. In order to find out, whether it is possible to contribute to the reduction of carbon dioxide emissions in the residential sector, we assume a market launch in 2014. This approach is based on different Japanese and European prospects. In Japan the application of small fuel cell systems for the residential sector is widely advanced and ~2,200 units are under operation. All these units are part of a large-scale demonstration project. The Japanese specialists are expecting a cumulated installed capacity of 10 GW at ~2020, while the European Hydrogen and Fuel Cell Technology Platform (HFP) sees ~ 10,000 installed units up to 2015.

Due to these expectations we decided to calculate the market adoption of the fuel cell house heating systems in the OECD using a logistic function which describes the correlation between the market penetration of a product and the time until saturation. Two scenarios were developed, a low one where the fuel cell systems will reach a market share of 5% and a high one where the share reaches 20% of all house heating systems sales, see left part of figure 2. In both scenarios the introduction starts in 2014 and reaches its saturation in 2030, whereby the sales will not remain at the 2030 values, they will increase further according to the total sales of house heating systems.

The total number of heating systems sold in 2050 is in the range of 16 million systems. The introduction into the mass market starts in 2014 with nearly 6,000 units for the low penetration scenario. The sales graph achieves an exponential rise and has a point of inflection at around 2020. The maximum market share is reached at around 2030. In 2030 ~630,000 fuel cell house heating units are sold so that around 4.6 million units are operated worldwide.

The high scenario is characterized by a more dynamic development of the fuel cell system sales. It starts with nearly 70 thousands in 2014, comes up to 2.5 million units in 2030 and ends with 3.2 million sold units in 2050.

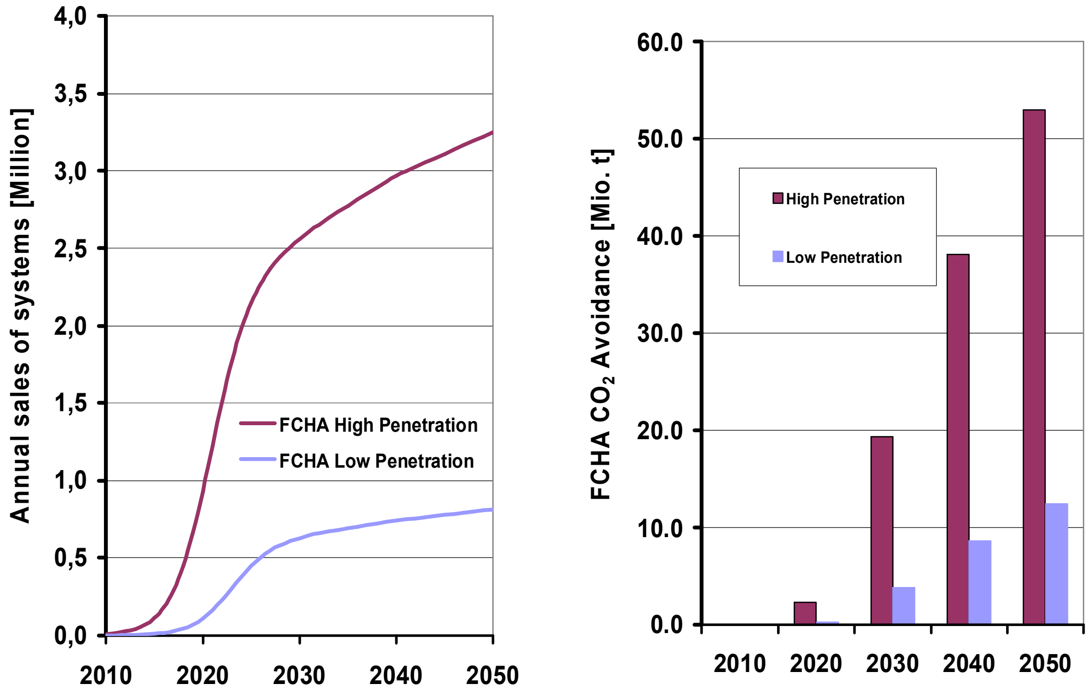

Figure 2: Sales of Fuel Cell Heating Appliances (FCHA) and CO_2 avoidance, OECD

The heat demand for the houses was taken from a calculation for a detached single family house. The house has a living space of 140 square meter and a cubic contents of 528 m^3. The fuel cell has an average electrical capacity of about 1 kW_{el} and is supported by an integrated peak burner/boiler and a hot water storage, which will ensure the supply of the heat peak demand. The calculations for heat demand takes into account different climatic conditions and different system layouts and thus is an average number for the OECD case.

The CO_2 reduction potential is calculated in comparison to state of the art natural gas fired boilers and electricity consumption out of the grid. For the development of energy prices, CO_2 emissions of the power plant sector etc. the scenario of the IEA [IEA 2006] are assumed and supplemented.

Under these assumptions a CO_2 reduction for the deployment of Fuel Cell Heating Appliances in the residential sector can reach between 14 to over 50 million tonnes of CO_2, right part of figure 2. That corresponds to a reduction of emissions from 1 to nearly 4 % of the emissions in the residential sector of the OECD.

REFERENCES

BBT 2006, Bosch Thermotechnik GmbH, Marktreport 2006- Energie effizienter nutzen, http://www.bosch-thermotechnik.de/sixcms/detail.php?id=2326456

BRISA 2006, Building Services Research and Information Association (BSRIA) UK, World Market for Heating 2005, www.bsria.co.uk

UNFCC 2008, United Nations Framework Convention on Climate Change, database, http://unfccc.int/ghg_emissions_data/items/4133.php

IEA 2006, International Energy Agency, World Energy Outlook 2006, www.worldenergyoutlook.org