Cost-Efficiency of a CHP Hydrogen Fuel Cell

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Abstract
The project H2home - decentralized energy supply by hydrogen fuel cells - is part of the HYPOS initiative (Hydrogen Power Storage & Solutions East German) and will develop an embedded system suitable for the highly efficient use of electrical and thermal energy, provided by green hydrogen in domestic applications. This system is characterized by a hydrogen CHP plant based on a low temperature PEM fuel cell; a hydrogen-based heat generator module with the application of condensation technology and an integrated solution for the use of electrical energy in an AC and DC grid through power electronic components. The electric efficiency of the CHP is higher than 50% and the total efficiency higher than 95% (related on the low heating value [LHV]).

The first step was the identification of possible fields of application with the help of the simulation tool TRNSYS. The results showed favorable economic conditions for the CHP operation in apartment buildings, hospitals and nursing homes.

With these simulation results, the parameters of an economical operation were determined by a parametric study based on at least 5.000 full load hours, a private consumption share of electrical energy with more than 80%, full consumption of the generated thermal energy, hydrogen costs similar to natural gas costs as well as the low investment costs. The most relevant parameter is low-cost hydrogen.

Keywords: Hydrogen; Fuel cell; Combined heat and power; Building energy supply; TRNSYS

I. Introduction

With the climate protection plan published in October 2016, the German government specifies the realization of COP 21 at national level. Covering all relevant sectors, a part of the plan outlines the decarbonisation process for the German economy. Therefore the plan identifies six different sectors: energy sector, building sector, mobility sector, industrial sector, agricultural sector and the land use sector. Furthermore, the plan sets the following three goals: (1) general increase of energy efficiency, (2) expansion of the energy supply by renewables for all sectors and (3) linkage of all relevant sectors with different technological possibilities (cross-sectoral). Accordingly, the plan refers to the application of Power-to-Gas and Power-to-Liquids technologies.

The HYPOS initiative (Hydrogen Power Storage & Solutions East German) aims the development of a sustainable hydrogen economy in east Germany. Because of several unique position features the project has defined a ‘core region’ with the highest probability of implementation of the hydrogen applications. Besides the high surplus of wind- and solar energy there is the second largest hydrogen pipeline in Germany (length: 157 km), a major part of Germany’s chemical industry and storage caverns in the immediate vicinity. The actual hydrogen demand in the region with the highest need inside the core region can be summarized as followed: 54 consumers in total and a demand of 4.8 billion m^3/a hydrogen (76 % of regional demand in the core region).

HYPOS, as a network open to all sorts of members from the hydrogen community with 120 partners, has the mission to develop an indispensable hydrogen network by combining expertise from SMEs, large companies and scientific institutions, reflecting the research tasks necessary to achieve the goal of the economically integration of renewable energies into an existing infrastructure of gas pipelines and gas storages in East Germany.

A very promising concept in the field of micro-cogeneration plants is the fuel cell combined with heat and power (CHP) plants for the use in the building energy supply. A proof of function in the building sector was given by the completed national project CALLUX (field test of fuel cell for home ownership, 500 units in Germany) and the ongoing European project ene.field (which will deploy up to 1,000 residential fuel cell micro-CHP installations across 11 key European countries).

If a fuel cell CHP is operated with pure hydrogen, advantages are obtained due to the higher efficiency and lower emissions. The required hydrogen can be generated by the electrical energy surplus of the renewable energies. The final hydrogen carrier is already available today in some parts of Germany, especially in the field of industrial parks, in corresponding hydrogen networks. Because of the increasing possibility of the use of excess electrical energy from wind parks and photovoltaic plants for the electrolysis in the future, hydrogen networks with regenerative hydrogen will be generated in the foreseeable future.

A part of the HYPOS initiative is H2home (decentralised energy supply by hydrogen fuel cells). In the present paper the aim and the current state will be presented.

II. Description of the H_2 fuel cell CHP

Hydrogen supplied buildings are a promising option for the prospective energy supply with renewable energies (in particular photovoltaics and wind power). When electrical overcapacities are occurring, there will be a production of hydrogen by electrolysis. The hydrogen is then transported through a pipeline to the consumer, where it will be used as efficient as possible.

The R&D project "H2home" (decentralized energy supply with hydrogen fuel cells) is developing a hydrogen based system for the prospective and efficient energy supply with electrical, thermal and cooling energy in buildings.

That system consists of a hydrogen fuel cell CHP (H2-CHP) based on a PEM fuel cell, a hydrogen condensing boiler and an integrated system for the use of the electrical energy in an AC and DC network. The electrical efficiency of the CHP is over 50 % and the overall efficiency is over 95 % (related on the calorific value).

Thus, the project H2home will develop an embedded system suitable for the high efficient use of the complete home energy supply (electrical, heating and cooling energy) provided by 100 % 'green' hydrogen in domestic applications.

Figure 1 shows a schematic representation of this concept.

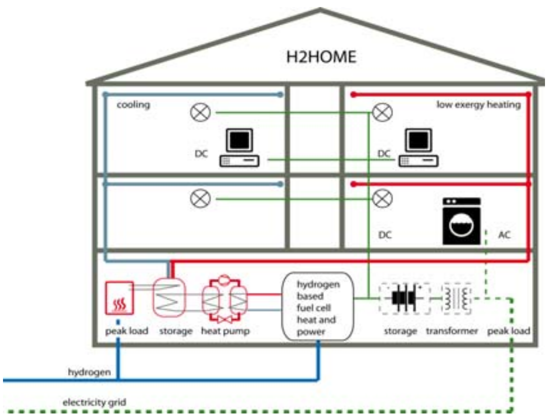

Figure 1: Schematic overview of the H2home concept

III. Energetic and economic modelling

The simulations in this work have been carried out using the TRNSYS® program (Solar Energy Laboratory of the University of Wisconsin) for simulating energy and material flows in buildings. TRNSYS® is suitable for the project requirements due to the possibility to integrate three-dimensional building structures into modelling, to interlink boundary conditions and to picture complex systems, such as a hydrogen fuel cell CHP.

The building model is a four-storey multi-family house (MFH) consisting of 16 residential units. On each floor four apartments are arranged. Each residential unit was presented as a zone to be simulated in TRNSYS®, resulting in 17 simulation zones (16 apartments and top floor). In Figure 2 the residential building model can be seen. Table 1 shows the energetic characteristics according to DIN V 18599.

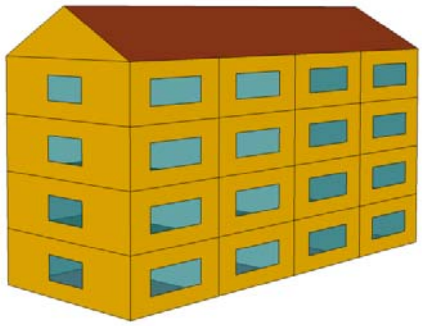

Figure 2: 3D residential building model

After simulating the reference buildings (energetic modelling), the next step is the definition of other energy supply concepts. The energetic assessment of the monthly values on the basic of existing standards have to be carried out (in particular DIN V 18599 'Energetic assessment of buildings - Calculation of the useful, final and primary energy requirements for heating, cooling, ventilation, drinking water and lighting').

There were detailed investigations to identify the overall costs for an apartment house with 16 apartments and a heat and water demand of 80,000 kWh/a. In addition, the electricity requirement of 3,000 kWh/household was regarded.

Table 1: Important usage conditions and energetic characteristics according to DIN V 18599

Conditions	*Unit*	*MFH*
Daily usage time	-	00:00 – 24:00
Annual usage days	d	365
Room temperature heating	°C	20
Room temperature cooling	°C	25
Daily operating time heating	-	06:00 – 23:00
Air exchange	1/h	0.6

IV. Result

In contrast to other energy sources (natural gas, oil, electricity, wood pellets) the production costs of hydrogen vary widely. Thus, the numerous results are evaluated statistically (lower quartile, median, upper quartile) and are used for further analysis.

Figure 3 shows the specific energy demand of different supply systems in usable energy, final energy and primary energy. Furthermore the specific CO_2 emission are plotted. The variants distinguish only in supply system. Thus the usable energy is identical for all variants. The final energy demand varies in a follow of plant efficiency and the usage of renewable energy like solar thermal and geothermal energy.

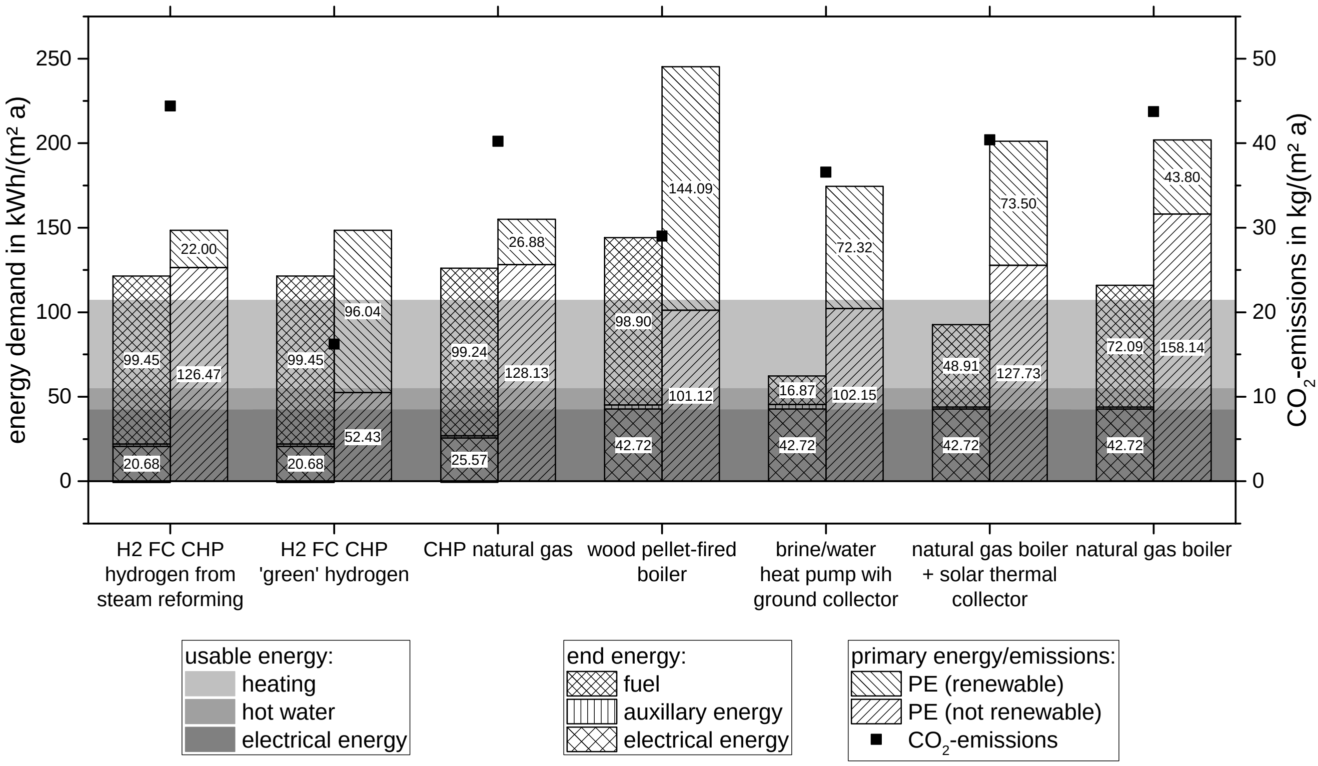

Figure 3: Comparison of energy accounting of different variants

Both the primary energy demand and the CO_2 emission of H2home concept are the lowest one of all compared systems.

The following, two process routes of hydrogen production are investigated in detail [1-4]:

- Production of hydrogen from natural gas by centralized steam reforming (0.042 €/kWh) as typical reference case as well as
- Production of 'green' hydrogen by electrolysing with energy produces by wind turbine (0.150 €/kWh) as the promising new production way.

Grid costs of 0.015 €/kWh (transportation costs from supplier to building) have been added to the calculation of total costs [5].

The economic analysis was calculated according the german standard to VDI 2067. The capital costs, operation costs, consumption costs and revenues for grid feed including the compensation according to CHP Act (KWKG) were taken into account. Results are shown as total costs per m² usable area (see Figure 4).

Currently 'green' hydrogen is about three times more expensive than hydrogen generated in steam reforming plants. It can be assumed that it will be realistic to reduce the costs of 'green' hydrogen significantly reaching costs similar to conventionally produced hydrogen in the future.

The cheapest supply concepts are the natural gas boiler and the H_2 fuel cell CHP by using hydrogen from centralized steam reforming. Using 'green' hydrogen is more expensive than wood pellets boiler or heat pumps. Consumption costs of electricity from grid could be reduced by about 50 % (that means the decrease from 12.42 €/(m² a) to 6.01 €/(m² a), using an H_2 fuel cell CHP in combination with a hydrogen burner.

With the use of "green" hydrogen, the costs will increase and will be slightly over the costs of a wood pellet boiler or the heat pumps.

In conclusion, the calculated costs of the different energy supply concepts are similar to other studies [6-8].

The energy supply for buildings with hydrogen is a promising option under the following requirements:

- Production costs of hydrogen are similar to natural gas costs.
- Hydrogen is available and is transported through a pipe based network. The costs for that system are comparable to other energy carriers.
- There is a H2 fuel cell CHP with the electrical efficiency of about 50 %, a high overall efficiency and low specific invest costs.
- The produced electrical energy will be used more than 80% in the building.
- The H2 fuel cell CHP has a high operating time of at least 5.000 full load hours.

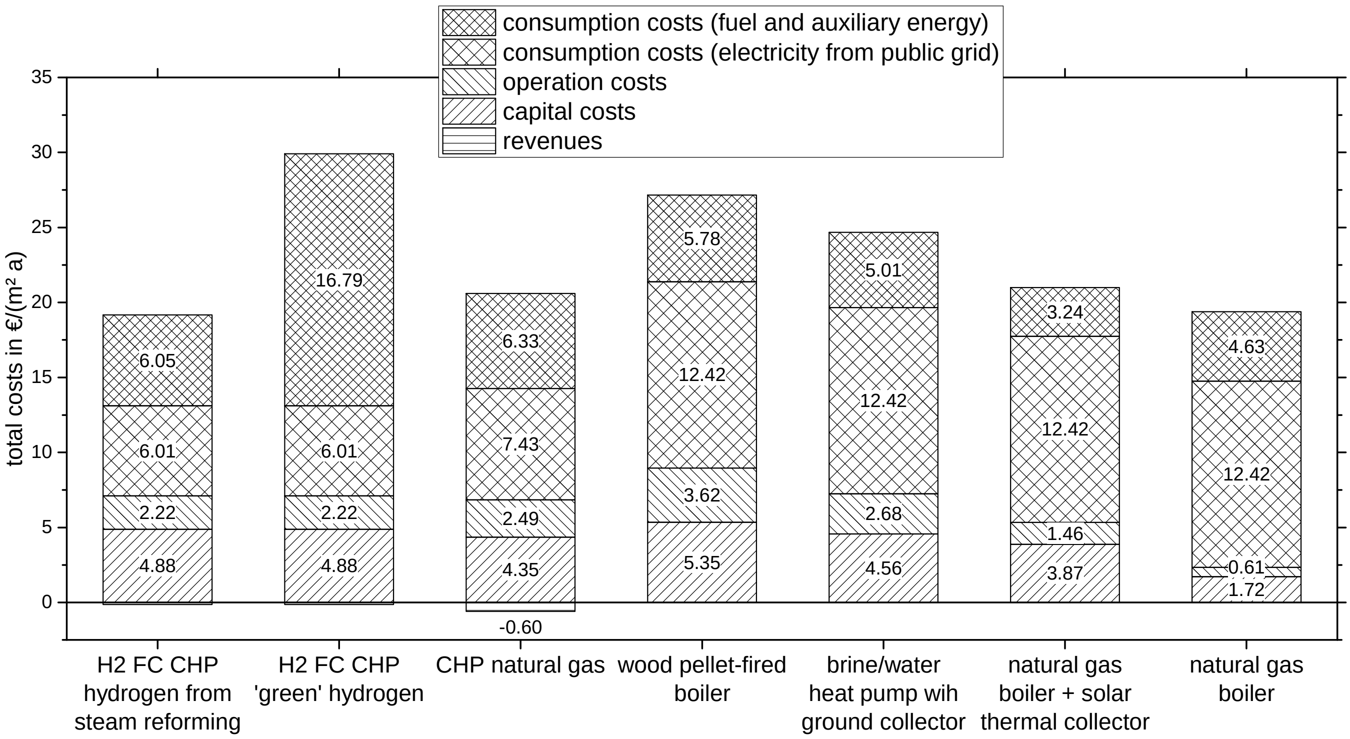

Figure 4: Schematic overview of the H2home concept

With these specified requirements, hydrogen supplied buildings are a realistic and energetically, economically and ecologically useful for the prospective energy supply of buildings.

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