УДК 621.6

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REDUCTION OF ENERGY CONSUMPTION BY USING LOW-TEMPERATURE FUEL CELLS

Limited resources, CO_2 debate and protection of our environment are subjects of public discussion nowadays. There is a consensus that the efficient use of energy will be one of the challenges with the highest priority in the future. From building services engineering to passenger and freight transport – there will be significant changes in all areas of daily life.

The world energy consumption in 2008 was met with more than 84.8 % by fossil fuels (figure 1). Currently, the elimination of fossil fuels cannot be compensated by renewable energy sources. But this should be the case in the next decades. Then a solution must be found to guarantee the energy supply without fossil fuels. According to [1], the maximum delivery rate of today's common energy sources will be achieved in the years between 2015 and 2025. From that point, the delivery of these substances will be declining, due to scarcity of resources and difficult conveying conditions.

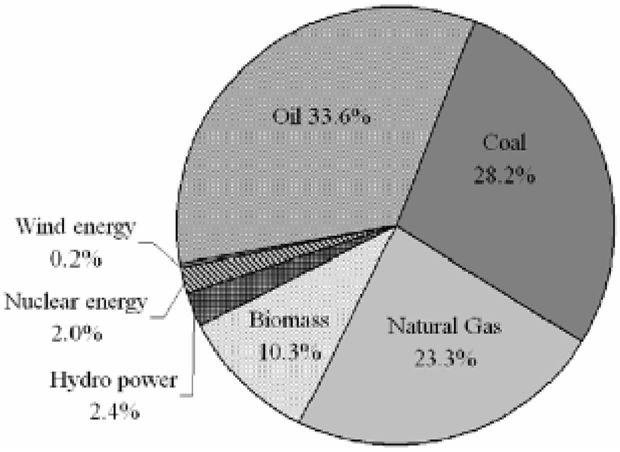


Fig. 1: World Energy Consumtion 2008 [1]

To meet the increasing energy demand it requires a substitution of fossil fuels through renewable energy sources. Furthermore, it is important to increase the efficiency of energy conversion processes for both stationary and mobile applications. This may also mean that currently used technologies for energy conversion must be replaced by seminal technologies. For example using natural gas, if this is not burned as usual, but reformed into hydrogen and thereafter into electricity by a fuel cell, much higher efficiencies can be achieved. The thermal energy produced by thermal engines first has to be converted into mechanical and afterwards the energy can be converted into electrical energy. A fuel cell provides directly heat and electrical power.

Use of fuel cells to increase energy efficiency: Fuel cells are electrochemical conversion devices, which produce electrical and thermal energy directly from chemical energy. Low-temperature fuel cells, such as the Alkaline Fuel Cell (AFC) and the Polymer Electrolyte Fuel Cell (PEMFC), produce electricity and heat from hydrogen and oxygen and the only byproduct is water (see equations 1 to 6).

AFC: Anode: $H_2 + 2OH^- \rightarrow H_2O + 2e^-$ (1)

Cathode: $1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$ (2)

Total: $H_2 + 1/2O_2 \rightarrow H_2O$ (3)

PEMFC: Anode: $H_2 \rightarrow 2H^+ + 2e^-$ (4)

Cathode: $2H^+ + 1/2O_2 + 2e^- \rightarrow H_2O$ (5)

Total: $H_2 + 1/2O_2 \rightarrow H_2O$ (6)

A big advantage of the mentioned fuel cell types is that they are not bound to a stationary operating point, like batteries. Depending on the electrical or thermal need they can be operated over a wide power range. Thereby the voltage is a function of the flowing current (polarization curve). The Well-to-Wheel efficiency (WtW) will increase by using fuel cells in vehicles. The WtW efficiency contains all the losses of the entire energy chain. Figure 2 shows the WtW efficiencies of several drive systems. The dark grey areas represent the worst case and the light grey areas represent the best case. For the fuel cell (FC H2) in the worst case the hydrogen is manufactured by electrolysis with the electrical power out of coal-fired power plants and in the best case it is from reformation of methane. For the battery vehicle (Battery) the electrical power comes from coal-fired power plants in the worst case and from hydropower in the best case. The black crossbars represent the average values from the electricity mix of the European Union [2].

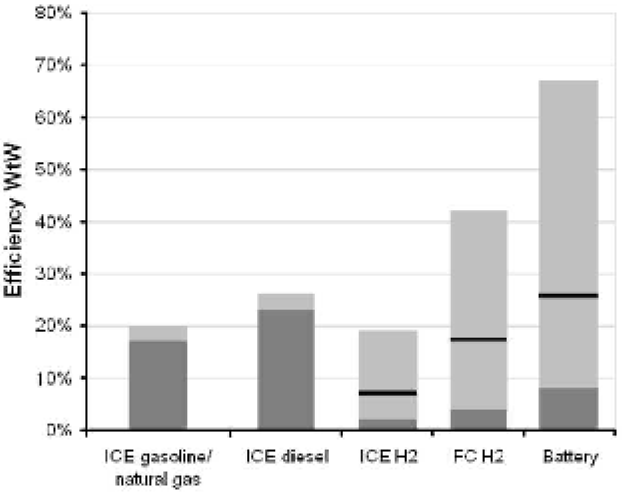


Fig. 2: Well-to-Wheel efficiency [2]

Battery vehicles can achieve the best WtW efficiencies. However, their small driving range is still a big problem. For a time there was talk of battery and fuel cell vehicles as competing technologies. Meanwhile, fuel cells and Batteries are seen as complementary. The combination of fuel cell and battery in a vehicle will have the advantage of both technologies and will minimize their disadvantages.

Nowadays heat produced by an onboard fuel cell is not utilized, so the electrical efficiency of the fuel cell plays an important role in total electrical vehicle efficiency. However, if a fuel cell is used as a cogeneration unit for building supply, then the thermal efficiency must be considered when evaluating the total efficiency.

The equations 7 and 8 describe a reversible case. Based on these equations the thermal and electrical power can be calculated. Equation 9 describes the irreversible case. Based on this equation the real cell voltage can be calculated by subtracting the losses from the reversible cell voltage. The losses will be dissipated in form of heat.

$$P_{el} = -\frac{I}{z_e \cdot F} \cdot (\Delta g_R) \tag{7}$$

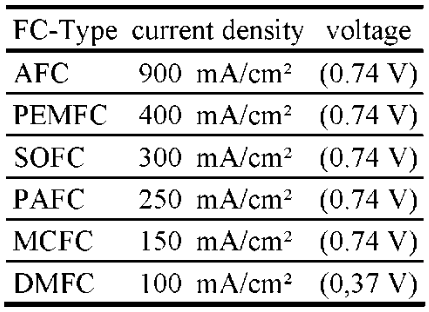
$$\dot{Q} = -\frac{I}{z_e \cdot F} \cdot \left(\Delta h_R - \Delta g_R\right) \tag{8}$$

$$U_{cell} = U_{rev} - \left(\left|\eta_a(j)\right| + \left|\eta_c(j)\right| + R_e \cdot j\right) \tag{9}$$

The used energy carrier (hydrogen) can be completely converted into heat and electric power by a fuel cell. According to [3] there are only 10 % losses when using a fuel cell cogeneration unit. On average, 30 % are converted into electrical energy and 60 % into heat. So the costs will be reduced by using such decentralized power plants. At the same time the overall efficiency will be improved because of the co-generation of electricity and heat.

Selecting the appropriate fuel cell type: In principle all fuel cell types can be used for stationary applications. For mobile applications one fall back, due to the operating temperature and the system engineering, on low-temperature fuel cells such as the Direct Methanol Fuel Cell (DMFC), the AFC or the PEMFC.

The DMFC is similar to the PEMFC but operated a slightly higher temperature to improve the power density. It is appealing because of the use of methanol, which has a high energy density and is easy to handle. Also there is no need for gas humidification, air cooling and reforming. However, it has the worst performance data (see table 1) and the electrical efficiency of 20 – 30 % is not convincing. A Disadvantage is that CO_2 is formed as a byproduct of the chemical reaction.



FC-Type	current density	voltage
AFC	900 mA/cm²	(0.74 V)
PEMFC	400 mA/cm²	(0.74 V)
SOFC	300 mA/cm²	(0.74 V)
PAFC	250 mA/cm²	(0.74 V)
MCFC	150 mA/cm²	(0.74 V)
DMFC	100 mA/cm²	(0,37 V)

Table 1: Current density of different FC-Types [4]

The PEMFC is the most advanced low-temperature fuel cell type. The operating temperature is between 60 – 120 °C. It has a membrane (ionomer membrane) as electrolyte and can be operated with ambient air. This makes it easy to implement a PEMFC in systems. However, the material and manufacturing costs of individual components make it considerably difficult to enter the market. For example, cost-intensive technologies are used in producing the Membrane Electrode Assembly (MEA) and the expensive platinum is used as catalyst. The costs of the bipolar plates are still a major part of the stack price (30 – 50 %) [5, 6]. Considering the availability and delivery volume of platinum, the platinum price will rise because of higher demand in the future. It is clear that the cost share of the bipolar plates will be reduced for the higher proportion of catalyst costs [7].

The development of AFC has been done with little effort because of the CO_2 intolerance and the liquid electrolyte. In a typical AFC a KOH solution is used (in concentrations of 30 – 45 %) as electrolyte. The advantage by using a KOH electrolyte is that the oxygen reduction kinetics are much faster than in a acid fuel cell like the PEMFC [8]. The problem is that potassium hydroxide reacts with CO_2 from the air and form potassium carbonate (K_2CO_3**)**, whereby at the beginning the efficiency of fuel cell decreases and finally the electrochemical reaction comes to a standstill. On the one hand the supply of reaction gases is disabled and on the other hand the conductivity of the electrolyte is reduced.

Through recent research activities membranes appeared on the market, which can be used to replace the liquid electrolyte in an AFC. Both types of membranes are available, those that serve as carriers for the caustic potash solution and those whose operation is similar to the membrane in the PEMFC. The weightiest issue regarding to mass production is that nickel can be used as catalyst. The company CellEra is working on the development of their so called Platinum Free Membrane Fuel Cell (PFMFC, see figure 3). It is an alkaline fuel cell, in which a membrane is used as electrolyte.

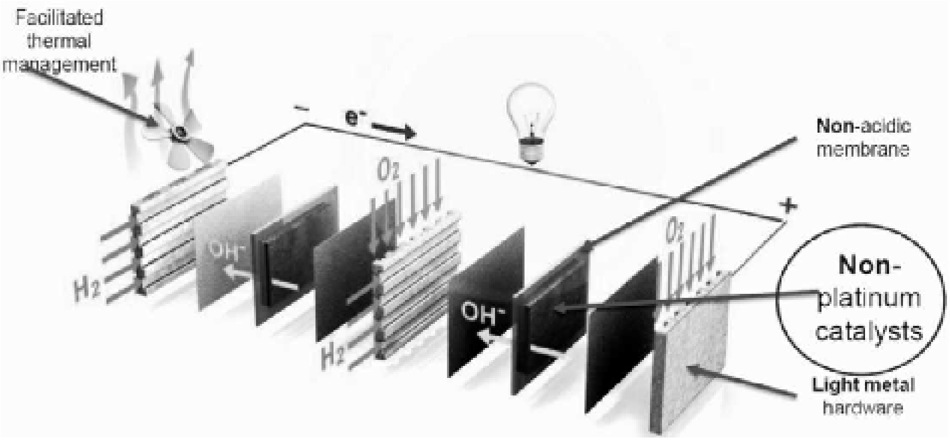


Fig. 3: PFMFC by CellEra [9]

At the beginning CellEra met the CO_2 intolerance mainly by using two CO_2 filters. In a reversible process, CO_2 from air is filtered. While one filter clogs up the other is regenerating. In the second quarter of 2010 CellEra was able to run the PFMFC without additional CO_2 filters [9]. Now, they succeed in reliably producing 1 kW fuel cell stacks without platinum, which operate with hydrogen and air.

Comparing the PFMFC with the above mentioned low-temperature fuel cells, it clearly to see that it can be a favorable alternative to the PEMFC, although it is still in its infancy. The main criterion is the price: The costs for a PFMFC are around 420 €/kW, compared to 1,400 €/kW for PEMFC [9]. This mainly due to the use of a not acidic membrane with the result of advantages in selection of the Materials. A forecast of future price trends for higher production volumes is shown in figure 4.

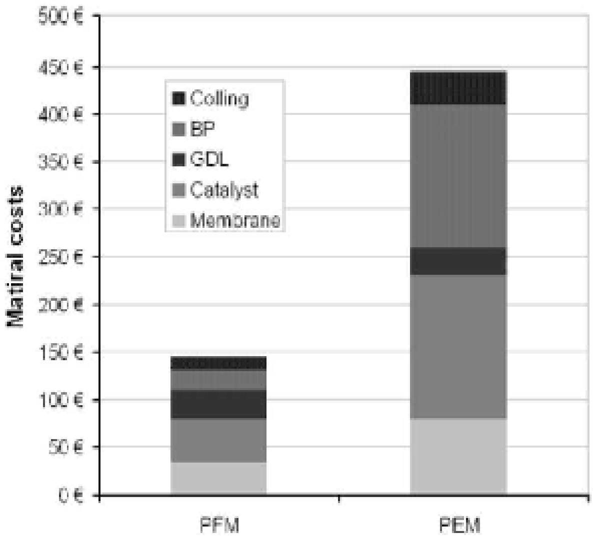


Fig. 4: PFM vs. PFM, comparison of in future possible material costs in €/kW [10]

The Institute of Fuel Cell Technology (IBZ) sees the chances of this new fuel cell and took up the research work in this area. In the first phase single fuel cells will be built up to examine stationary modes under various conditions. Several tests will be carried out with different membranes, catalysts and reaction gases with the aim to find opportunities for improvements.

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