UNIVERZITA J. E. PURKYNĚ V ÚSTÍ NAD LABEM

TU WIEN

Hydrogen: Fuel for Cars

Barbora Řehořová
Thomas Kopf

Co-operating Universities

UNIVERZITA J. E. PURKYNĚ V ÚSTÍ NAD LABEM

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Content

1. Introduction and General information

This paper was part of the Winter/Summer-School exchange student program of Austrian and Czech students. The work was supervised by Prof. J. Knapek from CVUT in Prague.

2. ABSTRACT

The global climatic problems and the ongoing technological progress suggest a lookout for alternative fuels. The demand for transportation is rising and the resources of fossil fuels are shrinking. The potential of alternative fuels needs to be analyzed. Because of the enormous range of this topic, the paper is focusing on hydrogen. The main approach is an outlook for applications in the regions Austria, Czech Republic and Europe. Surprisingly there are many niche implementations, where the usage of hydrogen has advantages. Nevertheless, we came to the conclusion that the technology is still too expensive and inefficient, but already shows high potential.

3. PAPER

Motivation

Technological Approach

The global climatic problems and the ongoing technological progress suggest a lookout for alternative fuels. Hydrogen shows some excellent qualities.[2] It is has a high energy density (35,7kWh/kg). The raw material is cheap (H_2O). It can be implemented in cars in different ways; combustion engines or fuel cells. The production is basically emission-free, if a photovoltaic Generator is used. This can be seen in Figure 1, which is the principle model of a Photovoltaic-Electrolysis plant. Of course any other renewable source like wind or water can be used as well. The efficiency of recent technologies is poor, but the crucial point about hydrogen is its unlimited availability.[3]

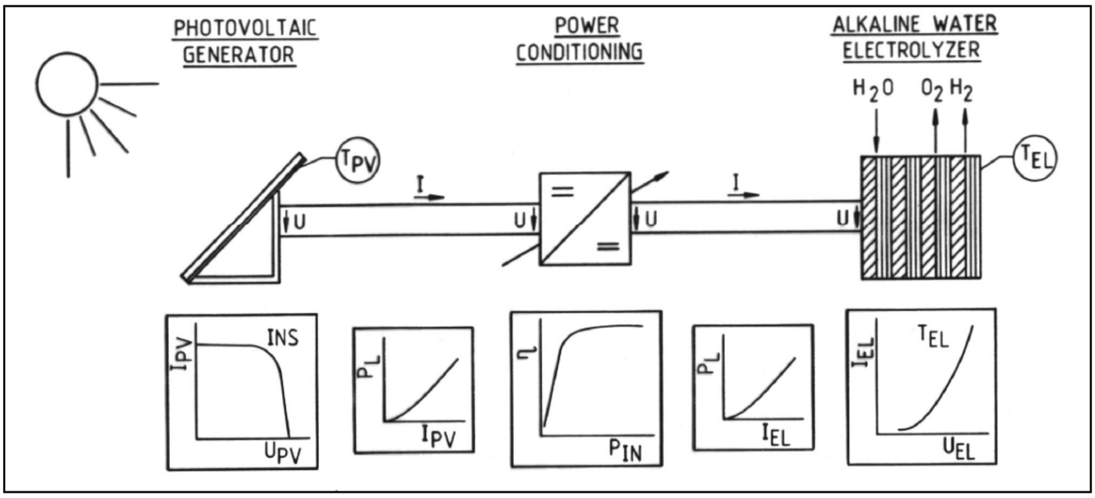

Figure 1: Principle of a PV-Electrolysis Plant [2]

Without going into detail the chemical reaction for energy production can be written as

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g).$$

This means that hydrogen (H_2) reacts with oxygen (O_2), resulting in Water and release of energy. Therefore, if hydrogen can be applied to cars, mobility can be emission-free.

But there is no free lunch in life and along advantages also come disadvantages. Although H_2 has high energy concerning its weight, it has low energy related to its volume. To be accurate 600kWh/m³ at 200 bar, which is roughly 5% of the energy density of gasoline.Considering transportation this leads to a higher amount of trucks; because more space is required. Furthermore, the infrastructure has to be renewed, because of the different properties of hydrogen. Hydrogen is a gas at temperatures above 20 K, unlike gasoline. This means that the storage has to be changed. Additionally, H_2 as a gas is volatile and it even evaporates in closed enviroments. Compression of hydrogen needs about 40% of the stored energy. Last but not least there are some safety issues. It is highly flammable, odourless and colorless.[3]

Fossil Fuels shortage and CO_2 Emissions

Looking for alternative energy sources isn't only a climatic necessity. Rising demands and decreasing amounts of obtainable sources of fossil fuels request other options. The International Energy Outlook 2014[5] states that the availability is at least granted for the next 25 years. Altough you can see that for EU-27 the petroleum consumption is dropping, in other parts of the world and in the world overall the consumption is on the rise.

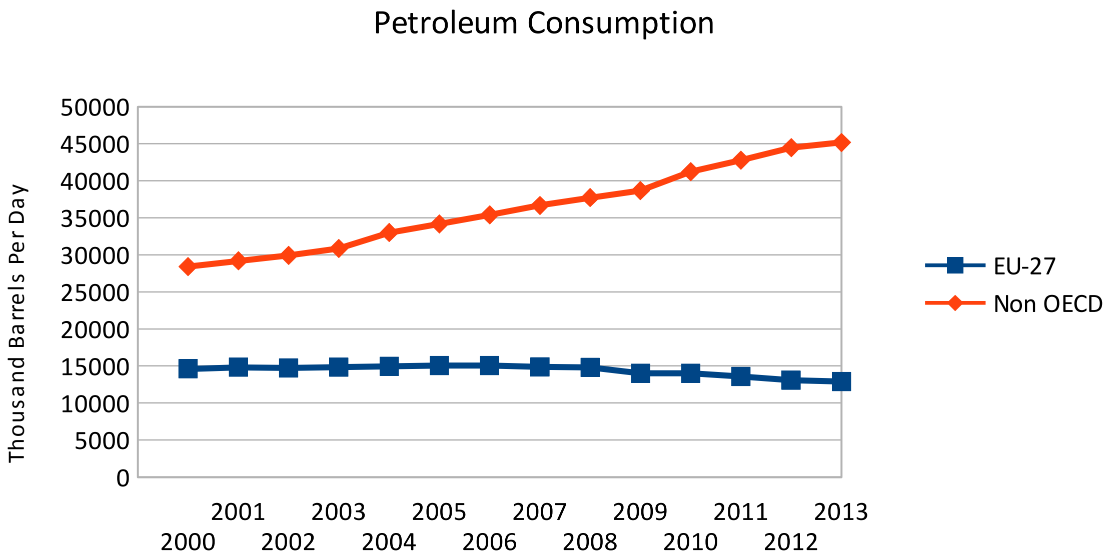

Figure 2: Petroleum Consumption: EU-27, Non OECD[6]

Figure 3 shows the CO_2 Emissions caused by the consumption of Petroleum in EU-27 and Non-OECD countries. The comparison is not fair because of the amount of people in those two regions, but there is a visible trend. The Emissions in Non-OECD countries is drastically rising, while in EU-27 it is stable.

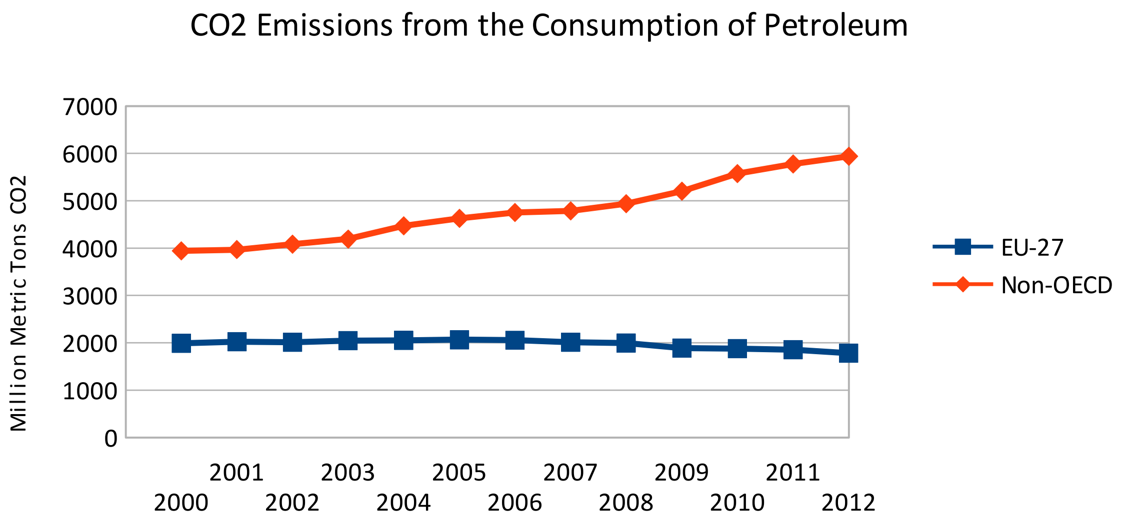

Figure 3: CO_2 Emissions[6]

Fuel cell: Working principle

The fuel cell contains both negatively and positively charged electrodes. Molecules of hydrogen enters on anode, the positive side of the fuel cell, where electrons are stripped off. Positively charged hydrogen ions are produced and pass through a proton exchange membrane, electrons cannot pass through. Electrons flow to the wire providing a direct current. The hydrogen ion combines with oxygen atoms and electrons to form water and heat. By putting several fuel cells together enough electricity can be generated to power a car. [4] Disadvantages of fuel cell are slow reaction, higher prices for installed capacity and lower efficiency in overload. Therefore, vehicles with fuel cells are designed as hybrid. Another way is to combine a combustion engine with an hydrogen fuel cell. Figure 4 shows a proton exchange membrane fuel cell schematic.

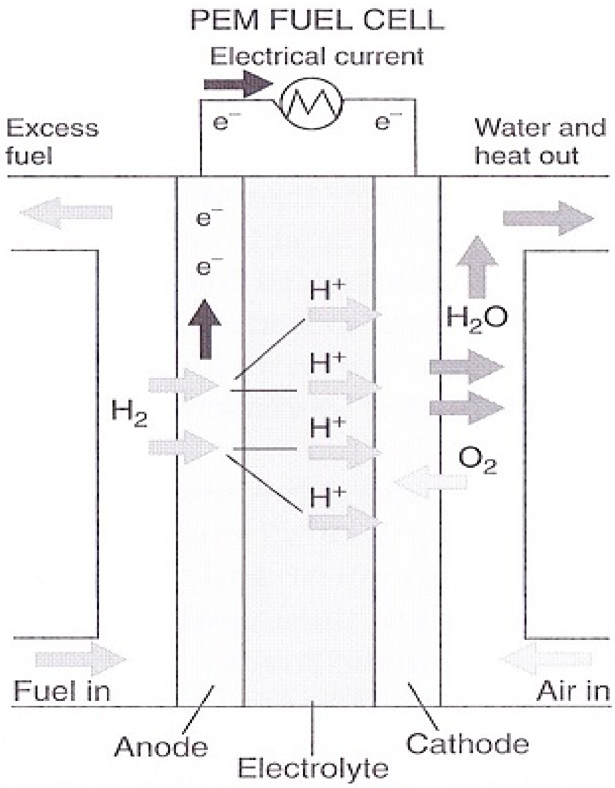

Figure 4: Proton exchange membrane fuel cell schematic [4]

Hydrogen combustion engine

The hydrogen combustion engine is a modified version of the standard internal combustion engine (ICE). According to good combustibility of hydrogen mixtures, the ingnition part of a gasoline engine is sufficient, just the injection needs to be modified. Beside hydrogen fuel cells, combustion engines achieve high efficiency at high load.

Problem statement

Is hydrogen applicable to cars? How? Is it worth it? Naturally, new technologies need to grow and diffuse through the market. But how long will it take and are there economical and ecological potent ideas in Europe – especially in Austria and in Czech Republic.

Furthermore, fueling stations will not provide hydrogen until sufficient demand exists, and consumers will not buy hydrogen vehicles unless they know hydrogen is available. [4] Can fuel cell vehicles compete economically with heat engines?

Production of hydrogen

A fundamental question is how and where the hydrogen will be produced. There exists a Hydrogen Future Simulation model, H2Sim. It considers 6 options to produce hydrogen. Steam methane reformation (SMR), coal gasification, electrolysis, non-catalytic partial oxidation (NPO) of crude oil, and thermochemical processes from nuclear or concentrated solar power technologies. Most of them are available already, just thermochemical processes are potential future option. Coal gasification makes sense for large-scale, centralized hydrogen production, while others could be also used as decentralized, small-scale solution. There are about 16 trillion cubic feet of hydrogen used in chemical and manufactoring sector. 48% is delivered from natural gas, 30% from oil, 18% from coal, and 4% from electrolysis.

The reformation of natural gas involves steam heating the natural gas under pressure in catalytic reactor. It results in hydrogen and carbon dioxide. It is option for large-scale and also small-scale production. Production economics favor large plants, decentralized plants greatly reduce distribution and storage costs. Coal gasification also utilizes high temperatures and pressures to separate hydrogen. Due to economies of scale, it makes sense only for large-scale centralized production. Electrolysis is used today to produce pure oxygen for hospitals etc. It uses positive and negative electrodes in water and water is dissociated. It offers a good decentralized option and could be used for fueling stations. The main resource is electricity. The idea is to use cheap off-peak electricity, but it is only cheap when demand for it is low, increasing demand for hydrogen production would increase the price of electricity. Partial oxydation of crude oil or natural gas, widely used by refineries, requires high temperatures, around 1300°C and pure oxygen. Thermochemical processes involve high temperature heat from nuclear or concentrating solar power to disassociate hydrogen from water. But it is still in experimenting stages.

The main reason for moving to a hydrogen economy still is to minimize carbon emissions. But producing hydrogen from coal could actually result in increased CO_2 emissions. [4]

Approach

We analyzed the current situation in Austria, Czech Republic and Europe. In particular we were looking for applications. We made the assumption that by studying the present implementations and the ecological advantages it is possible to get an overview of the potential of hydrogen as a fuel.

Results

The following chapters shows some implementation and approaches for hydrogen utilization. Particularly in Austria, Czech Republic and Europe.

Hydrogen in Austria

DB Schenker Austria[7]

The logistics company DB Schenker Austria is a prime example for profiting of the advantages of hydrogen. They set themselves the goal to become “the leading green transport and logistics provider”, therefore they use hydrogen powered indoor trucks (forklifts). This was installed by the company “Fronius” in Summer 2013. Figure 5 illustrates the supply chain. The basic idea is to use the solar energy to power the Fuell Cell Truck, without conventional batteries.

Fuel Cell vs. Battery

			Status	Target
Type		Lead Acid	H2-200bar	H2-350bar
Dimension Tray 4PzS L/W/H	[mm]	786/310/630	786/310/630	786/310/630
Nominal System Voltage	[V]	24	26,4	26,4
Current max.	[A]	450	450	450
Charging / Refuelling	[min]	>500	<3	<3
Lifetime @ Pnom=2,6kW	[h]	4.400	5.000	>10.000*
Energy Capacity	[kWh(el)]	9,6	6	9,6
Weight	[kg]	360	180	180
Operating Temperature	[°C]	-10 to +60	+2 to +60	-10 to +60

*to be confirmed

Table 1

The advantage of using hydrogen in this case is the significantly lower recharging time. Table 1 shows a comparison between a Fuel Cell and a Battery. As you can see it only takes 3 minutes to recharge the Fuel Cell, whereas the Battery needs about 8 hours. On the other hand the state of the art Fuel Cell only lasts 3 hours less than the Battery.

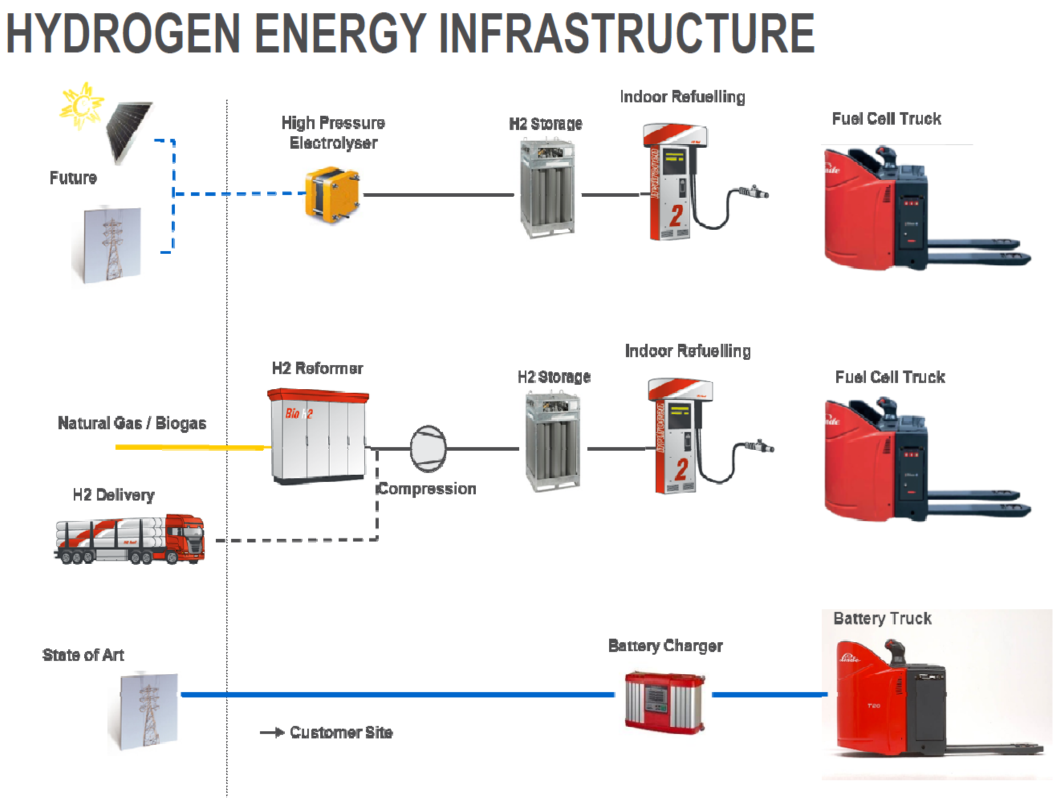

Figure 5: Future Hydrogen Supply of DB Schenker

Hydrogen gas stations

So far there is only one hydrogen gas station in Austria. It is located in Vienna in the 21. district. But the operating Company OMV has already planned two more stations; one in Tyrol and one in Upper Austria. Still, this shows how much more investment the hyrogen infrastructure needs. Even in Germany there are only 16 hydrogen gas stations so far – altough at least 13 new ones are planned to be finished until the end of the year 2015.

Filling the tank takes about 6 kg hydrogen, which roughly lasts for 500 km (*Toyotas Mirai*). The costs are 54 € with a price of 9€/kgH_2. The price in Vienna for diesel oil is about 1,1 €/l. A efficient car uses about 5 l/100km. This means you need 25 liters for 500 km and therefore 27,5 €. More powerful cares consume up to 7 l/100km, which results in 38,5€ for 500km. Compared to a state of the art gasoline car the hydrogen car is more expensive.

Additionally, OMV uses fossil fuels for the production of hydrogen, because other methods aren't competitive (e.g. PV-Electrolysis). Which isn't a renewable energy source, and therefore not a reliable solution for the future.

Hydrogen in Czech Republic

Skoda TriHyBus Skoda TriHyBus (from Triple Hibrid Hydrogen Bus) is prototype of Czech hydrogen bus. Three devices provide the energy: hydrogen fuel cells, Li-ion batteries and power capacitors. This unique system provides an efficient use of energy contained in hydrogen. It includes recuperation during braking. Only waste material is pure water. The bus was developed by Nuclear Research Institut in Řež.

Main source of electrical energy is hydrogen fuel cell with proton exchange membrane with 50 kW power. There is around 20 kilos of compressed hydrogen used as a fuel. Total volume of 4 high-pressure container, seated on the roof of the bus, is 820 litres. It was developed effective control system that optimazes energy flow. The system allows effeective recovery while driving downhill.

From year 2010, the bus is used for public transport in Neratovice and surroundings. The first hydrogen station in Czech Republic is located in the premises of Veolia Transport near Neratovice. The company is operator of TriHyBus. [8]

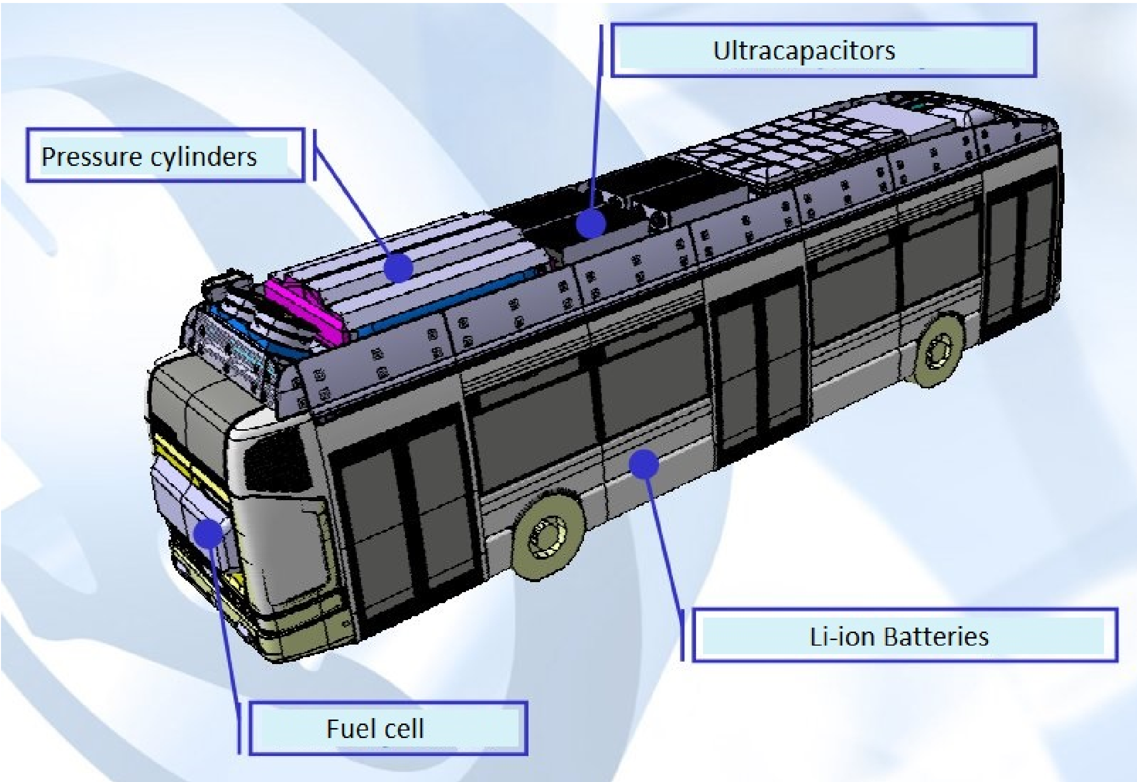

Figure 7: Bus

Hydrogen in Europe

BMW Hydrogen 7

German automobile BWM built a hydrogen vehicle in 2007. The car was based on gasoline cars BMW Series 7 and the production was limited to 100 cars. It does not use hydrogen fuel cells to produce electricity as other hydrogen prototypes. The engine was modified to allow combustion of hydrogen as well as gasoline. Thus it burns hydrogen in internal combustion engine. It was criticized for huge consumption, it can use 13,9 l/100 km of gasoline or it uses 50 liters per 100 km of hydrogen. Thus it is not as green as it may seem. As well using hydrogen in ICE is less efficient than hydrogen fuel cells. [9]

Mercedes Benz F-cell

The F-cell is hydrogen fuel cell vehicle developed by German corporation Daimler AG. There were sold 500 vehicles to European customers and 69 to American in the year 2010. Hydrogen tanks contains enough fuel to drive almost 400 km, later version using higher pressure enable range to 650 km. [11]

Germany filling station

In May, first hydrogen filling station on motorway was opened in Germany. There is already 18 stations along Frankfurt, Stuttgart and Munich. The idea is to open 50 hydrogen filling stations along major highways till the end of year 2015. It is important step towards hydrogen future. [10]

Toyota Mirai

The greatest progress in development and production of hydrogen cars is made by Japanese company Toyota. They should bring on market first serial produced hydrogen car Toyota Mirai in late 2015. On their website we can find manufactured suggested retailed price $ 57 500 (around 51 300 €). Mirai, which literally means "future" in Japanese, signals the start of next-generation cars.

Figure 8: Toyotas Mirai

Outlook into the future

Car companies are already preparing for the upcoming technology. Most of them have at least one prototype fuel cell car. General motors believe to sell million vehicles per year 2020. Ford modifies existing models in idea consumers are more likely to adopt new technology if it provides comparable services. Honda on the other hand approach more conventional look of hybrid vehicles. Most car companies have at least one prototype fuel cell car.

Conclusions

There are already many applications of hydrogen. The technology is ready, but not competitive for cars, because the necessary infrastructure is missing and the present production is inefficient. Building the infrastructure would be extremely expensive, because of the different storing needs. For example, there are just about 200 hydrogen filling stations world wide.[14]

Nevertheless, hydrogen as a fuel has a very high potential for becoming a leading future energy source. It supports the low emission policy[14], which many countries are encouraging. Even the production goes hand in hand with the growing renewable energy sector, because it can be used as an energy storage like a water storage power station.

References (Literature)

- [1] Milbrandt, A. *"Hydrogen Production from Key Renewable Resources in the United States"* (PDF). U.S. Department of Energy, National Renewable Energy Laboratory. Retrieved September 13, 2013.
- [2] Brinner, Philipps, *"Hydrogen as the fuel of the future"* (PDF). Institute for Technical Thermodynamics German Aerospace Center DLR. Stuttgart. 2001.
- [3] Zeilinger, Johannes: *Alternative Antriebsformen von Personenkraftwagen.* Vienna. 2010.
- [4] DRENNEN, Thomas E a Jennifer E ROSTHAL. *Pathways to a hydrogen future*. 1st ed. London: Elsevier, 2007, xiv, 288 p.
- [5] U.S. Energy Information Administration (EIA), *International Energy Outlook September 2014.* *[http://www.eia.gov/forecasts/ieo/pdf/0484%282014%29.pdf]*. Retrieved June 2015.
- [6] International Energy Statistics.http://www.eia.gov/beta/international/data/browser/. U.S. Department of Energy (EIA), Wahsington. Retrieved June 2015.
- [7] Wahlmüller *„E-LOG-Biofleet: Fuel Cell Systems for Intralogistics"(PDF)*. Fronius International GmbH Research Energy Cell. Vienna. December 2012.
- [8]*TriHyBus - Vodíkový autobus s palivovými články: Vodík palivo budoucnosti* [online]. Available at: http://trihybus.cz/
- [9] WÜST, Christian. BMW's Hydrogen 7: Not as Green as it Seems. In: *Spiegel online International* [online]. [cit. 2015-06-23]. Availeble at: http://www.spiegel.de/international/spiegel/bmw-s-hydrogen-7-not-as-green-as-it-seems-a-448648.html
- [10] Germany's first hydrogen filling station on the autobahn opens. In: *ETAuto.com: An initiative of The EconomicTimes* [online]. 2015 [cit. 2015-06-23]. Available at: http://auto.economictimes.indiatimes.com/news/aftermarket/germanys-first-hydrogen-filling-station-on-the-autobahn-opens/47162793
- [11] Mercedes-Benz B-Class F-CELL: The first fuel cell automobile in series production. In: *Website of Daimler* [online]. [cit. 2015-06-23]. Available at: http://www.daimler.com/dccom/0-5-1228969-1-1401156-1-0-0-1401206-0-1-8-7165-0-0-0-0-0-0-0.html
- [12] GRASMAN, Scott E. *Hydrogen energy and vehicle systems*. xxvii, 332 pages. ISBN 9781439826812-.
- [13] HORDESKI, Michael F. *Alternative fuels: the future of hydrogen*. Lilburn, GA: Fairmont Press, 2007, x, 242 p. ISBN 08-817-3547-7.
- [14] Umwelt Bundesamt. http://www.umweltbundesamt.at/umweltsituation/verkehr/kraftstoffe/wasserstoff/ [http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0012.pdf].Vienna. Retrieved June 2015.