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Professional MBA
Automotive Industry

Research of the current status of a fuel cell vehicle to be driven in the area of Vienna, Austria by 2017 and future prospects in 2025

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by

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Orth/Donau, September 20, 2017

Affidavit

I, **SASCHA KOLB**, hereby declare

1. that I am the sole author of the present Master's Thesis, "RESEARCH OF THE CURRENT STATUS OF A FUEL CELL VEHICLE TO BE DRIVEN IN THE AREA OF VIENNA, AUSTRIA BY 2017 AND FUTURE PROSPECTS IN 2025", 66 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 20.09.2017

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Signature

Acknowledgements

I would like to thank you all those who have offered me support throughout the research period necessary for this master thesis. I would also like to thank my parents, family and all my friends for their understanding for the last 2 years. I didn´t have the time, as I wished, for them to spent more time with them.

Abstract

By this master thesis the following question will be answered:

Is it possible to use a fuel cell vehicle for daily driving around Vienna, Austria, by today and in 2025?

Starting point question for hypothesis and used methods

Research of the current status of a fuel cell vehicle to be driven in the area of Vienna, Austria by 2017 and future prospects in 2025

Is there an advantage for public transport by using the fuel cell technology? How many fuel cell stations does exist already in the area of Vienna and how about future plans? Find out by reviewing press releases, published in the internet about the current status, activities and future plans. Interview organization, like the Austrian “OEAMTC” to get a direct feedback about using already today fuel cell cars in Austria. Interview of experts using a battery EV for comparison. Investigate in already established organizations, which are dealing with the fuel cell technology. Find out about the current status and future plans of the OEM´s.

Review the existing regulations from the Government and the European Union, like promotion for using alternative power units, CO2 reduction with the final goal to have zero emissions. How about the initiatives for E-mobility by using batteries? So far there are no scientific research results available.

Results

The result will be an answer, if it´s possible to use a fuel cell cars around Vienna, under the circumstances given by today, or in the near future until 2025?

Which power train solution, fuel cell versus battery concept will be the better one? Provide a clear structure of advantages and disadvantages for each technology today and in the near future. What might be the “optimal” solution for individual transportation and which one for public transportation. And which kind of infrastructure, mind setting and Government regulation we have to have in place to be able to use a fuel cell power train vehicle.

Contents

List of abbreviations

Table 1 List of abbreviations

Acronym	Definition
AFC	**A**lkaline **F**uel **C**ell
App	**App**lication software
ARBOE	**A**rbeiter- **R**adfahrer-**B**und **Ö**sterreichs
BEV	**B**attery **E**lectric **V**ehicle
BMW	**B**ayrische **M**otoren **W**erke
CNG	**C**ompressed **N**atural **G**as
DMFC	**D**irect **M**ethanol **F**uel **C**ell
E.G.	**E**xempli **G**ratia
EFCV	**E**lectric **F**uel **C**ell **V**ehicle
EU	**E**uropean **U**nion
EV	**E**lectric **V**ehicle
FCV	**F**uel **c**ell **v**ehicle
MCFC	**M**olten **C**arbonate **F**uel **C**ell
NASA	**N**ational **A**eronautics and **S**pace **A**dministration
NEFZ	**N**euer **E**uropäischer **F**ahr**z**yklus
OEAMTC	**O**esterreichischer **A**utomobil, **M**otorrad und **T**ouring **C**lub
OPEC	**O**rganization of the **P**etroleum **E**xporting **C**ountries
PAFC	**P**hosphoric **A**cid **F**uel **C**ell
PEMFC	**P**roton **E**xchange **M**embrane **F**uel **C**ell
PHEV	**P**lug-**I**n-**E**lectric **V**ehicle
RDE	**R**eal **D**riving **E**mission
SOFC	**S**olid **O**xide **F**uel **C**ell
SUV	**S**port **U**tility **V**ehicle
TTW	**T**ank-**t**o-**W**heel
UNECE	**U**nited **N**ations **E**conomic **C**ommission for **E**urope
V	**V**olt, voltage
WLTP	**W**orldwide Harmonized **L**ight-duty Vehicles **T**esting **P**rocedure
WTT	**W**ell-**t**o-**T**ank
WTW	**W**ell-**t**o-**W**heel

1 Introduction

1.1 Motivation

By these days, if someone is reading, or hearing something about alternative power trains used for vehicles, the first idea will be an electric car driven with a power train, powered by batteries. However, there are more alternatives already existing to have other solutions and possibilities, for example the fuel cell technology. That´s why in this thesis it will be researched, if there are other solutions available and how far Austria around Vienna, is ready and capable to drive with a fuel cell car as a daily driver.

1.2 Definition of the research problem

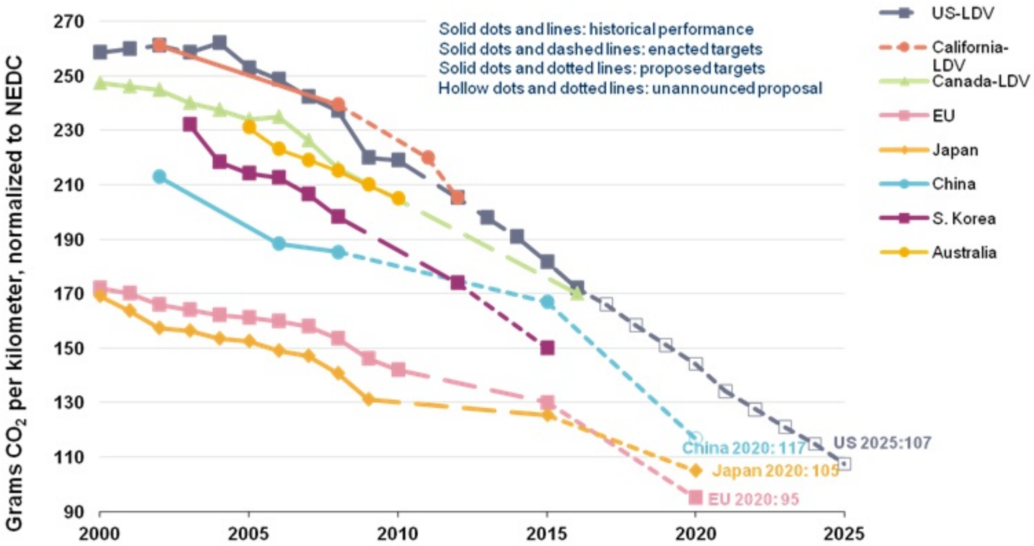
So far no one knows what kind of power train we will use in the future for individual, public transport, digger and fork lifts.

It is a fact that the fossil fuel has a limited supply. Even the experts aren´t sure how long the fossil fuel can be used for 50 years or even longer, but for sure the fossil fuel is limited.

Electrical power and hydrogen could be generated in an unlimited period. The main problem will be to get the electrical power and the hydrogen from wind power, solar or other alternative power.

The Governments around the world do not know what kind of technology will be used in future, but all of them will reduce the CO2 Emissions to zero. By that they are forcing the industry to develop new technologies and bring them into the market. Especially the OEM´s spent quit a lot of money in the research, development and production facilities for combustion engines. They are not interested, do switch now to a total new technology, new facilities and they have to convince the end customer to buy finally, those new cars with the new technology. They have to spend a lot of money and resources for facilities, to suppliers and into marketing to be successful in the future. More than 100 years the combustion engines have dominated the market around the world, but the change to different power train will come. The first OEM who is investing into the “right” technology will be successful in the future. All they others could only follow. Currently the electric vehicle with battery seems to be the future technology, but they are a lot of technical and commercial questions open, like the high weight of the battery, the price of the batteries and the high development costs which have to be allocated to the piece price of the car, which makes it, by today very expensive, compared to the combustion engines powered cars.

The fleet average which have to be achieved for all OEM´s until 2020 will be 95 grams of CO2 per kilometer. This means a fuel consumption of around 4.1l/100 km of petrol or 3.6 l /100 km of Diesel (Comission, 2017). (Taken from the European Commission published on www.ec.europa.eu)



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

Source: ICCT

Remark: Recalculation in ICCT July 2012 report indicates level of 93g for passenger cars only for the US in 2025. EU's targets are comparitively more stringent. Vehicle definitions are different in the US and EU, and not directly comparable.

Fig. 1: Showing the CO2 reduction for the world (theicct.org, 2017)(accessed on 2017-07-13)

Based on the facts above the OEM´s have to find a way to reach the targets given for example by the European Commission.

How to achieve those targets, and how will the behavior of the customers change?

Will be the FCV a reasonable solution for the CO2 targets given from the European Commission?

1.3 Outline of the main research question

The following two questions will be researched and investigated to find an answer for it.

1.3.1 Hypothesis 1

Will it be possible by today to use a FCV in Austria around Vienna? What are the obstacles today to drive a fuel cell car, which is currently available on the market, in Vienna for daily use? What does a daily driver need to switch to a fuel cell car? How about the suitability for daily use? Are there any restrictions for winter or summer time use? Like using the air-conditioning, or the heating system in summer? Or might be the battery electric car the better alternative solution for combustion engines? Or will we stick to the diesel and gasoline powered vehicle for a longer time, then we think today?

1.3.2 Hypothesis 2

Will it be possible to drive a fuel cell car in Vienna Austria by 2025? Which criteria's must be defined, improvements and investigations for the future use of the fuel cell car to make it more attractive for the future car drivers at Austria. What will be the future government regulation look like? What are the plans from the OEM´s for their future alternative power units?

1.4 Main research question

Known facts by today it will be possible to use today a FCV for the daily driving in Vienna, Austria, because there are already 4 fuel cell stations in place in Austria and it is possible to buy today a FCV from OEM´s (e.g. Toyota Mirai, Hyundai iX35 FCEV).

Might it be possible to use the FCV for daily driving and are the customers willing to spend more money on an alternative transportation solution and will the customer accept possible restrictions by daily driving with the fuel cell car? How about the availability of the refueling stations in Austria? Are there enough stations available to refuel the fuel cell vehicle today? What are the future strategies from the hydrogen producers and the OEM´s? In which direction the government benefits will go? Might be the public transportation a possible user of the FCV´s? To have more success by using a FCV the car price must be reduced to an almost equal price of a Diesel or Gasoline powered car. The infrastructure has to be in place and the European Union have to support the zero CO2 Emission car customers, OEM´s and the fuel suppliers.

1.5 Aim of the Master Thesis

The target of this Master Thesis will be to figure out, in which way a fuel cell car can be used in the area of Vienna, Austria by today and what kind of investigations, commercial environment has to be in place in 2025. Current and future plans of the industry will be considered to be able to provide an outlook for 2025. The main target will be to get the hydrogen fuel cell vehicle more popular in Austria and to push the investigations for the development for the needed infrastructure for FCV. If this will be

1.6 Structure of the Thesis

Starting with the historical background information, like how the fuel cell technology have been founded, first applications in vehicles and technical explanations about the main different variants of the fuel cell itself. Then the topic market and regulations will be described. Considering the status of serial vehicles on the market by today. What are the emission regulation in Europe and around the world? Why and how the OEM´s have to reduce their fleet emissions, by introducing vehicles with less fuel consumption and lower emissions. To be able answer the main question of the Master Theses the background information will be evaluated, like network and availability of hydrogen and refueling stations in Europe, America and Austria. What are the alternatives of fuel cell vehicles? What are the alternatives available today und in the near future? What kind of plans does they OEM´s have? How will be customer behavior change in the next years until 2025?

The facts will be combined in an overview and including experience from users of a Fuel cell vehicle and an electric vehicle with battery. Finally the results and the interpretation from the author will be validated and finally a conclusion will be made.

1.7 FCV history

In this chapter the historical background and timeline of the FCV will be described.

1.7.1 **Background**

Hydrogen was discovered in 1766 by Mr. Henry Cavendish (University of Ulm, 2017). He demonstrated that water is a combination of hydrogen and oxygen. By electrolyze you can split water to hydrogen and oxygen. In the year 1839 the lawyer and physicist Sir William Robert Grove (Brennstoffzelle.de, 2017) found out by experimental studies that you can also invert this electrolyze of water. By doing so he found out that during this process electrical energy is generated.

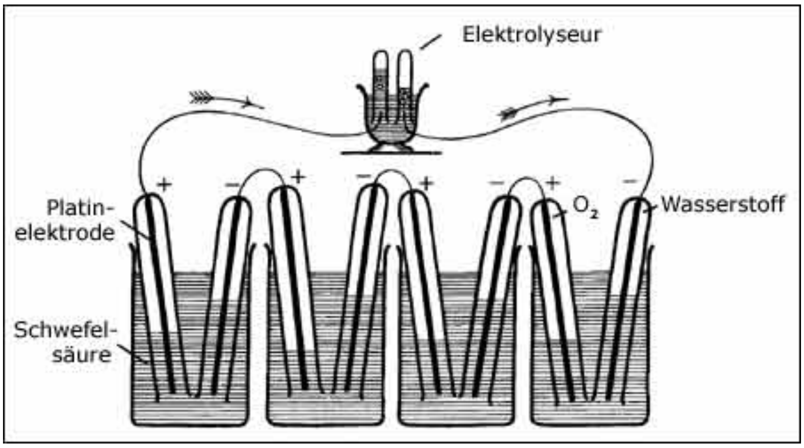


Fig. 2: Principle of a fuel cell from Robert Grove (Brennstoffzelle.de, 2017) (accessed on 2017-08-28)

At that time the measureable voltage and current was too low compared to the electro dynamo so the fuel cell technology has not winning recognition at that time.

Hydrogen is the first element in the periodic table. No other element is lighter or more abundant in the universe, so it´s pure energy. For example, the sun persists of 92, 1% of hydrogen. So, hydrogen is available on earth without any limitation. Because oxygen and hydrogen will never disappear from the earth, "*water is the coal of the future*" [1]

In 1801 Humphry David, Cornish inventor and chemist (Knight, 2004), demonstrates the basic principle of fuel cells. Later, in 1839 William Grove develops the gas voltaic battery, which is considered the first fuel cell (sciences, 1839).

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[1] Abridged from The Mysterious Island by Jules Verne, 1874

In the 1950's small 5kW – 15kW fuel cell engines are developed, but later in the 1960', NASA continues the fuel cell development with the Apollo Program. About the same time, General Motors develops the first fuel cell road vehicle, the Chevrolet Electro-van. It ranged about 190 km and had a top speed of around 110 km/h (Eberte et al., 2012).

In the 1970's and the 1980's research continued on PEM fuel cells, but only in the 1990's interests for fuel cell implementations raised amongst automobile manufactures. Toyota began already in 1992 development of fuel cell vehicles. In 1996 the launched their first FCEV which was equipped with a proprietary fuel cell stack. This car was only a prototype and have never been sold to customers. It took almost 10 years until the first FCV for customer was available.

1.8 Technical description

The technical principle of a fuel cell (hyfive.eu, 2017) is that you have 2 plates which are separated by a membrane. On one side oxygen from the ambient air is supplied to one side of the membrane and with hydrogen on the other side of the plate. The positive particles of the hydrogen atoms can pass through the membrane, the negative once are not able to pass the membrane. The negative atoms have to change their path and this is creating an electrical current which can be used for example in EFCV for the drive train.

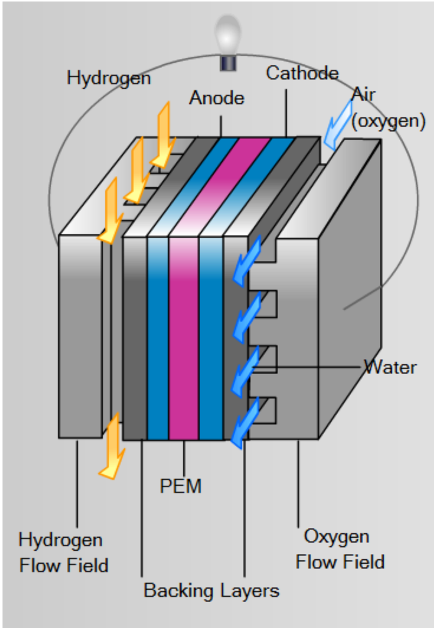

Fig. 3: Working principle scheme of a fuel cell (hydrogenics.com, 2017)(accessed on 2017-07-13)

Today we can differ to six main types of fuel cells:

- PEMFC Proton exchange membrane fuel cell
- SOFC Solid oxide fuel cell
- AFC Alkaline fuel cell
- MCFC Molten carbonate fuel cell
- DMFC Direct methanol fuel cell
- PAFC Phosphoric acid fuel cell

Each type of fuel cell has advantages and disadvantages which will be described in the upcoming chapters.

1.8.1 **PEMFC Proton exchange membrane fuel cell**

For this type of fuel cell a noble metal catalytic converter is used mainly platinum. Without platinum hydrogen and oxygen wouldn´t have a chemical reaction. The electrolyte of this membrane is not liquid it is hard. It is a polymer membrane which is conductive.

On both sides of the membrane is a porous graphite electrode mounted were the surface of it is slightly covered with platinum. One side is the cathode and the other side is the anode of the fuel cell. Hydrogen which is going to the anode will be divided to proton and electron. The protons will go thru the anode side via the membrane to the cathode side and during this process electric power will be generated. On the cathode side protons, electrons and oxygen will connect to each other to water. One membrane could theoretically generate 1, 23 V but practically only between 0,6 and 0,9 V due to reaction inhibition. The power range of this type of fuel cell is between 1 kW and 100 kW. The operating temperature is up to 120°C. PEMFC is very attractive for mobile use because of the easy handling and the power control can be controlled uncomplicated.

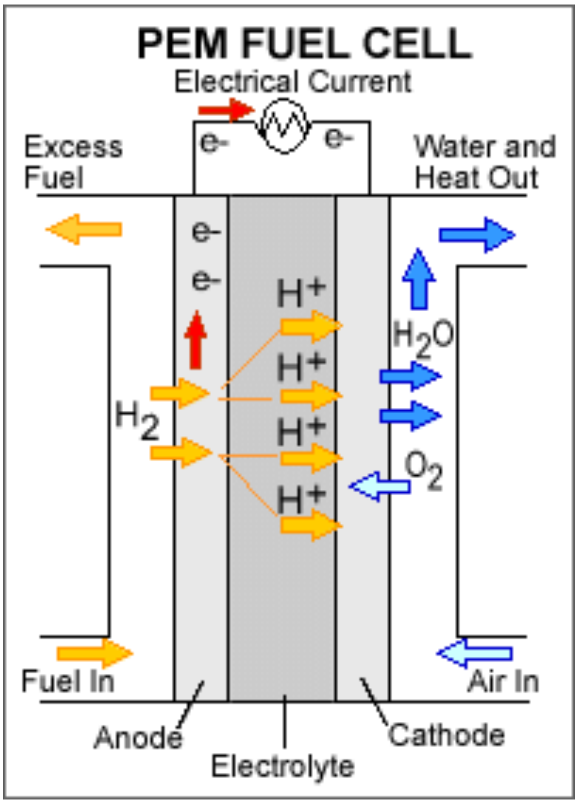

Fig. 4: Schematic description of a PEM fuel cell (fuelcellmarkets.com, 2017)(accessed on 2017-07-13)

Currently the PEM fuel cell is the most promising type of fuel cell for the automotive industry.

1.8.2 **SOFC Solid oxide fuel cell**

At the solid oxide fuel cell an oxide ceramic bond as electrolyte use. The cell itself can be divided in cube or flat cell form. In operation mode the oxide ceramic have to be very hot, which will be done by external heating up system, e.g. gas.

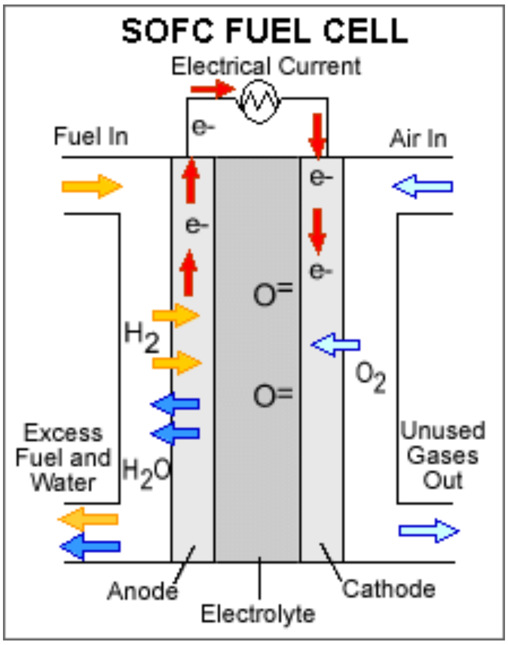

Fig. 5: Schematic description of a SO fuel cell (energy.gov, 2017)(accessed on 2017-07-13)

Only when the oxide ceramic is heated up to 650°C – 1000°C the fuel cell is working. Currently this type of fuel cell is not used in the automotive industry but it has a high degree of efficiency. The Solid oxide fuel cell technology will be used in power stations. Some experimental application in the automotive industry was done so far by using gasoline to heat up the ceramic and to generate electricity for the electro motor.

1.8.3 **AFC Alkaline fuel cell**

The alkaline fuel cell is a low temperature fuel cell. A solvent calcium hydroxide is used as electrolyte. The degree of efficiency is lower compared to the PEMFC. AFC have been used in the crewed spaceflight by NASA. Meanwhile the NASA switched

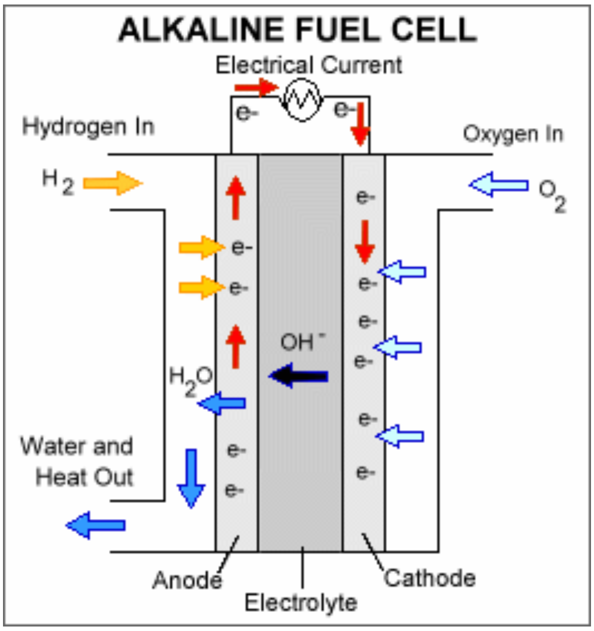

Fig. 6: Schematic description of an alkaline fuel cell (energy.gov, 2017)(accessed on 2017-07-13)

over to PEMFC´s technology, mainly because of cost reasons, because the AFC is produced in custom built machinery. Nevertheless, the arms industry is still convinced of the advantages of this type of fuel cell. Especially by using it in a submarine. The benefits for the submarine by using the alkaline fuel cell is that the AFC is working without fresh air from outside, low noise and the generation of heat is low and the waste is only pure water compared to nuclear submarines.

1.8.4 **MCFC Molten Carbonate fuel cell**

The molten carbonate fuel cell high temperature fuel cell. As electrolyte, in this type of fuel cell, molten carbonate is used. The used materials for this fuel cell is, compared to the other types, cheaper. It has a high-power output from 300kW to 3 MW but has a long start up time, to heat up the system you will need fusil fuels and cannot be used for automotive industry.

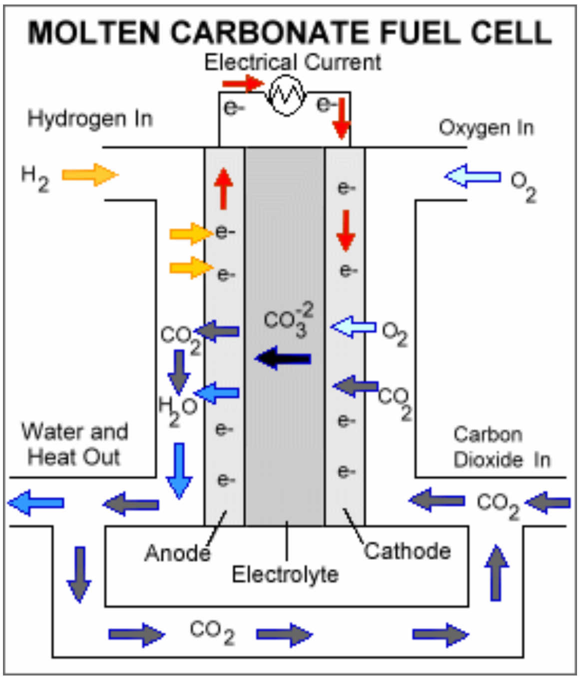

Fig. 7: Schematic description of a molten carbonate fuel cell (energy.gov, 2017)(accessed on 2017-07-23)

1.8.5 **DMFC Direct Methanol fuel cell**

Compared to the other types of fuel cells the DMFC is not powered by hydrogen, the DMFC will be powered by methanol, which is mixed with water. Methanol can be very easily stored and transported. This is one reason why this type of fuel cell could be the “winner” instead using the PEM fuel cell. Because the existing gasoline stations could be very easily adapted to supply methanol and do not have to be adapted for hydrogen supply which is a high cost factor. The working temperature is around about 100°C.The main application of direct methanol fuel cells are up to now in practice used for portable systems like power unit. The future of DMFC´s in the automotive industry is not fixed yet, but might have a high potential to be used in future.

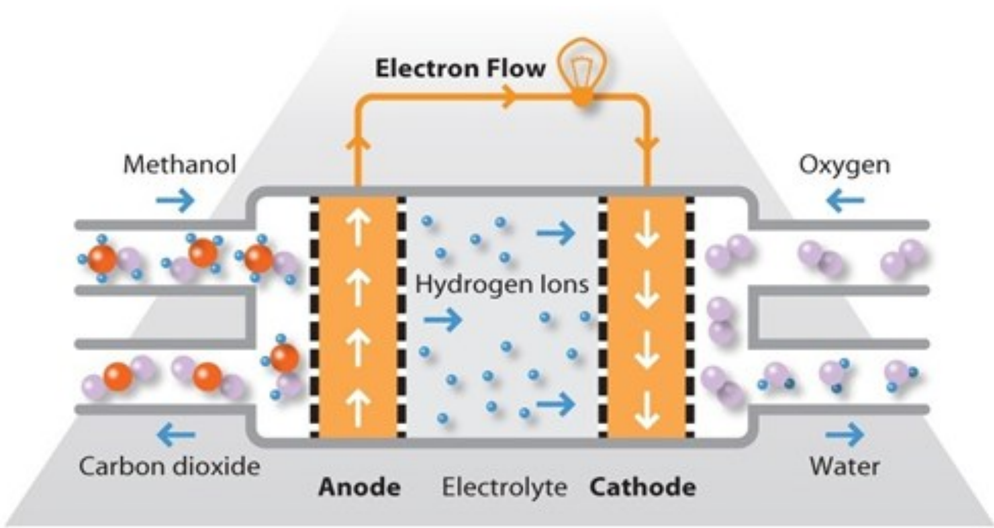

Fig. 8: Schematic description of a direct methanol fuel cell (fuelcelltoday.com, 2017)(accessed on 2017-07-23)

1.8.6 PAFC Phosphoric acid fuel cell

For this type of fuel cell phosphoric acid is used as electrolyte. The working temperature is at around 200°C.The degree of efficiency is lower compared to other types of fuel cells and is round about 40%.This type of fuel cell was the first one which was used commercially and is typical for powering stationary power generator. Also it was used to power heavy vehicles like trucks and buses.

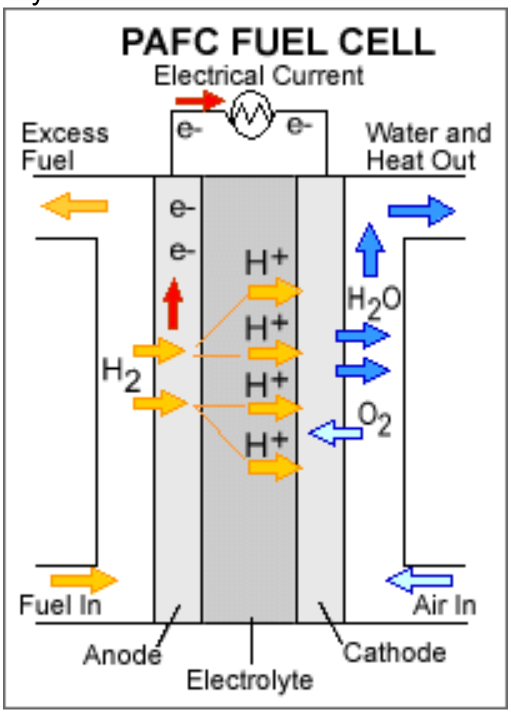

Fig. 9: Schematic description of a phosphoric acid fuel cell (energy.gov, 2017)(accessed on 2017-07-23)

2 The market and regulations

2.1 Status of the available fuel cell serial vehicles on the market today

Different OEM´s do have currently available fuel cell cars for the public market.

Toyota is offering one model, the “Mirai” (toyota.at, 2017). The car was awarded with the “Environmental award” (Umweltpreis) from the ARBOE in Austria.

The “Mirai” is a sedan car were 5 passengers can be carried. It has a fuel cell, hybrid battery, 2 high pressure tanks for the hydrogen and a power unit to control all the functions. It has an electric motor with 113 kW, maximum speed of 175km/h, battery capacity of 6,5Ah, 2 tanks with 60l in front and 62,4l in the rear, the pressure inside is 70MPa and a maximum range of 550 km.

The second OEM that is selling a fuel cell car in Austria is Hyundai (hyundai.at, 2017). The model is called: “ix35 Fuel Cell”. It has an electric motor with 100kW, maximum speed of 160km/h, battery capacity of 24kW, 2 tanks with total 144l, the pressure inside is also 70MPa and it has a maximum range of 594km. Until today there are no more passenger vehicles with a fuel cell unit available in Austria for public. In Europe, we had some more experimental FCV available such as the Mercedes Benz A class presented in 2002 with a range of 160km and a top speed of 132km/h. The next generation was the B class introduced in 2010, with a range of 400km and a maximum power of 100 kW. Those cars very only used by some randomly chosen people mainly in the United States of America, California. Honda is also selling since 2017 the model “Clarity” as FCV, but only available in the state of California.

Compared to the availability of fuel cell vehicles the current available electric cars with battery are significant higher and also the availability of plug-in hybrids are also much higher.

In Austria there are 58 (OEAMTC, 2017) electric passenger cars from different OEM´s available, but only 2 fuel cell cars, which you can buy as a private person.

2.2 EU regulations on emissions, today and in the near future

According to the European Commission on climate action, passenger cars are responsible for approximately 12% of the total emissions of carbon dioxide (the main greenhouse gas) in the EU (ec.europa.eu, 2017) .Therefore the EU and also most of the other countries established a plan to reduce the C=2 emissions in the near future. Targets are defined until 2021 in the European Union. There will be incentives and penalty system installed for the fleet emissions of the OEM´s. Small OEM´s, they are clustered depending on the number of produced cars, will be charged in a different way.

2.3 EU emissions targets

Car manufacturers need to comply with the EU enforced fuel consumption targets. In 2015 target of emissions for a new sold car was 130 g CO_2/km. On the other hand, the average emission level for a new car was around 118.1 grams of CO_2/km, below the target. This translates into an average fuel consumption of 5.6 l/100 km of petrol or 4.9 l/100 km of diesel.

By 2021, all the new cars must follow the 95 grams of CO_2 per kilometer target. This translates into a fuel consumption of 4.1 l/100 km of petrol or 3.6 l /100 km of diesel. (ec.europa.eu, 2017) The European Union has future plans to reduce the CO2 Emissions until the year 2030 by 40% until 2040 by 60% and by 2050 by 80% compared to the values from 1990. That means that all the European Union economy has to participate on those new targets. Especially for the Automotive economy there will be a high challenging future ahead. However the Volkswagen diesel scandal has shown that all the regulations in place have to be executed and clearly controlled by the European Union. Beside the fact that the CO2 emissions have to be reduced, the way how to measure the CO2 emissions are now in the focus of the EU. By today the European Union commission is working on the improvement of testing procedures for emissions and fuel consumption. By today 2 main test procedures are developed, real driving emissions (RDE) and the worldwide harmonized light-duty vehicle testing procedure. The main difference to the existing testing procedure is that in future the real emissions by driving on the road will be measured and not only in a laboratory. So far the NEFZ within the European Union is valid to fix the fuel consumption of a vehicle. The NEFZ was established in the European Union in 1996.Since then al lot of circumstances have been changed. In the NEFZ the average speed of the vehicle is 34km/h and the top speed during the laboratory tests is 120km/h. Air condition, radio, seat heating and other power consuming units are not considered in the measurements of the fuel consumption of the car. From today's point of view those measurement procedure is not realistic. The European Union has defined a new test method together with the UNECE (UNECE, 2017) for more realistic fuel consumption and CO2 emissions. The new WLTP will be more practical real driving test procedure as the old NFEZ. The European commission CO2 target of 95g/km is valid for the NFEZ testing method. If the new WLTP will be in place the experts calculating that the fuel consumption will be up to 20% higher compared to the NFEZ test method. Therefore the European commission has developed a recalculation method, at the beginning of the empowering of the WLTP, not to adjust the CO2 emission target valid from 2021.

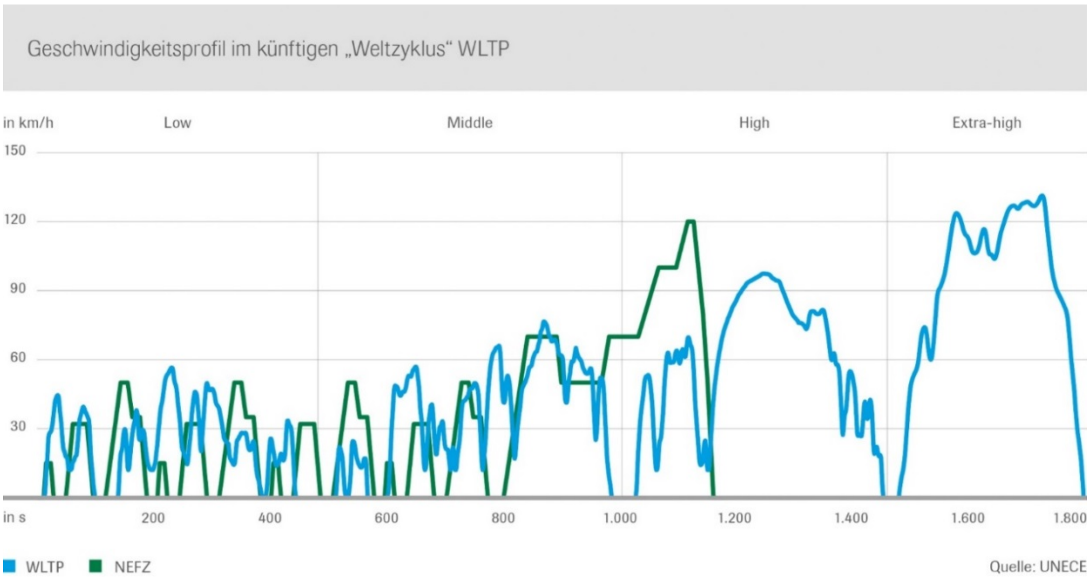

Fig. 10: Speed profile comparison between WLTP and NEFZ (Autoindustrie, 2017)(accessed on 2017-08-27)

The figure above is showing the difference of the speed of the vehicle between the NEFZ and the new WLTP measurement method. The maximum speed and the timing is higher and longer compared to the NEFZ method. OEM´s will have a higher CO2 emission value than before, with this new test method, but for the end user of the vehicle the fuel consumption will be more realistic. However the automotive industry will have to invest a high amount of Research and development costs to reach the new CO2 emission regulations. That might impact also the development of alternative power train solutions, like the fuel cell power train.

They also considering the emissions targets of heavy duty vehicles as well, which are responsible for a quarter of the CO2 emissions from road transport and for 6% of total EU emissions. Also for the heavy duty vehicles in the near future they will have to invest in alternative power units, to be able to fulfill the targets of CO2 emission regulation.

2.4 Emissions reduction incentives

Since 2012, each car manufacturer has to pay emissions penalties for every registered car if it exceeds the average CO_2 emissions target. The costs vary from €5 to 95€ depending on the amount of exceeded grams per kilometer. Starting 2019, the cost will raise to 95€ from the first gram of exceeding.

On the other hand, car manufacturers are granted emissions credits, for emissions eco innovations. Even more, if they would produce vehicles with emissions below 50 g/km, car manufacturers would get additional incentives. (ec.europa.eu, 2017). OEM´s will, most likely spend the money not for penalty payments, but for research and development. The fleet emissions regulation will also push the ongoing trend to reduce the CO2 emissions for big cars with plug-in hybrids, to reach the future targets.

2.5 EU emissions statistics

EU's target is to reduce greenhouse gas emissions by 20% by 2020 and by 40% by 2040 compared with the 1990 emissions levels (ec.europa.eu, 2017).

According to Fig. 11: Greenhouse gas emissions trend, EU-28, 1990-2015 (Index 1990=100) , there was a downward trend of the emissions between 1990 and 1999, followed by a relatively unchanged evolution until 2006. In 2009, there was a sharp drop in the emissions trend, because of the global economic crisis. In 2010, emissions increased again, and later on in 2011 and onwards, they continued to decrease. Only in 2015 there was small 0.6% increase compared to 2014.

In 2015, Germany was ranked first with 21% from the total EU-28 share of emissions, followed by the United Kingdom and France (ec.europa.eu, 2017). On the other hand, as seen in, countries like Cyprus, Spain and Portugal had a higher level of emissions compared to their 1990 index. Austria had a similar level of greenhouse emissions with the 1990 index.

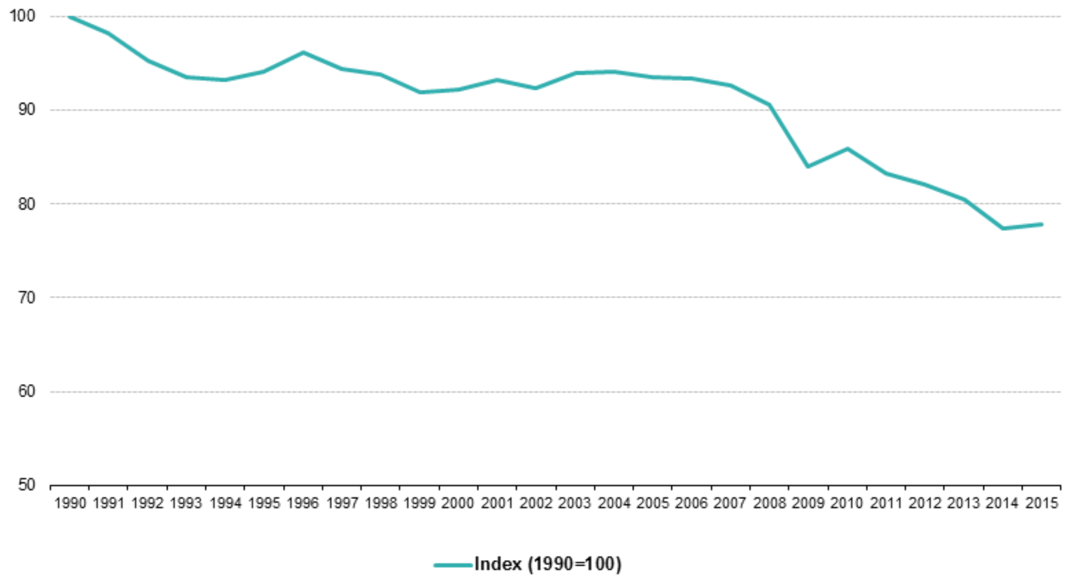

Fig. 11: Greenhouse gas emissions trend[2], EU-28, 1990-2015 (Index 1990=100) (ec.europa.eu, 2017)(accessed on 2017-08-27)

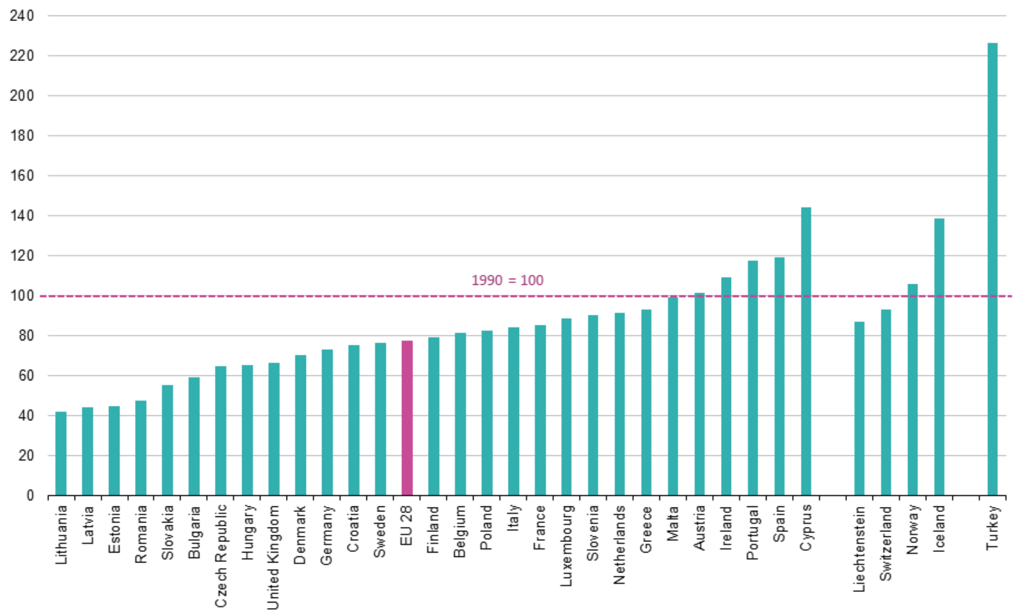

Fig. 12: Total greenhouse gas emissions by countries 2015 (Index 1990 = 100) (ec.europa.eu, 2017)(accessed on 2017-08-27)

2.6 **Strategies for low-emissions**

According to the European Commission on climate action there are three priority strategically directions:

[2] Including international aviation, indirect CO_2 and excluding land use, land use change and forestry

- "Increasing the efficiency of the transport system"
- "Speeding up the deployment of low-emission alternative energy for transport"
- "Moving towards zero-emissions vehicle" (ec.europa.eu, 2017)

There is a considerable amount of funding to support these EU policies. For e.g. , the European Structural and Investment Fund includes EUR 39 billion for supporting the shift to low-emissions mobility, out of which EUR 12 billion for low-carbon and sustainable urban transportation (ec.europa.eu, 2017). The Horizon2020 research program (2014 – 2020) allocates approximately EUR 6.4 billion for low-carbon low-emissions projects (ec.europa.eu, 2017). Currently the strategy for the low emissions are contrary because of the long time trend of buying SUV´s which have a higher CO2 emission then typical 5 seats passenger cars.

3 Background information

3.1 Definition of the state of the art

Today we have four major power trains in use:

- Combustion engines
- Hybrid power trains incl. plug-in hybrids
- Electric vehicle with battery, some cases also with range extender powered by a combustion engine
- Fuel cell vehicles

If we compare the new registrations of passenger cars in Austria from January to July 2017. There was an increase of new registrations of pure electric vehicles with battery by 42,2%. One reason could be that the Austrian government in Austria (Bundeskanzleramt, 2017) is now promoting, in 2017 and 2018, the buying of a new electric, or a hydrogen vehicle for private persons by 4.000 Euro, one time. Plug-In hybrids and range extenders with a minimum range, for pure electric driving, of 40 km, with 1.500 Euro, and they also promoting the private installation of a wall box, or the buying of an intelligent charging cable with 200 Euro.

Following charts of numbers of new registrations of passenger vehicles with different power units will show the big difference between the combustion engines, plug-in, electro and hydrogen power units.

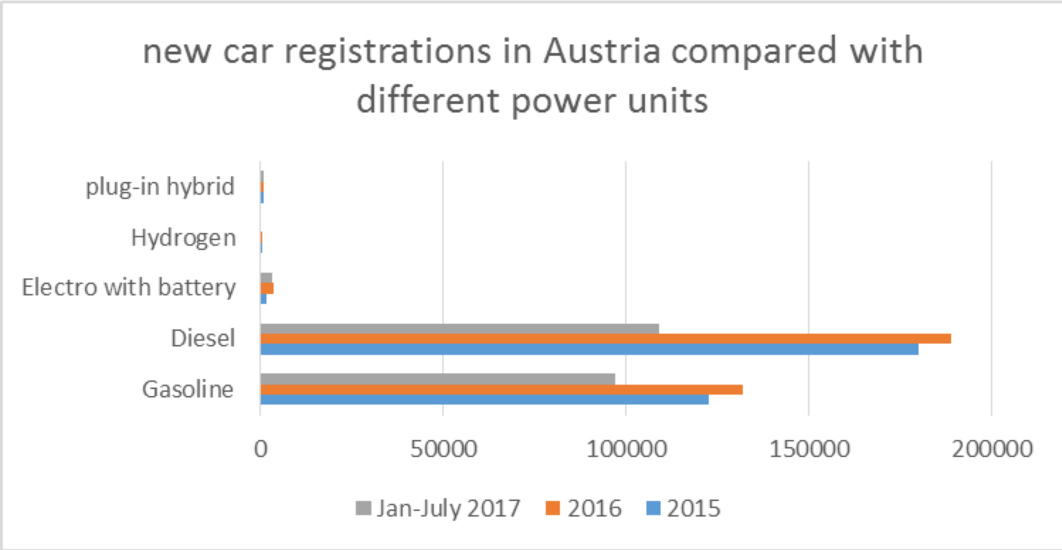

Fig. 13: New car registrations in Austria compared with different power units (AUSTRIA, 2017)(accessed on 2017-07-21)

The chart above is showing that the total number of new registrations is growing year by year. The diesel powered passenger vehicles are the most popular once in Austria.

However, the passenger vehicles with electro power units and batteries are growing significant from 2015 up to the first half year of 2017. If the trend in 2017 continues, and the Austrian government promoting will help and push this trend, the new registration of pure electric vehicles will reach by end of 2017 a new record.

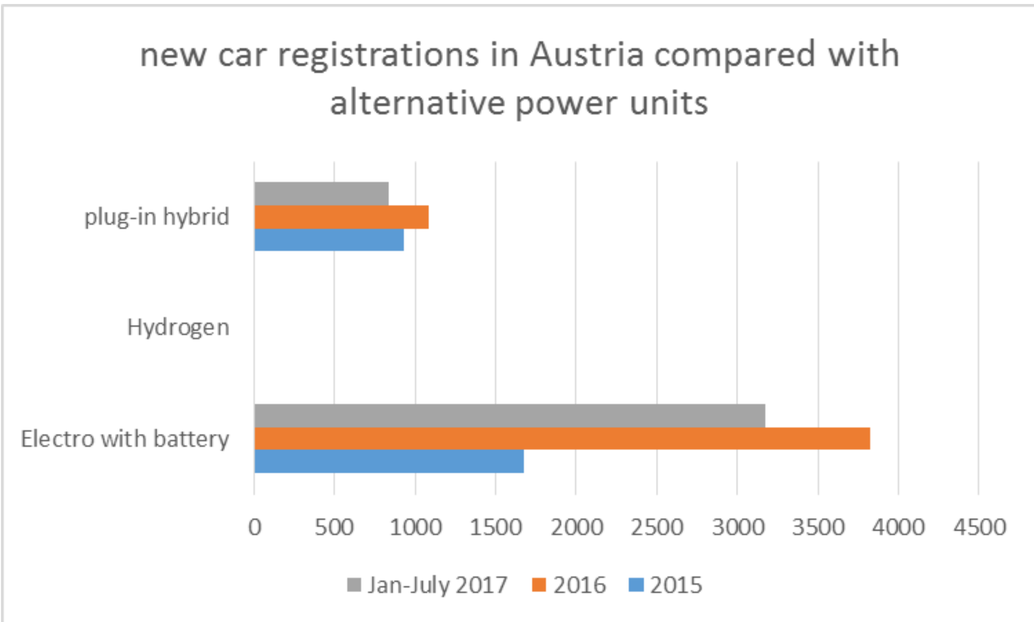

Fig. 14: New car registrations in Austria compared with different alternatve power units (AUSTRIA, 2017)(accessed on 2017-07-21)

The same promotion will boost the new registration numbers of plug-in hybrid passenger vehicles, but not the fuel cell cars. Why does the combustion engines still have such high new registration numbers? Why does the Austrian people still buying passenger vehicles with diesel engines?

Starting with the Volkswagen diesel scandal the governments of Germany and also the European Union are investigating penalties for the OEM´s, as it seems that not only Volkswagen have manipulated the emissions of their diesel engines. So far the figures of the new car registrations are not reflected this scandal at all.

3.2 Hydrogen production processes

Hydrogen can be produced using a number of different processes. With the thermochemical process heat and chemical reactions to split hydrogen from organic materials such as fossil fuels and biomass. Using electrolysis or solar energy water can be split into hydrogen and oxygen. Microorganisms like bacteria and algae can also produce hydrogen through biological processes.

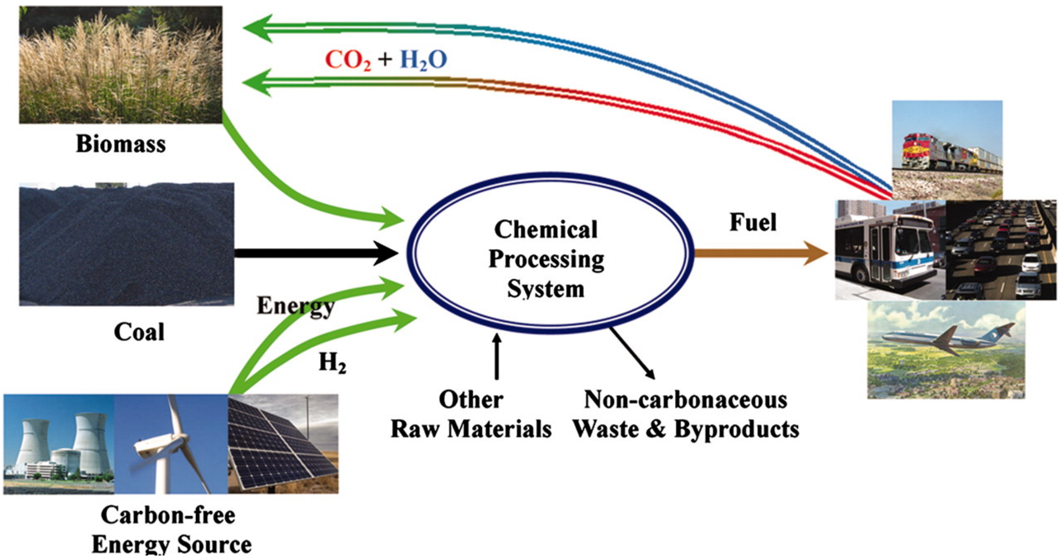

Fig. 15: Principles of generating hydrogen from different source (US, 2017)(accessed on 2017-09-02)

The picture above is describing the principles for hydrogen production from different sources. The next chapters will explain the main possible processes in a more detailed way.

3.2.1 **Thermochemical processes**

Thermal processes using the energy in various resources such as natural gas, coal and biomass to split hydrogen from their molecular structure. In other methods, heat, in combination with closed-chemical cycles produces hydrogen from feedstock such as water. There are mainly 5 different thermochemical processes used:

3.2.2 **Natural gas reforming**

Natural gas reforming is a mature production process that builds upon the existing natural gas pipeline delivery infrastructure. 95% of the hydrogen produced in the United States of America is made by natural gas reforming. Approximately 25% of the incoming natural gas is burned to provide the necessary energy for the reaction, while the rest is stripped of its sulfur content. Steam with a pressure of 25bar is added which reacts with the methane over a nickel-alumina catalyst. The synthesis gas will be passed into the cooler shift reactor. Out of the shift reactor will come 75& hydrogen. In the pressure surge adsorption unit, the impurities are removed and recycled back through the burner.

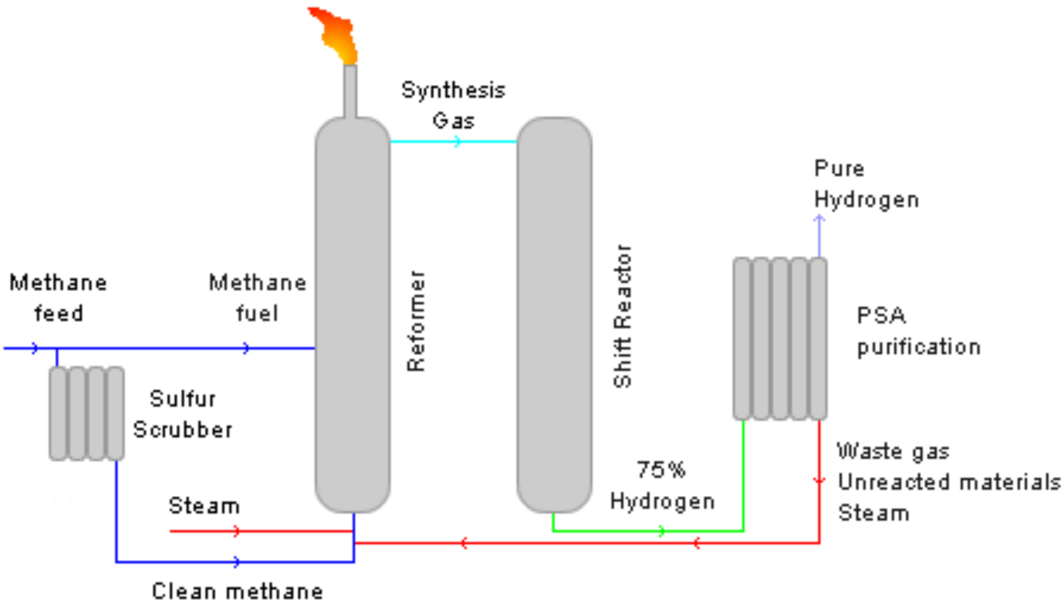

Fig. 16: Schematic of natural gas reforming (accessed on 2017-08-31)

3.2.3 **Coal gasification**

The coal gasification is a similar method like the natural gas reforming. Hydrogen is produced by a first reacting of coal with oxygen and steam under high pressure and temperature. The result will be a gas mixture of carbon monoxide and hydrogen. In a second step the impurities are removed from the carbon monoxide gas mixture and by adding steam through the water-gas shift reaction additional hydrogen will be produced.

3.2.4 **Biomass gasification**

The biomass gasification is similar to the natural gas reforming, but instead using natural gas, biomass is used to get hydrogen. Organic or fossil-based carbonaceous materials will be converted at high temperature (>700°C), without combustion, with oxygen and/or steam into carbon monoxide. The carbon monoxide reacts with water to form carbon dioxide and hydrogen. Absorbers or special membranes separate the hydrogen from the gas stream.

3.2.5 **Biomass-derived liquid reforming**

Liquids derived from biomass resources can be reformed for hydrogen production. It is a similar process like the natural gas reforming, but the biomass-derived liquids can be transported more easily than their biomass feedstock's. The liquid fuel is reacting with steam at high temperature by using a catalyst to produce a reformed gas composed of hydrogen, carbon monoxide and carbon dioxide. Hydrogen and carbon dioxide are produced by reacting the carbon monoxide with high temperature steam. The hydrogen will be then separated out, of this high temperature steam and purified.

3.2.6 **Solar thermochemical hydrogen**

This long-term technology pathway has a high potential for low or no greenhouse gas emissions. Thermochemical water splitting uses high temperatures from concentrated solar power and chemical reactions to produce hydrogen and oxygen from water. At high temperature heat (500° -2.000°C) a chemical reaction produces hydrogen. The chemicals used in the process can be reused within each cycle. This closed loop consumes only water. The needed high temperature can be created in the followings ways:

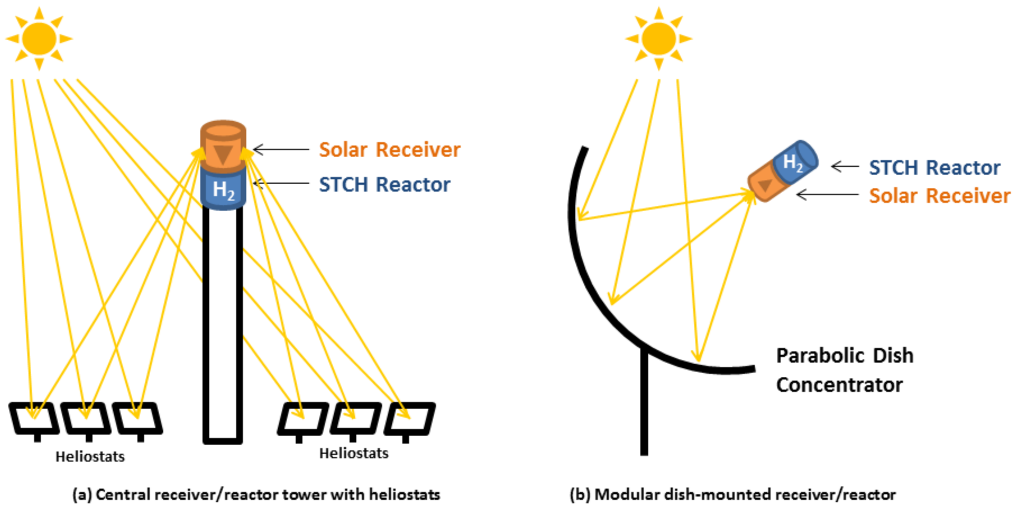

Fig. 17: Principle of a thermochemical water splitting (US, 2017)(accessed on 2017-09-02)

Concentrating sunlight onto a reactor tower using a field of mirrors, as illustrated in the picture above. By this the necessary temperature will be created and the chemical process will start to separate water into hydrogen and oxygen.

3.3 Network and availability of hydrogen

In this chapter the network and availability of hydrogen and different pathways will be explained.

3.3.1 Network of hydrogen

Can be a fuel cell vehicle used today for daily driving? Can it be used to go to the workplace, drive to the supermarket and go out on the weekend for doing hobbies and meet friends?

Before doing the deep dive on this topic let´s have a look on the initiatives and background information of the network and availability of hydrogen. What are the differences between countries within the EU and which one is more development is case of numbers of fuel cell vehicles infrastructure? How does the hydrogen be delivered to the fueling stations?

The Austrian company OMV, main manufacturer of petrol, oil, and gases for the industry is producing already almost 100.000 tons of hydrogen every year. This amount of hydrogen will allow the cars in Vienna, 660.000 cars registered in Vienna, to use hydrogen for driving one year. Main problem is, how the hydrogen have been produced, from fusil burning, or from alternative energy like solar, water power or from wind-energy. To store the produced hydrogen is currently, still a huge problem for the question, how to distribute it to the fueling stations. Hydrogen is highly flammable and can very easily interfuse. This could be solved by cool down the hydrogen to -253°Celsius, which would mean, again beside the production of it, another high effort from energy need. Hydrogen can be delivered, after centrally produced, in liquefied form, by tube or via pipeline, can be also produced on site via reforming of natural gas, or also produced with alternative like solar or wind-power. Hydrogen can be stored then on side a liquid or as compressed gas, in which it could also compressed on side. The cost of one hydrogen refueling station is today, around 1 Mio Euro, but the price will decrease as soon there is more business behind.

Best alternative might be to use green power to produce the hydrogen on side of the refueling stations and store them on-side.

Fig. 18: OMV fuel cell station (omv.at, 2017)(accessed on 2017-05-23)

Picture showing the first public hydrogen fuel station in Austria, opened in October 2012 in Vienna.

The Honda Motor Co., Ltd begun to work on a smaller solar hydrogen station prototype intended for use at home and could fit within the home´s garage for overnight charging of fuel cell vehicles.

Fig. 19: Showing the first Honda´s hydrogen refueling station for home use (Digitaltrends.com, 2017)(accessed on 2017-09-07)

Currently the main problem is still the availability of hydrogen for daily drive. On the following pages you can find different maps from different countries, to get an overview about the current status at Austria, Germany and USA, State of California.

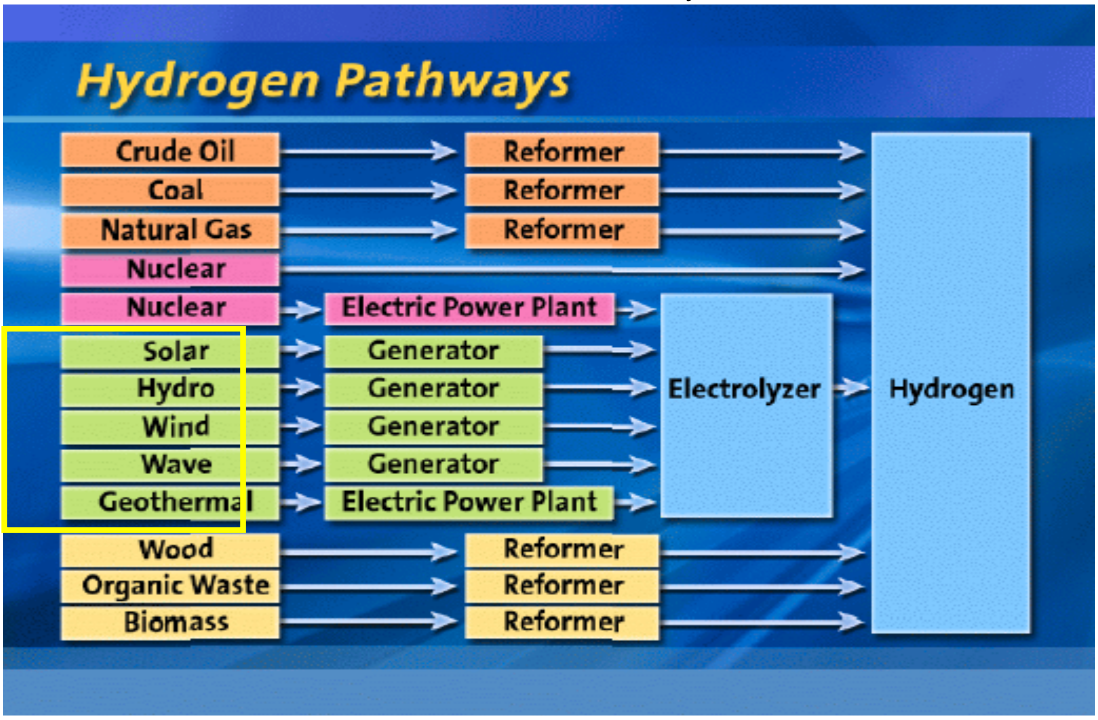

Fig. 20: Overview of Hydrogen pathways (Sai, 2017)(accessed on 2017-06-08)

The figure above showing the different possibilities to produce hydrogen from different source. The energy used from the yellow marked frame are the most economic one because they are produced from renewable energy. Important for the correct calculation of the CO2 emissions are not only the CO2 emissions which will be polluted by driving the car, more and more the CO2 emissions from recovery of the raw material of the fuel you will use to the transportation and storing, until the usage in the vehicle. This total CO2 emission is named as “Well-to-Wheel (WTW) The WTW could be divided into the fuel production Well-to-Tank and the vehicle usage Tank-to-Wheel. The difference is that for the WTT only the greenhouse emissions for the fuel production and for the Tank-to-Wheel (TTW) only the vehicle usage will be considered. In all the analysis the energy and emissions involved by building facilities and vehicles are not considered. The picture below is showing the definition in a graphical illustration.

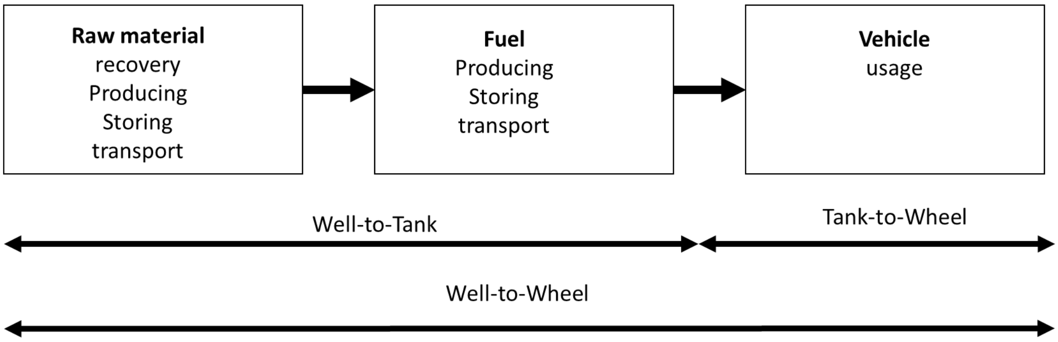

Fig. 21: Description of Well-to-Wheel, Well-to-Tank and Tank-to-Wheel

The figure above is showing the difference between “Well-to-Wheel”, “Well-to-Tank” and “Tank-to-Wheel”.

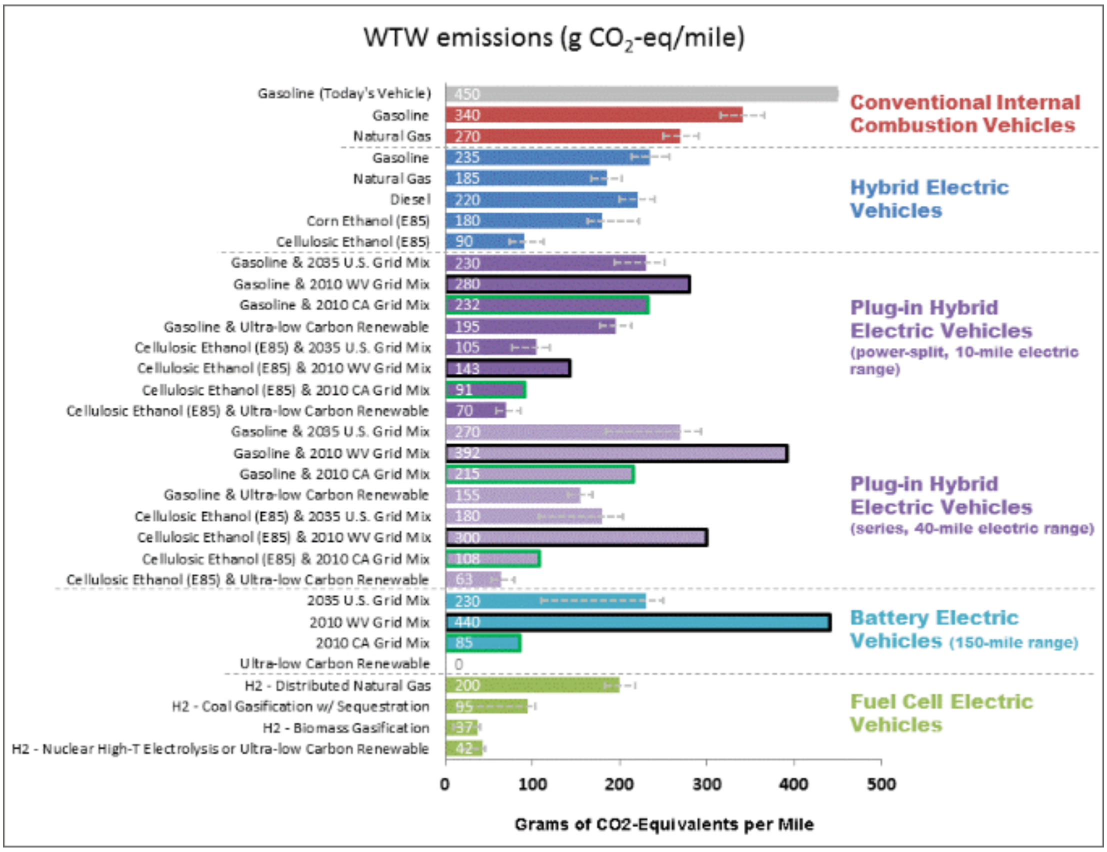

Fig. 22 WTW emissions comparison for different types of power units (wordpress.com, 2017)(accessed on 2017-08-27)

The figure above is showing the CO2 emissions in grams per mile compared to different power unit types. Hydrogen produced from renewable source have to lowest Well-to-Wheel CO2 emissions, compared to all other power unit types. Gasoline vehicles have the highest CO2 emissions. In the chart above the CO2 emissions which are populated by producing the vehicles are not considered and have to be investigated too. For BEV the Well-to-Wheel the air pollution is reduced, but it is transferred to the power plant.

3.3.2 **Availability of hydrogen**

In this chapter the availability of hydrogen, meaning the already existing fuel cell recharging stations will be evaluated. Starting with Austria, taking a look also abroad to Germany and then checking the situation in California, United States of America.

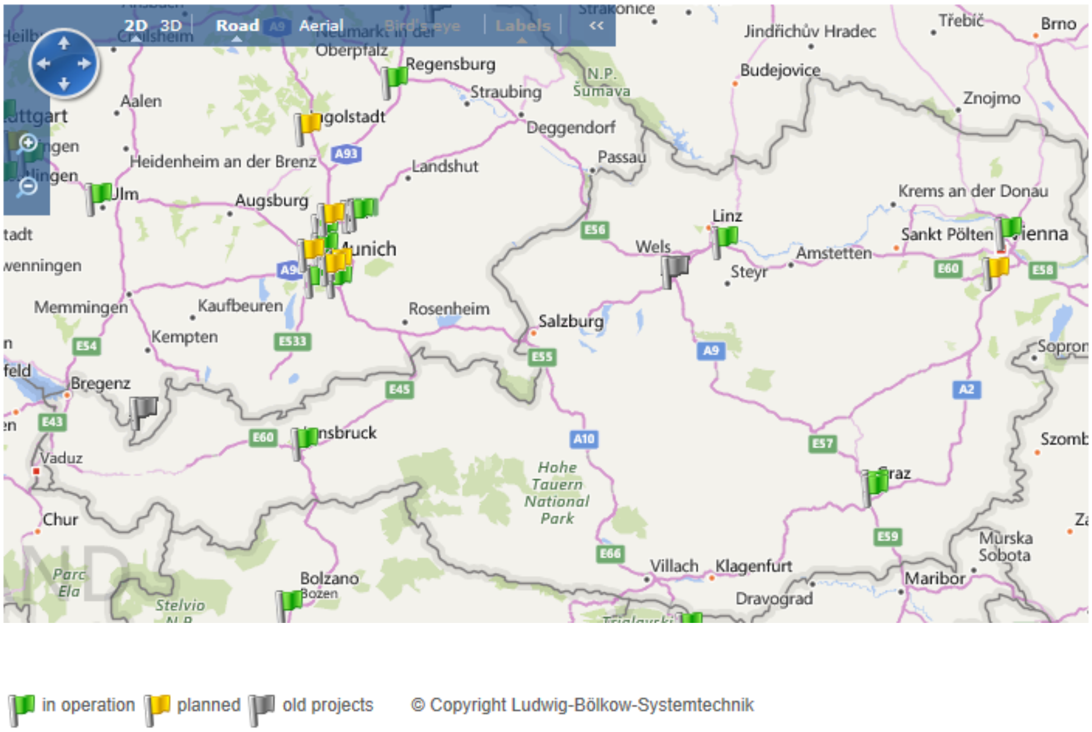

Fig. 23: Available and planned stations in Austria (netinform.de, 2017)(accessed on 2017-06-17)

The map above is showing the current availability of public refueling stations of hydrogen. In total there are 4 stations in Austria available, and one is under construction. Main interest is now the area of Vienna in which there will be until end of 2017 2 hydrogen refueling stations available. Currently 2 main companies are providing the service to build up hydrogen refueling stations in Austria. One is the OMV (omv.at, 2017) and the Linde Gas (Gas-Linde, 2017) both companies are also members of the German company “H2 mobility Deutschland” (h2-mobility.de, 2017) partners of this joint venture are Air Liquide, Daimler, Linde, OMV, Shell and Toyota. Linde Gas have presented an E Bike (Gas-Linde, 2017) with hydrogen powered electric motor, with a range of 100 km by caring only 33g of hydrogen. However, the EU will push the CO2 emission reduction for the fleet consumption of the OEM´s in the next upcoming years. Target for 2015 was 130g CO2/km and in 2021 it will be 95g CO2/km. Unfortunately, in Austria there are no clear commitments, or plans available to improve the numbers of hydrogen fuel stations, or to find information where currently new refuel stations are under construction, accept the one at Wiener Neustadt, which should be opened until end of 2017.

Looking abroad, for example to Germany the map is looking already much more optimistic in the term of number of public hydrogen refueling stations.

Fig. 24: Public hydrogen refueling stations in Germany (h2euro.org, 2017)(accessed on 2017-07-16)

The green dots, on the map above showing available hydrogen refueling stations.

There are by today 28 refueling stations in operation. The plan for 2018 is to have 100 hydrogen stations in operation (h2-mobility.de, 2017). According to the website "*H2-mobility.de*" the plans for building up more refueling stations are depending of the number of fuel cell cars in operation within the next years. Plans existing to enlarge the number of refueling stations until 2023. Which would mean a fuel coverage of hydrogen stations. If we compare Germany with Austria from population and area point of view there is a numeric proportion of 1:10. That would mean Austria should have 10 hydrogen refueling stations by end of 2018 and 40 by end of 2023, where the plans do not realistically exist. If we look to the United States of America, the current situation looks more promising, especially in the state of California in regards to the numbers of hydrogen refueling stations.

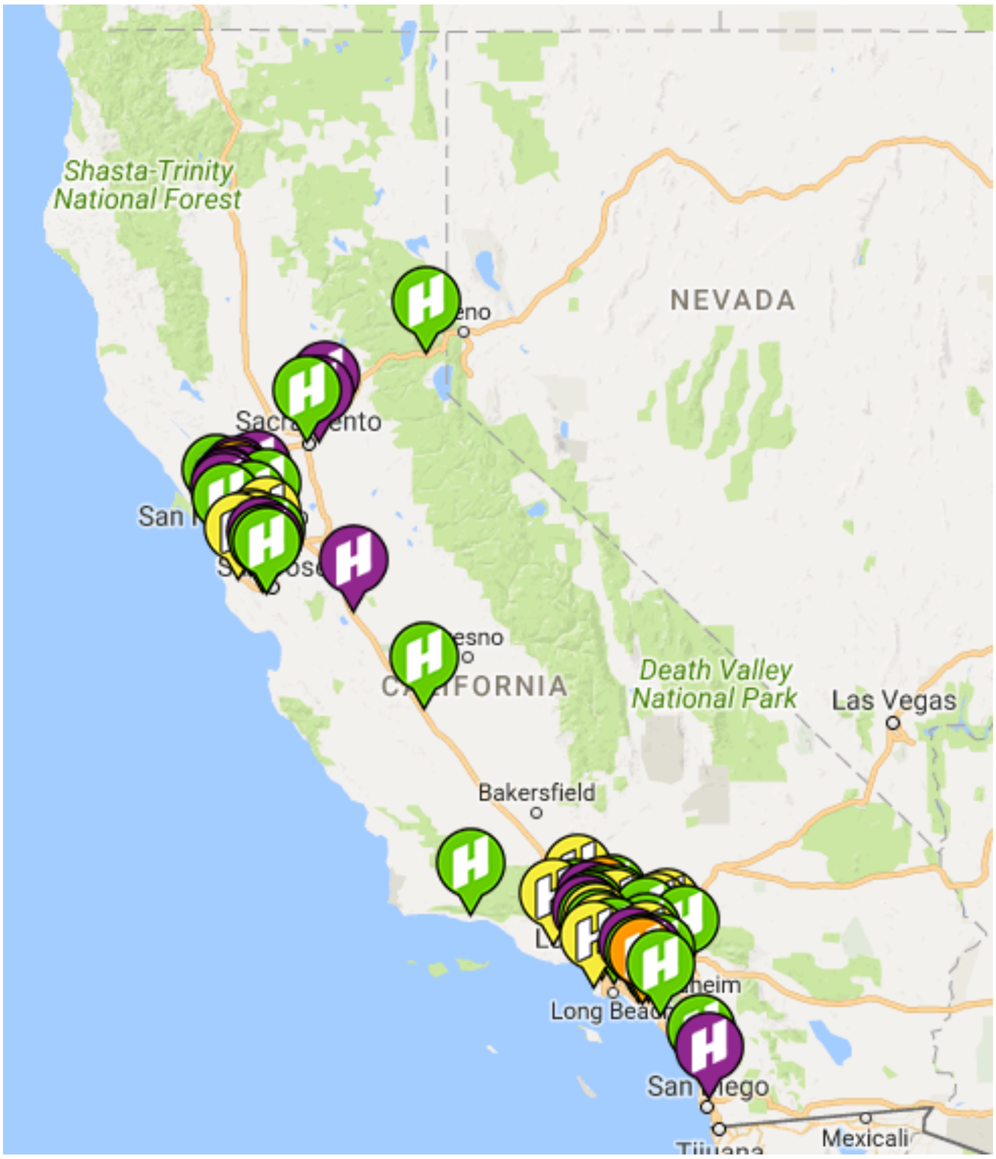

Fig. 25: US California hydrogen stations map (cafcp.org, 2017)(accessed on 2017-06-20)

In total, there are 29 stations available and working, status from 31.07.2017, and 6 additional stations planned to be operative within 2017. Conspicuous is that all the fuel cell refueling stations, in all countries investigated, are in congested urban areas located and along important highways, which makes the fuel cell vehicle attractive in those areas.

Let´s have a look on the current car population compared to other different countries. In Austria, we have by end of 2016 6,65 Mio (AUSTRIA, 2017) vehicles registered, thereof 11.860 with electric power train and 16 FCV. That would mean that theoretically 4 cars / refueling station.

In Germany, there are currently 314 FCV registered and they have 28 refueling stations in operation. 11 cars / refueling station in Germany. In California, state in the USA, there are 1400 FCV registered and they have 29 refueling stations working, so 48 vehicles / refueling station. That makes the market for refueling stations, transport, distribution and much more very attractive for the suppliers. Even the buyer can benefit from the government, when buying or lease a FCV, because they can get 5.000$ rebate and other benefits like using the carpool line on the high way. For comparison in Austria we have by end of 2016 2.614 public gasoline stations for 6,65 Mio registered vehicles, 2.543 cars / refueling station, it´s even 50 times more than the number of FCV for hydrogen refueling stations in California.

3.4 **Storage of hydrogen**

Hydrogen is the lightest element which is known so far. It is 14 times lighter than air, therefore it requires high efforts to storage it. Hydrogen can be stored as either gas or liquid. Hydrogen stored as gas requires typically high-pressure tanks. The pressure inside is between 350 and 700 bar. If the hydrogen is stored in liquid form then it requires a temperature of -252, 8 °C. The high density of hydrogen storage is a challenge for stationary and portable applications. As the hydrogen molecules are very small the storage containers have to be very diffusion resistant. In the past hydrogen have been stored and transported in steel tanks under a pressure of 200 bar. By today the tanks for a fuel cell vehicle are made of plastic which are rapped with carbon fiber and will be finished with a epoxy resin. Diffusion is now under control with this type of tanks and it´s possible to use garage and parking areas without any restriction on the contrary to liquefied petroleum gas vehicles.

3.5 Safety aspects of fuel cell vehicles

In 1937 a dramatic accident happened with the airship "Hindenburg"[3] at Lakehurst United States of America. Many people thinking that the root cause for this disaster was caused by the hydrogen, but the root cause for the accident was caused by the painting of the surface of the airship. Hydrogen only goes in one direction, which is straight up, because hydrogen is 14 times lighter than air and goes away very quickly. Toyota published a video were a fuel cell tank, which they are using in the Toyota Mirai, have been shot with a high-powered caliber gun. The bullet pierces the tank, but the structure remains intact and the tank doesn´t burst. The hydrogen escapes through the hole disperse into the atmosphere. There was no fire or explosion, as most people would expected. Fuel cell vehicles have hydrogen sensors scattered near the fuel cell stack and next to the hydrogen tanks. If one of the sensor's, for example, detects hydrogen next to the tank, the tank will release their pressure in a controlled way, but the will not explode. If the sensors detecting hydrogen next to the fuel cell stack, the system will shut down and vents on the front and at the filler cap will blow away the hydrogen. The tank itself is also equipped with sensors which are continuously checking the temperature and the pressure inside. Fuel cell vehicles which are launched on the market today, are fulfilling all necessary standards in terms of safety requirements which are effectual.

3.6 Benefits and challenges of the fuel cell vehicle

Fuel cell can cover a high range of power, rom a few kilowatts up to megawatts, which makes the fuel cell very attractive for a huge spread of usage. Fuel cell for vehicle use have a higher efficiency than patrol or diesel engines.

3.7 FCV alternatives

Alternatives like hybrid cars, E vehicles with only battery supply, advantage and disadvantages

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[3] http://h2-mobility.de (accessed on 2017-06-21)

There are existing quite a huge range of alternative drive train concepts beside the combustion engines. A hybrid car has 2 or more engines, usually one combustion engine and one electro motor. The electro motor is powered by a battery, which could be charged only by recuperation, for example when you are reducing the speed, or when you brake, the electro motor is generating electrical current (working as a generator) and is charging the battery. The electromotor is providing extra power when you start get started, or when you would like to accelerate up, then the electro motor is “helping” the combustion engine with extra power, or the fuel consumption of the petrol engine is less. In most of the available hybrid cars you can also drive with only with the electric motor, but the range is mostly not more than several kilometers.

The next level of hybrid cars is the so-called plug in hybrids. Here the battery will be charged by recuperation or from external electric power supply. Those cars have even a better range where they can drive only with battery (up to 50km), but they have disadvantages, like higher price than the hybrid car, they are more heavy, service costs are higher compared to non-hybrid cars. The charging time is still some hours at a classical plug socket. To improve the charging time a special charging station is recommended by almost all car manufacturers. In Austria the tax for hybrid cars is lower than to combustion engines because the tax calculation, by buying a new car only, is calculated with the CO2 emission of the car. This calculation makes the new cars more expensive in Austria then for example in Germany where they do not have this tax based on the CO2 emissions. Even you want to import a used car you have to pay the CO2 emission tax, before you can register the car. The tax is called in Austria: NOVA-“***No****rm****v****erbrauchs****a****bgabe”.*

The advantage of a hybrid car, compared to an electric vehicle with battery, is that you can also drive with the car, although the battery is empty, because you still have the combustion engine.

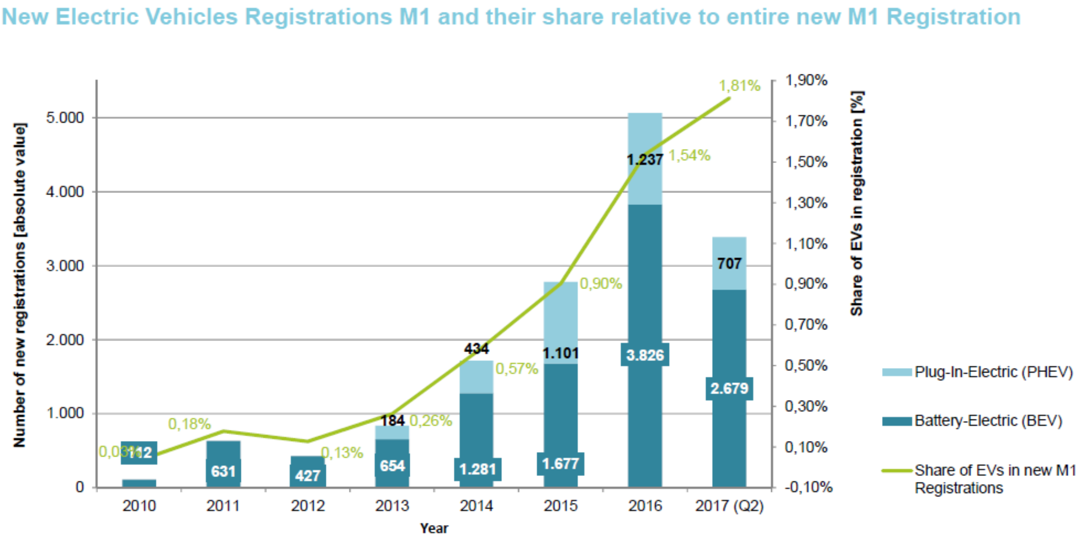

Fig. 26: New vehicle registrations M1 relative to the entire new M1 registration (bmvit, 2017)(accessed on 2017-06-21)

The table for M1[4] registered vehicles above is showing the increase of PHEV and BEV vehicles in Austria from 2010 to quarter 2 in 2017. From 2015 to 2016 the BEV increased from 1.101vehicles in 2015 to 1.237 vehicles in 2016, which correlates to 11% growing rate. Even until the second quarter of 2017 the number of new registered BEV in Austria is showing again a high growing rate, minimum like the years before. Caused by the fact that the Austrian government is now promoting the buying of hybrid, plug-in hybrid, battery cars and fuel cell cars, up to 4.300 € for private owner, this might and up until end of 2017 in a new record for new registered cars in Austria with alternative power unit. In chapter 3.1 we have seen that the availability of hydrogen refueling stations are very weak in Austria, compared to other countries. In the next picture we can see the current availability of the electric vehicle charging stations by today. 2.592 charging stations in work, thereof 416 fast charging stations. Main highways are covered with enough charging stations to drive all over Austria in

[4] M1 vehicles for carriage passengers (Observatory, 2017)

all main 4 geographic directions. There are, by end of 2016, 2670 public petrol fuel stations in place at Austria.[5]

Currently the Austria logistic- and post service provider is the biggest user of electric vehicles. Currently more than 1.400 electric vehicles are registered. They established an internal program called “E-Mobility Post” (Post.at, 2017) together with the ministry for transport, innovation and technology (Austrian Ministry for Transport, 2017)

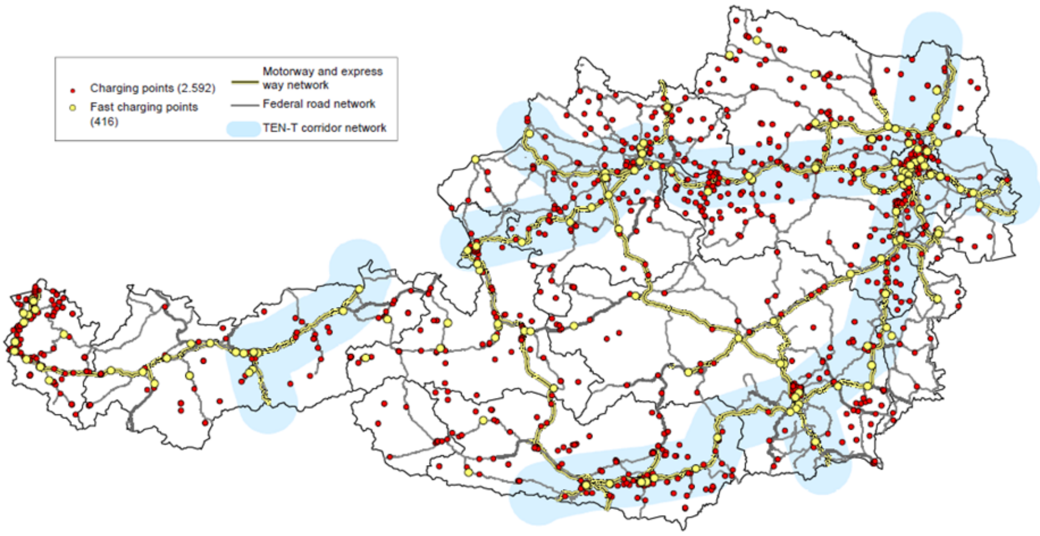

Fig. 27: E-cell charging station map in Austria (e-tankstellen-finder, 2017)

(accessed on 2017-08-02)

Another alternative is the E-Fuel. E-fuel is a synthetic produced gasoline. With the power of electricity water and carbon dioxide will be gasoline produced. This alternative is impressive as it uses carbon dioxide which is the number one reason for the global warming and it looks like that it could be produced emissions free. However, to produce the E-fuel you will need per km driving double times more electricity than for a fuel cell vehicle and compared to a BEV, five times more electric power.

Compressed natural gas vehicle is also an alternative type of power unit. In principle the engine is a petrol one, but could be powered with compressed natural gas and also with petrol. Those types of cars are also called “Bi-fuel vehicles. Petrol combustion engines could also be modified, in after sales, to a “Bi-fuel” vehicle. The

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[5] Data from Austrian Gas Grid Management AG, http://www.aggm.at, (accessed on 04.09.2017)

main reason why to drive with a CNG, for the owner, is that to drive with CNG is cheaper than to use gasoline. Approximately 50% cheaper compared to a gasoline, and round about 40% than a diesel combustion engine[6]. As the natural gas has less carbon content then gasoline, the emissions of carbon dioxide are reduced by 80% compared to gasoline fuel (mobility, 2017). Disadvantage is that you have two tanks, one for the CNG and one for gasoline, which is reducing your capability for carrying transport material and also the cargo load is reduced. Advantage is that it could be also installed in after sales.

For the gasoline powered combustion engine are also new technologies planned and in some of them already in place. Currently the down-sizing of the petrol engines is very common. Downsizing means, that the cylinder capacity is reduced and by using a turbo support, the power will be comparable, or is even higher than for a combustion engine with a higher cylinder capacity. By using the turbo support the maximum torque is on his maximum level in a wither range in terms of engine speed. That gives the driver the opportunity to drive with lower engine speed, without missing the power and you can save petrol consumption. Currently most of the OEM´s working on new technologies, like Infinity has presented a gasoline engine with variable compression[7]. With this new technology the Infinity will combine the advantages from a gasoline and a diesel engine. High power output form the gasoline engine and a high torque from the diesel combustion engine, with the support of a turbo. Depending from the drivers need, the engine could change the compression from 8:1 to 14:1. As the engine will always work on the "optimum" working point the gasoline consumption should be less than compared to other gasoline engines. Also for the diesel engines the OEM´s working on the efficiency for this type of combustion engine. Main targets are the reduction of the diesel consumption and to reduce the emissions and particles. This will end up into additional technical equipment, which you will need to reduce the emissions and will lead to additional costs. Which might be a problem for cheap cars, as the price increase will be much higher than for a more expensive car.

[6] http://www.erdgasauto.at (accessed on 05.09.2017)

[7] http://infinitinews.com/en-US/infiniti/usa/releases/infiniti-vc-turbo-the-world-s-first-production-ready-variable-compression-ratio-engine - (accessed on 05.09.2017)

3.8 Customer behavior change due to the City Megatrends

Customer behavior will change in the future. Two mean reasons for that; one is that the government of different countries are taken different approaches to get the pollution reduced. One contributor is the car. In the future people will be forced to buy cars with reduced emissions, even up to zero emissions, but they don´t want to be restricted in their way of life. Currently quite a lot of capital cities in Europe have announced during the last weeks, that the German government started a public discussion not to register from 2030 new cars with combustion engines anymore. England also stated that they will not register new cars with combustion engines after 2040. Most likely the discussion about the zero emission have been light up by the diesel scandal, but the fact will be that zero emission will come. They question will only be when? Currently around the world the trend to move from the country side to mega cities is meanwhile a fact. This requires new thinking in the perspective of air pollution, because they young generation are grown up with "green thinking". In the mega cities you will need a lot of transportation service, like bringing you the online orders to your home, the online supermarket, have to deliver to you. So there will be a strong need for vehicles in future for sure, but they shouldn´t produce any emissions if they would drive in mega cities. Global warming, increasing CO2 concentration and environmental pollution is a topic for the world and specially also for the big cities. The awareness of the younger generation about the facts described before, is more serious then we think. The car as a status symbol is not important for the younger generation. Education, traveling being successful in the job, having a good life balance are more important for them. Safety and environmental protection will be the key factor for the automotive industry for the upcoming future. Intensification of emissions, traffic safety and security will be the motor for new technologies. Electrification, using for individual and public traffic renewable energies will be the main driver for buying, or using cars. Car to car connection, online service and autonomous driving will be the main technologies which have to be considered by the car manufacturer in future. Even the "old" automotive industry are facing new challenges, because of new competitors are showing up, like Tesla and Google Car and a lot of , not yet, known startups, which are developing already on those new technologies. So the "old" automotive economy have to be watchful not to lose their technology competencies. In 2015 75% of the world's population is online, ten years before, in 2005 there have been only 15% online. More and more people getting used to use the World Wide Web for daily live, why the car shouldn´t be part of it? Globally the share of 65yr+ is doubling; more than 30% of them will live in mega cities. This section of the population will have their specific needs and wishes, which we have to understand and to be able to provide them our service and products. Each region will have their own needs, like low price vehicles and different types of cars, like SUV for the 65yr+ generation with an high level of autonomous driving technology on board.

The awareness of health and well-being and quality of life will be a main trend (Miorini, 2017), which all the industry and governments will have to follow. Beside this fact the population will growth.

New areas of business will come for the OEM´s as well. Online assistance service for the driver and passengers, high flexibility for extra car features. Why the customer have to spend quite a lot of money for a navigation system, even it will be used maybe only once, or twice a year? Dealers will offer special features only on demand by customer request. The needed hard ware will be already equipped in the car, only the software and the release code will be provided, for example by flashing over the air. After a certain time period the feature will be disabled and can be activated again if the user would like to do so. This will be also important for car sharing user and rental car user. When they will order a car they will also order there specific need on additional car features and will only pay for it when the really will use it. The same approach can be done with horse power, for example, if you have to drive with a heavy trailer and you would like to have more torque and horse power, the dialer will release this power to your engine for a limited time period, and you can use it. Even the tax, calculated by your, in most of the countries a common law, emission and or your fuel consumption. If you will use the increased power, you will only pay more tax for the defined time period and after the period is over, you will pay your standard tax, as before.

By today, car sharing is becoming popular, even in Europe, but there are still some open questions that might need answering. Table 2 is showing which distance you can drive when you spend one minute of refueling.

Table 2 Comparison on refueling per one minute for which distance (accumotive.de, 2017)(accessed on 2017-08-14)

Fuel Type	Range
Diesel	300 km /min
Battery electric 400V	10km/min
Hydrogen	230km/min

Car sharing companies only earning money, when the cars a rented to the customer, refueling, service and maintenance will reduce the net available time for rental. Best might be the diesel engine powered cars and worth will be the electric cars with battery. This is a todays point of view and in future they battery recharging time will be reduced, but not so significant until 2025 to be close to the refueling time of a Diesel or an hydrogen powered car. Based on the facts described before the EFCV could be a serious alternative for the car sharing companies

4 Methodological approach

4.1 Facts overview

Considering the facts and information from the previous research, it is oblivious that the world and specially the automotive industry is changing and facing a complete new challenge. If we are looking at the cars:

- Change in the power drive concept
- Customer behavior change
- New megatrends
- New competitors for the “old” economy
- Current car user do not want to change their used behavior

4.2 Existing solutions for hydrogen powered vehicles

Currently, four OEM´s are offering fuel cell vehicles. Nevertheless, hydrogen powered vehicles are also relevant in other areas where transportation is needed. Forklift in the logistic area is very often powered by fuel cell. Inside of storage buildings, any vehicles which are powered by a combustion engine will create exhaust emissions, which will require a very expansive air-handling system, as long as employees also work there. Battery powered vehicles would require a long recharging time and the vehicles could not be used at that time, this is very important for companies which have a 24/7 shift model. Hydrogen powered vehicles, could be refueled within some minutes and have as emission only water. Even the public transportation area is using fuel cell powered vehicles (Buses, 2016). Overall, there are 645 buses with fuel cell power unit in place and working in different cities across Europe. Main facts for using fuel cell buses are the short refueling time, zero emission when driving, lower service costs and the benefits provided by the government and the bus manufacturer. Fig. 28, is showing an overview about the current usage of fuel cell buses. Interesting, that the countries, more in the North, like Benelux countries, Norway, Sweden and Finland are always ahead in alternative power units, not only for the buses, also for electric vehicles in general.

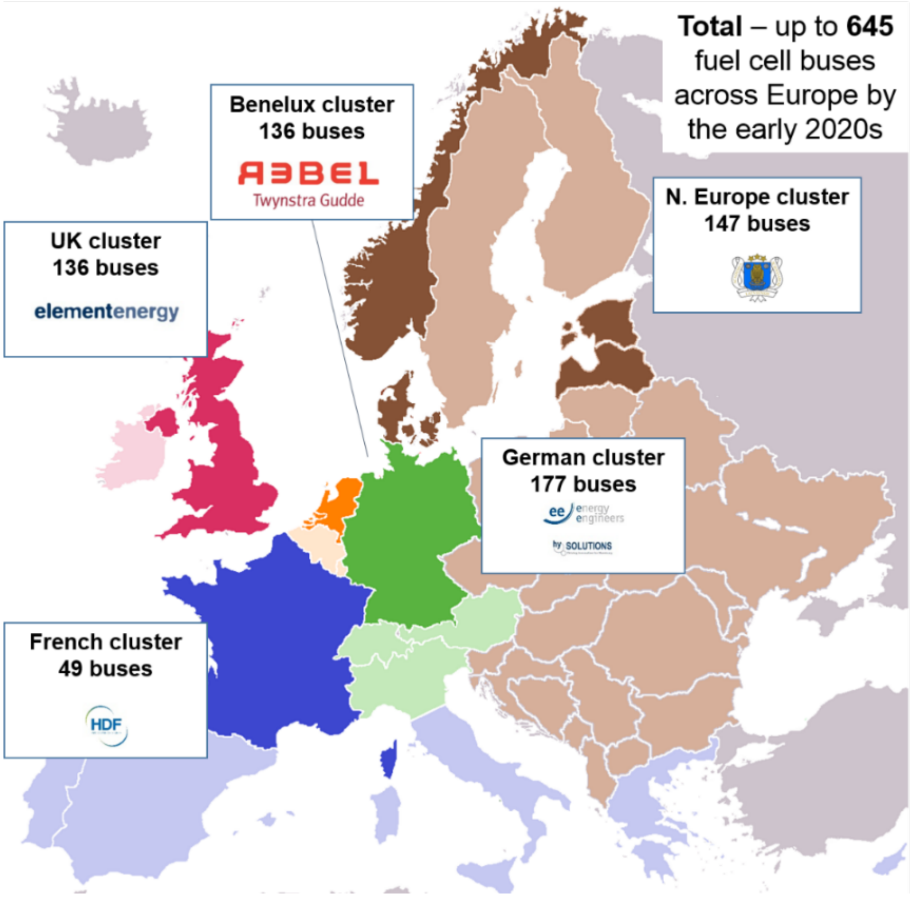

Fig. 28: Fuel cell usage overview in Europe (element-energy.co.uk, 2017)(accessed on 2017-08-04)

Fuel cell for buses can also be used for heavy weight trucks, but so far, only experimental versions have been build up. The latest update was provided by Toyota Motor North America (Stewart, 2017). Even in the aviation sector, fuel cells have been already tested. Prototypes of airplanes have been produced and those airplanes have been able to fly by themselves. One of the key driver for research in the aviation area, is the fact that currently big airplanes needing 4 to 20 tons of kerosene. The weight specific energy content of hydrogen is 2, 8 times higher, then for kerosene, which will bring an advantage for the load capacity because the weight of hydrogen is lower compared to kerosene.

The Austrian aircraft manufacturer presented in 2007 an aircraft powered with a fuel cell. Below drawing is showing the technical equipment used for the fuel cell power unit.

Fig. 29: Principle of an fuel cell powered aircraft (diamond-air.at, 2017)(accessed on 2017-08-06)

Besides that, Boeing and Airbus are also doing research and testing in the area of fuel cell power for airplanes.

Space flight is considering hydrogen already for long time, meanly in two area of use, one is the usage of hydrogen for the rocket propulsion and the second one is for the supply for electrical power and drinking water for the crew. Since the Apollo space program have been launched, fuel cells have been always on board of one of the Apollo missions. The moon car was already powered by a fuel cell.

More experimental areas for fuel cell usage is for rail trains and boats. First train prototype have been used in the mining industry for usage in the underground. Main reason are to avoid any emissions, reduced noise and vibrations.

4.3 Future plans from the Original Equipment Manufacturer

If we take today an outlook for the future plans of different OEM´s then we can see at least one major trend: all the OEM´s investigating in electric vehicles with batteries and also quite a huge amount of EV will be launched in short due time.

Besides that, in January it was announced that Daimler, BMW, Linde Gas and 10 more companies have established the “Hydrogen Council” (Council, 2017) with the main target to increase the attention for fuel cell vehicles.

Currently all the 16 members of this council are spending 1,4 Billion Euros per year into the development of the fuel cell technology and the infrastructure. Main reason for that is that they believe that a fuel cell car has more advantages in the near future then an electric vehicle with batteries, mainly the short refueling time and a larger range. As a result from the world climatic conference from 2015, which took place in Paris, France the global warming have to be limited. Today Toyota, which is also member of the hydrogen council, has produced and sold currently the most numbers of fuel cell cars. By end of the year 2016, 2840pcs of Toyotas Mirai have been produced.

Fig. 30: Toyota Mirai (Auto-motor-und-sport, 2017)(accessed on 2017-08-26)

Beside that Toyota presented micro EV for the urban market, with 2 passengers and a low range. Toyota is currently pushing there hybrid and plug-in hybrid models as they have been one of the first OEM´s, who produced hybrid cars for end-customers.

Daimler announced (Daimler, 2017) that they will launch a new fuel cell car by end of 2017, which will be the Mercedes-Benz GLC F-Cell. This new model will have a battery with a higher battery capacity to be able to drive also with the electric source of power only from the battery to overcome a possible shortage of hydrogen. You can charge the battery also with external electric power, like a plug-in hybrid today.

Fig. 31: Mercedes Benz GLC Plug-in Fuel Cell car (Driver, 2017)(accessed on 2017-08-26)

Daimler has also announced at the "38th International Vienna Motor Symposium" (Symposium, 2017) that they will continue in the development of fuel cell vehicles, as they have already collected quite huge experience with this technology. For example with the first generation of the B-class F-Cell in total they drove more than 8 Million kilometers in Europe and USA. One car was driving for more than 300.000 km, and the average for one refueling is less than 3 minutes based on 36.000 fuel-fillings. They also mentioned there experience with busses powered with electricity from the fuel cell. Mainly sued in Switzerland by the local transportation company "Postauto". The Citaro fuel-cell bus was able to drive more than 1 Million kilometers. Overall currently there are 23 Mercedes-Benz Citaro fuel-cell-hybrids on the road. Also in Germany, Hamburg, Italy, Milan and Bozen.

Fig. 32 Mercedes Benz Fuel cell bus (Mercedes-Benz.com, 2017)(accessed on 2017-08-26)

The European Union has stated that they will continue to support the development and launching of fuel cell buses. Daimler announced in 2016 at the Paris motor show, that they have founded a new brand for their future electric vehicles, called "EQ". Under this new brand from Daimler AG the will bring a new generation of pure electric vehicles in a modular set up of train technologies with a high variety of derivatives. It will be flexible for different car types and also flexible for each market around the world and it will also include the infrastructure for private recharging possibilities including wireless charging.

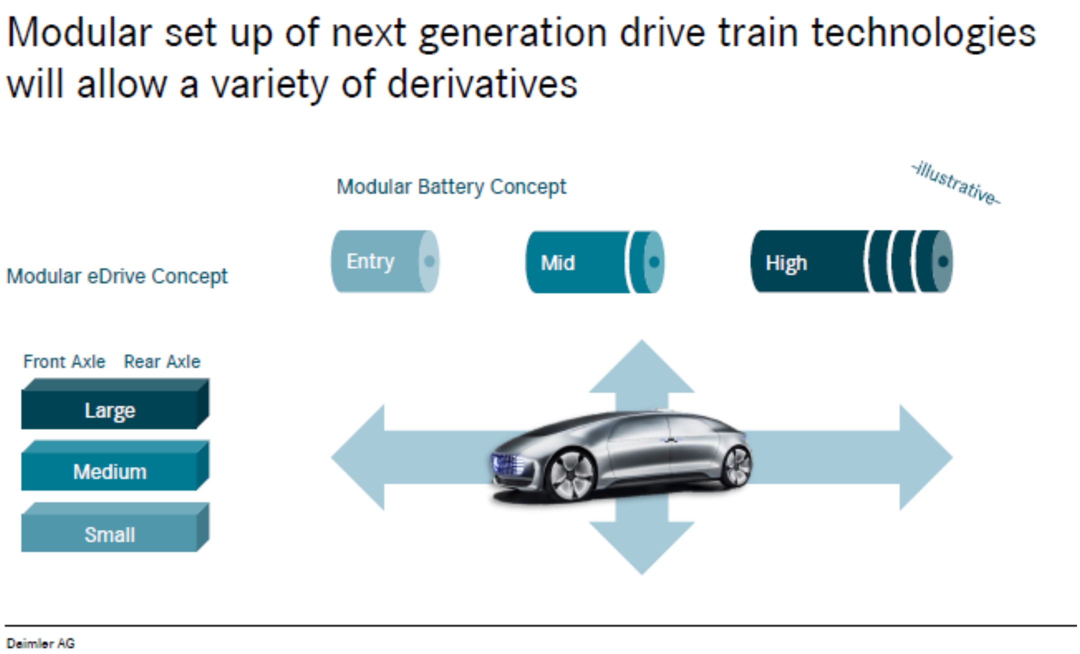

Fig. 33: Modular battery concept (daimler.com, 2017)(accessed on 2017-08-20)

Even they will also produce the batteries in their own factory, which is 100% part of the Daimler AG, ACCUMOTIVE GmbH & Co, KG (accumotive.de, 2017), located in Kamenz, Germany. By the new initiative for the new brand "EQ", they will expand the production space from 20.000 to 60.000m^2 for the Lithium Ionen battery production by summer 2017. This will give the Daimler AG the advantage to have their own battery production facility and the can keep the know-how internal, compared to other OEM´s, which have to spend research and development cost to other Tier 1 suppliers, and Daimler is hoping to have an advantage in terms of battery costs. However, if you build a plug-in hybrid, or an electric, or a fuel cell powered car, they will always need batteries for all of these power unit variants.

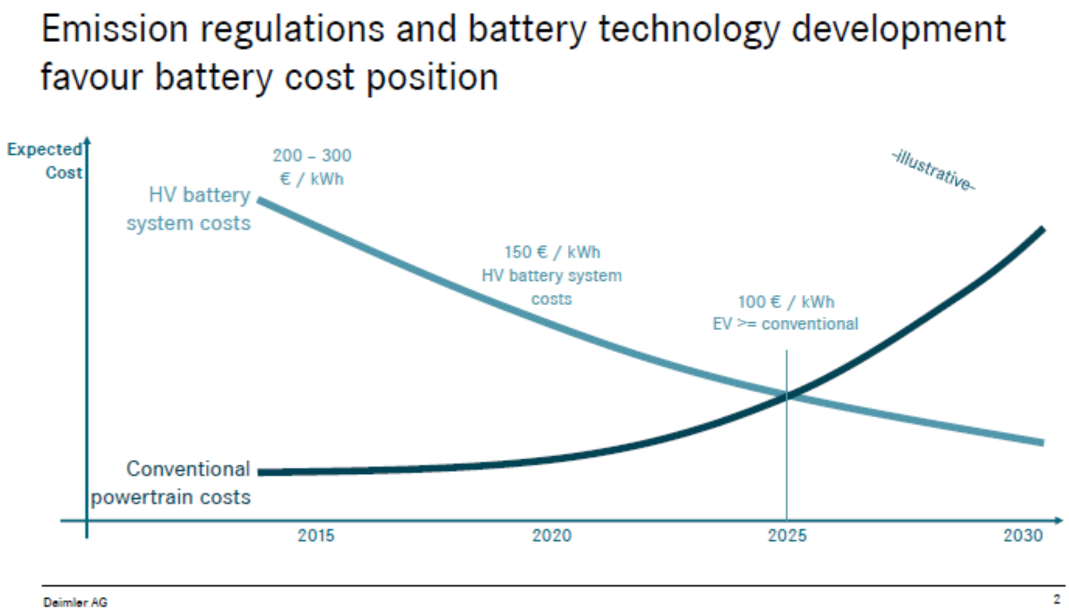

Fig. 34: Emission regulations vs. battery technology development

(daimler.com, 2017)(accessed on 2017-08-20)

The figure above is showing the expected costs for conventional power train costs compared with the battery system costs, considering the emissions regulations until 2030. According to the calculation from Daimler AG, in 2025 the conventional and the battery system costs will reach the breakeven point. Daimler AG has forecasted that until 2025 the share of EV on total sales for Mercedes-Benz cars could reach up to 25%. The market with the highest potential will be China, then America and Western Europe.

Hyundai has presented in March 2017, at the Geneva International Motor Show a new Fuel Cell Concept car, which should representing an outlook for the 2nd generation of their fuel cell cars. The power density of the fuel cell stacks could be increased by

30%, the weight could be reduced by 20% and the overall efficiency could be also increased by 10%, compared to the first generation from Hyundai´s ix35 Fuel Cell model.

Fig. 35: Hyundai next generation concept fuel cell car (gims.swiss, 2017)(accessed on 2017-08-13)

Hyundai also mentioned that this fuel cell car would have a maximum range of up to 800 km, which will be the best maximum range for an alternative car. Beside that it´s interesting that, Hyundai Motor Company is presenting now the 2nd time a fuel cell car as a SUV. Hyundai announced that they will start serial production for this new FCV in 2018 and it will be then also available on the market. The price of the 2nd FCV will be 20% less than the 1st generation.

Honda has presented in 2017 there new fuel cell vehicle , called “Clarity” (Honda, 2017), it´s a 5 seat sedan model , which is equipped with a fuel cell power unit, or it is also available as a pure electric car with batteries and also launched as plug-in hybrid. Honda is currently promoting their new vehicle in the USA with a voucher up to 15.000 $ for hydrogen fuel and a rebate for clean vehicle, as they are offering this car model as a zero emission car. The European Commission is supporting the FCV with the HyFIVE (hyfive.eu, 2017) program only in Great Britain and Denmark.

Fig. 36: Honda Clarity (Honda, 2017)(accessed on 2017-08-13)

Tesla, which is known so far, as a pure electric vehicle manufacturer, is currently offering only luxury high powered EV. They have started now to produce there new model 3 (Tesla, 2017) by summer 2017 which is a full electric vehicle with a maximum range of 350 km, a full 5 seat sedan car for a starting price in the USA of 35.000 $. The price for a Model 3 in Austria is by today not available, or published on the Tesla homepage in Austria. So far only a preordering is possible by paying a deposit of 1.000 Euro. They have already more than 300.000 advance bookings for their new model 3. Currently the waiting time, if you order today, is up to 18 months.

Below a picture of the first car presented by Tesla in 2008,the Tesla Roadster.

Fig. 37: Tesla Roadster (Tesla, 2017)(accessed on 2017-08-13)

Above a picture of the first car presented and produced by Tesla in 2008, Tesla Roadster.

Fig. 38: Tesla Model 3 (Tesla, 2017)(accessed on 2017-08-27)

BMW has invested until now nearly 6 billion Euro on electric car research and development. Currently BMW is offering a huge range of hybrid and plug-in hybrid cars, from the 1 series up to the 7 series. As full electric car they offering today only the i3. The sales increase for the model i3 is 50 per-cent year by year, according to BMW. For the upcoming Frankfurt Motor Show (IAA) in September 2017, the CEO form BMW, Mr. Krueger announced a surprise in the context of e-mobility. Most likely the BMW 3 series and a Mini will be presented as EV. For fuel cell, there was no clear statement from BMW available, but anyhow they are member of the hydrogen council. BMW has already longer experience with fuel cell cars. In the year 2000 BMW build up a small number of FCV based on the platform of the BMW 7en series. Later in 2005 BMW presented the BMW Hydrogen 7 car, which is based also on the platform of the 7series with a fuel cell power train and a combustion engine. Those cars have not been sold to private users, they have been used only for internal usage. They also build some prototypes of a fuel cell car, based on the BMW 5series platform in 2015.On the homepage of "Hydrogen cars now" (Kantola, 2017) first pictures and some technical details of BMW i8 Hydrogen car have been published.

Fig. 39: BMW i8 Hydrogen (Kantola, 2017)(accessed on 2017-08-27)

Also Renault-Nissan, Volkswagen and Volvo announced a huge increase of electric vehicles in the near future. The new registrations of electric cars in Europe showing a growth rate of more than 50%. So all the "big" OEM´s would like to participate on this growth rate.

The future plans of all the OEM´s are directly linked to the new emission regulations of the European Union, the behavior change of the people and who will have the best tactic to be ready for the future. As no one knows today, which future technology will become accepted by the customers? Currently main open technical questions are not answered, like how to recycle the used batteries? How to get the right quantities of rare earth metal, which you need for the batteries production? Does questions are valid in general for all types of vehicles were you need batteries, as bigger they are, and as to more important will be the answer to those questions. The electric provider have to clarify how to supply the needed electricity gained from solar and wind powered stations.

4.4 Technical approach to find an answer

Considering now the facts that have been collected, the following evaluation of the question: Can we drive a fuel cell car in 2017 in the area of Vienna? Will be done.

Suppose the daily driving distance from the home town of the author of this master thesis (2304 Orth/Donau, Austria) to the office at Vienna, Dresdner Strasse 91 is 30,9 km one way.

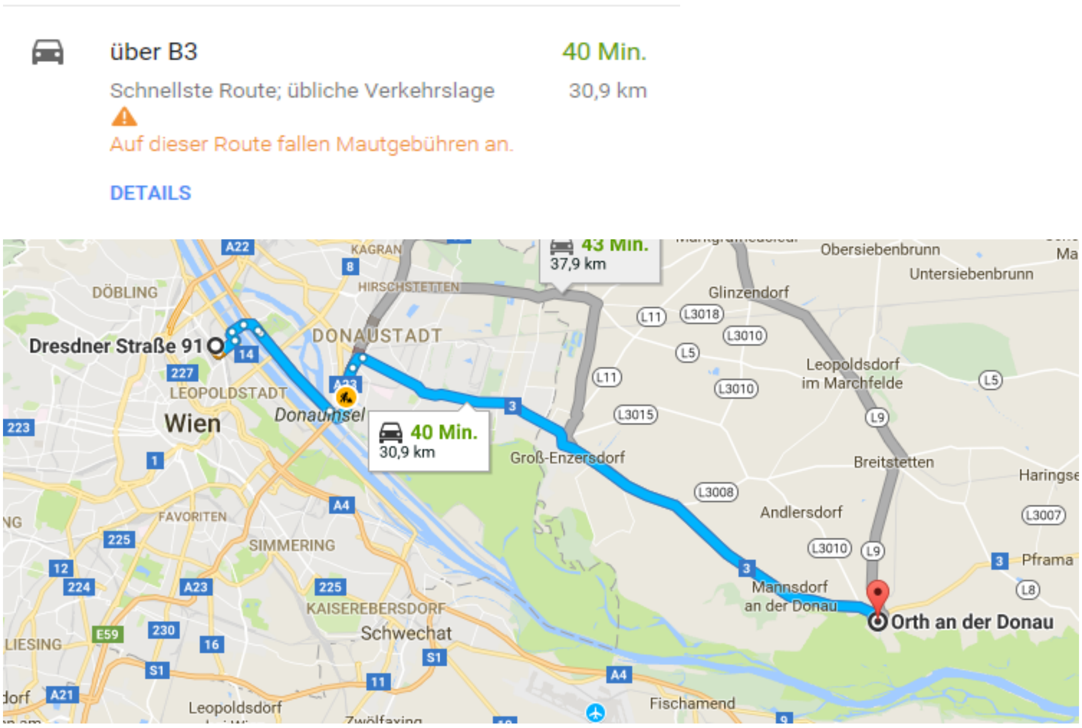

Fig. 40: Overview of typical travelling distance from home to the office (maps.google.com, 2017)(accessed on 2017-08-07)

So the daily distance from home to the office and back will be: (30,9 km multiple by 2= 61,8 km). Driving this distance 5 times a week, the result will be a total of: (61,8km multiple by 5)= 309km).

So the weekly total driving distance is, in our example 309km. Compare the results with the technical data sheet from Toyota Mirai (Austria, 2017) the maximum operating distance is according NEDC-cycle (Autoindustrie, 2017) 550 km at +20°Celsius. So for one week driving there is a security percentage of 45% (309km divided by 550km = 0,45%).

This should guaranty enough “spare range” to be able to drive one week also during winter time, when the ambient temperature is lower, or in hot summer time when you will use the air condition.

Let´s compare the result now with a battery electric car. BMW is providing on their homepage a tool to calculate the possible range considering different aspects. In this case the BMW i3 with battery capacity of 94Ah:

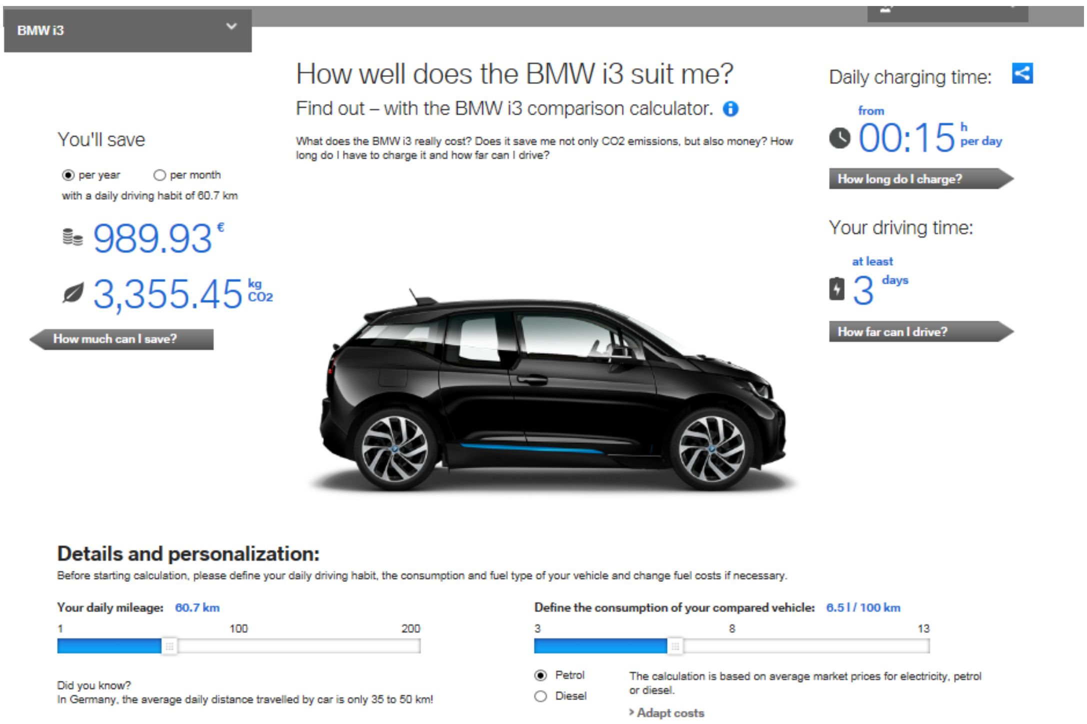

Fig. 41: BMW i3 personalized range calculator (bmw.com, 2017) (accessed on 2017-08-07)

According to the calculation provided by BMW you can drive at least 3 days, without recharging.

Anyhow, for an electric battery car you will need a high voltage and high current charging station. The life time of the battery will be reduced, if you charge the battery with high current, or you have to charge for 12h on a normal household plug socket, or you have to charge your car every 3 days on a public charging station. The calculation model provided by BMW is considering a high current charging station.

Above facts and figures will be evaluated by the author and the experience from users by using a scoring system. The evaluation is done for passenger vehicles and the customer is a standard owner of a car. Using it for going to work, shopping to the supermarket and using it two times per year for vacation. The scoring is done in that way that the different criteria's for the customer are listed horizontal (list is not complete) and the main available power train concept are listed in the vertical line score (1) means that this criteria is worst, compared to the other criteria's score (5) means that this type of vehicle power train concept, or the customer related criteria is the best. As scale a standard Volkswagen Golf with a petrol engine is considered as a reference.

Table below showing the scoring and a sum for each power unit variant.

Table 3 Assessment of the different power units for vehicles (5) is best-(1) is worst

assessments criteria	fuel Cell	petrol	battery	hybrid
cost of the vehicle	1	5	2	3
fuel cost	3	3	2	2
maintenance cost	2	4	2	3
range	3	3	1	2
refueling time	5	5	1	3
amount of available refueling stations	1	5	3	4
Result	15	25	11	17

Petrol powered vehicles have the highest score sum in this table, because all the disciplines are high scored in general, because the petrol powered car is still an affordable and easy to use type of passenger vehicle. The result showing a high acceptance of the petrol powered cars, although the awareness for biologic products, to be sporty and life healthy in general, is very common and highly established. For the vehicle, it seems, this awareness is not soaked into the public mind of the people.

Hybrid and fuel cell cars are following behind with a high gap. Interesting that the difference between the fuel cell and the hybrid technology is not as big as it can be seen in the numbers of first car registration. The refueling availability and to the public almost unknown fuel cell technology, together with the low numbers of available cars, is reflected in the lowest score for the criteria “ amount of available refueling stations”.

At the end of the ranking score table the battery powered car is placed. Main reasons for that are still high costs of the vehicles itself, the low range and the long charging time.

Overall the petrol powered engines have still a lot of advantages, although they are the worst in term of emissions. The hybrid powered vehicles, are the most comparable one to the petrol engines and the battery and fuel cell powered vehicles have to be improved in the main relevant areas.

5 Conclusion

5.1 Validation and Conclusion

In this chapter the conclusion if we can use a FCV in the area of Vienna, Austria for longer/short distances, or will the EV be the better solution for urban mobility, and FCV only suitable in the urban area for public transport will be described.

5.1.1 Validation

Starting with the founding of the fuel cell technology, going to the first fuel cell vehicles and finally the first hydrogen passenger vehicles which you can buy at your car dealer. Considering the fact that the combustion engines are much more common than any other power unit, the alternative power units will have to show up in the mindset of more people as an alternative to mineral fuel. The politics, European Union and different governments from different countries have already placed new regulations for the fleet emission of every OEM for the next upcoming years. However the OEM´s are forced to establish alternative power units to avoid any penalties from their governments. Talking with user and organizations, which are driving already vehicles with alternative power units, the main common comments is, that it can be used those alternative vehicles, BUT……one user of an BMWi3, driving with this car already one year, for going to the workplace every day and back, described that the driver always have a kind of "stress" when driving the i3, because the user always have in their mind to check the remaining range of the car. In summer time user have to abstain of the air condition, because the driver never knows, will the driver get into a traffic jam and will need more battery power, as usual? Will my wife call me and ask me to pick up the children, instead of here because she has to stay longer in the office and I have to drive a longer distance as expected? The expert also mentioned that if you don´t have your own parking space were you can charge your vehicle during the day or night and you have to use only public charging stations might not work, because very often they charging stations are occupied by other users, or you are not registered for this provider, who is offering there a charging place. He also told me that when you are driving to down town of Vienna, people simple do not recognize you, because you are to quiet and the people are used to hear a motor noise, which is warning them indirectly, that there is someone coming. Since this year, if you are registering your electric vehicle in Vienna, you will get license blades with green numbers and letters, instead of white one. The reason is that in Vienna for example you do not have to pay parking fee, you can use the bus lane and some more benefits with green license blades. The disadvantage in Vienna is currently, that the people seeing you driving with the green blades, they are thinking you are driving with a car for handicapped people and they are shoving and overtaking you very risky, which makes you very nervous and upset as a driver of such a car and might also be dangerous. The driving characteristics are also different to the cars, you are used to, because on the one hand the center of mass is very low, because of the fact that the batteries, are in the most cases, placed on the very lowest point of the car and not very far away from the ground. This gives you a dynamic feeling when you for example drive truth a landscape with a lot of curves. On the other hand the electric vehicle have small tires, for a smooth running and to have a low rolling resistance, but this is not helping, if you would like to drive curves. The smaller and thin tires does not support any dynamic driving.

Interviewing one of the main driver of an fuel cell car, here in Austria, operated by the OEAMTC, as they are owning a Hyundai ix35 Fuel cell car since more than 2 years and they have been driving this car more than 40.000km, the experience from them will be the main input for my research questions: If you can drive in the area of Vienna, today with a fuel cell car? And what will be there experience with driving and using this car in Austria. First of all, there have been no any extra scheduled stop at the service station for any technical reasons. The car was driving always without any technical forced stops. The OEAMTC is using the fuel cell car as a pool car for their employees, when they have to travel in Austria and the near neighborhood for business purpose. According to their experience, the range with fuel hydrogen tanks is going up to almost 400km, but highly depending on the weather condition and which kind of roads you are suing for driving. Cold weather and highway driving are the most factors which are reducing the range for one tank, but this is also generally valid for the battery powered vehicles.

When the author of this master thesis was doing the interview on side with the employees from OEAMTC which have experience with driving there fuel cell vehicle, the showed him the vehicle itself. When entering the passenger cabin on the driver side, the dashboard was looking familiar to any other combustion engines powered cars, only the revolution counter have been changed to a display which shows the driver, what is the current power output from the battery and in the case the car is recuperation, because of breaking, the user can see that also on the display.

Considering the rear seats of the car and as well the trunk of the Hyundai ix35 Fuel Cell and compared to the version with combustion engines powered, there have not been discovered big differences between both versions of the Hyundai ix35.

They author of this master thesis was asked to do a test drive with the fuel cell car. Starting the fuel cell car is like an electric car with batteries, you just turn on the ignition and put the gear shift to "D" for drive and you can start driving. The same procedure is needed for the fuel cell variant. Just turning on the ignition, move the gear shift to drive position and you can start driving, without waiting until the fuel cell is started. There is no any delay, you can start driving immediately. I was driving for around 30 minutes through Vienna, without using highways and the car was driving like every other electric powered vehicle. Coming back to the OEAMTC headquarter I was asking the people what kind of experience they have by using the fuel cell car? Main problem is the availability of hydrogen, not the distance to go there, because there is one in Vienna available, but you always have to call the refuel station if the hydrogen tank station is working and if the tanks are not empty! This is needed to do for all the stations available in Austria and partly also valid for Germany. The explanation from the refueling station provider is that the frequency of using the hydrogen station is simply to less today, and to keep the service always available is simply to expansive for them. However if you have luck and the refueling stations is working, then the refueling process is simple. Place the pipe with the connection part on your car and after a short leakage test the refueling process is started automatically and will also stop after your tank is full. This takes round about 3-4 minutes, which is comparable to the refueling process we know from the combustion engines powered cars.

Fig. 42: The author with the Hyundai ix 35 Fuel Cell car

So their opinion from the OEAMTC is, that the fuel cell vehicles might become an alternative, but driving in Austria, there are too many obstacles to use those cars for daily driving.

On the other hand in a German Car magazine the 2 authors[8] wrote an article in this magazine (Bild, 2017) the authors making an experiment to drive with a Renault Zoe a tour through Germany. They reported that, when they were driving through Germany for 3000km with the BEV, they following challenges:

- Charging stations are very often hided, meaning although they are marked in the map, they are difficult to find, because it is located in a underground garage, but isn´t marked like that. So you spent much time for searching the charging station.
- If a charging station is free or already occupied by another BEV you are not informed about that. Even you see that one car is currently being charged on the charging station, it is not possible to know for how long the car will still be recharged and when the charging station will be free again.
- Very often happened, during the trip through Germany that the charging station, or used wrongly as a simple parking place.

[8] Tim Dahlgaard and Lars Busemann

- In Germany there are more than 60 payment systems existing to pay your charging fee. Very often it doesn´t work simply to charge your BEV there.

The recommendations from the experts are the followings (valid for Germany, but will be similar in Austria):

- One payment system for all charging stations
- Online possibility to be able to check, if the charging station which will be used is free, and if not how long it will take that the previous charger will have finished the charging process.
- Significant reduction of the recharging time
- Significant increase of the range when driving in winter time, or using the air condition in summer time.
- Respect the parking areas for EV by none EV drivers

The authors have compared the bad marking of some recharging stations with a gasoline station which is hided and not easily to find. Those gasoline station will not have enough customers and will be closed, soon. For recharging stations the driver of an EV have to be more patient and it looks like that it will be accepted by them, so far. Most likely the alternative power train solutions for vehicles might be fit to the personal needs of each vehicle user. Mainly of them doesn´t know, or could not charge, if they might be ready for an alternative powered vehicle. Mercedes-Benz announced in September 2017[9] that they will launch, within September 2017 an App, which you can install on your smart phone, and will help you to find an answer, if the user can change over to an EV or a hybrid model. The App will record your driving behavior, for a defined time, and it will give you a proposal, based on your individual operational profile, if it would make sense to change to an EV, or a hybrid vehicle. This might be a good future tool for everyone to find out, if your personal operational profile will fit to alternative powered vehicles.

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[9] Mercedes-Benz press release from 06.09.2017 (accessed on 07.09.2017): http://presse.mercedes-benz.at/News_Detail.aspx?id=53525&menueid=10018

Validating the facts:

- For the battery electric vehicle:
    - Price is less than for a fuel cell vehicle, but higher than for a combustion engine car
    - More than 2000 electric charging places available in Austria, Vienna
    - Charging takes too long time, to charge the EV during travelling
    - Possibility to charge at your home is necessary, if you would like to use your EV for daily driving
    - Different handling of an EV then for a combustion engines car
    - Government benefits available
    - Huge planning's in place to increase the numbers of charging stations
    - OEM´s investing a high number of money to shorten the charging time and to increase the battery power capacity and reduce the weight of the needed batteries
    - Find a green method to recycle the used batteries
    - One payment system for all charging stations

- For the Fuel cell vehicle:
    - Price for a 4 doors sedan, like the Volkswagen Golf 1,5 TSI Highline with double clutch gear box is in Austria, 29.460 Euro[10]. From the size and the features comparable to the Toyota Mirai EFVC, which costs 78.000 Euro[11]. The price for this FVC today in Austria is more than double of a comparable combustion engine vehicle with similar features and horse power.
    - Too low numbers of refueling stations for traveling in Austria existing
    - Refueling stations not always in operation, have to be double checked and could take longer time, until they are working
    - Refueling time comparable with gasoline powered cars

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[10] http://www.volkswagen.at (accessed on 2017-09-07)

[11] http://www.toyota.com (accessed on 2017-09-07)

- For public transportation, there are much more vehicles in use
- Only a small number of OEM´s investing into the fuel cell technology

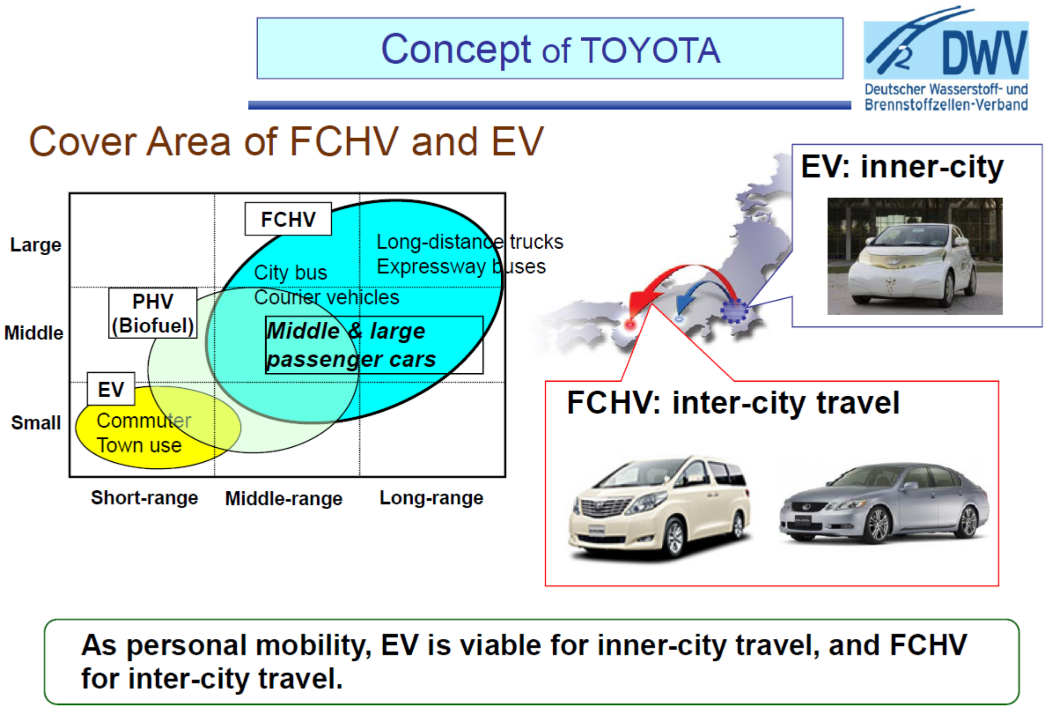

Fig. 43: Cover Area of FCHV and EV Toyota (union, 2017)(accessed on 2017-08-28)

Above the cover area of FCHV and EV from Toyota. EV for short range and FCHV for middle and long range vehicles.

5.1.2 Conclusion

In this chapter the final conclusion will be given by summing up the facts for the answer to the 2 hypothesis.

Hypothesis 1: *Will it be possible by today to use a FCV in Austria around Vienna?*

Hybrid, plug-in hybrid and vehicles with combustion engines are more reasonable for daily driving in Austria, Vienna. For short distances and as a second car the BEV could be used. To use a fuel cell electric vehicle, for daily driving is **not** possible today in Austria, Vienna. Fuel cell cars could be used for public transport, like buses, in the logistic area (e.g. fork lift) and for trucks where a long range is needed and the refueling time is important. Hydrogen production is already established in Austria for using, but not from alternative sources.

Hypothesis 2: *Will it be possible to drive a fuel cell car in Vienna Austria by 2025?*

Fuel cell vehicles could be used in Austria by 2025, by the following assumptions:

What should be done to push the fuel cell vehicles population in Austria?

- Existing hydrogen refueling stations have to be always in operation
- Price of the FCV must become lower, comparable to today's combustion engines prices.
- Invest into advertising, to make the fuel cell technology more popular
- Reduce the price of hydrogen, to have another argument for the customers to change the type of power unit.
- Start investigations to use FCV for public transport and heavy duty vehicles, or find more suitable solutions.

5.1.3 **Outlook**

Which technology will be the best one, for the customer, environmental and the industry? Do we know already today the technology for future vehicles, or will be there a new one in front of us? Which technology will the most reasonable and suitable one for each individual? In the near future the used behavior of the people will change, like the automotive industry is currently in a transition phase to another area. Trends like for the big cities, or the way how we will work in future, or what will be needed in future, or which kind of status symbol will be important for the next upcoming years? Today, to have a driving license and also own a car is very common and the people would like to be independent for their mobility. As a trend we can already experience that the internet shops are growing and more and more people buying their products online. Even the supermarkets in Austria pushing the online shopping also for their products and providing some benefits, if you buy online. They owners of the supermarket have established their own distribution logistic to be able to deliver you there goods. Only from economic reason this will make sense, because in almost every village you have more than 2 supermarkets from different brands. If they will be successful to convince there customers to order online, they might could close a lot of supermarkets and save a lot of personal and building costs, or could even sell the land , where they have now there supermarkets. That would mean that the delivering for products will increase and most likely the people will not need vehicles to go to the supermarket to buy their products there. If the online shopping will still grow in the next years the needs for small transportation vehicles will increase. As they have to deliver all day long, they companies, which are delivering those goods, as a service, will not have the possibility and the time to use battery vehicles, although the CO2 emissions targets have to be fulfilled. That might be a turbo for the fuel cell vehicles, as they could also be very easily used for bigger cars, where a long range is needed.

However, the question, how to get the needed electric power, doesn´t matter if you need it for recharging or for producing hydrogen, isn´t answered yet. By law it will be needed to get the electric power from renewable sources, like wind-power, solar or from water-power plants. But to build wind-power parks, huge solar parks and new water-power plants will also destroy, or influence our nature. The area which will be needed for the electric power which will be needed will cover quite a huge one. Also wind-power and water-power plants cannot be build up so easily, because of environmental specification. How will the surroundings look like, if you have the areas full covered with wind-power and solar parks?

Other possibility might be that in future the individual traffic might decrease, because the public will not need to drive to the supermarket, because they are delivering. To go daily to your office might also not needed in the future, because emailing, telephone conferences and business trips will not be needed in future, or will be dramatically reduced in future, because of the availability and distribution of internet. This will also reduce the needed electric power for charging our BEV or the production of hydrogen.

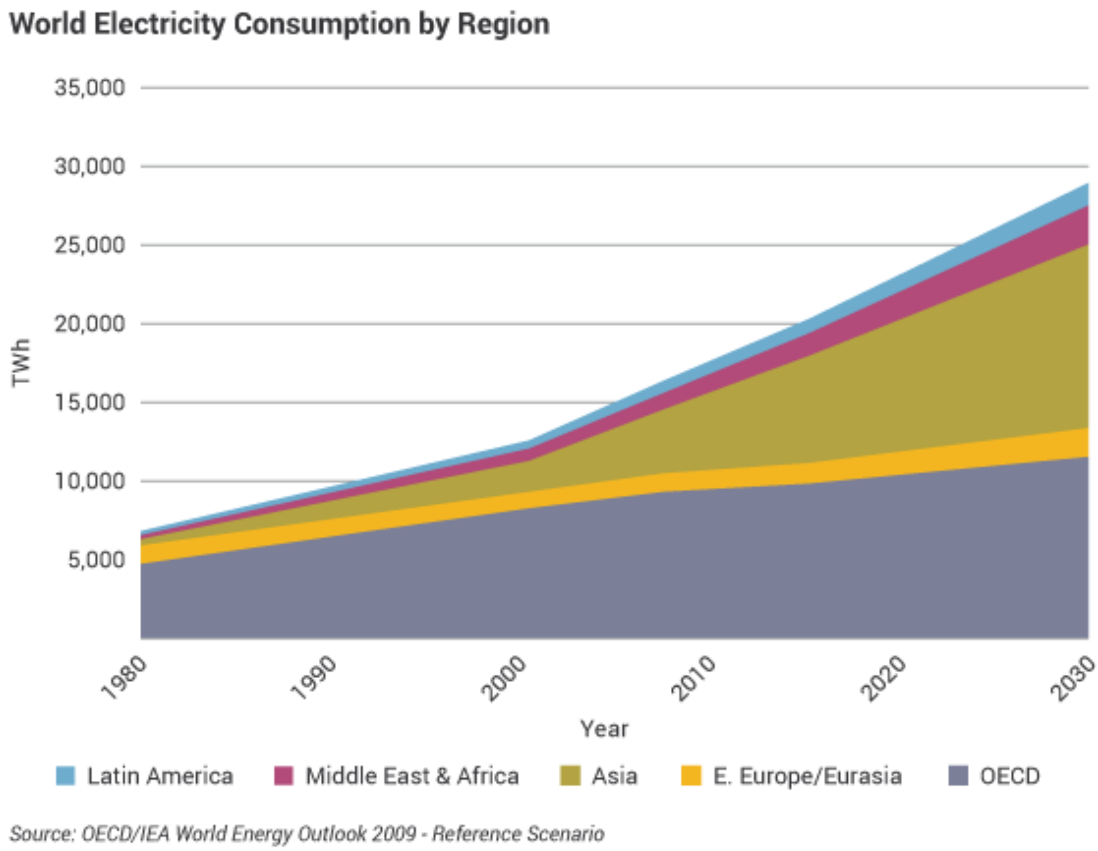

Fig. 44: World electric power forecast (OECD, 2017)(accessed on 2017-09-02)

In 1990 the consumption was 10.000 terra watt hours, in 2015 it was 20.000 terra watt hours. So the electric power consumption increased doubled in 15 years and up to 2030 it will reach a level of 30.000 terra watt hours, which is another increase, within 15 years of 10.0000 terra watt hours. The question, where to get the needed electric power will be one of the important once in the future and how we can produce, recycle and produce vehicles with low CO_2 emissions.

6 Bibliography

accumotive.de, 2017. *Home page*. [Online] Available at: https://www.accumotive.de/en/home-en/ [Accessed 13 August 2017].

Atlas, N., 2017. *Honda's next gen solar-powered hydrogen fuel cell station for home use*. [Online] Available at: http://newatlas.com/honda-solar-hydrogen-fuel-cell-refueller-electric-vehicle/14049/ [Accessed 2 September 2017].

AUSTRIA, S., 2017. *Kraftfahrzeuge - Bestand*. [Online] Available at: http://www.statistik.gv.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/verkehr/strasse/kraftfahrzeuge_-_bestand/index.html [Accessed 21 July 2017].

Austria, T., 2017. *Toyota Mirai*. [Online] Available at: https://www.toyota.at/new-cars/new-mirai/index.json#1 [Accessed 6 August 2017].

Austrian Ministry for Transport, I.a.T., 2017. *Home page*. [Online] Available at: https://www.bmvit.gv.at/en/index.html [Accessed 13 August 2017].

Autoindustrie, V.d., 2017. *Exhaust emissions*. [Online] Available at: https://www.vda.de/en/topics/environment-and-climate/exhaust-emissions/emissions-measurement.html [Accessed 6 August 2017].

Auto-motor-und-sport, 2017. *TOYOTA MIRAI IM TEST*. [Online] Available at: http://www.auto-motor-und-sport.de/einzeltests/toyota-mirai-brennstoffzelle-wasserstoff-test-11521971.html [Accessed 27 August 2017].

Benz.com, M., 2009. *Direct route to a cleaner future*. [Online] Available at: http://www.mercedes-benz.com.cy/content/cyprus/mpc/mpc_cyprus_website/enng/home_mpc/bus/home/buses_world/update/news_2009/Citaro_FuelCELL-Hybrid.html [Accessed 27 August 2017].

Bild, A., 2017. *Home page*. [Online] Available at: http://www.autobild.de [Accessed 25 August 2017].

bmvit, 2017. *Electromobility in Austria - Facts & Figures*. Vienna: AustriaTech Austrian Ministry for Transport, Innovation and Technology.

bmw.com, 2017. *The all-electric BMW i3*. [Online] Available at: https://www.bmw.com/en/all-models/bmw-i/i3/2016/at-a-glance.html [Accessed 7 August 2017].

Brennstoffzelle.de, 2017. *Die Geschichte der Brennstoffzelle*. [Online] Available at: http://www.diebrennstoffzelle.de/zelltypen/geschichte [Accessed 28 August 2017].

Brennstoffzellen-Verband, D.W.-, 2017. *Home page*. [Online] Available at: https://www.dwv-info.de [Accessed 28 August 2017].

Bundeskanzleramt, 2017. *Elektroautos und E-Mobilität – Förderungen und weiterführende*. [Online] Available at: https://www.help.gv.at/Portal.Node/hlpd/public/content/6/Seite.060021.html [Accessed 12 August 2017].

Buses, F.C.E., 2016. *Hydrogen refuelling concepts*. [Online] Available at: http://www.fuelcellbuses.eu/wiki/concepts-hydrogen-refuelling-stations/hydrogen-refuelling-concepts [Accessed 5 August 2017].

cafcp.org, 2017. *California fuel cell partnership - Stations*. [Online] Available at: https://cafcp.org/stationmap [Accessed 2 August 2017].

Council, H., 2017. *Home page*. [Online] Available at: http://hydrogencouncil.com/ [Accessed 12 August 2017].

daimler.com, 2017. *Mobility of the Future -Connected-Autonomous-Shared-Electric*. [Online] Available at: https://www.daimler.com/dokumente/investoren/praesentationen/daimler-ir-presentationmobilityofthefutureparis-20160930.pdf [Accessed 13 August 2017].

Daimler, M., 2017. *Mercedes-Benz GLC F-CELL: The fuel cell gets a plug*. [Online] Available at: http://media.daimler.com/marsMediaSite/en/instance/ko.xhtml?oid=11111320 [Accessed 12 August 2017].

daryanenergyblog, 2013. *The future of cars, a review of different drivetrain options*. [Online] Available at: https://daryanenergyblog.wordpress.com/2013/06/22/the-future-of-cars-a-review-of-different-drivetrain-options/ [Accessed 27 August 2017].

diamond-air.at, 2017. *Motorsegler von Diamond bald mit Brennstoffzellen-Antrieb*. [Online] Available at: http://www.diamond-air.at/de/media-center/pressemeldungen/aktuelles/article/motorsegler-von-diamond-bald-mit-brennstoffzellen-antrieb [Accessed 6 August 2017].

digipac.ca, 2017. *Steam Reforming of Natural Gas*. [Online] Available at: http://www.digipac.ca/chemical/mtom/contents/chapter4/steamreform.htm [Accessed 31 August 2017].

Digitaltrends.com, 2017. *Road Rave Honda Solar Hydrogen Station*. [Online] Available at: http://s3.amazonaws.com/digitaltrends-uploads-prod/2015/03/Road-Rave-Honda-Solar-Hydrogen-Station.jpg [Accessed 7 September 2017].

Driver, C.a., 2017. *H2 Go: Mercedes Set to Launch Plug-in Fuel Cell GLC-class*. [Online] Available at: http://blog.caranddriver.com/h2-go-mercedes-set-to-launch-plug-in-fuel-cell-glc-class [Accessed 27 August 2017].

Eberte, U., Mueller, B. & von Helmolt, R., 2012. Fuel cell electric vehicles and hydrogen infrastructure: status 2012. *Energy & Environmental Science*, (10), p.1.

ec.europa.eu, 2017. *Greenhouse gas emission statistics*. [Online] Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics [Accessed 11 August 2017].

ec.europa.eu, 2017. *Horizon 2020 - Smart, green and Integrated Transport*. [Online] Available at: https://ec.europa.eu/programmes/horizon2020/en/area/transport [Accessed 16 August 2017].

ec.europa.eu, 2017. *Reducing CO2 emissions from passenger cars*. [Online] Available at: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en [Accessed 11 August 2017].

ec.europa.eu, 2017. *Reducing emissions from transport*. [Online] Available at: https://ec.europa.eu/clima/policies/transport_en [Accessed 14 August 2017].

element-energy.co.uk, 2017. *FC-bus cluster coordinators*. [Online] Available at: http://www.element-energy.co.uk/wordpress/wp-content/uploads/2016/07/FC-bus-cluster-coordinators.png [Accessed 4 August 2017].

energy.gov, 2017. *Fcel diagram molten carbonate*. [Online] Available at: https://energy.gov/sites/prod/files/fcell_diagram_molten_carbonate.gif [Accessed 23 July 2017].

energy.gov, 2017. *Fcel diagram pafc*. [Online] Available at: https://energy.gov/sites/prod/files/fcell_diagram_pafc.gif [Accessed 23 July 2017].

energy.gov, 2017. *Fcell diagram alkaline*. [Online] Available at: https://energy.gov/sites/prod/files/fcell_diagram_alkaline.gif [Accessed 2017 July 23].

energy.gov, 2017. *Fcell diagram sofc*. [Online] Available at: https://energy.gov/sites/prod/files/fcell_diagram_sofc.gif [Accessed 23 July 2017].

Energy, U.S.D.o., 2017. *Hydrogen and Fuel Cell Programs*. [Online] Available at: https://www.hydrogen.energy.gov/index.html [Accessed 26 August 2017].

e-tankstellen-finder.com, 2017. *charging stations finder map*. [Online] Available at: https://e-tankstellen-finder.com/at/de/elektrotankstellen [Accessed 4 August 2017].

fuelcellmarkets.com, 2017. *Fc diagram_ pem*. [Online] Available at: http://www.fuelcellmarkets.com/content/images/articles/1/Fc_diagram_pem.gif [Accessed 12 July 2017].

fuelcelltoday.com, 2017. *Technology dmfc*. [Online] Available at: http://www.fuelcelltoday.com/media/993454/technology_dmfc_crop_497x285.jpg [Accessed 23 July 2017].

Gas-Linde, 2017. *Home page*. [Online] Available at: http://www.linde-gas.at/de/index.html [Accessed 2 August 2017].

gims.swiss, 2017. *FE Concept Stand 1040*. [Online] Available at: https://www.gims.swiss/de/premieres/welt-premieren/fe-concept-10905 [Accessed 13 August 2017].

GMBH, H.R., 2017. *Home page*. [Online] Available at: www.hycenta.at [Accessed 28 August 2017].

h2euro.org, 2017. *H2 Public Station Navigator*. [Online] Available at: https://fusiontables.googleusercontent.com/embedviz?q=select+col9+from+1TeFUPhf4PqJRI9S6kdUu-9mzADi5oj-pF-D64002&viz=MAP&h=false&lat=50.67812219521065&lng=9.316796406249978&t=1&z=4&l=col9&y=2&tmplt=2&hml=TWO_COL_LAT_LNG [Accessed 16 August 2017].

h2-mobility.de, 2017. *H2-Stationen*. [Online] Available at: http://h2-mobility.de/h2-stationen [Accessed 2 August 2017].

Honda, 2017. *Clarity Fuel Cell*. [Online] Available at: https://automobiles.honda.com/clarity [Accessed 13 August 2017].

hydrogenics.com, 2017. *Fuel Cells*. [Online] Available at: http://www.hydrogenics.com/technology-resources/hydrogen-technology/fuel-cells/ [Accessed 12 July 2017].

hyfive.eu, 2017. *HYDROGEN & FUEL CELLS*. [Online] Available at: http://www.hyfive.eu/hydrogen-and-fuel-cells/ [Accessed 2 August 2017].

hyundai.at, 2017. *ix35 Fuel Cell*. [Online] Available at: https://www.hyundai.at/Showroom/SUV/ix35-FCEV.aspx [Accessed 1 August 2017].

Kantola, K., 2017. [Online] Available at: http://www.hydrogencarsnow.com/index.php/bmw-i8-hydrogen/.

Knight, D., 2004. Davy, Sir Humphry, baronet (1778–1829). In *Oxford Dictionary of National Biography*. Oxford University Press.

Laughlin, P.R.B., 2017. [Online] Available at: http://large.stanford.edu/publications/coal/references/wood.

maps.google.com, 2017. *Dresdner Str. 91, 1200 Wien to Orth an der Donau, 2304*. [Online] Available at: https://www.google.at/maps/dir/Dresdner+Stra%C3%9Fe+91,+Wien/2304+Orth+an

+der+Donau/@48.2247441,16.3902815,11z/data=!4m13!4m12!1m5!1m1!1s0x476d0653eb819735:0x67a33e8dee6d403e!2m2!1d16.3851085!2d48.232625!1m5!1m1!1s0x476cf86ffe3cf219:0x40097572de62610!2m2! [Accessed 7 August 2017].

Matthey, J., 2017. *FuelCellToday*. [Online] Available at: http://www.fuelcelltoday.com/history [Accessed 28 July 2017].

Miorini, D.H., 2017. *Globale Automobile Trends*. [Online] Available at: https://fahrzeugtechnik.fh-joanneum.at/veranstaltungen/2013-2014/2014-01-29-Globale-Automobile-Trends.pdf [Accessed 4 August 2017].

mobility, A.w.f.C., 2017. [Online] Available at: http://www.erdgasauto.at.

netinform.de, 2017. *Hydrogen Refuelling Stations Worldwide*. [Online] Available at: https://www.netinform.de/H2/H2Stations/H2Stations.aspx?Continent=EU&StationID=-1 [Accessed 2 August 2017].

Observatory, E.A.F., 2017. [Online] Available at: http://www.eafo.eu/content/european-vehicle-categories.

OEAMTC, 2017. *Home page*. [Online] Available at: www.oeamtc.at [Accessed 12 August 2017].

OECD, 2017. *Home page*. [Online] Available at: http://www.oecd.org/ [Accessed 2 September 2017].

omv.at, 2017. *Factsheet Wasserstoff - zukunftsweisende Technologie*. [Online] Available at: http://www.omv.at/SecurityServlet/secure?cid=1255764892229&lang=de&swa_id=391906964441.3318&swa_site=, [Accessed 4 August 2017].

post.at, 2017. *E-MOBILITÄT*. [Online] Available at: https://www.post.at/co2neutral/e_mobilitaet.php [Accessed 2017].

Sai, R., 2014. *Seminar on Hydrogen Fuel Cell Vehicle Presentation*. [Online] Available at: https://www.slideshare.net/raghusai2/ppt-34532021 [Accessed 6 August 2017].

sciences, A.d., 1839. Note sur une pile voltaique d'une grande énergie, construite par M. Grove; communication de M. Becquerel. *Comptes Rendus*, p.497.

Stewart, J., 2017. *Toyota's still serious about hydrogen - It built a semi to prove it*. [Online] Available at: https://www.wired.com/2017/04/toyotas-still-serious-hydrogen-built-semi-prove [Accessed 19 April 2017].

Symposium, I.V.M., 2017. *Home page*. [Online] Available at: https://wiener-motorensymposium.at/en/ [Accessed 12 August 2017].

Tesla, 2017. *Model 3*. [Online] Available at: https://www.tesla.com/de_AT/model3 [Accessed 13 August 2017].

theicct.org, 2017. *CO2 reduction for the world*. [Online] Available at: http://www.theicct.org [Accessed 23 July 2017].

toyota.at, 2017. *Toyota Mirai*. [Online] Available at: https://www.toyota.at/new-cars/new-mirai/index.json#1 [Accessed 3 August 2017].

UNECE, 2017. *Transport*. [Online] Available at: https://www.unece.org/trans/welcome.html [Accessed 27 August 2017].

union, G.h.a.f.c., 2017. *Home page*. [Online] Available at: https://www.dwv-info.de [Accessed 28 August 2017].

University of Ulm, G., 2017. *Geschichte der Elektrochemie*. [Online] Available at: https://www.uniulm.de/fileadmin/website_uni_ulm/nawi.inst.251/Didactics/Geschichte_der_Elektrochemie/mittel/caven.html [Accessed 11 August 2017].

US, E.G., 2017. *Hydrogen Production: Thermochemical Water Splitting*. [Online] Available at: https://energy.gov/eere/fuelcells/hydrogen-production-thermochemical-water-splitting [Accessed 2 September 2017].

US, N.A.o.S.o., 2017. *Sustainable fuel for the transportation sector*. [Online] Available at: http://www.pnas.org/content/104/12/4828/F1.expansion.html [Accessed 2 September 2017].

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