MSc Program
Renewable Energy in Central and Eastern Europe

IMPLEMENTATION OF HYDROGEN IN AUTO INDUSTRY

Hydrogen technology in comparison to other alternative technologies from economic, environmental and technical aspect

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **Dusan Blagojevic,** hereby declare

1.That I am the sole author of the present Master Thesis, "Implementation of Hydrogen in Auto Industry – Hydrogen technology in comparison to other Alternative technologies from economic, environmental and technical aspect", 99 pages, bound, and that I have not used any other source or tool other than those referenced or any other illicit aid or tool,

And

2. That I have not prior to this date submited this Master Thesis as an examination paper in any form in Austria or abroad.

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Date Signature

Abstract

The core objective of this work is showing if the Hydrogen fuel and technology is the solution for Auto Industry in the future and why. All types of Hydrogen implementations will be covered throughout this work and are going to be compared to other alternative technologies such as: electric drive, biofuels, est.

The questions that this work should answer are: which type of hydrogen implementation is the most efficient one and also in comparison to other technologies, can hydrogen technology be competitive to other alternative and conventional technologies and which steps potentially are necessary to be made in order to implement hydrogen and secure its place as the solution of transport problems.

Method of approach is conducted by using as much data as possible from real life and complements it with theory, as well. In other words, data acquired from the companies involved in transport problems and solutions, up-to-date research, available data based on professional research will be used in this work for presenting and analyzing different conventional and alternative technologies in purpose of finding the conclusion which technology has a potential to be solution of future of auto industry.

Considering impact of transport to environment as well as its importance to our everyday life and its inability to be substituted means that it is of great importance to find the solution on how are we going to approach with further development of transport and how. Analyses and comparison of all present conventional and alternative technologies conducted in this work has a purpose of showing that hydrogen technology is the solution of auto industry and its future.

Table of content

List of tables

List of figures

List of Abbreviations

AIT	Austrian Institute of Technology
BF	Biofuels
BMW	BMW Automobiles
BP	British Petroleum
CCPI	Clean Coal Power Initiative
CT	Conversion Technology
CTG	Cradle-to-grave Analyses
CO2	Carbon Oxide
EC	Electric Car
EOR	Enhanced oil recovery
EOS	Economies-of-scale
FC	Fuel Cell
FCV	Fuel Cell Vehicle
GT	Gigatones
H2	Hydrogen
HC	Hybrid Car/Cars
HECA	Hydrogen Energy California
IGCC	Integrated gasification combined cycle

LCA	Lyfe Cycle Analyses
LPG	Liquid Pressurized Gas
LI	Lithium Ion
MHI	Mitsubishi Heavy Industry
O&M	Operation and maintenence
OMV	OMW Group
R&D	Research and Development
VW	VolksWagen
ZLD	Zero Liquid Discharge system

1 INTRODUCTION

Ever since automobile has been invented in the late 19th century, people started finding ways of using them in everyday life. From only hand full of people who could afford a car in late 19th and early 20th century, now most people in the world own a car. In other words, situation has changed dramatically, especially from environmental point of view.

Although the Industrial Revolution began more than 250 years ago, more than half of all industrial carbon emissions have been released since 1988, after major fossil fuel companies knew about the harm their products were causing. In the year 1915 roughly 4 Gt a year (Giga tones) of CO2 (Carbone Oxide) was a total pollution output of entire world industry. Today this output is around 44 Gt of CO2 a year and it comes from transport industry alone [1].

CO2 emission is not even the only problem. Life cycle analyses show even greater concerns. Also, transport as a whole has no substitute. People must use any form of transport to get themselves from one place to another.

Nonetheless, car industry plays a major factor in transport structure. According to IEA World energy outlook, 76% of CO2 emission of entire transport structure comes from road transport alone. There are those who suggest solutions such as substituting cars with electric bicycle, use of public transport and many others. However, it is hard to reach such a goal in any distance future. What is more, if one takes cars out of the transport structure, one must fulfill demand with other ways.

The main motivation of this work is to have suggestions at the end of the work after analyses from many aspects – technical, environmental and economic one. Suggestions should reflect on: environment, technical possibilities of implementing or modifying certain technology, finding ways to preserve and use current potentials and infrastructure.

For instance, work places should be preserved when implementing certain new technology. Also, such implementation should not allow radical change of the industry and should still be sustainable and should have solutions how to make new technologies more economically competitive.

Most likely solution is finding ways which can provide cars to be more environmentally friendly in the whole Life cycle, as soon as possible. In order to achieve that, certain technology or technological mix has to be applied. In this thesis, Hydrogen fuel and technologies will be analyzed from technical, environmental and economic aspect. After showing potentials of this technology it will be compared with similar analyses of conventional technologies and with other alternative technologies.

The reasons why Hydrogen technology is topic of this thesis are: Hydrogen is by far mostly spread element in the entire Universe and it can be created as a fuel from almost anything, Hydrogen can be implemented in conventional internal combustion engines or with using fuel cell cars. Even with second solution car structure is not dramatically changed.

Hydrogen technologies also have the ability to preserve our way of using cars, e.g range, it is safer than electric cars (EC) when it comes to noise in city streets, and many more which will be covered in this work. If there are ways to implement Hydrogen fuel and hydrogen technologies with economic competitiveness, advantages of this Hydrogen are than truly overwhelming.

1.1 Motivation

Motivation for choosing implementation of Hydrogen fuel and hydrogen technologies in Auto industry as the topic of my Master thesis comes from simple reason – finding potential solution for the future of auto industry and preserving environment at the same time. After studying a master course which covered and gave an overview of all different alternative technologies, logical step was choosing master thesis which focus is on transport.

Analyses in this work should show that Hydrogen is the most logical path to choose, especially when it comes to sustainability. Hydrogen technology would not change the cars as a whole (for instance, transport infrastructure, filling stations, and est.) as we know them, especially if it is implemented as a conventional combustion engine conversion. In that respect hydrogen has potentially ability to preserve cars, rather than radically changing or replacing them all together.

The purpose of this work is to potentially contribute to scientific research and to show in an objective way through analyses of all present technologies which way is potentially the best for preserving our way of life (every day transport needs) and our environment.

What is more, aim is also to show that hydrogen technologies have the potential to accomplish both. Also, it is important to present proof that this technology can be economically and technically competitive and not only environmentally competitive. In order to achieve that data acquired from current situation in auto industry could show its weaknesses and suggestions of how it may look like in the future.

1.2 Core objective and core questions

Core objectives and core questions of this thesis regard to alternative auto motive technologies, primarily hydrogen, compared to conventional technologies and discovering actual limitation and future solutions. To be more specific core objective and core questions reflects on the following:

1) Stating actual situation in car industry or more specific impacts, limitation and potentials. All current conventional technologies will be analyzed and discussed trough the work. The analyses will be done in technical, environmental and economic way. What impact do they have on the environment, what changes are necessary or possible, are these technologies sustainable, will also be covered. The same approach will be done with alternative technologies as well – hybrids, electric cars, biofuels and hydrogen cars.

2) Hydrogen technologies will be in the center of the analyses. Furthermore, core objective on hydrogen is to determine which hydrogen technology is best – fuel cell or conversion of internal combustion engine to run on hydrogen.

3) Analyses of actual situation of technological development of major car manufacturers and fuel industries and what are they plans and promises for the future, as well.

4) Steps which are potentially necessary in order to make hydrogen technology economically competitive.

5) Technological aspect – technical basics, infrastructure challenges, life cycle analyses.

The most important objective is giving answer at the end of the work is/why Hydrogen technology is solution and what is necessary to overcome its limitation in order to make this technology suitable for implementation and able to secure future of auto industry.

1.3 Method of approach

The method of approach of this work is reflected in collecting data from scientific journals and publications, leading companies in transport sector. In other words combining data from leading research institutions with leading companies is formula used for creating this work.

With this data, introduction is given with current situation in auto industry and its limitation and problems. This provides the starting point of analyses and clear picture what position hydrogen technologies have in transport structure and what are limitations of implementation of hydrogen in this structure.

Key of the method of approach is analyses of major alternative technologies with special focus on hydrogen based on exiting literature. Specific analyses will be done for hydrogen and at the end of the work comparisons and conclusions will be made in order to state what necessary steps are in order to implement hydrogen fuel and hydrogen technologies in transport structure. Also, after all analyses and conclusion the aim of the work is to answer if hydrogen has the potential to solve problems and secure future of auto industry.

There are several crucial steps in method of approach. Firstly, it is necessary to have a reliable and up-to-date data. Secondly, using this data for analyses which is conducted by analyzing technical, environmental and economic aspect of each technology covered in this work. Lastly, calculations and figures and tables use this data in order to give more precise picture of the problems and potentials and to support drawing out conclusions and suggestions at the end of the work.

1.4 Citation of major literature

The major literature used in this work is acquired primarily by researching and reading scientific literature, scientific journals. Firstly, TU Library is used for acquiring technical and theoretical background. Union of concerned scientists - Climate Deception Dossiers was used for climate change data. Basically, abovementioned sources were used to set up introduction and a path to start further analyses.

Navigant research, Elsevier, Science AAAS (American Association for the Advancement of Science), Scientific research (Journals of Transportation technologies), Scientific and Academic publishing, Intellectual property & Science, Science Direct and Multi science were source of theoretical data used in description of alternative technologies combined with data acquired from news and journals from companies like BMW (BMW automobiles), Toyota, Honda, Tesla, VW - Volkswagen (VW sustainability report for instance) in order to present figures, tables and own calculations.

Furthermore, data necessary for Hydrogen assessment and analyses were acquired from scientific journals and news such are: SJR (Scientific Journal Rankings) – International Journal of Hydrogen energy, ASME (The American Society of Mechanical Engineers) – Hydrogen fuel: opportunities and barriers, Cambridge Journals on Hydrogen fuel alternative, IAHE (Indian Academy of Highways Engineers) and of course IEA (International Energy Agency), EIA (U.S Energy Information Administration), World fuel Cell council and ICCT (The International Council on Clean Transportation).

The purpose of using such literature was to give technical description of certain technology, limitations and potentials from technical, environmental and economic aspect and to create conclusions which countries/companies are more successful than others in hydrogen technology implementation and which lessons might be learned from such experiences. Of course having a clear picture of current situation with transport technologies is always a focus in each chapter.

What is more, certain amount of data used in this work is acquired by personal visits to companies like OMV (OMV group) and AIT (Austrian Institute of technology). Data acquired from these companies was used in late chapters in order to have clear picture on real life data collected from leading European companies in transport sector.

1.5 Structure of work

This Master thesis is consisted of 6 Chapters. After general explanation based on general framework: Introduction, Motivation, Core objective and core questions and Citation of major literature, work is focused on Chapters 2 to 6.

Chapter 2 analyses and discusses current situation in auto industry. Motivation of this chapter is giving an overview of limitations of current approach in auto industry and its unsustainability. Based on such analyses, conclusions and suggestions, it is possible to go in the direction of finding solutions via alternative auto motive technologies.

Chapter 3 is very important chapter. In this chapter, analyses of all mainstream alternative technologies (except Hydrogen) are carried out from technological, environmental and economic point of view. What is more, it is done in a way so limitation and potentials are covered for each technology from this aspect.

Chapter 4 is dedicated to Hydrogen only. Hydrogen as a fuel and hydrogen technologies are analyzed in the same manner as it is done in chapter 3 for other alternative technologies. Since economic aspect is crucial for this work, for each technology (conventional or alternative) there is a calculation of economic costs.

In the Chapter 5, examples of current use of alternative technologies are stated in order to back up analyses and personal statements in chapters 3 and 4. Also, examples are given so the sense of the real situation is understood. However, this chapter will also serve as a base for Chapter 6 – Summary and conclusions. Chapter 6 is basically focused on drawing out conclusions of the entire work in order to have a clear picture of why hydrogen is the solution of current and especially future auto industry and what steps are necessary so this technology is competitive in all aspects but most importantly what is necessary for this technology to be economically competitive.

2 Current situation in Auto industry

In this chapter current situation in auto industry will be described mostly reflecting on conventional technologies. However, at the end of the chapter some comments are going to be given regarding progress with alternative technologies and potential future expectations. It is well known that auto industry is a huge part of transport structure. CO2 emission and its overall pollution make a lot of interest and controversy among green parties and scientists. How much of accusations that the cars are to blame for Green House effect are true?

There is no doubt that entire Life Cycle, CTG (Cradle to grave) analyses and CO2 emission during production and exploitation of cars is quite significant. Number of cars in the world is vast and most clams made that cars are one or main driver of the climate change is true. However, the situation is far more complex. Cooling and heating of Earth is natural cycle of Earth itself. It happens every 10.000 years and it had been happening well before cars were invented. Furthermore, world industry as a whole makes a lot of CO2 and other kinds of pollution – soil, air and water.

There are also other kinds of transport vehicles (commercial or other) that produce pollution - aviation transport, water transport and rails. Also, worldwide wars or military industry in the past 70 years or so, have been contributing to CO2 and all forms of pollution quite substantially. But, all abovementioned does not mean that car industry and cars themselves do not create pollution. It also does not suggest that situation regarding pollution in auto industry is perfect and should not be improved. From production of cars to exploitation of cars as well as potential improvements in efficiency of cars are significant and ought to be researched, developed and implemented.

As it can be seen on the figures 1-2, radical changes need to be made in not too distant future in order to preserve our way of life we firmly grow accustomed. Figure 1-2 shows development of sales of all types of cars in the world from 1990 to 2015 year. It is obvious that the numbers are increasing and this trend will continue in the future.

It is no longer a question of if changes need to be made or not but it is a question of which path are we going to choose in order to secure a future of transport and ourselves also. As in most industries, auto industry main or maybe only drivers are: profit, profit, profit. It is not only connected to Auto Industry but certain industries have more responsibility than others. In addition to that, Auto industry has politics of major Oil companies as a way of direction. In other words, there is no doubt that car manufacturers are influenced and restrained in their technology application in their products by major Oil companies.

It is not an accusation but a fact. To support this there are several examples. For instance, first diesel engine ran on peanut oil. Some of the first cars were steam, ethanol and electric driven. What is more, prototypes of electric and hybrid cars existed in the 80's. Many more were shown to the world in 21^{st} century. Some are in production of course, but in small numbers.

Due to the fact that 1 kg of hydrogen costs 5$ per kg [2], many people believe that it is too expensive to produce. However, building an oil platform thousands of kilometers away from coast, drilling 12 km into the Earth and shipping it to the refinery and so on costs a lot. Mobile phones were expensive as well. What is the case? It is the Economies-of-scale (EOS). Same would happen with hydrogen or other alternative technologies, for sure. For the last 10 years there have been innovation and changes in auto industry regarding alternative technologies.

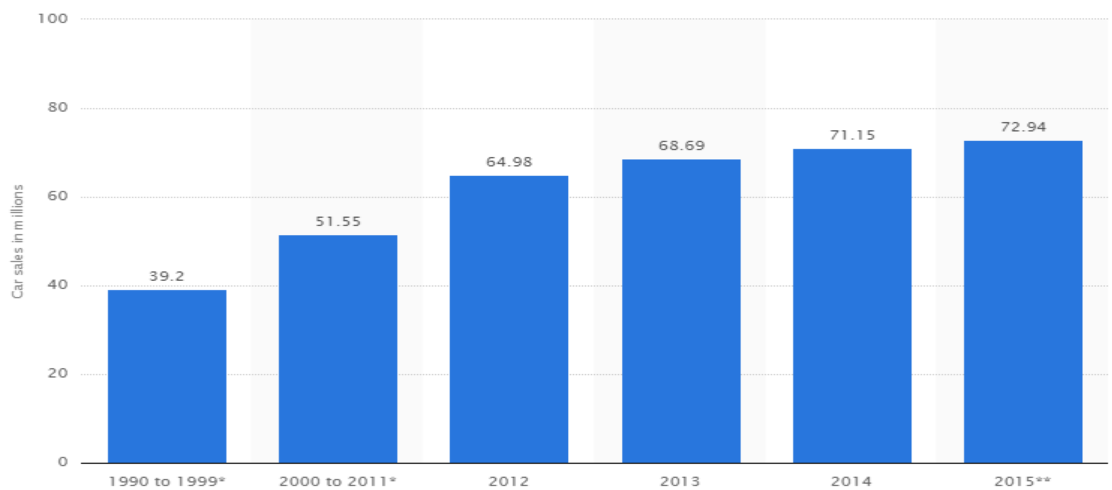


Figure 1-2: Number of cars sold worldwide from 1990 to 2015, Statista, 2015 [3]

Several figures and tables in this chapter state current situation in auto industry regarding conventional and alternative technologies. What is more, there are several projections or plans on how auto industry may look like in the close future.

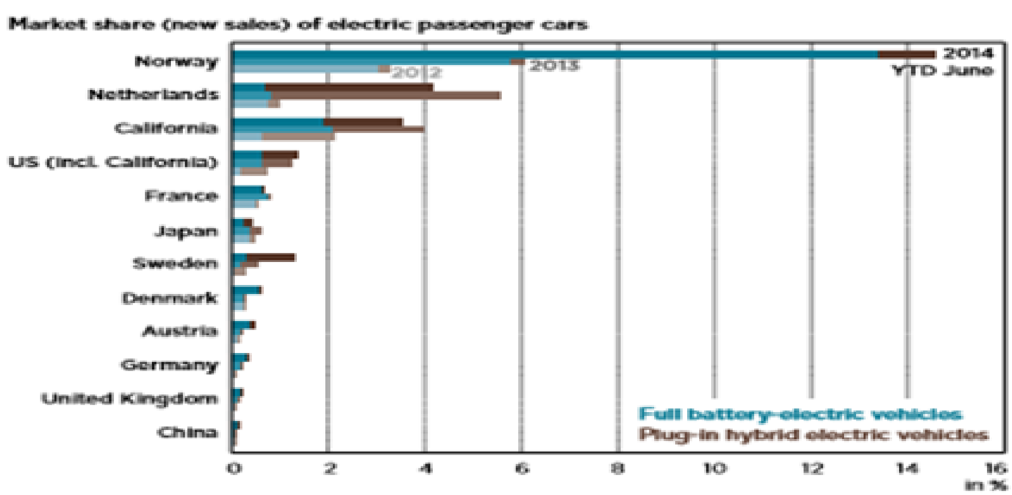


Figure 2-2: Market share of electric and hybrid vehicles in leading countries regarding renewables, ICCT, 2015 [4]

Figure 2-2 shows leading countries in the world regarding implementation of renewables. Implementation of car alternative technologies in these countries is primarily focused on electric or hybrid cars. When ambition mainly focused on reduction of CO2 emission combined with ambitions of leading car manufacturers and most advanced car markets are take into account it can be concluded that close future of auto industry will have main focus on small, efficient turbo diesel or turbo petrol engines alone or implemented in hybrid cars and plug in electric vehicles. Figure 3-2 presents development in shipment of Fuel cell systems worldwide. Between year 2008 and 2013 there is roughly five times increase. This suggests development of implementation of hydrogen technologies.

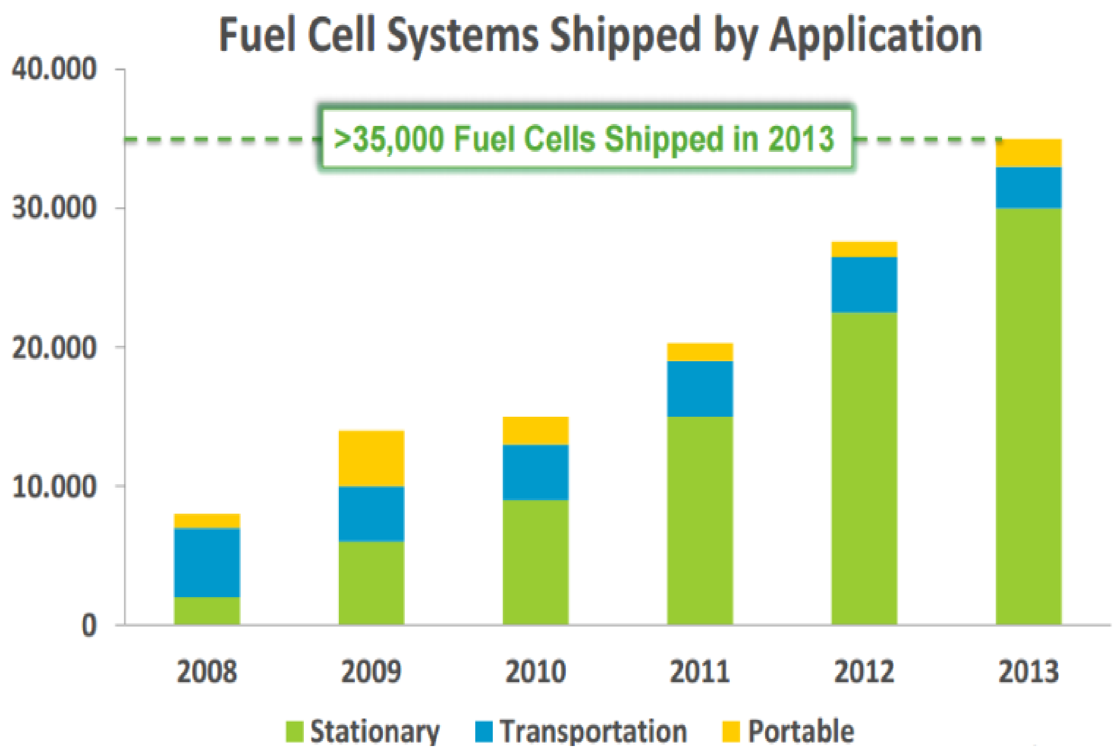


Figure 3-2: Development in Fuel Cell systems application and market, IPHE, 2014 [5]

Table 1-2 shows level of hydrogen implementation in leading markets in the world. USA has the highest number of FCV (Fuel Cell Vehicle) and filling stations. What is more, Government funding is the highest in USA as well. EU as a whole is still behind

USA in hydrogen implementation based on number of FCV, hydrogen filling stations and amount of money invested by governments in hydrogen technologies.

Table 1-2: FCV and Hydrogen Infrastructure in leading markets and government funding, IPHE, 2014 [6]

Region	FCEVs	Hydrogen Stations	Partnerships	Government Funding
EU	40	~30	Fuel Cells and Hydrogen Joint Undertaking (FCHJU) H_2-Mobility	FCH-JU, 2014-2020: **€667M** ($911M)
Germany	110	~12	National Innovation Program-Clean Energy Partners	National Innovation Program, 2014: *R&D:* ***€13M*** *($18M)* *Station Build Out:* ***€47M*** *($64M)* *Total:* ***€60M*** *($82M)*
Japan	65	16	The Research Association of Hydrogen Supply/Utilization Technology	R&D: **¥3,250M** ($32M) Station Build Out: **¥7,200M** ($70M) Total: **¥10,450M** ($102M)
Korea	100	12	Korea Hydrogen Industry Association (KHIA)	Ministry of Environment Deployment and Infra Structure Program 2014: **$7.8M** (includes HRS, vehicles)
Scandinavian Countries	40	10	Scandinavian Hydrogen Highway Partnership	SHHP, 2006-2013: **€100M** ($137M) Norway, 2014-2018: **€44M** ($60M) (includes HRS, vehicles and O&M)
United Kingdom		6	H2 Mobility	A total of **£7.5M** (~$12M) from Government together with **£3.5M** (~$5.5M) from industry to cover 4-7 new HRS, 6-8 upgraded HRS and the deployment of approximately 40 FCEVs in 2015.
United States	>230	~50 (10 public)	H2USA California Fuel Cell Partnership Hawaii H2 Initiative (H2I) Other State Associations (CT, MA, etc.)	California (CEC), 2014: **$47M** CEC, 2015 - 2023: **$20M/yr** DOE, FY2014: **$170M**
Total	***>585***	***~136***		***~$750M***

2.1 Current challenges and problems in Auto Industry

Firstly, most discussed challenges should be addressed. Afterword, focus will be switched to ones which people tend to put in the second plan when it comes to discussion and analyses of transport problems and impacts. Usually, main focus is just on CO2 emission. However, Life Cycle analyses (LCA) or Cradle to Grave (CTG) of certain technology as a whole (conventional or alternative one) is slightly neglected.

The following limitations that will be covered in this chapter refer to conventional technologies. Afterword, in the chapter 3 alternative technologies which are in current use will be analyzed in the same manner. What is more, in addition to current situation analyses the following chapter, certain scenarios and projections will be presented as well.

First limitation is **CO2 emission**. It is very important of course, but slightly overestimated when it comes to general public and auto industry discussion. However, importance of CO2 emission is more than real and should be addressed. The table below shows CO2 share of cars in total transport mix. It is important to state that civil commercial transport is taken in consideration only. Of course this work is just civil commercial technologies based only but it must be emphasized that military, rocket industry and others have significant share in CO2 emission as well.

Governments and all world environment organizations should address these aspects more than they do at the moment. That does not mean that transport as a whole and auto industry should not be given more attention than it is been given but solving transport or car pollution is not sufficient if other CO2 producers are left neglected. Due to the huge number of cars in the world and their CO2 emission (result of using oil or oil derivate to power them) it is quite clear that this way is not sustainable. There are different theories of how many years we can keep on using this model from environmental point of view. Unfortunately, oil will be used until it runs out.

Table 2-2: Share of Cars CO2 emissions in Transport Structure, Own creation, IEA World energy outlook, Vattenfall, Siemens, 2014 [7]

CO2 emission		Road transport	Air trafic	Shipping	Rail traffic
Share in %		76	12	10	2
Gt of CO2		33,44	5,28	4,4	8,8
Total	44 Gt CO2				

On the up side auto makers have made a lot of effort in the past 10 years or so to make cars with low emissions. Efficiency has been improved in this time dramatically. Use of small turbo engines (petrol or diesel) as well as computer optimization of engine and gearbox, aerodynamic improvements, fuel consumption, thus CO2 emission is far less than it was the case in the past. However, fuel consumption combined with more safety features and entertainment made the cars more appealing to buy and cheaper to run and therefore used to cover even more kilometers.

The next problem is **Life - Cycle Analyses (LCA).** LCA is a procedure used in the field of industrial ecology to evaluate systematically the environmental implications and impacts of material, product, or process across its entire life cycle (**cradle-to-grave analyses**) [8]. LCA is most often used in material selection and product evaluation, and to make comparison among alternatives based on such environmental impact measures as:

-resources depleted,

-environmental wastes generated (air emissions, water effluents, solid wastes),

-embodied energy,

-recycling and waste management practices,

-energy used during service life,

-indoor air quality;

When auto industry as a whole is analyzed from the aspect of this definition it leads to a conclusion that this might be auto industry's major limitation. As it was said it the chapter 2, auto industry is obviously profit/money driven which is fine because almost all companies in the World go in this direction. However, if your business model is creating huge amount of pollution it has to be at least modified. Car industry does not recycle cars anywhere near necessary sustainable amount.

Furthermore, there are huge "graveyards" of relatively new cars which purpose is reduce number of second hand cars, so the people would buy new models in the showroom which is hardly environment friendly and sustainable. This method of approach applies for most aspects of business model used in auto industry, as well as fuel source. At first glance abovementioned statements may not have direct connection to hydrogen, but they very much have. All limitations mentioned in this chapter are not only mentioned as a criticism but as guidance for the future of auto industry, with or without hydrogen in it. This approach should not be applied in the future of auto industry.

F**uel source**, it is definitely the most commonly mentioned limitation together with CO2. Not only the oil creates pollution from the car exhaust pipe and the entire process of producing oil derivate but it is not sustainable. As said earlier in the chapter oil will be used in auto industry until it runs out. This process definitely can't be stopped. Maybe it should not be stopped. We can use oil in auto industry as a support in transition of auto industry as we know today to auto industry of the future Firstly, it is hardly enough considering environment aspect and secondly, existing technologies allow us to act much more and much faster in our transition from now to future of auto industry. Figure 4-2 shows delivered energy required for transport demand on a global level for cases of six different energy sources. Also, projection of future scenarios is included. Based on this figure regarding future projections, prices of oil will continue to increase as the supply or reserves to be more specific, decrease.

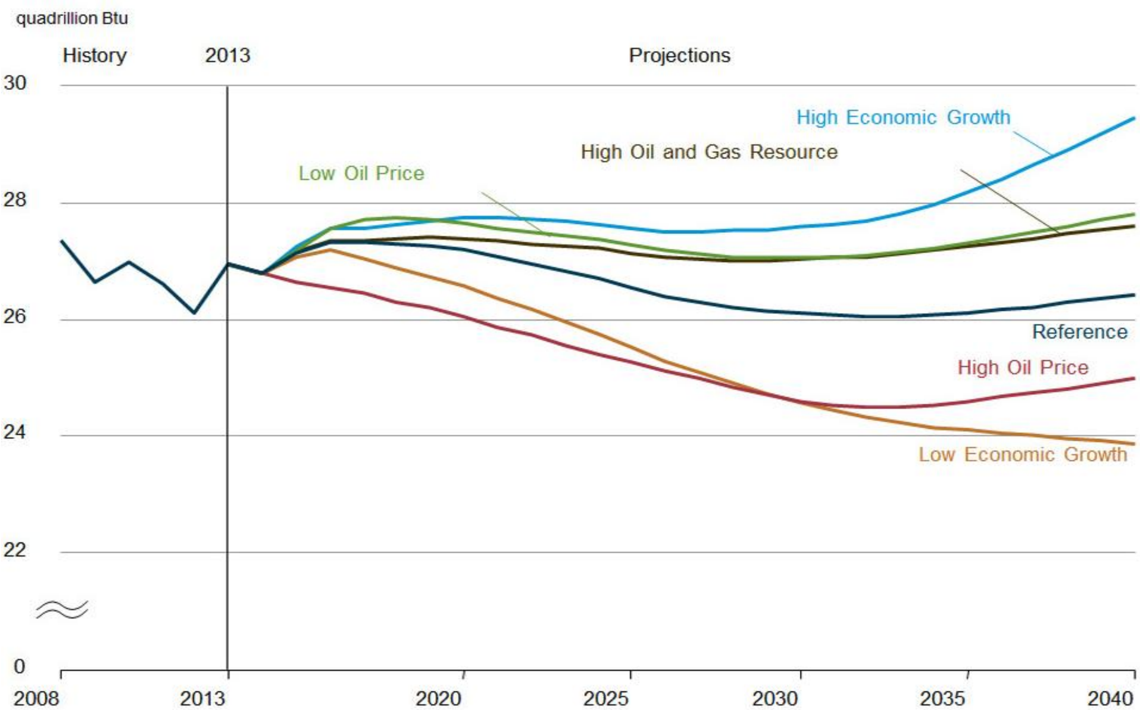


Figure 4-2: Delivered energy for transport regarding 6 different cases, EIA, 2014 [9]

Why are we still going in this way? Well it brings us advantages of current approach in auto industry. The most advantages will be reflected to most limitations of alternative automotive technologies which are going to be presented in the following chapters. Focus, of course, will be on hydrogen which will be covered in chapter 3. Afterword, examples of current use of these technologies especially hydrogen will be presented in chapter 4. In chapter 5 conclusions will be made based on analyses of all technologies and examples.

3 Limitations and potentials of treated automotive technologies

The main focus in the chapter 3 is going to be on mainstream alternative automotive technologies, which are:

- Hybrid cars,
- Electric cars,
- Biofuel cars.

Hydrogen fuel and technologies will be covered separately in the Chapter 4.

Firstly, short technical description of each technology will be presented and afterword each technology will be analyzed from technical, environmental and economic aspect. The analyses will be done by presenting potential and limitations of these technologies.

Since economical aspect is focus of this work at the end of analyses of each technology certain economic parameters will be presented. In Chapter 5, examples will be given of how hydrogen implementation works for these technologies in real life and will be compared and discussed with what was mentioned in the Chapters 3 and 4.

3.1 Hybrid cars Limitations and Potentials

Firstly, short technical description of characteristics of the Hybrid cars (HC) will be given out of which conclusions about limitations and potentials can be drawn out. Focus of analyses for HC and for each technology covered in this work will be limitations and potentials from technical, environmental and economic aspect. As it can be seen on the figure 5 -3, hybrid car uses internal combustion engine (petrol or diesel) which together with electric engine powers the car. It is worth mentioning that there can be more than one petrol/electric engine in the HC. Usually petrol engine is used in modern hybrid cars while diesel engine is mostly used in: trains, mining transport trucks, and others.

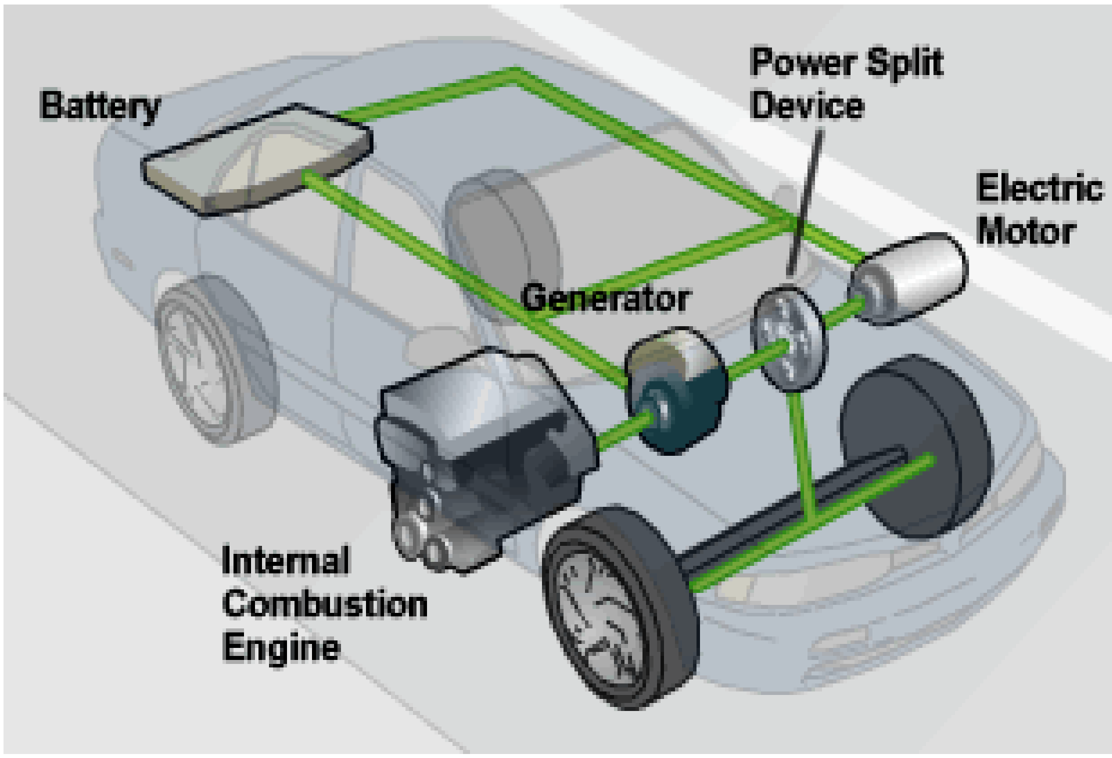


Figure 5-3: Hybrid Car Layot, Fuel Economy, 2015 [10]

Besides petrol engine additional components of a hybrid car are electric motor, batteries, various parts connecting electric and petrol engine and usually in modern hybrid cars – KERS or kinetic energy recovery system. This system collects energy produced by braking and converts it in electric energy which is used as an additional way to power the batteries. It is worth mentioning that this system can be used in conventional cars for additional electric supply in order to take some of electric supply from a petrol engine in order to reduce fuel consumption. There are several most common types of usage of this technological combination:

1) Petrol/diesel engine powering batteries for electric engine, thus propelling wheels using electric engine only while making petrol/diesel engine a generator for electric motor.

2) Petrol/diesel engine powering batteries of the electric engine while at the same time is able to power wheels of the car, thus two engines working together.

Usually there are 3 modes for the second combination:

- Electric power alone,
- Combination of using one or the other engine depending on the driving style or driving circumstances (e.g. town driving, highway),
- Two engines working together all the time,
- Usually in case of supercars (e.g. Ferarri la ferarri) third option only.

This system used in supercars is different to hybrid system used at the moment. It is actually HI-KERS system. It may seem irrelevant to mass produced cars but all hi-tech systems developed in supercars are usually implemented in mass produced cars sooner or later. This system uses batteries shown on the left side which capture energy form braking or from brakes themselves and the engine energy which is normally wasted during braking.

This energy stored in the batteries is then transferred to electric engine connected to petrol engine. The main difference is that electric engine and petrol one work together all the time. This technology will be discussed and analyzed deeper in the chapter 5 – Examples and chapter 6 – Conclusions.

What are the **limitations** of Hybrid technology?

Firstly, **technical limitations** should be covered. There are not many. These cars already exist and are mass produced. They are able to fulfill our everyday transport needs and the current infrastructure is sufficient. The only drawback is petrol/diesel engine that runs on petrol/diesel fuel. Therefore, it is not sustainable. The potential solution is usage of biofuel for internal combustion engine. Is this really the solution? It will be analyzed in the chapter regarding biofuels.

There is something else worth mentioning which is not necessary technical limitation, but it reflects actual picture which can be relatively easy altered. That is current way of using hybrid technology. In order to be hybrid which is really eco - friendly petrol/diesel engine must be used either as the first combination or the second combination should have higher power input of the electric motor rather to have around 10% of electric input and around 90% of petrol/diesel input as it is usually the case.

Why? Electric engine has between 90-98 % efficiency and internal combustion engine has 30-45 % efficiency. Also, electric engine has 0 CO2 emissions. Secondly, and maybe most important are environmental limitations. First of which is connected to technical limitation – fuel. Also, usage of electric engine means usage of Lithium - Ion batteries (LI). The reason for this being environmental problem lies in the graph below.

Finally, there is **economic competitiveness** of hybrid cars. At the moment these cars are still quite expensive. This is no surprise. Firstly, these cars have two or more engines. Furthermore, these cars are usually produced by top auto companies like:

Toyota, BMW and Honda. Finally, effect of the EOS is not reached. There are doubts that it will at all if hybrids continue to be built in this way.

Table 3-3: Comparison of Electric, Diesel and Hybrid vehicle from economic aspect, Own creation, Cleantechnica, 2015 [11]

Car model	Time horizon	Purchase price	Maintenance	Fuel costs	Total
Nissan Leaf	4 years	27.000,00 €	800 €	1.000,00 €	28.800,00 €
VW Golf TDI	4 years	24.000,00 €	2.000 €	2.800,00 €	28.800,00 €
Toyota Prius	4 years	34.500,00 €	1.700 €	1.500,00 €	37.700,00 €

Table 3-3 shows comparison from economic point of view for electric, diesel (turbo) and a hybrid. Despite lower maintenance and fuel costs electric car presents equal economic competitiveness as diesel car. Surprisingly hybrid technology is still very expensive regarding initial investment. If a potential buyer was only looking at the economic aspect Nissan Leaf would be the best choice unless he/she is interested in covering more km per day. Hybrid technology still can't offer lower price probably due to costs of installing two engines in the car.

What are the **potentials**?

From **technical** point of view, infrastructure exists. There are no necessary to change existing fuel stations. Also, car factories are changed as they would be for the production of their new car model.

Environmental potentials exist as well. If HC would be built in a case of petrol/diesel engine only serve as generator to electric engine and if petrol/diesel would be biofuel and if battery problem would be solved. With a current approach it is more looking as a marketing strategy than care of the environment and serious step to future automotive industry.

Economical potentials are related to economies-of-scale. In the end HC needs two engines and batteries as well. Besides Economies-of-scale several future generations of perfecting HC technology might offer lower prices. Technology as a whole does not need additional investment in filling infrastructure.

3.2 Electric cars Limitations and Potentials

This chapter describes technical background of Electric cars (EC) and then analyses EC's limitations and potentials in a manner described in the previous chapter. EC works by using electricity to power electric engine in order to move the wheels. Below is a picture that shows all major components of an electric car: batteries, electric engine and drive mechanism. Figure 6-3 shoes technical displacement of the newest Tesla model. The only discrepancy to text above is that this specific car uses two electric engines.

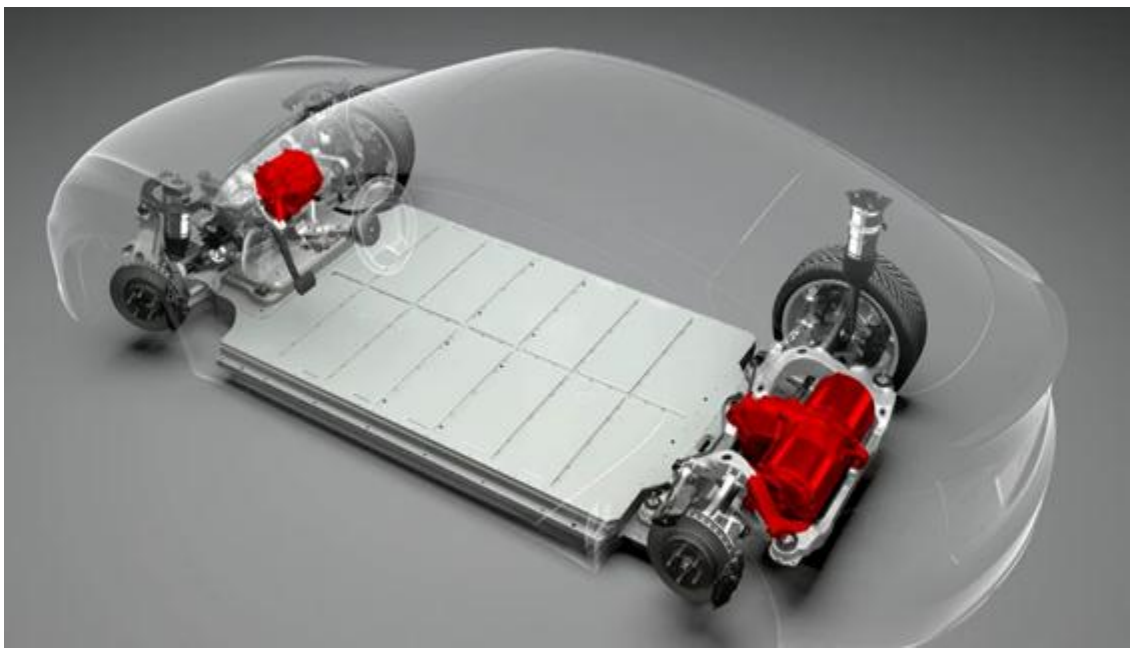


Figure 6-3: Electric car displacement, Tesla 2015 [12]

It is rather simple principle. Electric motor is powered by LI batteries. Batteries can be charged via socket, which can last for 8 to 10 hours. Special charging stations are available for the last few years which charge the batteries in around 4 hours to the maximum. Also, supercharging stations are available which can charge 100 % in one hour.

It is worth mentioning that electric cars can have more than one electric engine. There are cars with even one electric motor for each wheel. Whichever layout is chosen the principle of how electric car works is the same. As with Hybrid cars method of approach is the same on electric cars. Therefore, **limitations** come first.

Firstly, **technical limitations**: The main one is the range. Even the most advanced electric cars like Tesla model S have the range of around 400 km. Therefore, electric cars at the moment can fulfill our city driving needs. In order to cover thousand kilometers technology has to be developed further.

Next technological limitation is infrastructure. There are simply not enough charging stations in the world as there are conventional ones, for instance. Technically it is relatively easy to install sufficient number of these stations but economy wise it is not.

Also, time of charging makes range and infrastructure problem even greater. Although new supercharge electricity filling stations can charge electric car within one hour even it is till way too slower than then it is the case of conventional cars. What is more, these supercharged station costs more and they tend to shorten life time of the batteries.

If range and charging time (in most cases it is between 2 to 6 hours) is taken into consideration it is easy to calculate how long would have a 1000 km trip last. We consider in our example a car with 200 km of range and charging time of 2 hours. Average speed is 100 km, for instance. In this case 1000 km trip would last without stopping (with only charging included) around 20 hours. With a conventional car which has a range of 700 km on average this trip would take between 10 -11 hours. Table 4-3 shows environmental, technical and economical comparison between fossil fuel (diesel) and electric car. CO2 alone is obviously advantage of electric car. However, energy source is not renewable with electric car as it is the case with conventional one. Technically and practically electric vehicle is currently well as being conventional vehicle. Fuel costs of electric car are its biggest advantage.

Table 4-3: Comparison between Diesel and Electric vehicle, Own creation, Green24, 2014 [13]

Electricity vs Fossil fuel		
	Fossil fuel vehicle	Electric vehicle
Emission	80-400 g of CO2	0 g of CO2
Energy source	Non-renewable Oil	Mostly non-renewable
Range	400 km on average	170 km on average
Time to fill up/charge	between 5 and 10 minutes	between 1 and 8 hours
€ cent/1km	8-10	2-3

Lastly, there is issue of noise or rather lack of it. Although it is very pleasant not to have much noise in the cabin of the car it can be quite dangerous for the pedestrians. This problem is obvious in city streets. When electric car is passing through a city street it is very difficult to hear it coming. Next part of the analyses is environmental impact or **environmental limitation**. As it is the case with electric engine in electric car, hybrid car has environmental limitations regarding its batteries it is the same situation with electric car. Except there are even more lithium ion batteries in electric car, considering that electric engine moves the wheels alone without petrol/diesel engine and therefore needs more electricity, thus more batteries. In order to achieve more power and higher range quantity of the batteries is even higher. Lastly, but perhaps the most important aspect is electricity source. Currently electricity is produced mostly by nonrenewable sources (coal, for example). CO2 emission from electric car itself is 0, but in order to produce electricity with conventional technologies great amount of CO2 is produced which at the end means pollution and unsustainability.

Economic limitation is above all the price of an electric car itself. Electric cars are very expensive. The cheapest one, Nissan Leaf, costs around 25.000 euro. Tesla Model S costs between 65.000 and 90.000 euro. Again, EOS is necessary. Also, certain amount of money is necessary for constructing power charging infrastructure. What is more, the charging infrastructure is simply not sufficient in almost all the countries in the world. Investment in such infrastructure presents another economic limitation. Table 5-3 is a comparison between electric Tesla and price and class equivalent Audi. Calculation below shows annual costs of buying and operating these cars. Formulas used in the calculation in table 5-3 are:

C transport = **C** energy + **C** vehicle

C energy = **FI** * **P** fuel

α = z*(1+z)^n / (1+z)^n-1

A = IC * α

The symbols in the formulas are:

- C – cost,
- P – price,
- FI – Fuel intensity,
- A – annuity,
- IC – Investment cost,
- α – Capital recovery factor,
- z – interest rate.

However, Audi is around 4 times more powerful and has much higher range. Also, Audi is far more luxurious, more comfortable and better made. With abovementioned limitations of an electric car, it is quite hard to choose Tesla rather than equivalent Audi model.

Table 5-3: Comparison of ownership costs between Tesla Model S and Audi A7 petrol equivalent, Own creation, UBSe, , 2014 [15]

Car model		Audi A7 TFSI	Tesla Model S
Investment horizon		5 years	5 years
Time period of a loan		5 years	5 years
Power (hp)		300,00	410,00
Price of the car (€)		70.000,00	75.000,00
Fuel costs €/year		1.650,00	450,00
Interest (%)		5,00	5,00
Total annual costs (€/year)		18.973,11	19.423,11

What are the **potentials** of electric cars?

Firstly, technical potentials must be addressed. Range is at the moment an issue, but technological development and evolution is inevitable. Tesla Model S can cover around 400 km on one charge, which is not enough for most people needs. However, 10 years ago electric cars could hardly cover more than 100 km. The same is with infrastructure. It is not rocket science it simply needs to be constructed. If auto industry goes in the direction of electric cars there is a huge potential in this respect. As for the noise, car manufacturers need to find the solution for this problem.

Environmental potential exist as well. As for the batteries it is the same as for hybrid cars. Regarding electricity source the potential is probably the same as is the potential for converting conventional electricity sources to alternative sources. Which one will happen first and what will be the transition paste in the future is very hard to say. Ideally the paste should be the same with both.

Economic aspect is more complicated than it is the case with hybrid cars. Constructing the infrastructure is not necessary with hybrid cars. It already exists. With electric cars reality is far different. Furthermore, it is far from cheap. Also, for electric car to be eco - friendly and sustainable current electricity supply must be converted to alternative one. That needs a lot of time and money. Finally, economies-of-scale need to be achieved in order to make electric cars more affordable. In the end, it is hard to measure the overall potential of electric cars. It definitely exists but it is quite complex to reach sustainable way of producing and more important using electric cars. Figure 7-3 shows current sale and projection of sale of electric cars by world's most famous and most successful electric car manufacturer. Based on sale results and estimates there is a potential for electric cars in the future. Of course, the same question must be asked: Is it sustainable?

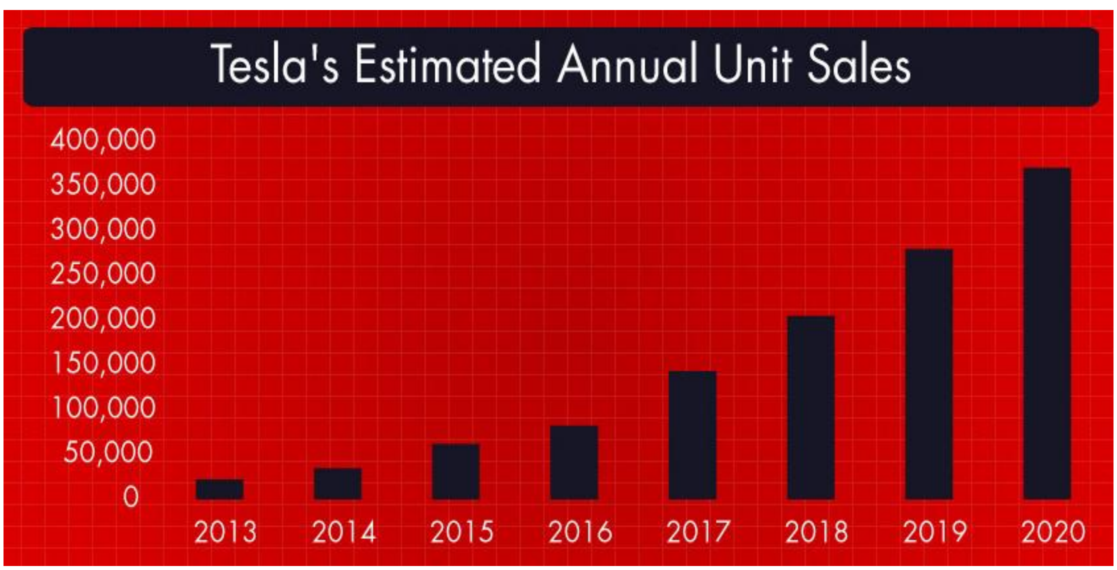


Figure 7-3: Tesla's estimated Annual sales of their cars, Morgan Stanley research, 2015 [16]

3.3 Biofuels Cars Limitations and potentials

Biofuels cars (BC) use the internal combustion engine. There are no alternative or renewable technologies in the entire power train itself. There are certain modifications necessary but the major difference is that the car or rather the engine uses biofuels as an energy source. What is more, besides to certain engine components that need to be changed, the rest of the car is unchanged. In certain ways this technology is rather similar to hydrogen conversion technology (CT) which will be mentioned later in the chapters.

Furthermore, the engine can be petrol or a diesel one. For petrol engines bio methanol or bio ethanol is normally used. For diesel engine bio diesel is used which can be produced from: waste vegetable oil, crop seed, est. Figure 8-3 shows in simplified manner how production of biofuels looks like. What is more, on this figure are all “materials” which are normally used for production of biofuels – from animal fat to wet biomass.

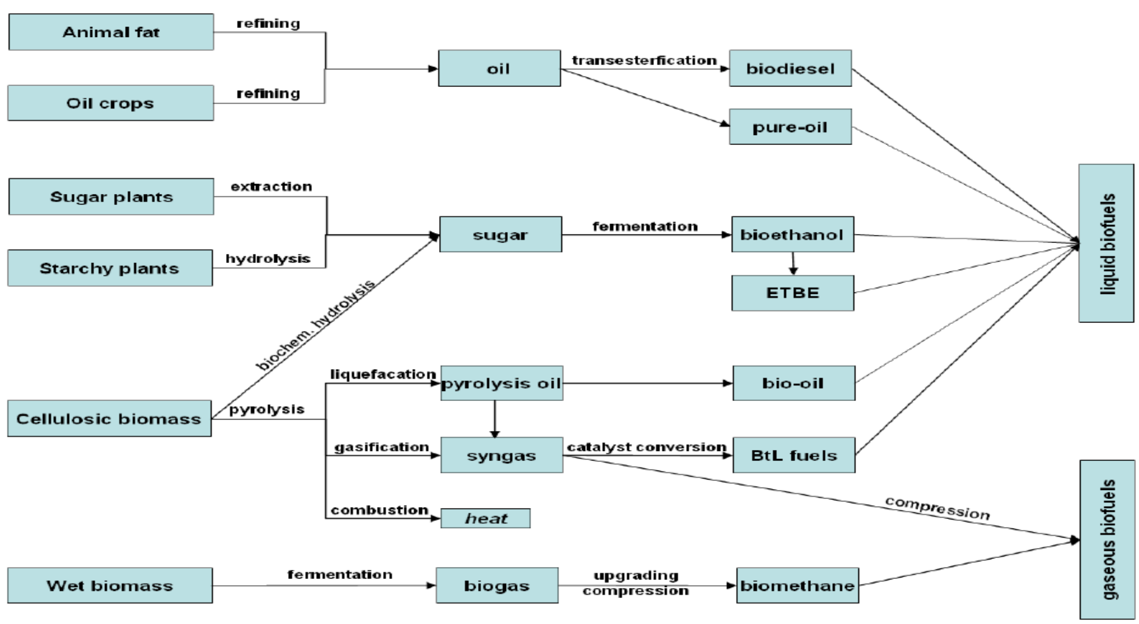


Figure 8-3: Ways of producing Biofuels, Bio Top, Biofuel options, 2013 [17]

Implementing biofuels technology in a car itself is rather simple. In certain ways it is very similar to LPG (Liquid Pressurized natural Gas) conversion. All that is necessary is to make several conversions or rather replacement of several parts, such are:

- fuel filter,
- oil filter,
- fuel injection system,
- new type of engine oil,
- fuel tank
- est.

It is possible to run conventional petrol/diesel engine without any conversion/replacements but it affects the reliability and the life span of the engine. Since the technology itself is not too complex (replacing several parts of the engine with one with different specifications) the main focus (analyses) will be on fuels themselves.

Furthermore, for this technology technical and environmental aspect will be analyzed at the same time since they are much more connected and inseparable than it is the case of other technologies. Therefore, **technical limitations** concern only on biofuels production process.

Petrol engine normally uses bio ethanol or bio methanol as a biofuels. In order to produce bio methanol, for instance, corn, maze, or other type of crops is necessary …Therefore, land for "farming" is also necessary. Unfortunately land used for this process is usually destroyed and unsuitable for farming for decades in certain cases. Also, a lot of CO_2 is produced in the production process itself (machines used for growing and collecting process, trucks used for transport, est.).

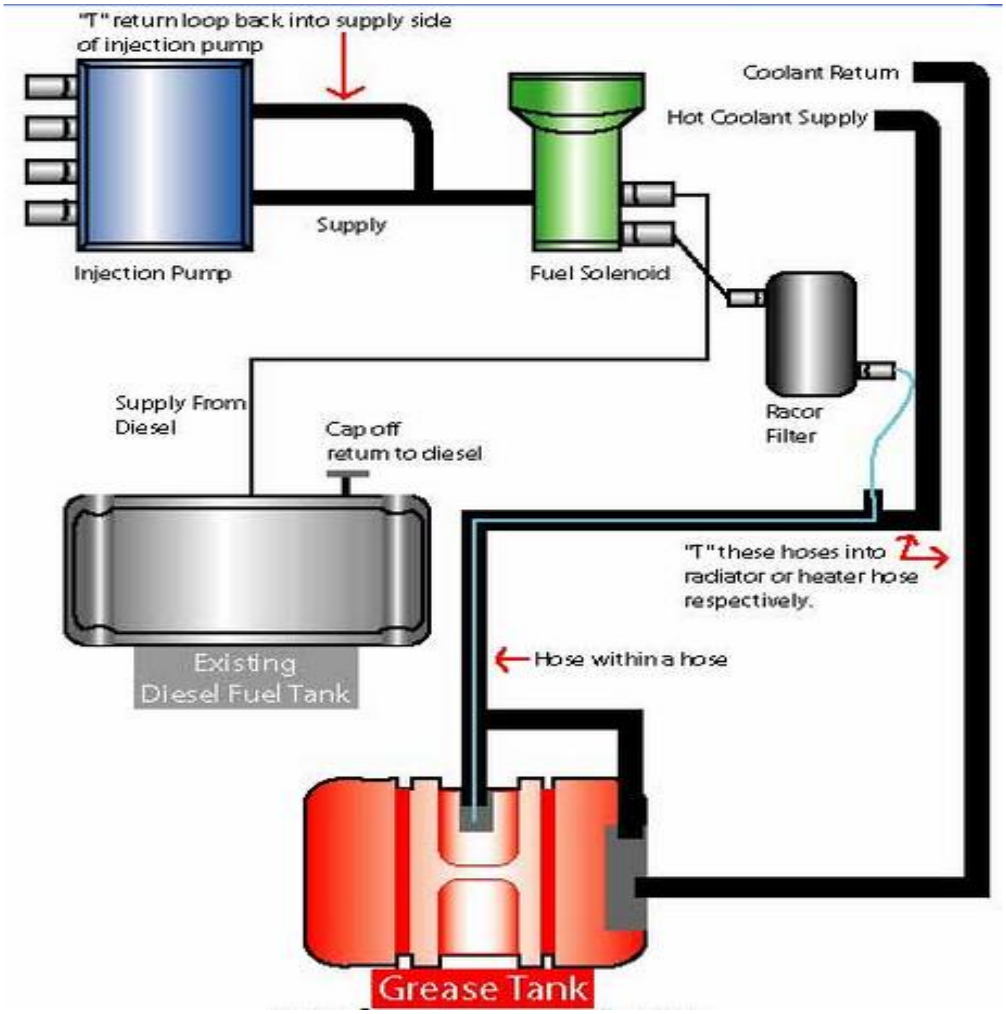


Figure 9-3: Technical overview of a Biofuels Car, Green Trust, 2014 [18]

Diesel engine uses biodiesel fuel obviously. Biodiesel can be produced by:

- Many ort of plants – maze, corn, est.

- algae and

- collecting used cooking oil.

The first option, using crops, comes with the same limitation as bio methanol. Not only the production process creates soil and air pollution and is unsustainable but supply is also questionable. There are those who suggest food supply problems especially in the future. In order for biofuels can fulfill transport or at least car demand this would make this problem even greater.

The last two options may appear the most environmentally friendly at first glance but these types of biofuels (vegetable oil waste) can hardly fulfill world's fuel demand. With current supply/amount it is most probably not applicable in the close future.

After abovementioned fact it is relatively easy to conclude that this is not an ideal solution from environmental point of view. What is more, use of biofuels reduces CO2 emissions but it does not eliminate them all together. Some biofuels create more CO2 than the others. In order to have clearer picture graph below is presented which shows specific impact for each fuel. Figure 10-3 shows carbon footprint of various types of biofuels. In order to keep environmentally safe approach non land using biofuels type is the obvious choice.

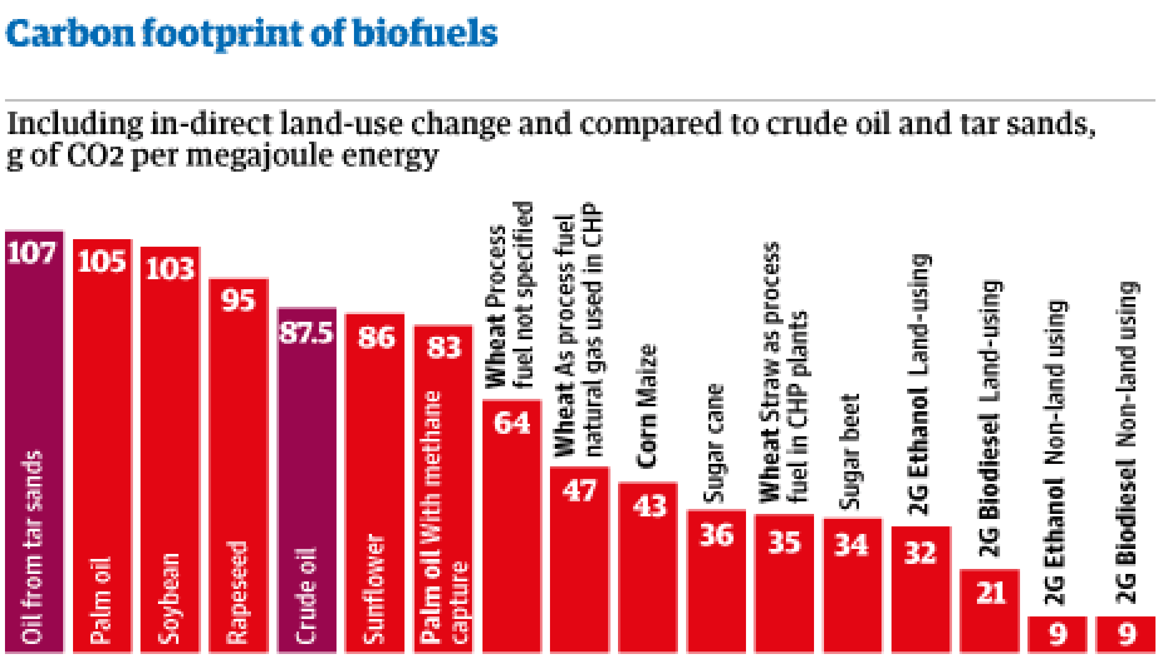


Figure 10-3: Carbon Footprint of Biofuels, The Guardian, 2012 [19]

Finally, **economic limitations** are going to be analyzed. Bio methanol production is mainly situated in Brazil. Europe mostly import bio methanol from Brazil. The reasons are: cheap land, chap labor, thus cheap production process. Also, in all honesty environmental regulations in Brazil are quite lower than those in Europe. Not only they are lower but they causing pollution and are not sustainable.

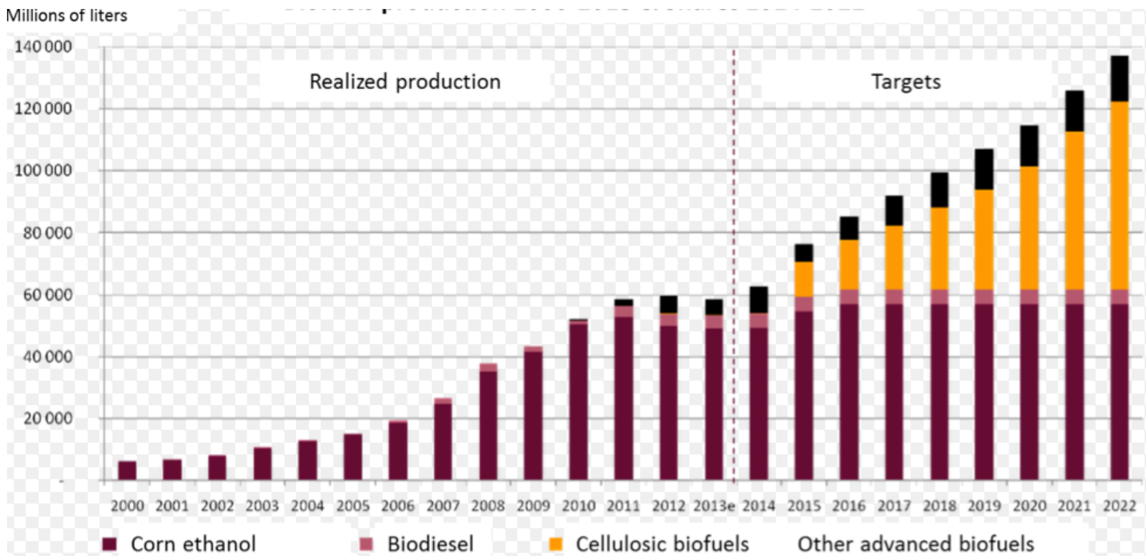


Figure 11-3: Realized global biofuels production and future targets, ICCT, 2014 [20]

Algae are way too expensive at the moment and are not economically feasible. Used cooking oil is cheap. The restaurants or food producers give it away for free or very cheap. If auto industry would go in the direction of used cooking oil as a solution for transport problem the price would probably be higher. In addition to that it is hardly unlikely that used cooking oil can fulfill our transport needs.

Technical potentials of biofuels cars are existing ones but biofuels alone are hardly a solution. Perhaps in a technology mix they can contribute from current point of view. As with hybrid cars no significant changes regarding infrastructure are necessary. It is worth mentioning that conversion of cars themselves is technically easy to conduct.

Environmental potentials can be seen if this technology is used as a transition solution for future auto industry or supplement or one of technologies which will be used in a potential technological mix.

Economic potentials reflect on conversion of petrol/diesel cars to run on biofuels which is rather simple and relatively cheap. Depending on a country entire conversion costs are in a range between 500 and 2000 euro. Beside these several benefits and based on limitations stated above it is hard to say that biofuels will be the direction of future auto industry.

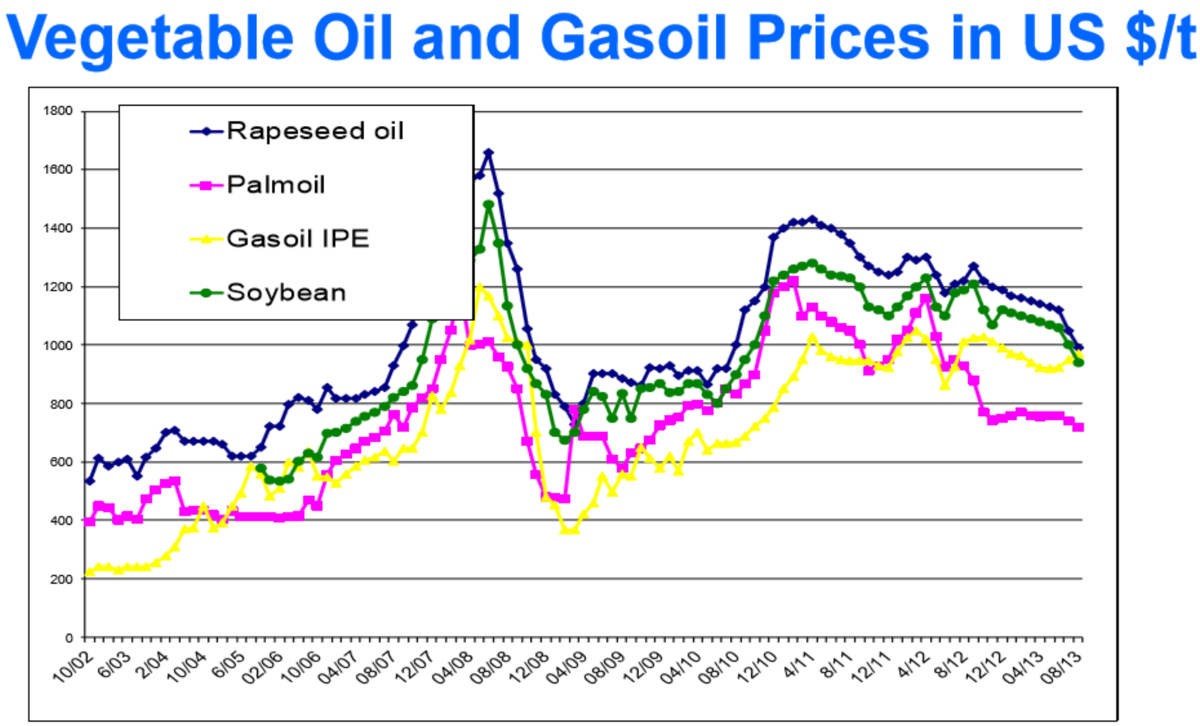


Figure 12-3: Increase in production of several types of Biofuels, Mittelbach 2013 [21]

4 Limitations and potentials of Hydrogen use in car transport

As the title of the work suggests main focus will be on Hydrogen. First few chapters will be focused on general technical introduction of hydrogen as a fuel. Methods of production will be covered as well. Afterword, implementation of hydrogen in auto industry and hydrogen technologies will be presented and analyzed.

Same approach of analyses will be done by discussing and analyzing technical, environmental and economic limitations and potentials of hydrogen as it was the case in earlier chapters regarding other alternative technologies.

Major difference in analyses of hydrogen compared to other technologies will be amount of attention on hydrogen and Chapter 5 dedicated only to hydrogen in which examples of existing and operating hydrogen implementation models will be presented.

4.1 Introduction of Hydrogen as a fuel

Firstly, short decription of Hydrogen as a fuel needs to be presented. Hydrogen is the most common element in the Universe. Theoretically it can be extracted or produced by using anything. In practise water or several kinds of biomass are used. In the end the product is compressed liquid hydrogen fuel which produces water wapor from the pipe or no CO2 emission.

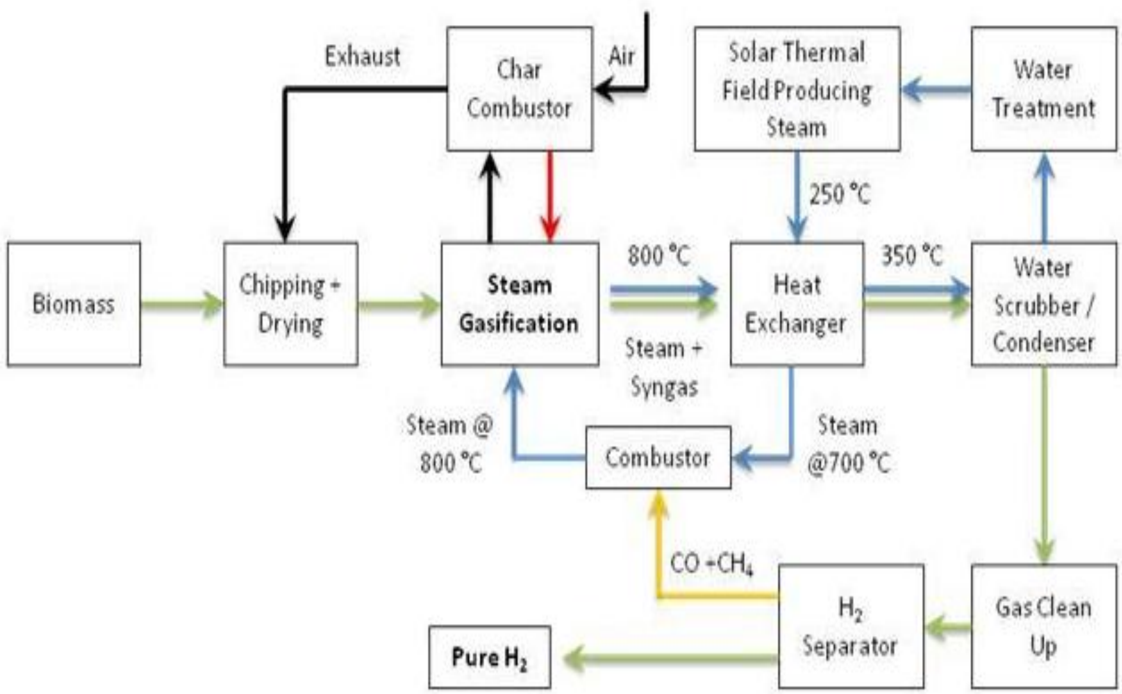


Figure 13-4: Hydrogen Production process using Biomass, Florida State University, 2015 [22]

Figure 13-4 shows hydrogen production process when biomass is used as production material. Based on figure above it is not difficult to conclude that biomass has to be eco-friendly and that electricity used for electrolyzes must be produced using renewables. If hydrogen production is not sustainable than hydrogen as a fuel itself makes little sense. Technically this is relatively easy to achieve. Below is figure 14-4 which shows Hydrogen production via electrolyzes with plants as a source.

In simple words, it needs plants as biomass and electricity to perform extraction of hydrogen atoms from the plant and other "components" of the plant. In the end, hydrogen is produced which can be used as a fuel in various vehicles but most importantly in cars.

Of course, this process has many byproducts and they as well as hydrogen can have many applications. It is worth mentioning that this way of hydrogen production also needs electricity. In this case as with biomass, electricity must be produced using alternative or renewable methods or it is unsustainable.

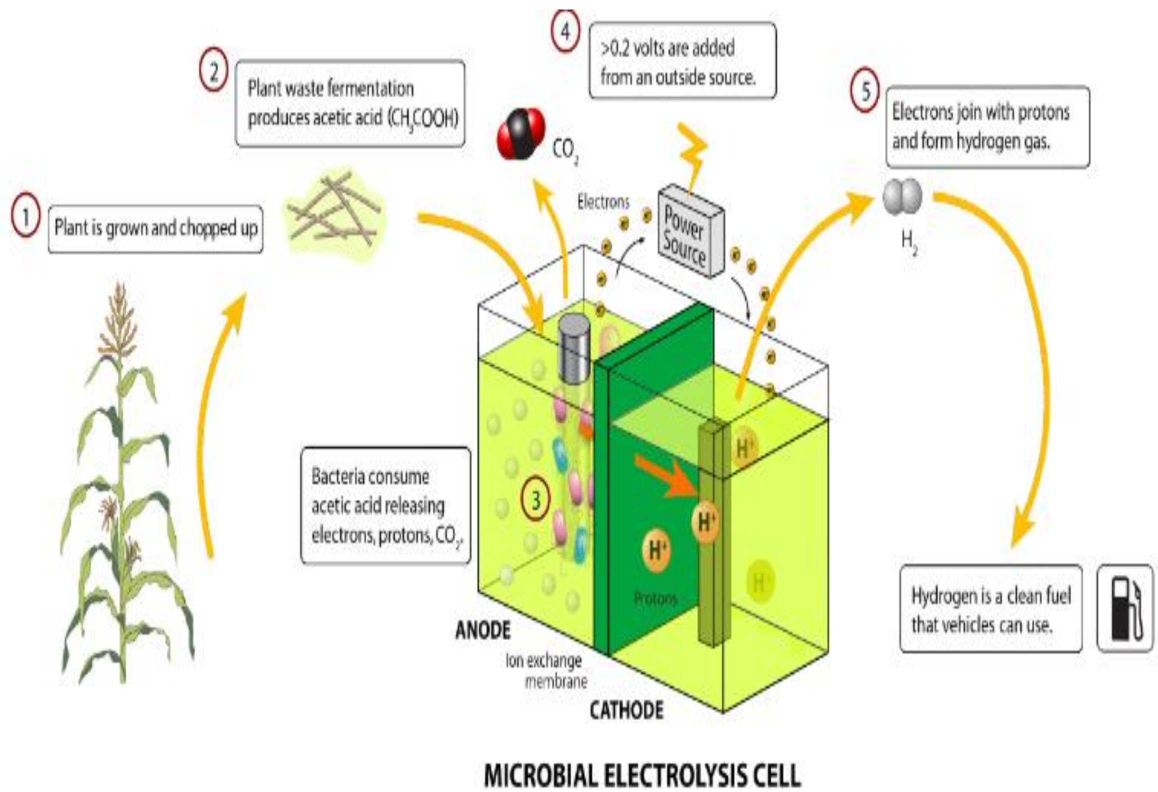


Figure 14-4: Hydrogen Production using Electrolyzes process, MIT Technology Review, 2013 [23]

Conventional ways of producing electricity can potentially serve as transition period device. If hydrogen becomes solution for the future auto industry this will probably be the case. But at one point electricity production has to use renewable sources 100 % or hydrogen production is never going to be sustainable.

Examples of the existing facilities which produce hydrogen in either of these two cases (using biomass or water) will be presented and shortly analyzed in Chapter 5 – Examples.

Technical overview is main focus of this chapter. Existing (successful) examples in Europe or in the World will be analyzed from all aspects taken in consideration in the case of other technologies/fuels.

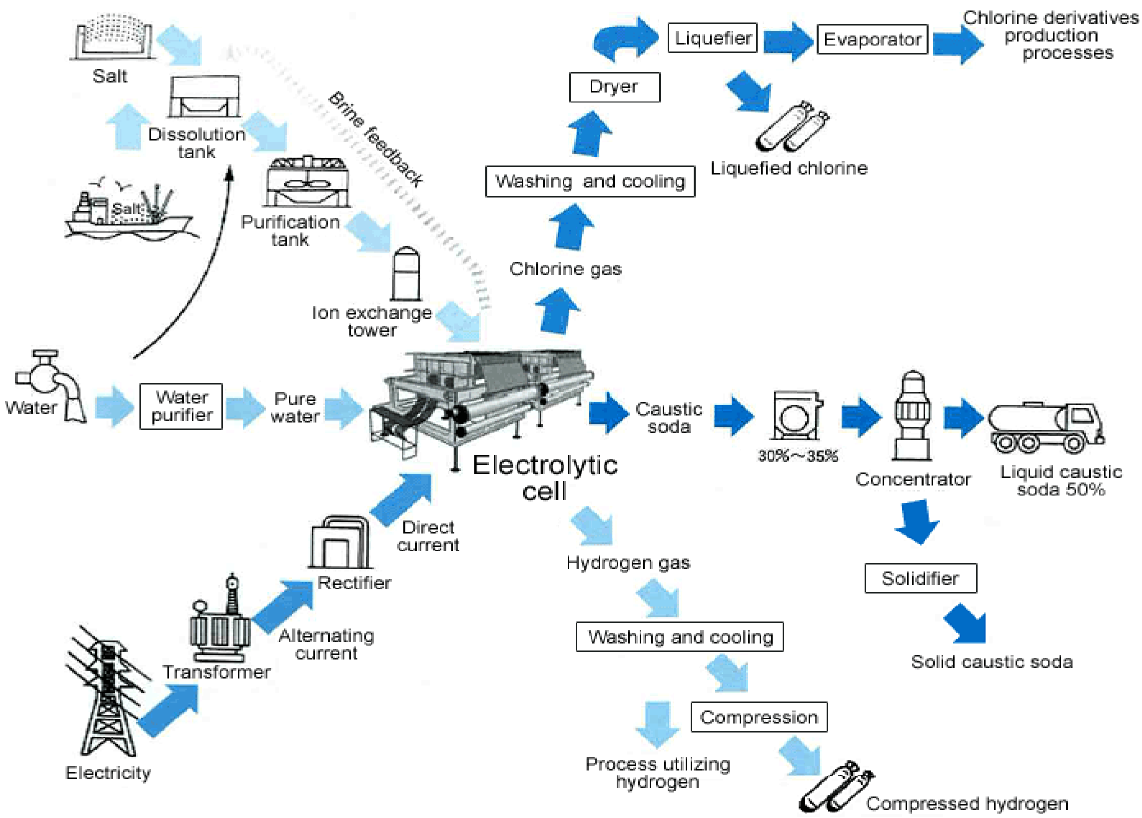


Figure 15-4: Hydrogen Production using Water as a fuel, M&V, 2014 [24]

Figure 15-4 shows how production of hydrogen looks like when water is used as a source. Primarily, salty water is used. Electrolytic cell separates O2 (Oxygen) atoms and H2 (Hydrogen) atoms. Produced hydrogen gas is than compressed and can be used as compressed liquid hydrogen for internal combustion petrol engines. What is more, regular tap water can be used as well. In this case there is no need for dissolution and purification tank ad ion exchange tower. In other words this process is less complex.

Technical limitations are connected mostly to the hydrogen source or type of biomass/water used in electrolyzes process for hydrogen fuel production. On one hand using water for this process results in producing hydrogen with less calorific value than it is the case when using biomass. On the other hand, using certain type of biomass is either limited with supply of that certain biomass or it is unsustainable.

What is more, significant amount of any type of biomass is necessary to produce 1 kg of hydrogen, for instance. This is definitely technical disadvantage. Also, amount of electricity needed for electrolyze process is quite significant as well. Technically hydrogen production process is definitely possible and it is already proven to work but abovementioned limitations has to be reduced.

Environmental limitations are easy to notice based on technical limitations. Using biomass for instance if unsustainable makes no sense for any technology. Either using biomass is sustainable way as well as water can be solution. Another limitation extracted from technical ones is amount of electricity necessary for hydrogen production. Giving a fact that majority of electricity produced in the world today comes mostly from coal and nuclear power creates huge environmental limitation for hydrogen fuel.

Even if production of electricity worldwide is 100 % renewable (which one day will probably be the case) it has to be used rationally.

Economical limitations are the most significant. Giving the fact that water or biomass which is sustainable is selected for hydrogen production process amount of electricity necessary is significant and thus expensive. What is more, amount of biomass selected for the electrolyze process is also significant. If water is selected hydrogen gas which is produced is lower calorific one and it means that more of it is necessary to get compressed hydrogen.

Next part of analyses is potentials of hydrogen fuel. Based on analyses in the next few paragraphs it is environmental potential.

Technical potentials can be extracted from the picture below. Figure 17-4 shows entire oil production process. It also shows that production of hydrogen is not so complicated when compared to oil production process. What is more, this graph shows that complicated production processes can be cheap if EOS is working.

Hydrogen production is even simpler that oil production on the picture above. As it was said at the beginning of this chapter there are two mostly used ways to produce hydrogen: electrolyzes process using plants (biomass) or using water. Facilities using water as a source can simply be situated on the cost of see. In any case entire production process analyzed from Cradle-to-grave is far simpler and produces less CO2. What is more less energy input is necessary in the case of hydrogen production.

Environmental potentials come firstly from the fact that hydrogen fuel emits 0 CO2. Based on the figure 16-4 (gasoline supply chain) it is clear that production process also emits 0 CO2 especially when compared to Oil production process. Not only hydrogen production process emits less CO2 but CTG is far more environment friendly. Based on figure 16-4 it is not difficult to conclude that a lot of energy (oil primarily) is needed to complete this process.

What is more, hydrogen may technically seem as more complicated technology than electric car for instance but environment wise it comes without lithium ion batteries. Also, amount of electricity needed for supplying (entire world transport needs) electric cars only (renewable or non - renewable sources) would be more significant than one that is necessary for hydrogen production.

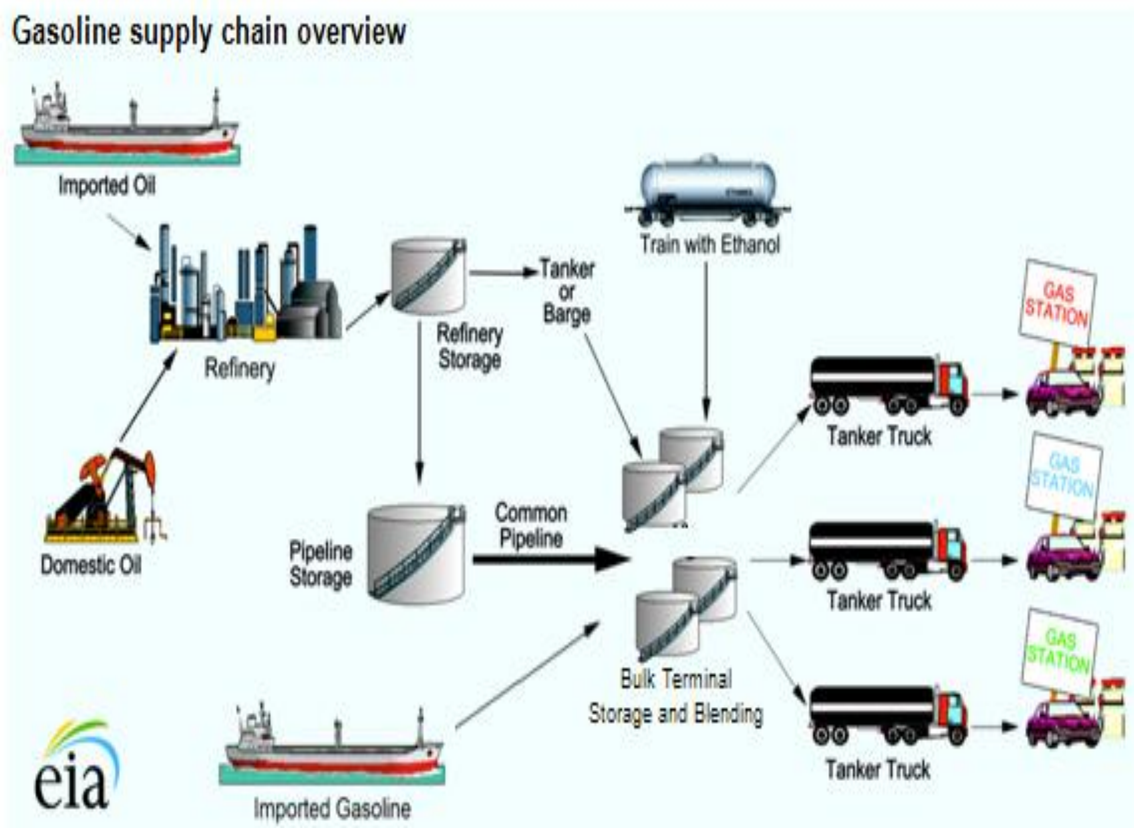


Figure 16-4: Gasoline Supply Chain, U.S Energy Information Administration, 2013 [25]

Economic potentials are somewhat scarce but they do exist. The first factor to increase economic potentials is EOS. The graph above clearly suggest that complicated and multi faze production processes can be economically feasible and profitable if effects of economies-of-scale exist. Production technology itself can be improved in terms of efficiency in order to use biomass/water in less quantity inputs and achieve more outputs.

Table 6-4 is a comparison of economic and environmental parameters of conventional petrol, petrol hybrid, FCV and Electric vehicle. Besides initial investment FCV and EV are much more competitive. Of course it is very significant aspect. However, CO2 emission, maintenance and fuel costs are advantages of FCV. Fuel source and economies-of-scale is major barrier to FCV and electric car as well.

Table 6-4: Economical comparison of different fuels, CCO, 2013 [26]

Parameter	Petrol	Petrol Hybrid	Hydrogen FCV	Battery EV
Fuel costs (€ cent/km)	11,2	8,25	5,5	2,1
Range (km)	800	1000	560	250
Price of a car (€)	25.000	35.000	45.000	40.000
CO2 g/km	120	80	0	0

4.2 Hydrogen use technologies

Next two chapters will cover two hydrogen technologies. Advantages and potentials of the fuel necessary for operating this technology are covered in the previous chapter. Two technologies will be mostly analyzed in some ways "isolated" from their fuel – hydrogen. Focus will be on technologies themselves.

There are two types of implementation of hydrogen fuel in auto industry and thus there are two technologies:

1) **Conversion technology (CT)** which replaces several components of internal combustion petrol engine enabling it to run on hydrogen fuel rather than petrol.

2) **Fuel cell technology (FC)** which uses liquid hydrogen fuel and converts it into electricity via fuel cell stack and uses that electricity to power electric engine.

To begin, analyses will be carried out in the same way as other technologies were in the previous chapters. Therefore, technical introduction comes first and afterword limitation and potentials from both technologies will be carried out from technical, environmental and economic point of view.

4.3 Conversion technology

This technology looks relatively simple but is it not entirely the case. Conversion itself is rather complicated and needs a lot of engine parts to be replaced or modified. For instance, fuel tank, injection system, electronic control unit, est. It is worth mentioning that hydrogen conversion kits do not replace petrol fuel tank. Usually, hydrogen tank is added. This is clever solution so in the case that there is no hydrogen fuel station in the certain area petrol can be used instead. Giving a fact that hydrogen filling stations exist only in few countries in the world and even in those countries filling infrastructure is insufficient, implementing conversion in this way is a must at the moment.

Major component missing is hydrogen fuel tank. On the figure 17-4 is a BMW 7 series which is one of the first production cars to run on hydrogen fuel. More important it uses CT and not fuel cells. However, conversion can be done in way that car or engine uses hydrogen fuel only. At the moment it is technically limited due to no existence of sufficient fuel source infrastructure.

Once conversion is done how does the car/engine operate? Internal combustion engine continue to work on the similar principle as it does when the fuel is oil (petrol). It mix compressed liquid hydrogen with air instead of mixing petrol and air to create explosion which propels pistons inside of the engine. In this sense this really is a conversion not entirely different technology. The only byproduct that comes from the car exhaust is water vapor. Therefore, CO2 emission is 0.

Existing infrastructure (fuel filling stations) can fulfill all requirements of this technology. Only that is necessary is the installment of hydrogen filling unit in existing fuel station. Entire transport process from production facility to filling station is the same as it is with oil – with cistern. After brief technical introduction potential and limitations of hydrogen conversion technology follows. Comparison of this technology and fuel cell technology will be performed in the chapters 5 and 6.

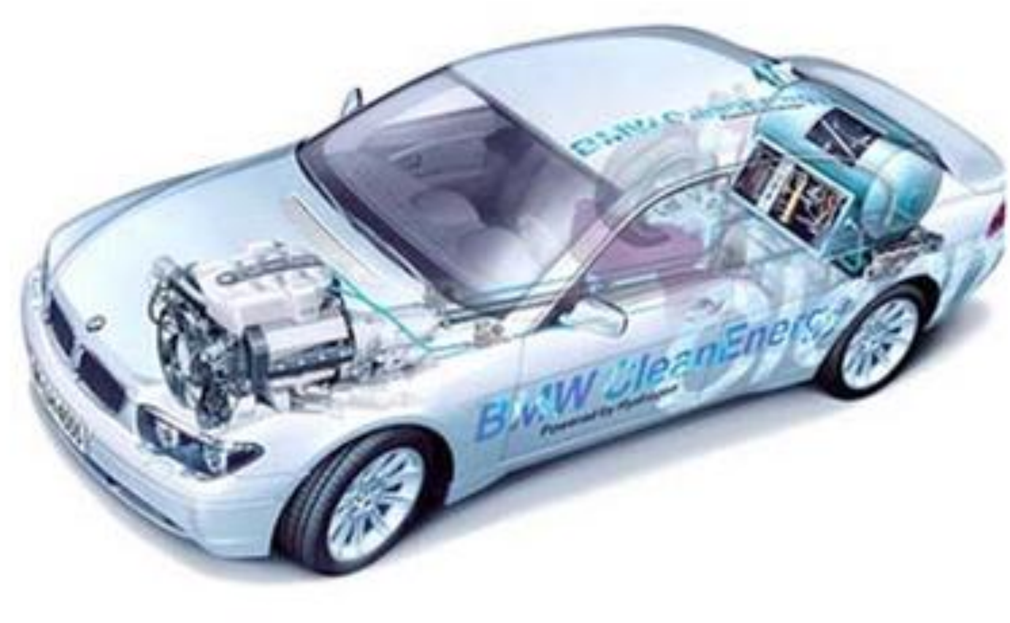


Figure 17-4: BMW 7 Series Hydrogen, BMW 2004 [27]

Technical limitations are reflected by hydrogen fuel production. Since it was said that hydrogen technologies will be analyzed “isolated” from hydrogen fuel, the main disadvantage of this technology alone especially when compared to fuel cell technology is engine efficiency. Petrol engine has around 30 % efficiency while electric engine has around 90 %. Also, it is worth mentioning that current trend in auto industry when it comes to hydrogen cars are fuel cell cars. When efficiency is compared it brings the question does the conversion makes sense at all and is that the reason why car makers are found of fuel cell technology.

Beside efficiency implementation of hydrogen to electric engine (FCV) also brings out another limitation to implementation of hydrogen to internal combustion engine – design. Compared to electric engine petrol engine has many more parts than electric one which means it is much bigger and heavier and takes more time to produce.

Environmental limitations - CO_2 emission is 0. In that respect there are not any. However, the CTG analyses suggest that vehicle that uses this technology is produced as a conventional one. Any limitation that conventional car production has is transferred to the vehicles that use conversion technology. Figure 18-4 is a part of VW's sustainability report. It shows parts or components necessary to produce a single car. In this case it is a small range city car – VW Polo which requires over 4.000 components to be produced.

These pictures enhance conversion technology environmental limitations. In order to reduce or remove this limitation of this technology car production has to be slightly redesigned and ways that we exploit cars has to be changed also.

Economical limitations are scarce if CT itself is considered without taking price of hydrogen fuel. Conversion in countries like California, USA which is one of most advanced countries in the world regarding hydrogen implementation and development costs not much more then conversion to LPG in Europe. However, price of hydrogen has to be taken in consideration since it presents major if not only significant factor which can be described as economical limitation of this technology.

However, **potentials** of this technology in many ways overshadow the limitations.

Technical potentials at first reflect on existing car production technology. In that sense it is obvious that implementation of this technology does not acquire complete transformation of production process. When time, money and production of new components are taken into calculation this technology makes a lot of sense, at least in close future transition period. Current production facilities do not have to be completely changed and a lot of second hand cars can be converted and used for some time period rather than being disposed to junk yards. Also, there are many companies which perform conversion which means that technological or know-how infrastructure already exists. CTG is, therefore, far more environment friendly.

What is more, many car components manufacturers and suppliers do not have to lose their businesses. This reflects on the next potentials of this technology: environment and economy.

Figure 18-4: VW Polo - All conmponents, VW 2013 [28]

Environmental potentials can be mostly extracted out of technical ones. Not having to make entirely new fuel supply infrastructure analyzed from CTG is huge potential and advantage, especially compared to electric cars. What is more, production of these cars means that production itself needs to be only modified and not fully changed in case that the car manufacturers adopt conversion technology for the future. Perhaps the main potential of this technology is its implementation as a transition period device. Using existing cars rather than disposing them may not be economical for car manufacturers but this is environmental potential not economic one.

Economical potentials can be drawn out of technical potential as well. In other words, modifying or upgrading production and infrastructure rather than replacing or radically changing is more economical and needs less time and development.

It is worth mentioning again that EOS is contributing to economical potentials of this technology since is basically using conventional car production. This means that this technology is at the moment economically more competitive than FCV.

There is one potential which is not mentioned in any other analyses and that is driving experience which this technology definitely offers. This may not seem to be very important but too many drivers car represent more than a transport vehicle. Since economical potentials are being considered at the moment, costumers or market needs should be taken in to consideration as well.

4.4 Fuel cell technology

Like conversion technology Fuel Cell Technology uses compressed liquid hydrogen. However, this is the only significant similarity. Fuel cell technology uses liquid hydrogen which is sent to fuel cell which produces electricity out of hydrogen fuel. This electricity is then sent to electric engine to power the wheels. This means that this kind of car uses completely different power train infrastructure compared to conversion technology. What is more, unlike electric car, FCV does not use batteries. It has fuel source in its fuel tank – hydrogen. This means that car is lighter and does not acquire lithium ion batteries which cause pollution.

Figures 19-4 and 20-4 show how Fuel cell works. Fuel cell separates positive and negative hydrogen atoms. Negative atoms flow via external circuit to “chamber” where Oxygen comes in, while positive atoms go through membrane and are merged with Oxygen. This causes electrical current. At the cathode positively and negatively charged atoms merge with Oxygen which causes water vapor to form. This is only byproduct that FCV produces. This also means that CO2 emission is 0.

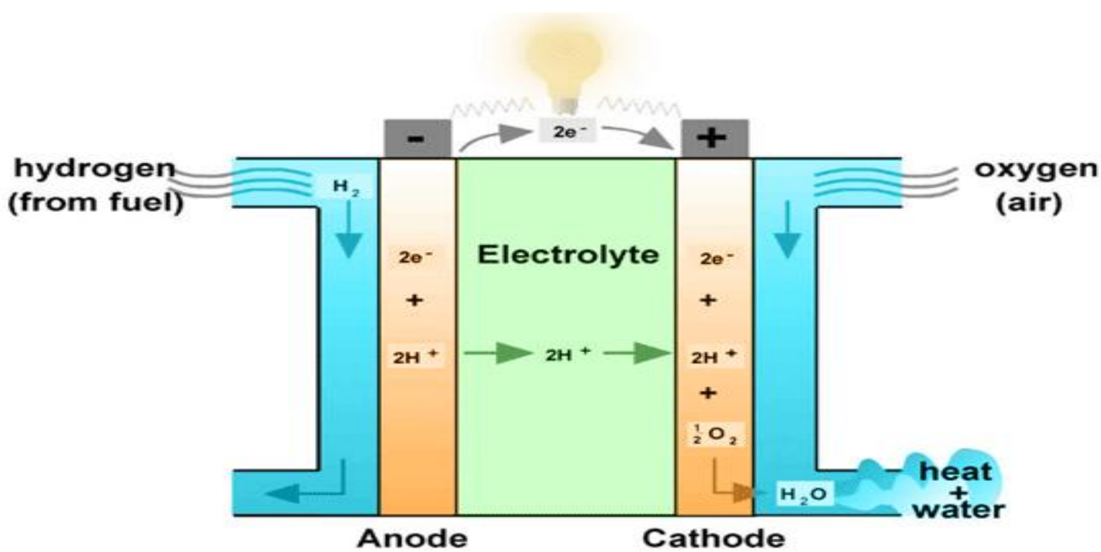


Figure 19-4: Fuel Cell Layout, World Fuel Cell Council, 2013 [29]

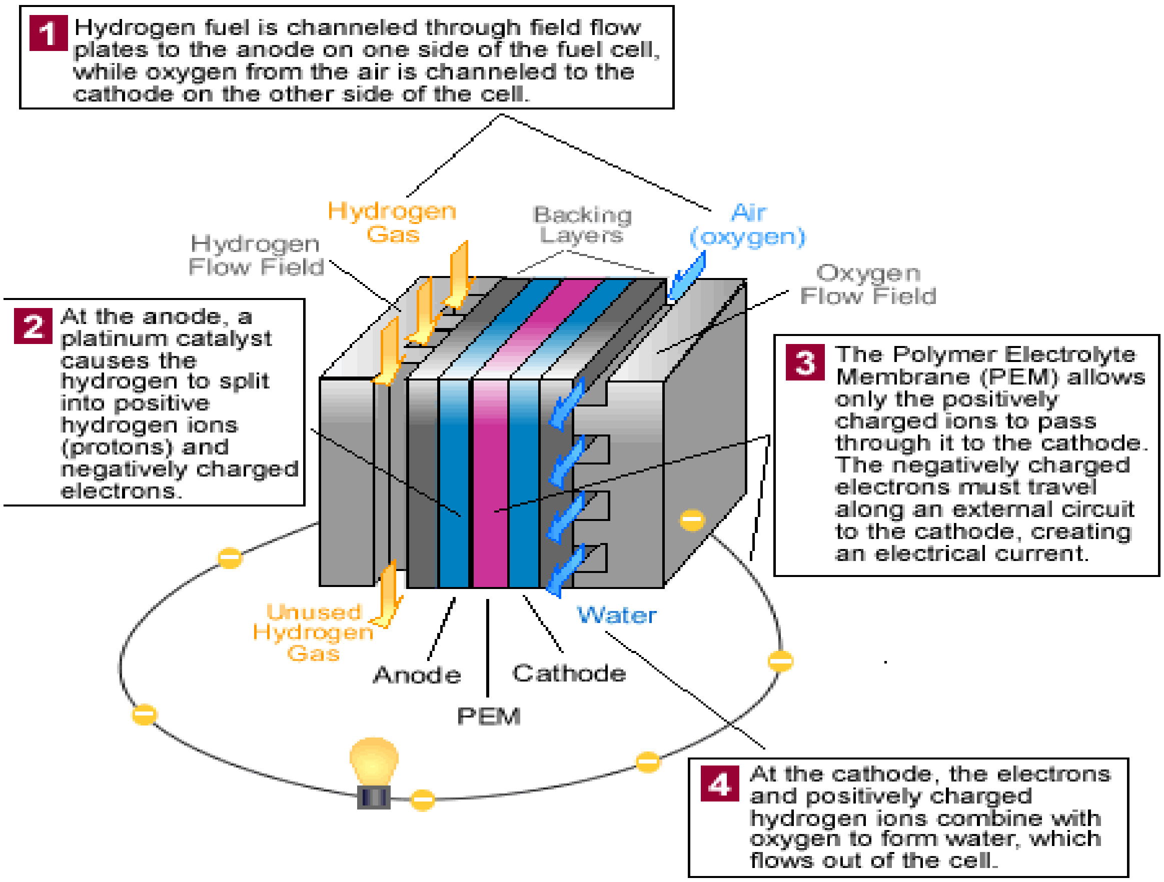


Figure 20-4: Fuel Cell, U.S Department of Energy, 2015 [30]

Below is a picture of Honda FCX Clarity model (figure 21-4). This car works on exactly the same principle mentioned in this chapter. It is worth mentioning that this car is mass produced and it had high sale in Japan and California.

FCV like Honda model below is driven like any conventional automatic car. Like electric car its gearbox has only one gear so it does not come with manual gearbox. It is refueled like conventional car on a filling station. Only difference is leaver on a filling hose which needs to be pressed for safety reasons so high compressed hydrogen would not escape.

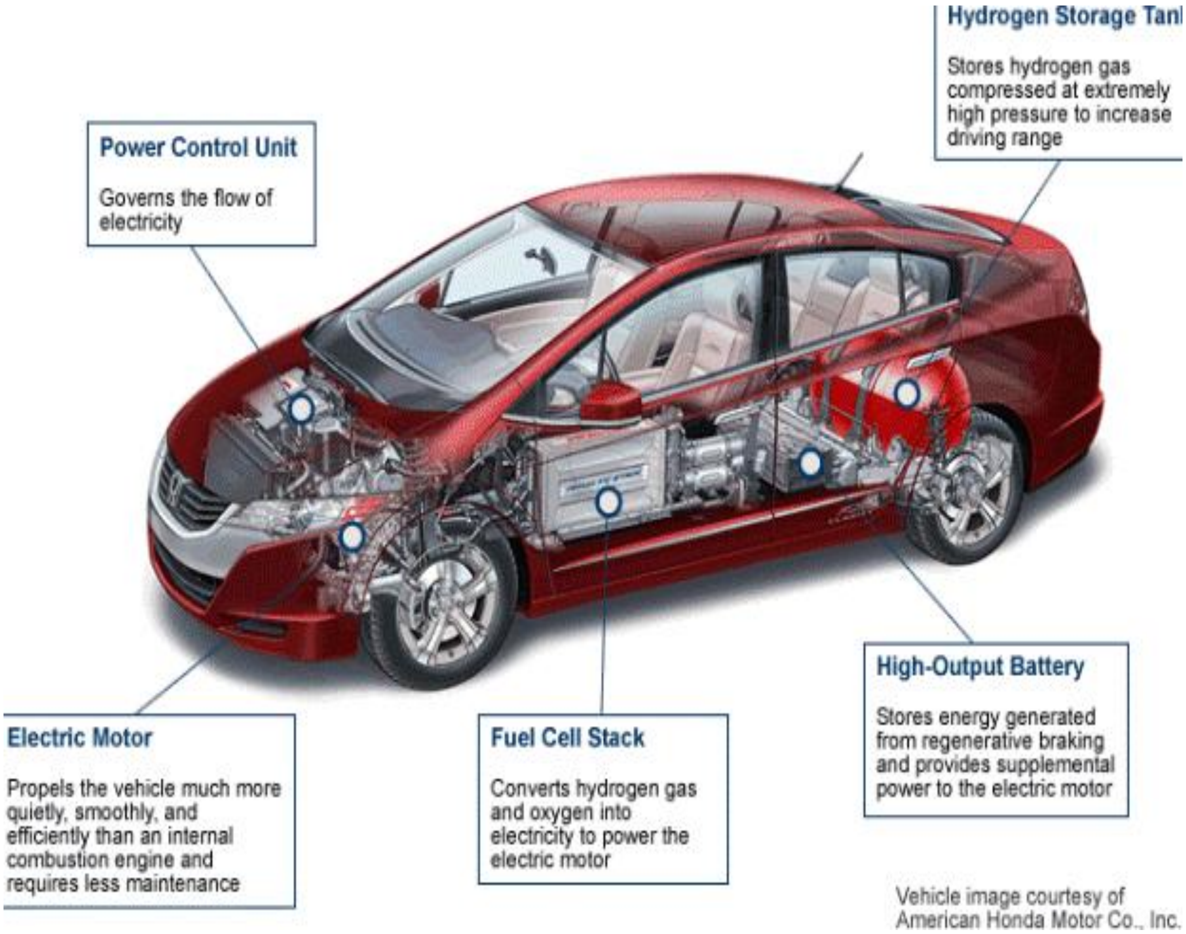


Figure 21-4: Honda FCX Clarity, UCC, 2012 [31]

Maintenance of this car is even simpler than conventional car and electric car as well. Giving the fact that electric engine has only one moving part virtually no maintenance is necessary. Also FCV uses no batteries so there is no need for replacing them.

Technical limitations are in small numbers, especially when only technology itself is analyzed. However, most significant one is necessity to replace entirely (most likely in not too distant future) conventional car production which involves producing: engines, gearboxes, exhaust and many other parts.

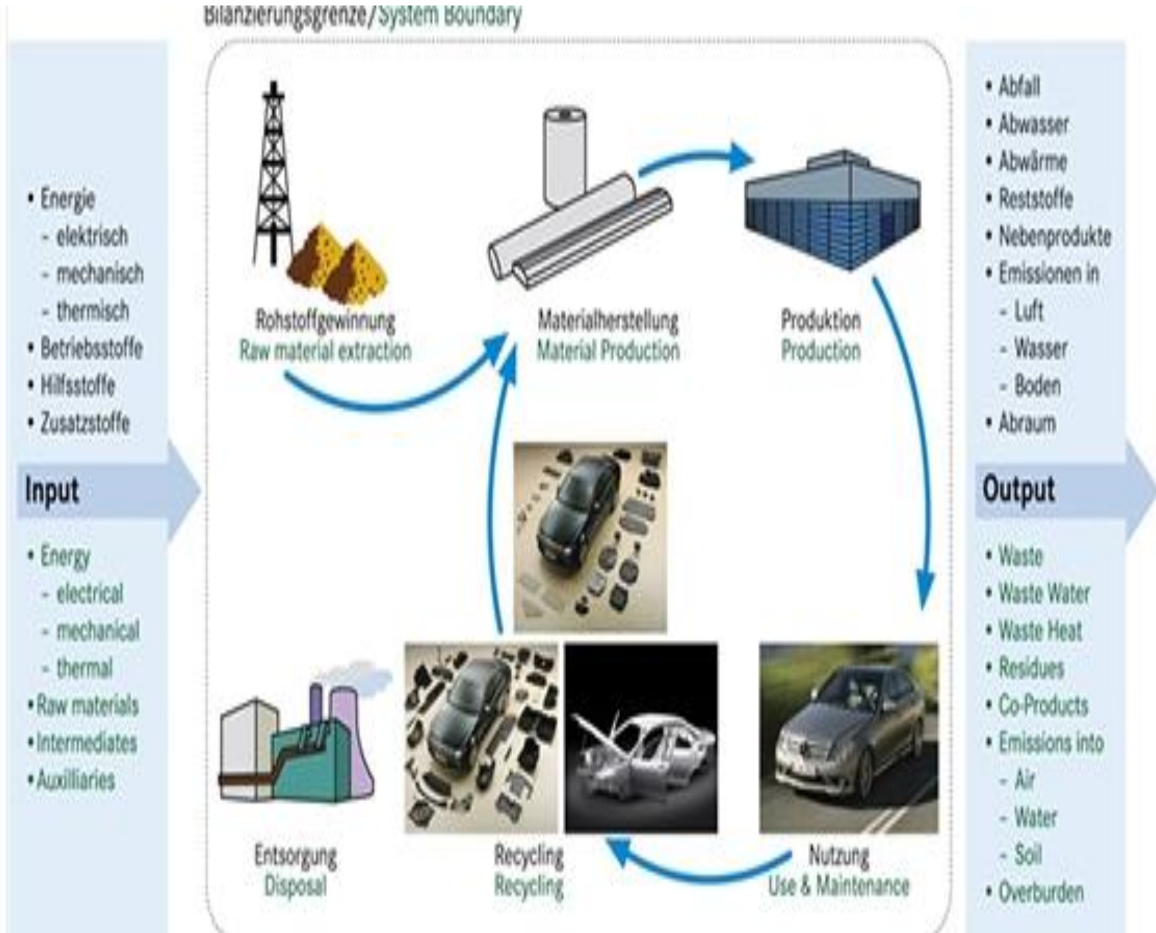


Figure 22-4: Inputs and Outputs of Fuel Cell production, Fuel Cell e-mobility, 2012 [32]

Environmental limitations concern fuel cell or its production. How much pollution does it create? On the figure 22-4 Life Cycle assessment is shown. It can be seen that production of Fuel cells does create air, soil and water pollution. However, production of any goods acquires energy, materials and it produces pollution. Furthermore, this process is far less complex and needs less energy (especially oil) and emits less CO_2 compared to Oil production process shown on the figure 17-4.

Economic limitations are caused mostly because of the economies-of-scale. Toyota's FCV costs around 40.000 euro, for instance. In the same price range there are many other models which come with more luxury and better performance. Obviously, fuel cell system influences the price significantly.

What is more, price of hydrogen is the same as it is for the conversion technology and same limitation for this technology as well. Price of hydrogen fuel and fuel cell system need to be reduced pricewise in order to make this technology economically competitive.

Technical potentials - Electric engine is second important difference next to fuel cell compared to conversion technology. Reason for choosing electric engine for hydrogen implementation is its efficiency. Furthermore, combining electric engine efficiency with calorific value of hydrogen which is 180,40 MJ/kg (Wikipedia), makes this technology from technical aspect much more appealing. As a comparison, diesel fuel has 44,80 MJ/kg.

However, unlike electric cars range of fuel cell car is limited to the size of the fuel tank not the batteries. Taking in consideration calorific value of hydrogen and average fuel tank capacity (around 60 l) and efficiency of electric motor, range is on average 3-5 times higher than electric car's. Despite having to change current car production radically there are certain advantages in that process. Fuel cell car come with fewer parts than conventional car. Thus it is more simple and easier to produce.

Environmental potentials of this technology are many. As with conversion technology CO_2 emission is 0. Another similarity and potential is possibility of using current infrastructure (petrol station) with modifications only. That means that less energy or CO_2 is necessary for construction.

Next is usage of electric engine. With its efficiency transport needs can be fulfilled with less fuel than it is the case with conversion technology for instance. Production of a car with a fuel cell system means producing car which is simpler than conventional car. That means fewer parts are necessary for its production and that means more environmental friendly life cycle.

Economic potentials of FCV definitely exist. Due to the fact that FCV has electric engine rather than conventional one it needs no maintenance. Thus, running costs are virtually 0. As it was mentioned the combination of calorific value of hydrogen combined to efficiency of electric engine is not only technical or environmental advantage but financial one as well.

1 kg of hydrogen costs around 5 € in California for instance [33]. 1 kg of hydrogen is enough for 100 km range. It means that FCV is more efficient than any other fuel consuming engine and thus the one with the lowest fuel consumption.

5 Examples of Hydrogen implementation

This chapter is dedicated to giving successful examples of existing and operating hydrogen implementation models. These models refer to:

- Legal (Country) infrastructure,
- Filling infrastructure,
- Hydrogen production facilities,
- Existing hydrogen car models,
- Est.

This is perhaps the most important chapter because its goal is to present real situation in auto industry when it comes to hydrogen and to present successful examples of how hydrogen can be implemented in auto industry in certain country.

This chapter is also very important because it will give the base for extracting conclusions in Chapter 5 and give answers what is necessary to implement hydrogen in economically competitive way while preserving environment.

5.1 Legal infrastructure

In this chapter examples will be given on how certain (ecologically aware) countries approach transport problems and what are potential duties of governments in order to successfully implement hydrogen technologies or to create sustainable transport. Certain countries in the World are more advanced in hydrogen implementation than others for a certain reason/reasons. On one hand, technological level of a country is the main reason. But on the other hand what is the case of equally technologically and economy developed countries and their differences in levels of hydrogen implementation.

For instance, question can be asked why California or Japan is more successful than Great Britain? Or one can also ask why California is the most advanced country in USA in hydrogen development and implementation? The answer is simple. Government policy directed in a way of supporting implementation of hydrogen by legal, political and financial measures to companies, universities specialized in the area of hydrogen development and implementation.

Since California is probably most advance country in the World in hydrogen implementation steps of California Government will be taken in consideration for this chapter. Below are tables 7-5 and 8-5 which are acquired from California's Energy department. As it can be concluded from the tables from California's Government has made progressive political, legal and financial climate in order to facilitate hydrogen implementation on all fields: R&D (Research and development), production, filling infrastructure and vehicles. What is more, California has been going in this direction for around 10 years. Based on the table 8-5 it can be concluded that majority of Californian Government funds go to electric drive development.

Table 7-5: Funding of Hydrogen Implementation in California, EPA, 2013 [34]

CALIFORNIA ENERGY COMMISSION

ARFVTP Funding Summary: 2009-13

As of June 30, 2013

2009 – 2013 Alternative Vehicle, Fuel & Infrastructure Investments

Investment Areas	Funding Amount ($ millions)	Percent of Total (%)	Number of Awards
Electric Drive	135.4	33	80
Biofuels	127.6	31	47
Natural Gas	62.8	15	51
Hydrogen	43.3	11	10
Workforce Development	23.3	6	30
Market and Program Development	17.3	4	15
Total	409.6	100	233

CALIFORNIA ENERGY COMMISSION

AB 118 Funding and Objectives

- Invest in a **portfolio** of alternative low-carbon and renewable fuels and advanced vehicle technologies in California to help meet our energy, environmental, and economic goals.
- Alternative fuel production, distribution and dispensing
- Alternative technology vehicle development and manufacturing for trucks and light duty vehicles
  - (EVs, CNG/LNG, Fuel Cell, Flex Fuel)
- Workforce training
- Environmental, market and technology assessments
- Leveraging Private Sector Investments

Figure 23-5: California's Funding and Objectives, EPA, 2013 [35]

Figure 23-5 states that objectives of Californian Government are directed towards development of renewable in the future. The most important objective based on the figure 23-5 is alternative fuel production, distribution and dispensing.

Table 8-5: California's Final Investment Plan concerning Hydrogen implementation, EPA, 2013-2014 [36]

CALIFORNIA ENERGY COMMISSION

2013-14 Final Investment Plan

	Project/Activity	Approved Funding FY 2013-2014 (Millions)
Alternative Fuel Production	Biofuel Production and Supply	$23
Alternative Fuel Infrastructure	Electric Charging Infrastructure	$7
	Hydrogen Fueling Infrastructure	$20
	Natural Gas Fueling Infrastructure	$1.5
Alternative Fuel and Advanced Technology Vehicles	Natural Gas Vehicle Incentives	$12
	Light-Duty PEV Incentives	$5
	Medium- and Heavy-Duty Advanced Vehicle Technology Demonstration	$15
Emerging Opportunities	Emerging Opportunities	$4
Manufacturing	Manufacturing Facilities, Equipment and Working Capital	$5
Workforce Development and Training	Workforce Development and Training Agreements	$2
Market and Program Development	Regional Alternative Fuel Readiness and Planning	$3.5
	Centers for Alternative Fuels and Advanced Vehicles	$2
	Total Available	**$100**

It is obvious what is necessary to implement hydrogen and make it economically competitive in close future in certain country and in the end worldwide:

- Government policy directed to renewables but on a much higher level than in most developed countries are doing at the moment. In other words, governments actions have to be much more progressive and dynamic even in most countries which are considered as such progressive and dynamic in developing and implementing renewables,

- Providing market profitable climate for all aspects of hydrogen technology starting from fuel to filling infrastructure and all up to vehicles. This climate can be built via government's programs and concrete actions via subsidies, financial support, legal support, tax support,

- Developing public awareness regarding climate change, renewables, transport problems,

- Investing in R&D for domestic companies and universities in this field.

5.2 Filling infrastructure

At the moment filling infrastructure, or lack of it, presents huge problem for further expansion of hydrogen technology. This is not technical problem. As it was mentioned in Chapters 4.3 and 4.4 upgrading existing infrastructure with additionally filling station for hydrogen is all that is necessary. This chapter presents analyses and comparison of Europe and California and their current progress with implementation of hydrogen fuel stations.

Lack of filling infrastructure does not only cause limitations for future implementation and expansion of hydrogen but it also discourages potential buyers of hydrogen cars giving the fact that they can't use them day-to-day.

Figure 24-5: OMW's Hydrogen Filling Station, OMV 2015 [37]

Figure 25-5: Shell Hydrogen Filling Station in California. MDA, 2012 [38]

This is, therefore, very urgent issue to be solved. In the chapter pictures are shown of existing and planned filling stations in Austria, Germany and California. On the figure 24-5 OMV hydrogen station is shown. This hydrogen and petrol and diesel filling station is in Vienna and it is only filling station in Austria which offers hydrogen fuel. On the other hand it is first commercial filling station in Austria and OMV plans to build many more in not only Austria but across Europe as well.

OMV has also announced that 400 Hydrogen stations will be constructed in Germany in next years. There is not much to say what to solve with filling stations. They simply need to be constructed. Figure 26-5 shows cluster of hydrogen filling stations in California. It is worth mentioning that many of stations which are marked as “in development” are constructed by now. Figure 28-5 shows situation in Europe regarding filling infrastructure.

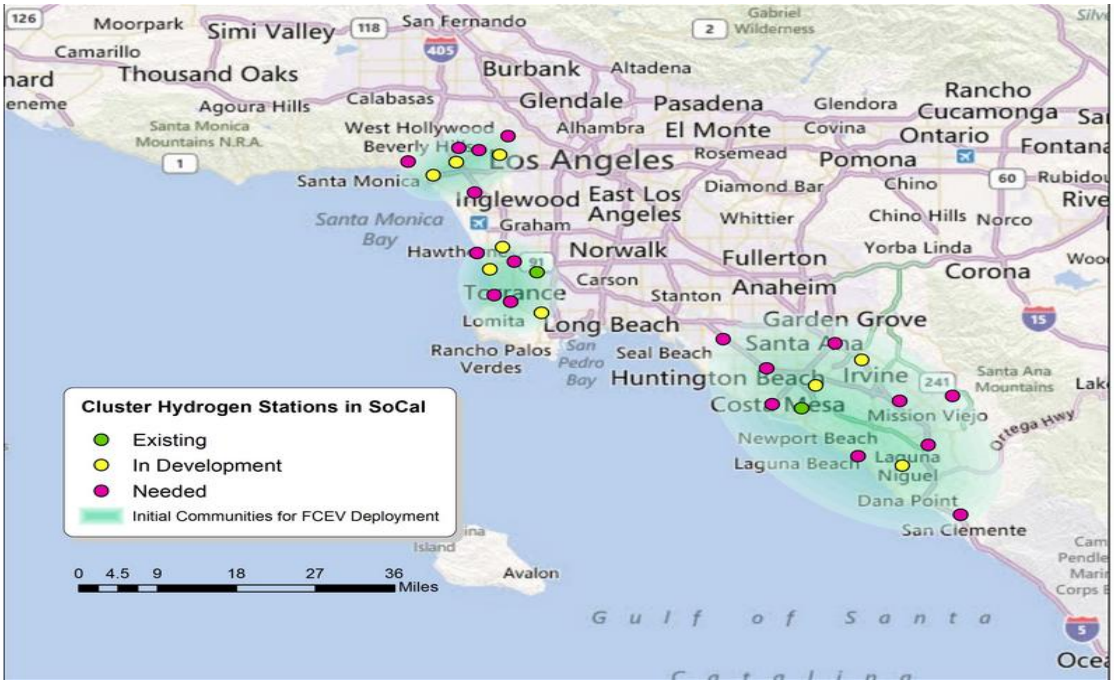


Figure 26-5: Hydrogen Filling stations in California [39]

Figure 27-5: Hydrogen Filling Stations in Europe, Fuel Cell Works, 2014 [40]

5.3 Hydrogen production facilities

This chapter is similar to the chapter before – 5.5. Only in this case, hydrogen production infrastructure is analysed. In Austria, the first one was opened in 2012; more are planned in Austria and abroad. There are not many differences from fueling with conventional fuels. Hydrogen even offers some advantages over diesel and gasoline.

Figure 28-5: OMV Refunery – Schwechat, OMV, 2015 [41]

In 2012 OMV opened the first publicly accessible hydrogen filling station in Austria. More hydrogen filling stations are planned for 2015–2017 in Austria and Germany. OMV's partner in Germany is the Initiative H2 Mobility, which plans on building around 400 public hydrogen filling stations by 2023. There are not many differences from conventional filling stations for customers: cars are filled with kilos instead of liters and the hydrogen is stored on site.

The hydrogen is compressed and fed into the pressure tank of the vehicle through a nozzle. This is a quick process and over 500 km can be driven on a full tank. A major advantage over diesel and gasoline is definitely that refueling with hydrogen is completely odorless and clean.

The greatest challenges in terms of hydrogen mobility are currently in cutting costs of equipment, service, and maintenance as well as achieving the perfect reliability. Because in the long term, only solutions that are reliable and competitive will be accepted by consumers.

In 2015 the first fuel cell powered hydrogen cars will come off the production line.

Figure 29-5: Toyota's Stationary Fuel Cell, California Hydrogen Business Council, 2013 [42]

The 1.1 MW Fuel Cell System at Toyota's Sales and Marketing Headquarters began operation in October of 2012 and is powered by Ballard's proprietary proton exchange membrane fuel cells. Ballard's ClearGen™ system enables Toyota to satisfy peak and mid-peak power needs using electricity from either the clean energy fuel cell system or from the power grid. Hydrogen fuel is delivered directly to the system by means of an existing pipeline, which also supplies a local hydrogen fueling station [43].

Figure 30-5: HECA Power Project, Energy Gov, 2013 [44]

On November 6, 2009, DOE announced the signing of a “Cooperative Agreement” with Hydrogen Energy California, LLC (HECA) under the Clean Coal Power Initiative (CCPI) Round 3 program. With additional funding provided under the Recovery Act, the total DOE funding potential is $354 million.

Along with private capital cost sharing, the HECA Commercial Demonstration of Advanced IGCC with Full Carbon Capture (HECA CCS) project will demonstrate an advanced coal-fired generating plant that co-produces electricity and fertilizer products. SCS Energy acquired the HECA power project from its original developers British Petroleum (BP) and Rio Tinto in May 2011.

The HECA CCS project will employ integrated gasification combined cycle (IGCC) technology to nominally generate up to 400 MWe (gross) of electricity and produce approximately one million tons per year of fertilizer using a 75 percent sub-bituminous coal and 25 percent petroleum coke fuel blend. The CO2 off-take agreement contemplated by HECA will enable the capture of CO2 at a rate of approximately 2.6 million tonnes per year. The captured CO2 will be transported via pipeline to the Elk Hills oil field, approximately four miles from the power plant, for use in enhanced oil recovery (EOR).

The HECA CCS project will utilize the Mitsubishi Heavy Industry (MHI) two-stage oxygen-blown gasification technology and combined cycle power block. A Rectisol® acid gas removal system will be employed to achieve the intended CO2 capture efficiency. Water quality and availability issues are addressed by utilizing local brackish groundwater treated on-site to meet all industrial process water requirements. The brackish groundwater will be supplied from the Buena Vista Water Storage District (BVWSD), which is a local water district with some groundwater sources not suitable for agricultural use.

The project will also incorporate a Zero Liquid Discharge (ZLD) system. All project wastewater, including wastewater generated from the IGCC, raw water treatment, and cooling tower will be directed to ZLD system(s) with the recovered water recycled for reuse in the process. This further reduces the water demands of the project.

The project will be located in Kern County, California. Current participants include: MHI; Fluor; the Japanese Bank of International Cooperation; and, Societe Gener [45].

5.4 Existing hydrogen car models

Several hydrogen cars in the last 10 years have proven to be successful - some only technically, some technically and financially. The focus of this chapter is presenting several significant HC produced in the last ten years or so. The most important is that leading car manufacturers were involved in developing and mass producing these cars and not only focusing on prototypes.

In this chapter several hydrogen car models will be shown in calculation table. Figure 31-5 shows comparison of 3 different hydrogen car models. The first one – BMW 7 series Hydrogen uses CT. The main disadvantage is that BMW implemented CT in their most expensive model. Despite that, rage, fuel economy and maintenance are economically competitive.

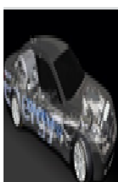
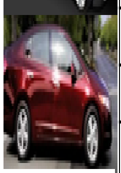
	Car type	Price	O&M	Power output	CO2 emission	Production period	Range	Fuel economy
								
	Conversion technology	90.000,00	1.100 €	250 hp	0	2005-2007	1000 km	8 l /100 km
	BMW 7 Hydrogen							
								
	Fuel Cell Vehicle	40.000,00	350 €	130 hp	0	2008-2015	372 km	4,6 l/ 100 km
	Honda FCX							
								
	Fuel Cell Vehicle	40.000,00	300 €	152 hp	0	2014-	502 km	3,6 l/100 km
	Toyota Mirai							

Figure 31-5: Price comparison of CT and FCV cars (BMW, Honda FCX, Toyota Mirai), Own creation, 2015 [46]

BMW 7 series Hydrogen model produced between 2005 and 2007. It is the first production vehicle to use hydrogen fuel. For reasons of scarce filling infrastructure it had petrol tank as well so it could run on petrol or hydrogen. This vehicle uses conversion technology.

Second car in the figure 32-5 is Honda FCX Clarity. It may be one of most important cars for the future of automobiles giving the fact that it is first Fuel Cell production car. It uses Fuel Cell technology and it is being produced since 2008. Honda claims that 2015 is the last year of this model's production. Majority of FCX was sold in Japan and California. It has competitive price compared to Toyota Prius for instance. Being a FCV it has decent range and low maintenance costs. Last car is Toyota FCV model which was launched in 2014. Toyota claims that FCV technology developed for this vehicle is the technology for next 100 years. Such statement from one of the leading car manufacturers has to be taken seriously. This car is very similar to Honda FCX but it is newer and more sophisticated FC car. Therefore, it has better performance, lower maintenance costs and it consumes least fuel of the tree cars.

It can be concluded from figure 31-5 that even if CT is implemented in less expensive car (BMW 3 series rather than 7 series, for instance) it would have higher price and operational competitiveness but it could newer reach efficiency and low fuel consumption of FCV.

6 Summary and Conclusions

This chapter is dedicated to answering the question if hydrogen is solution for the future of the car industry and what steps are necessary to be made in order to facilitate implementation of this technology and above of all to make it economically competitive.

Also, conclusions will be drawn out of analyses carried out in chapter 3 and chapter 5. After presenting technical description of mainstream technologies – Hybrid, Electric, Biofuels and Hydrogen cars and presenting and analyzing their limitations and potentials conclusion can be given which one should be the solution for the future of auto industry.

However, before arguments and facts are given for Hydrogen it is necessary to reflect on limitations and disadvantages of Hybrid, Electric and BF (Biofuels) cars. Also, it is important to mention that arguments regarding implementation will be presented for Hydrogen only.

The reason is simple. If any technology is not sustainable, than it makes little difference if it is economically competitive or not. Therefore, only sustainability aspects will be covered in this chapter for abovementioned technologies.

HC or Hybrid technology has three major disadvantages. First one is the fact that it uses two or more engines. More engines means more energy needed to produce them. Second disadvantage is that one of these engines uses petrol or a diesel fuel. Lastly, Lithium Ion batteries or pollution caused by their production is huge and unsustainable.

EC have two major sustainability disadvantages or limitations. First one is shared with Hybrid technology and it is Lithium Ion batteries. Second one is electricity source. It is well known that electricity production relies on nonrenewable, fossil fuels. Only solution is transition on renewable sources. There are two major limitations with this solution.

Firstly, this process would take very long amount of time. Secondly, cars are not only factor in the transport structure. Solution for car industry would potentially be the solution for other types of transport which use internal combustion engines.

Biofuels technology shares some of its advantages with Hydrogen Conversion technology. However, it has two major limitations which make it unsustainable. Firstly, BF does create pollution. Weather it is CO2 or soil pollution or if it is low or not it is effectively pollution. Also, it is quite controversial if there are enough material sources necessary for production of BF so it could fulfill current transport demand.

Based on analyses conducted throughout this work it can be concluded that **Hydrogen** has the potential to be solution of future of auto industry. Despite having certain disadvantages it is still the most sustainable one.

The very first mentioning of hydrogen causes discussions that it is too expensive to produce. One of the first pictures in this work to overthrow this claim was oil cradle-to-grave (CTG) production process. Also, one of most mentioned expression in the work was the **economies-of-scale** which is sufficient and necessary to make any technology or product economically competitive.

Before one relies on the EOS it is crucial that one provides conditions in order expect the effects of it. Below is the figure 32-6 which suggests how Hydrogen implementation in the future should look like. It is shown on the figure 33-6 that all electricity sources are renewable. There are no fossil or conventional ways of producing electricity. If such implementation would be carried out Hydrogen would then be truly sustainable. If hydrogen or any other auto technology (electricity for instance) uses unsustainable production methods it makes no difference which CO2 emission car has.

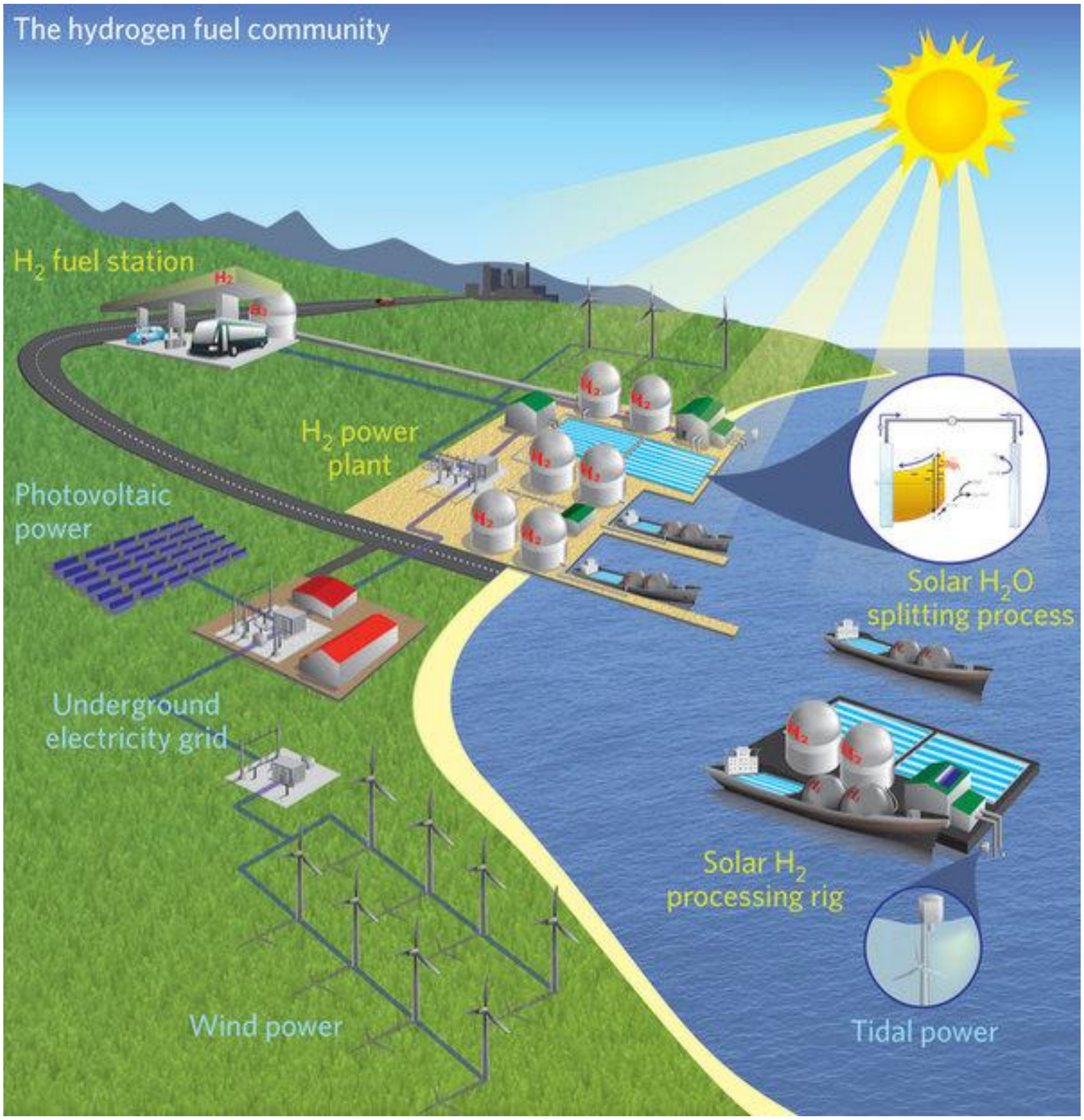


Figure 32-6: Hydrogen Fuel Community, Nature, 2012 [47]

Figure 32-6 shows technical and environmental sustainability also. Future of renewables and therefore transport as well probably relies on technological mix. As it is shown on the picture all alternative technologies are used for production of hydrogen.

Probably all technologies will be used in the future and we will not rely only on one technology. Similar case might be with transport as well. However, combination of electric motor with hydrogen appears to be most sustainable and most efficient. Electric motor can be sustainable only without lithium ion batteries. Hydrogen is the most common element in the universe.

Electric engine is the most efficient engine. Hydrogen fuel has the highest calorific value. Running such car is very cheap. What is more, running electric motor needs practically no maintenance. Also, production of electric motor requires fewer parts for production and almost no for maintenance. This means less energy is necessary for production and running FCV. Therefore, conclusion of this work and my personal one is that **Fuel Cell Car** is the solution of future auto industry.

All abovementioned statements suggest that CT – Conversion technology is less efficient and sustainable than FC. Petrol engine can't compete with electric engine efficiency. However, CT should be used before FCV is fully implemented. Huge number of cars running on hydrogen instead on petrol would be far more environmentally friendly. Plus it could boost EOS that hydrogen fuel needs so much.

From efficiency point of view, economic and environmental aspect and consumer aspect, H2 in FCV implementation fulfills all of them. However, position of Oil companies, car manufacturers and governments needs to be considered also. Without them, implementation of any auto technology is impossible.

Oil companies, car manufacturers and governments are aware that one day oil will run out. That day is not too far away. In order to continue with their businesses they need to switch to new fuel sooner or later. Will Hydrogen be their choice? It is difficult to say. Based on this work hydrogen has the greatest potential.

As it was said in the chapter 5.1, there are several potential steps in order to facilitate implementation of Hydrogen fuel and technology:

- Government policy directed to implementation and development of Hydrogen fuel and technologies. Based on example of California, for instance, it is clear that government of certain country has to take certain actions in order to implement technology, product or behavior in its country.

- Suitable market climate. In order to bring certain products or services in any market it is critical that companies which provide products or services have a chance in creating profit while conducting such activities. Government has to influence to certain extent. However, companies have to find opportunities in new markets.

- Rising public awareness. It is crucial that public (consumers) is aware of climate changes and importance of transport sector. This is something that both governments and companies have to do. It can be done by advertising, public meetings, scientific programs, est.

- Stimulation of R&D both in companies and universities. R&D is critical for development and potential implementation of any technology. Via R&D hydrogen technology can be more economically competitive during passage of time.

After all abovementioned suggestions activities of hydrogen implementation have hierarchy which looks like: government ->companies -> public.

ADDENDUMS

Table 9-7: Economic comparison of all analyzed technologies of this work and CO2 emission, Own creation, 2015

Car	Technology	Price	km/y	Maintenance costs €/year	Fuel costs	Total investment	CO2 emission (g/km)
VW Golf TDI	Turbodiesel	23.000,00	20.000,00	700,00	1.000,00	24.700,00	125,00
Toyota Prius	Hybrid electric	35.000,00	20.000,00	1.000,00	1.400,00	37.400,00	90,00
Nissan Leaf	Electric Battery	27.000,00	20.000,00	300,00	700,00	28.000,00	0,00
VW Golf Biodiesel	Biodiesel conversion	25.000,00	20.000,00	750,00	1.200,00	26.950,00	110,00
VW CT	Conversion Technology	26.000,00	20.000,00	800,00	2.000,00	28.800,00	0,00
Toyota Mirai	FCV	38.000,00	20.000,00	300,00	800,00	39.100,00	0,00

Table 10-7: Alternative and conventional fuels comparison

Fuel	Energy density	CO2 g/100km	Price €/100 km	Sustainability	Applicability	Availability
Diesel	45,4	150	9	Not sustainable	Absolute	next 50 years
Petrol	44,4	120	12	Not sustainable	Absolute	next 50 years
Biodiesel	40,05	34	15	Partly	Absolute	max 30 % od World demand
Biomethanol	19,9	21	18	Partly	Absolute	max 20 % od World demand
Electricity	/	0	3	Only if it is produced by renewables	Absolute	Indefinite
Hydrogen	142	0	4	Sustainable	Absolute	Indefinite

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