

The Fundamentals to Fuel the Future

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Abstract

The following report is a comparison study of the alternative for the future automobile sector, where the fuels in focus are bioethanol, bio gas, electrical vehicles and hydrogen gas. Through this comparison one or multiple of fuels will be decided to be the better solution for a future without greenhouse emissions. Since transportation one of the major areas of polluting an instant change has to be made sooner than later. The main purpose is to give people an understanding of the fuels and then give simple data to interpret. By comparing the vehicle performances and society integration for each fuel there will be many different perspective to analyze and take into consideration.

The structure of the comparison is divided into two major sections, one that is based on how the fuels interact with the vehicle. Categories are created within the sections, where Content of Energy tells the potential of energy extraction and Fuel Efficiency shows consumption of energy and operational cost. To this category does the WTW expression belong as well for specification of the energy losses. A final performance category in acceleration gives an indication of how attractive the fuel might be. Following the performance section, the society integration focuses more on the big picture, such as investment cost and convenience.

First of all regarding the performance of the fuel, after summarizing the categories Fuel Cell H₂ was the number one choice. As the runner-up was the electrical vehicle and worst case was bio gas. Secondly, the society integration based on cost and convenience, the electric vehicle had an estimated investment cost of 41,300 MSEK to supply Sweden. To combine these two major areas the conclusion leads to an announcement of EV:s as the best option out of the studied. As a consequence of the simplicity to use electric power without any direct emissions from the vehicle itself, the EV:s are the most convenient vehicle fleet to establish.

This would be with conditions that are based on today's advances in technology and knowledge about possible developments over time. The conclusion is open for the unknown and eventually correct itself to upcoming fuels. But as for now, the important part of this discussion is to make a move away from the gasoline-dependent society and give the future generations better conditions.

Sammanfattning

Följande rapport är en jämförelsestudie av alternativa bränslen för framtidens fordonsindustri, där de inblandade bränslena är bioetanol, biogas, eldrift och vätgas. Med denna jämförelse ska ett eller flera bränslen beslutas vara det mer lovande till en framtid fritt från växthusgaser. Eftersom transportsektorn har en stor bidragande faktor till global förorening behövs en förändring göras inom en snar framtid. Huvudstyftet med denna rapport är att ge folk en generell överblick av vilka bränslen som finns tillgängliga och hur de står sig mot varandra. Mer i detalj kommer bilars prestanda och samhällsintegrering att jämföras för varje bränsle, för att sedan analyseras.

Som nämnt ovan kommer jämförelsen vara indelad i två sektioner, en där prestandan mäts och en hur enkelt en etablering av bränslet i samhället skulle var. För prestanda kommer delarna att vara energiinnehållet av bränslet och bränsleförbrukning för bilen, där tillhörande kategorin WTW används för mer specifikation av energiförluster. Till sist en kategori som jämförs de olika bränslenas acceleration. På andra sidan jämförelsen kommer samhällsintegreringen bestämmas av etableringskostnad och omställningsmöjlighet.

Efter att ha gått igenom alla kategorier tillhörande prestanda är det bränslecellsbil med vätgas som presterar bäst. Näst bäst blir den elektiska bilen och sämst blir biogasbränslet. Gällande fallet för kostnad och smidighet av samhällsetablering blir det ett klart övertag för eldrivna bilar. En total kostnad på 41,300 MSK skulle krävas för fullskalaig förseelse i Sverige. För att sedan sammanställa det slutgiltiga beslutet från jämförelsen eldrift av fordonsflottan skulle vara det bästa alternativet.

Det slutgiltiga beslutet baseras på den tills idag kända teknonogin och utvecklingen utav denna. Självklart står slutsatsen öppen för uppkommande bränslen som inte i dagsläget har etablerats eller visat likvärdig potential. Huvudmålet med hela diskussionen är att ta några steg ifrån det besninsamhälle som vi lever i idag och på så vis ge framtida generationer bättre förutsättningar.

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Nomenclature

A tabular for the upcoming parameters used throughout the document seen in Table 1.

Table 1: The used variables and constants

Parameters	Explanation
n_{spec}	Specific Vehicle Data, used in Eq. (1)
N	Total Number of Data, used in Eq. (1)
C_{Energy}	Content of Energy, used in Eq (2)
K_{fuel}	Specific Fuel Energy, used in Eq (2)
C_{kg}	2.205 lbs/kg, used in Eq (2)
η_{comb}	Maximum Efficiency for Combustion Engine, used in Eq. (5)
T_{cold}	Initial Cold Reference Temperature [K], used in Eq. (5)
T_{warm}	Warm Reference Temperature [K], used in Eq. (5)

Abbreviations

Table 2: Explanation of upcoming abbreviations

Abbreviation	Explanation
E85	Bioethanol containing 85% alcohol
Hydrous Ethanol	Water/Ethanol mixture fuel (Wet Ethanol)
Anhydrous Ethanol	Water/Ethanol, less than 1% water
CNG	Compressed Natural Gas
CBG	Compressed Bio Gas
CoE	Content of Energy
FE	Fuel Efficiency
SMR	Steam Methane Reforming
STCH	Solar Thermochemical Hydrogen
PEM	Polymer Electrolyte Membrane
H2ICE	Hydrogen Gas Internal Combustion Engine
WREN	The World Renewable Energy Network
BLDC Motor	Brushless Direct Current Motor
EV	Electrical Vehicle
FC	Fuel Cell Electrical Vehicle
TWh	Tera Watt Hours (10^{12}) Energy
WTW	Well to Wheels
WTT	Well to Tank
TTW	Tank to Wheels
RUS	Regional Utvecklings Samverkan
R.A.M.	Required Annual Mass
MSEK	Million Swedish Krona
SPBI	Svenska Petroleum och Biodrivmedels Institutet
gge	Gallon of Gasoline Equivalent
Acc.	Acceleration

1 Introduction

Wherever you go in the world today there is a necessity of transportation to get from one place to another. It could be by car, bus, train, boat or airplane, all depending on the distance to your final destination. In the beginning of the 20th-century people got the independence to go to places whenever they want to. That's where it all started and the car became a part of everyone's daily life. More than a century later there are thousands of car models with different functionalities, which are made for certain applications. As the automobile industry has grown, there can be no doubt that it has had an impact on our way of living and on our consumption natural resources. The major natural resource in focus is oil, that is constantly used as fuel in our everyday driving. The concern is not only regarding the increase in consumption but also the side effects of rising levels of CO_2 in the atmosphere, as everybody knows this will raise the concentration of greenhouse gases, which will contribute to an enhanced greenhouse effect.

During the 21st century this has drawn many scientists attention to find better energy sources for a more sustainable automobile sector. Many options have been developed over the past years, even though no major change has been made yet. The gasoline industry is standing strong and needs to be subjected to other fuels if anything is going to happen. To raise people's awareness that changes have to be made they need to be told what they should do based on solid statistics and proof. This can only be done by comparing what options available today and what improvements can be expected in the future. By contrasting data people can see what would suit their application of the vehicle. The adjustment to better resource usage cannot only be made by the costumers but has to be addressed by the society as a whole. It has to be planned well with big investments to see what would benefit the society best economically and sustainably. When these two major areas have been aligned change might take place, but there is a long way to go until that.

Therefore, this paper will be an attempt to clarify some of the questions that appears when trying to understand the automotive market. The focus will be to define some of the existing vehicle fuels, which also have a potential to become green fuels. In other words, the fuels can be produced and consumed in such a way that they will not aggravate the impact of the greenhouse effect. There are already many scientific studies out there that will be analyzed and compiled with others. By comparing these fuels side by side a clearer picture of the current situation will be obtained. By the end of the comparison this can be seen as a guideline to follow or go even further into the subject for more exact data and understanding.

1.1 Problem Specifications

As the introduction and the title declare the main statement for this report will be how mankind should choose their future source of fuel? The future does, in fact, seem rather threatening if no major change of the current situation is done. Between all the existing options, the central difficulty is to decide which might be the most beneficial to costumers and for the society as a whole?

1.2 Limitation & Assumptions

For this analysis in the field of automobile simplifications have to be made to minimize the impact of non-vital factors. In the comparison, although the vehicles are different, parameters in the form of drive train resistances, weight load and the driver's way of driving are similar. Since this is a research including the impact on our climate from the actual vehicle there has to be an assumption that all the fuel is supplied from sustainable sources. As for the case of electrical charging, the assumption is that unlimited sustainable power supply is available. As for fuel distribution, the cost of transportation from source to supply station will not be examined. This is to not dig too deep into those businesses, but for a full-scale research this has to be taken into consideration. When comparing fuels, especially going between gas and liquid fuels, a common term called gallons of gasoline equivalent is used. The inclusion of this measure felt unnecessary as the subject of this paper does not only focus on chemical based fuels, but includes electrical powered vehicle as well. When values in ranges are displayed the maximum value is used in calculations or comparisons to overestimate the final value. This to compensate some lost extra expenditures for the financial part. When losses for each fuel type are compared it is made as an overview, with less focus on the depth. For the society integration Sweden is used as a reference with a vehicle fleet of 6 million. A little bit more than the actual number of vehicles, but could give the wanted overestimation and accounting for a growing population over the years.

2 Background of Subject

2.1 Biological Fueled Vehicles

Biological is the way of producing fuel from above ground natural resources and organisms. By using the word "bio" it claims that combustion of the fuel does not contribute any additional carbon to the carbon cycle. There are multiple ways to create such products, but in this paper the focus will be on bioethanol and bio gas. These are two of the most common bio fuels on the market today. The vehicles that use bioethanol or bio gas have a combustion engine customized for fluid or gas. Even if they are both bio fuels there are differences to be derived.

2.1.1 Bioethanol

Bioethanol is an alcohol produced from trees, plants and cereals, such as corn, potatoes, sugar cane and vegetable waste. When the base product has been chosen it has to go through a process of fermentation, distillation and dehydration to become the liquid bioethanol. One of the essential building blocks in the process is starch that will, when exposed to additional enzymes, turn into the pursued alcohol. The outcome of this production process is the already mention bioethanol and also a co-product called stillage. This is used to create pelleting to feed livestock on farms and thereby a part of the base product has been brought back to its natural cycle. For more clarification of the bioethanol process Figure 1 shows an illustration of the cycle. Finally, the almost pure alcohol is officially ready as the fuel bioethanol. An interesting aspect is how

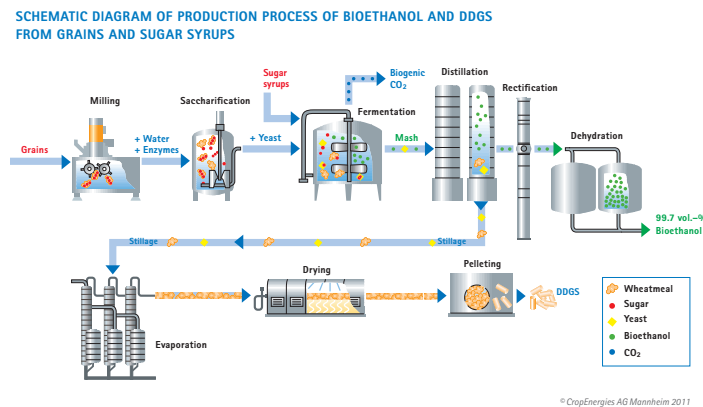


Figure 1: *The illustration of the production process from grains to bioethanol and pelleting, which in this particular case is wheatmeal*

good performance an ethanol-driven car actually has. To be able to determine anything the bioethanol has to be explained a little bit further. Since the fuel is normally mixed with a ratio of one part alcohol and one part gasoline, this will affect the outcome and can be modified for different purposes. Today E85 is the

most common mixture, which translates to that 85% alcohol and 15% gasoline. This is the type of bioethanol this study will focus on. Other types of bioethanol that are used in Brazil is called hydrous and anhydrous ethanol. These instead have a ratio of the domestic produced bioethanol and water, which makes the fuel a non-gasoline mixture [1]. This type of bioethanol will be discussed later on in this study.



Figure 2: *A typical plantation of sugarcane in Brazil for bioethanol production*

According to a study in 2013 made by "International Journal of Ambient Energy" the change in the ratio between the two will change the properties significantly [2]. The octane number will increase if the alcohol is added to the mixture. An octane number defines the fuel's tendency to burn and an increase will make it burn easier and the engine runs smoother. On the other hand, the trade-off is a decrease of vapour pressure and lower heating value. Both of these will have a negative effect regarding the ignition of the car. If a car is used in areas of varying temperatures and altitudes this will become a big issue. The change of lower heat value [MJ/kg] results in less extraction of energy from 1 kg of fuel, which could cause worse fuel economy and shorter range in one liter of bioethanol. The fuel as a whole will be a grown product from nature, which will be used to fuel our vehicles.

2.1.2 Bio gas

The second bio fuel of interest is bio gas, which appears when organic materials are digested. CBG should not be mixed up with natural gas, CNG, which have very much the same properties except for one being a fossil fuel. To maintain the initial focus of the report, CNG will not be discussed since it has not been categorized as a sustainable energy. However, in the case of CBG it has to be kept well isolated from the surroundings since it is a gas. Which is also a necessity for the gas production and is said to be anaerobic for wanted outcome, the example illustrated in Figure 4. The major products that are put into the process are food or sewage waste. The waste is mixed and heated up, where the gas is a rest product of the fermentation that goes on in the tank. As in the case of bioethanol production, more solid materials are also rest-products of the process. These will in the same way be returned to nature and the cycle

of materials as fertilizer or animal bedding. On the other hand, the gas has to go through procedures to reduce secondary unwanted gases to be ready for the consumers. All this can be seen in Figure 3 below.

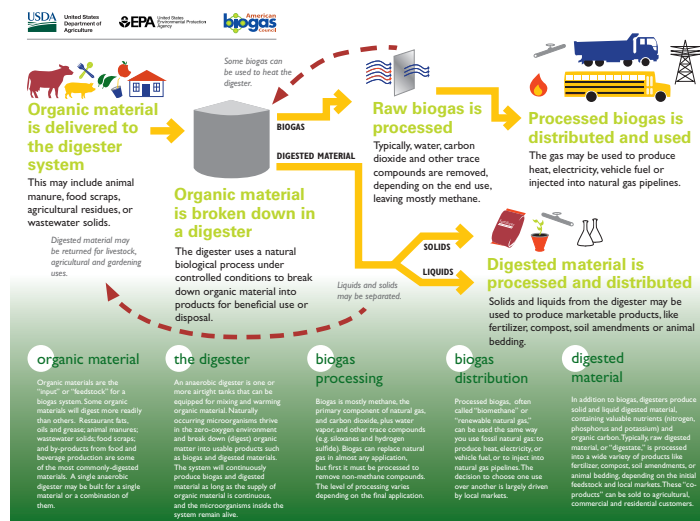


Figure 3: The illustration shows the way from food waste to final products of Bio gas and other marketable products

Moreover, the same situation as for production has to be regarding the consumption of the gas, it has to remain sealed. Within the car the bio gas is contained in pressure tanks with a rate of 200 bars to not escape. That pressure will be regulated before injection into the engine to the optimal level for the system. Then the combustion process is similar to a regular gasoline combustion, with a fuel-air mixture that is injected into the cylinder. Gases like CBG contain a lower amount of energy per mass unit than the same amount of gasoline or bioethanol, such as [kWh/kg]. This has to do with the molecular structure of the gas, but the significant reason is the fact that it is a gas. A gas is less dense, which leads to fewer molecules in the same space and equates to less energy. This is a way to make use of all the waste products that our society produces in order to fuel our vehicles with gas. By looking at the both mentioned bio fuels they are based on similar purpose, but as described the products come from different sources.



Figure 4: *The anaerobe structure of a CBG plant, where the big bubble constructions contains the bio gas*

For these two explained bio fuels, as well for the upcoming fuels, each section will be summarized in a table. The table contains interesting data that is collected for the comparison of each fuel. There are three columns with different categories that correspond to a specific fuel. How these are compiled and calculated will be described in the Comparison Creation in next chapter. As for now, this is just to relate the data to each fuel type. But each category and abbreviation in Table 3 are as follows, CoE is the Content of Energy, F.E stands for Fuel Efficiency and the last column is the acceleration time from 0 to 100 km/h. The data is an average for bio fuel vehicles made by U.S. Department of Energy[3].

Table 3: The properties of the Bio fuel vehicles, where E100 is the pure bioethanol without any additional gasoline. Units can be seen in the brackets

Fuel	CoE [kWh/kg]	F.E [kWh/10km]	0-100 km/h [s]
E85	5.81	4.32	8.7
E100	4.67	5.00	8.7
Biogas	9.83	5.40	11.6

2.2 Electric Powered Vehicles

Instead of using the chemical energy of the fuel, and convert it into mechanical energy via thermal energy, there is another source of energy that man has been known for a long time. The usage of electrical energy has a long history and even for the car industry there are documentations of electric powered vehicles from as early as the middle of the 19th century. There has been an ongoing process of the development since beside the, until today, popular gasoline car. Especially in the last 20 years EV:s have been in the center of focus and production. What could be the reason behind this rapid change at the manufacturing stage?

2.2.1 The Electric Energy

An electrical vehicle is powered by electric energy that is stored in a battery located in the vehicle. That energy is mainly transferred from an external charger, but can also come from installed generators. In the case of generators they will be located on the rotating axis of the vehicle. The purpose is to convert the mechanical rotation, when deceleration occurs, into electrical energy, which is transferred to the battery. Even if generators reduce the net loss of energy it will not cover the whole energy supply, due to the basic laws of energy. Therefore the earlier mentioned external source is necessary for supply.

Charging is a similar procedure as refuel the gasoline vehicle, with the exception of a longer period of time to refill. There are three different types of well-established ways of charging available today, they are called AC Level 1, AC Level 2 and DC Fast Charging. The first two are commonly used for residential charging. AC means that alternating current is used and the difference between the two are the voltages used 120 V and 240 V, for Level 1 and Level 2 respectively. This results in a refill charging time of minimum 8 hours and 4 hours [4]. For public charging on parking lots the AC Level 2 is still used, but also the DC Fast Charging. The DC Fast Charging usage direct current (200/480 AC three phase voltage) which will make a big difference in charging time, as it would normally it takes between 40 to 60 minutes for a full charge [4]. The main benefice of this short charging time in relation to public locations is mainly in regard to the duration the driver will spend there. The driver is more likely to spend a longer period of time at home than in a mall. For any type of charging, it will stop when the battery is full or when the driver disconnects.



Figure 5: *An illustration of what electrical charging looks like, with the external pole attached to the outlet on the car*

In electric powered vehicles today the most frequently used type of battery is the lithium-ion battery, due to the high capacity of storage per unit mass. If batteries have high energy density [Wh/kg] the cars will become lighter and consume less energy. For the currently used batteries, according to the jour-

nal "Renewable Energy" by WREN, the average energy density is around 140 Wh/kg.

2.2.2 The Engine

The electrical engine that generates the mechanical movement is a matter of current and magnetism. Basically, the motor contains a static part, either called armature or stator, and a rotating part, called rotor. Through wires in the static part current is flowing and generates an electromagnetic field, which can create rotation in different ways. Most commonly a brushless electric motor or an induction motor.

The brushless motor, or BLDC motor, uses direct current and has a permanent magnet rotating around the generated magnetic field. By locating winding of wires 180° apart a pole pair has been created, where one is positively charged and one negatively. If three pole pairs are used around the stator their magnetic fields can be controlled by turning on and off the current through that particular pair. This will cause the permanent magnet to attract or repel towards the energized pair, seen as the illustration in Figure 6. With the right timing of active pairs, the permanent magnet will start to spin and mechanical rotation is created.

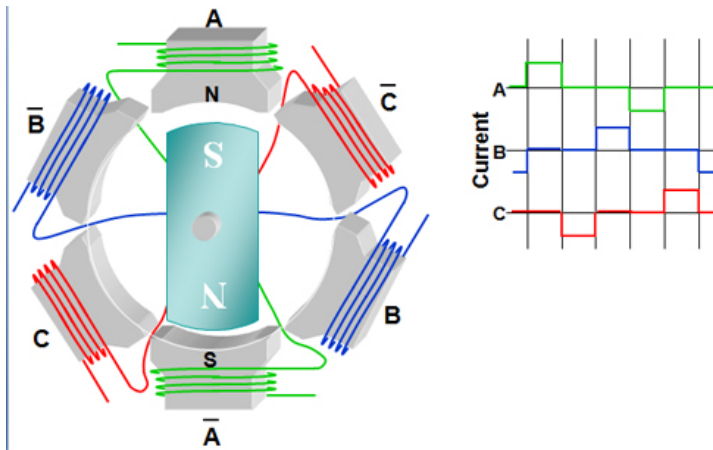


Figure 6: *The principle of the BLDC Motor with the coils for each pole pair in same color & energized at certain points in time*

For the induction motor it follows similar principles, but instead of using DC current three-phase AC current is used. The wiring in the stator has a phenomenon to generate a rotating magnetic field, which will induce a current in the rotor due to Faraday's law. "Faraday's law of induction is a basic law of electromagnetism predicting how a magnetic field will interact with an electric circuit to produce electromagnetic induction".

Then a magnetic force is generated, according to Lorentz' force law, which will push the rotor around. For Lorentz's force law the magnitude of the force is $F = qvB \cdot \sin\theta$ where θ is the angle less than 180 degrees between the velocity, v , and the magnetic field, B . Then q stands for the charge. This implies that the magnetic force on a stationary charge or a charge moving parallel to

the magnetic field is zero. The rotor itself is connected to the car shaft and mechanical motion is transferred.

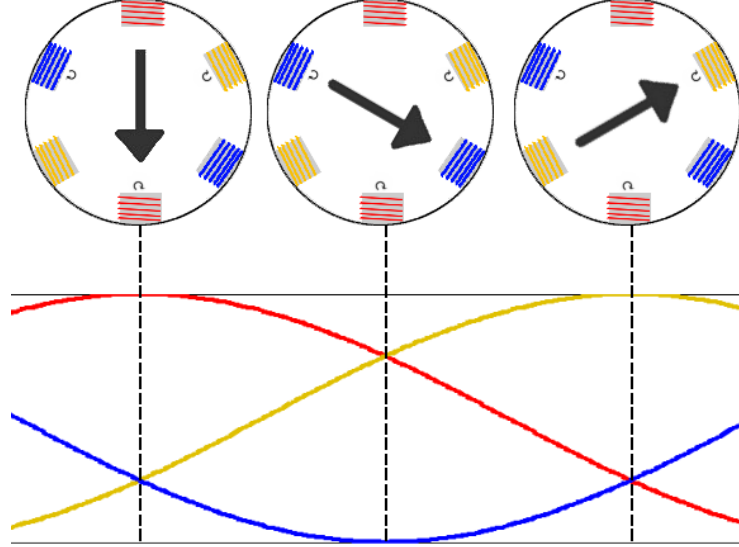


Figure 7: How the induction motor works in theory, where the arrow represents the rotor and points towards of on pole pair for that three phase voltage

Two types of engines with the same source of electrical energy will transform it to mechanical energy that will power the vehicle.

Table 4: Properties of Electric cars

Fuel	CoE [kWh/kg]	F.E [kWh/10km]	0-100 km/h [s]
Electrical	0.140	1.41	10.4

2.3 Hydrogen Fueled Vehicles

The third and last fuel that this paper will cover is the usage of hydrogen as an energy source. Even if hydrogen is the most common chemical substance in the known universe, pure hydrogen gas, H_2 is not as common here on earth. H_2 often comes in combination with other elements as a part of substances, which can be separated. This can be done in multiple of ways, but today the hydrogen supply comes from the thermochemical and the electrolytic sectors.

All above processes include water and exposure to heat. The thermochemical method can be divided into SMR, biomass gasification and STCH. In the case of SMR, Steam Methane Reforming, the water reacts with methane in the natural gas. After a few process stages the byproducts are CO_2 and the pure hydrogen H_2 . Biomass gasification is almost equivalent to the SMR process, with the exception that the base is biomass, such as corn starch. In the end, the same byproducts are the output, CO_2 and H_2 . In the STCH process, Solar Thermochemical Hydrogen, energy from the sun is used to heat the water. By

adding some chemicals to the system hydrogen and oxygen start to separate, in the temperature range between 500 to 2000°C. In contrast to the two other methods the only byproducts from STCH will be H_2 and O_2 , which means that there are no carbon emissions from this type of production. Overall the idea of heating water, with or without additions, will generate the pure hydrogen that is needed to fuel a hydrogen car. According to The U.S. Department of Energy 95 % of the world's hydrogen production comes from the SMR process. This because of the cheap natural gas that is available today [6].



Figure 8: *An ideal illustration of a Solar Thermochemical Hydrogen plant, made for south Europe. Reflectors are surrounding the tower where water is separated*

As for the second method in the creation of H_2 gas, there are not many components needed. A power supply, a hydrogen-based substance, a membrane and a defined cathode and anode. It is based on driving DC current through water, H_2O . Where the positively charged anode makes the water to form oxygen. The remaining hydrogen ions move towards the negatively charged cathode and becomes hydrogen gas, H_2 . From the input of water to the output of oxygen and hydrogen gas, this way of generation of pure hydrogen is free from fossil emissions, in line with the as earlier assumption that the current from the power supply is renewable as well.

This shows that there are variations as to how to provide society with hydrogen gas, but that is not the only part that could vary. As a matter of fact, a hydrogen fueled car can have two different engines based on fuel cells or internal combustion. The gas can either be used in compressed form under a high pressure of 200 to 700 bars or in a liquefied form with temperatures below - 235° C. This will not be covered any further than just mentioning for this brief information.

2.3.1 The Fuel Cell Vehicle

For a vehicle in the category fuel cell it means that it takes energy from the fuel substance and generates electricity, which runs the electrical engine. This process from chemical energy to electrical energy is made through electrolysis, described earlier, but this time in the opposite direction. With the tank filled

with hydrogen gas it supplies the PEM fuel cells together with the addition of air. This chemical reaction generates DC current which is powering the engine, as the illustration in Figure ?? shows.

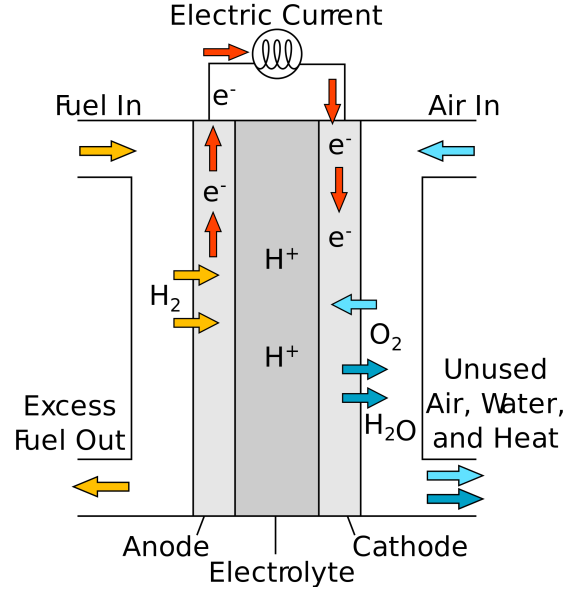


Figure 9: The illustration shows how the electrolysis process in a PEM fuel cell works.

2.3.2 The Internal Combustion Engine

Since hydrogen is an ignitable gas there are possibilities to use it as a direct fuel, as for CNG and CBG combustion engines. By using the concept of combustion the base is a regular combustion engine with modification for hydrogen application. This conversion is well described in the book "Progress in Energy and Combustion Science" by Hai Wang and Christof Schulz [7]. The way to use hydrogen as a direct fuel could be either as pure hydrogen gas or as an air-hydrogen mix with an optimal ratio. After combustion the residues will be heat and water, as the hydrogen gas mixes with the surrounding oxygen.

For the two above-discussed types of hydrogen powered vehicles the same comparison as earlier will be used. This can be seen in the Table 5 with data specifications from U.S. Department of Energy and Gona Bilister[3] [10].

Table 5: Properties of Hydrogen as fuel, where there was acceleration data was not defined for particular engine type.

Fuel	CoE [kWh/kg]	F.E [kWh/10km]	0-100 km/h [s]
Fuel Cell	33.3	6.53	10.3
ICE	33.3	8.68	10.3

3 Methodology

As seen in the previous chapter there are differences between the types of fuel, in the way the fuels are produced and how they are consumed. To be able to compare them all there must be a way to differentiate the fuels with the same initial conditions. The biggest reason why our generation needs to see a change in the automobile industry is because of the emission quantities that the sector contributes with. Therefore a vehicles' fuel emissions are one area of interest to make a comparison. Emissions will come from the fuel that is consumed during various operations, which leads to the fuel economy of the vehicle. How much fuel, or energy, is needed to power the car for a certain distance? Therefore the energy content of each type of fuel could be of big importance to deviate each and see how much potential energy there is in a specific mass or volume. Then take a closer look at the operation efficiency of the vehicle to optimize that output energy that powers the car. Outputs of the performance are of interest for potential customers, to see how attractive it might be. A good measurement of how fun a car is could be represented by its acceleration. All of this can be classified under the category how good of a car performance each fuel corresponds to.

There are many other areas that could be of big importance surrounding the different types fuel, but one major factor to successfully assess a fuel would be to look how easily the world could adjust to the fuel. This includes how good the quantitative supply of the fuel will work and how well-distributed the supply can be done in different environments? The biggest aspect is still the cost; what could be a good estimation of the cost to make the change? Can components of today's gasoline supply be used to reduce cost by modifying existing sectors?

3.1 Comparison Creation

To generate the required comparison, data for the different fuels were collected. Already seen in Chapter 3 each fuel had a Table (3 to 5) with given category data. This section will describe how those values were collected and compiled. For each fuel type the content of energy, CoE, was retrieved from the U.S Department of Energy and "insatsen.se" [8] [9]. Regarding the two other categories a data sheet, by the Swedish organisation Grona Bilister, of 30 cars that was on the 2015 automobile market was used as a reliable source [10]. From this sheet information about acceleration and fuel efficiency was gathered for the different fuels.

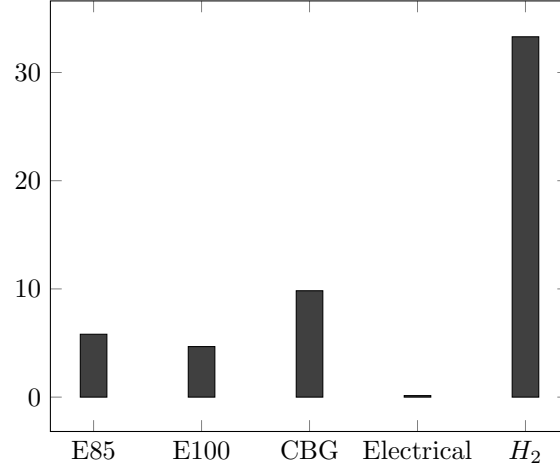
From the data of the two last mentioned an average was made through each category and in order to achieve a value that represents the fuel, see Eq (1). In the case of acceleration, there are outstanding data excluded from the average, where this performance is related to the automaker Tesla Motors. The superior acceleration does not fit the electrical car standard of 2015, but will be taken into consideration in upcoming sections and chapters.

$$Fuel_{avg} = \frac{\sum n_{spec}}{N} \quad (1)$$

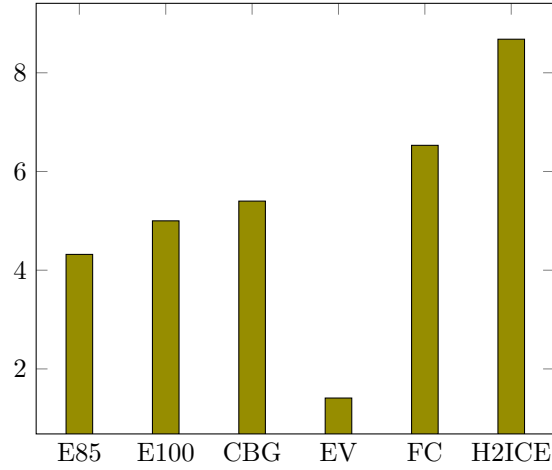
To have a reasonable unit for energy content that most people could understand the standard unit BTU/lb is converted to kWh/kg. This also makes it easier to compare electrical power with chemical combustion. By taking each energy

value from the US. Department of Energy (K_{fuel}) the wanted unit is calculated through Equation (2). The summary of each category can be seen in Graph 7 to 9.

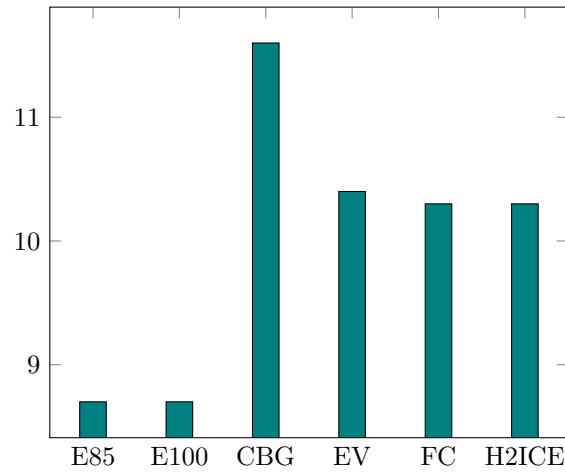
$$C_{Energy} = K_{fuel} \cdot \frac{C_{kg} \cdot C_{kWh}}{C_{MJ}} \quad (2)$$



Graph 10: The values for the Content of Energy, kWh/kg on the vertical axis



Graph 11: The average values for the Fuel Efficiency on the car market 2015, kWh/10km on the vertical axis



Graph 12: *The average values for the Acceleration (0-100km/h) on the car market 2015, time in [s] on the vertical axis*

3.2 The Car Performance

The comparison will focus on how cars with different fuels perform relatively each other and initially derive how great they actually are. A basic characteristic of all types of fuel is the ability to contain energy and even more interesting is the density of the energy [kWh/kg]. If being able to store a big amount of energy into a small mass it will become beneficial for the weight and reduce usage of space. This will also reduce the quantity of the fuel necessary for different operations and save natural resources to produce the fuel.

For this entire section the collected data in Table 3 to 5 is used as a reference for each type of fuel. Starting with the biological fuels the pure E100 and the biogas has an energy content of 4.67 kWh/kg and 9.83 kWh/kg, respectively. These digits show that the maximum energy that can be obtained through one kilogram CBG is twice as much as for the bioethanol. That would result in two times the operation range if there were two engines with the same efficiency. The energy content for an electrical battery is on average 0.140 kWh/kg. Finally, for the hydrogen powered vehicle hydrogen gas, H_2 , has the energy content of approximately 33.3 kWh/kg. It can clearly be seen from these results that hydrogen gas has by far the highest input of energy per kg to the engine. However, what should be kept in mind is that a gas requires being confined within a tank with high pressure and the gas properties often impose lower quantity, in terms of mass, compared to fluid fuels. The question to now be answer is if that big of an advantage can be obtained or if there are other factors that would make the other types of fuel more beneficial in practice?

3.2.1 On the road

The initial purpose of a car is to transport people from one location to the other. However, there are many parameters in between those two locations that have become of bigger interest in later years, such as pollution, comfort and cost. When purchasing a car it is an investment where you choose a type of

independence from public transportation, but also how you want to travel. Most people view their car as fulfilling their needs and meeting their requirements of comfort. In this report that comfort will correspond to how good of an acceleration [0-100km/h] the vehicle has. In most cases, the major factor is cost and that is where fuel efficiency comes into the picture. Since the fuels in this analysis are chosen to be directly environmentally sustainable the pollution factor will not be covered in this section.

Based on the data from Grona Bilister the best average acceleration for cars on the market 2015 were in favour of bioethanol, with 8.7 [s]. A possible reason to this could be the similarities between an ethanol engine and a gasoline engine, which both have been through modifications over a long time. So the high performance of a gasoline car has affected the ethanol engine. The similarities of the combustion engines have been beneficial for a fast developed use of E85 and the maintenance of the acceleration is a result of that, where the rest can be seen in Graph 12.



Figure 13: *The automobile industry is driving towards new horizons*

As Graph 11 illustrates the fuel efficiency is to the EV's benefit in terms of kWh/10km. The electrical vehicles require the lowest amount of energy per distance driven, 1.41 kWh/10km. With the values displayed in Table 3 to 5 the difference between hydrogen-fueled ICE, which has the worst fuel efficiency, and the EV, the energy consumption is six times higher for ICE. Even though the high energy content of hydrogen, the efficiency is far from the best, therefore big losses must appear between the source and what is finally used, leading into the areas of energy use and energy dissipation.

3.2.2 Losses and Efficiency

For each type seen in previous sections fuel efficiency was relevant in every one of them. These are calculated based on how much fuel is put in and then how far the vehicle will reach on that full refill. This is the classical way to

communicated fuel efficiency with a customer of a car. In reality efficiency of the fuel is more complex, which is of interest from a scientific point of view. When a customer puts fuel into their car the purpose is to energize the vehicle with stored energy. This energy has in this study the form of either chemical energy or electrical energy, which due to the first law of thermodynamics has been transferred from another form. At first, it might seem like all the energy going into the car will be used as mechanical energy to power the vehicle. But due to all the transfers between types of energy there will be losses. In the case of automobile fuels this is called WTW, "Well to Wheels", energy from the source to actual powering. Measured to find out energy per covered distance [MJ/100km], but for this report the unit will be converted to [kWh/10km] as earlier for convenience. This conversion can be seen in Equation (3).

$$[kWh/10km] = J \cdot \frac{km}{10} \cdot 3.6 \cdot 10^{-6} \quad (3)$$

In a report from 2011 made by the European Commission data from the automotive industry with respective data for each fuel types have been compiled [11]. The purpose of the WTW is to gain a wide understanding of the path efficiency takes from the source of the fuel, "Well", to the actual powering of the vehicle, "Wheel". With knowledge of this data it is easier to detect where losses might occur and consecutively make possible improvements. Furthermore, this efficiency is divided into two parts, first there is WTT, "Well to Tank" and then TTW, "Tank to Wheels", which is shown in Equation (4). WTT aims more to losses in producing the fuel and supplies it to the customer, where TTW is the actual car efficiency. Even if this study has the main focus on the vehicle itself it could be interesting to see both parts of the energy path.

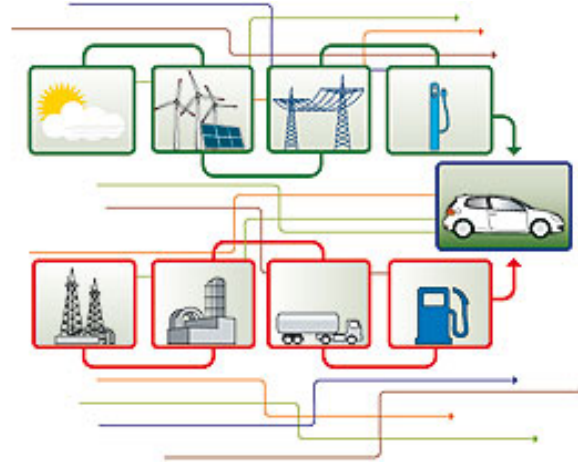


Figure 14: An illustration of alternative paths for automobile industry fuel Well to Tank

$$WTW_{tot} = WTT_{Transport} + TTW_{Vehicle} \quad (4)$$

By going through the results of the WTW report, with updated data from 2014 in "Appendix 1", the existing vehicles in 2010 were used. As a good

reference regular gasoline is applied to get an understanding what would be a better solution than gasoline from an energy perspective. The gasoline car has a WTW of 6.94 [kWh/10km], where 1.08 [kWh/10km] correspond to the WTT and 5.86 [kWh/10km] to the TTW. In contrast bioethanol has a WTW of 14.7 [kWh/10km], following the WTT 9.27 [kWh/10km] and TTW 5.47 [kWh/10km]. As can be seen in Graph 11 the calculated efficiency is around where the European Commission announced that the E85 should be. A similar comparison is done for all the remaining fuels and is displayed in Table 6, where the differences between the two sections of efficiency in each of the fuel types can be seen.

Table 6: A range for the efficiencies [kWh/10km] of each fuel type that indicate area of losses

Fuel	WTT	TTW	WTW
Gasoline	1.08	5.86	6.94
E85	9.27	5.47	14.7
Biogas	9.89	6.44	16.33
Electrical	0.17	1.44	1.61
Hydrogen (FCV)	1.31	1.5	2.81

In addition to Table 6 there have to be notes added, which can be seen in the Appendix. With a more specific view of the fuel efficiencies it might be easier to compare the differences for each of them. The beneficial parts for one or another can be decided and where there is room for improvements. However, once the more reliable fuel is decided the initial work is done, what remains is to see whether the best performing one should be chosen or if other influences could result in something different?

3.3 Society Integration

One of the reason to own a car, if not the main reason, is to gain a certain independence with regards to public transportation schedules. Maintenance and the accessibility of fuel supply are also a big factor for keeping the automobile industry a reliable way of transportation. Today the gasoline sector has accomplished to produce cars to prices in a wide range that remain affordable to the public. The supply of fuel works through gas stations that are located along trafficked roads where consumers fill up their tanks. This is a 5 minutes process from entering to a full tank, including payment. Simple and fast, which is what most areas today have adjusted to regarding the claims of the society. For each fuel there are different challenges to achieve and in this section the focus will be more on how good the future fuels can suit today's everyday demand. To start with there has to exist a supply that could provide the quantity needed for all the vehicle. If the demand is higher than the supply there will be a shortage and will therefore not be an independent source of energy. The practical aspects surrounding the new fuels will be vital in the assessment of whether to invest in these future fuels.

An investigation of this data was made by WSP Sweden regarding the bio gas supply in Sweden [12]. Here they have studied how big potential the domestic biogas supply could develop in the future through sustainable extraction. It shows that Sweden could, assuming the right investments were made, reach a gas production from 22 to 89 TWh biogas energy per year. With earlier values for energy content in Table 3 this would correspond to a mass of 2.24 up to $9.05 \cdot 10^9$ kg biogas. This supply can be put into context by using the fuel economy for biogas. A study from "Trafikanalys" is used, in collaboration with RUS, where the annual average distance per inhabitant is calculated [13]. As for the case of Sweden they claim the number of vehicles was around 5.35 million spread out over a population close to 10 million people. With a minor rounding up to the assumption that will be used is a total of 6 million cars in Sweden.

With an average distance of 12,200 km/year the potential could lead to a supply in energy for up to almost 13.5 million vehicles. Sweden with a vehicle fleet of 6 million would need an annual supply of $4.02 \cdot 10^9$ kg bio gas. Therefore the country has potential to be able to use bio gas as the only source of fuel for the automotive sector. This kind of research and assessment has to be made for all potential fuels to determine whether they could be considered a potential candidate in substitution of gasoline.

In the same fuel category, a country that was early with bioethanol integration in the vehicle industry was Brazil. The production started already in the 1930s where the main source to the bioethanol is sugarcane. With much available land for growth of plants and cereals, the initiative was beneficial for the nation on a whole. Throughout the 20th century, during all the oil crises the Brazilian government improved the domestic ethanol production to hold a more independent fuel source. As a consequence, mandatory restrictions were statutory that gasoline has to contain at least 25 % bioethanol. Furthermore, the development of, non-gasoline mixtures (as mentioned in the last chapter), hydrous and anhydrous vehicles has resulted in Brazil as a frontier in the bioethanol consumption. The domestic automobile industry has adjusted to these claims and minor changes of the drive trains to flex fuel system are done before sale. This to give customers the possibility to choose which fuel is preferred regarding the fluctuating market prices of bioethanol and gasoline, respectively. According to the statistic from "The International Council on Clean Transportation" more than 90 % of newly sold cars in Brazil from 2012 and 2013 was flex fuel vehicles [14]. In the long run, Brazil has managed to create a transportation fleet that consists of 45 % flex fuel vehicles. The system of creating a domestic industry that creates jobs, reduces emissions and cost of the fuel must be seen as a success of society integration, which is a big step in the right direction.

Going back referring to Table 3 the bioethanol has an annual claim for the automotive sector in Sweden has a supply of $7.84 \cdot 10^9$ kg. As an actor on the Swedish bioethanol market, SEKAB has done research on possible cellulosic bioethanol production, based on using the Swedish forest [15]. For today's technology, the expected minimum annual capacity per bioethanol plant lies around $23.7 \cdot 10^6$ kg. So by establish this type of plant Sweden might be able to reach the required quantity.



Figure 15: *Big areas of land are only used to produce the base of bio fuels, in this case colza flowers grown to become bioethanol*

If the same investigation is made for EV:s the important question is how often the consumer would need to charge their vehicle? As mentioned in the assumption section, the supply of electrical power is said to be sustainable and unlimited. With the same annual driving distance of 12,200 km the focus is regarding the biggest issue for EV:s, which is to determine the capacity of a fully charged battery. In gathered statistics from U.S. Department of Energy the average range of today's electrical vehicles is 181 km. This would statistically lead to an average full recharge for every car 68 times in a year. Thereby the consumers have to charge once every fifth day and this will require a big accessibility of charging devices. Assume there are 6 million EV:s in Sweden and spread their charging out on 1 week. The result is 1.2 million cars that have to be charged every day. Depending on whether AC Level 2 or DC Fast Charging is used, the amount needed is different. If the distribution of electrical charging only was available between 6:00 to 22:00 (16 hours) for the public chargers, the required amount of chargers would be of 300,000 for the AC Level 2 chargers, in comparison to about 75,000 DC Fast Chargers. All this with respect to last chapter's description of full charging, 4 hours and 60 minutes respectively.



Figure 16: *There are multiple of charging poles on the market, most of them in both AC and DC categories.*

When it comes to the necessity for a future where hydrogen gas plays a more central role the estimation of energy usage is based on sections from a conceptual hydrogen plan from Sweco [16]. With the fuel economy from Table 5 and with the earlier mentioned average annual distance, Sweden has an average energy demand of 10.6 MWh for a ICE vehicle and 7.96 MWh for a FCEV, respectively. By assuming that Sweden would have 6 million hydrogen cars to supply, the total energy demand would be somewhere around 64.0 TWh per year. Once again with reference to Table 5, with regard to the energy content of hydrogen gas, the amount of hydrogen gas that has to be produced is $1.94 \cdot 10^9$ kg.

Table 7: A summary of the Required Annual Mass of the chemical fuels

Fuel	R.A.M.[kg]
Bioethanol	$7.84 \cdot 10^9$
Biogas	$4.02 \cdot 10^9$
Hydrogen	$1.94 \cdot 10^9$

3.3.1 Refill Supply

Once the quantity of fuel production is solved the next issue to address concerns how to deliver the fuel to the consumers? To have stations nearby highly trafficked routes for fast refills, but as mentioned in the electrical car section this will not work for EV:s, where the process of recharging stretches over at least 40 minutes.

Today the refill of an EV happens meanwhile another task is done. It could be errands in the mall, having lunch at a restaurant or just being at home. This is of course with the prerequisite that these locations offer to charge at the parking lots. According to the Swedish energy authority, "Energimyndigeten", the country has over 500 charging stations and more than 1600 charging poles spread out [17]. This in order to provide the possibility to charge vehicles on public location. However, further studies show that up to 90 % of the EV owners

today charge their vehicle through private or office chargers. A major reason for this is that vehicles are more stationary at these locations for a longer period of time. Thinking in terms of time there will be no need of DC Fast Charging. As a result of this, the cost can be reduced by using AC Level 1 or 2. The way in which we perceive owning a car would change drastically with all chargers available to public use. There would be no need to take the car to the station for a refill. Instead, multitasking would have influenced the automobile sector as well and the niche fuel service as we know it would be phased out.

As for the two other fuels, Bio fuels and Hydrogen, the necessity to refill at specific locations would remain as the distribution grid of these fuels are not constructed in the same way as for electricity. Electrical consumption exists in every home and facility, which results in no additional grid for the extra supply. For the others there is a limited usage for transportation fuel only, therefore the demand will be less than electricity per household. By having a public place where supply trucks fill up big quantities for customer consumption, as the current situation, seems more beneficial than a private supply. The situation for Swedish bio fuel today is a well-established distribution with E85 at almost every nationwide gas station and over 150 locations for CBG refill, according to Energigas Sverige [18]. In comparison, hydrogen gas has a very low demand and therefore a low rate of supply. With statistics from Sweco and the U.S. Department of Energy, Sweden has three official H_2 stations and the entire United States has 24 stations 2016. So the number of stations per inhabitants in Sweden is much higher than for the USA. However, this number will not be suitable if future consumption increases. In a conceptual plan for the Swedish hydrogen society from 2014 to 2020, proposed by Sweco, there is a strategy detailing how this should be handled [16]. The plan is to increase the number of stations to between 10 and 20 and spread them out, in order to establish a base that the population can rely on and then create a nationwide grid.

3.3.2 Future investments

The three different scenarios of fuel studied would all achieve national supply in different ways. Each fuel has its' benefits against the others, but one common denominator is the actual cost they would entail. What would a good cost estimation be for a society, like Sweden, with just one of these fuels, if all necessary changes as of today were made?

Initially by investigating the bio gas sector on of the main focuses will be to produce the fuel. This has to be done on a big enough scale so that the $4.02 \cdot 10^9$ kg per year is fulfilled. According to the study from WSP a bio gas power plant with a 100 GWh capacity has estimated the cost to be between 200 to 350 MSEK [12]. To then expand the supply to the corresponding capacity of 39.5 TWh per year the amount of power plants needed would be around 395. In order to establish production facilities capable of meeting the quantity needed, the total cost would be in the region of 138,000 MSEK. Furthermore, the CBG has to be distributed to customers through gas stations customized for gas. During the past five years in Sweden the cost of a new gas station has been in between 9 to 15 MSEK. Today there are approximately one hundred bio gas stations the number would have to increase to compensate the gasoline supply, which

regrouped 2,720 stations spread out over the country in 2015 in accordance with SPBI [19]. With a necessary expansion of 2600 new stations the sum of this becomes 39,000 MSEK. Finally adding the production and supply expansion costs together the total cost ends up at 177,000 MSEK.

For the category of bio fuels, the second part consists of bioethanol. In comparison to the other fuels bioethanol is well-established already, therefore there would be no need to build new gas stations because of the widespread supply of E85. Moving on to where investments have to be made for a big enough coverage. In 2014 the biorefinery constructors Enerkem finalized a bio fuel project in Canada, where a bio fuel plant was created for methane and bioethanol production [20]. The capacity of this plant is supposed to generate around $30 \cdot 10^6$ kg bioethanol per year, for a cost of 850 MSEK. As mentioned earlier in the chapter, this type of plant has been investigated by SEKAB. As for Brazil, which is a well-established bioethanol based country, the second generation of bioethanol production has started. The cellulosic ethanol factory, finalized by "GranBIO" in 2014, has an annual capacity of $64.7 \cdot 10^6$ kg at a cost of 784 MSEK [21]. When establishing which of these two plants would suit the Swedish conditions the Canadian plant seems as a better fit, as sugarcane cannot grow in Sweden due to the climate. But for more global perspective this shows that there are possibilities with a different base product, which can generate better efficiency and lower cost.



Figure 17: *These gas stations in California could become a more common sight in the future, if an expansion of bio fuels occurs*

With the distribution claim to meet of $7.84 \cdot 10^9$ kg the required number of Canadian plants with same capacity in Sweden would be 262. To then look at the financial investment needed for these production plants the sum ends up around 223,000 MSEK. According to the "NILE Study" by 6th RTD Framework Programme of the European Commission Sweden had in 2010 around 29.1 TWh available biomass annually from the forest sector [22]. A corresponding number in mass would be $6.23 \cdot 10^9$ kg of bioethanol and therefore not enough

to provide the full scale. On the other hand, the study claims a raise in total available biomass with 45 % between 2010 and 2030. If the prediction is right and results in a growth of the Swedish forest biomass the establishment of this production would be realistic.

When it comes to the electrical charging expansion the question is all about provide enough spots to refill all the vehicles. The supply of electricity in the Swedish national grid already an enlarged scale might be taken into consideration for future plans. Especially when the assumption of green electricity is made, the scale of wind, water and solar power has to expand. All of this would include an additional cost to the investments, but will be left out to maintain the focus of this analysis. However, either 300,000 AC Level 2 chargers or 75,000 Fast Chargers has to be purchased and well-distributed. In a compiled summary from the Swedish Department of Energy the overall cost for these chargers is between 7,000 to 20,000 SEK or 200,000 to 550,000 SEK per station [23]. Included in the cost are a possible foundation, installation and extra facility maintenance. With given amount of chargers needed the total sum would result in a total cost of 6,000 MSEK or 41,300 MSEK, respectively. An additional part of the scenario would be if all households in Sweden purchase an electrical charger for their homes instead of public chargers. According to reports of the American market from "Plugincars.com" and "HomeAdvisor.com" the cost for a AC Level 2 charger lies between 5,000 to 9,000 SEK [24] [25]. So if every household has two cars, a necessary total purchase of 3 million home chargers for Sweden, which correspond to a cost of 27,000 MSEK.

Regarding the final case with hydrogen gas as the fuel source, there are investments that have to be made. First, a production of the pure gas is made through earlier chapter mentioned processes. To circle the most sustainable methods of producing H_2 the STCH process and the electrolysis costs are analyzed. A project started 2014 by the European group "Fuel Cell Hydrogen" where a STCH power plant "Hydrosol-Plant" is planned and to operate at the 750 kW scale [26]. This means that during one year the capacity of this plant is around 6.57 GWh, which leads to 197,000 kg of H_2 . The cost of the power plant is estimated to be 33 MSEK. Furthermore, the scale of the power plant will just cover a fraction of the required amount consequently, there has to be a total of 9,845 STCH plants to meet the Swedish needs. This leads to a total cost for the production sector of 325,000 MSEK. No information has been found for hydrogen gas station (only distribution), but there will be an additional cost to the final sum. Most likely in the scale of the bio gas stations, earlier mentioned in this chapter.

Besides, the hydrogen can be produced through electrolysis as mention in the earlier section. This can be flexible done on the spot of the station as long as water can be provided to the site. The National Renewable Energy Laboratory covers in a paper "Hydrogen Station Cost Estimates" the field of potential H_2 station and how an establishment could look like [27]. In the study there is an estimate of H_2 stations that will be able to produce as much as 1500 kg/day and to a construction cost of 42.6 MSEK. By knowing the daily capacity of one station and the requirement of annual hydrogen supply, $1.94 \cdot 10^9$ kg, the amount of station necessary is approximately 3,543. That results in a total construction cost of 151,000 MSEK.

The customers who purchase the vehicles also make an investment in themselves. A big interest in the everyday life is the price when to refilling your car. By comparing the cost to pay at the gas station it could give an indicator of how attractive a vehicle with specific fuel is related to financial aspects. An estimation of the Swedish energy taxation is made to be 25 % of the production cost, which will be added to the costs displayed below for electricity and hydrogen. For the E85 in June 2016 was about 11,3 SEK/l, which leads to a cost of 13.6 SEK/kg. As for the situation today an estimation is made that the wanted E100 has a similar price as the E85. During the same month, the price for bio gas was around 18 SEK/kg. When it comes to EV:s the situation is much harder to state what the general price could be. The chargers used in public locations are free to use, but for the case of charging at home it can vary from vehicle and distributor. The automobile company Tesla Motors claims that their latest release, Tesla Model X, cost around 2.43 SEK/10km [28]. By adding the Swedish energy tax the cost ends up around 3.04 SEK/10km. The last estimation of the cost for hydrogen methods was made in 2015, through STCH process the price would be 126 SEK/kg and by using the electrolysis process 33.2 SEK/kg according to the US Department of Energy. As for the electricity, the energy tax is added to each and results in 158 and 41.5 SEK/kg, respectively. Column 3 to 5 in Table 8 is based on the given data in this section, but also data from earlier chapter in Table 3 to 5. By going through units the conversion is fairly simple.

Table 8: A summary of the investments for each fuel and the current cost of the fuels for customers with reference to different bases. FCV is used for the case of hydrogen

Fuel	Establish Cost[MSEK]	Fuel Costs [SEK/kg]	- [SEK/kWh]	- [SEK/10km]
Bioethanol	223,000	13.6	2.91	14.6
Biogas	177,000	18.0	1.83	9.89
Electrical				
Public	6,000-41,300	Free	-	-
Home	27,000	(Not Useful)	2.16	3.04
Hydrogen				
STCH	325,000 +	158	4.74	31.0
Electrolysis	151,000	41.5	1.25	8.14

4 Results

To follow up previous chapter, where an entire methodology of the comparison is described, there is no doubt that the multiple of perspective to approach each fuel will make a concrete decision harder. However, by using all the collected data it can be compiled into the wanted side-by-side comparison. Furthermore, this will show if there are better options for different circumstances. As in the methodology, the results will be divided into two separate categories. This because of the differences in data, where the performance is related to the fuel and vehicle. On the other hand, there is a society and financial world that has to be taken into consideration when future fuel expansion wants to be established.

4.1 Performance

Already in the background chapter some major categories of interest were introduced, such as Energy Content, Fuel Efficiency and Acceleration. Moreover, the terms WTW, WTT and TTW including their definitions are all additional categories to the resulting comparison of all the fuels. To sum all these up a rating from best to worst in each category, then sort the highest overall rated fuel that will be at the top. This can be seen in Table 9 where 1 is the best rating and 5 is the worst. There are some categories that have not been found, which are marked with "-" in the table.

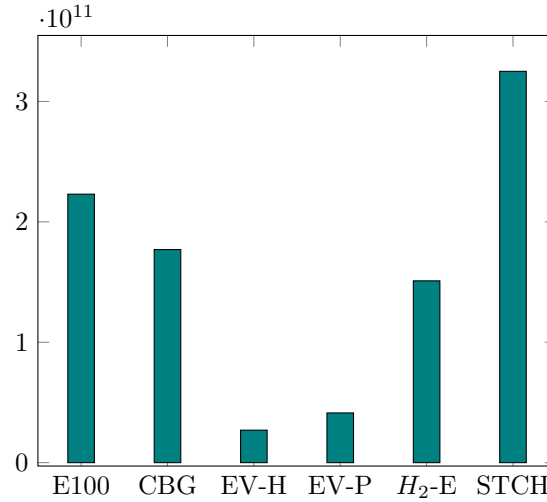
Table 9: A summary of the ratings from (1) to (5) for each category in the performance field, where the ranking is descending from top to bottom

Fuel	CoE	F.E	Acc.	WTT	TTW	WTW
FCV	33.3 (1)	6.53 (4)	10.3 (2)	1.31 (2)	1.50 (2)	2.81 (2)
EV	0.140 (5)	1.41 (1)	10.4 (4)	0.17 (1)	1.44 (1)	1.61 (1)
ICE	33.3 (1)	8.68 (5)	10.3 (2)	1.31 (2)	-	-
E100	4.67 (4)	5.00 (2)	8.7 (1)	9.27 (4)	-	-
CBG	9.83 (3)	5.40 (3)	11.6 (5)	9.89 (5)	6.44 (3)	16.3 (3)

To judge from the table there are some definite rankings for some fuels and some more uncertain. In the case of bio gas it should end up in the bottom because of the low ratings in each category, as for the bioethanol that belongs in the middle of the ranking even though there is a lack of information for the final two categories. In the top, there is a much finer line between the hydrogen and electric powered vehicles. The absence of information for the ICE could affect the outcome of the ranking. Moreover, the fact that a combustion engine is used the values of TTW will most likely follow the trend and become higher than the two above. Regarding that the efficiency of a standard electrical engine is much better than a standard combustion engine. The reason to FCV before EV is energy content of rating 5 meanwhile FCV has a 1. As a result, the hydrogen-fueled Fuel Cell Vehicle is the best performing with found data for these studied cases. However, there is another part that has to be taken into account to get the whole result.

4.2 Integration

Moving on with the as important part besides the actual performance of the fuels, how well an integration would work in the society? The only measurable quantity, in this case, is how big financial investments that have to be made for the required supply. By using the data from Table 8 there is no doubt of which fuel that has the least direct economic impact. If the Swedish infrastructure were about to focus on EV:s this would lead to less than half the cost of H₂ electrolysis or less than a third of the CBG investments, as seen in Graph 18.



Graph 18: *The values on the vertical axis in the investment cost in SEK, on the horizontal axis the categories follow the same order as Table 8*

As the graph shows the direct investments in Solar Thermochemical Hydrogen, STCH, would be the most expensive one from today's perspective and knowledge. So to judge from this point of view a Sweden with just electrical cars would require least investments. Furthermore, the customer price estimations for the fuels is also displayed in Table 8. To make a certain fuel more attractive on the market the price has to be lowered. In this category it's clear that bioethanol is the cheapest one, except for free electrical chargers. If that is due to the more established bioethanol in Sweden or not remains to be discussed in the next chapter.

To summarize the result there is no doubt that the best solution regarding both performance and society integration would be using electricity as fuel. By ending as runner-up as a good performing vehicle and the cheapest investment either through public charging or home charging. All this from the numbers point of view, where some important factors lie, but there is also so much more behind a decision than just numbers. There will be other parameters to take into consideration, which will be involved in the upcoming chapter. However, the electricity seems to be a great candidate at the current stage.

5 Sensitivity Analysis & Discussion

With last chapter as the basic data to this comparison all the values has to be put into context, where realistic scenarios are questioned in relation to that specific case. Throughout this report there have been some limitations made, as explained in the initial chapter, to remain this thesis as a lighter overall study. This will lead to deviations from the actual data, which will cause uncertainties that might be important to keep in mind.

5.1 Uncertainties

First of all the collected data is based on what is given today, existing facts or estimations that are made from current knowledge. This will most likely lead to changes in the vehicle performances in the future, where they can be more fuel efficient or have a better acceleration. In other words, there will be changes in the areas where the major investments in research and development are done over time, thereby give a completely different comparison. But as mention earlier during the comparison, by using today's knowledge the initial stage is from now and leads to a certain point to start the study from.

Furthermore regarding the performance of the vehicles the values are average of around 30 cars from the 2015 market. If they represent the typical values for that particular fuel type is maybe not fully sure. Since averages are made the peaks of performance are canceled or can create misleading data. Such was the case for the Tesla Model S, where the acceleration was so superior that it would decrease the average by 0.7 s. For the category of EV:s this would have lead to a better rating for that category, but would it have shown the actual average for the entire market. The Tesla Model S could possibly be the most popular EV at the market and should maybe be a part of the final average. However, as pointed out in the comparison Tesla Model S was excluded. Moreover, the data for an ICE vehicle should not be hundred percent trustworthy since the technology is in the initial stages. Therefore the type of engine is not tested to a big extent of multiple reliable sources. As can be seen in Table 9 there is a difference between fuel efficiency and TTW, in some cases more than reasonable. The two values should be fairly similar, but the reason for the variation is not determined. One possible reason could be the source average, as above mentioned, from the 30 cars. There might also be some errors in the conversion for some fuels to the wanted units.

The most unreliable part when it comes to accuracy in numbers is the society integration. For a better understanding of what might be required for a full supply of the vehicle fleet in Sweden, these numbers are necessary to give a good picture. It will also give a sense of the big amount of money that has to be invested in these national projects. A consequence to this, there are uncertainties in the estimations of costs for the production sector. Based on already built factories or planned projects on other locations the cost can vary for a multiple of reasons. Differences in countries tax policies or construction subsidies could be a major factor in the procedure of a final decision. Then the availability of locations, choice of material for facility or functionality with more niche to the specifications. Regarding the supply sector, the calculations can be, as wanted

in the initial assumption section of the report, an overestimation of the total cost. Less expensive upgrading of the existing gas stations in the country might be achieved. Besides that the numbers should be in a realistic area regarding reliable existing sources and applied on Sweden as a frame.

5.2 Discussion

For the country of Sweden, the government stated that the nation's vehicle fleet should be completely independent of fossil fuels by 2050. With this said the bar is set very high, which will lead to a challenge for the whole society. However, with government funding faster improvements will appear and also encourage companies' research and development to reach towards this goal. By saying all this there is no doubt that Sweden is a nation with a mindset to change the fossil fuel consumption. All the way from the top there is a focus to put big resources in the area of this report.

5.2.1 Vehicle Analysis

Since the first day a car rolled out on the streets there has always been about pushing the limits further, which will require exceptional engineering, creative entrepreneurs and a little bit of luck. The usage of gasoline took an exponential growth as the automotive industry became bigger. At first, it was about reach the highest speed, then it moved on to the comfortable transportation, later on the prices were reduced to the lowest possible and finally the cars were supposed to be fuel efficient. All these concepts have survived and the focus has fluctuated over time, but now all have been integrated more or less in new type fuel for next generation of vehicles. New limits have to be pushed and more parameters have to be taken into account when creating what will be the future cars that roll out on the streets.

By taking a closer look at Graph 7, where the content of energy is displayed, the amount of energy for each fuel per mass unit is compared. There are 4 out of 5 that can be merged into a group of chemical substances, containing their chemical energy. The one left is the electricity, which has electrical energy and a little bit different ability. In the chemicals there are a certain amount of energy that is stored in the liquid or gas, a constant number that will not change. For the case of electricity its' energy content is based on storage in a battery, a man-made product with a specific capacity. As a consequence, this is a variable that can be changed over time, related to a variety of reasons. A higher capacity will lead to a bigger CoE for electricity and that is what currently happens in the area of battery development according to nature.com in 2014[29]. The batteries at the moment have peaked around 250 [Wh/kg], but with the big focus in this area Nature believes that we can reach 400 [Wh/kg] by 2017. Another topic to also take into account should be a possible change of battery type, such as magnesium ion or lithium-sulphur. As already mentioned in the methodology this will lead to an optimizing between vehicle weight and battery size to get best possible performance. So for this particular category there is a clear advantage for the hydrogen gas, but for the future we should wait and see what the EV development can achieve.

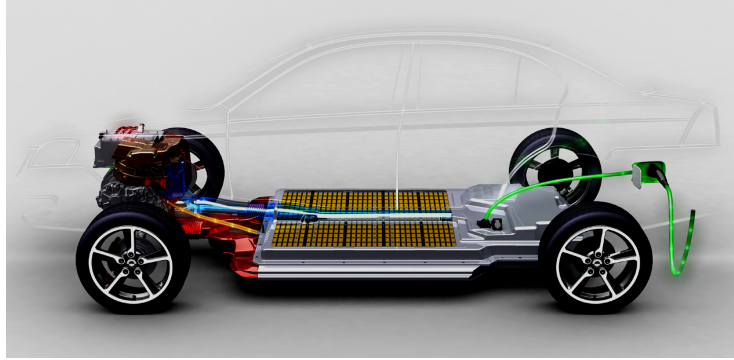


Figure 19: *The general view of battery storage in electric vehicles, spread out in the bottom of the car keep the center of mass as low as possible*

In addition to this subject, the improvements of the batteries will also push the controversial question about EV:s battery range. The studied vehicles had a range between 120 to 210 km, with the exception of the Tesla S and Tesla X which can reach up to 490 km. For a gasoline car to drive 120 km in one refill would be seen as not acceptable. Some of the modern gasoline cars can reach as far as 1200 km in one refill. To meet the standards of today's driving the electrical vehicle has to step up a few steps. A closer discussion about the old refill standard will be in next section of the chapter.

Moving on to the next category in Graph 8 with the focus on fuel efficiency (FE), which together with TTW summarize the consumption of fuel and energy. This is where the performance of the vehicle comes into the picture, how much energy is used to power and how much goes to waste. As can be seen in Table 6 the electrical engines have a big advantage against the combustion engines. The combustion process generates a lot of heat, which is the major loss from tank to wheels. By focusing on the electrical engines for EV:s and FCV:s they are already far ahead and can still be improved. To achieve the same efficiency for a combustion engine the definition of "Ideal Maximum Efficiency of a Heat Engine", see Equation 5, is used as a reference. The higher the warm temperature, T_{warm} , is, or the lower the cold temperature, T_{cold} is, the better efficiency you will get. However, the surrounding air limits how cold a gas or a fluid's lower temperature boundary is. What follows is the upper boundary for the engine, if too hot the engine will fail due to material properties or other functionalities.

$$\eta_{comb} = 1 - \frac{T_{cold}}{T_{warm}} \quad (5)$$

Consequently, to reach the level of an electrical engine the warm temperature required is so high that the combustion engine needed would not become financial stable. Materials needed would lead to more expensive production and make it hard to maintain low prices on the market. However, consider that this was made for the production sector, WTT, it could look a little bit different. Electricity could be produced through combustion processes and would result in similar production efficiencies as for the vehicle engines. For high efficiencies expensive and durable materials have to be used, which would increase the price

of the vehicle and lead to less consumption.

Acceleration was an easier way of measuring people's willingness to buy the vehicle with that certain fuel. The better acceleration, the more of a thrill to drive and thereby attract more car lovers. For this case, displayed in Graph 9, the bioethanol vehicles, in general, gave the best acceleration of 8.7 s from 0 to 100 km/h. However, by studying specific vehicles as mentioned in the previous chapters the Tesla Model S has a surprisingly good acceleration, 2.9 s to be exact. Even if you like the screaming sound of a V8 combustion engine the feeling of that kind of acceleration cannot be other than pure joy. There is not so much more to say about the acceleration that has already been said. The bioethanol fueled vehicles are the best because of the similarities to the gasoline vehicles. Eventually, the other fuel standards will reach the same level of the development over time. In just a few years there will most likely look a whole lot different on the market.

5.2.2 Production Analysis

Moving on to the as important part of the comparison, what an establishment in the society might be like for each fuel. One mention area was the quantity of fuel needed to provide Sweden as a country with that particular fuel. To suit those requirements there has to exist a big enough production of fuel domestically and a good number of stations for distribution. As a consequence of this, it leads to the second area of interest, the financial aspects of the integration. For the three chemical fuels, there is a certain mass to fulfill the estimated Swedish average of 6 million vehicles. On the other hand, for EV's there was just a matter of how long time to charge and how often, thereby calculate how many electrical chargers are necessary. Summing these two up there was a clear benefit to choosing electricity over the other fuels, displayed in Graph 15. This was an uncertain estimation for all the fuels without taking improvements in technology into consideration and changing the final cost. These potential changes are important for getting margins and better accuracy to the whole picture with included errors.

Regarding the production, there will be major changes over the years if Sweden is going to reach the goals that the government has set for 2050. Starting off with the definition of "free of fossil fuels", the point is to have the entire vehicle fleet on alternative, green, fuels. Therefore this states that the well-established E85 in Sweden cannot be used and has to be phased out since that 15 % of gasoline will not be accepted. Referring to the Brazilian market where the vehicles have to be modified to flex fuel and run on E100, Sweden could possibly achieve a similar nationwide modification. Taking the question of no fossil fuels further, will that include all transportation of products to the country from abroad? Does that mean that Sweden will ban all incoming transportation if not followed and lead to an increase of domestic production? For a fully expand supply of bioethanol in Sweden the estimated cost would be 223,000 MSEK with an additional cost of the already mentioned modification of vehicle drive train. On the other hand, if the policy wasn't as strict for the national import this would lead to similar trade as for gasoline today. For a more realistic scenario of the future bioethanol market would be a worldwide competitive situation be-

tween distributors like United States and Brazil. This could lower the financial cost of bioethanol production and most likely lead to cheaper customer prices.

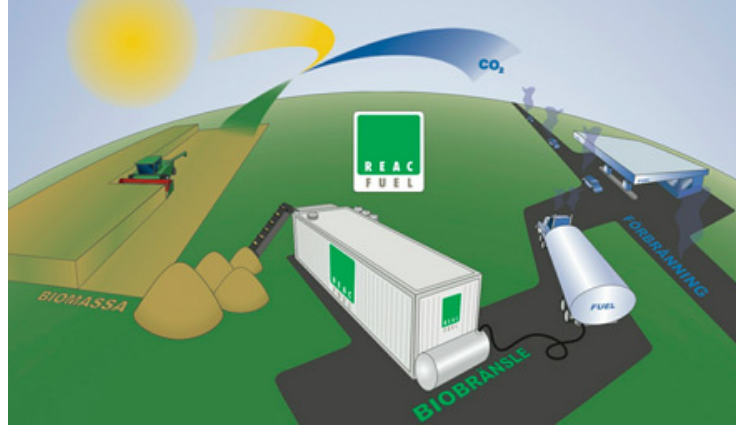


Figure 20: *An illustration of the bio fuel cycle*

Speaking of these two major ethanol producers in the world today there is a debate about ethanol, fuel or food. Especially in the case of Brazil with a huge poverty throughout the country, shouldn't the sugar cane go to help the population from starving rather than fueling their cars? It should definitely be seen as a problem against this type of ethanol production and has to be solved for each location in different ways. A certain amount that goes to the food industry and the rest goes to the fuel production. The good conditions of Canada exist in Sweden as well with a lot of forests, which contributes to the type of cellulose-based bioethanol production Canada already have started. This would solve the complaints about food waste, but instead there must be restrictions to control where and how these trees will be consumed. Sweden as a country has a great potential in the bioethanol sector, the question remain if this is the best solution in the bigger picture?

Staying in the production sector but now for the bio gas, which for a green purpose should be made from food waste and sewage. A cost of 177,000 MSEK would give the required bio gas, 39.5 TWh, from Swedish sources. This excluding the current biogas production that is mainly used for the public transportation sector. The beneficial of biogas is the usage of a waste or rest product, this in comparison to the ethanol for which would be a grown cereal or tree with the purpose to become fuel. Though the biogas production is dependent on how generous investment the area get. According to Energigas Sverige in a study from 2011 they believe Sweden can reach from 15 TWh all the way up to 74 TWh [30]. As already mentioned in the methodology WSP Sweden estimated the production somewhere in between 22 to 89 TWh [12]. For the domestic independence, it would be fantastic if Sweden had the possibility to supply itself with the bio gas or maybe even international trade to export. If not, the case would be an import from the international market and most likely a lower cost than the prediction. So from the environmental and economic perspective the bio gas production would be a better solution than the bioethanol.

As the methodology and result showed, the case of hydrogen gas production the financial cost was either 325,000 or 151,000 MSEK for STCH and Electrolysis respectively in Table 8. For the general population H_2 is something that was mentioned on the periodic table in the chemistry class and nothing more. In other words, there is a small knowledge of using hydrogen gas as a fuel even if the research has been going on for a while. Due to the lack of focus from the society there have not been as big improvements in the area, which would be necessary for that big establishment. With the comparison as a reference, the electrolysis process is the second least expensive type of the six. The benefits of this type of production are that all fuel is made on the spot, a convenient way for Sweden with a lot of water and electricity available. In areas where the sun is a major energy source, the STCH production might become the dominant out of the two. However, with the current situation for Sweden electrolysis would most likely be the one to invest in regarding the climate, but also the total cost. That cost will over time decrease with more efficient installations and construction. As for the other fuels, this would lead to a fuel independence for Sweden without import through international trade.

By going through the production perspective of the fuels some thought appears behind the numbers. What might have been noticed is that the EV's are not mentioned. This is due to the assumption of the clean electricity production available is taken for granted and will not be discussed into details. Additionally to this subject if Sweden was about to develop an entire EV fleet, or H_2 likewise, the electrical production has to be increased. Therefore the estimation of the financial cost might increase a bit more. Furthermore, the worldwide electricity is mainly not produced in a sustainable way, which also increases the chances of a higher investment cost. But this will not be covered in this report and EV:s are seen to be the least expensive alternative due to production.

5.2.3 Distribution Analysis

The distribution situation for the Swedish population is the part that links the production with the vehicle performance together. There has to be a convenient way to refill your vehicle and the fuel cannot cost a fortune for the customers. In the case of convenience bioethanol, bio gas and hydrogen gas will all have a similar type of refill as today. A public station where to go when the tank is empty. In contrast to the EV:s they can be charged at multiple locations, such as home, at work, by the mall and other public places. The flexibility with the locations of these chargers is a great advantage in our world of constant change. If that flexibility was about to be used for the chemical fuels the grid of these would be enormous and extremely expensive. Since the grid of electricity is already exists there is no need of any major changes and modifications. For the public stations, regarding bio gas and bioethanol, the changes are small from the existing ones. A society of H_2 vehicles will see all stations change to the production/distribution service they have to be. To make these stations financial stable in the start a suggestion would be for the government to subsidize the construction until reasonable prices on the market. If not only the economical cost to implement this, it will also be a material waste to rebuild same but different. Hopefully, by that time there are some recyclable thinking of how most

of the structure can be maintained and reduce new material usage.

Furthermore regarding the important term "convenience" in the modern world, how to as simple as possible fuel your vehicle? Once again the change is very small for biogas, bioethanol and hydrogen gas in relation to today's system. The owner will go to the station, fill up their vehicle and pay within 5 minutes. There is nothing for the society to adjust to, just keep on as the regular refill.



Figure 21: *Could be the future look of Hydrogen refill stations, a clean and simple Japanese concept*

On the contrary, the mention electric powered vehicle will have to change that habit, as mention in earlier chapters. A full refill with current technology takes at least 40 minutes. That would be 40 minutes of just waiting at the charging pole. Therefore, a different way of refill has to appear, such as multitasking meanwhile the vehicle is charging. Not necessary a difficult change, due to the already mentioned flexibility of these charging stations this would be possible. The only accounted cost for electricity as a fuel are the charging stations of maximum 41,300 MSEK. These to put outside your work or the mall, which is already done at this very point, lead to a meanwhile activity. Who have said that the vehicle has to be fully charged during your time at the mall? The only necessity is to get to next location of a charger. The full charge can be done at home, where the household has their own AC Level 2 charger. By the time at home, two cars can be fully charged over the night. So why take a few extra minutes, that will become a lot of time in the long run, to refill your vehicle? With the lack of time everyone seems to have these days, is it not better to spend that time doing something more important?

Whatever is said it always comes down to the cost, the cheapest possible will at-

tract more customers. As displayed in Table 8 the price of H_2 varies depending on the production cost, but it is still far more expensive than the competitive fuels. Here is a problem for the hydrogen gas, the expensive production will not attract enough customers to build a base. Therefore the earlier mentioned subsidy for the fuel would be necessary for full establishment. According to a national study from U.S. Dep. of Energy's Hydrogen and Fuel Cell Program the price of hydrogen gas is estimated by 2020 to reach the low levels of 19.3 SEK and 25.4 SEK per gge for electrolysis and STCH, respectively [31]. For the industry of hydrogen, that prediction would lead to a fast increase of the consumption. All of that with the assumption that research is done. With more domestically based production the cost for bioethanol and bio gas the customer price would drop, due to fewer stops between production and distributor. To estimate a price is too hard to say, but prices can drop fast if the technology is there. Finally as in the case of EV:s the cost of charging at home will be based on each households' electric company contracts. As mentioned Tesla Motors calculations for home charging will cost around 2.46 [SEK/10km] [28]. But on public locations the charging situation for customers is free at poles and stations. However, there are places where the distributors have started to charge a few SEK per fully charged vehicle. All Tesla customers can also drive to the Super Chargers and charge their car for free, but the question is how long this will last? Free electricity will not last too long, nothing comes for free. Regarding Tesla Motors their way of having Super Chargers is probably a PR thing to attract more customers, which they have successfully done. But if the entire vehicle fleet would consist of EV:s someone has to pay the bill of you driving. And that someone will not be the automobile producers, it will be you. The started trend of a minor payment for public charging is just the beginning of the future. So if you think that you should buy an electrical car just because the fuel is free, you haven't thought in the long terms of what will be.

6 Conclusions

The question remains to be answered, what type of fuel should be the one for the future? First of all the reason of this report was to show the width of alternative fuels on the market available to people. There are more potential fuels that have not been brought up outside the coverage. As the report has proved from an environmental perspective all of them bio gas, bioethanol, electricity and hydrogen gas are better solutions than gasoline. Regarding the performance of bio gas and bioethanol, which have at least 15 years on the market, are getting closer to the gasoline average performance. The mentioned limits for an ideal combustion engine, heat engine, will cause issues sooner or later for these two. On the other hand, the two remaining fuels, electricity and H_2 , are in the area of an electrical engine, if fuel cells are assumed for hydrogen gas. Here there are bigger improvements to be made and are already showing results. A variable content of energy for a better future, a fuel economy that beats all others by far and that great acceleration due to instant torque makes the EV:s the best choice due to all categories.

Earlier said for the society integration there are big resources that have to be invested for such a major change of an entire country, but some would be bigger than others. From the financial point of view the electricity once again succeeds to be the most beneficial one, where hydrogen gas was the runner-up. Additionally, to the society integration this will take time and cannot be done over a night. Regarding Brazil as a well-established bioethanol country should not close down the whole production immediately. Bioethanol is a much better solution than the gasoline, which can be used as a transition step. For a big population as Brazil, the change will take longer time and bioethanol could be used until further has been decided. As for the convenience, these two remain at the top since there is no need of any major transportation of fuel to the location of the supply. For hydrogen gas distribution water is the necessary base together with electricity. Speaking of water the same speculations as for bioethanol can appear of ethical reasons, why waste our water to use it as fuel? There is a point in that thought, but in the case of Sweden there is no lack of water and the water treatment is one of the best in the world.

There is nothing that says that the future can have multiple of fuel supplies. There are benefits for using combustion engines, such as when operation in low temperatures. In the developing countries around the world, there might take longer time for the new technology to reach out. Thereby a solution for fast temporary improvements could be done with bioethanol to fuel the existing vehicles.

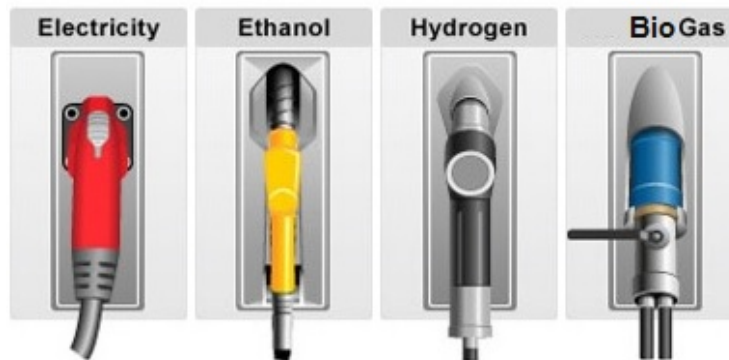


Figure 22: *The fuels of the comparison*

It might look like the discussion is promoting to buy a Tesla Model S, which is not the case. But the performance of the EV:s manufactured by Tesla Motors is in one class of its' own. They have shown the world what an alternative fuel can accomplish if given some time and effort. Over time and with technology development there might be a different solution for the automobile sector as shown in this report. In a scenario where clean electricity cannot be achieved, other options might be discussed. As for the future of electricity as a fuel, based on given facts, it has the brightest future ahead and can reach great potential.

7 Further Investigation

7.1 Deeper Analysis

As for this report, it is based on existing research done within the past 10 years. Some of these sources could have changed until this day 2016, and thereby multiple of data presented throughout the study can be better representative if a more updated versed personality were asked. As a consequence of that, for better accuracy in the result and conclusion outcome there has to be some tuning of values up to date.

Regarding the area of Well To Wheels, it would have been interesting to dig even deeper into the subject to get more information about how the industry is using the term. How is the WTT and TTW analyzed respectively to understand the performance of the fuels on the market? Will it be used in terms of see where improvements have to be done and find examples where such has been done? Furthermore, what are the engineers of combustion engines thinking of TTW? Since there are big losses in terms of heat and contribute to a higher TTW number, how are they speculate to improve a vehicle knowing that the temperature difference cannot be too big? On the contrary, what can be done on the production side to make the transportation more efficient? This would have given the study more depth and given a more scientific picture in the discussion, which would have lead to a more concrete conclusion.

Now the report has the main focus of personal vehicles, cars, which is the most frequently used vehicle of all. But to expand the study a little bit further it would be interesting to see how the sector of trucks looks like. They contribute to a big part of the polluting greenhouse gases and there has to be a change there as well. This could have given a different result since the trucks are in a different area of performance and have other claims. If analyzing the vehicle fleet as a whole, as in the case of the Swedish statement to be fossil free 2050, the important transportation by the truck sector needs to be included.

7.2 Suggestions for the Future

As the results and conclusion shows the electrical vehicles are a well-developed area in the automobile sector. A lot of great data is presented and positive promises are made for the future. Speaking of the future it is something we have not reached yet for the electrical vehicle, but what will happen then? Even electric vehicles will eventually getting old, like everything in this world, and at that point we will have millions of old vehicles containing tons of chemicals within their batteries. Therefore, an included subject for the society integration would be how to take care of battery leftovers? There have to be projects started how to recycle as much as possible to make the material usage sustainable as well. For the battery industry, this should be included beside the improvements of the batteries, to choose materials that are more recyclable friendly.

Thinking of the scenario if EV:s are going to replace the existing vehicle fleet one question remains to be asked, where will all the old vehicle go? We cannot just demolish them and buy new ones, instead as mentioned in the paragraph

above recycling is a necessity. Entrepreneurs have to create companies that take care of the cars and turn them into electric vehicles with a minimal waste. All the essential parts of a combustion vehicle, such as the engine and drive train, might be hard to convert to good usage for EV:s. The kind of recycling in mind is more aiming of structural parts of good condition as far as possible. Therefore, this will add another big investment cost that has not been included in this study, which would raise the total cost of society integration. However, in the case of hydrogen and biogas the modification from fluid to gas is an investment as well, not as big but still to take into account for the total cost.

8 Appendix

Referring to Table 6 on page 19: In the case of Table 6 and the WTW values for each fuel some clarifications has to be made about what they correspond to. First of all for the bioethanol is made for E85, which is a mean from different sources that covers multiple of fields. Then in the case of the bio gas the value is also just the average from a variation of sources. As for the electrical car the WTT energy was chosen to come from wind power, due to the criteria of environmentally friendly energy, which results in the low number of the losses. Finally, for the hydrogen powered car the Fuel Cell Vehicle (electrolysis process) is used and the electricity + hydrogen comes from wind power and through pipes, respectively. Worth to notice about the values for hydrogen vehicles in the EU Commission report is that they are estimating the values of what the efficiency might be 2020.

References

- [1] http://www.heblends.com/index.php?option=com_contenttask=view&id=25, (2016-07-03)
- [2] *"Effects of blends on the physical properties of bioethanol produced from selected Nigerian crops"* by International Journal of Ambient Energy, 2013
- [3] http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf, (2016-03-21)
- [4] <http://www.evtown.org/about-ev-town/ev-charging/charging-levels.html>, (2016-05-22)
- [5] *"POWERFUL POTENTIAL: BATTERY STORAGE FOR RENEWABLE ENERGY AND ELECTRIC CARS"* by WREN, 2015
- [6] <http://energy.gov/eere/transportation/hydrogen-and-fuel-cells>, (2016-03-22)
- [7] *"Progress in Energy and Combustion Science" Volume 35* by Hai Wang, Christof Schulz, 2009
- [8] www.afdc.energy.gov, (2016-04-10)
- [9] <http://www.insatsen.se/page12.html>, (2016-04-14)
- [10] *"Miljöbästa bilar 2015"*, by Gröna Bilister 2014
<http://www.gronabilister.se/rapporter>, (2016-04-22)
- [11] *"Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context"* by R. Edwards, J-F. Lariv  , M. Himabindu, J-C. Beziat, at European Commission Joint Research Centre
- [12] *"REALISERBAR BIOGASPOTENTIAL I SVERIGE ÅR 2030"* by WPS Sweden, 2013
- [13] <http://www.trafa.se/vagtrafik/korstrackor/>, (2016-06-04)
- [14] *"Brazil Passenger Vehicle Market Statistics"* by The International Council on Clean Transportation
- [15] <http://www.sekab.com/sv/bioraffinaderi/framtiden/>, (2016-06-27)
- [16] *"V  tgasinfrastruktur F  r Transporter"* by SWECO, 2014
- [17] <http://www.energimyndigheten.se/klimat-miljo/fossilfria-transporter/laddinfrastruktur/>, (2016-04-10)
- [18] <http://www.energigas.se/Energigaser/Fordonsgas/Tankstallen>, (2016-05-23)
- [19] *"SPBI Branchfakta 2015"* by SPBI, 2015
- [20] <http://www.biofuelnet.ca/2013/08/07/what-does-it-take-to-build-an-advanced-biofuels-plant/>, (2016-06-27)
- [21] <http://www.granbio.com.br/en/conteudos/biofuels/>, (2016-07-05)

- [22] *The NILE Project "Advances in Lignocellulosic Ethanol"* by 6th RTD Framework Programme of the European Commission
- [23] *"Laddat för kunskap, Laddstationer, Den kompletta guiden* by Energimyndigheten 2016
- [24] <http://www.homeadvisor.com/cost/garages/install-an-electric-vehicle-charging-station/>, (2016-07-09)
- [25] <http://www.pluginCars.com/quick-guide-buying-your-first-home-ev-charger-126875.html>, (2016-07-09)
- [26] <http://www.fch.europa.eu/project/thermochemical-hydrogen-production-solar-monolithic-reactor-construction-and-operation-750kw>, (2016-07-09)
- [27] *"Hydrogen Station Cost Estimates"* by National Renewable Energy Laboratory, 2013
- [28] <https://www.tesla.com/modelx>, (2016-07-28)
- [29] <http://www.nature.com/news/the-rechargeable-revolution-a-better-battery-1.14815>, (2016-07-11)
- [30] *"BIOGAS"* by Enerigas Sverige, Avfall Sverige and many more, 2011
- [31] *"DOE Hydrogen and Fuel Cells Program Record"* by U.S. Dep. of Energy's, 2015-2016