EUROPEAN PROJECT SEMESTER – SPRING 2019

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Table of abbreviations

CO_2 = Carbon dioxide

CO = Carbon monoxide

NO_X = Nitrogen oxide

O_2 = oxide

H_20 = Water

H_2 = Hydrogen

CH_4 = Methane

NO = Nitric oxide

LHV = lower heating value

HHV = higher heating value

PEM = polymer electrolyte membrane

PP = particle pollution

VO_s = volatile organic compounds

WTP = well to pump

PTW = pump to wheel

WTW = well to wheel

CNG = compressed natural gas

CBG = compressed bio gas

1. INTRODUCTION

Global warming is for everyone a term. The emissions of industry, agriculture, traffic and the population are reasons for the global warming. And that is not all the polluters of the environment.

To decrease the emissions of the road traffic, specific from passenger cars, trucks and buses, is one solution to slow down the Global warming. In this case the carbon dioxide, nitrogen oxides and particles have to be reduced. That is the reason to improve renewable fuels, find new fuels or make the way to use the existing fuels smarter because in the near future we are running out of fossils.

The share of biofuels used in Finland's road traffic will be gradually increased to 30% by the year 2029, according to new legislation passed by the Finnish parliament on 6 February 2019. Finland has also set a world-leading advanced biofuel target of 10%. A share of all light fuel oil that is intended for heating, construction machines and fitted motors, will be replaced by bio-based fuel oil starting from 2021. By 2028, there will be a distribution obligation of 10% for bio-based fuel oil.

"Finland is showing Europe the way for the decarbonisation of road traffic by setting the bar significantly higher than the EU's modest targets of 14% for renewable fuels and 3.5% for advanced biofuels," says **Jari Tielinen**, Head of Bio & Circular, Invest in Finland

Finnish companies are at the forefront of developing biofuel technologies. Neste is the world's leading producer of renewable diesel, Neste MY Renewable Diesel™ which is a low-carbon biofuel produced 100% from renewable raw materials. Finnish forest industry company UPM makes its BioVerno biofuel from wood-based tall oil and Finnish energy company St1 produces ethanol from bio waste and residues. (BUSINESSFINLAND 2019).

But not only biofuels could be the solution, as previously said to improve the use of the fuels and the engines or maybe hydrogen is the right answer.

1.1 Participants

Alec Van Doninck

Belgium

Home institution:

Thomas More Kempen

Degree program

Electro Mechanics

Carl Nots

France

Home institution:

National Engineering School of Tarbes

Degree program:

Mechanical Engineering

Felix-Maximilian Sprado

Germany

Home institution:

University of Applied Sciences Osnabrueck

Degree program:

Mechanical Engineering

Kent Roefs

Belgium

Home institution:

Thomas More Kempen

Degree program:

Electro Mechanics

Quentin Salles

France

Home institution:

National Engineering School of Tarbes

Degree program:

Mechanical/Industrial Engineering

1.2 What is European Project Semester?

The EPS is a one semester-long programme, which is designed to train and prepare engineering students to work in international teams. The semester consists of:

- Short courses in different topics such as
  - Teambuilding (1 cr)
  - Project Management, including lectures, practical training within the project and guidance throughout the semester. (2 cr)
  - English, academic writing and cross-cultural communication skills. (3 cr)
  - Local language, Swedish. (2 cr)
  - Supporting technical courses may be added if needed.

A project performed by a multi-national, multi-disciplinary team of 3 to 6 students. This is the main content of the semester. In the beginning of the semester, the available projects are presented after which the students are given the opportunity to give their preferences for which project they want to participate in. The students are then divided into teams in the beginning of the semester based on their own preferences, major studies, and nationality. The aim is to have a good mix of both nationalities and competences in each team.

The EPS-projects at NOVIA UAS are typically in the fields of renewable energy, energy saving, robotics and "cleantec" but other topics can occur.

The students should note that the aim in EPS is not only to have multidisciplinary teams, but also multidisciplinary projects. This means that one project typically requires different competencies. Since we try to do as many projects as possible with the local industry, we are unfortunately usually notable to inform the students in advance about the project topics. The decisions usually come in late.

EPS is a recognized 30-credit unit course according to the ECTS Qualitative Scale System. The language for oral and written communication during the semester is English. We also expect our EPS students to use the English language whenever working together in their teams.

The main objective is to train students from different countries and different disciplines to work together in multi-cultural and multi-disciplinary groups. The students work together to execute an integrated engineering-design-and-business project, focusing on:

- The development of personal competences, especially the ability to work and communicate within cross-cultural groups.

- The interrelated work of several disciplines like mechanical & electrical engineering, information technology, business & management, etc.

The EPS concept was developed in 1995 at Ingeniorhoskolen i Kobenhavn (IHK), Department of Export Engineering, in Denmark. At NOVIA UAS, we started EPS in 2010 and have since that had 195 incoming EPS-students of 24 different nationalities. General information about EPS and links to other organisations can be found at europeanprojectsemester.eu. More information about EPS at NOVIA and examples of earlier projects is found at eps.novia.fi.

European Project Semester (EPS) is a program offered by European universities in several countries throughout Europe to students, who have completed at least two years of their particular studies.

EPS is primarily provided for engineering students. However, students of other studies can participate as well in order to support the project with their specific knowledge.

Furthermore, EPS was launched to address the design requirements of the degree and prepare engineering students with ail additional necessary skills to face the challenges of today's world economy. It is a mixture of "project-related" courses and project organized/problem based learning.

Students work in international and interdisciplinary teams of three to six students on their multidisciplinary projects. Some of these projects are performed in cooperation with commercial businesses and industries whereas others are academic.

A main aim is that students learn to take responsibility for their studies and their work. In addition, the development of their individual intercultural competences, communication skills and interpersonal skills is essence of EPS. The language for ail oral and written communication during the semester primarily is English.

EPS is an experience, which helps students to grow up as engineers but as individual as well. Changing the personal approach to projects, the way of team-working and the mentality of working at ail should be the outcome of the project semester.

Taking part in this program means that students need to be determined to pursue their goals to grow up on the level of career and collaborate in teams with people from all over the world: knowing different countries as well as people and create links, respectively, collaborations between schools, students, professors and everyone, who's providing a constructive experience to the own work.

EPS is a unique way of growing up together and to improve the continuous exchange of ideas and knowledge with people of different cultures, backgrounds and languages.

1.3 Subject introduction

Nowadays, air is more and more polluted by car’s exhaust. CO_2 and other greenhouse gases are destroying our planet, while CO and particles matter are killing more and more people. So, acting right now is important.

During this project, an alternative to fossil fuels for powering cars in a near future is going to be searched and most especially, for Finland.

Many solutions are already possible, but the best one from an ecologically and economically point of view needs to be found.

In order to accomplish this mission, every source of information available to collect a maximum of data on every possible fuel and to compare them are going to be used. At the end, the best fuel possible for Finland should be found.

Before starting the research, it’s important to make us a team, in order to know each other, our strengths and weaknesses. For that, team building lessons have been followed. Then, project management lessons were useful to manage the project well.

2. TEAM BUILDING

2.1 Belbin Roles

After the Belbin test every team member got his Belbin role:

MEMBER OF THE TEAM	PRIMARY ROLE	SECONDARY ROLE
Quentin	Resource Instigator	Shaper
Alec	Plant	Monitor
Kent	Evaluator	Team-worker
Carl	Specialist	Plant
Felix	Completer/Finisher	Resource Instigator

According to the Belbin test, the team is supposed to be based on the Thinking part more than on the Acting. So, the team will have to make some efforts to work on the acting part of the project.

After the Belbin test, every team member should know on which type of activities he should perform. But, to make us a good team, it is important to define some team roles. It also important to plan meetings to improve them and make them the most efficient possible.

For our meetings, it is important to define who is going to be the secretary. The secretary is very important, he has to note every topic treated during the meeting and every solution proposed before sharing it with the group. Thanks to this work, everyone can know what was done and what must be done and how. The other important point during the meeting is the freedom of speech, everyone should be free to speak and to comment every point. But all critics have to be productive.

For helping the team during the meetings and also during the job, is useful to give all team members a role according to the skills of everyone:

TEAM MEMBER	ROLE
Quentin	Practical work, Documenter
Alec	Team-leader
Kent	Agenda
Carl	Group Manager
Felix	Research, Practical work, Group Manager

Even if all these roles look strict, every team member is on the same level and all the decisions are taken together.

2.2 Team Contract

The team contract is here to tell the team members how they should work together following the values and the goal of the team.

Here, our team's values are:

- **Respect the freedom of speech of each other**. This is the most important for the team, every member has to feel free to talk during meetings and work. This is the only way to work together.

- **Have fun.** The good mood is really important to improve our work. So, having fun together regularly is the best way to create and improve links between team members.

- **Looking for the best results.** The team exists for working and maybe finding a solution for the environmental issues due to engines, that is why the team must always look for the best results.

This contract is composed by 14 rules turning around these 3 values but also it also discusses about common rules on topics like respect, critic or punctuality for example.

It contains also a sanction for those who breaks a rule.

And finally, all team members signed it to show their engagement to this contract.

TEAM CONTRACT

Fuel Boomers

Team members:

Alec Van Doninck

Kent Roefs

Quentin Salles

Carl Nots

Felix Sprado

Team rules:

1. Team members will always be looking for the best result.
2. Team members will always be honest.
3. Team members will do meetings at least once a week.
4. All team members will respect the freedom of speech for other members. Every team member is free to speak and to bring any idea during the job.
5. Every critic will be constructive and helpful.
6. During meetings, secretary will take notes and share them with the rest of the team, the secretary will change for every meeting.
7. Decision making policy: by majority vote.
8. Team members will share their job regularly on Trello, Dropbox or Google drive.
9. Team members will always respect deadlines.
10. Kent will manage the agenda and will remind the team for all deadlines.
11. The team will always work in the good mood.
12. Team members will take a drink together at least once a week.
13. If a team member is late, he must text the team as soon as possible to prevent.
14. Sanction: If a group member is late for more than 15 minutes and he doesn't text the team to prevent, he will have to bring coffee for all the team.

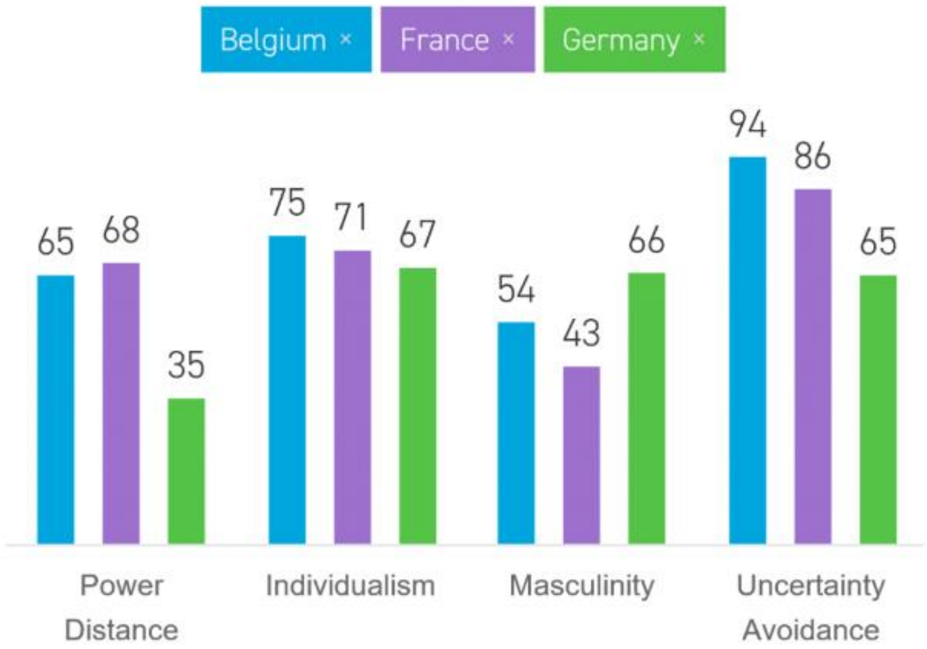
Signatures:

Alec	Felix	Carl	Quentin	Kent

2.3 Hofstede

The Hofstede's study consists by comparing every nation and culture around few topics. This study is supposed to explain comportment of a person by his nationality, and, thanks to this, it can say what types of conflicts can appear in a group of different nationalities.

Our team is composed of Belgian, German and French people.



Picture 1 - Hoeftede's Cultural Table

The first problem that we can expect is on power distance, especially for German people. They have a very low power distance, it's means that they feel very close to their boss, so they can be a bit informal.

We also see that French people tend to start working close to the deadline, but German and Belgium people prefer working in advance so this situation can be a source of conflicts. The solution could be to put some deadlines earlier to prevent this type of problem.

2.4 Tuckman/Katzenbach

Katzenbach

Katzenbach´s explanation for a team is: "a small group of people with complementary skills who are committed to a common purpose, performance goals and approach for which they are mutually accountable".

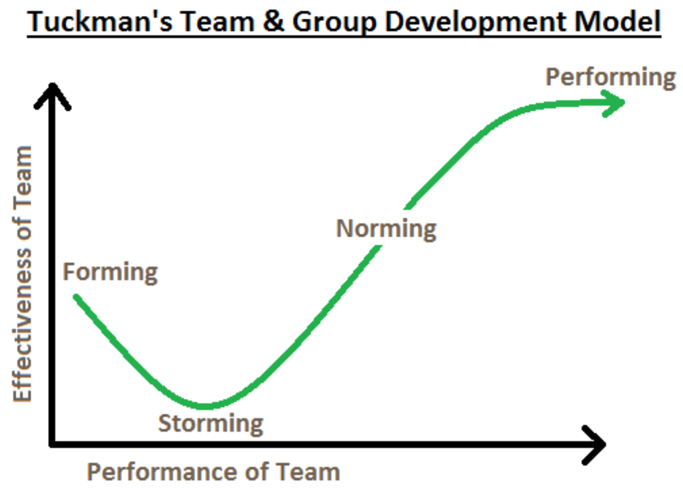
The group members interact primarily to share information, best practices or perspectives and make decisions to help each individual, perform within his or her area of responsibility, without any real common purpose, common performance goals, and mutual accountability or join work-products.

The description from Katzenbach for a team sounds simple and easy, but the reality is different. Tuckman has his imagination from team-work.

Tuckman

To lead a team is not always easy. On the way to the destination or to find the solution are always situations with highs, but these situations could take turns with deeps. In the high situations the team is productive, make good experiences and the progress goes on but on one point everything can change and it seems to be you walk on one spot.

Dr. Bruce Tuckman published in 1965: "Forming, Storming, Norming, and Performing Model". In this model he explained the previous described situations. Furthermore the model explains that as the team develops maturity and ability, relationships establish and the leader changes leadership style. Beginning with a directing style, moving through coaching, then participating, finishing delegating and almost detached. At this point the group is working successful (THECOACHINGTOOLSCOMPANY 2014)



Picture 2 - Tuckman model (THECOACHINGTOOLSCOMPANY 2014)

FORMING:

In the first phase everybody has to know each other and has to find his position in the group. All members are quiet and are not sure what they have to do.

STORMING:

The members knowing each other better, the tasks are divided and they start motivated with their work. The Problem is they are over motivated a result is that they are not always properly matched to each other and a bad mood can happen.

NORMING:

A next step is organisation. The leader has to build clear structures.

PERFORMING:

Structures are clear and everyone knows what he has to do. The group is getting creative and flexible they are working together be efficient and productive. Reach the destinations by working together and not against.

3. PROJECT MANAGEMENT

3.1 Project Interrogation Management

First of all, in order to understand why we use Project management in our project to get the necessary methods for completing our project, the term “Project Management” must be defined. The definition of Project Management is as following: “Application of knowledge, skills, tools and techniques to project activities to meet the projects requirements. Project management is accomplished through the appropriate application and integration of the 42 logically grouped PM processes compromising the 5 process Groups:”

- Initiating
- Planning
- Executing
- Monitoring and controlling
- Closing

For every project, you need to be able to identify three things:

Now that we know the definition and the meaning of project management, we can now use those methods and techniques in our advantage to complete our project and get the results we are working for. Without it, it’s difficult to create the optimal path for getting the optimal result on an efficient way. In the following paragraphs, each specific part of the project management will be explained and showed how we, as a team will use the different technics in our project.

But before any further details about project management, let us look at another important term which is “Project”. The definition of a “Project” is: “A temporary endeavour undertaken to produce a unique product, service or result”, in our case the wanted results are the conclusions and recommendations gather from technical and scientific sources in order to provide a solution, or multiple solutions, for the current rising fuel crisis and ecological problems in Finland in terms of fuel consumption and pollution.

So we can say that a Project is a single task, selected from other tasks, which must fulfil a specific object, controlled by assigned resources, within a specific time limit. For our project the task is already explained above, the assigned resources are the school building and its properties, Tritonia (library), and any other sources or locations we can get access to. The time limit is approximately 4 months, from the 4th of February until 14th of May. It is true that we have a specific task but there are a lot of different ways to approach the task so there is no specific objective which will result in the success of our project. Nevertheless, the objective is to find a solution for the ongoing fuel crisis.

With the following said we can say that our research fits the terms of being a project and therefore we can use of the different techniques and tools used in project management to work out our research project.

Now follows the different steps we will need in requirement to complete the project.

3.2 Project Scope Management

Mission, Vision and Objective

In the beginning of a project it is important to define the Mission, Vision and Objectives of your project. Defining for a certain project is one of the most important steps. It is vital for a project to succeed because the definition will affect the way you will start looking for solutions. An ill-defined problem can lead to the right solution for the wrong problem! This said make always sure the defining at the correct at the beginning. The mission of a project defines the statement about what problem should be address and the Vision tells us how it looks when the problem/task is solved. It is a feedback of what has been solved and its influences on other parts.

It is important to have a good mission statement because a bad/wrong statement can lead to a failure of the project, examples are unclear costumer, too narrow mission statement, etc. Once a Mission and Vision statement has been made we can determine the defining of the objective. The objectives are specified outcomes, results that must be achieved in order for the mission to accomplish, they describe the desired end results. It is important that a well-formulated objective does not describe how they will be achieved.

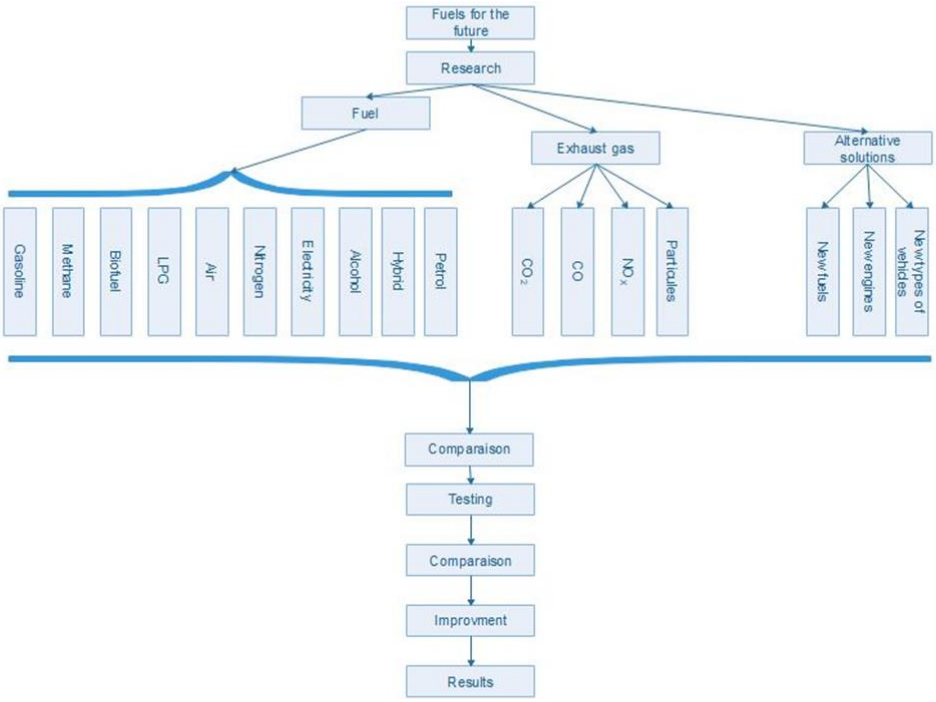
For that project assigning our Mission, Vision and Objective could be done that way:

MISSION	VISION	OBJECTIVE
Research about all the fuels and compare them	Provide the best solution for Finland	Find the fuel of the future

WBS

Now we start planning our project. For this we need to answer some questions like: what, who, when, etc. To answer the first question we are going to use a WBS. WBS stands for Work Break Structure and is designed to identify all work to be done. Reminder is that it doesn't say anything about the sequential order, it just say's what. A WBS goes as following: it breaks the work down in smaller units so it is possible to do estimations on things like: time, cost, resources needed, etc.

WBS applied

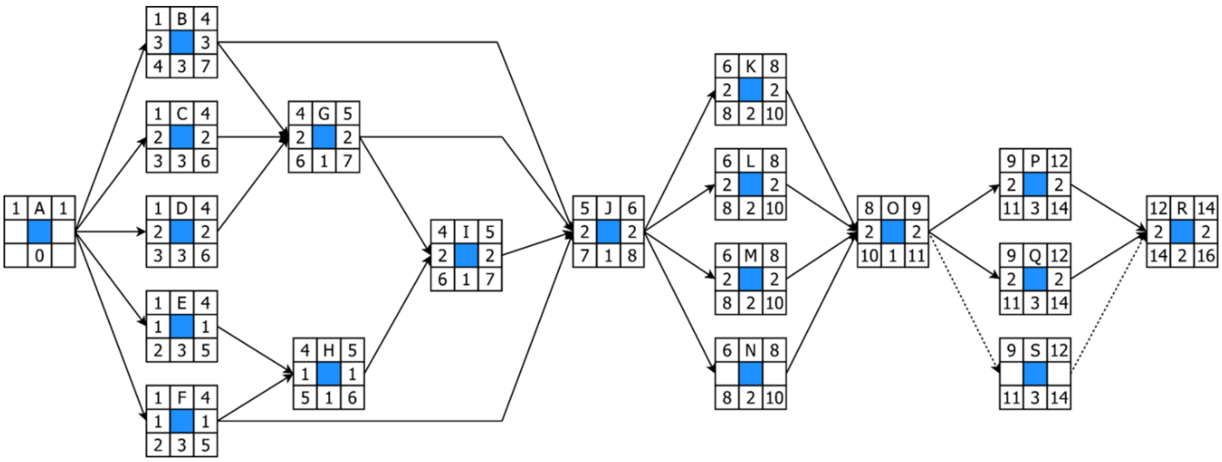


Picture 3 - Work Breakdown Structure applied

The image above is a WBS scheme designed according our project. As you can see there are a lot of tasks, this is because we have a very broad project, there is no direct way to solve our mission and reach the objective, instead there a multiple ways we found at the beginning of reaching our objective. This is because new technologies and new inventions causes rapid changes in the development of new solutions and ways to find solutions. As of pollution being one of the largest problems today combined with the ongoing growth in energy demand, every country is developing in new and better/greener ways of developing solutions for this problem. Therefore, our path to the solution of our mission is changing. This explains the wide part of the WBS in the beginning. Once we have what we think is the best solution or are the best solutions we move to the field-testing phase where we will confirm our research. As the testing is completed, we move the end phase of our project; the report. In the report you will find all our researching and testing result that we found or accomplished during the project. Since as said before the world is constantly changing, the things you can find in the report can be outdated on a rather quick level. Therefore, the actual time of this project to reach the best results is infinite. This project is ongoing and has to been done in multiple timelines to get the optimal results.

3.3 Project Time Management

Next step in the project management is to make a schedule, or to schedule the problem until the moment you want the solution. It is interesting to start the schedule from the WBS and any other relevant documents you have that have influence on the project. A CPM is a helpful way to determine the time needed for each part of the project. CPM stands for Critical Path Method and was developed by Du Punt. It is designed to help identify the critical activities, those where delays cannot be allowed. Delaying to those activities can result in delaying the entire project. The following CPM has been made according our WPS



Picture 4 - Arrow Chart

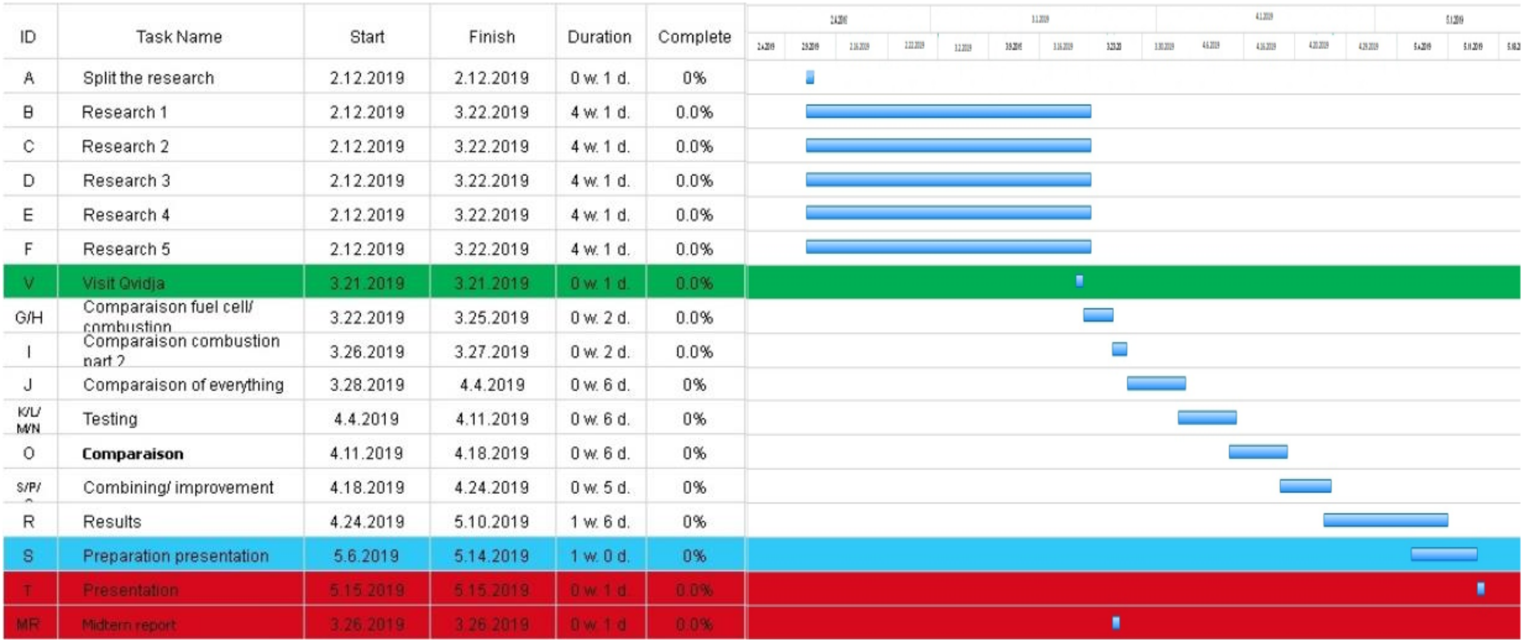
A: Split the research
B: Research 1: Hydrogen and Electricity
C: Research 2: Bio methane and Methane
D: Research 3: Ethanol and Methanol
E: Research 4: Diesel, kerosene
F: Research 5: Gasoline and Engine
G: Comparison Fuel Cell
H: Comparison ICE I: E & F
I: Comparison ICE II: B, C, D, E & F
J: Comparison all fuels
K: Testing Fuel Cell
L: Testing Combustion engine
M: Electricity
N: Testing Air
O: Comparing again
P: combine different fuel types
Q: Improve fuel types
R: Write report and final answer
S: Develop new prototype engine

ES	**ID**	**EF**
SL		**SL**
LS	**DUR**	**LF**

ES = Earliest start
ID = Identification
EF = Earliest Finish
SL = Slack
LS = Latest start
DUR = Duration
LF = Latest Finish

The explanation of each number is given bellow in the following drawing:

Next is a bar chart, it gives us a better visual overview of our time and estimated time over different parts of our project. This was one of the only tools available in the mid 50's for scheduling. It was developed by Henry Gantt who developed a complete notional system for showing progress with bars. The following bar chart is designed according our project:



ID	Task Name	Start	Finish	Duration	Complete
A	Split the research	2.12.2019	2.12.2019	0 w. 1 d.	0%
B	Research 1	2.12.2019	3.22.2019	4 w. 1 d.	0.0%
C	Research 2	2.12.2019	3.22.2019	4 w. 1 d.	0.0%
D	Research 3	2.12.2019	3.22.2019	4 w. 1 d.	0.0%
E	Research 4	2.12.2019	3.22.2019	4 w. 1 d.	0.0%
F	Research 5	2.12.2019	3.22.2019	4 w. 1 d.	0.0%
V	Visit Qvidja	3.21.2019	3.21.2019	0 w. 1 d.	0.0%
G/H	Comparaison fuel cell/ combustion	3.22.2019	3.25.2019	0 w. 2 d.	0.0%
I	Comparaison combustion part 2	3.26.2019	3.27.2019	0 w. 2 d.	0.0%
J	Comparaison of everything	3.28.2019	4.4.2019	0 w. 6 d.	0%
K/L/ M/N	Testing	4.4.2019	4.11.2019	0 w. 6 d.	0%
O	**Comparaison**	4.11.2019	4.18.2019	0 w. 6 d.	0%
S/P/	Combining/ improvement	4.18.2019	4.24.2019	0 w. 5 d.	0%
R	Results	4.24.2019	5.10.2019	1 w. 6 d.	0%
S	Preparation presentation	5.6.2019	5.14.2019	1 w. 0 d.	0%
T	Presentation	5.15.2019	5.15.2019	0 w. 1 d.	0.0%
MR	Midterm report	3.26.2019	3.26.2019	0 w. 1 d.	0.0%

Picture 5 - Bar Chart

The bar chart shows each layer of time there is for the needed part of our project.

3.4 Project Cost Management

Making a cost structure is really important if you want to start a project because you need a good overview from the costs and at what time you are going to have them. Then you don't have that much surprise from unexpected expenses. You also can follow if you are on trajectory with the costs you already used and the time over that.

Making a cost structure of our project is more difficult because we have not really costs only work hours and maybe the excursion we do to companies about biofuels.

We don't have to buy anything because we got our own laptops and have free entrance to all the information sources we need e.g. we got a cooperation between NOVIA University of Applied Sciences and the library Tritonia, internet and final papers from formal student with side information.

Another problem is that this is not a project whit a normal time limit, only time limit for the time we are here but actually on this project research never stops because there are always coming new technics.

Now following a cost structure for our project assuming that we are a company. The factors we have to think about is the work hours for five members in a working week of 38 hours. Further the excursion we already did to biomass factory.

The cost for buying our laptops and rent an office and fixed costs for each month.

- Work hours

This is the biggest cost. How much it cost for a firm or government that wants to hire us, the price we ask for our working hours.

- Buy work material

The cost that we have if we are a real company to buy our laptops for example.

- Excursion

This cost exist out of a few things: the travel, hotel, food and the excursion itself at the company. If we estimate the cost of this is 200euro, 225euro, 30euro and 50euro total of 505 euros.

- Office

The cost that we have if we are a real company once a month for an office with electricity and internet.

Tasks	week1	week2	week3	week4	week5	week6	week7	week8
Work hours (38h/week) (25€/h)	4750	4750	4750	4750	4750	4750	4750	4750
Buy work material e.g. 5laptops	5000							
Excursion biomass factory							505	
Office rent	950				950			
Weekly cost	10700	4750	4750	4750	5700	4750	5255	4750
Cumulative spending	10700	15450	20200	24950	30650	35400	40655	45405

Tasks	week9	week10	week11	week12	week13	week14	week15	week16
Work hours (38h/week) (25€/h)	4750	4750	4750	4750	4750	4750	4750	4750
Buy work material e.g. 5laptops								
Excursion biomass factory								
Office rent	950				950			
Weekly cost	5700	4750	4750	4750	5700	4750	4750	4750
Cumulative spending	51105	55855	60605	65355	71055	75805	80555	85305

In conclusion, for the cost part, we can say that the estimation of that kind of a project research in a formal company should be around 85.000 €.

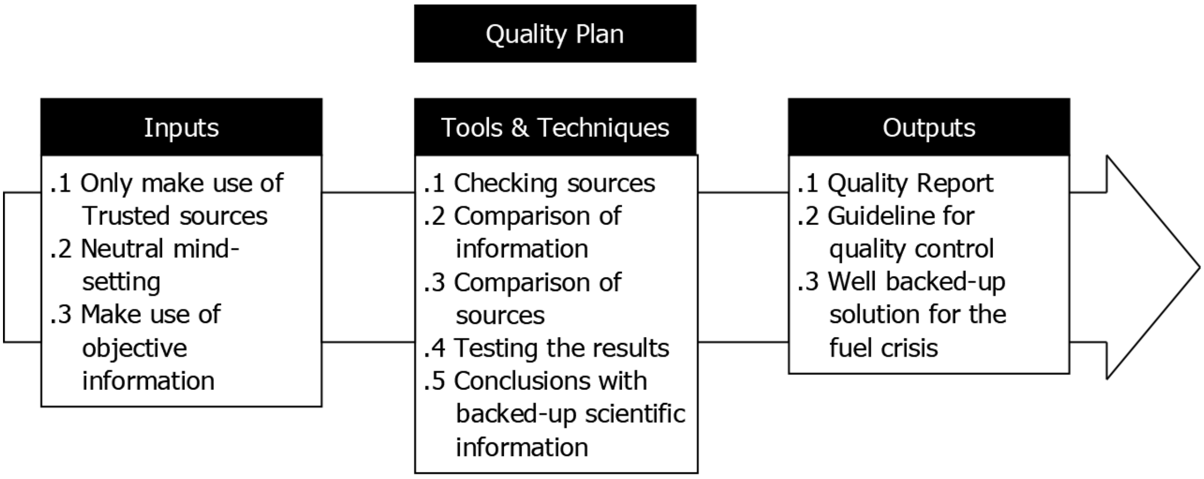
3.5 Project Quality Management

Another important step in project management is the quality management of your project. The quality is important because it will reflect heavily on the outcome of your product. Also, it is important to notice that when little effort is put on quality in order to save costs could lead to the opposite result in failure costs like scrap, rework, lost work hours, etc.

So therefore, it is to say that quality is something that can't be ignored in the goal of achieving the right solution for the project.

In our case the quality does not reflect on an output quality like a product or service, but more on the quality of the input, the informational documents, videos, visits at local industries, etc. This is because the quality of the input reflects heavy on the quality of the output. Getting wrong information will lead in a wrong conclusion. Also, the way how we use that information, the tools and techniques, are important. It is necessary that we use the given information on the correct way to ensure a correct result/output. To accomplish this, we will make use of a quality plan.

Quality plan



Inputs:

For the inputs it is important that we make only use of trusted sources that are well known for their quality in reports like certain books or articles. Certain publishers of books can indicate for the authenticity of the information. What is also important in a research like our project is to keep objective during the research. Mixed opinions and preferences toward certain subject can lead towards false statements which will lead to a negative impact in our end quality.

Tools & Techniques:

Here we need to do a lot of consistency checks on the retrieved information. A well trussed source doesn't mean a hundred percent authenticity! Is important to check the source every time you get new information and to double check the information as well as the source of the information. Testing our retrieved information can be a good way to verify its content. As for conclusions it's important to always back them up with good reliable information to support its statement.

Outputs:

We desire a report which has an optimal solution for the current problem combined with the highest possible quality to increase its effectiveness of the project. Without the desired quality our project can't ensure a proper solution.

3.6 Project Communication Management

The most important point about the communication in this project is the way of we resume and present our research. The presenting data have to be explained and compare to make sure that the reader will understand them. The way in which we choose between different fuels have also to be explained in detail to convince the reader.

At the end of the project, all data will be present in a book and during an oral presentation. This oral has to be the clearest possible to make understand others our choices. This is why a good communication is important during the work but also when the results will be presented.

3.7 Project Risk Management

Planning the risk is the goal of this part. Anticipate this risk to avoid them is the best way to protect the project. A risk is defined as an event which can put in danger the project realisation, by slowing it down or even stop it. If you ever know what kind of risk you can encounter during your project, you can already plan some actions to avoid or solve every problem.

The principle is to define, at the project beginning what kind of problems could appear, their probability and the impact that could have this problem on the project. Of course, the goal is also to find in advance solutions to avoid this project before they appear or, to define what to do if these problems are unavoidable.

For our project we have found out six main potential problems:

- Using wrong information. This is the most probable problem (3/5 of probability). A big part of our project is based on research and it's very possible to find out wrong information on the internet. This could be very problematic (4/5 of Impact), if we base our choice of fuel for the future on wrong information, all the project will be wrong and useless.
  To avoid this problem, it exits a simple solution. This is to work with different sources to be sure of the information.
  But this problem could happen even with this precaution, so to solve the problem, we should delete every information on the concerned subject to restart more carefully the research.

- The second most likely risk is that we are going to miss some time for the testing part (3/5 of probability). But even if this risk has a high probability, his impact will be low on the project (1/5 of impact). Testing will be a good bonus for our project, but it is not essential. But to try to avoid this problem we have to respect the agenda.
  And if it happens, the solution will be to improve the research part to give enough information to convince the reader without tests.

- The next most possible risk is that a new fuel or a new technology is discovered after the end of our research (2/5 of probability), this will make our result obsolete if this is a major advance in the fuel field (3/5 of impact).
  To avoid this type of risk, the best solution is to keep looking regularly for the new technologies in this field. Like this we could react faster to include this invention in our study.
  And if we can't avoid it, the best way to solve the problem is to quickly make a study on this new topic to see if it's a better solution than ours.

- Even if we are a good team, some conflict can appear in our group (2/5 of probability). This is a big risk for us because it will slow down a lot the project so we will have to fix it quickly (3/5 of impact).
  To avoid these conflicts, the best way is to have fun regularly all together, to improve the links between us.
  But sometime conflict can appear even with strong links between the team members. So, to solve this problem the most quickly possible is to take few minutes of break and to talk all together to solve any conflict.

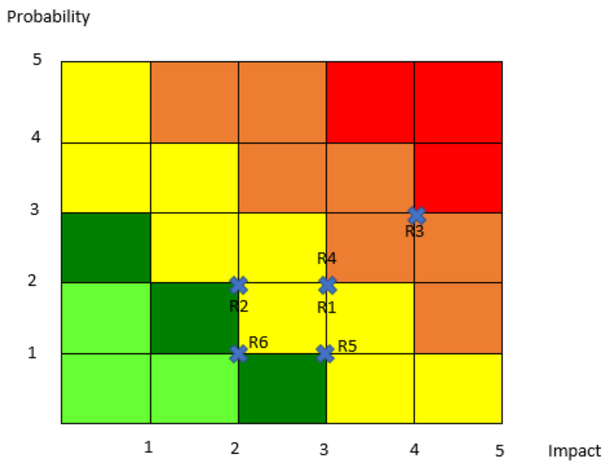
- The materiel that we use is not infallible, so a computer failure can happen (2/5 of probability). If any precaution is taken before, work can be lost (2/5 of impact).
  So, it is important to save the work online, on Dropbox or Trello for example. By doing this the work can't be lost.
  And if a computer broke down, we will just have to transfer the work save online on another computer.

- The last problem that we found is that we miss some time to finish the project (1/5 of probability, 2/5 of impact).
  The simple way to avoid it is just to follow the agenda.
  But if it happens anyway, we should be the most precise possible on our research, like this the reader can make is own deduction based on our information.

You can find a recap of these risks below:

Number	Risk	Probability	Impact	How to prevent?	What to do if it happens?
R1	New fuel/technology is discovered after our researches	2/5	3/5	Be regularly aware on new technologies about the topics	Make a quick study to know if this invention can be useful for our project
R2	Computer failure	2/5	2/5	Save all our work on Dropbox or Trello	Transfer all the work from Dropbox on another computer
R3	Wrong information	3/5	4/5	Use different sources	Delete all information on the topic and restart searching
R4	Team conflict	2/5	3/5	Having fun regularly all together	Take few minutes to talk all together to make everything clear
R5	Not enough time for the testing part	3/5	1/5	Try to respect the agenda	Work more on the research part to be sure of the results
R6	Not enough time to finish the project	1/5	2/5	Try to respect the contract	Be the most precise on the research then the reader can make a choice by himself

Here is the risk matrix:



Picture 6 - Risk Matrix

4. PRESENTATION OF THE DIFFERENT FUELS

4.1 Introduction

4.1.1 Fuels

What is a fuel?

"A fuel is any material that can be made to react with other substances so that it releases chemical or nuclear energy as heat or to be used to work." Trinitia Academy

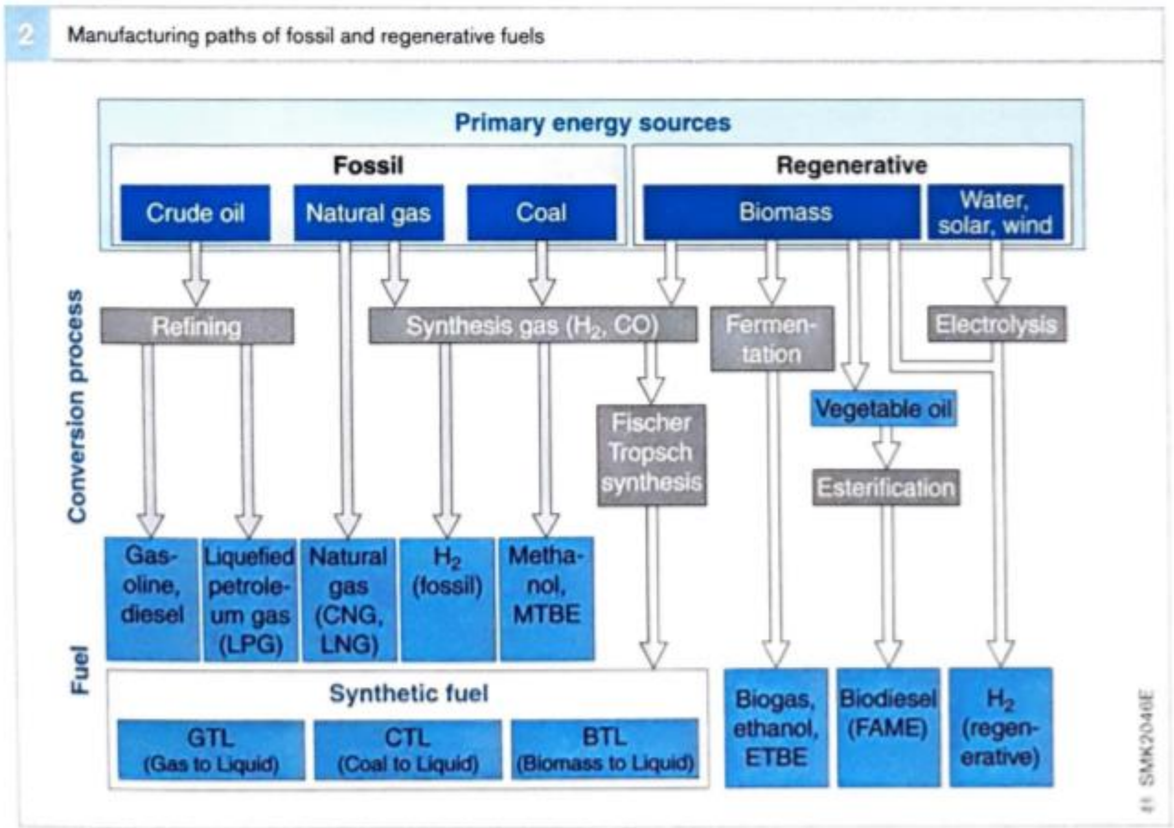
The most important energy source from which fuels are extracted is petroleum or crude oil. Crude oil was formed over millions of years from the remains of decomposed living organisms and is made up of many different hydrocarbons. High-quality fuels make an important contribution to trouble-free vehicle operation and to low exhaust-gas emissions. The composition and properties of fuels are therefore governed by legal provisions.

4.1.2 Alternative fuels

As well as the processes for producing gasoline and diesel fuels, there are different technical formulations for producing alternative fuels from different sources of energy. The main creation and conversion processes are shown in Figure 2. The complete journey fuel takes in the course of its production and provision - from primary-energy extraction through to its introduction in the vehicle's fuel tank - is known as the "well to tank" path. In order to evaluate the different fuel options with regard to C02 emissions and energy balance, it is necessary not only to include this entire path but also to take into account the efficiency of the respective vehicle drive system as it is this latter factor which determines fuel consumption. It is not enough simply to evaluate the combustion of the fuel.

In this context, a distinction is made between fossil fuels, which are produced on the basis of crude oil or natural gas, and regenerative fuels, which are created from renewable sources of energy, such .is biomass, wind power or solar power. Alternative fossil fuels include liquid fuel petroleum gas, natural gas, synfuels (synthetic liquid fuels) created from natural gas, and hydrogen produced from natural gas. Regenerative fuels include methane, methanol and ethanol, provided these fuels are created from biomass. Further biomass based regenerative fuels are synfuels (synthetic liquid fuels) and biodiesel. Hydrogen extracted by electrolysis is then classed as regenerative if the current used comes from renewable sources (wind energy, solar energy). Biomass-based regenerative hydrogen can also be produced.

With the sole exception of hydrogen, all regenerative and fossil fuels contain carbon and therefore release C02 during combustion. In the case of fuels produced from biomass, however, the C02 absorbed by the plants as they grow is offset against the emissions produced during combustion. The C02 emissions to be attributed to combustion are thereby reduced.



Picture 7 - Alternative fuels

4.1.2.1 Alternative fuels for spark-ignition engines

Natural gas and liquefied petroleum gas are primarily used as alternative fuels in spark ignition engines. Spark-ignition engines that run on hydrogen are currently restricted to test vehicles. Alcohols are mainly used in Europe and the US as gasoline additives. In Brazil, pure ethanol is also used as a fuel. Synthetic fuels are used exclusively in diesel engines.

To enable engines to run on many of the alternative fuels mentioned, it may be necessary to adapt the fuel-injection components and where required the vehicle engine and the fuel tank. Today, more and more vehicle manufacturers are offering natural-gas vehicles straight off the production lines. Bivalent vehicles are primarily used here, i.e., the driver can switch between gasoline and gas operation.

Natural gas (CNG, LNG)

The primary component of natural gas is methane (CH4), which is present in proportions of 80...99 %. Further components are inert gases, such as carbon dioxide, nitrogen and low-chain hydrocarbons. Natural gas is stored either in gas form as Compressed Natural Gas (CNG) at a pressure of 200 bar or as a liquefied gas (LNG: Liquefied Natural Gas) at -162 °C in a cold-resistant tank. LNG requires only one third of the storage volume of CNG, however the storage of LNG requires a high expenditure of energy for cooling.

Natural-gas vehicles are characterized by low CO2 emissions, due to the lower proportion of carbon in natural gas. The hydrogen-carbon ratio of natural gas stands at approx. 4:1, that of gasoline, on the other hand, is 2,3:1. Thus, the process of burning natural gas produces less CO2 and more H2O. A spark-ignition engine converted to natural gas - without any further optimizations already produces roughly 25% fewer CO_2 emissions than a gasoline engine.

Because of the extremely high knock resistance of natural gas of up to 130 RON (gasoline 91...100 RON), the natural-gas engine is ideally suited for turbocharging and enables the compression ratio to be increased. In this way, it is possible in conjunction with a downsizing concept (reduction of displacement) to improve engine efficiency and further reduce CO2 emissions.

Liquefied petroleum gas (LPG)

Liquefied Petroleum Gas (LPG) is primarily a mixture of propane and butane and is use< to a limited extent as a fuel for motor vehicles. 1t is a by-product of the crude-oil-refining process and can be liquefied under pressure. The demands placed on LPG for use in motor vehicles are laid clown in the European standard EN 589. The octane number MON is at least 89. CO2 emissions from an LPG engine are roughly 10 % lower than from a gasoline engine.

Alcohol fuels

Specially adapted spark-ignition engines can be run on pure methanol (MIOO) or ethanol (El00). These alcohols are, however, mostly used as fuel components for increasing the octane number (e.g., E24 in Brazil and E10, E85, M85 in the USA). Even the ethers that can be manufactured from these alcohols MTBE (methyl tertiary butyl ether) and ETBE (ethyl tertiary butyl ether) are important octane-number improvers. Ethanol, because of its biogenous origin, has become a highly significant alternative fuel in some countries, above all in Brazil (manufactured by fermentation of sugar cane) and the USA (from wheat). Methanol can be manufactured from readily available natural hydrocarbons found in plentiful substances such as coa1, natural gas, heavy oils, etc.

Compared with petroleum-based fuels, alcohols have different material properties (calorific value, vapor pressure, material resistance, corrosivity, etc.), which must be taken into consideration with respect to design. Engines with can burn gasolines and alcohols in any mixture ratio without the driver having to intervene are used in "flexible fuel" vehicles.

Hydrogen

Hydrogen can be used both in fuel-cell drives and directly in internal-combustion engines. CO2 advantages are enjoyed, particularly when the hydrogen is created regeneratively by electrolysis from water or from biomass. Today, however, hydrogen is predominantly obtained on a major industrial scale by means of steam reforming from natural gas, in the course of which CO2 is released. Even the distribution and storage of hydrogen is still technically complex and expensive today. Because of its low density, hydrogen is mainly stored in one of two ways:

- Pressure storage at 350 bar or 700 bar; at 350 bar, the storage volume referred to the energy content is 10 times greater than with gasoline.
- Liquid storage at a temperature of -253 °C (cryogenic storage); this gives rise to four times the tank volume of gasoline.

Air

Air as a fuel could sounds weird but it could be a reality in the next coming months and years. Indeed, nowadays two different technologies are using the air to powered cars without emitting pollution. The first one which is going to be present on this report is the PSA Hybrid-Air technology, and the second one is the MDI Airpod.

Electric drive with fuel-cell power supply

The fuel cell converts hydrogen with oxygen in the air in a cold-combustion process into electrical current; the only by-product of this process is water vapor. The currents serves to power an electric motor acting as the vehicle drive. Polymer-electrolyte fuel cells (PEM fuel cells), which operate at relatively low temperatures of 60...100°C, are primarily used for the vehicle drive. The system efficiency of a hydrogen-fuelled PEM fuel cell including electric motor is in the range of 30...40 % (referred to the New European Driving Cycle NEDC) and thus clearly surpasses the typical efficiency of an internal-combustion engine of 18...24 %.

Hydrogen in a spark-ignition engine

Hydrogen is an extremely ignitable fuel. Its very high ignition performance permits a strong leaning of the hydrogen/air mixture up to approx. $\lambda = 4...5$ and thus extensive dethrottling of the engine. The extended ignition limits compared with gasoline, however, also increase the risk of backfiring. The efficiency of a hydrogen combustion engine is generally higher than that of a gasoline engine, but lower than that of a fuel-cell drive. The process of burning hydrogen produces water and no CO_2.

4.2 Splitting the research

First step of the project was actually to split the research, the result can be found below:

Topics		ALEC	CARL	KENT	FELIX	QUENTIN
OIL	Diesel		X			
	Petrol					X
	Kerosen					X
	Alcohol	X				
	Biofuel		X			
GAS	Methane				X	
	Hydrogen			X		
	Air		X			
	LPG				X	
	Nitrogen					X
ELECTRICITY	Electric			X		
EXHAUST GAZ	CO2	X	X	X	X	X
	CO	X	X	X	X	X
	CO4	X	X	X	X	X
	NOx	X	X	X	X	X
	Particules	X	X	X	X	X
ALTERNATIVE SOLUTIO	New fuels					
	New engines					
	Hybrid					
	Dual fuel engine					
	New types of vehicles					

Picture 8 - Split of Research

4.3 Finnish oil statistics

http://www.oil.fi/en/statistics

The Finnish Petroleum and Biofuels Association collects and compiles statistics for the use of its members and Finnish and foreign authorities. Beside Statistics Finland, the statistical data is used e.g. by the National Emergency Supply Agency and by various state and municipal authorities. On this web site you will find statistics on oil, both international statistics and statistics on the oil sector.

4.3.1 Prices and taxes

4.3.1.1 Consumer price update

The consumer price update does not reflect the average prices of the whole country but changes in consumer prices. Please see the explanatory notes of compiling these statistics after the table. The statistics will be updated approximately 4 working days after the 15th of each month.

Prices : Consumer prices

(A) = price incl. taxes. (B) = amount of tax included in the price. (C) = price without taxes

	Petrol 95 E10			Petrol 98 E5			Ethanol (E85) automotive fuel			Diesel fuel			Heating oil (sulphur free)		
	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)
	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l	c/l
2018															
15.11.	155.0	97.3	57.7	166.0	100.9	65.1	108.6	66.1	42.5	154.6	80.9	73.7	103.3	44.4	58.9
15.10.	153.8	97.1	56.7	162.3	100.2	62.1	109.7	66.3	43.4	144.5	79.0	65.5	107.6	45.2	62.4
15.9.	157.8	97.8	60.0	166.0	100.9	65.1	108.3	66.0	42.3	140.3	78.1	62.1	104.1	44.5	59.5
15.8.	157.0	97.7	59.4	166.1	100.9	65.2	108.1	66.0	42.1	139.6	78.0	61.6	103.3	44.4	58.9
15.7.	151.6	96.6	55.0	160.4	99.8	60.6	106.6	65.7	40.9	135.6	77.2	58.4	101.1	44.0	57.2
15.6.	155.4	97.4	58.1	164.3	100.6	63.7	105.8	65.5	40.2	139.7	78.0	61.7	102.3	44.2	58.1
15.5.	150.2	96.4	53.8	158.7	99.5	59.2	101.4	64.7	36.7	134.6	77.0	57.5	101.9	44.1	57.8
15.4.	144.7	95.3	49.4	152.7	98.3	54.4	98.2	64.1	34.1	130.8	76.3	54.5	97.4	43.2	54.2
15.3.	143.3	95.0	48.3	150.7	97.9	52.7	97.4	63.9	33.5	131.8	76.5	55.3	91.2	42.0	49.2
15.2.	144.5	95.3	49.3	152.6	98.3	54.3	98.4	64.1	34.3	132.6	76.7	55.9	91.5	42.1	49.4
15.1.	146.4	95.6	50.8	154.2	98.6	55.6	100.2	64.5	35.8	135.1	77.1	57.9	98.2	43.4	54.8
2017	146.0*	95.5*	50.5*	153.6*	98.5*	55.1*	99.7*	64.4*	35.3*	129.2*	76.0*	53.2*	88.2*	39.9*	48.3*
15.12.	142.6	94.9	47.8	150.6	97.9	52.7	100.2	64.5	35.8	130.5	76.3	54.3	92.1	40.7	51.4
15.11.	149.3	96.2	53.1	156.7	99.1	57.6	100.4	64.5	35.9	134.8	77.1	57.7	93.1	40.9	52.2
15.10.	143.2	95.0	48.2	151.1	98.0	53.1	99.9	64.4	35.5	127.1	75.6	51.5	88.9	40.1	48.8
15.9.	145.8	95.5	50.3	153.4	98.5	54.9	99.8	64.4	35.4	126.6	75.5	51.1	87.9	39.9	48.0
15.8.	144.6	95.3	49.3	152.2	98.2	54.0	97.9	64.0	33.9	125.0	75.2	49.9	84.8	39.3	45.5
15.7.	144.6	95.3	49.3	152.3	98.3	54.1	97.5	63.9	33.5	124.4	75.1	49.3	82.4	38.8	43.6
15.6.	146.1	95.6	50.5	153.9	98.6	55.4	98.7	64.2	34.6	125.2	75.2	50.0	82.2	38.8	43.4
15.5.	145.6	95.5	50.1	153.5	98.5	55.0	99.9	64.4	35.5	125.1	75.2	49.9	85.2	39.4	45.8
15.4.	147.1	95.8	51.3	154.7	98.7	56.0	100.0	64.4	35.5	128.5	75.9	52.6	91.0	40.5	50.5
15.3.	146.3	95.6	50.7	153.6	98.5	55.1	100.4	64.5	35.9	132.1	76.6	55.5	87.3	39.8	47.5
15.2.	150.5	96.4	54.1	158.2	99.4	58.8	102.7	64.9	37.7	136.5	77.4	59.1	90.1	40.3	49.8
15.1.	147.5	95.8	51.7	155.1	98.8	56.3	101.2	64.7	36.5	136.1	77.3	58.8	90.0	40.3	49.7
2016	137.1*	91.8*	45.3*	144.7*	94.7*	50.0*	93.4*	62.0*	31.4*	118.8*	72.8*	45.9*	76.3*	36.2*	40.2*

* the average price of the year weighted by monthly sales volumes

Picture 9 - Consumer prices

Column A: the consumer price comprising all taxes and other fees included in the final price of the product, i.e. fuel tax, security of supply charge and VAT

Column B: the amount of the charges mentioned above

Column C: the calculatory price without taxes calculated from the consumer price on that line

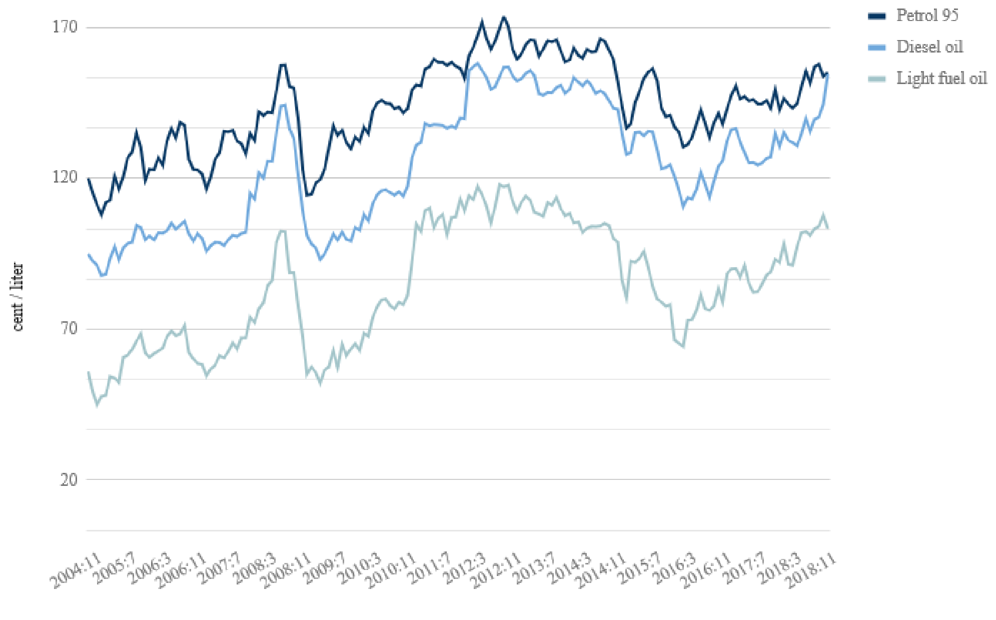
The tax on gasoline is for the reformulated grade and the tax on diesel fuel for the sulphur-free grade.

Consumer prices vary in line with competitive situation at local markets and service stations. The prices of gasoline, diesel fuel and heating oil have been calculated according to consumer prices at six localities (Helsinki, Mikkeli, Oulu, Rovaniemi, Seinäjoki, and Turku) on 15th of each month. The calculation of the ethanol automotive fuel price covers those localities of the above-mentioned listing where the product is available. Prices have been weighted by the annual sales of the localities and the market shares of oil product sales.

The consumer price of gasoline and diesel fuel reflects the pump price at service stations. The price does not include customer specific reductions. The price of diesel fuel consists of prices of grades being each time for sale. The price of heating oil is the price of summer grade delivered to a customer's tank.

4.3.1.2 Consumer prices of petroleum products

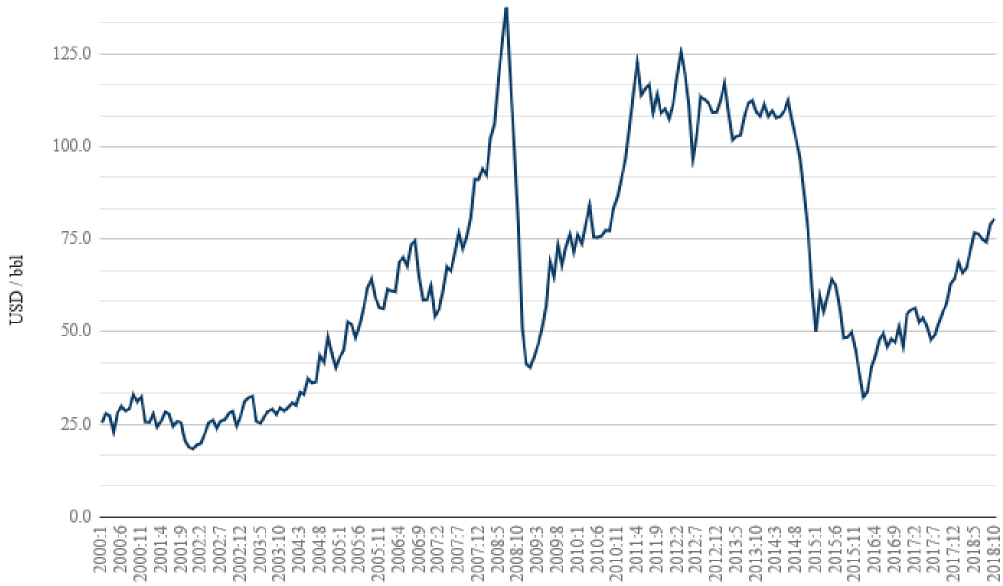
Consumer price taken from the sampling of the Finnish Petroleum and Biofuels Association, comprising all taxes and other fees included in the final price of the product, i.e. fuel tax, security of supply charge and VAT. The price of light fuel oil as delivered to a customer's tank.



Picture 10 - Consumer prices of petroleum products

4.3.1.3 World market prices of crude oil

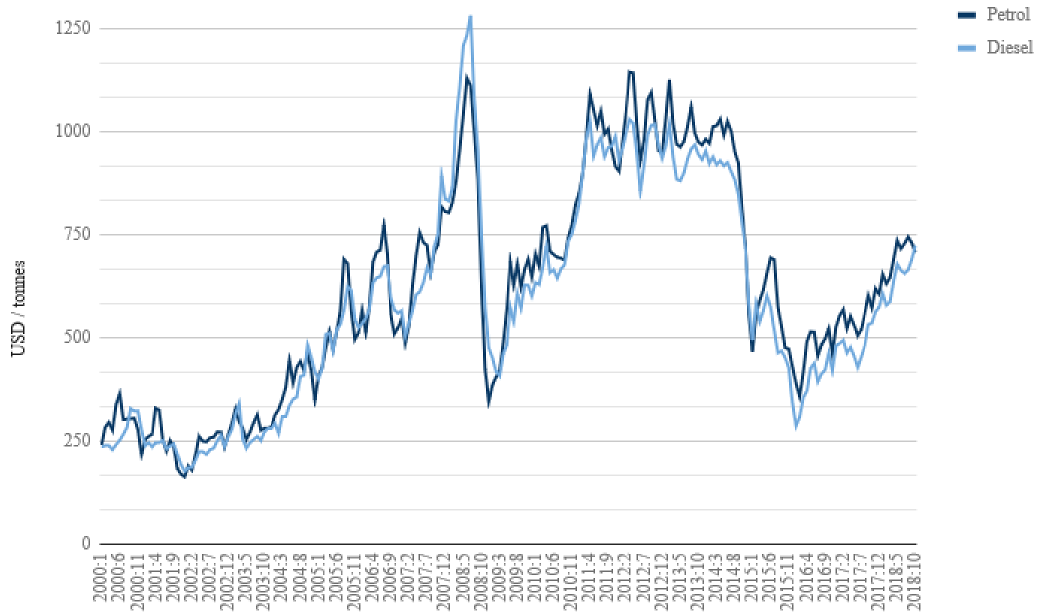
Crude oil world market prices react to a variety of factors. The graph below shows the USD price of the Brent crude. USD = United States Dollar, barrel (bbl.) = 159 litres



Picture 11 - World market prices of crude oil

4.3.1.4 World market prices of petroleum products

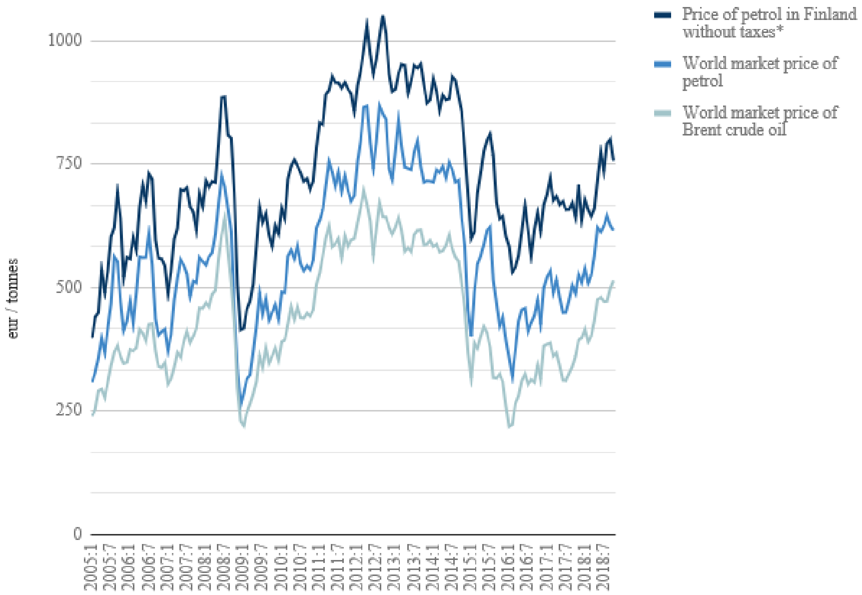
World market prices of petroleum products react to changes in demand, geopolitical events and the economy, among other things. The prices are also affected by freight and insurance costs, among other things.



Picture 12 - World market prices of petroleum products

4.3.1.5 Prices of crude oil and petrol

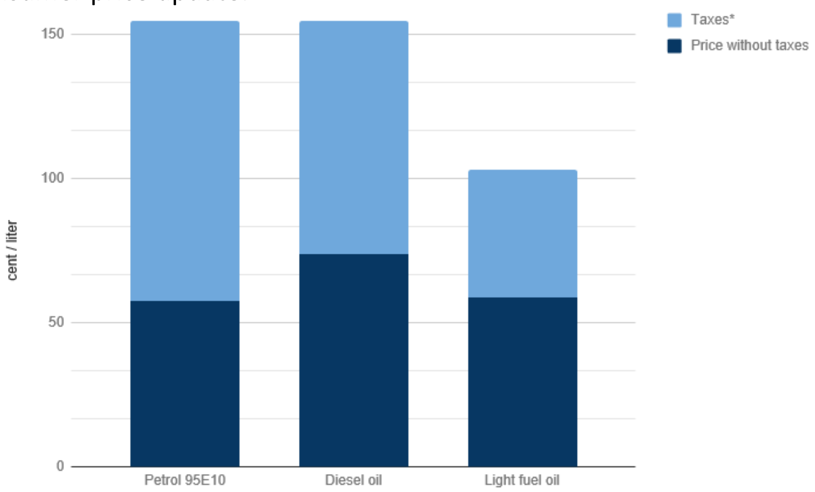
Petrol consumer prices follow crude oil and petrol world market price fluctuations. In Finland, tax constitutes the main component in the petrol consumer price, a component which is not impacted by world market price fluctuations. The petrol consumer price is further impacted by the costs of refining, transport and distribution. The price of crude oil is just one of the many factors impacting the petrol price. The import price of crude oil is also subject to the effects of the Euro exchange rate in relation with the United States Dollar.



Picture 13 - Prices of crude oil and petrol

4.3.1.6 Price formation of petroleum products

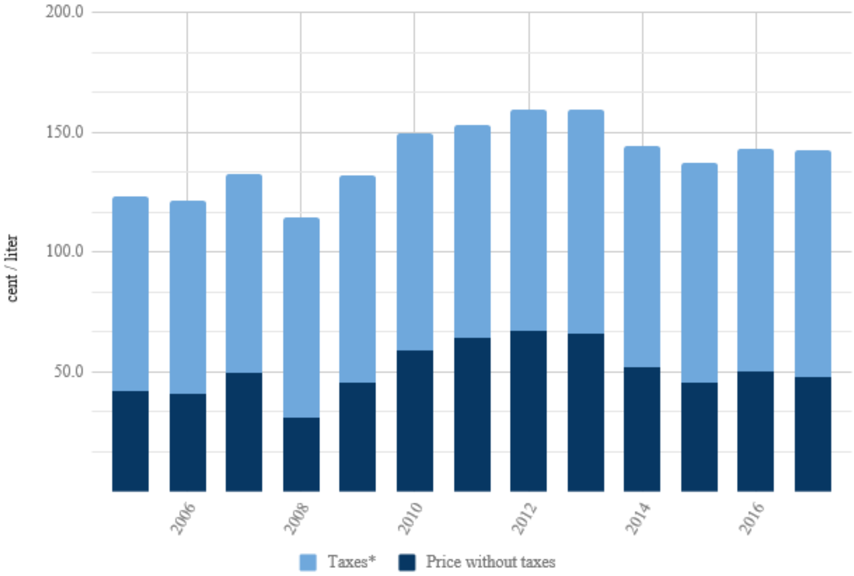
The price for petroleum products 15th November 2018 according to Finnish Petroleum and Biofuels Association's consumer price update.



Picture 14 - Price formation of petroleum products

4.3.1.7 Price formation of petrol

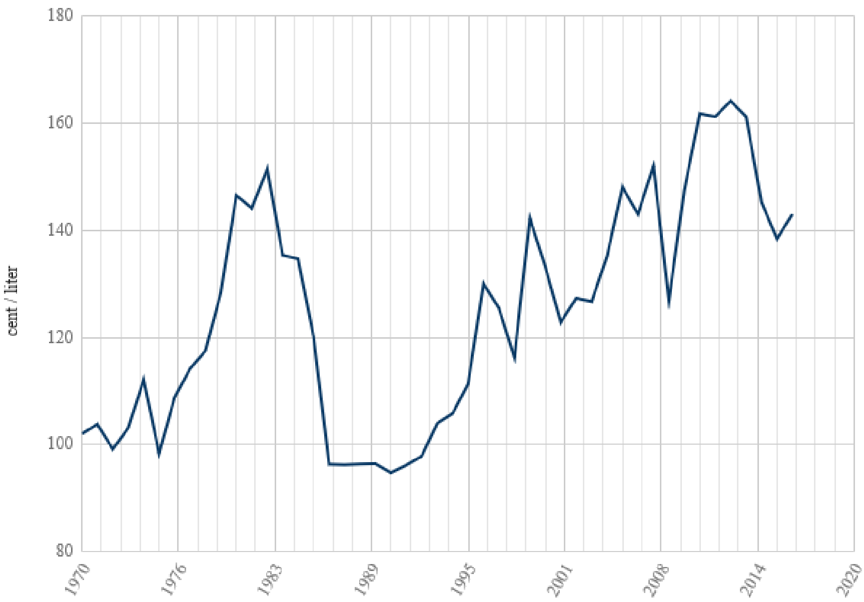
The price for 95 octane petrol in each year's December according to Finnish Petroleum and Biofuels Association's consumer price update.



Picture 15 - Price formation of petrol

4.3.1.8 Real prices of petrol

Real prices of 92/95 octane petrol in December 2016 money (cost-of-living index 1951=100). The listed price is that of the 15th day of each December for the commercially available low-octane grade (95 Oct. from year 1989 on).



Picture 16 - Real prices of petrol

4.3.1.9 Excise taxes on principal petroleum products

Energy taxation in Finland

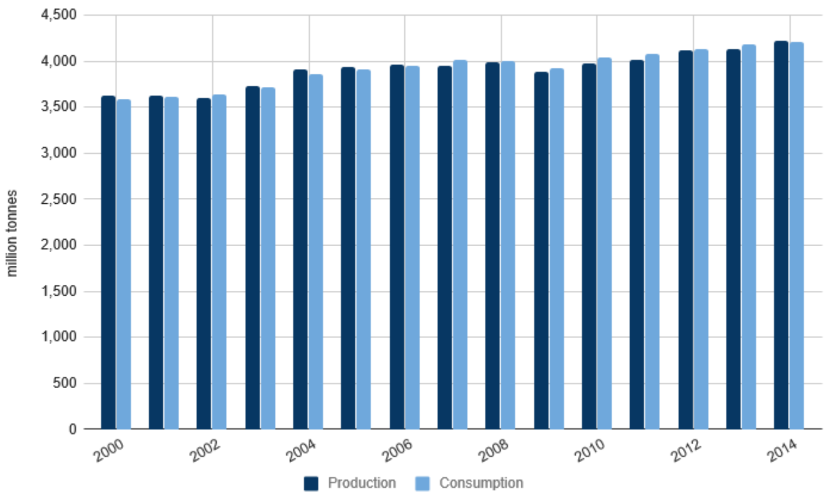
A comprehensive reform of Finnish energy taxation came into force on 1 January 2011. The reform amended the Act on Excise Duties of liquid fuels, electricity and certain other fuels so that taxation is based on the fuels' energy content and on the specific carbon dioxide emissions emitted in combustion. This structural change was also expanded to apply to heating and power plant fuels. At the same time, the name of the tax was changed to Energy Content Tax and Carbon Dioxide Tax. No changes were made to the Strategic Stockpile Fee levied on imported fuels.

The structural change of the transport fuel taxation came also into force on 1 January 2011 as a part of the overall energy tax reform. According to the new model, a proportional energy content tax based on the known caloric value of the fuel is levied on all fossil and bio-based transport fuels. The earlier per litre tax did not take into account the caloric content of the fuels and was inequitable in the case of ethanol, for example.

The regulatory character of energy taxes was emphasized in the structural change, as the share of the tax based on carbon dioxide emissions was made bigger. The change benefits carbon dioxide poor biofuels, and takes into account especially the emission reductions attained through biofuel use as compared with fossil fuels. A new quality scaling was introduced for the transport fuels, which takes into account local emissions that are hazardous for health. No changes were made to the transport fuel tax level or the strategic stockpile fee.

4.3.2 Oil production and consumption

4.3.2.1 World oil production and consumption

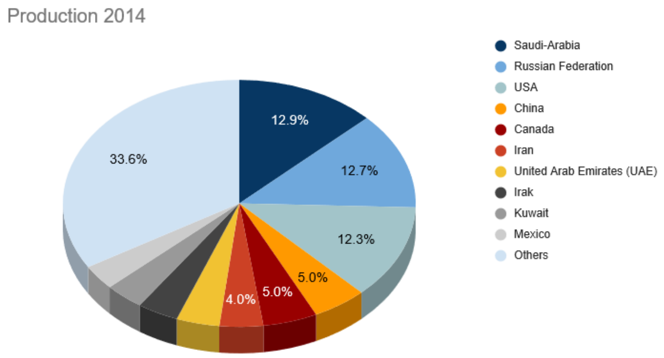


Picture 17 - World oil production and consumption

Production figures include natural gas condensates. Natural gas condensates (natural gas liquids, NGL): liquid hydrocarbon mixtures derived in the production of oil and gas, extracted by means of compressing or cooling; condensates are refined into petroleum products.

4.3.2.2 Oil production by country

Moving the cursor on top of the graph will display each country's oil production in million tonnes. Production figures include natural gas condensates*.

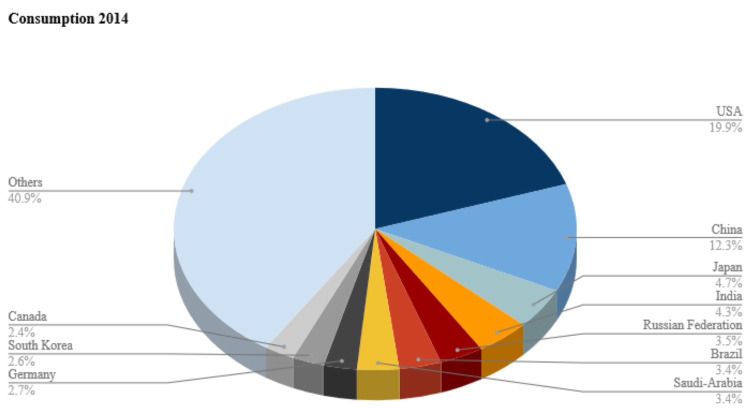


Picture 18 - Oil production by country

*Natural gas condensates (natural gas liquids, NGL): liquid hydrocarbon mixtures derived in the production of oil and gas, extracted by means of compressing or cooling; condensates are refined into petroleum products.

4.3.2.3 Oil consumption by country

Moving the cursor on top of the graph will display each country's oil consumption in million tonnes. Consumption figures include natural gas condensates*.



Picture 19 - Oil consumption by country

*Natural gas condensates (natural gas liquids, NGL): liquid hydrocarbon mixtures derived in the production of oil and gas, extracted by means of compressing or cooling; condensates are refined into petroleum products.

4.3.2.4 European oil refining capacity

Refineries 2014 :

	Capacity		Number of refineries
	1,000 t/a	1,000 bbl/d	
Germany	105,080	2,153	13
Italy	90,820	1,892	12
Spain	80,310	1,606	10
United Kingdom	72,280	1,475	7
France	71,650	1,447	10
Netherlands	65,380	1,321	6
Belgium	40,530	804	4
Poland	29,330	586	4
Turkey	27,740	568	4
Greece	25,650	516	4
Sweden	23,030	471	5
Portugal	16,070	325	2
Finland	13,200	265	2
Lithuania	10,250	250	1
Romania	12,120	242	4
Denmark	11,680	235	3
Austria	9,890	204	1
Czech Republic	9,770	195	3
Bulgaria	9,750	195	1
Serbia	8,330	167	2
Hungary	7,950	159	1
Slovakia	6,270	126	1
Switzerland	5,910	122	2
Croatia	5,320	106	3
Ireland	3,480	71	1
Slovenia	-	-	-
Cyprus	-	-	-
Latvia	-	-	-
Malta	-	-	-
Estonia	-	-	-
European Union	761,790	15,501	106
Norway	17,740	368	3
World	**4,917,450**	**98,349**	**752**

Picture 20 - European oil refining capacity

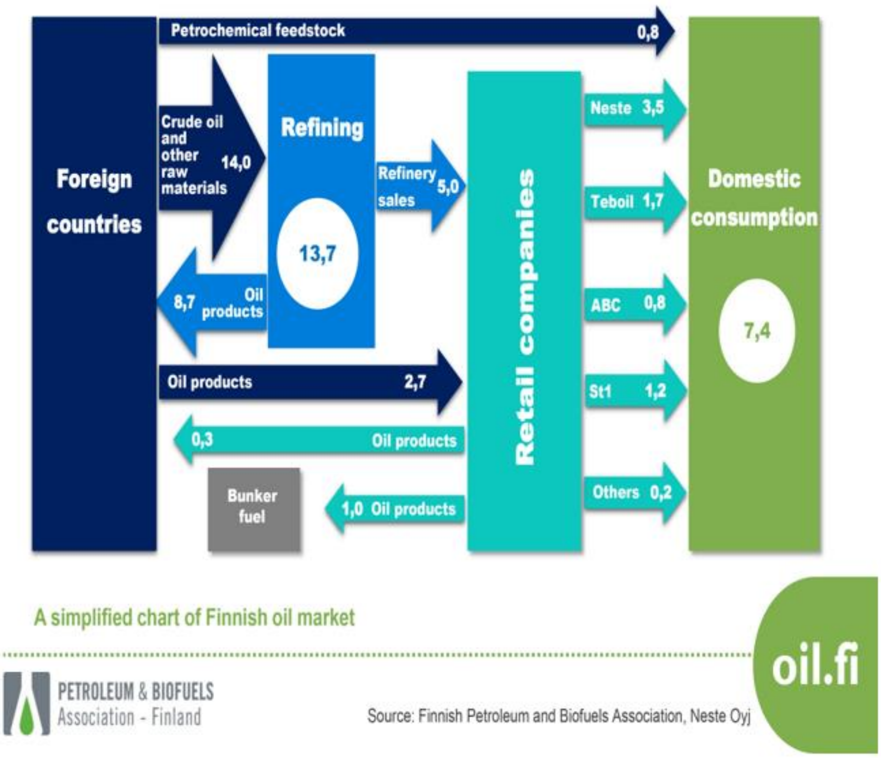
t/a = tonnes per annum, bbl/d = barrels per day, barrel = 159 litres

Source: Wood MacKenzie

4.3.3 The Finnish oil market

4.3.3.1 Finnish oil market

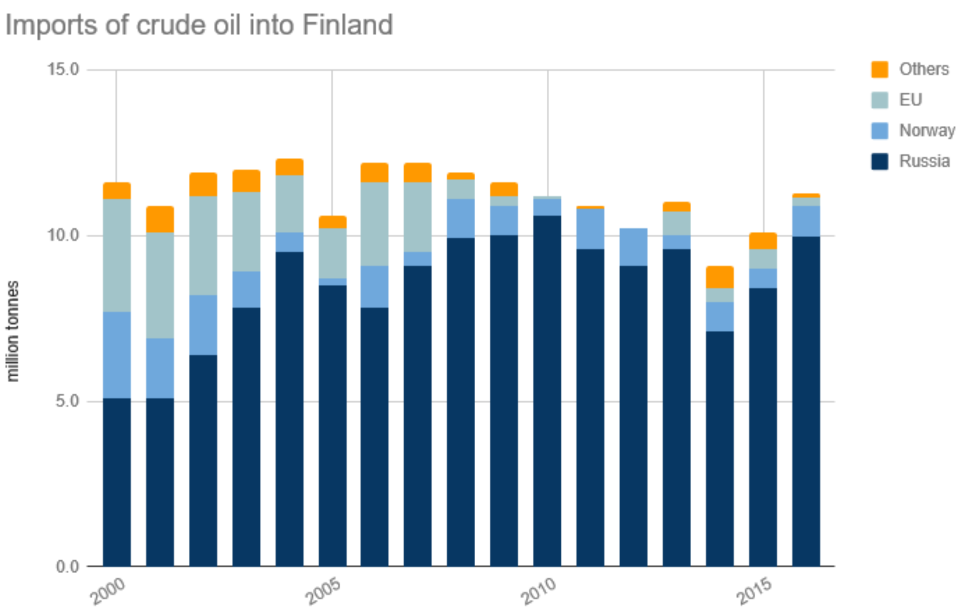
Below you can find a simplified illustration showing crude oil and petroleum product streams in Finland. Inventory changes are not taken into consideration in the figures.



Picture 21 - Finnish oil market

4.3.3.2 Finnish oil imports

Imports of crude oil into Finland since the year 2000. In the year 2016 the group others included Algeria, Angola and Kazakhstan.



Picture 22 - Finnish oil imports

4.3.3.3 Exports of Finnish petroleum products

PETROLEUM & BIOFUELS Association - Finland

Exports of Finnish Oil Products
1,000 tonnes

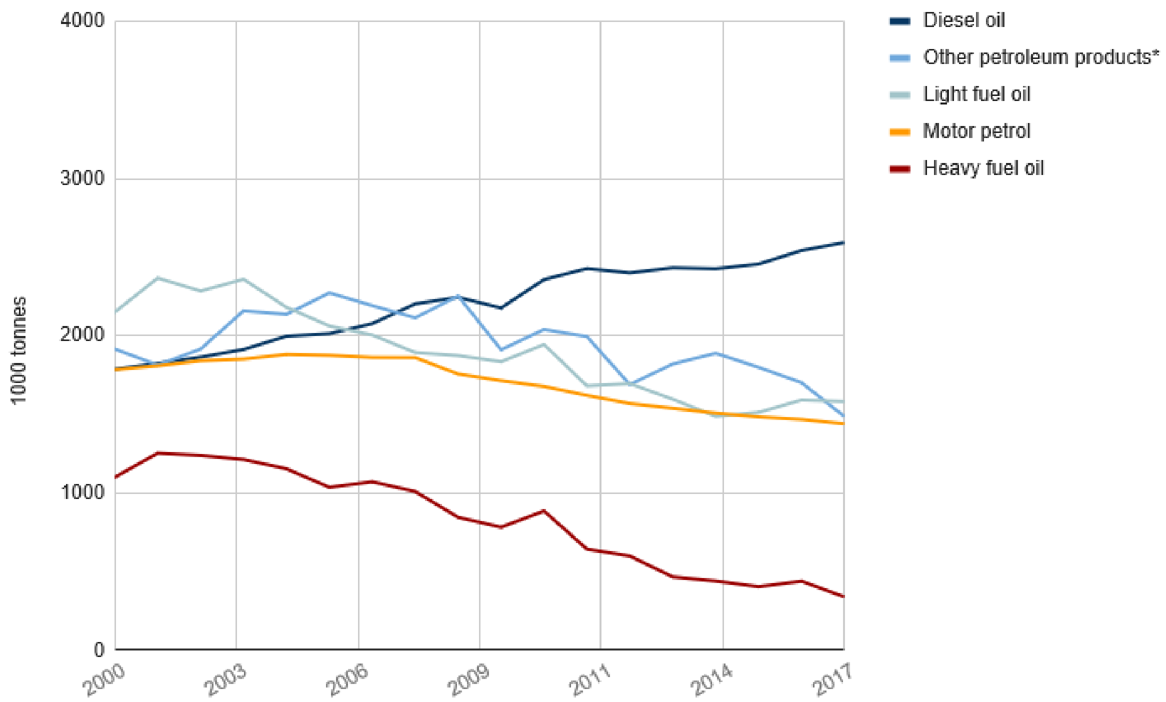
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016*
Motor Gasoline											
EU	1 203	973	693	661	1 103	1 047	1 162	1 922	1 632	1 846	1 832
Norway	35	7	11	40	44	48	5	5	-	-	15
Russia	7	8	6	71	6	5	4	21	1	-	-
Others	1 170	1 435	1 560	1 584	1 157	1 343	1 319	1 156	1 491	536	1 144
Total	**2 415**	**2 423**	**2 270**	**2 356**	**2 310**	**2 443**	**2 490**	**3 104**	**3 124**	**2 382**	**2 991**
Gasoil											
EU	2 148	2 501	3 071	2 469	2 690	2 787	2 774	3 685	3 484	2 799	3 486
Norway	0	0	1	49	0	5	223	61	42	72	140
Russia	0	0	0	0	0	5	27	64	6	-	-
Others	74	74	0	40	201	44	98	194	106	40	188
Total	**2 222**	**2 575**	**3 072**	**2 558**	**2 891**	**2 841**	**3 122**	**4 004**	**3 638**	**2 911**	**3 814**
Heavy fuel oil											
EU	77	462	515	858	705	913	1 052	1 034	807	744	1 309
Norway	0	-	-	-	-	0	29	0	15	9	-
Russia	0	0	0	0	-	-	0	-	-	-	-
Others	-	-	-	10	0	14	16	63	23	32	15
Total	**77**	**462**	**515**	**868**	**705**	**927**	**1 096**	**1 097**	**845**	**785**	**1 324**
Other petroleum products	737	728	669	760	777	907	891	850	989	690	800
TOTAL OIL EXPORTS	**5 451**	**6 188**	**6 525**	**6 542**	**6 683**	**7 118**	**7 599**	**9 055**	**8 596**	**6 768**	**8 929**

0 = exports less than 1,000 tonnes, - = no exports
* = advance information
Source: National Board of Customs/Foreign trade statistics

Picture 23 - Exports of Finnish petroleum products

4.3.3.4 Sales of petroleum products

Annual Finnish domestic petroleum products sales. The PDF file contains details of petroleum product sales.



Picture 24 - Sales of petroleum products

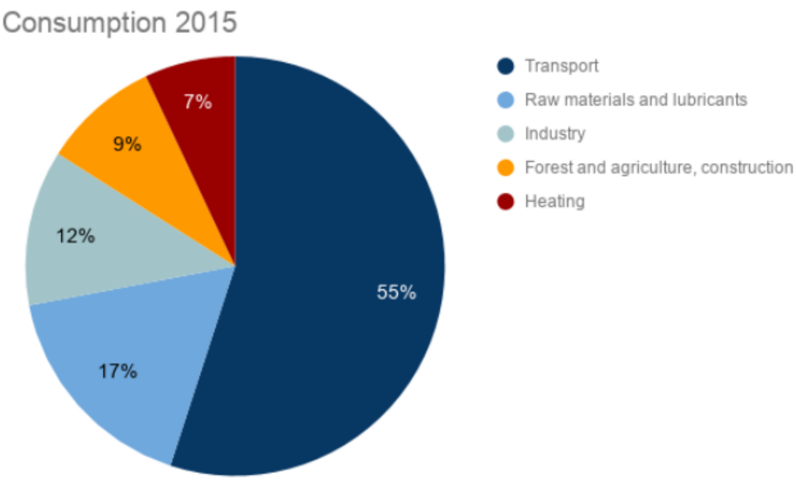
4.3.3.5 Petroleum product market shares

Market shares

Year 2017	%			
	Gasoline	Diesel oil	Light fuel oil	Heavy fuel oil
ABC Chain	31.8	14.5	0.5	0
Neste	27.9	38.4	33.6	52.1
SEO (Finnish Energy Cooperative)	2.7	1.5	1.6	0
St1	21.9	18.7	23.2	5.4
Teboil	15.7	26.9	37.0	42.5
Others	0	0	4.1	0

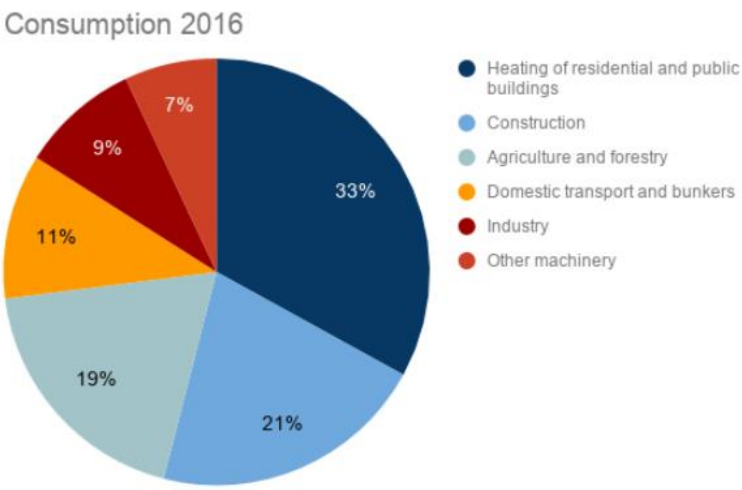
Picture 25 - Petroleum product market shares

4.3.3.6 Consumption of petroleum products by end-use sector



Picture 26 - Consumption of petroleum products by end-use sector

4.3.3.7 Consumption of light fuel oil by end-use sector



Picture 27 - Consumption of light fuel oil by end-use sector

In the class Agriculture and Forestry, Statistics Finland includes dryers, agricultural machinery, greenhouses and forestry machines. The class Domestic and International Transport covers waterborne and railway transports. The class Industry includes separate production of electricity, other production of electricity and heat, and other industry use.

4.3.4 The service station network

4.3.4.1 Service stations

Service stations

Company 31.12.2017	Service stations	Unmanned stations	TOTAL	Heavy traffic fuel distribution outlets*
ABC Chain	124	321	**445**	0
Neste	243	218	**461**	309
SEO (Finnish Energy Co-operative)	90	110	**200**	0
Shell	116	55	**171**	102
St1	57	187	**244**	51
Teboil	114	213	**327**	217
TOTAL	744	1,104	1,848	679

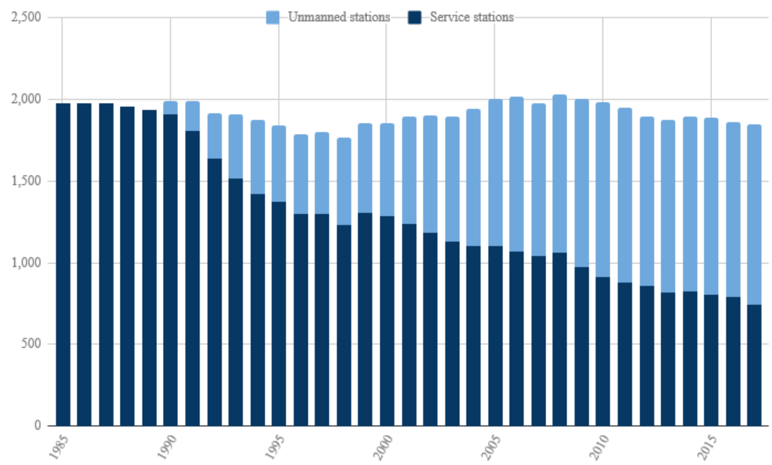
* Some distribution outlets designed for heavy vehicles are located at service stations or at unmanned stations.

In addition to these, there are 32 service stations for boats that operate only in the summer season recorded in the Finnish Petroleum and Biofuels Association statistics.

Picture 28 - Service stations

The Finnish Petroleum and Biofuels Association has gathered the service station statistical data from its member companies Neste, the ABC chain of the S Group, St1 (and Shell service stations owned by St1) and Teboil. The figures also cover Finnish Energy Co-operative SEO. In addition to those recorded in the statistics, there is a small number of other service stations and transport fuel distribution outlets in Finland.

4.3.4.2 Service station network developments



Picture 29 - Service station network developments

4.4 Petroleum research

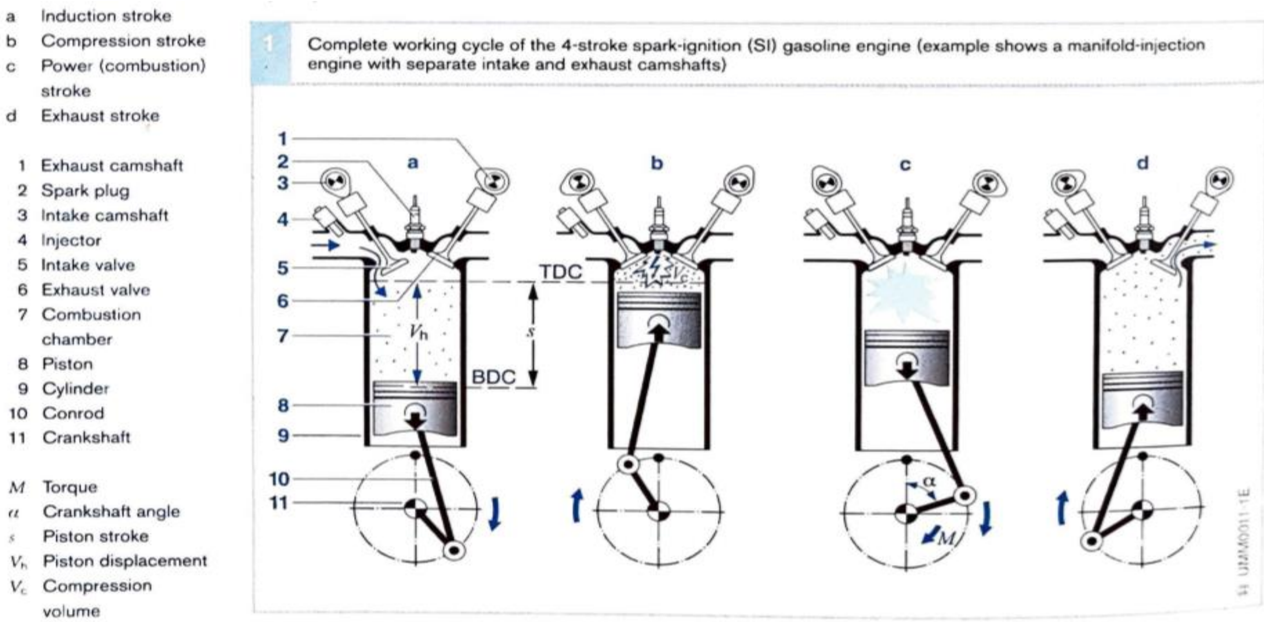
Gasoline-Engine Management – System and Components – Robert Bosch

4.4.1 Basics of the gasoline (SI) engine

The gasoline or spark-ignition (SI) internal-combustion engine uses the Otto cycle 1) and externally supplied ignition. It burns an air/fuel mixture and in the process converts the chemical energy in the fuel into kinetic energy.

For many years, the carburetor was responsible for providing an air/fuel mixture in the intake manifold which was then drawn into the cylinder by the downgoing piston. The breakthrough of gasoline fuel injection, which permits extremely precise metering of the fuel, was the result of the legislation governing exhaust-gas emission limits. Similar to the carburetor process, with manifold fuel injection the air/fuel mixture is formed in the intake manifold. Even more advantages resulted from the development of gasoline direct injection, in particular with regard to fuel economy and increases in power output. Direct injection injects the fuel directly into the engine cylinder at exactly the right instant in time.

1) Named alter Nikolaus Otto (1832- 1891) who presented the first gas engine with compression using the 4-stroke principle al the Paris World Fair in 1878.



Picture 30 - 4 Strokes explanation

4.4.2 Method of operation

The combustion of the air/fuel mixture causes the piston (Fig. 1, Pos. 8) to perform a reciprocating movement in the cylinder (9). The name reciprocating-piston engine, or better still reciprocating engine, stems from this principle of functioning. The conrod (10) converts the piston's reciprocating movement into a crankshaft (11) rotational movement which is maintained by a flywheel at the end of the crankshaft. Crankshaft speed is also referred to as engine speed or engine rpm.

4.4.2.1 Four-stroke principle

Today, the majority of the internal-combustion engines used as vehicle power plants are of the four-stroke type. The four-stroke principle employs gas-exchange valves (5 and 6) to control the exhaust-and-refill cycle. These valves open and close the cylinder's intake and exhaust passages, and in the process control the supply of fresh air/fuel mixture and the forcing out of the burnt exhaust gases.

1st stroke: Induction

Referred to Top Dead Center (TDC), the piston is moving downwards and increases the volume of the combustion chamber (7) so that fresh air (gasoline direct injection) or fresh air/fuel mixture (manifold injection) is drawn into the combustion chamber past the opened intake valve (5). The combustion chamber reaches maximum volume (V_h+ V_c) at Bottom Dead Center (BDC).

2nd stroke: Compression

The gas-exchange valves are closed, and the piston is moving upwards in the cylinder. In doing so it reduces the combustion-chamber volume and compresses the air/fuel mixture. On manifold-injection engines the air/fuel mixture has already entered the combustion chamber at the end of the induction stroke. With a direct-injection engine on the other hand, depending upon the operating mode, the fuel is first injected towards the end of the compression stroke. At Top Dead Center (TDC) the combustion-chamber volume is at minimum (compression volume V_c).

3rd stroke: Power (or combustion)

Before the piston reaches Top Dead Center (TDC), the spark plug (2) initiates the combustion of the air/fuel mixture at a given ignition point (ignition angle). This form of ignition is known as externally supplied ignition. The piston has already passed its TDC point before the mixture has combusted completely. The gas-exchange valves remain closed and the combustion heat increases the pressure in the cylinder to such an extent that the piston is forced downward.

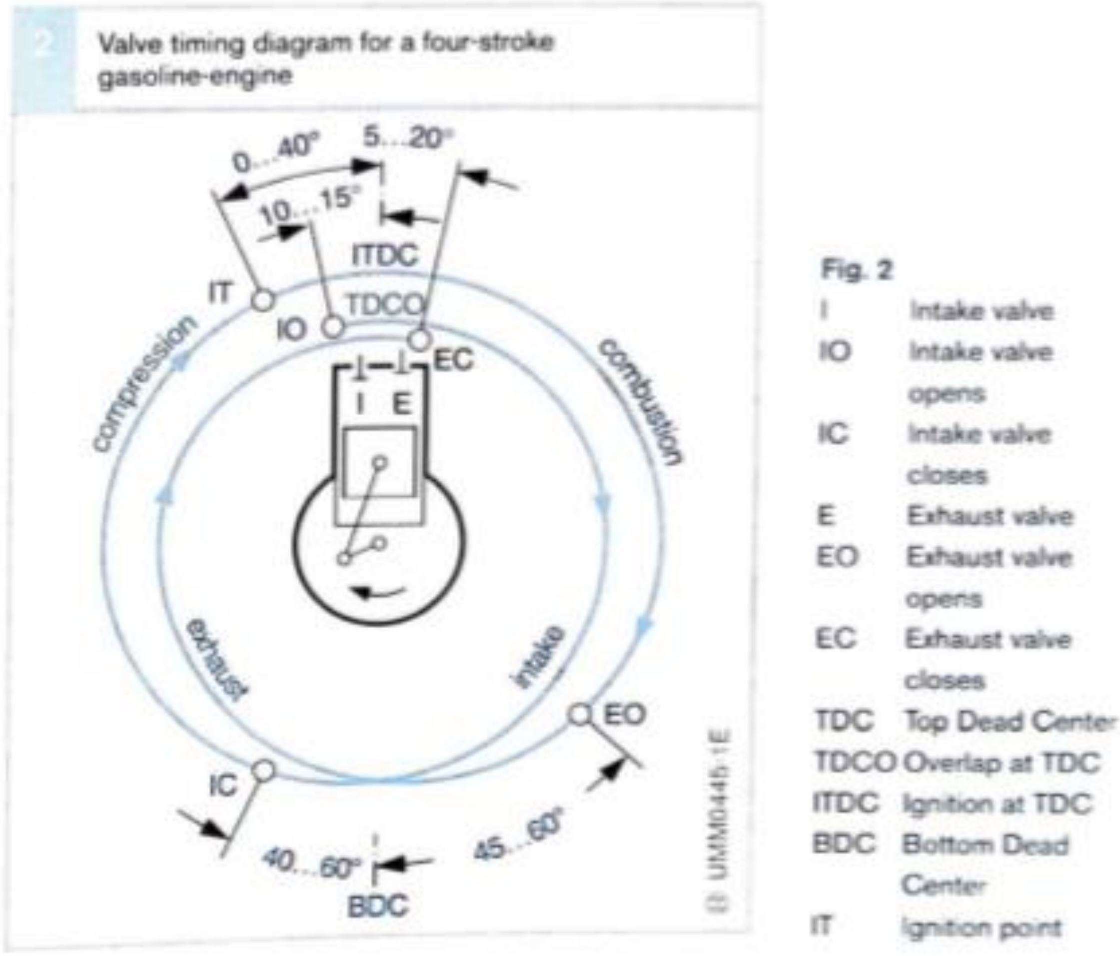
4th stroke: Exhaust

The exhaust valve (6) opens shortly before Bottom Dead Center (BDC). The hot (exhaust) gases are under high pressure and leave the cylinder through the exhaust valve. The remaining exhaust gas is forced out by the upwards-moving piston.

A new operating cycle starts again in with the induction stroke after every two revolutions of the crankshaft.

4.4.2.2 Valve timing

The gas-exchange valves are opened and closed by the cams on the intake and exhaust camshafts (3 and 1 respectively). On engines with only 1 camshaft, a lever mechanism transfers the cam lift to the gas-exchange valves. The valve timing defines the opening and closing times of the gas-exchange valves. Since it is referred to the crankshaft position, timing is given in "degrees crankshaft''. Gas flow and gas-column vibration effects are applied to improve the filling of the combustion chamber with air/fuel mixture and to remove the exhaust gases. This is the reason for the valve opening and closing times overlapping in a given crankshaft angular-position range. The camshaft is driven from the crankshaft through a toothed belt (or a chain or gear pair). On 4-stroke engines, a complete working cycle takes two rotations of the crankshaft. In other words, the camshaft only turns at half crankshaft speed, so that the step-down ratio between crankshaft and camshaft is 2:1.



Picture 31 - Valve time diagram

4.4.2.3 Compression

The difference between the maximum piston displacement V_h and the compression volume V_c is the compression ratio

$$\varepsilon = \frac{(V_h + V_c)}{V_c}$$

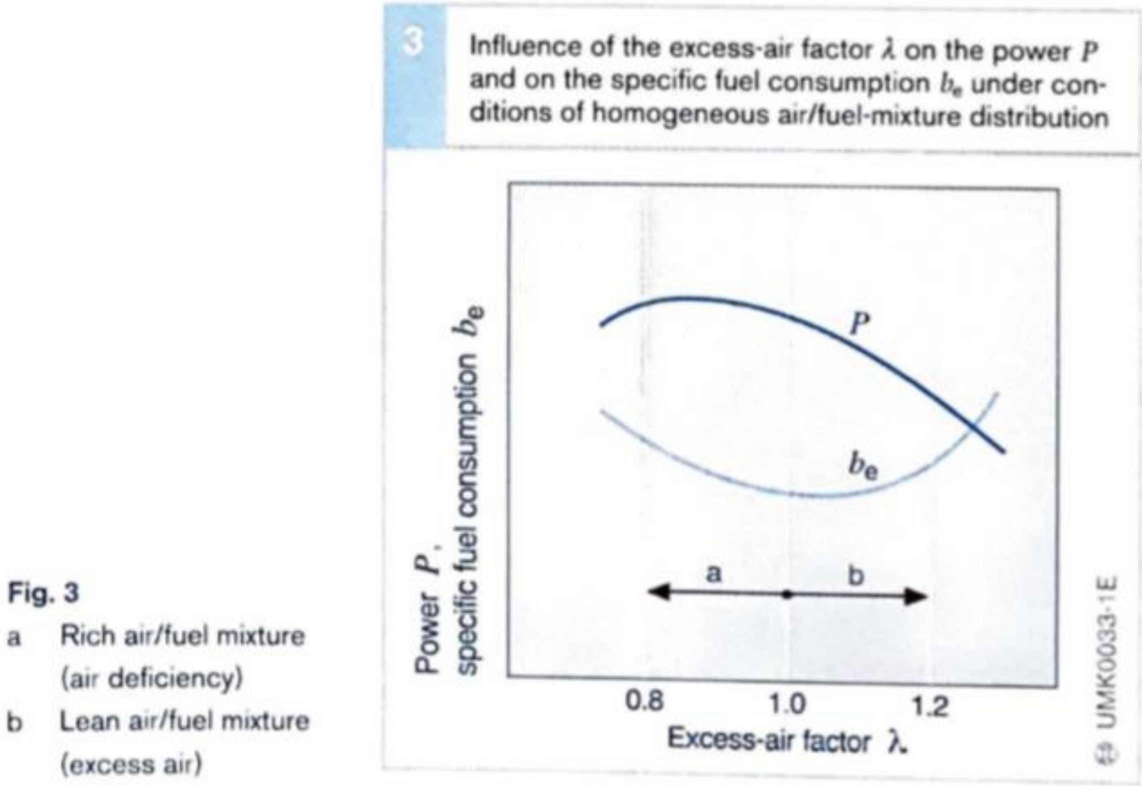
The engine's compression ratio is a vital factor in determining

- Torque generation
- Power generation
- Fuel economy
- Emissions of harmful pollutants

The gasoline-engine's compression ratio ε varies according to design configuration and the selected form of fuel injection (manifold or direct injection ε = 7 ... 13). Extreme compression ratios of the kind employed in diesel powerplants (ε = 14 ... 24) are not suitable for use in gasoline engines. Because the knock resistance of the fuel is limited, the extreme compression pressures and the high combustion-chamber temperatures resulting from such compression ratios must be avoided in order to prevent spontaneous and uncontrolled detonation of the air/fuel mixture. The resulting knock can damage the engine.

4.4.2.4 Air/fuel ratio

Complete combustion of the air/fuel mixture relies on a stoichiometric mixture ratio.



Picture 32 - Influence of the excess-air factor on the power

A stoichiometric ratio is defined as 14.7kg of air for 1 kg of fuel, that is, a 14.7 to 1 mixture ratio. The air/fuel ratio λ (lambda) indicates the extent to which the instantaneous monitored air/fuel ratio deviates from the theoretical ideal:

$$\lambda = \frac{induction\ air\ mass}{theoretical\ air\ requirement}$$

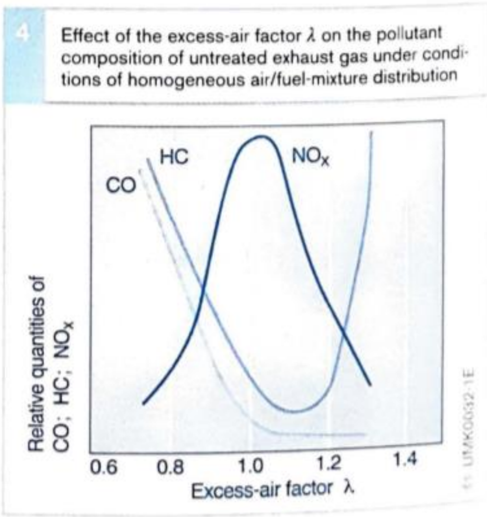
The lambda factor for a stoichiometric ratio is λ 1.0. λ is also referred to as the excess-air factor.

Richer fuel mixtures result in λ figures of less than 1. Leaning out the fuel produces mixtures with excess air: λ then exceeds 1. Beyond a certain point the mixture encounters the lean-burn limit, beyond which ignition is no longer possible. The excess-air factor has a decisive effect on the specific fuel consumption (Fig. 3) and untreated pollutant emissions (Fig. 4).

4.4.2.5 Induction-mixture distribution in the combustion chamber

Homogeneous distribution

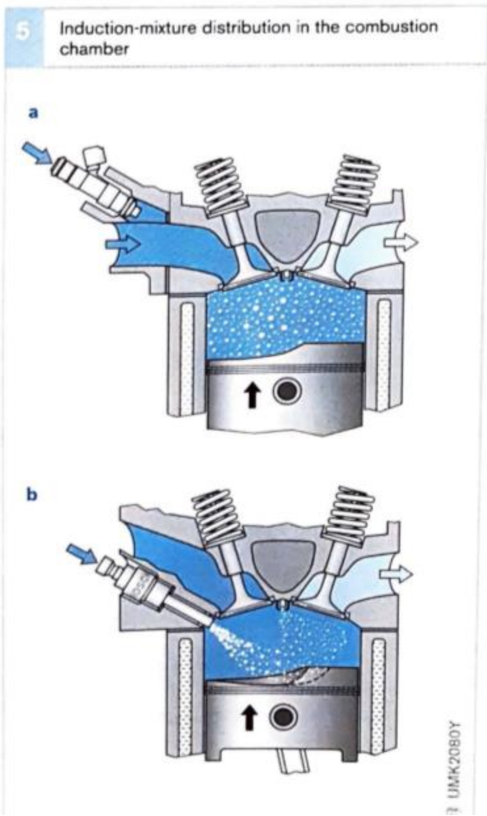
The induction systems on engines with manifold injection distribute a homogeneous air/fuel mixture throughout the combustion chamber. The entire induction charge has a single excess-air factor λ (Fig. 5a). Lean-burn engines, which operate on excess air under specific operating conditions, also rely on homogeneous mixture distribution.



Picture 33 - Effect of the excess-air factor on the pollution

Stratified-charge concept

A combustible mixture cloud with λ ≈ 1 surrounds the tip of the spark plug at the instant ignition is triggered. At this point the remainder of the combustion chamber contains either non-combustible gas with no fuel, or an extremely lean air/fuel charge. The corresponding strategy, in which the ignitable mixture cloud is present only in one portion of the combustion chamber, is the stratified-charge concept (Fig. 5b). With this concept, the overall mixture (meaning the average mixture ratio within the entire combustion chamber) is extremely lean (up to λ ≈ 10). This type of lean operation fosters extremely high levels of fuel economy.



Picture 34 - Induction mixture distribution in the combustion chamber

Efficient implementation of the stratified-charge concept is impossible without direct fuel injection, as the entire induction strategy depends on the ability to inject fuel directly into the combustion chamber just before ignition.

4.4.2.6 Ignition and flame propagation

The spark plug ignites the air/fuel mixture by discharging a spark across a gap. The extent to which ignition will result in reliable flame propagation and secure combustion depends in large part on the air/fuel mixture λ, which should be in a range extending from λ = 0.75 ... 1.3. Suitable flow patterns in the area immediately adjacent to the sparkplug electrodes can be employed to ignite mixtures as lean as λ ≤ 1. 7.

The initial ignition event is followed by formation of a flame-front. The flame front's propagation rate rises as a function of combustion pressure before dropping off again toward the end of the combustion process. The mean flame front propagation rate is on the order of 15...25m/s. The flame front's propagation rate is the combination of mixture transport and combustion rates, and one of its defining factors is the air/fuel ratio λ. The combustion rate peaks at slightly rich mixtures on the order of λ = 0.8...0.9. In this range it is possible to approach the conditions coinciding with an ideal constant-volume combustion process (refer to section on "Engine efficiency"). Rapid combustion rates provide highly satisfactory full-throttle, full-load performance at high engine speeds. Good thermodynamic efficiency is produced by the high combustion temperatures achieved with air/fuel mixtures of λ = 1.05...1.1. However, high combustion temperatures and Jean mixtures also promote generation of nitrous oxides (NOx), which are subject to strict limitations under official emissions standards.

4.4.3 Engine efficiency

4.4.3.1 Thermal efficiency

The internal-combustion engine does not convert all the energy which is chemically available in the fuel into mechanical work, and some of the added energy is lost. This means that an engine's efficiency is less than 100%, (Fig. 1). Thermal efficiency is one of the important links in the engine's efficiency chain.

Pressure-volume diagram (PV diagram)

The PV diagram is used to display the pressure and volume conditions during a complete working cycle of the 4-stroke IC engine.

The ideal cycle Figure 2 (curve A) shows the compression and power strokes of an ideal process as defined by the laws of Boyle/Mariotte and Gay-Lussac. The piston travels from BDC to TOC (point 1 to point 2), and the air/fuel mixture is compressed without the addition of heat (Boyle/Mariotte). Subsequently, the mixture burns accompanied by a pressure rise (point 2 to point 3) while volume remains constant (Gay-Lussac). From TOC (point 3), the piston travels towards BDC (point 4), and the combustion-chamber volume increases. The pressure of the burnt gases drops whereby no heat is released (Boyle/Mariotte). Finally, the burnt mixture cools off again with the volume remaining constant (Gay-Lussac) until the initial status (point l) is reached again.

The area inside the points 1 - 2 - 3 - 4 shows the work gained du ring a complete working cycle. The exhaust valve opens at point 4 and the gas, which is still under pressure, escapes from the cylinder. If it were possible for the gas to expand completely by the time point S is reached, the area described by 1 - 4 - S would represent usable energy. On an exhaust-gas-turbocharged engine, the part above the atmospheric line (1 bar) can to some extent be utilized (1- 4 - 5').

Real PV diagram

Since it is impossible during normal engine operation to maintain the basic conditions for the ideal cycle, the actual PV diagram (Fig. 2, curve B) differs from the ideal PV diagram.

Measures for increasing thermal efficiency

The thermal efficiency rises along with increasing air/fuel-mixture compression. The higher the compression, the higher the pressure in the cylinder at the end of the compression phase, and the larger is the enclosed area in the p-V diagram. This area is an indication of the energy generated du ring the combustion process. When selecting the compression ratio, the fuel's antiknock qualities must be taken into account. Manifold-injection engines inject the fuel into the intake manifold onto the closed intake valve, where it is stored until drawn into the cylinder. During the formation of the air/fuel mixture, the fine fuel droplets vaporize. The energy needed for this process is in the form of heat and is taken from the air and the intake-manifold walls. On direct injection engines the fuel is injected into the combustion chamber, and the energy needed for fuel-droplet vaporization is taken from the air trapped in the cylinder which cools off as a result. This means that the compressed air/fuel mixture is at a lower temperature than is the case with a manifold-injection engine, so that a higher compression ratio can be chosen.

Further losses stem from the incomplete combustion of the fuel which bas condensed onto the cylinder walls. Thanks to the insulating effects of the gas jacket, these losses are reduced in stratified-charge operation. Further thermal lasses result from the residual heat of the exhaust gases.

4.4.3.2 Losses at λ = 1

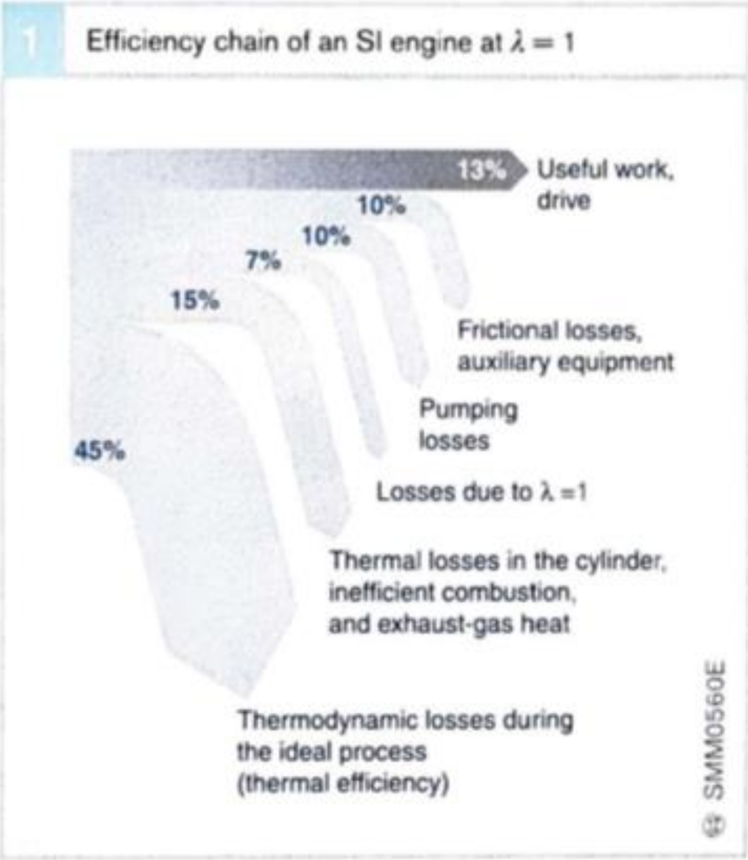
The efficiency of the constant-volume cycle climbs along with increasing excess-air factor (λ). Due to the reduced flame-propagation velocity common to lean air/fuel mixtures, at λ > 1.1 combustion is increasingly sluggish, a fact which has a negative effect upon the SI engine's efficiency curve. In the final analysis, efficiency is the highest in the range λ = 1.1...1.3. Efficiency is therefore less for a homogeneous air/fuel-mixture formation with λ = 1 than it is for an air/fuel mixture featuring excess air. When a 3-way catalytic converter is used for emissions control, an air/fuel mixture with λ = 1 is absolutely imperative for efficient operation.

4.4.3.3 Pumping losses

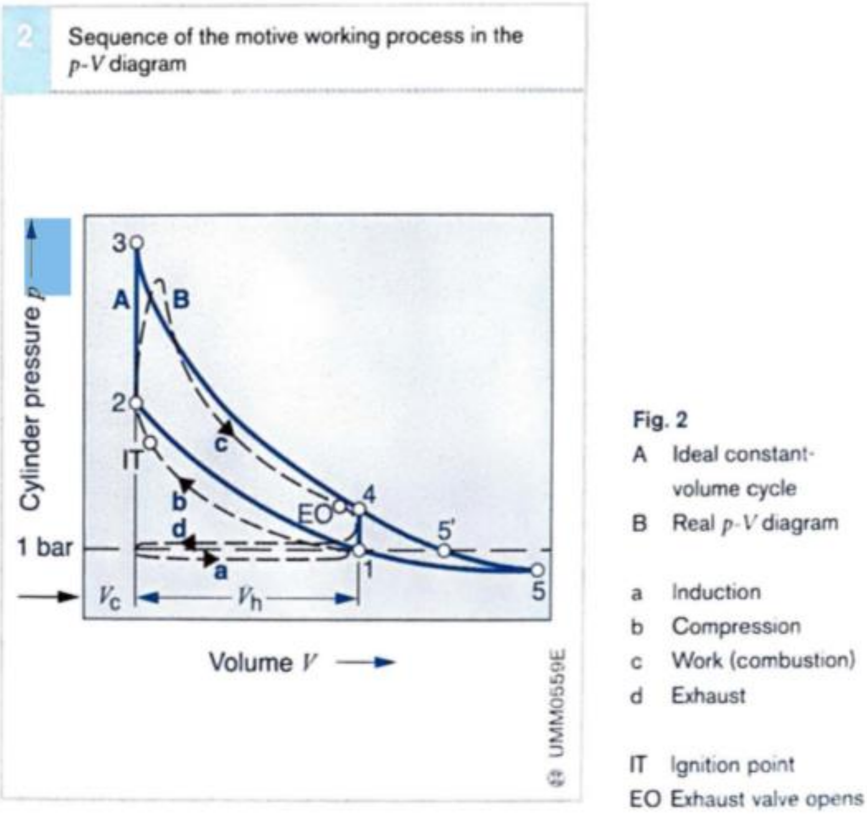
During the exhaust and refill cycle, the engine draws in fresh gas during the 1st (induction) stroke. The desired quantity of gas is controlled by the throttle-valve opening. A vacuum is generated in the intake manifold which opposes engine operation (throttling losses). Since with a gasoline direct-injection engine the throttle valve is wide open at idle and part load, and the torque is determined by the injected fuel mass, the pumping losses (throttling losses) are lower. In the 4th stroke, work is also involved in forcing the remaining exhaust gases out of the cylinder.

4.4.3.4 Frictional losses

The frictional losses are the total of ail the friction between moving parts in the engine itself and in its auxiliary equipment. For instance, due to the piston-ring friction at the cylinder walls, the bearing friction, and the friction of the alternator drive.



Picture 35 - Efficiency chain of an engine



Picture 36 - Sequence of the motive working process in PV diagram

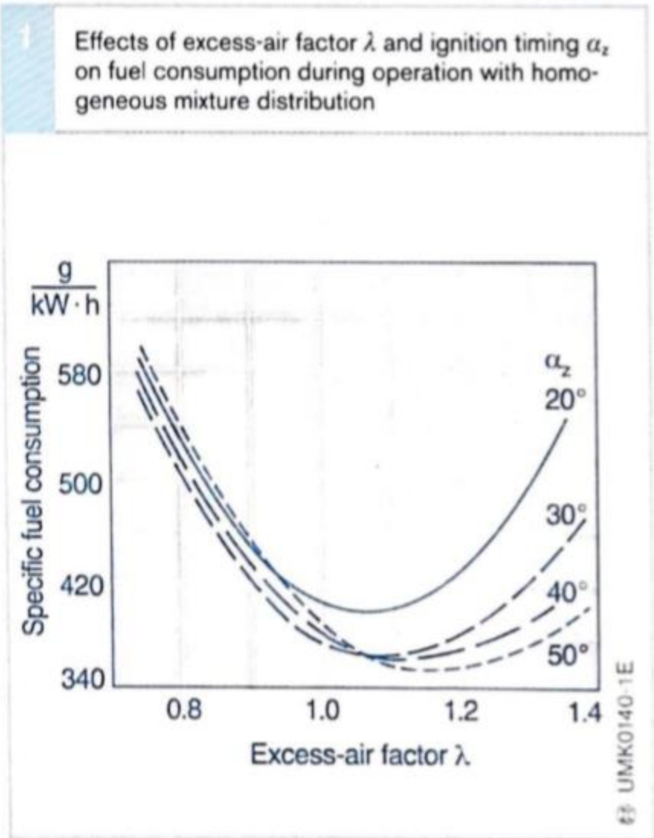
4.4.4 Specific fuel consumption

Specific fuel consumption be is defined as the mass of the fuel (in grams) that the internal-combustion engine requires to perform a specified amount of work (kW· h, kilowatt hours). This parameter thus provides a more accurate measure of the energy extracted from each unit of fuel than the terms litters per hour, litres per 100 kilometres or miles per gallon.

4.4.4.1 Effects of excess-air factor

Homogeneous mixture distribution

When engines operate on homogeneous induction mixtures, specific fuel consumption initially responds to increases in excess-air factor À by falling (Fig. 1). The progressive reductions in the range extending to λ = 1.0 are explained by the incomplete combustion that results when a rich air/ fuel mixture burns with inadequate air. The throttle plate must be opened to wider apertures to obtain a given torque during operation in the lean range (λ > 1). The resulting reduction in throttling lasses combines with enhanced thermodynamic efficiency to furnish lower rates of specific fuel consumption.



Picture 37 - Effect of the excess-air factor on the consumption

As the excess-air factor is increased, the flame front's propagation rate falls in the resulting, progressively leaner mixtures. The ignition timing must be further advanced to compensate for the resulting lag in ignition of the combustion mixture. As the excess-air factor continues to rise) the engine approaches the lean-burn limit, where incomplete combustion takes place (combustion miss). This results in a radical increase in fuel consumption. The excess-air factor that coincides with the lean-burn limit varies according to engine design.

Stratified-charge concept

Engines featuring direct gasoline injection can operate with high excess-air factors in their stratified-charge mode. The only fuel in the combustion chamber is found in the stratification layer immediately adjacent to the tip of the spark plug. The excess-air factor within this layer is approximately $\lambda = 1$. The remainder of the combustion chamber is filled with air and inert gases (exhaust-gas recirculation). The large throttle plate apertures available in this mode lead to a reduction in pumping losses. This combines with the thermodynamic benefits to provide a substantial reduction in specific fuel consumption.

4.4.4.2 Effects of ignition timing

Homogeneous mixture distribution

Each point in the cycle corresponds to an optimal phase in the combustion process with its own defined ignition timing (Fig. 1). Any deviation from this ignition timing will have negative effects on specific fuel consumption.

Stratified-charge concept

The range of possibilities for varying the ignition angle is limited on direct-injection gasoline engines operating in the stratified-charge mode. Because the ignition spark must be triggered as soon as the mixture cloud reaches the spark plug, the ideal ignition point is largely determined by injection timing.

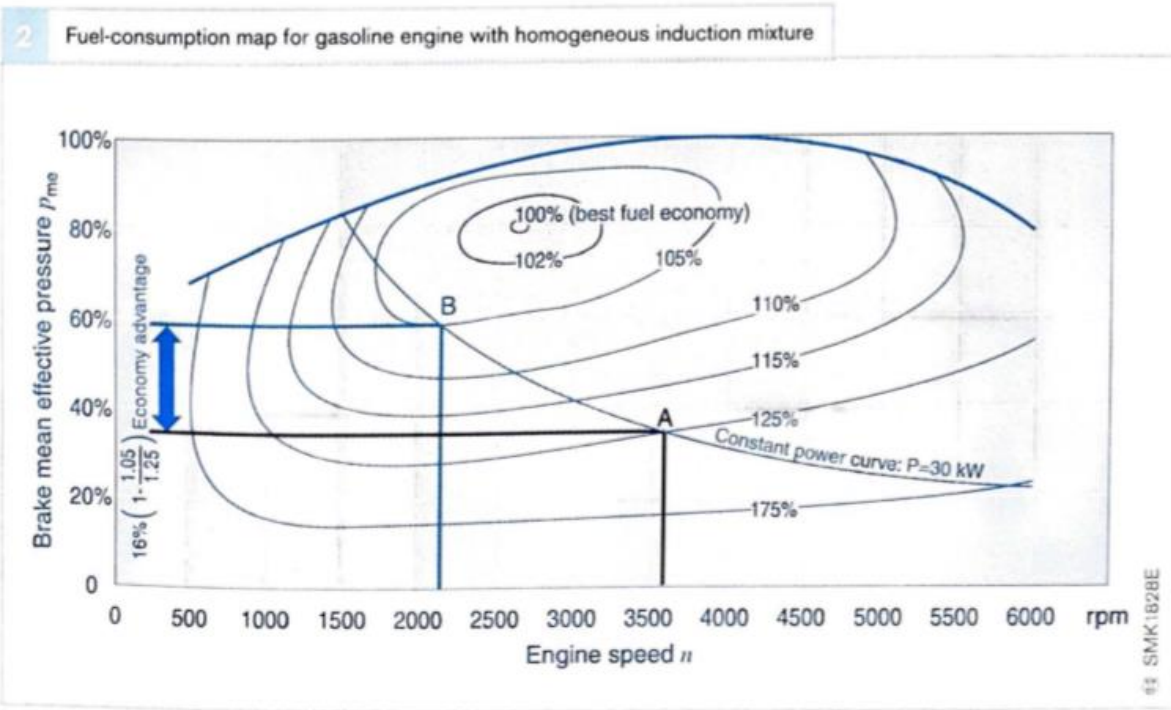
4.4.4.3 Achieving ideal fuel consumption

During operation on homogeneous induction mixtures, gasoline engines must operate on a stoichiometric air/fuel ratio of $\lambda = l$ to create an optimal operating environment for the 3-way catalytic converter. Under these conditions using the excess-air factor to manipulate specific fuel consumption is not an option. Instead, the only available recourse is to vary the ignition timing. Defining ignition timing always equates with finding the best compromise between maximum fuel economy and minimal levels of raw exhaust emissions. Because the catalytic converter's treatment of toxic emissions is very effective once it is hot, the aspects related to fuel economy are the primary considerations once the engine has warmed to normal operating temperature.

4.4.4.4 Fuel-consumption map

Testing on an engine dynamometer can be used to determine specific fuel consumption in its relation to brake mean effective pressure and to engine speed. The monitored data are then entered in the fuel consumption map (Fig. 2). The points representing levels of specific fuel consumption are joined to form curves. Because the resulting graphic portrayal resembles a sea shell, the lines are also known as shell or conchoids curves. As the diagram indicates, the point of minimum specific fuel consumption coincides with a high level of brake mean effective pressure P_{me} at an engine speed of roughly 2600 rpm.

Because the brake mean effective pressure also serves as an index of torque generation M, curves representing power output P can also be entered in the chart. Each curve assumes the form of a hyperbola. Although the chart indicates identical power at different engine speeds and torques (operating points A and B), the specific fuel consumption rates at these operating points are not the same. At Point B the engine speed is lower and the torque is higher than at Point A. Engine operation can be shifted toward Point A by using the transmission to select a gear with a higher conversion ratio.



Picture 38 - Fuel consumption map for gasoline engine

(Gasoline-Engine Management – System and Components – Robert Bosch)

4.4.5 Pros & Cons of PETROLEUM

A particular type of fossil fuel that is used in powering vehicles, petroleum has been widely used and offers people with a lot of advantages. However, just like other energy sources, it also has its own sets of disadvantages. Some of its common downsides are negative environmental impact, cost and availability. Its cost tends to fluctuate, and this is somehow attributed to many different factors. As for the environmental impacts, this is more on its production and combustion. Of course, petroleum has both advantages and disadvantages that we should be aware of. Details about these are helpful to determine its proper and practical use. They also serve as guide for us especially those who are using it often for a variety of purposes.

The Advantages of Petroleum

1. It can be extracted easily.

Technologies that are used for extracting oil beneath the planet's surface are well developed. These days, it is extremely easy to exploit oil deposits in different geological conditions. It does not matter if these reserves are to be extracted beneath the ocean's surface or in regions with special climate conditions.

Petroleum is also not that difficult to produce, though most of the low-cost locations are already depleted. Now, it is being mined off sea coasts and tar sands. Technology for oil refineries has also reached its maturity, which means that refining it to get valuable products, such as gas and diesel, have also become quite easy.

2. It has high density.

The average 1 kilogram of burnt oil can generate up to 10,000 kilocalories. This means that, for only small amounts, petroleum can generate a substantial amount of energy.

3. It can be extracted at a low cost.

Due to the fact that petroleum production requires reduced technical and physical effort, it is sold cheaper compared to other sources of energy.

4. It can easily be transported.

Because petroleum is in liquid form, it is just easy to transport. It can be brought from extraction sites to power plants through pipes or vehicles. Aside from easy transport, it can also be stored conveniently.

5. It is highly available with good infrastructure for transport and use.

Oil is widely distributed to almost every part of the globe. In fact, there exists a massive infrastructure to transport it through ships, pipelines and tankers.

6. It has broad areas for application.

Aside from being the primary energy source of power plants to supply the high demands for energy of the modern world, it is used to power machines of all types, including heavy equipment, power generators and vehicles.

7. It is a crucial element in industries.

Besides being an essential commodity for transport, petroleum is a critical component in a wide variety of industries. It is difficult to think of another product that has such a huge role to play for creating other products, such as Vaseline, medicines and clothing.

8. It can power up almost all types of vehicles.

This is an obvious advantage of petroleum. Whether they are diesel or gasoline vehicles, they can be run by oil. Using oil is beneficial in terms of satisfying our need to quickly move from one place to another.

9. It can support constant power use.

Unlike alternative energy sources, such as solar and wind, oil can produce power 24/7 and is highly reliable. Plus, oil engines are a technology in a mature state and are highly reliable to work with.

10. It is a powerful source of energy.

Taking into consideration cars, they can travel longer and run faster when powered by petroleum.

The Disadvantages of Petroleum

1. Its resources are limited.

Like any other natural fossil fuel, petroleum is a limited resource. High demands for energy by the modern society have stressed the conventional sources of oil reserves. The decrease in supply is clearly indicated by the ever increasing cost of petroleum on the market these days. Now, power plants are having a hard time extracting petroleum as reserves are nearly drought. In fact, studies reveal that almost half of oil reserves (which is about 2 trillion barrels) have been utilized, where only one trillion barrels left.

There might be some other sources of petroleum on earth, but experts say that these cannot produce enough oil to sustain all our needs.

2. It contributes to environmental pollution.

Extracting and burning petroleum generates greenhouse gases that contribute to environmental pollution and, consequently, global warming. This means that degradation of our ecosystems will be quicker if we choose petroleum as our main source of energy.

3. It produces hazardous substances.

Production of petroleum, especially refining, produces harmful and toxic materials, including plastic. Take note that oil exists as a mixture of hydrocarbons with traces of sulphur and other compounds, which are elements of harmful gases, such as carbon monoxide, and plastic.

4. It is a non-renewable form of energy.

Once burned to generate electricity, petroleum cannot be replaced. Depletion of fuels can occur overtime and can lead to their limited supply. When this happens and demands are high, oil costs will significantly increase, leading economical conflicts between nations. Thus, we should find alternative energy resources, so oil reserves can still continue to supply energy for many years to come.

5. Its transport can cause oil spills.

If petroleum spills in bodies of water, adverse effects in marine life are expected. Spills have caused massive ocean pollution, causing the death of thousands of animals and fishes each year. As an example, the BP Oil Spill had caused billions of dollars in losses.

6. It sustains growth of terrorism and violence.

Truth be told, oil is drilled in some of the worst dictatorships in the world. Oil money goes directly into the hands of despots who are amassing trillions of dollars. This gives rise to violence and growth in terrorism, as oil money is somehow used in funding terrorist organizations. Aside from this, this powerful pool of money also managed to suppress voices of protests.

Despite the many advantages brought by petroleum, it still cannot be denied that it also leads to unfavourable consequences. So, we need to be aware of these factors and take them as reminders that petroleum needs to be utilized wisely.

https://greengarageblog.org/16-marked-advantages-and-disadvantages-of-petroleum

4.4.6 Recap about Gasoline

Here is a recap about all the data that have been found on gasoline. All these data are meant to be used in a comparison part.

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Energy per Volume	MJ/m^3	36816
Density	kg/m^3	780
Energy per Mass	MJ/kg	47,2
Octane		90
LHV	MJ/kg	43,4
HHV	MJ/kg	46,4
Air/fuel Ratio	kg	14,7
Min. Ignition Energy	MJ	0,8
Self-Ignition Temperature	°C	280
Price/L	€	1,52
Average Car Price	€	25000
Approximate range	km	950
Cost per 100km	€	7,9

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	121
CO	g/km	1,845
NOx	g/km	0,011
PN	nb/km	1,77E+12

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	121
Greenhouse emissions	g/km	238

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	169
Greenhouse emissions	g/km	296

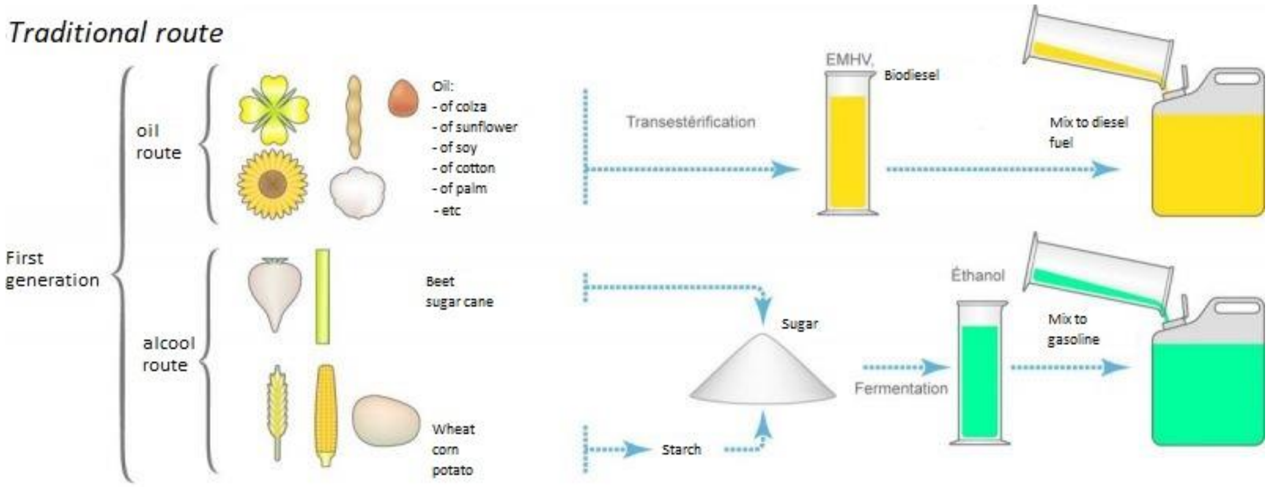
(green)	Energy data
(orange)	Consumer acceptance
(red)	Pollution

Picture 39 - Recap about Gasoline

4.5 Biofuel

For the moment, biofuel is more used as a complement added to gasoline or to petroleum diesel than a real fuel. For example, biofuel is used in the 95 E10 which means that into the gasoline we find 10% of bioethanol. These biofuels are made from organic matter (plants, trees, etc.).

How does it works?



Picture 40 - Process of biofuel

The main advantage of biofuels is that by mixing biofuel with classic fuel it permits to reduce our consumption of fossil fuels. But these fuels have also a lot of disadvantage.

- The first one is the pollution. Brazil is one of the countries which use the most biofuel and Brazil is suffering a lot of air pollution. Indeed, in Brazil air we found 160% more of formaldehyde and 260% more of Acetaldehyde than in the air of a country which doesn't use biofuel (these hydrocarbons are responsible of breathing disorder and cancer).

- But biofuel process is also problematic. For producing biofuel, we need fields to make crops, so, we use fields and crops for fuels instead of for feeding humanity. So, by this process, agriculture for food is put into competition with fuels for cars. Because of this competition, prices of corn for example are rising based on the request, and in poor country this rising can't be supported by populations.

- Then, in Asia or South America, forests are destroyed to put oil palm instead to answer to the rising request of biofuels. This action could be an ecological disaster.

To conclude about biofuel we can say that there are useful to reduce our fossil fuels consumption but they present also an important economic and ecologic risk.

4.6 Diesel research

Diesel engine is one of the most common engines used on different types of transport, like cars but also trucks, boats or even aircrafts. So, the efficiency of this type of engine does not need to be proved anymore.

Picture 41 - Diesel engine

Indeed, since his creation by Rudolf Diesel, a German scientist and inventor, in 1897, diesel didn't stop to be more and more popular, in Europe for example, until this last years. This popularity is due to the lowest using of fuel of this engine compare to a petrol engine, but also because diesel emit less CO_2 and at the fuel station, petroleum diesel is cheaper than petrol fuel.

Petroleum diesel is made by refining the petrol and adding a lot of chemicals in order to destroy undesirable component like suffer, or to improve his efficiency, for example adding detergent component to clean the engine. But all this process uses a lot for energy and all this chemical can also pollutes. But we can also go further to realize how making diesel fuel can pollute. For example, to destroy suffer, fuel makers are using hydrogen, but hydrogen production can be a big source of pollution.

Picture 42 - Diesel refinery

In addition, during the last years, scientists started to find links between diesel exhausts and the raising number of premature deaths and cancers in the whole world.

Even if diesel emit less CO_2 than petrol engine, this is not the only harmful gas for the planet and for the people's live. By analysing diesel exhaust, a lot of harmful gases appear. The most harmful from diesel engine are:

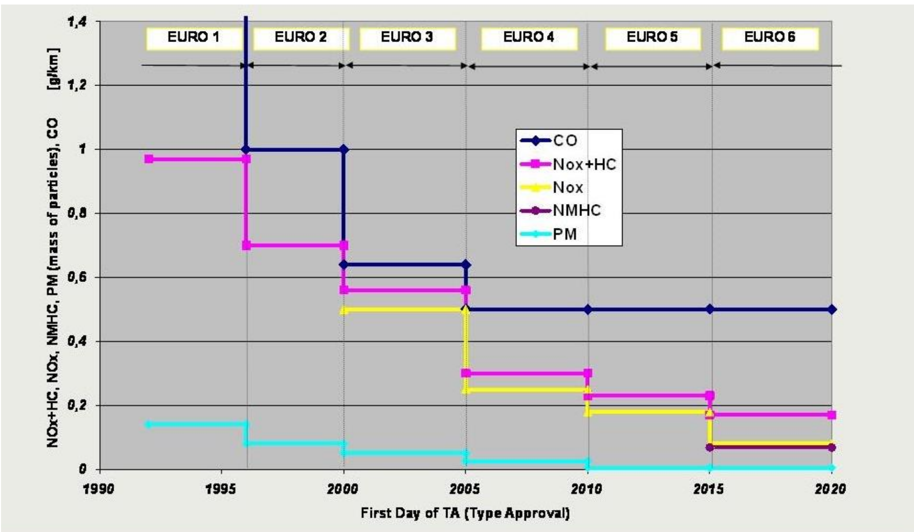
- Carbon Monoxide (CO), produced during the fuel combustion, this gas could be deadly for humans.
- Nitrogen oxide (NO_x), is also created during the combustion and it depend of the temperature of this one. This gas can be responsible of breathing disorders and it took part in the formation of the ozone layer. So, NO_x is as dangerous for peoples as for the planet.
- Hydrocarbon (HC) are residues of the combustion and can react with particles in the air to form different types of chemicals. They can take part in the global warming or, if they react with NO_x, the new chemical can be harmful for humans. For example, the formaldehyde or the benzene can be responsible of breathing disorders and even of cancers.
- Particles matter (PM) can be responsible of breathing and cardio disorders and can even be deathly for humans.

In order to protect the environment and the people, norms have been created to limit the quantities of gases created by a car. The first European norm "Euro 1" was approved in 1992 by the European Union. Then, since, this norm is regularly reviewed and goes stricter and stricter.

Tier	Date (Type Approval)	Date (First Registration)	CO	THC	NMHC	NO_x	HC+NO_x	PM	PN [#/km]
Diesel									
Euro 1†	July 1992	January 1993	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)	-
Euro 2	January 1996	January 1997	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	January 2001	0.66	-	-	0.50	0.56	0.05	-
Euro 4	January 2005	January 2006	0.50	-	-	0.25	0.30	0.025	-
Euro 5a	September 2009	January 2011	0.50	-	-	0.180	0.230	0.005	-
Euro 5b	September 2011	January 2013	0.50	-	-	0.180	0.230	0.0045	6×10^{11}
Euro 6b	September 2014	September 2015	0.50	-	-	0.080	0.170	0.0045	6×10^{11}
Euro 6c	-	September 2018	0.50	-	-	0.080	0.170	0.0045	6×10^{11}
Euro 6d-Temp	September 2017	September 2019	0.50	-	-	0.080	0.170	0.0045	6×10^{11}
Euro 6d	January 2020	January 2021	0.50	-	-	0.080	0.170	0.0045	6×10^{11}

Picture 43 - Pollution norms

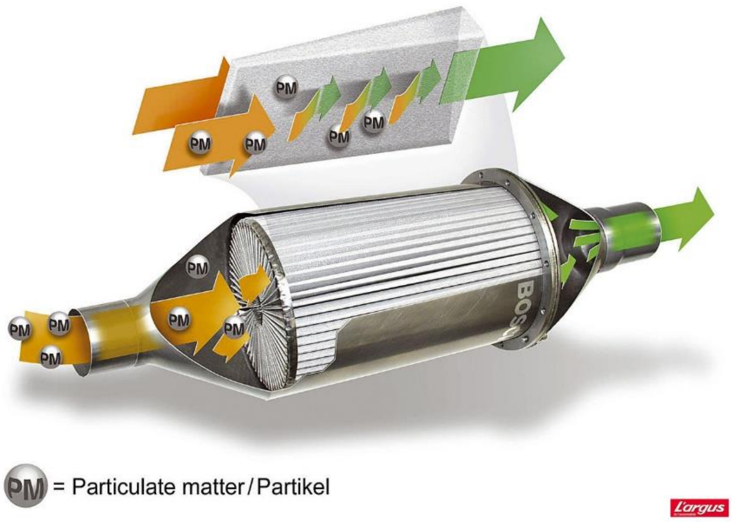
But, since this norm appeared and with these numerous adjustments, the level of all these gases didn't stop decreasing.



Picture 44 - Evolution of pollution since 1990

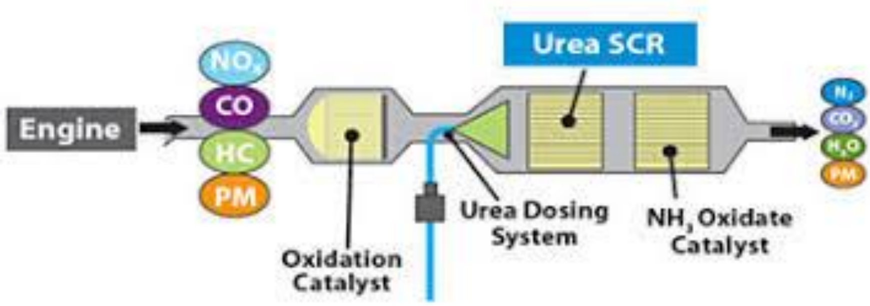
But how cars constructors do to always decreased the among of pollution? Thanks to three main technologies:

- Diesel Particulate Filters (DPFs) remove 99.9% of particles coming from the engine, including ultrafine particles. Ceramic wall flow filters remove nearly all carbon particulates, including fine particles less than 100 nanometres (nm) in diameter. Since the Euro 5b exhaust emissions legislation was introduced in 2011, DPFs are effectively mandatory.



Picture 45 - Diesel Particles Filter

- DeNOx exhaust after treatment systems such as Selective Catalytic Reduction (SCR) and NOx traps further reduce and control tailpipe NOx emissions of diesel cars. In the SCR system, ammonia is used to convert over 70% (up to 95%) of NO and NO2 into nitrogen over a special catalyst system. AdBlue®, for example is a urea solution which is carefully injected from a separate tank into a diesel car's exhaust system where it hydrolyses into ammonia ahead of the SCR catalyst. A growing number of diesel cars registered after September 2015 (predominantly Euro 6-compliant vehicles) are equipped with this technology.

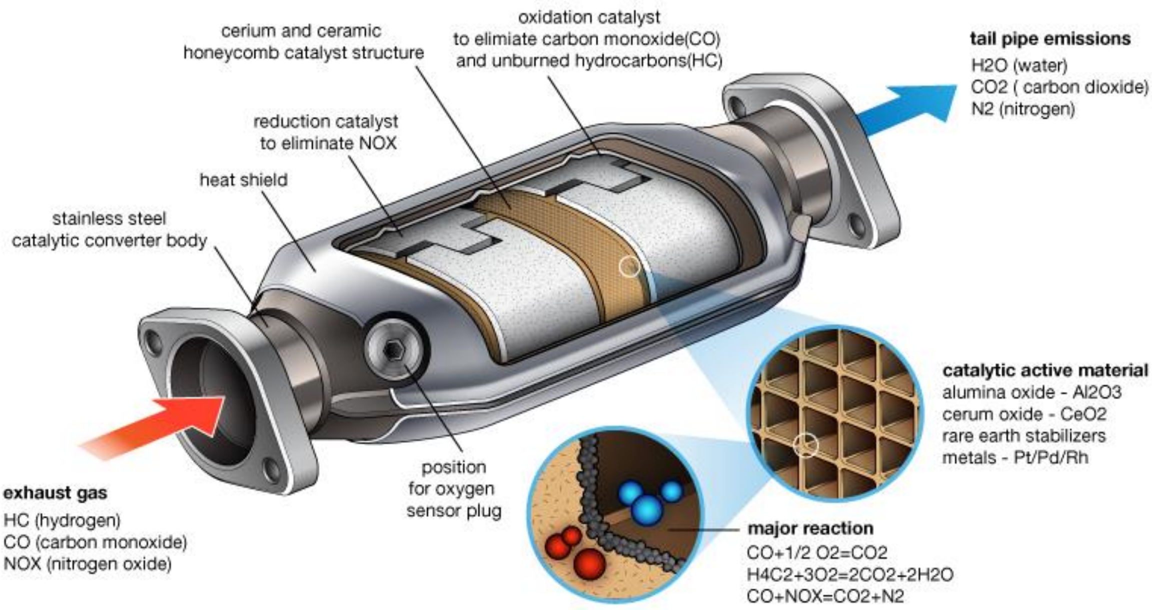


Picture 46 - Selective Catalytic Reduction

- Oxidation catalysts remain a key technology for diesel engines and convert carbon monoxide (CO) and hydrocarbons (HC) into CO2 and water.

Since 1992, successive Euro emission standards have set stricter limits on the amount of pollutant emissions a vehicle can emit, such as PM, NOx, unburnt hydrocarbons and CO.

A European diesel passenger vehicle was permitted to emit 140 milligrams of PM per kilometre in 1992, but this number dropped to just 4.5 milligrams in 2014. In addition, NOx and unburnt hydrocarbon emission limits have seen reductions of more than 90% over the same period.



Picture 47 - Catalytic treatment of the exhaust

4.6.1 How diesel innovation is reducing air pollution?

The new generation of diesel engines is made up of an integrated three-part system: a highly efficient engine, ultra-low sulphur diesel fuel and an advanced emissions control system.

The advanced electronic engine management system is the “brain” of a modern engine which controls, among others, emission levels, as it collects and processes signals and data from on-board sensors and then coordinates the DPF and SCR exhaust after treatment systems.

The ultra-low level (less than ten parts per million) of sulphur in the fuel allows the use of improved emission control devices. This enables the engine to utilise the particulate filter to trap the soot particles, reduce its emissions and thus improve air quality.

Additionally, the common rail high pressure diesel injection systems contribute to the high efficiency of diesel engines. These systems increase the pressure in the injectors and provide better fuel atomisation, which in turn improves the ignition and combustion processes. This ensures that only the necessary amount of fuel required by the injectors is supplied to the common rail. It also enables the filter to be regularly ‘regenerated’ by burning off the collected soot.

The latest generation of diesel engines uses catalytic converters, absorbers and particle filters that convert up to 99% of combustion engine exhaust pollutants (HC, CO, NOx and particulates). The catalytic converter plays an important role in controlling emissions: carbon monoxide (CO) and unburnt hydrocarbons (HC) are oxidised into CO_2 and H_2O while NOx, i.e. NO and NO_2 is reduced into inert N_2, thus virtually eliminating toxic gases and reducing air pollution.

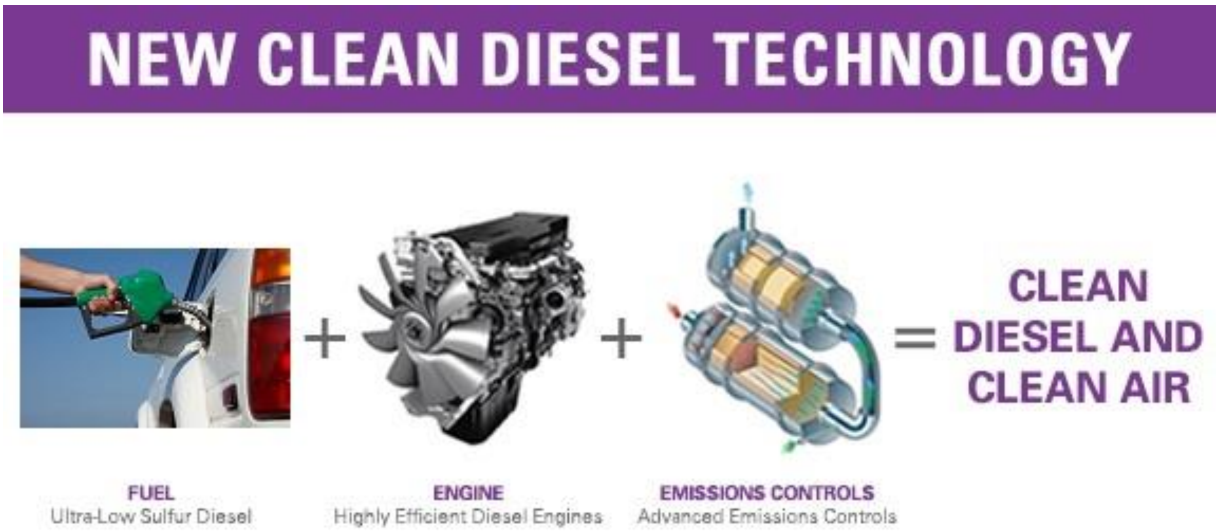
The industry has demonstrated its commitment to improving air quality by developing and combining technologies that can directly address air pollution issues.

At a time when there was still a lack of epidemiological evidence regarding health effects of particles, the "precautionary principle" was invoked, requiring the elimination of carbon particles through the use of DPFs on all new diesel cars sold in Europe from 2011 onwards. This was confirmed by the 2013 World Health Organization (WHO) Review of Evidence on Health Aspects of Air Pollution which indicated that ultrafine particles have toxic effects on the human body.

The wall-flow DPF has the function of trapping and storing particulates over the whole particles' size range. The exhaust gas passes through a porous ceramic wall honeycomb structure, where soot particles are deposited as a soot layer. This 'soot cake' not only stores soot but also filters out the ultrafine particles.

Consequently, particle mass and number emissions from diesel vehicles are efficiently controlled under real-world driving conditions, as the number of particles is being reduced by several orders of magnitude. High exhaust temperatures then periodically burn the soot collected in the DPF thus regenerating the filter and making it ready for the next round of soot collection.

The industry has demonstrated its commitment to improving air quality by developing and combining technologies that can directly address air pollution issues.



Picture 48 - Clean diesel equation

4.6.2 High-performing, efficient diesel engines

Improvements in diesel engine performance mean that, over the past 15 years, NOx and particulate matter (PM) emission limits have both been drastically reduced.

In practice, DPFs remove over 99.9% of particles, including ultrafine ones. The reduction of real-world NOx emissions did not always improve at the same pace as the Euro 3 to 5 standards.

While engine improvements tend to decrease NOx emissions, they also tend to increase PM emissions. In other words, decreasing NOx through lowering the maximum combustion temperature increases the PM emissions from the engine, as it inhibits the complete oxidation of soot. This is called the 'NOx-PM trade-off'.

The majority of manufacturers in Europe have chosen to use this trade-off to minimise particulate emissions at the engine-out, while using SCR after treatment to control emissions of NOx coming from the engine. This method allows the improvement of fuel economy compared with the previous generation of engines.

4.6.3 What innovations can we expect next?

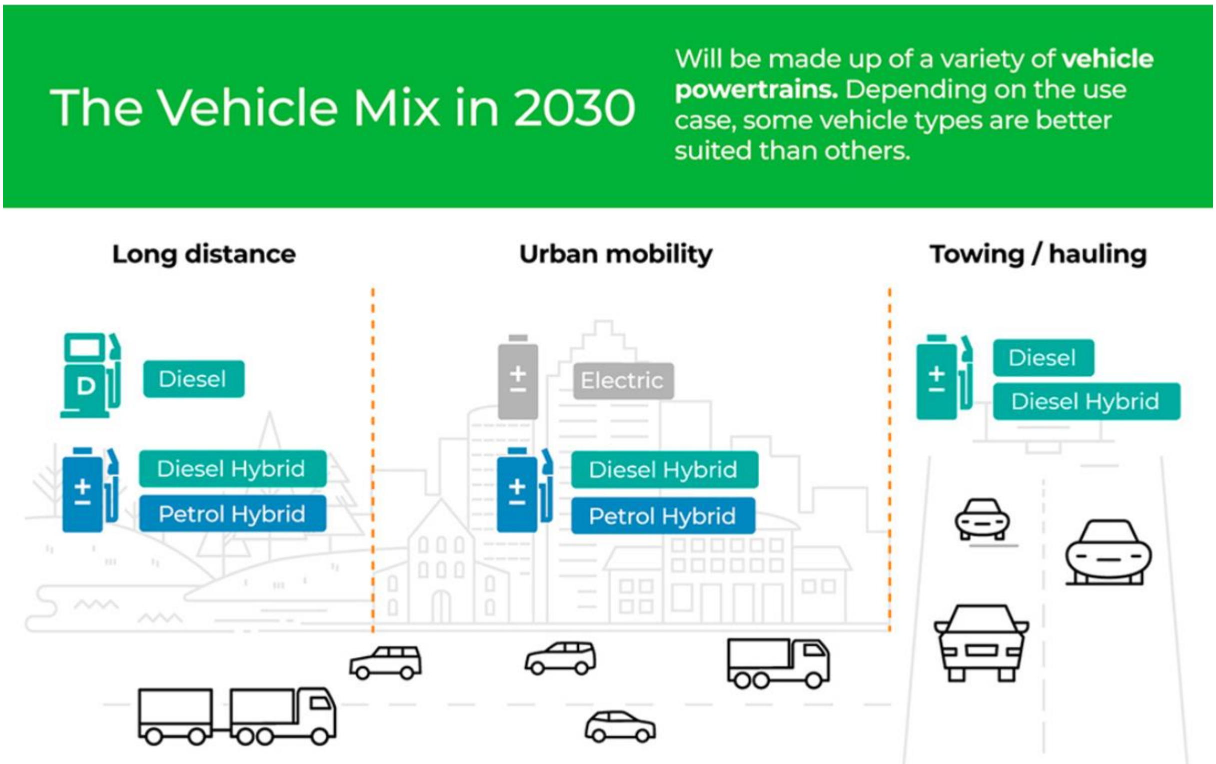
Since the early 90s, the European Union has introduced increasingly strict emissions limits on vehicles known as the "Euro standards series". The Euro 1 to 4 standards were not as stringent as the Euro 5 and 6, as they did not require particle or NOx after treatment devices to be fitted to diesel cars. These older, "dirtier" diesel cars are contributing to the air quality challenges European cities are facing.

In order to follow Europe's new and more stringent emissions standards, the diesel vehicle industry has consistently innovated and improved engine efficiency.

Diesel engine technology has come a long way in an incredibly short timeframe. Compared to what they used to be 10 years ago, today's diesel engines are cleaner and more efficient, being equipped with emission control systems to eliminate harmful emissions from the vehicle's tailpipe.

Ever more-stringent targets mean the diesel industry will continue to reach even higher efficiency standards.

For the future we can imagine different situation like this one:



Picture 49 - Diesel in the future

In this vision of the future can be used in different ways. Alone for a long-distance trip thanks to the low using of fuel that give this type of engine and the better autonomy than they offer. Or, diesel engine could be used in a Hybrid electric way to decrease again more the use of fuel and the pollution of the thermal engine.

Diesel has some disadvantages, engine more complicated to maintain, less efficient at cold so it pollutes and uses more fuel when it starts. Nowadays, a lot of politicians are asking for the end of diesel (France, China…), but car constructors are always working to make the diesel safer for the planet and for humans by creating new technologies which control the exhaust, or by introducing the hybrid electric-diesel. So, thanks to these innovations, it might not be the end of diesel engines.

4.6.4 Recap about Diesel

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Energy per Volume	MJ/m^3	38408
Density	kg/m^3	846
Energy per Mass	MJ/kg	45,4
Cetane		51
LHV	MJ/kg	42,6
HHV	MJ/kg	45,6
Air/fuel Ratio	kg	14,5
Self-Ignition Temperature	°C	210
Price/L	€	1,4
Average Car Price	€	24000
Approximate range	km	1200
Cost per 100km	€	5,74

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	100
CO	g/km	0,037
NOx	g/km	0,463
PN	nb/km	1,23E+10

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	100
Greenhouse emissions	g/km	205

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	140
Greenhouse emissions	g/km	217

Green	Energy data
Orange	Consumer acceptance
Red	Pollution

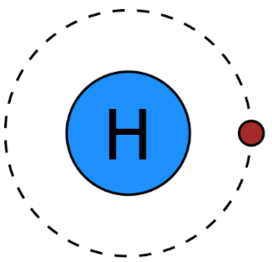
Picture 50 - Recap about diesel

4.7 Hydrogen & Electricity as fuels

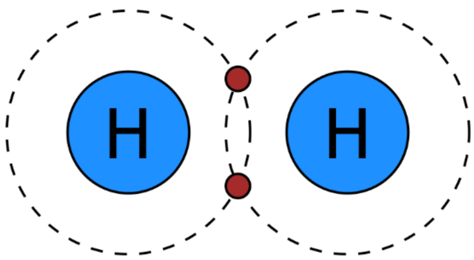
4.7.1 Hydrogen

4.7.1.1 Physical properties

Hydrogen atom is the lightest element that exists, with its most common isotope consisting of only one proton and one electron. Because of it chemical structure, hydrogen atom readily form H_2 molecules which are smaller compared to other molecules. Hydrogen is colourless, odourless and tasteless and is about 14 times lighter than air. On cooling, hydrogen turns into liquid at a temperature below -253°C. Ordinary hydrogen has a density of 0,09 kg/m^3 and gaseous hydrogen has one of the highest heat capacity (14.4 kJ/kg K).



Picture 51 - H2 element



Picture 52 - Hydrogen atom

4.7.1.2 Fuel properties

Hydrogen is flammable over a wide range of temperature and conditions. It has a high combustion efficiency and is truly outstanding as a fuel of the future in terms of physical and chemical properties. Unfortunately there are still technological challenges that needs to be solved on the following fields; safety, storage and transportation. There are at the moment two main uses for hydrogen as a fuel, HICE and Fuel cell. On reaction with oxygen, hydrogen releases its energy explosively in HICE combustion engines or quietly in Fuel cells with water as its only by-product. Hydrogen, unlike coal, is not available by itself on earth, instead it is available as chemical compounds of oxygen and carbon. For example, hydrogen is present in water, fossil hydrocarbon such as coal or natural gas and biomass such as protein. Although it is not directly available there a still different ways to obtain it. Hydrogen itself has similarities compared to methane (natural gas), liquefied petroleum gases (LPG) and liquid fuels. Because of this hydrogen can also serve as a fuel used to about mixtures with other fuels to improve its characteristics.

Comparison of Hydrogen with Other Fuels

Fuel	LHV (MJ/kg)	HHV (MJ/kg)	Stoichiometric Air/Fuel Ratio (kg)	Combustible Range (%)	Flame Temperature (°C)	Min. Ignition Energy (MJ)	AutoIgnition Temperature (°C)
Methane	50.0	55.5	17.2	5–15	1914	0.30	540–630
Propane	45.6	50.3	15.6	2.1–9.5	1925	0.30	450
Octane	47.9	15.1	0.31	0.95–6.0	1980	0.26	415
Methanol	18.0	22.7	6.5	6.7–36.0	1870	0.14	460
Hydrogen	119.9	141.6	34.3	4.0–75.0	2207	0.017	585
Gasoline	44.5	47.3	14.6	1.3–7.1	2307	0.29	260–460
Diesel	42.5	44.8	14.5	0.6–5.5	2327		180–320

Source: Adapted from *Hydrogen Fuel Cell Engines and Related Technologies*, College of the Desert, Palm Desert, CA, 2001.

Picture 53 - Comparison of Hydrogen with Other Fuels

4.7.1.3 Energy content

Hydrogen has the highest energy content per unit mass of any fuel. Hydrogen has about 140.4 KJ/Kg, this is three times more than the mass energy content of gasoline (Diesel), 48,6MJ/ kg. However on a volume base the situation is reversed 8,491 MJ/m^3 for liquid hydrogen versus 31,150 MJ/m^3. The low volumetric density of hydrogen result in problems in terms of storage. A large container is needed to store the hydrogen, energy is needed to convert hydrogen to liquid for storage or for increased density pressurization.

One of the important and attractive features of hydrogen is its electrochemical property, which can be utilized in a fuel cell. At present, H_2/O_2 fuel cells are available operating at an efficiency of 50-60% with a life-time up to 3000h. The current output ranges from 440 to 1720 A/m^2 of electrode surface, which can give power output ranging from 50 to 2500W.

LHV Energy Densities of Fuels

Fuel	Energy Density (MJ/m³ at 1 atm., 15°C)	Energy Density (MJ/m³ at 200 atm., 15°C)	Energy Density (MJ/m³ at 690 atm., 15°C)	Energy Density (MJ/m³ of Liquid)	Gravimetric Energy Density (MJ/kg)
Hydrogen	10.0	1,825	4,500	8,491	140.4
Methane	32.6	6,860		20,920	43.6
Propane	86.7			23,488	28.3
Gasoline				31,150	48.6
Diesel				31,435	33.8
Methanol				15,800	20.1

Source: Adapted from *Hydrogen Fuel Cell Engines and Related Technologies*, College of the Desert, Palm Desert, CA, 2001.

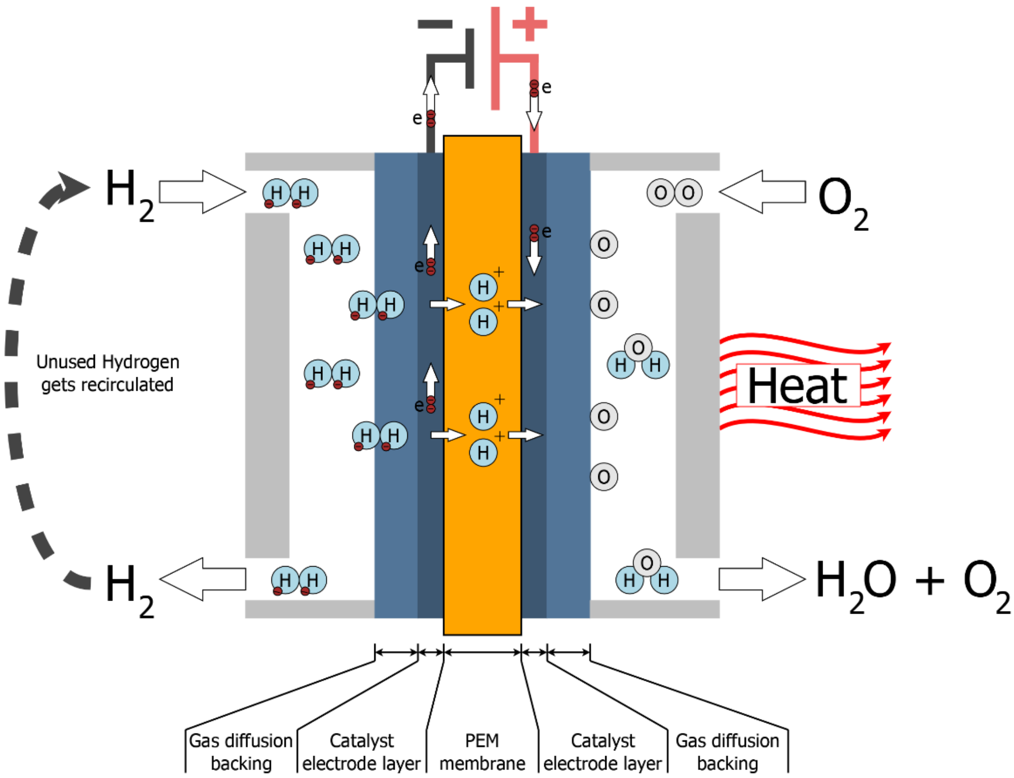
Picture 54 - LHV Energy Densities of Fuels

4.7.2 Fuel Cell

Fuel cell technology allows us to create electricity out of hydrogen using an electrochemical process. In the process hydrogen and oxygen are inserted into a fuel cell and the two element combine, turning them into water. During this process electricity can be generated. Out of different fuel cell technologies the hydrogen fuel cells, PEM, are currently used for vehicle and transport applications. Fuel cell technologies can offer an emission free energy source if produced on certain conditions.

4.7.2.1 Fuel cell Explanation

The fuel cell turns the chemical energy in hydrogen, which is obtaind in the electrolysis process, into electrical energy. Fuel cell consist out of two separated chambers divided by the PEM membrane



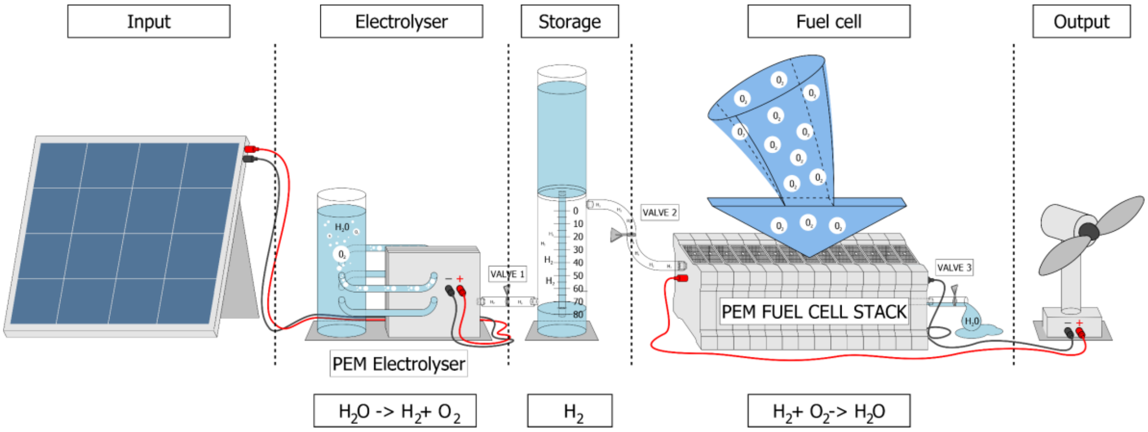
Picture 55 - PEM fuel cell

In the Fuel cell Hydrogen is being inserted on one side an oxygen into the other side. Hydrogen enters the chamber and is being attracted towards the oxygen. The following chemical reaction will take place:

$$2H_2 + O_2 \longrightarrow 2H_2O$$

The hydrogen and its electron both enter through the gas diffusion layer the catalyst layer. In the catalyst layer the hydrogen proton and the electron separate. This happens because only the hydrogen proton can travel through the PEM membrane and the electron can't. The electron has to go around the PEM layer and this can be achieved by making a bridge around it. By doing so we can create an electron flow through the bridge and therefore generating current that can generate power to recharge a battery. The theoretical electromechanical potential is 1.23V (0,4 $V_{hydrogen}$ + 0,83 V_{oxygen}). The electrons join the hydrogen and oxygen atoms behind the PEM membrane and combine themselves into water. During this process electricity is generated and can be used to drive electromotor's. This can be a continue process and stacking multiple fuel cells increases the output voltage. During this process energy losses are rather low because there is no mechanical friction. There is however energy loss because of heat released during the process. The temperature of the fuel cell can reach up to 85°C.

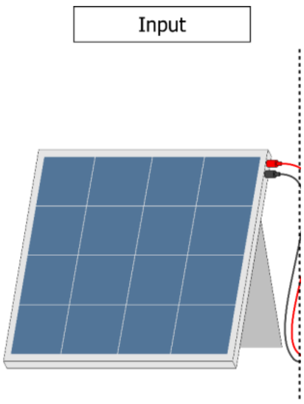
4.7.2.2 Fuel cell test



Picture 56 - Fuel cell test

Now that we know the process of obtaining hydrogen from water we can use the following setup as seen on the picture above, simulate and test the efficiency of hydrogen fuel cell on a smaller scale. The setup above is theoretically 100% emission free as the required energy is obtained throughout sunlight. Such a setup where the required energy is provided by an emission free process result in an energy transfer from the input to the output where no negative or bad consequences for its environment or surrounding. Therefore, in theory, this as an interesting contender for replacing fossil fuels. To determine if this is also true in practical use will did some testing on the system and tested its efficiency from the input to the output

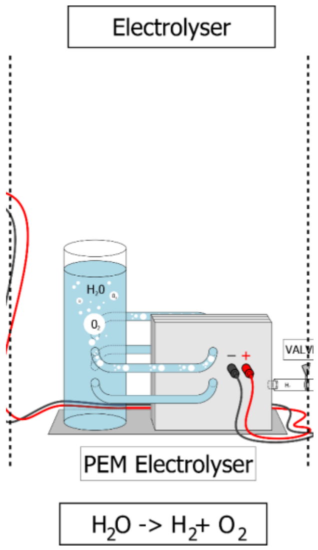
Step 1: Input



The electrolyser requires an input power. This power can be obtained in many different way. In the case of the test we used a solar panel to generate power needed for the electrolyser. Another good alternative can be wind energy. By using green methods to generate power the system is emission free.

Picture 57 - Solar panel

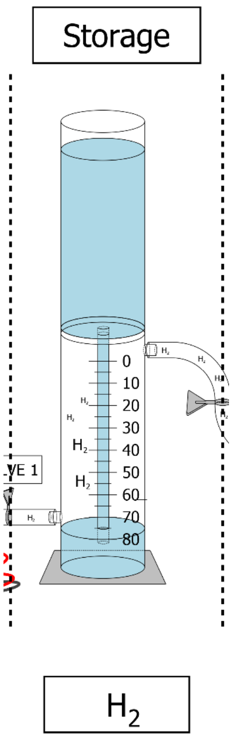
Step 2: Electrolyser



Picture 58 - Electrolyser

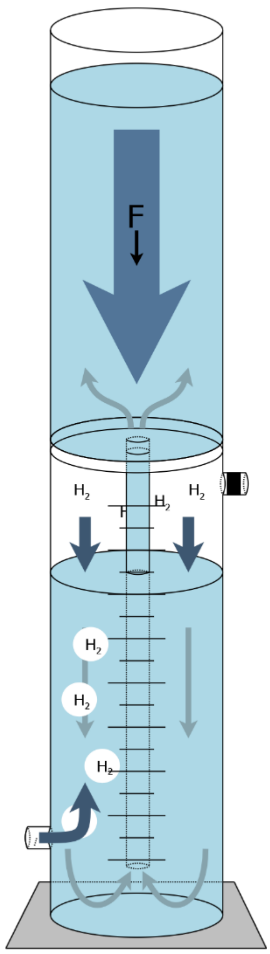
The electrolyser will convert water into hydrogen and oxygen with the use of electricity. Distillate water is used as liquid in the electrolyser, by using distillate water there will be no other substances inside the water that could pollute or clog any of the systems of the electrolyser. Water is stored in a storage tank besides the electrolyser. Water flows into the electrolyser using the two tubes bellow and oxygen leaves the electrolyser out the two tubes on top and then escapes via the storage tank into the atmosphere. Hydrogen leaves the tubes located on the right of the electrolyser. The valve on the left is used to prevent hydrogen flowing back into the electrolyser.

Step 3: Storage



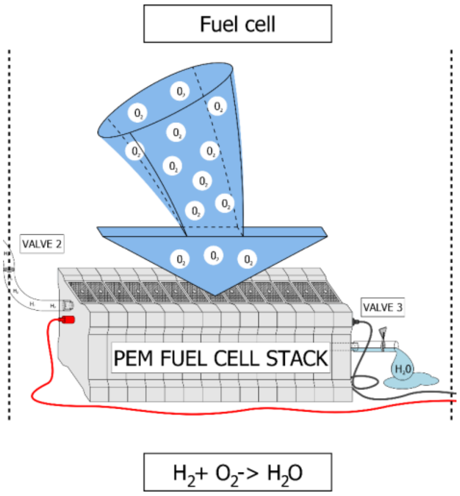
Picture 59 - Storage

Once the hydrogen is produced in the electrolyser, it is stored in a pressurised storage tank. The water provides the pressure in this case. A separate storage filled with water is placed on top of the hydrogen tank. If hydrogen flows inside it will push against the water inside the small tube and forces it out of the hydrogen tank inside. On the picture to the right you can see that the hydrogen forces the water to go up. The weight of the water (F) causes a force that is pressing against the hydrogen. This causes a pressurization of the hydrogen resulting in a larger capacity in the storage tank. Using this method we can increase the storage capacity with 2%. Unfortunately this is not that much but still a useful method to increase a bit of the capacity because of the low density of hydrogen means small storage capability. On the storage tank we also can see the volume in cm^3 from 0 to 80.



Picture 60 - Storage forces

Step 4: Fuel cell

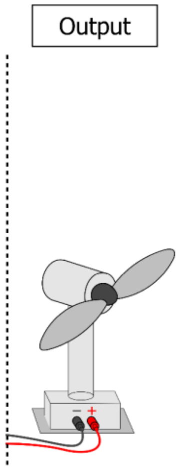


Picture 61 - PEM Fuel cell stack

In the Fuel cell we will convert the hydrogen into electrical power again using oxygen and hydrogen. Opening Valve 2 will cause hydrogen to flow through the fuel cell and this will start the reaction that will generate electricity. Valve 3 is used to drain the water out of the fuel cell and used to change to flow rate of the hydrogen and therefore changing the output power. There are 15 fuel cell stack up in this system to optimize its output power

Step 5: Output

A fan is used as the output for the setup. We will measure the voltage, current and time in order to calculate the output power. With these number we will find the efficiency of the complete setup.



Picture 62 - Motor

Results

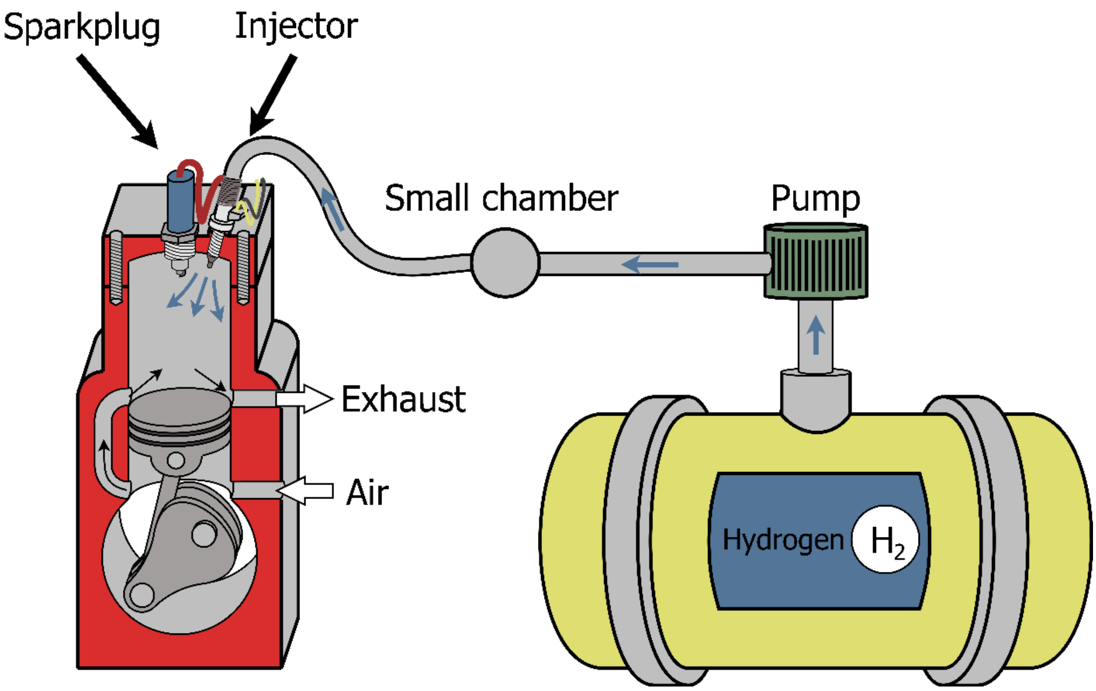
Elektrolysis PEM E106		
Time	0,13327778	h
Volume	0,00008	m^3
Water height	0,098	m
Gravity	9,81	m/s²
Density water	1000	kg/m^3
Water presure	961,38	N/m²
Hydrogen presure in storgae chamber	102271,38	N/m²
	1022,7138	hPa
	1,0227138	bar
Density H_2 (1atm)	0,08987	kg/m^3
Density H_2 (1,022atm)	0,09191129	kg/m^3
Quantity H_2 (1atm)	7,1896E-06	kg/m^3
Quantity H_2 (1,022atm)	7,3529E-06	kg
	0,00072058	g
Increased capacity	102	%
Power Input	0,01599516	kWh

Fuel cell PEM F110		
Volume	0,00008	m^3
Quantity H_2	7,3529E-06	kg
Power Input	0,01599516	kWh
Test #1 time	0,25555556	h
Test #1 peak output W	0,00076304	kWh
Test #1 average output W	0,00023932	kWh
Test #2 time	0,11111111	h
Test #2 peak W	0,00099549	kWh
Test #2 average W	0,0004618	kWh
Test #3 time	0,03333333	h
Test #3 peak output W	0,00585	kWh
Test #3 average output W	0,00290298	kWh
Test #1 peak effiency	4,8	%
Test #1 average effiency	1,5	%
Test #3 peak effiency	36,6	%
Test 3 average effiency	18,1	%

Picture 63 - Test results

4.7.3 HICE

Hydrogen can also be used as a fuel directly in an ICE with only small modification to the engine. ICE who run a hydrogen are called HICE. The HICE has the characteristics of low spark-energy and high flammability range offer a good alternative for SI gasoline engines. HICE can run a Pressurised hydrogen and liquefied hydrogen. Below is a picture of the basic principle of an HICE. It looks and works similar as a SI gasoline engine



Picture 64 - HICE concept

Hydrogen is transported into the system using a pump if liquefied. It is then transported to the small chamber where it is pressurised. Then the injector spray's it in the piston chamber and is ignited using a spark plug. As of diesel engines don't have spark plugs a modification is needed for diesel engines, sparkplugs are required and a mixture of diesel in the piston chamber for ignition. Using hydrogen as fuel for SI engines it offers a CO_2 and hydrocarbon free combustion resulting in lower NO_x emissions.

4.7.3.1 Power output

The power output from a HICE depends mainly on two major factors, the A/F ratio and the fuel injection method used and can be affected by volumetric efficiency, fuel energy density and pre-ignition. The stoichiometric A/F ratio for hydrogen is 34:1, this result in 29% of chamber displacement for hydrogen and the rest, 71% for air. The energy of this mixture is less than gasoline and since the mixture is indirectly injected the theoretical power output is 85% of a gasoline engine. However with direct injection, which mix the fuel with air after the camber is closed, the chamber is already filled with 100% air and can increase the maximum performance with 15% higher than gasoline engines. Unfortunately this will result in a higher combustion temperature which causes the formation of large amount of NO_X which is a pollutant. Because HICE are being used to reduce exhaust emissions, they are not designed to run at the stoichiometric A/F ratio but instead twice as much air is used. This result in only half the performance of gasoline engines but reduces NO_X near zero. Solutions for power loss are the usage of turbo or supercharges. Also direct injection with multiple stages can be a solution for lower power.

4.7.3.2 Hydrogen gas mixtures

Hydrogen can also be advantageously used in ICE as an additive to hydrocarbon fuels. Hydrogen can for example be mixed stored in the same tank as methane and when used with liquid fuels, hydrogen is stored separately and mixed in the gaseous state before injection. Hydrogen mixture-powered ICE has several operational advantages. Thanks to the hydrogen increased performance in different extreme weather conditions can be achieved as they have no cold start issues, even at sub-zero temperatures, and require no warm up.

Hythane, a gas that exists out of 20% hydrogen and 80% natural gas, is a commercial available gas that can be used in a natural gas engine. It is shown that by using this fuel emissions can drop with 20%. Any amount above 20% of hydrogen can reduce emission further but requires modifications to the engine. Also adding hydrogen to methane reduces hydrocarbon, CO_2, CO, but with the tendency of increasing NO_x emissions. However, since hydrogen enrichment leads into using leaner fuel mixtures, lean operations result in lower NO_x without sacrificing output efficiency. So it can be said that hydrogen mixtures offer leaner engine operation which will result in lower of CO and unburned hydrocarbon emissions as extra oxygen is available to oxidize CO and CO_2 and lower NO_X can be achieved.

4.7.4 Hydrogen challenges

Hydrogen is at this moment one of the most promising fuels for modern replacement of fossil fuels. It high energy content and efficient burning cycle with low emission output makes it a likely replacement fuel. However, producing hydrogen and getting it to it's the tank proves to be a rather difficult task preventing it from being used worldwide. Current production and storage methods proves to be very inefficient and a lot of emission are being created during the process producing the hydrogen, which makes it even less interesting. Also because its spontaneous combustion characteristics, a lot of safety procedures are required in hydrogen power vehicles and production facilities. Technological advancement is needed in Production, transport, storage and safety.

4.7.4.1 Production

As hydrogen itself cannot be found on itself on earth its needs to be produced using chemical processes from hydrocarbons, water, or other elements that exist out of hydrogen. Current world hydrogen production I production is about 50 million tons each year, about 2% of the current world energy consumption. Hydrogen can be produced using different methods. Most of the world's hydrogen production today is being produced through a more CO2 intensive process called Steam Methane Reforming (SMR).

4.7.4.2 SMR

SMR is by far the most important and used process for industrial manufacture of hydrogen. The technologies is well developed and commercially available from 1 t/h H_2 for small units to about 100 l/h H_2 for larger plants. This process is mostly for industrial levels only.

Methane is being transported in the system and mixed with Steam. This mixture is being heated to high temperatures where a chemical reaction is started with the help of a catalysator that turns the methane and steam into hydrogen and carbon dioxide. There is also still a bit of methane and steam mixed with the hydrogen and carbon dioxide. This needs to be filter out so that only the hydrogen remain to use. Using this method a purity of 99,99% hydrogen can be reached

4.7.4.3 Electrolysis

Process where water (H2O) is split into hydrogen (H2) and oxygen (O2) gas with energy input and heat in the case of high temperature Electrolysis. An electric current splits water into its constituent parts. If renewable energy is used, the gas has a zero-carbon footprint, and is known as green hydrogen.

4.7.4.4 Transport

Hydrogen can be transported in long distances and different formats. At this time hydrogen is being mainly transported in the following ways:

Compressed gas cylinders or Cryogenic liquid tankers

Compressed Gas Containers: Gaseous hydrogen can be transported in small to medium quantities in compressed gas containers by lorry. For transporting larger volumes, several pressurized gas cylinders or tubes are bundled together on so-called CGH 2 tube trailers. The low density of hydrogen also has an impact on its transport: under standard conditions (1.013 bar and 0°C), hydrogen has a density of 0.0899 kg per cubic meter (m3), also called normal cubic meter (Nm3). If hydrogen is compressed to 200 bar, the density under standard conditions increases to 15.6 kg hydrogen per cubic meter, and at 500 bar it would reach 33 kg H 2 /m3.

Liquid Transport: As an alternative, hydrogen can be transported in liquid form in lorries or other means of transport. In comparison to pressure gas vessels, more hydrogen can be carried with an LH 2 trailer, as the density of liquid hydrogen is higher than that of gaseous hydrogen. Since the density even of liquid hydrogen is well below that of liquid fuels, at approx. 800 kg/m 3, in this case too only relatively moderate masses of hydrogen are transported. At a density of 70.8 kg/m3, around 3,500 kg of liquid hydrogen or almost 40,000 Nm 3 can be carried at a loading volume of 50 m3. Over longer distances it is usually more cost-effective to transport hydrogen in liquid form, since a liquid hydrogen tank can hold substantially more hydrogen than a pressurized gas tank.

Pipelines

A pipeline network would be the best option for the comprehensive and large-scale use of hydrogen as an energy source. However, pipelines require high levels of initial investment, which may pay off, but only with correspondingly large volumes of hydrogen. Nevertheless, one possibility for developing pipeline networks for hydrogen distribution is local or regional networks, known as micro-networks. These could subsequently be combined into Trans regional networks.

Blending with natural gas

Blending hydrogen into natural gas pipeline networks has also been proposed as a means of delivering pure hydrogen to markets, using separation and purification technologies downstream to extract hydrogen from the natural gas blend close to the point of end use. As a hydrogen delivery method, blending can defray the cost of building dedicated hydrogen pipelines or other costly delivery infrastructure during the early market development phase.

4.7.4.5 Storage

Batteries are not suitable in storing large amounts of electricity over time. A major advantage of hydrogen is that it can be produced from (surplus) renewable energies, and unlike electricity it can also be stored in large amounts for extended periods of time. For that reason, hydrogen produced on an industrial scale could play an important part in the energy transition.

Compressed Hydrogen

Hydrogen is a light element and therefore compression is needed in its storage to increase its energy storage capacity. This is done by increasing its pressure up to 690 bar. This process requires about 30% of the stored energy content of the hydrogen.

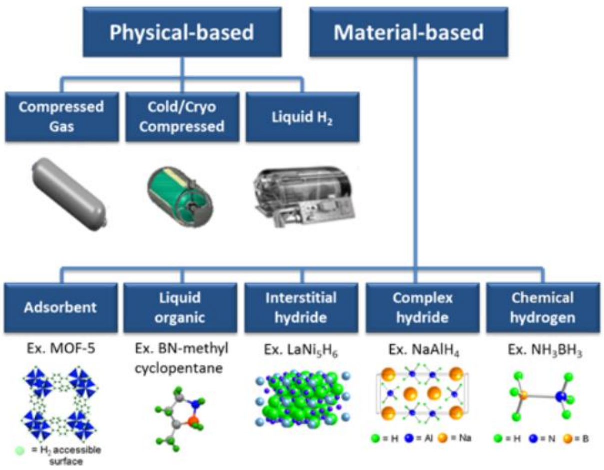
Liquefied Hydrogen

As well as storing gaseous hydrogen under pressure, it is also possible to store cryo-genic hydrogen in the liquid state. Liquid hydrogen (LH2) is in demand today in applications requiring high levels of purity, such as in the chip industry for example. As an energy carrier, LH2 has a higher energy density than gaseous hydrogen, but it requires liquefaction at –253 °C, which involves a complex technical plant and an extra economic cost. When storing liquid hydrogen, the tanks and storage facilities have to be insulated in order to keep in check the evaporation that occurs if heat is carried over into the stored content, due to conduction, radiation or convection.

Cold- and cryo-compressed Hydrogen

In addition to separate compression or cooling, the two storage methods can be combined. The cooled hydrogen is then compressed, which results in a further development of hydrogen storage for mobility purposes. The first field installations are already in operation. The advantage of cold or cryogenic compression is a higher energy density in comparison to compressed hydrogen. However, cooling requires an additional energy input.

Currently it takes in the region of 9 to 12 % of the final energy made available in the form of H2 to compress hydrogen from 1 to 350 or 700 bar. By contrast, the energy input for liquefaction (cooling) is much higher, currently around 30%.



Picture 65 - hydrogen storage systems

4.7.5 Electricity

4.7.5.1 History of electric vehicles

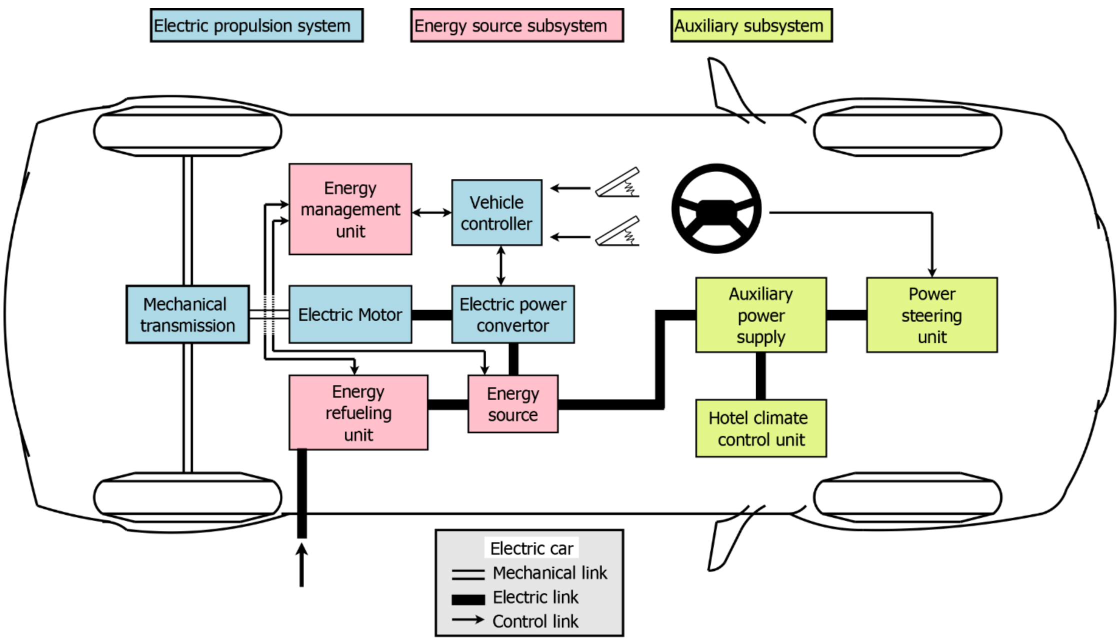
The first electric vehicle was invented in 1881 by a Frenchmen called Gustave Trouvé. It was a tricycle powered by a 0.1 hp DC motor fed by lead-acid batteries. In total the vehicle weighed about 160 kg including the driver. In 1883 a similar vehicle was built by two British professors. These early electric vehicles did not attract much attention because the technology was not mature enough to compete with horse carriages. Speeds like 15 km/h and a range of 16 km were not exiting for potential customers. Things changed in 1894 in the Paris to Rouen race. This was a race organised by the Parisian "Petit Journal" in order to promote their newspaper and the automotive sector. 21 out of the 101 contenders started the 126 km race which was run in 1 hour and 48 minutes at an average speed of 20.5 km/h. This speed was superior to that of horse carriages and so the general public became interested in horseless carriages or automobiles, as these vehicles were called now. For the following 20 years electric and gasoline engines competed with each other. This was particularly true in the US because there were not many paved roads so the limited range of electric vehicles was not a large problem. However, in Europe, the rapidly increasing number of paved roads demanded for an increase of extended ranges, favouring the gasoline engine. The most significant technical advance of the area was the invention of regenerative braking by Frenchmen M.A. Darracq on his 1897 coupe. This method allowed recuperating the vehicle kinetic energy while braking and recharging the battery. It's one of the most significant contributions towards today's hybrid electric vehicles as it contributes towards energy efficiency more than anything else in urban driving.

As gasoline cars started to become more powerful, more flexible, and, above all, easier to handle, electric vehicles started to disappear. The high cost of electric cars did not help, but it is their limited driving range and performance that really impaired them against gasoline counterparts; the last commercially significant electric vehicle was sold in 1905. For nearly 40 years electric cars were out of the theatre but things changed in 1945. Three researchers at Bell Laboratories invented a device that was meant to revolutionize the world of electronics and electricity: the transistor. It replaced vacuum tubes and soon after the thyristor was invented which allowed switching high current and high voltages and therefore made it possible to regulate the power fed to an electric motor and allowed the running of an AC motor and variable frequency. In 1966 General Motors built the Electrovan, which was propelled by motors fed by inverters build with thyristors. During the 1960s and 1970s concerns about the environment triggered some research on electric vehicles. However, despite advances in technologies and power electronics, their range and performance were still obstacles.

The modern electric vehicle culminated during the 1980s and early 1990s with the release of a few realistic vehicles by firms such as EV1 by General Motors. Although these vehicles presented a real achievement, it became clear that during the 1990s the electric automobiles were never going to be able to compete with gasoline engines in terms of range and performance. The most important reason for the lack of performance and range is that in batteries energy is stored in the metal of electrodes, which weigh far more than gasoline for the same energy content. Therefore the automotive industry abandoned electric cars and focused more on research on hybrid cars. Only after a few years these were far closer to the assembly line for mass production than electric vehicles have ever been. Great effort has been put in the research of batteries, with the intention of improving the performance to meet the electric vehicle requirements. Unfortunately, progress has been very limited and since the batteries are the weakest link in electric cars so has the progress of electric cars as well. In fact, basic study shows us that electric vehicles will never be able to challenge liquid fuelled vehicles even with optimistic value of battery energy capacity. Thus, in recent years advanced vehicle technology has turned to hybrid electric vehicle as well as fuel cell vehicles.

4.7.5.2 Modern EV concept

The first electric vehicle where achieved by replacing in ICEV their combustion engine and fuel tank with an electric motor and batteries while retaining all the other components. This resulted in poor flexibility, lower performance and heavier weight. To solve a new concept of the electric car was needed and thus came next structure for modern EVs

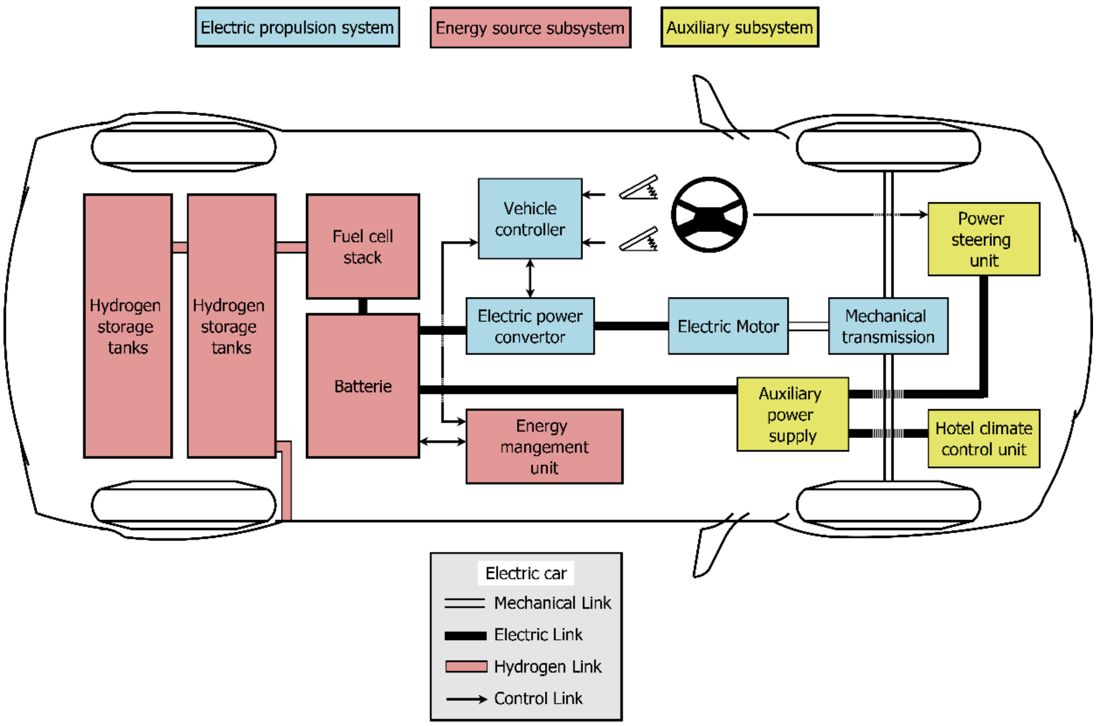


Picture 66 - EV concept

This structure has the same has the original body and frame designs but it satisfies the structural requirement unique to an EV. The following modern concept of an electric car consist out of three major sub systems, the electric propulsion, energy source and auxiliary sub system. Electric propulsion serves as the drive for the car. Based on the control input from the accelerator and brake pedals the vehicle controller provides the proper control signals to the electric convertor which functions to regulate the power flow between the energy source and the electric motor. Backwards power flow is also possible due regenerative braking of the EV and electricity will be stored in the energy source. Energy management unit cooperates with the vehicle controller to control the regenerative braking and its energy recovery. It also works with the energy refuelling unit to control the energy refuelling. The auxiliary power supply provides the necessary power at different voltage level's for all the other EV auxiliary, this is mostly used for the hotel climate control and the power steering unit. There are different variants of the EV configurations, this is because of variations in electric propulsion and energy source but the basic concept of the EV remains the same.

4.7.6 Combination of Hydrogen and Electricity

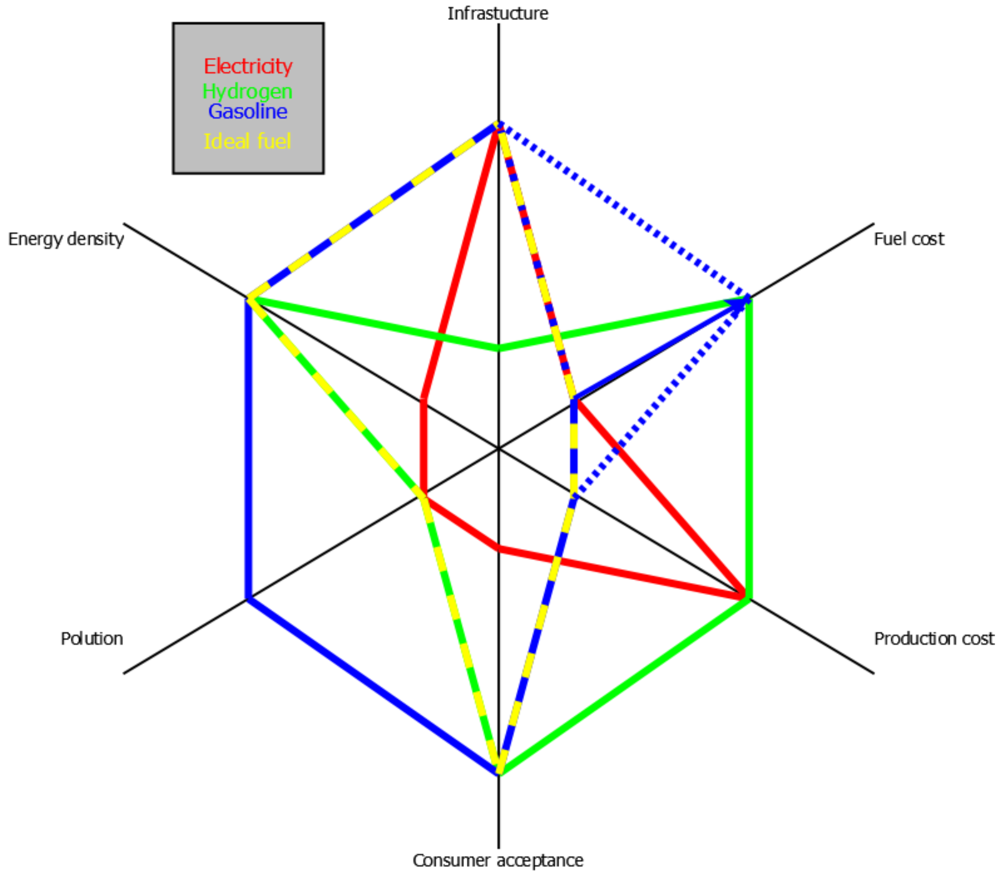
Modern fuel cell cars, like the Toyota Miraï, are combinations of fuel cell and EV. The fuel cell is used to recharge a smaller battery and therefore combine benefits from both methods, High torque and good performance from EV and quick refuel and CO_2 free energy converting process from the fuel cell. Also the hydrogen tanks can make the vehicle lighter than the large batteries in electric cars, this will increase its range and handling.



Picture 67 - Fuel cell concept

The electric propulsion system and the auxiliary subsystem are relatively the same as in the EV, differences can depend on the manufacturer. The energy source system has been change with the hydrogen Fuel cell and battery combination. The advantage of regenerative braking are still possible in this setup. Hydrogen can be stored as a liquid or pressurised at 690 ATM pressure.

4.7.7 Compare the advantages and disadvantages

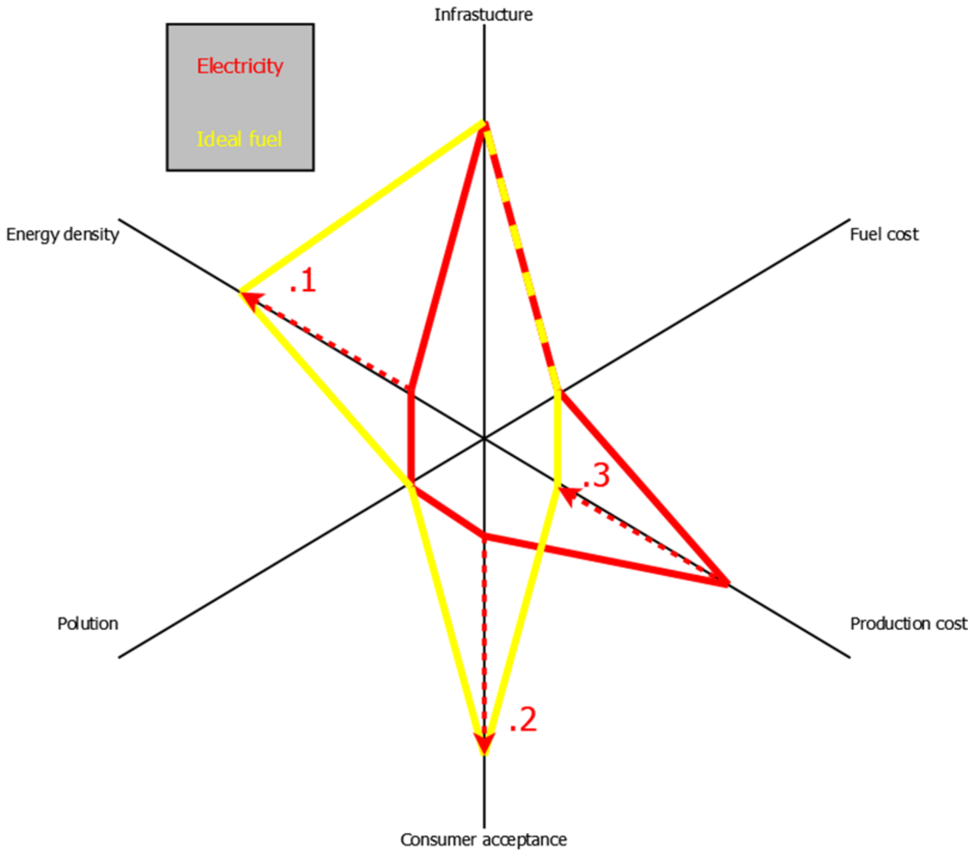


Picture 68 - Comparison 4 fuels

In this diagram above we can somewhat see a comparison between Electricity, Hydrogen, Gasoline and the ideal fuel. We can see that although hydrogen and electricity offer low emissions, there is still research and technological advances needed for application of using either fuels for mass production. The chart shows on what levels there is need for improvement for the different fuel types. The levels are explained below in cw position

- Infrastructure: This is the station/equipment used to transport the fuel from a container or electric net in to a fuel tank/battery. Without any proper infrastructure a solution towards a newer and cleaner fuel will never reach its potential since it will be difficult to distribute, which then again affects the consumer acceptance which then again affects the automotive industry from researching and producing certain engine types resulting in a stop of producing.
- Fuel cost: The cost of the fuel depends on the quantity available, cost of the process to make the fuel and the ability to distribute the fuel.
- Production cost: The cost of the mechanical parts needed for the car to make it run on a certain engine
- Consumer acceptance: The attractiveness toward the consumer. Shorter refuel times and lower fuel prices lead to a better consumer acceptance.
- Pollution: Is the negative effect of the fuel towards the environment because of emissions
- Energy density: Is important for the amount of energy which can be stored in the vehicle fuel storage. This is a very important level as it affects the consumer acceptance.

4.7.7.1 Electricity as an ideal fuel



Picture 69 - comparison Electricity and ideal fuel

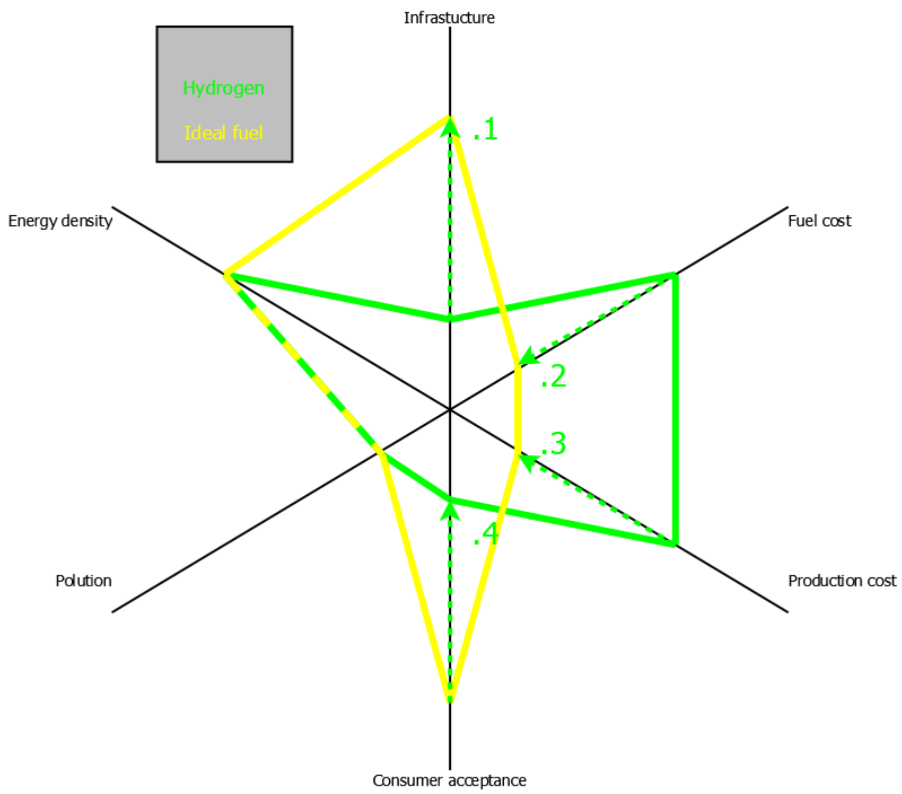
Electricity has a lot of promises as an alternative fuel if used and produced in an eco-friendly way. If so it can be said that electricity offers a non CO_2, CO or NO_X emission therefor being an interesting replacement for fossil fuels. However at the moment the majority of the electricity that is being produced is made by non-alternative methods such as nuclear energy or coal centrals. There needs to be a large world-wide scale investing in the production and construction of green alternative energy. This will require several years and is therefore a good long-term solution but certainly a plausible one. However that's currently not the only problem that needs to be solved in order to replace the fossil fuel with electric cars: we can see on the diagram that the following issues should be addressed:

- Energy density: The current major problem with electric cars itself is that they have a low energy capacity, therefor their range is rather limited and a rather high storage weight compared to other fuel storage methods. These two problems are caused by its storage container: lithium-ion battery. Lithium-ion is currently the most used battery in cars but because of the properties' of the battery and most metal batteries as well the capacity/weight ratio is very low. Research and technological advancement is needed in the storage capacity of the electric car in order to be compatible with fossil fuels.

- Consumer acceptance: long refuelling times and short drive ranges are factors that causes for a low consumer acceptance. Improved range and shorter refuel times can be achieved in the improvement of the cars storage system that is needed as explain on "energy density"

- Production cost: current costs of electric cars are approximately twice as expensive compared to their diesel or gasoline variants and brands that produce only electrical cars like Tesla even boost u those price making them up to 4 times more expensive that the current average price for a diesel or petrol car. The main reason behind the high prices are the batteries. They require rare materials to be produced that cost a lot of money. Also the rather small selling numbers mean that the car can't be mass produced which is also a great cost saver. However there are ways to reduce the price, making them more interesting to buy them over fossil fuelled cars. Financial support by the government can help reducing the price. Tax refunds or financial discounts when owning an electric car can be good solutions although they require money and investment from governments. Sweden is a great example of the influence of the government on the mobility. Thanks to their work and effort more and more people are switching to electrical cars because of the many financial benefits it provides.

4.7.7.2 Hydrogen as an ideal fuel



Picture 70 - comparison hydrogen and ideal fuel

If we look at hydrogen pure as a fuel, and not its current state and methods of producing and storing, hydrogen is the best and most pure fuel there is for standard combustion engine and fuel cell technologies for cars. Hydrogen is the element that causes a combustion to occur in current fossil fuel engines and pure therefore hydrogen will result in an efficient combustion with zero CO_2 and NO_X pollution. We can say that theoretical hydrogen is the fuel of the future, it has a high energy density per mass and zero pollution, and however in practical use we see that this is far from the truth. Although hydrogen itself is green, the process of obtaining it rarely is. There is a way throughout electrolysis that we can obtain it in a environmentally friendly way, that is if of course that electricity is produced via windmills or solar panels, but most is still obtained using natural gas reforming or coal gasification. Then there is the storage problem. Altough hydrogen has a very high energy density per mass, it has a significant low energy density per volume. Therefor hydrogen needs to be compressed to increase its energy capacity of the car, resulting in energy losses during the compression. In the following area's there is need for improvement and new technologies if we want to use hydrogen as our next standard fuel.

- Infrastructure: At this moment infrastructure for hydrogen barely exist anywhere in the world, reasons for this is because of the storage issues with hydrogen it is better to produce hydrogen on distribution place. But these installation are often expensive and offer a low profit investment for the company or owner placing it. There are some fuel stations for hydrogen around the world but in order to extend this there will be financial help needed from the government. In Japan the government had announced that it will invest in hydrogen technologies and wants to build 900 hydrogen fuel stations by 2030. This could be a good example on how to increase the infrastructure

- Fuel cost: Because of limited and expensive infrastructure prices for hydrogen are rather high and can cost double of the price for fossil fuels for doing the same distance. Increased infrastructure and improved producing methods are solutions for reducing the cost price.

- Production cost: Producing cost for hydrogen cars are high for hydrogen cars. Most hydrogen fuel cell car technologies are new and therefore expensive because they are not mass produced. Low infrastructure and high fuel prices also result in low sale prices making mass production difficult. With increased infrastructure and higher consumer acceptance because of lower fuel prices and financial support from government will result in prices of the car to drop and be compatible with fossil fuel cars.

- Consumer acceptance: although it has fast refuelling times and good range (1kg H_2 per 100km) limited accessibility to hydrogen and high car prices result in a lower consumer acceptance. To increase this as said before increased infrastructure, lower car prices and lower fuel prices are required.

Although theoretically a very interesting, we can see that this unfortunately the opposite in the practical field. Nevertheless hydrogen will remain an interesting fuel for replacing fossil fuels, just not at current state regarding its technologies and methods for producing.

4.7.8 Recap about Hydrogen

ENERGY CONTENT TABLE			
Caracteristics	Unit	Value	information
Density	kg/m^3	0,08987	0°C and 1atm
Energy per Volume	MJ/m^3	8,491	
	kWh/m^3	2,830	
Energy per Mass	MJ/kg	140,1	
	kWh/kg	38,92	
Energy Density (Liquid at -162	kg/m^3	708	min. 253
	MJ/m^3	8,491	0°C and 1atm
	kWh/m^3	2,359	0°C and 1atm
	kWh/L	0,002	0°C and 1atm
	kWh/kg		
Energy Density (Gas at 1atm)	MJ/m^3	10	15°C
	kWh/L	0,036	15°C
	kWh/kg		15°C
Energy Density (Gas at 200atr	MJ/m^3	1,825	15°C
	kWh/L	0,007	15°C
	kWh/kg		15°C
nergy Density (Gas at 690atm	MJ/m^3	4500	15°C
	kWh/L	16,2	15°C
	kWh/kg		15°C
Price/kg	€	15	
Average Car Price	€	€ 78 540	"Toyota Mirai"
Average Fuel Storage size	kg	5	"Toyota Mirai"
Approximate range	km	500	"Toyota Mirai"
Consumption per 100 km	L	4,3	"Toyota Mirai"

POLLUTION TABLE: FUELCELL		
Caracteristics	Unit	Value
CO2	g/km	0
CO	g/km	0
NOx	g/km	0
O2	g/km	0
H2O	g/km	60
H2	g/km	0
CH4	g/km	0
PM	ppm	0

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	0
Greenhouse emission	g/km	0

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2 (EU electricity mix	g/km	174
CO2 (100% renewable)	g/km	8
Greenhouse emission	g/km	157

Energy data
Consumer acceptance
Pollution

Picture 71 - recap hydrogen

4.7.9 Recap about Electricity

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Energy per Volume	MJ/m^3	720
Density	kg/m^3	
Energy per Mass	MJ/kg	0
Energy Density (Liquid)	MJ/m^3	
	Wh/L	200
	kWh/kg	
LHV	MJ/kg	43
HHV	MJ/kg	46
Air/fuel Ratio	kg	15
Average Car Price	€	40 000
Approximate range	km	230
Cost per 100km	€	0,8

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	0
CO	g/km	0
NOx	g/km	0
PN	nb/km	0,00E+00

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	0
Greenhouse emissions	g/km	0

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2 (EU Electricity mix)	g/km	110
CO2 (100% renewable)	g/km	5
Greenhouse emissions	g/km	211
Greenhouse emissions (100% renewab	g/km	106

Green	Energy data
Orange	Consumer acceptance
Red	Pollution

Picture 72 - recap electricity

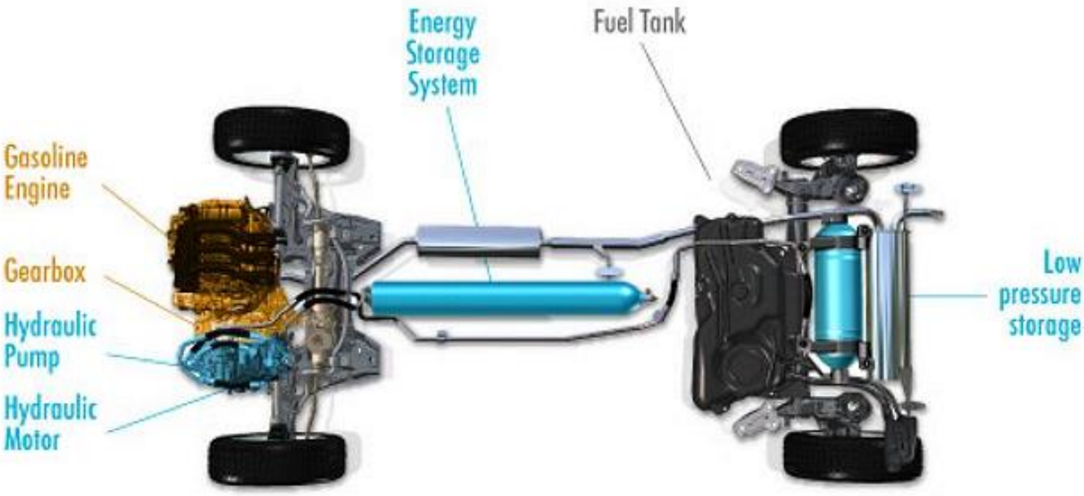
4.8 Air as a fuel

Air is all around us, is free and it doesn't pollute. If it could be used as a fuel, that could be a great progress economically and ecologically. Nowadays, there are two different technologies which propose to use the air as a fuel for powering cars.

4.8.1 Hybrid Air technology

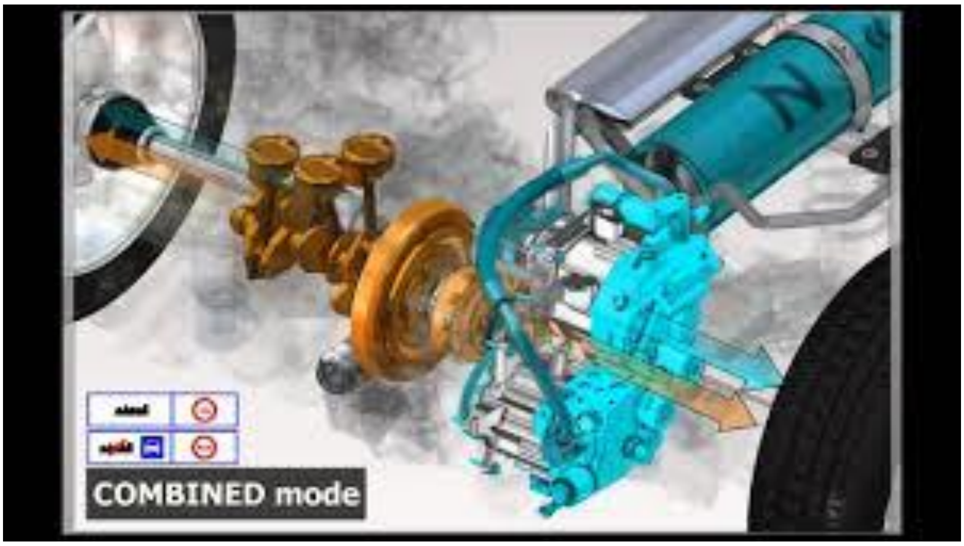
Picture 73 - C3 Hybrid Air prototype

At the end of the years 2000s the French company PSA (Peugeot/Citroën) started developing the technology named Hybrid Air. This is simple. Everyone knows the classic hybrid engine which combine a thermal engine with an electric engine, with the technology Hybrid Air, PSA combine a thermal engine (diesel) with a hydraulic engine powered by compressed air.



Picture 74 - Hybrid Air system

In this technology, air is used to push a piston in the Energy storage system to power the hydraulic engine.



Picture 75 - Hybrid Air engine

With this engine it is possible to drive in two different modes. The combined mode where the Air/Hydraulic engine will help the diesel engine. And the full air mode, where the engine is just using his hydraulic part then it does not pollute anymore, and the driver is saving fuel. To increase this saving of fuel, this technology is using the break energy regeneration which store the recover energy during decelerating and breaking.

PSA announced an increment of the vehicle range of 90% on urban driving, and a fuel saving up to 45% on an urban driving or 35% overall. Vehicles Hybrid Air display a consumption of 3L/100km and an emission about 70g of CO_2 per km, all these data are better than for a Hybrid electric.

Unfortunately, in 2014, the project was stopped by PSA because their only partner Dong Feng leaved the project. Indeed, in China, a hybrid car must be electric to get this statue and in the future years, China will allow only electrical and hybrid cars to drive in city centres. So, it will be useless for Chinese companies to spend money on this type of technology.

The project was too expensive for PSA alone, so they decided to stop the project, but this technology still exists and could be used.

4.8.2 Airpod car

Picture 76 - Guy Nègre with his invention

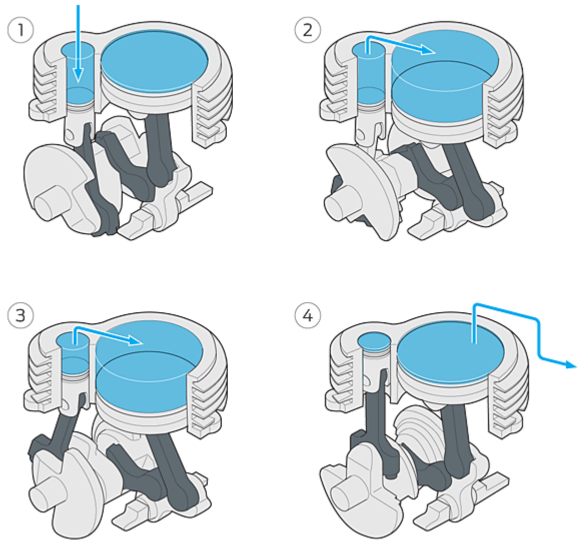
At the end of the 90s a prototype of powered by compress air is presented. With a futurist design, a joystick as a wheel, this project looks very promising. And even if this project let a lot of scientist dubious, it'll be soon a reality.

Picture 77 - Airpod

Picture 78 - Airpod's interior

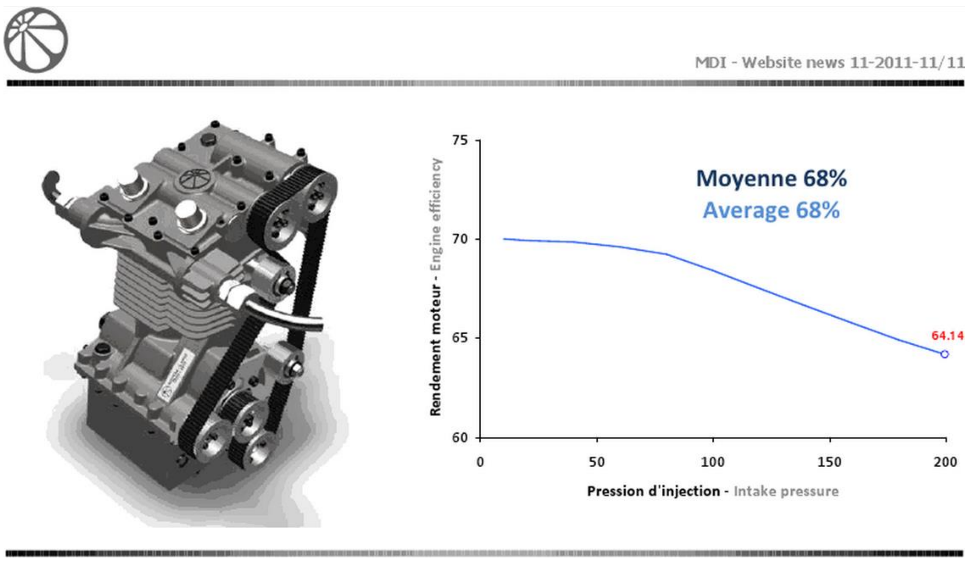
This small car, named Airpod, was invented by Guy Nègre, a French engineer, and now the project is developed by MDI (Motor Development International). The principle of this car is simple, using compress air as a fuel to push the pistons of the engine.

This engine is quite similar as a classic thermal engine.



Picture 79 - Airpod engine's pistons

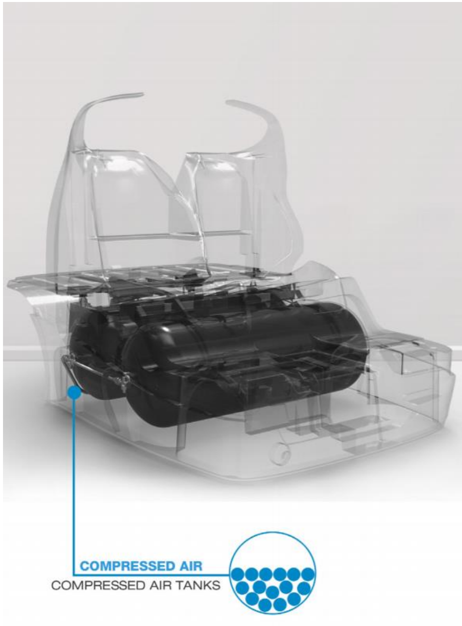
The only difference is on the pistons. Here, every cylinder is composed of two pistons. First the compress air pushes the small one, then it goes to the big one before living the cylinder. Using this system permit to improve the efficiency of the engine and to give him more power. This engine got an efficiency of 68%, much better than a thermal engine (around of 40%).



Picture 80 - Airpod engine's efficiency

For the moment, the last version of this engine develops 10 hp. It looks little but the body and the structure of the Airpod is made of glass fibre and polyurethane (100% renewable), so the car is very light (280kg empty) and 10 hp is enough to power this type of car. Also, the Airpod is using an electric management of the kinetic energy recover during deceleration phases to improve his autonomy.

MDI announced an autonomy of 130km for an urban used thanks to two air tanks of 125 L placed under the driver, and a speed max of 80km/h.



Picture 81 - Air tanks

This car has a lot of advantages, it's cheap and easy to build, it uses the compress air, so it doesn't pollute, and with an air station it takes only 3min to refuel the car for only few euros.

But we can also find some bad points. For now, Airpod is design for only two people and it doesn't offer a lot of space.

Picture 82 - Airpod's dimensions

For refuelling the car an electric energy is necessary, and it would be difficult to use this car out of the city (because of the small autonomy).

Picture 83 - Airpods

It's already possible to book one of this Airpod for the basic price of 7000€, and the Airpod should make his appearance in 2019 in the USA and 2020 in India.

The technology using the air as a fuel looks promising. It doesn't pollute and it offer a sufficient autonomy for an urban use, it seems to be a good alternative to fossil fuel actually used. And it gives also an alternative to the all-electric choosing by the politicians right now.

4.8.3 Recap about air

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Density	kg/m^3	1,2
Density (300atm)	kg/m^3	400
Energy Density (Gas at 300atm)	MJ/m^3	200
	MJ/L	0,2
	kWh/L	0,06
	MJ/kg	0,5
Average Car Price	€	7000
Approximate range	km	130
Cost per 100km	€	5

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	0
CO	g/km	0
NOx	g/km	0
PN	nb/km	0
	Energy data	
	Consumer acceptance	
	Pollution	

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	

Picture 84 - Recap about air

4.9 LPG

4.9.1 What is LPG?

Liquefied Petroleum Gas (LPG) describes flammable gases, which under low pressure and room temperature are staying liquid. Under normal conditions (atmospheric pressure) is LPG gaseous. For example like propane, butane and mixtures of these gases.

LPG can be used for fuel in heating, cooking and especially for this issue in vehicles. (MARQUARD-BAHLS 2015)

4.9.2 How can we produce LPG?

LPG is a by-product from drilling crude oil and natural gas wells. Because of the reason that upgrading these LPG is unprofitable it will be burned down at the drilling platform. Burn down the LPG is usually done on offshore platforms, the transport of the Gas from the sea to land is at the moment to expensive. Onshore platforms safe the LPG for the further using. Here it is easier to safe and upgrade the LPG. Furthermore it is also a by-product from petroleum refining. In this process the LPG is caught (AUTOGASTEC 2015). Round about 60% of components of LPG, butane and propane, comes from drilling crude oil and natural gas the other 40% out of refining petroleum (BENEGAS 2017).

4.9.3 Is LPG endless?

LPG is a by-product from petroleum refining and drilling crude oil, that means LPG is a fossil fuel and thus endless and not renewable.

4.9.4 How can we use LPG in Engines?

An engine powered by LPG is fundamentally the same as a petrol powered internal combustion engine. The two main differences are the fuel itself and the fuel storage and intake systems.

The engine block, pistons, spark plugs, ignition system, lubrication system and electrical all remain the same. With an octane rating of over 100, LPG is usable in virtually any petrol engine.

LPG cars can be OEM single fuel models or dual fuel LPG conversions that run on either LPG, also known as Autogas, or petrol.

An LPG conversion is taking a normal petrol powered vehicle and adding a secondary LPG fuel system. Almost all vehicles fuelled by petrol are convertible to LPG operation at a reasonable cost. But also diesel engines can be convert it is more difficult and more expensive than the petrol conversion. These dual-fuel LPG systems allow a vehicle to operate on either LPG or petrol. That works only by petrol cars. Because of the reason that the petrol tank still remains in the car the driver can switch from gas to petrol or vice-versa.

At the moment there are 25 million LPG powered cars worldwide (ELGAS 2019)

4.9.5 Pros and Cons of LPG

4.9.5.1 Pros

Transportation:

It is easy to transport propane or butane. These gases can be compressed into liquid under low pressure or by cooling them down. Because of the reason that they are liquid under low pressure the transport by tank trucks is a simple way. In this case it is nearly the same way like transport petroleum or diesel.

Butane is getting liquid under a pressure of 1,2 bar or at a temperature of -0,5 ° Celsius. On the other hand propane is getting liquid under a pressure of 7 bar or a temperature of -40° Celsius. By mixing butane and propane you can reach every pressure between 1,2 and 7 bar. This is a big benefit for different kinds of tanks or gas bottles or the storage container where ever the gas is used.

Furthermore butane and propane are more compact as a liquid as gaseous. In fact 1 litre of liquid butane gives approximately 250 litre of butane gas nearly the same applies to propane. That means a large amount of energy can be transport. A relatively small container with a lot of energy content. (BENEGAS 2017)

Emissions:

Investigations compare EU5 and EU6 passenger cars running on LPG, petrol and diesel. These tests should be as real as possible. Therefore the cars were testing on real streets in Real-Driving-Emissions-Mode (RDE)

In terms of LPG can be said that the emission of particles can be reduced about 90-99 % in relation to petroleum running engines. That means that the limits of particle emissions can be kept. The reason for less particles is the mixture formation property of LPG.

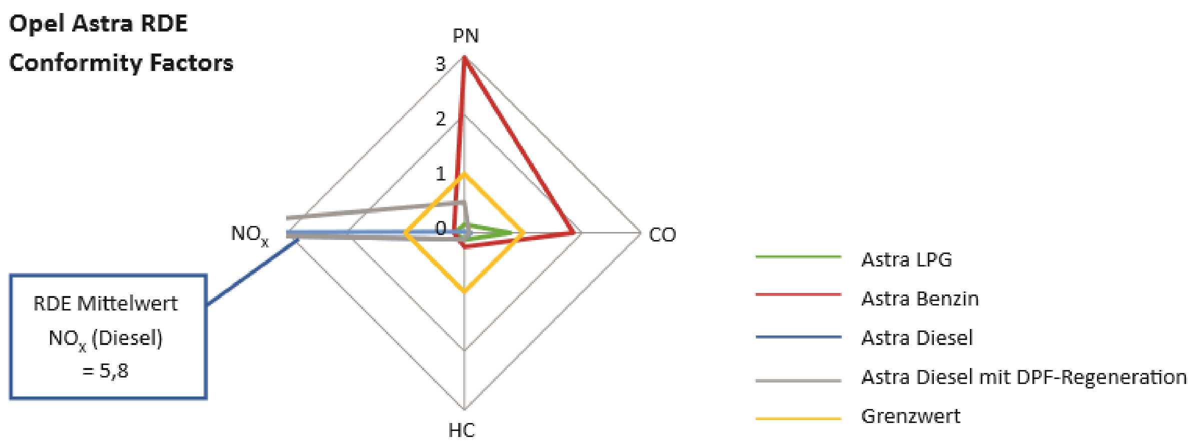
Further the emissions of carbon dioxide (CO_2) can be reduced about 10 – 13 % by using LPG instead of petroleum. Responsible for less CO_2 emissions is the lower carbon content.

The nitrogen oxides (NO_x) are the same in relation to the petroleum running engine but the NO_x emissions of diesel are 50 times higher (Heinze, T, 2016 DVFG).

Figure 1 shows the results out of the RDE-Mode. On the one hand the total emissions are listed and on the other hand on the right side of the chart are the emissions in relation to the limits. Figure 2 is an illustration of the results.

		Absolute Emissionen						CO_2-Homol. im NEFZ [g/km]	Emissionen im Verhältnis zum Grenzwert*			
Fahrzeug/ Kraftstoff	Mittelwert über n Messun-gen	PN [#/km]	CO_2 [g/km]	CO [g/km]	HC [g/km]	NO_2 [g/km]	NO_x [g/km]		PN	CO	HC	NO_x
Astra LPG	3	8,51E+10	110	0,777	0,012	0,009	0,009	132	0,143	0,777	0,119	0,160
Astra Benzin	3	1,77E+12	121	1,845	0,024	0,006	0,011	144	2,960	1,846	0,237	0,176
Astra Diesel	3	1,23E+10	100	0,037	0,009	0,349	0,463	97	0,020	0,113	0,111	5,830
Astra Diesel mit DPF- Regeneration	4	3,11E+11	105	0,046	0,010	0,357	0,466	97	0,518	0,086	0,111	5,830

Picture 86 - Results of investigation (Heinze, T, 2016 DVFG).



Picture 85 - Illustration of results (Heinze, T, 2016 DVFG).

The emissions shown in figure 1 and 2 are the tank-to-wheel emissions. For the European emission standard important numbers, but the well-to-wheel analyses is for the greenhouse gas emissions more important.

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Density	kg/m^3	540
Energy per Volume	MJ/m^3	25078
	kWh/m^3	6966
Energy per Mass	MJ/kg	46,4
	kWh/kg	12,9
Octane		110
Cetane		-2
LHV	MJ/kg	45,5
HHV	MJ/kg	49,3
Self-Ignition Temperature	°C	490
Price/m^3	€	1020
Price full tank	€	40,8
Average Fuel Storage size	L	50
Average Energy Storage size	MJ	1253,88
Approximate range	km	701,95
Cost per 100km	€	7,27
Modification price	€	2300

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	110
CO	g/km	0,777
NOx	g/km	0,009
PN	nb/km	8,51E+10

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	110

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	141

(green)	Energy data
(orange)	Consumer acceptance
(red)	Pollution

Picture 87 - Recap about LPG

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	169
Greenhouse emissions	g/km	296

Picture 88 - Well to Wheel of gasoline

In figure 3 is the number of carbon dioxide emission from the production of LPG until the combustion at an internal combustion engine. Figure 4 shows the emissions of gasoline at the same cycle. If both charts will be compared can be noticed that LPG emit less carbon dioxide than gasoline. At first it does not look that much, but this number is only for one kilometre and if this number get extrapolate to one year, the saved amount of CO_2 is big. That depends heavily on the driven km per year. The difference are 28 g/km saved CO_2 emissions by approximately 20000 km per year is this a total amount of 560kg saved CO_2. According to the 25 million LPG cars worldwide the saved CO_2 emissions are up to 14 billion tons per year.

4.9.5.2 Cons

Conversion:

The cost for a LPG conversion are in the range of 1.800-3.500 € it depends on the manufacturer. All the manufacturer prescribe a regular maintenance of the LPG system. For example all 20000 km or once in a year. For one maintenance there are costs about 100 – 150 €.

Whether a conversion worth it depends on the manufacturer, driven kilometre and the car. The following figure shows a few options of cars respectively the engines. In addition, there is also an increase of consumption by driving with LPG, which is the reason of lower energy density of LPG.

The calculations were carried out with the following values:

Maintenance: 125€ after 20000 km

Petroleum: 1,37 €/l

LPG: 0;67 €/l

Model	kW	Consumption l/100km	Range in km	Conversion	Costs / 1000 km	Driven km
smart fortwo coupé						
- Benzin	45	4,7 l Super	33 l / 702		64	
- Autogas	45	5,6 l Autogas	34 l / 486	2300	44	**112000**
Audi A4 2.0						
- Benzin	96	8,1 l Super	70 l / 864		111	
- Autogas	96	9,7 l Autogas	60 l / 495	2400	71	**61000**
BMW 740i						
- Benzin	225	11,2 l SuperPlus	88 l / 786		162	
- Autogas	225	13,4 l Autogas	70 l / 418	3200	96	**49000**

Over here are three examples of cars lower-class, medium-class and upper-class. The chart shows that the profitability depends heavily on the consumption of the engine. With a smaller car the kilometre has to be driven to worth it are much more than the kilometre as with a bigger one (ADAC 2019).

Availability:

At the moment is LPG in Finland not available. There is no infrastructure for LPG as car fuel. It is available in little gas-bottles for example for BBQ or heating (AUTOTRAVELER 2019).

4.10 Methane

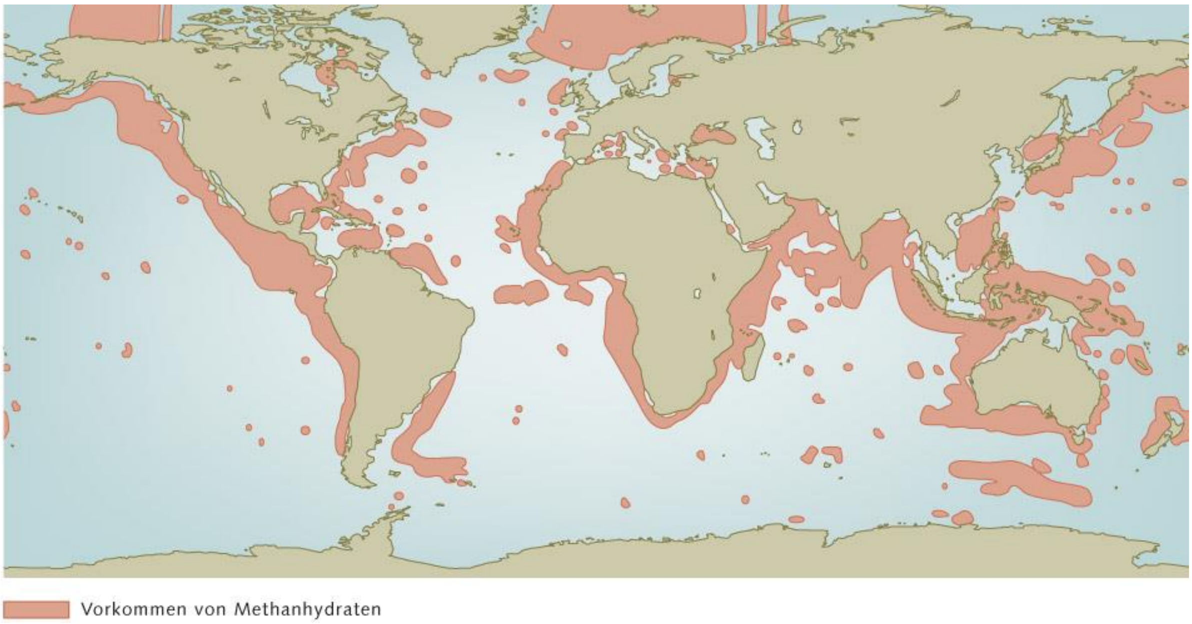
4.10.1 What is Methane?

Methane is a colourless and odourless gas which occurs abundantly in nature and as a product of certain human activities. It is the simplest hydrocarbon ever and the most potent of the greenhouse gases. Methane is 22 times worse than carbon dioxide. Furthermore Methane is the main content of natural gas and biogas. It will be continuously produced and released by biologic and geologic processes (CHEMIE 2006).

4.10.1.1 How can we get methane?

Methane is the main component of natural gas, up to 98%. There are three methods for natural gas extraction. The first one is to drill in natural gas fields. Natural gas fields are deposits of natural gas 5000m deep in the earth. The pressure in these deposits is really high, up to 600 bar. By drilling in these deposits to extract the gas, the gas come by itself to the surface because of the high pressure. If the pressure is decreasing the next method will be used, called fracking. In the process a mixture out of water, sand and chemicals is pumped under high pressure into the drilling hole. The high pressure and the mixture are cracking the stones in the earth where the gas is locked in and the gas can come out. Furthermore natural gas is a by-product by drilling crude oil. Over there the gas is on top of the crude oil and will extracted at first (TOPTARIF 2019).

Another reserve is methane-hydrate. Methane is locked in ice on the seabed in some regions around the world. The occurrences are almost always at the continental slopes, because over there exists more crops and biological material for producing methane. So far there is no common way to extract these methane hydrate, but there are some test fields and studies about the hydrate and how to get it on the most safety and economically way. The task is to get the hydrate to the surface without boil off the methane to the environment, because methane is a 23-times worse greenhouse gas than carbon dioxide. Critics fear, if the hydrate is extracted the continental slopes could be instable (WORLDOCEANREVIEW 2010).



Picture 89 - Sources of methane-hydrate (WORLDOCEANREVIEW 2010)

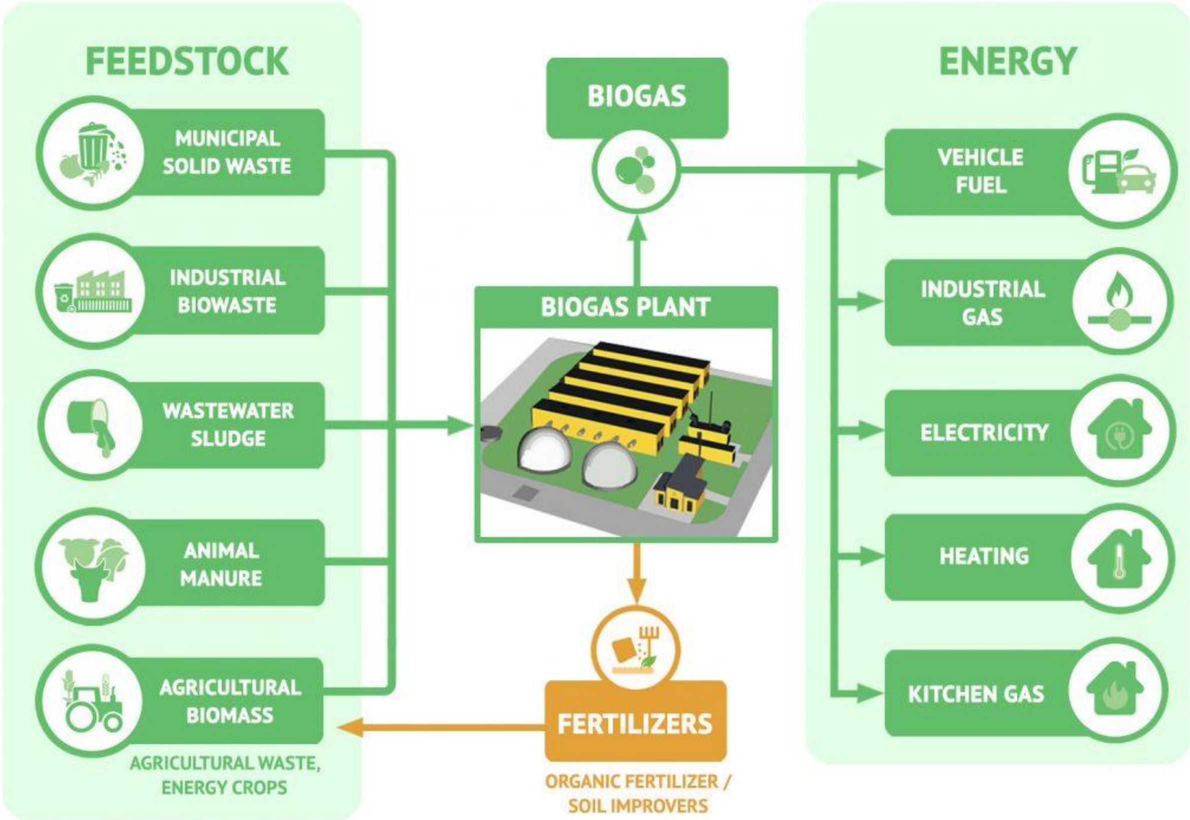
Methane not only can be extracted it can also be produced. On this way it is not anymore a fossil energy source it is renewable energy!

One way to produce methane is to produce bio-methane. Bio-methane is processed biogas. Bio-methane has to contain at least 96 percent of methane to become vehicle fuel (STORMOSSEN 2019). By producing biogas, methane is not the only gas which is produced. Biogas can be produced in biogas plants by anaerobic fermentation of organic material. That means that organic material get broke down in an environment without oxygen with the help of microorganisms.

The raw biogas contains:

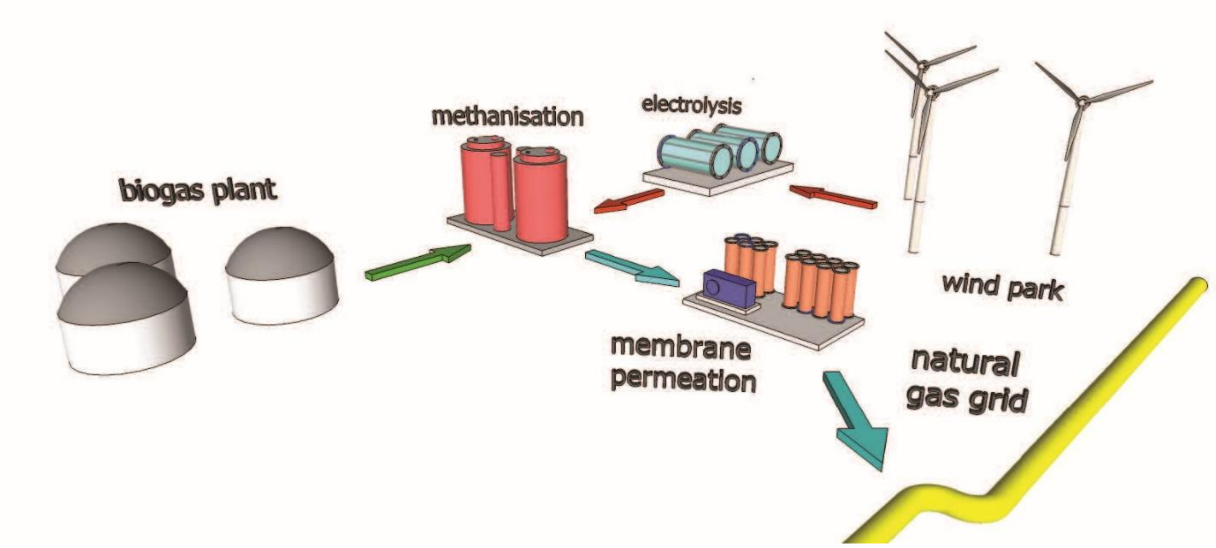
- 50-75% Methane – CH_4
- 25-50% Carbon dioxide – CO_2
- 0-5% Water vapour – H_2O
- 0-3% Ammoniac – NH_3
- 0-3% Hydrogen sulphide – H_2S

The amount of the different gases inside the biogas depends on the feedstock, the raw organic materials for feeding the biogas plant. All kinds of organic materials can be the feedstock. Biogas is a good alternative to utilize waste, which is actually not used anymore, to produce gas which is used versatile. In figure 1 is shown the feedstock and the usability. For producing heat or electricity it is enough to replace water vapour, ammoniac and the hydrogen sulphide. Without these gases a damage free combustion in the engines or machines can be guaranteed. Water vapour can create condensed water, ammoniac and hydrogen sulphide are aggressive chemical compounds which lead to corrosion (WASTECONVERTERS 2016). Using biogas as vehicle fuel requires more effort. Water vapour, ammoniac and hydrogen sulphide has to be removed anyways, but now the carbon dioxide has to be removed as well to reach the content of at least 96% of methane in the biogas. The most common way to remove all the undesired components is a process called water scrubbing. CO_2, H_2S and NH_3 are water soluble gases. While these process the raw biogas pass the water and the water absorb the undesired gases. Afterwards the gas will be dried. The result is bio-methane with a methane content of 96 to 98% (BIOGAS.FNR 2011). This bio-methane can injected in the natural gas grid, transported per pipeline to the gas filling stations or to the costumers. Another result of the fermentation, next to the gas, is an organic fertilizer. At the end of the fermentation there is a left over in the digester. This left over can be used as a fertilizer in agriculture (WASTECONVERTERS 2016)



Picture 90 - Biogas plant (BIOGTS 2018)

A different way is the Power-to-Gas process. In the first step not required electricity is used for producing hydrogen in an electrolysis process. The next step, called methanation, produced methane. During this process carbon dioxide is added to the hydrogen in a catalyser. Under chemical reactions is methane created. This methane can be injected in the natural gas grid or stored in big tanks till the moment it is needed again (GROUP.RWE 2019). The exhaust of industrial factories or the CO_2 out of the upgrading of Biogas can be used in the methanation (AUDI-TECHNOLOGY-PORTAL 2019). Under this conditions it could be possible to create a minus production of CO_2, because no CO_2 escapes in the environment instead, the crops and methanation adsorb CO_2. The hydrogen could also use directly, but that is not the common way because the energy density of methane is with 11,97 kWh/Nm³ way higher than the of hydrogen with 2,83 kWh/Nm³. On this way it is economically smarter to store methane. Last but not least methane is already used in a lot of cases and a natural gas grid exist. In the figure below is shown the process of Power-to-Gas.



Picture 91 - Power-to-Gas plant (INVENTIONSTORE 2018)

4.10.1.2 What kinds of methane exists?-

4.10.1.2.1 CNG/CBG

The abbreviation CNG/CBG means Compressed Natural Gas/Compressed Bio Gas and describe to 200 till 250 bar compressed Natural Gas. In the case of CBG it is compressed Bio Gas. It will be compressed because of the storage. If the gas is compressed the amount of storage gas is up to 300 times more than under normal pressure. How previous time said, the main content of Natural Gas is methane like in Bio Gas as well. The proportion of methane is round about 98 %. Because of the high energy density and the lower emissions at combustion, CNG/CBG is well suited as vehicle fuel. By using CNG/CBG as fuel the emissions of carbon monoxide (CO) and nitrogen oxides (NOx) are reduced up to 80 % and the emissions of carbon dioxide are reduced up to 25 % compared to a gasoline fuel. CNG/CBG is available at filling-stations in kg and not in litre like gasoline (ZUKUNFT ERDGAS 2019). Therefore the density is important. The density at standard temperature and pressure is 0,7 kg/m³ to 0,9 kg/m³. Under high pressure the density increase to around 180 kg/m³ at 200 bar and 215 kg/m³ at 250 bar. Under this conditions it is possible to store more kg of the Gas in the same Volume and that means the range of the car is higher (UNITROVE 2019).

4.10.1.2.2 LNG

LNG is the abbreviation for Liquefied Natural Gas. That means in fact that the natural gas is not anymore gaseous, like CNG, rather it becomes a liquid. To make natural gas liquefied it needs 10-25% on energy of the energy content of natural gas. The high amount of energy is needed depends on the reason that the natural gas has to be cooled down at -162°C to make it liquefied. After this process the density of the natural gas is 600 times higher as on normal conditions. On this way a really high amount of Natural gas and specially energy can be transported. The density of LNG is about 450 kg/m³ (ENERGIE-LEXIKON 2019).

4.10.2 Methane in Finland

Finland has to import all natural gas they use. Reason for the high amount of import is that Finland does not have any natural gas reserves. The natural gas pipelines contains natural gas imported from Russia and biogas from Finnish biogas plants (GASUM 2019).

4.10.2.1 Biogas potential in Finland

According to the fact that Finland has no natural gas reserves the natural gas or rather methane has to be produced. Biogas can be one solution for this problem! And the region Ostrobothnia offers definitely potential for producing biogas. A previous EPS-Group, called Wasteconverters, researched already for the biogas potential and how much usable biomass is available in the region of Ostrobothnia. The different kinds of biomass are shown below.

Mink manure:
With 2 million minks in Ostrobothnia are annually 38 000 tons available.

Fox manure:
Nearly the same number of foxes like minks, about 2,1 million produces 92 000 tons manure.

Pig manure:
With 715 733 m³ annually and an average density of 800 kg/m³ are 672 000 tons of pig manure available.

Slaughter house waste:
Slaughter house waste is made out of a mixture of animal bones, skulls, intestines, blood, fat and a small amount of meat. In Ostrobothnia are annually 78 tons of slaughter house waste usable.

Fish processing waste:
13 fish farms in 2009 produces 160 tons of waste.

Domestic bio waste:
20 000 tons of domestic bio waste are available in Ostrobothnia. Domestic bio waste can be human waste, animal manure, food waste, green waste, paper, or savage.

Cucumber plants:

The cucumber plant itself who bear the cucumber is the available waste. The amount of usable waste is about 2 000 tons per year.

Potato peels:

The potato industry in Ostrobothnia produces 6 400 tons of peel annually.

Brewer grains:

Only a small brewery is located in Ostrobothnia. This brewery produces 150 000 litre per year that is an amount of 30 tons brewer grains annually.

Bakery waste:

Bakery waste contains a lot of fat, sugars and fibres according to the Wasteconverters. Between 21000 and 25000 tons per year are available.

Used oil:

Oil and grease have high energy value and produces a lot of methane, when the biogas production is not good oil can be added and the biogas production increase again. Annually are 970 tons of used oil available (WASTECONVERTERS 2016).

That is a total amount of about 855 000 tons of available biomass as feedstock for biogas plants. Pig manure has with 672 000 tons annually an amount of about 80% at the total number of available feedstock.

The main task is to find the right mixture of the different substrates to get the highest amount of methane out of the mixture and decreases the undesirable gases. Of course in relation to the local available substrates. (WASTECONVERTERS 2016).

4.10.2.2 Biogas plants in Finland

In the year 2013 81 biogas plants were producing renewable gas in Finland. Almost 50 % are situated at landfills. 16 biogas plants are producing biogas by sewage and 12 plants using agricultural waste. That means in fact the biogas production is mostly from organic waste and on landfills, so no energy crops are specially plant as feedstock. Out of this reason there is no big fear to get in conflict with the food industry (EUROPEAN-BIOGAS 2014).

One of the visited plants was Jeppo Biogas Ab and is situated in Jeppo, Ostrobothnia, in west Finland. They are producing biogas for industrial and traffic use. The amount of raw material consumption in a year is round about 130.000 tons and the production of biogas is 30 GWh per year. The feedstock of the plant is a mixture out of pig slurry (main feedstock up to 50%), stomach content out of slaughter houses, potato peels, other by-products of food production and a small amount of grass silage. No energy crops are specially plant for producing the biogas. This is a benefit for the CO_2 balance sheet and no conflict is created with the food industry. The selling products are biogas with a methane content of 65-75% and bio methane with a methane content of 97-98 %. Bio-methane is upgraded Biogas. For cleaning the biogas, they use a water scrubber. The description of the functionality is written down in chapter X.

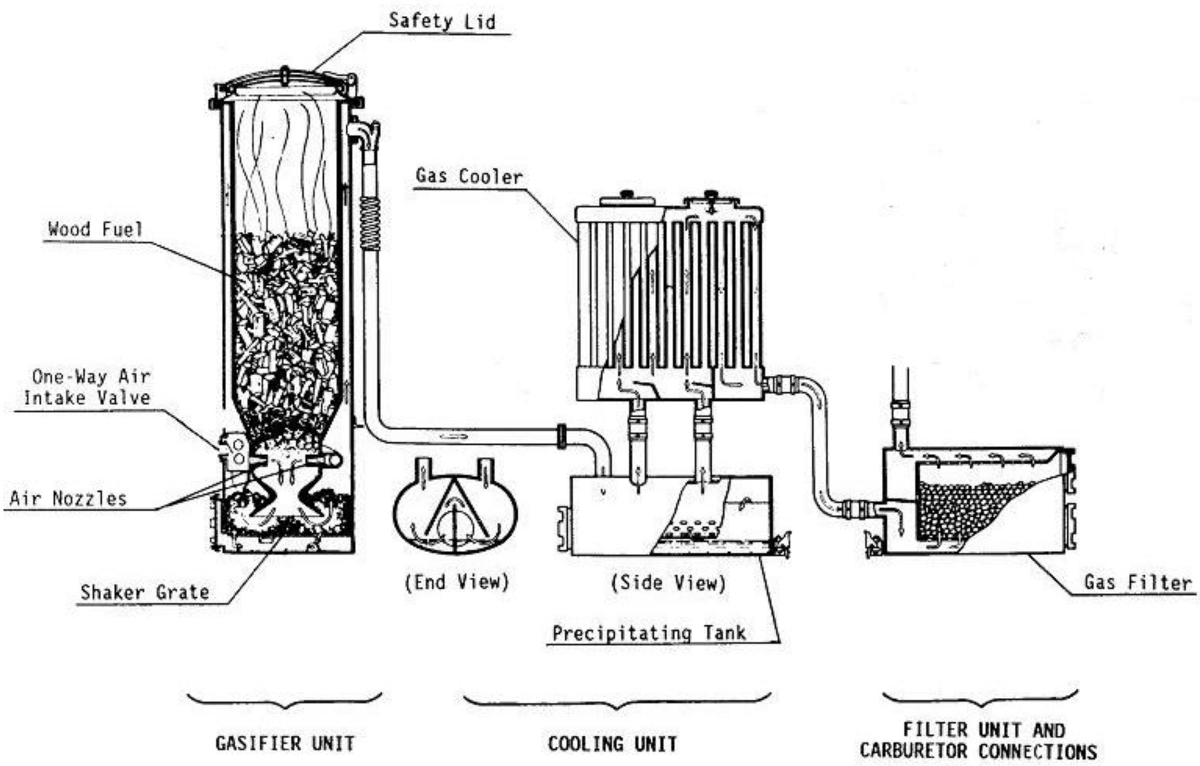
The main costumer is situated about 4 km away from the Biogas plant, they use the raw biogas for heating the machines in the factory. They are connected directly with a pipeline, that decreases the transportation costs and the biogas is always available. This factory heated previous time, before Jeppo Biogas Ab, their whole machines by combust oil. Nowadays the oil is 100% replaced by biogas.

The other product is bio-methane. After the filtration with the water scrubber the bio-methane get compressed up to 250 bar and stored in truck containers. The amount of compressed bio gas (CBG) per container consist 3000 kg. Some smaller companies get the upgraded bio-methane in containers. The transportation with the containers is easy and versatile. Another utilisation of bio-methane is as vehicle fuel. The filling station for CBG is directly next to the biogas plant and is available for all public cars (JEPPOBIOGAS 2019).

Picture 92 - Biogas plant Jeppo Biogas Ab (JEPPOBIOGAS 2019)

While the project another renewable gas plant was visited. They are producing bio methane as well, but not in digesters under anaerobic fermentation they are using a kind of the “power to gas principle”. The principle is to add wood gas (synthesis gas) with a main content of carbon monoxide (CO) and a small amount of carbon dioxide (CO_2) together with hydrogen (H) in a reactor. Together with special microbes under chemical reactions methane is formed. After this process the gas, with a methane content up to 98%, get compressed and is available as vehicle fuel at the filling station next to the plant.

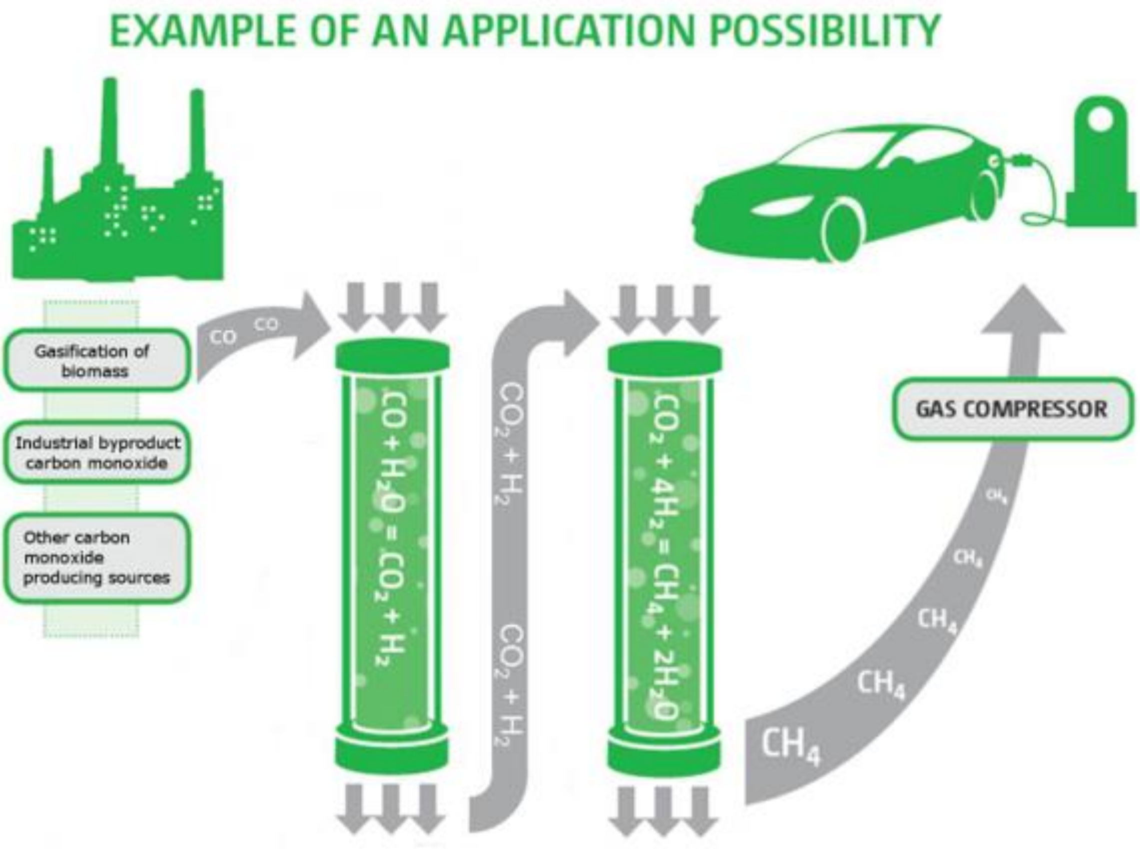
The main parts are the gasification-unit and the methanation reactors. In the gasification unit is the wood gas produced. The feedstock are wood chips. The woodchips are fed in the combustion chamber, but the wood is not really burning it is like inside a smoker. The resulting gas is getting filtered to replace the ash content in the gas. After this the gas is stored in gas reservoirs (Majabacka P.QVIDJA 2019).



Picture 93 - Gasification of wood (LOW TECH MAGAZINE 2010)

For the following methanation is hydrogen necessary. The wood gas contains already a little amount of hydrogen, but more hydrogen is needed. To keep the process green hydrogen is used from electrolysis with solar or wind energy.

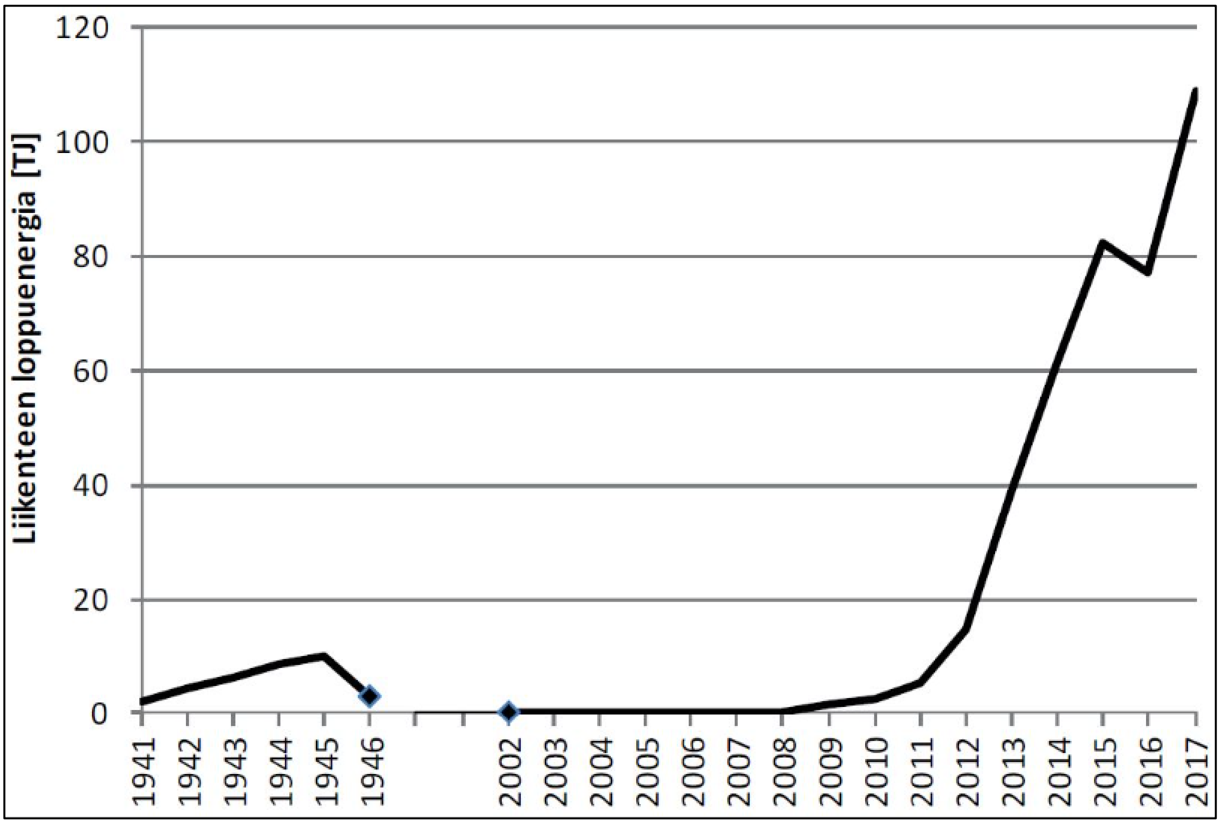
Here could be seen a possibility to reduce the CO and CO_2 emission from factories or other these gases producing resources. This technology can help in achieving a carbon-neutral society (LUKE 2016).



Picture 94 - Methanation (LUKE 2016)

4.10.2.3 Gas powered vehicles in Finland

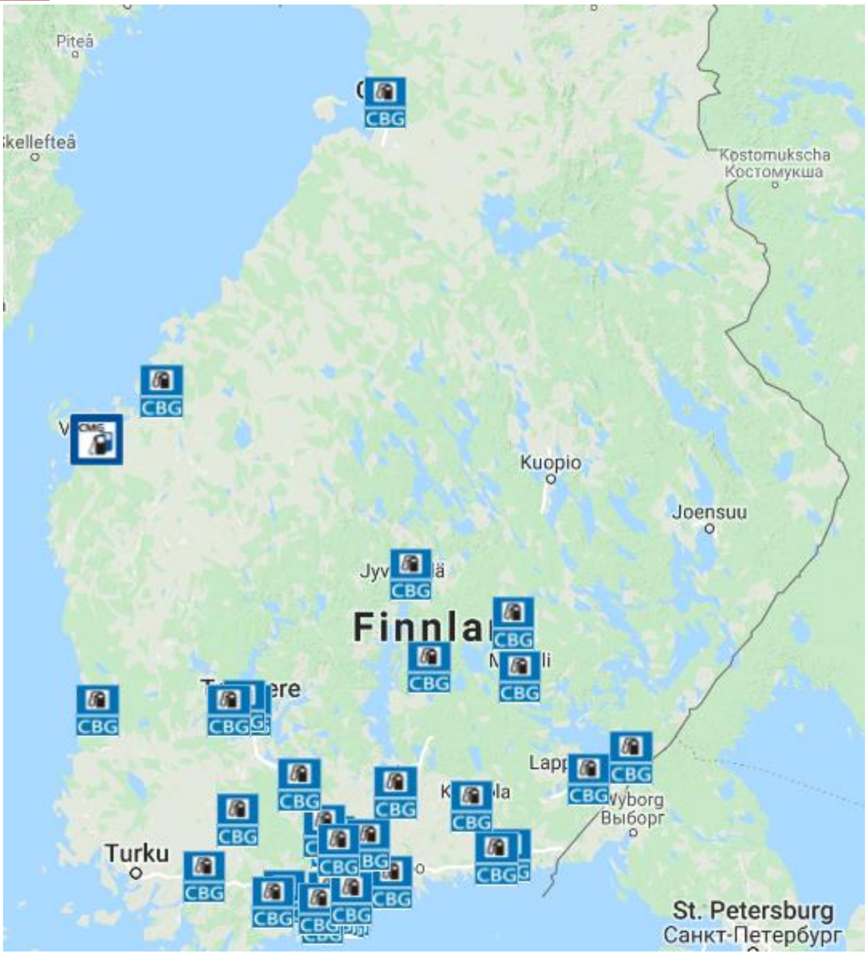
According to Ari Lampinen: “Utilisation of biogas as a vehicle fuel increased by 41% in the year 2017 compared to 2016”. The following chart in figure 7 shows the development of using biogas in Finland’s traffic. “Liikenteen loppuenergia” means end use energy consumption in transportation.



Picture 95 - Traffic use of biogas in Finland (Lampinen, A. 2018, CBG100)

The utilization of biogas in traffic increases strongly from 2012 till 2016. Reason for this heavy rise was the start of using biogas as fuel in the buses of Helsinki´s city. But in 2016 is a drop of consumption recognisable, because Helsinki decreases the use of biogas in city buses and switched over to imported natural gas from Russia. In the end of 2017 Helsinki stopped using biogas, produced by local municipal toilet waste water, in city buses. In 2017 Vaasa introduced biogas as city bus fuel and the consumption growth again (Lampinen, A. 2018, CBG100)

In 2018 were more than 5000 gas-fuelled vehicles on Finland´s roads. The number included CNG fuelled and LNG fuelled vehicles as well. These 5000 vehicles can be refuelled their tanks at about 40 CNG and 4 LNG gas-stations. Gas filling station network is expanding. The largest Number of stations can be found in southern Finland (GASUM 2018). 35 of these methane filling stations are CBG100 stations. CBG100 means that these stations sells 100% Biogas made out of biogas plants. The following picture shows the map of Finland with the distribution of the CBG100 filling stations (CBG100 2019). In Oulu is the one and only gas filling station in northern Finland.



Picture 96 - Gas filling stations Finland (CBG100 2019)

4.10.2.3.1 Pro´s

Methane can be sustainable:

Like previous time already written can methane produced by the fermentation of organic material or extracted out of power-to-gas plants. Under these conditions it is called bio-methane and renewable (Qartier, D. 2018.06.25 FLEETEUROPE).

Expanding infrastructure:

From the year 2016 till 2026 the gas company Gasum will invest in 35 new gas filling station in Finland. In 2016 there were 24 stations, which means in 2026 should in total 59 gas filling stations be available. Other companies like Oulu Jätehuolto, City of Pori, Stormossen in Vaasa and Bio10 in Kitee have plans to open gas filling stations as well (GASUM 04.28.2016).

CNG is safe

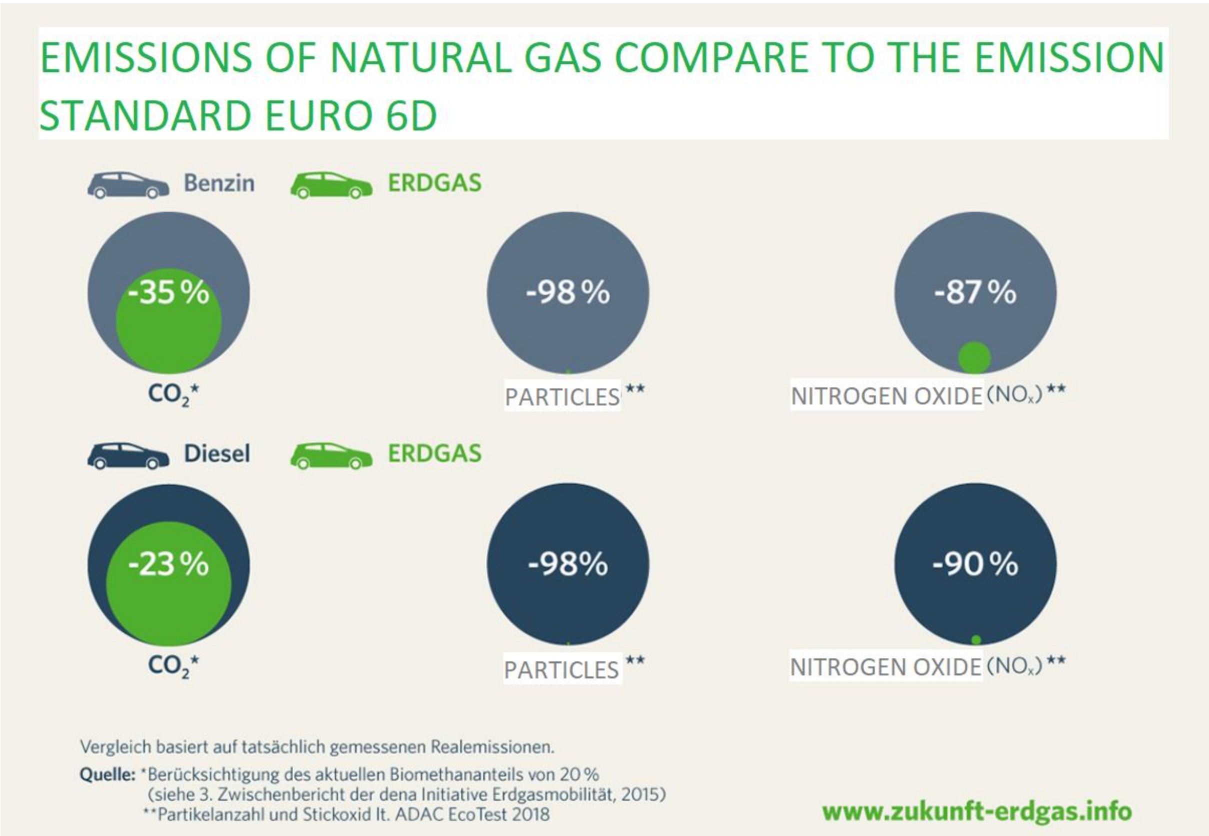
Gas tanks has to survive very strict safety tests, therefore they are made out of very strong materials. For example carbon fibre reinforced plastic. They can resist up to 750 bar of pressure, although CNG is only pressed up to 250 bar, extreme heat and crash impacts. Furthermore the tanks have safety valves (Qartier, D. 2018.06.25 FLEETEUROPE).

CNG/LNG is quite:

Gas engines are up to 50%, about 5 dB, quieter than diesel engines (Brandes, F. 2017.09.06, OSNABRUECK.IHK24). That is a big benefit for buses in the city centre. Furthermore it is a benefit for suppliers of supermarkets or other stores in the city centre. On this way the suppliers can deliver in the night or early in the morning and no local residents are disturb. But this is especially for the trucks if they are running on LNG.

Emissions:

Combusting Natural Gas decreases the harmful emissions massive. The following figure shows the decreasing of the emissions one time in comparison with gasoline and one time in comparison with Diesel. The huge reduction of nitrogen oxides and particles is a big benefit for the environment. Nitrogen oxides and particles are unhealthy for humans and they could cause infections in humans bodies (Brendler, M. 2017.19.08, FAZ). Less carbon dioxide is good for slow down global warming, because carbon dioxide is one of the most valued greenhouse gases.



Picture 97 - Reduction of emissions (ZUKUNFT-ERDGAS 2019)

The real emissions depending on the kind of car and of course the driving styles. The numbers in figure 10 shown the average emissions of a medium class car (BMVI 2013. 07.31). In the case of emissions are CNG and LNG the similar. The process in combustions engines is for CNG and LNG the same. A complete comparison table comes up in chapter X.

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Density	kg/m^3	0,9
Energy per Volume	MJ/m^3	43,09
	kWh/m^3	11,97
Energy per Mass	MJ/kg	47,88
	kWh/kg	13,3
Energy Density (Gas at 200atm)	kg/m^3	180
	MJ/m^3	8618,4
	kWh/m^3	2394
	kWh/L	2,39
	kWh/kg	13,3
Octane		130
LHV	MJ/kg	47,1
HHV	MJ/kg	52,2
Price/m^3	€	225
Price full tank	€	18
Average Car Price (A3 g-tron)	€	26500
Average Fuel Storage size	L	80
Average Energy Storage size	MJ	689,47
Approximate range	km	436,4
Cost per 100km	€	4,125
Modification price	€	4000

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	96
CO	g/km	0,46
NOx	g/km	0,0463
PM	PN/km	3,54E+10

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	96
Greenhouse emissions	g/km	196

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	127
CO2 (100% Biogas)	g/km	30
Greenhouse emissions	g/km	252
Greenhouse emissions (100% Biogas)	g/km	155

Green	Energy data
Orange	Consumer acceptance
Red	Pollution

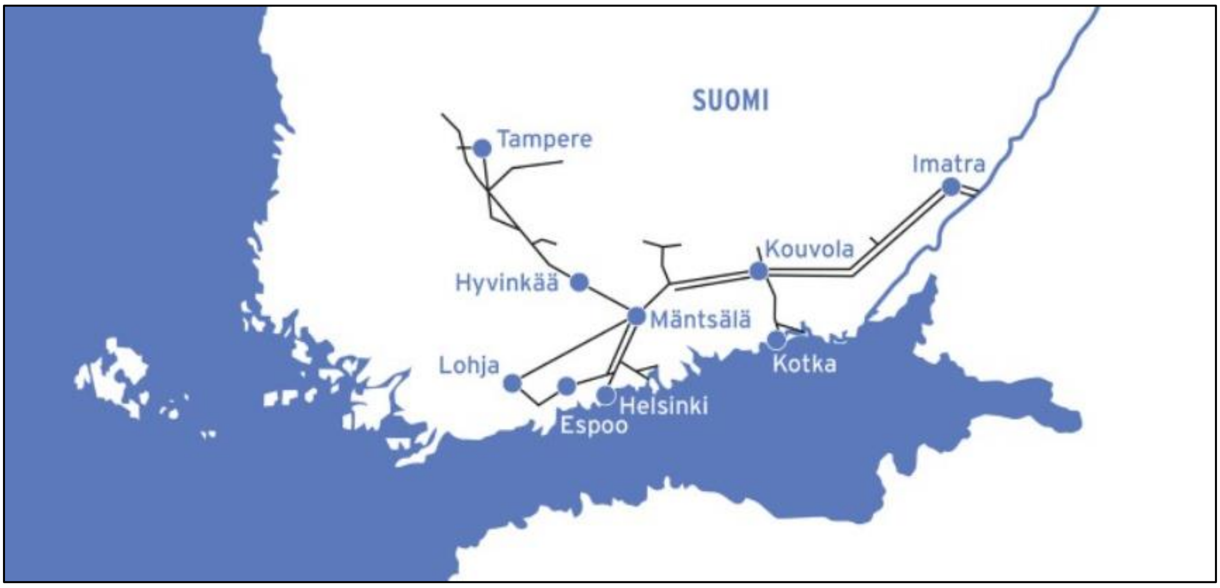
Picture 98 - Data of CNG (OSNABRUECK.IHK.24 2017; ENERGIE-LEXIKON 2018

The previous shown figure shows the "emissions on the road" especially called tank-to-wheel emissions. Another important way to consider the emissions is the well to wheel analysis. This is an analyses of the complete production process, the provision of fuel and at last the transformation of the fuel in kinetic energy (FIS 2010). Main focus is the detection of all direct and indirect emissions of the fuel production cycle. Relevant gases are carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (N_Ox). These gases are called greenhouse gases (GHG). Nearly the half of the GHG is carbon dioxide like the figure10 shows. A comparison with all fuels follows in chapter X.

The emission of GHG depends heavily on the source or rather of the production of the fuel CNG or LNG as well. If Bio-methane is used out of biogas plants with a feedstock purely from organic left overs and waste materials the carbon dioxide emissions can be reduced up to 97. The emissions of carbon dioxide are nearly in balance with the carbon dioxide the crops replaced out of the air while the photosynthesis (ERDGAS.INFO 2019).

Natural gas grid:

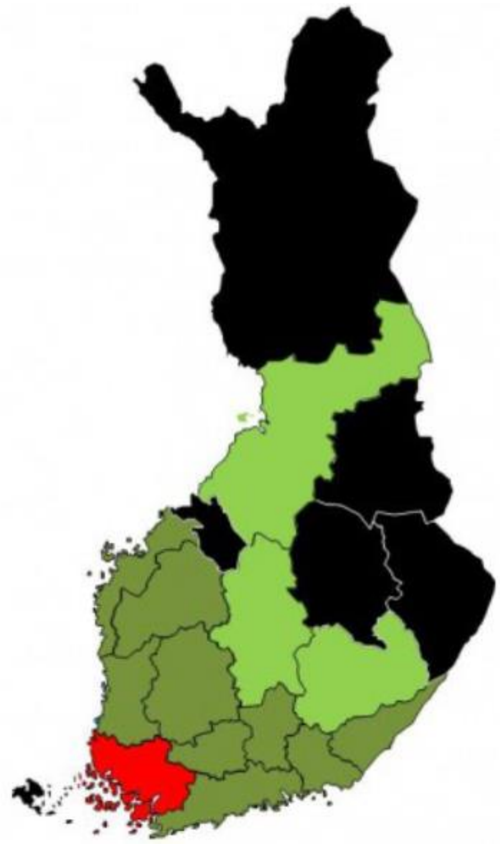
A natural gas grid exist only in southern Finland, therefore only a few biogas plants can inject the produced bio-methane in the natural gas grid.



Picture 99 - Natural gas grid Finland (GASUM 2019)

Out of this reason the biogas plants which are not situated near to the grid has to find other solutions. For example build their own grid to the nearest costumer or transport the bio-methane in container on trucks (JEPPOBIOGAS 2019).

Existing infrastructure:



Picture 100 - Regions with filling stations (CBG100 2018)

Like in chapter X already described, the existing infrastructure at the moment is only in southern Finland sufficient. Figure 12 shows the regions with filling stations and without. The black marked regions have no public gas filling station in their territories. The green marked ones have at least one CBG filling station, so at least one with renewable methane. Dark green means the distance to the next filling station is less than 150 km anywhere in these provinces. Light green means the nearest is over 150 km. The red province has only fossil powered gas filling stations, without any renewable methane (Lampinen, A. 2018, CBG100).

Modification costs:

The conversion of a conventional gasoline combustion engine to CNG powered engine includes a lot of effort and is expensive. Costs about 4000 – 5000 € are not uncommon. It is economically more efficient to buy a new CNG car from the manufacturer (CARGAS 2018).

4.11 Alcohol as alternative fuel

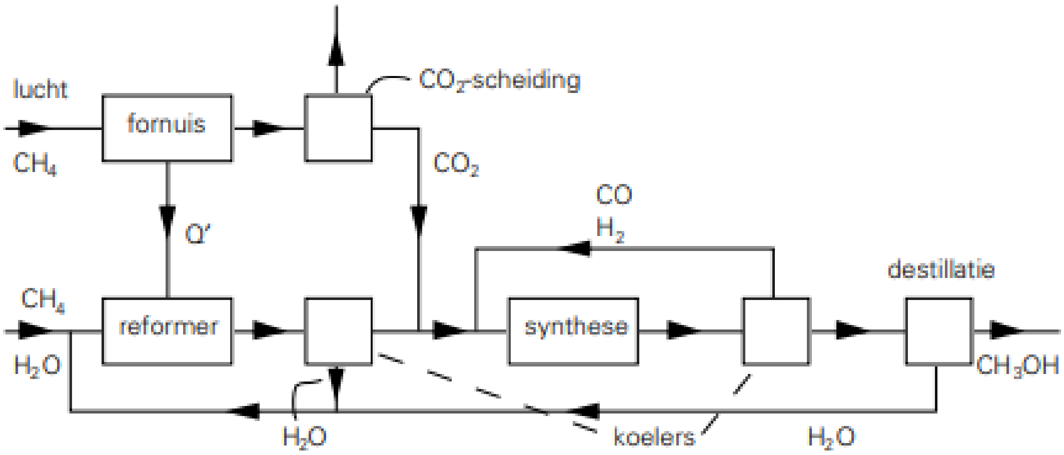
I will do research about alcohol as an alternative fuel for Finland. In the beginning I want to focus on what is methanol and ethanol. Does it already work in cars or not? How can you make the fuel? From renewable sources and are these sources stressful for the environment. If you need a lot of fields for making biomass and these fields were otherwise used for production of food so the food prices are going to increase.

4.11.1 Methanol

Methanol is a liquid that can be used as a fuel. The formula is CH_3OH. It is a wood alcohol this means that it's made of distillation of wood but these days it is mainly produced industrially. It can be produced from fossils, or biomass/biogas. The way we are going to investigate most is the biomass/ biogas method. The definition of Biomass is: the matter has to be direct or indirect from plants and has to be renewable in a period less than 100years. (Cooke, K. (2014, February 11))

How to make methanol?

There are two big ways to make methanol. From fossils (natural gas) or renewable. In the renewable way you have a few options as well: biomass, biogas or carbon dioxide emissions e.g. from a factory.



Picture 101 - process of methanol

You can make methanol from natural gas as shown in this diagram.

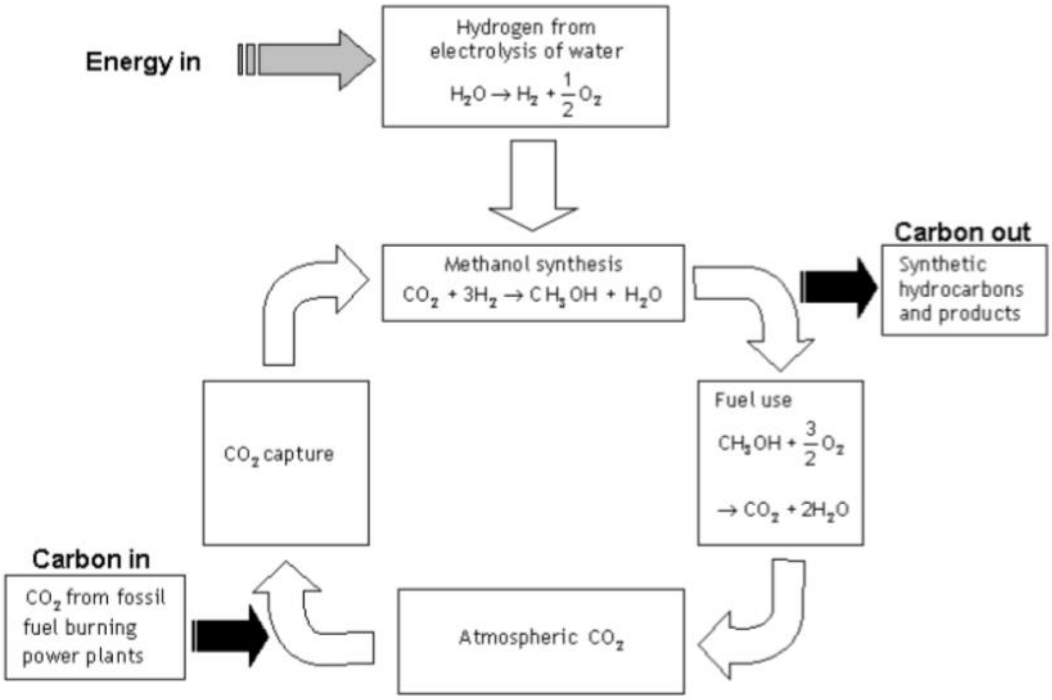
This is a diagram of the industrial process how to make methanol from natural gas. You need water (H_2O), methane (CH_4) and air for this process of making methanol.

Methanol can also made from biomass or the CO_2 exhaust from production of biogas then it is BIO methanol.
With the fermentation of biogas you have 50% CO_2 and 50% methane that can also be used as a fuel.

A disadvantage of making methanol from biomass is that making biomass needs a lot of space. This space can also be used for making food therefor there is sometimes a conflict between the food industry and the biomass industry. Another consideration that can be made is the problem that land has been uncultivated for a long time and stores a large amount of carbon in the soil. This carbon is then released in one go in the form of CO_2 when the soil is reprocessed. As a result, the use of biomass as an environmentally friendly fuel is sometimes cancelled out for more than 100 years. (Institute, M. (2009, May 08))

Methanol produced by CO_2 capacitation

There is a possibility to recycle CO_2, with this method we mean that we "catch" the CO_2 extraction out of the exhaust of companies e.g. electricity companies or other industrial companies with CO_2 in the exhaust. (Vaartjes, J. (2017) Vesterinen, E.)



Picture 102 - methanol by CO2 recuperation

Specs methanol

The first spec I would like to describe is that the volumetric energy is almost half lower than gasoline or ethanol. So for the same distance radius you need almost a tank double size but because the efficiency of a methanol engine is better, this is not entirely true. The mixture between air/methanol is also different than the mixture air/gasoline. This means that for a best mixture the methanol needs more air so the efficiency and power is higher with a methanol engine. Another fact is that the octane is higher with methanol. The octane number is a measurement for performance of the fuel, so the higher the number the better. The higher the octane number, the more compression the fuel can withstand before detonating (igniting). If you make DME the cetane number is important because it works on the self-ignition way by compression. The cetane number is a measurement for how fast the combustion happens when you inject the fuel, the delay between the injection and the combustion. The reason why methanol has some problems with cold start is because Methanol (CH 3 OH, MeOH) has a hydroxyl group. This hydroxyl group ensures that methanol is conductive and polar. Due to its polarity, methanol is corrosive and hydrogen bonds are made that make methanol more stable than other hydrocarbons. This results in a high latent evaporation heat and a low vapour pressure. That is why methanol engines have problems with a cold start. Due to the high latent evaporation heat and the low Ls, the intake air becomes better cooled, which has a positive effect on the delivery rate since cooling increases density. A disadvantage is that a normal engine block is cannot resist methanol that good as benzene. These means that the engine life time is going to be shorter. (Ingham, A. (2017)) (Maarten Van De Gnste, L. S. (2011).)

Countries

In Europe you never see methanol fuel stations for normal cars. In other parts of the world this is different. In Brazil for example most of the cars drive on methanol or ethanol. In Israel also a lot of cars drive on M15. For example in Australia the government does not have taxes on the methanol fuels for supporting this kind of fuel.

Methanol as a fuel

There are a lot of possibilities for using methanol as fuel. I am going to describe three of them which I found the most interesting. The main split is using methanol for a combustion process or as a fuel cell.

4.11.1.1 Liquid methanol

This is the main use when we think about methanol as a fuel. This method is actually not new because the VW group had already cars on methanol 50 years ago and in the race world methanol or ethanol are also well-know.

The working of an engine on methanol is almost the same as a gasoline engine. With a few changes on the engine it runs on methanol. There are many ways to use the liquid methanol, for better start performance you can mix it for example with gasoline, another mixture that is common is methanol/ethanol mixture. All of these mixture has some own advantages and disadvantages. (Berger, K. (2014, 12 19))

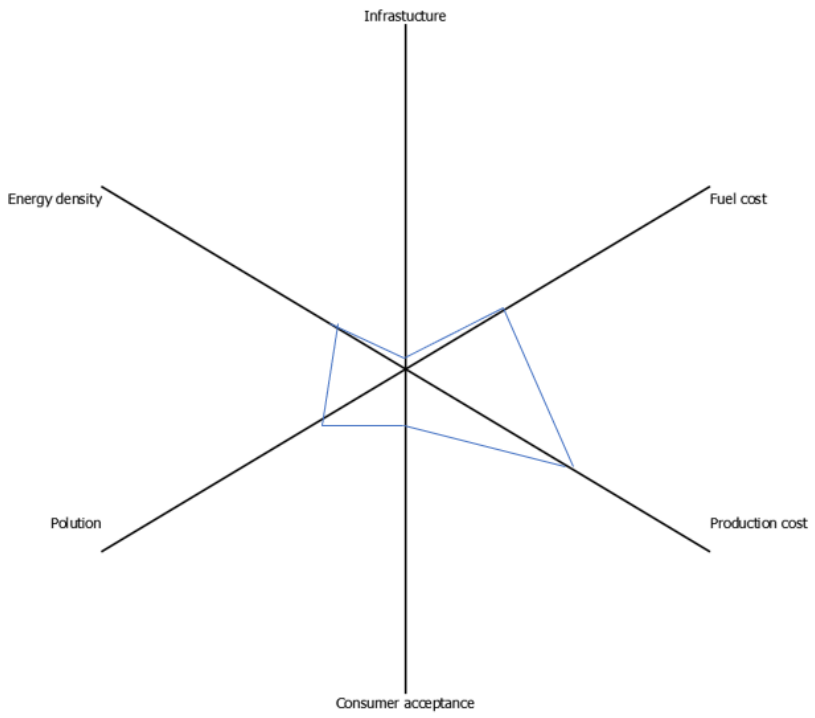
Mixtures
In Brazil and some other countries there are already cars and infrastructure for driving on methanol. The fuels are called M5, M10, M15 and M85. The number behind the "M" means the methanol percentage. So M10 means 10% methanol and 90%gasoline. M100 is not common for the main raison that it is really hard for cold start.

Emissions
The emissions of a car on methanol are lower than a gasoline car. I couldn't find exact numbers of emissions for a car of specific engine. A car on methanol has lower NOx than a diesel engine. A reason for these is because the ignition is on the LHV. This can be up to 80% less NOx than a diesel. The CO_2 pollution is also less and you can derive this from the chemical formulas between the methanol (CH_3OH) formula and the diesel formula ($C_{12}H_{23}$). The amount of carbon in the formula can be an indication of the amount CO_2 pollution. The Fiat Chrysler group has one Fiat that runs out from factory out on the M15, this means you do not have to do any changes for letting it run on methanol M15. This car complies with the new euro6 norms for pollutions. On this moment is that the cleanest norm in Europe.

Safety

Driving on methanol is a safer than a gasoline car. This and the higher octane number makes that in the race world methanol al lot of times the fuel is.

Drinking of methanol alcohol makes you blind, distract the nerves that can get you in a coma or even dead.
When there is some contact with methanol you have immediately to clean your skin or eyes and clean and changes clothes.



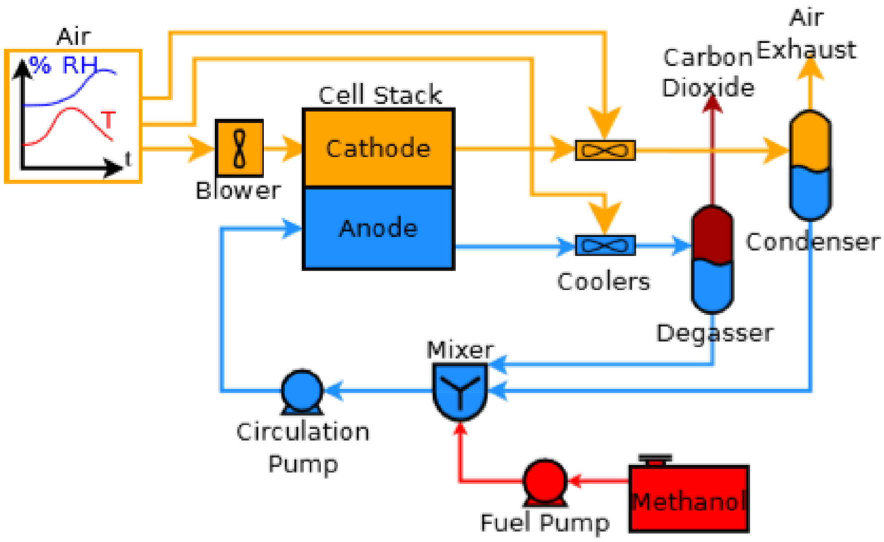
Picture 103 - methanol spider chart

This is a spider chart it is a quick and easy overview for a few specs. In this spider chart I selected: infrastructure, fuel cost, production cost, consumer acceptance, pollution and energy density. These factors where compared to the cars these days on benzene and diesel. With the middle of the line is the line for them. There is almost no infrastructure in Europe but making an infrastructure is really easy. It is a liquid so you can just use the normal pump stations if they want to make methanol infrastructure. The fuel cost is a little bit lower than by diesel and benzene. To make a car on a methanol would be almost the same price only for a few things you need better parts. On this moment is the consumer acceptance still low. The pollution is lower than fossil fuels and these are renewable. The energy destiny is the half from a benzene and diesel.

4.11.1.2 DMFC

A fuel cell vehicle is well known as efficient and clean vehicle. Especially direct methanol fuel cell because of their small size, the easy recharge because methanol is liquid and the high energy density of methanol. It also operates silently, at relatively low temperatures and offers much longer operating time than today's batteries. These are all big advantages. Better than a battery, DMFCs don't need to be recharged. They can provide electricity continuously to the consumer electronic devices as long as oxygen and fuel are supplied to the fuel cell. To achieve this, DMFCs can be "hot-swapped" and instantly recharged with replacement methanol cartridges (akin to batteries).

The chemical reaction for methanol as fuel cell is:
$CH3OH + H2O \rightarrow CO2\uparrow + 6H^+ + 6e^-$ (Anode) (1)
$6H^+ + 6e^- + 3/2\ O2 \rightarrow 3H2O$ (Cathode) (2)



Picture 104 - Working DMFC fuel cell

The diagram above is the most used system so it is the reference system. The reference system has one mixer to blend three flows of different compositions: the solution from the degasser has methanol concentrations ranging from 0.1M to 2M according to the operating conditions the liquid from the condenser is neat water and the liquid from the methanol tank is neat methanol. To join these different concentrations into a well-blended solution, the reference system is equipped with a mixer. However, this system is not able to instantaneously adjust the concentration of the solution entering the anode, because the large size of the mixer works as a buffer to mitigate concentration changes. (Pak, C. (2011))

The energy goes from the fuel cell to a battery as buffer or directly to the electromotor which drives the vehicle.

Specific working fuel cell

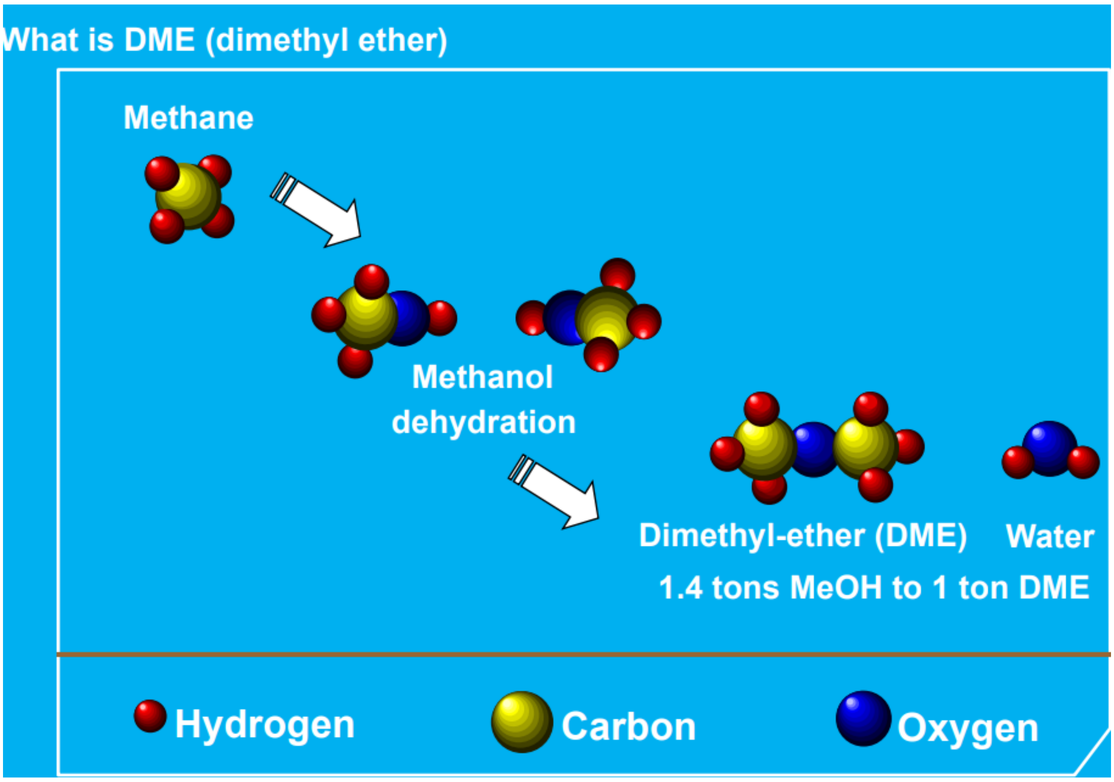
The heart of a fuel cell consists of catalysts for the electrochemical reaction and a special piece of plastic that can conduct protons. The technical term for this special plastic is polymer electrolyte membrane (PEM) and the most common PEM used in DMFCs today is NafionTM, produced by Dupont. The most common catalysts used are PtRu alloy for the anode and Pt for the cathode. (A/S, S. (Regisseur). (2017))

In the fuel cell, the fuel is not burned, but rather is converted into electricity through an electrochemical process that splits methanol into protons, electrons, and carbon dioxide at the anode and then combines these protons and electrons with oxygen at the cathode to produce water. It is a very simple concept. (A Blum, T. D. (2013, May 15)).

4.11.1.3 Dimethyl

DME or dimethyl ether is made from methanol, the Formula is CH_3OCH_3. Kind of usage of methanol is special because DME has a lot of common specs with diesel. That is also the reason why it runs on a diesel engine with little changes. The cetane number of DME is even higher than diesel which means that DME has a better self-ignition than diesel. From (Wikipedia, t. f. (2019, 03 21))

Under normal conditions DME is colourless gas. It has to be stored in a tank, the tank material for DME is steel. The pressure in the tank is 5.17 bar.



Picture 105 - process DME

In this picture you can see the process of the production for DME. You start with methane, methane is a gas that can come from natural gas or biogas. From the methane you make methanol, this process I told you before. You need two molecules of methanol to make a DME molecule and a water molecule. The reaction that you need for this is a catalysation reaction. (Szybist, J. P. (2014))

DME has some really good potential to replace a diesel car in the future. Because it works on the same way and the cetane is even higher. The cetane for diesel is between 40-55 and for DME 55-60. The scale for cetane is the same as octane, from 0-100 with zero is nothing and 100 is really good. The scale is until 100 but there are fuels that have higher octane than 100. More important for the environment is that this is a non-soot combustion. Soot means that there is an incomplete combustion and there stays black carbon behind. This black carbon is particle pollution. PP is one of the main reasons why the want the diesel to go together with the NO_x. In that opinion is the DME a really good alternative. There is even no particulate filter required. Not only the pp is a lot better than by the diesel there is also a 10% carbon reduction. Volvo did test with the DME and out of the results came there is a high well to wheel efficiency.

4.11.1.4 Pros and cons

Pros

- A lot of possibilities for how to make methanol
- There is no sulphur inside
- Less CO_2 and NO_x than with petrol or gasoline cars
- You need CO_2 to make methanol so with the right techniques it can help against global warming.
- Better mixture between air and methanol than between air and gasoline
- Safer in case of crash because there is less danger for taking the car fire
- High octane measurement

Cons

- Hard to start in cold weather
- Need some changes to an engine
- The volumetric energy is lower than gasoline so with the same tank size lower distance
- Methanol is bad for engine materials

4.11.2 Recap about Methanol

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Energy per Volume	MJ/m^3	15946,56
Density	kg/m^3	791
Energy per Mass	MJ/kg	20,16
Energy Density (Liquid)	MJ/m^3	15946,56
	kWh/L	4,43
	kWh/kg	5,60
Octane		110
LHV	MJ/kg	19,9
HHV	MJ/kg	23
Min. Ignition Energy	MJ	0,14
Auto Ignition Temperature	°C	470 (as liquid)
Price/L	€	0,93 (Amerika)
Average Car Price	€	100€ more than normal benzine
Average Fuel Storage size	L	55
Approximate range	km	Little bit more than half of range same car on benzine

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	84,5
CO	g/km	
NOx	g/km	
PM	ppm	

Green	Energy data
Orange	Consumer acceptance
Red	Pollution

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	84,5
Greenhouse emissions	g/km	212

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2 (Biomethanol)	g/km	5
Greenhouse emissions	g/km	291

Picture 106 - Methanol specifications

5. COMPARISON

Please find attached of this report an excel file (Comparison Chart).

Website: https://fuel-for-the-future-by-the-fuelboomers-eps-project-93.webself.net/

After carrying out researches for all the different fuels that have been agreed as a promising one, the part of comparison is the next step.

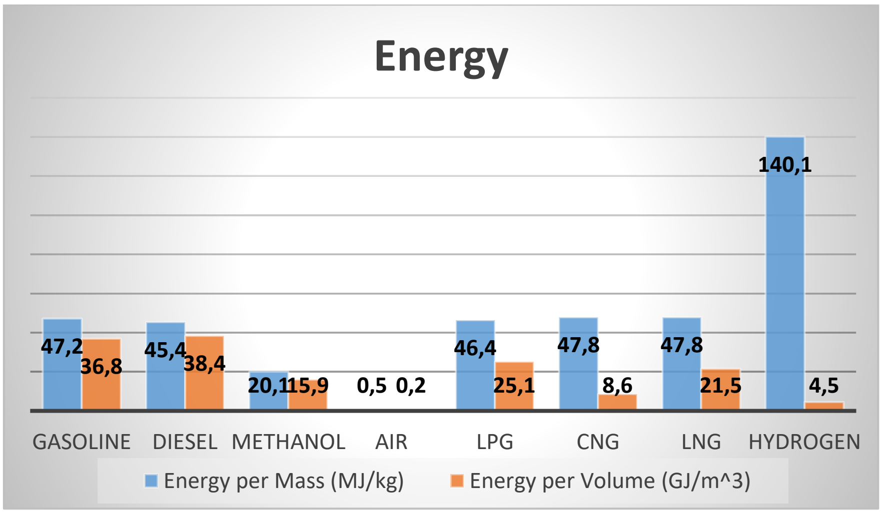
After collecting all those different data about these several fuels, now the goal of this study is to define which one of these alternative fuels could be a good option for our future.

First of all, we need to define on which criteria the comparison can be made. Three principal points have been chosen.

5.1 Energy Content

Energy Content is the amount of power that can be delivered during a certain time. The power of an engine comes in part from the fuel, so a powerful fuel is important. Here we compare the fuels on the energy per mass and per volume and the comparison of all the fuels contend in this study gives this result:

	Energy per Mass (MJ/kg)	Energy per Volume (GJ/m^3)
Gasoline	47,2	36,8
Diesel	45,4	38,4
Methanol	20,1	15,9
Air	0,5	0,2
LPG	46,4	25,1
CNG	47,8	8,6
LNG	47,8	21,5
Hydrogen	140,1	4,5
Electricity	0,43	0,7



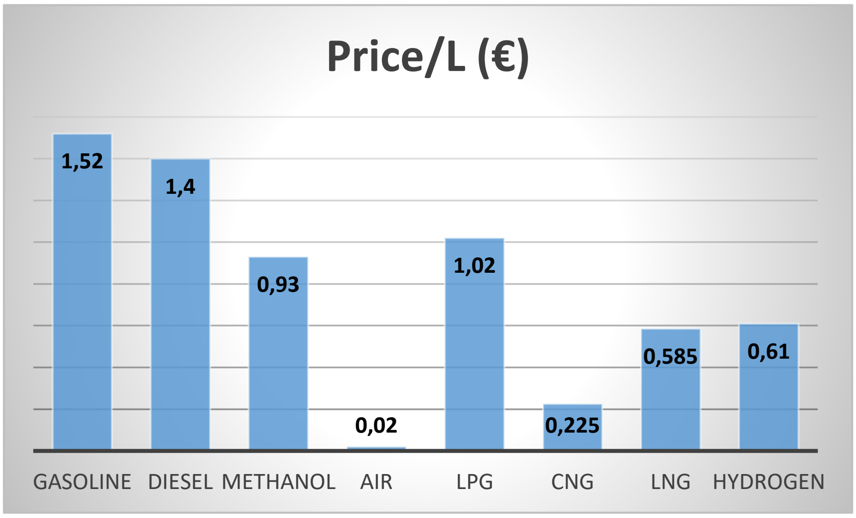
With this point, it appears clearly that Hydrogen is the fuel who can give the most energy. However, the amount on energy can be explained, indeed, the density of Hydrogen is around 0.09 kg/m3 so basically ten times less dense than the CNG (atmospheric pressure) which is a gas as well. So to conclude, it is mandatory to compare other points.

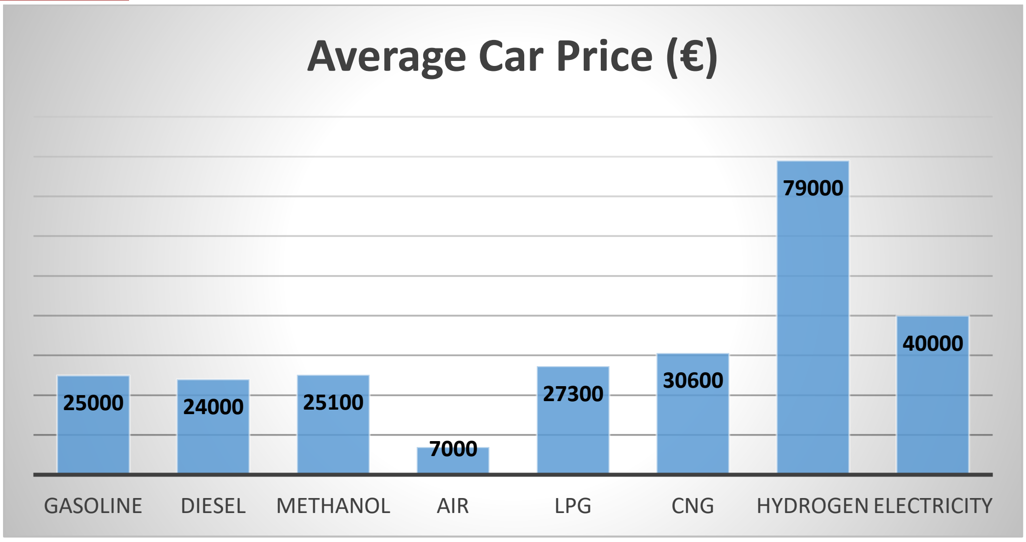
5.2 Customer acceptance

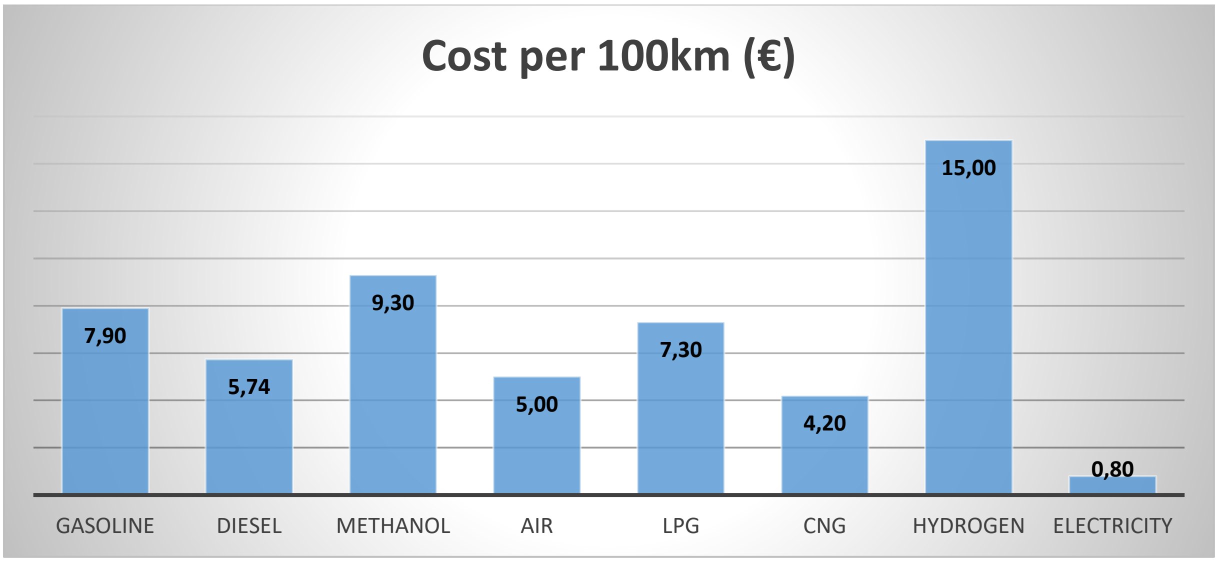
The second main point of this comparison will be the “customer acceptance”. A fuel, however powerful, can’t be a good option for our future if it is not available. It is important to choose a fuel which is easily findable and relatively affordable.

This comparison regroups few points like the price of cars which use this fuel (these cars are part of the most common cars using each type of fuel), and the range of these cars. It contains also a comparison on the price of all our fuels and the cost for 100km with the appropriate car.

	Type of car	Average Car Price (€)	Approximate range (km)	Price/L (€)	Price/kg (€)	Consumption of the car	Cost per 100km (€)
Gasoline	GOLF TSI	25000	950	1,52		5,2 L/100km	7,90
Diesel	GOLF TDI	24000	1200	1,4		4,1 L/100km	5,74
Methanol	GOLF Converted	25100	500	0,93		10 L/100km	9,30
Air	AirPod	7000	130	0,02		250 L/100km	5,00
LPG	GOLF Converted	27300	700	1,02		7,15 L/100km	7,30
CNG	Audi g-Tron	30600	430	0,225	1,40	3 kg/100km	4,20
LNG				0,585			
Hydrogen	Toyota Miraï	79000	500	0,61	15	1 kg/100km	15,00
Electricity	e-Golf	40000	230				0,80





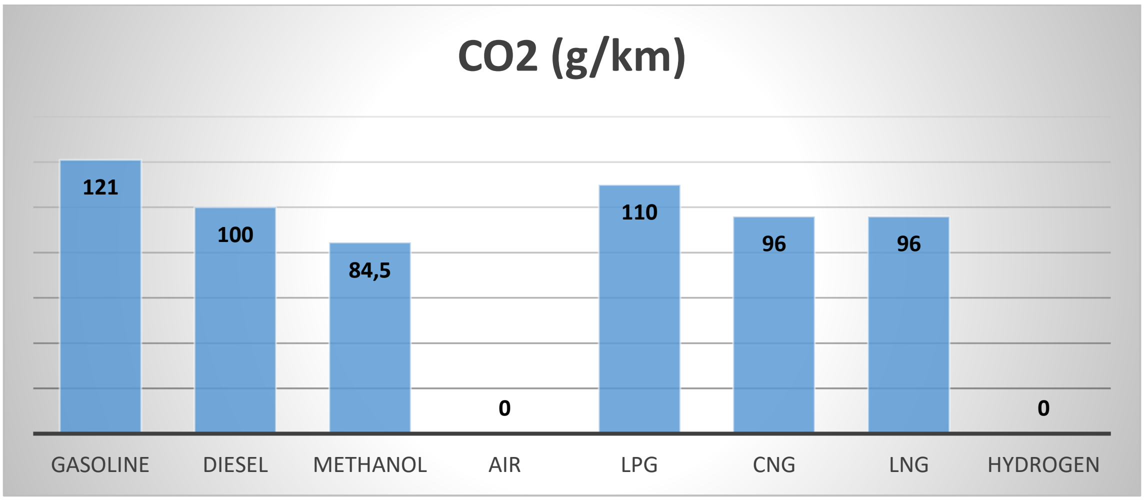


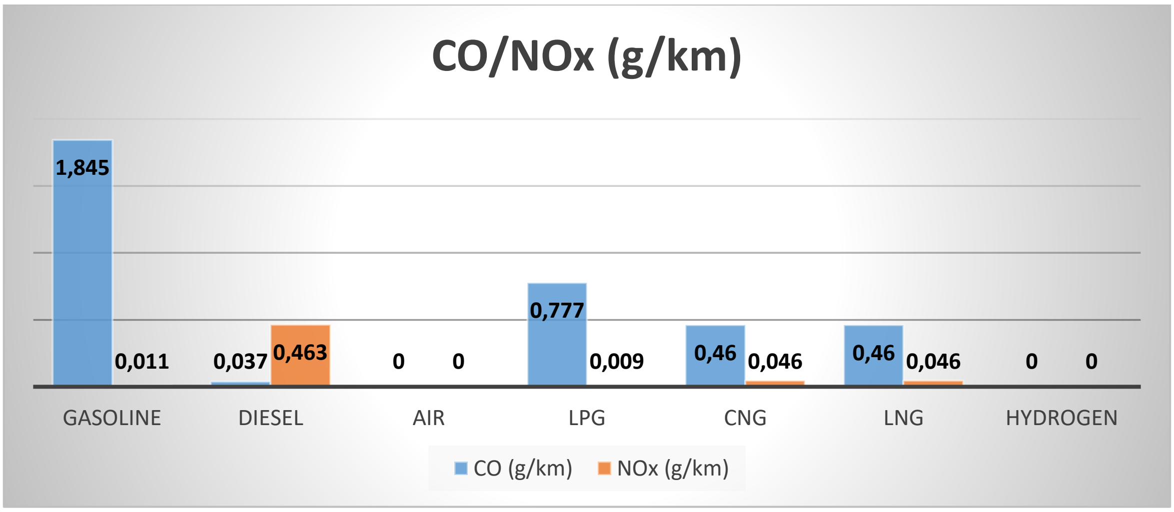
On this point, Electricity, Air, and Natural Gas look to be the best compromise. But the fuel for the future has to be more than powerful and affordable. It must be clean to reduce the global warming and to preserve human health.

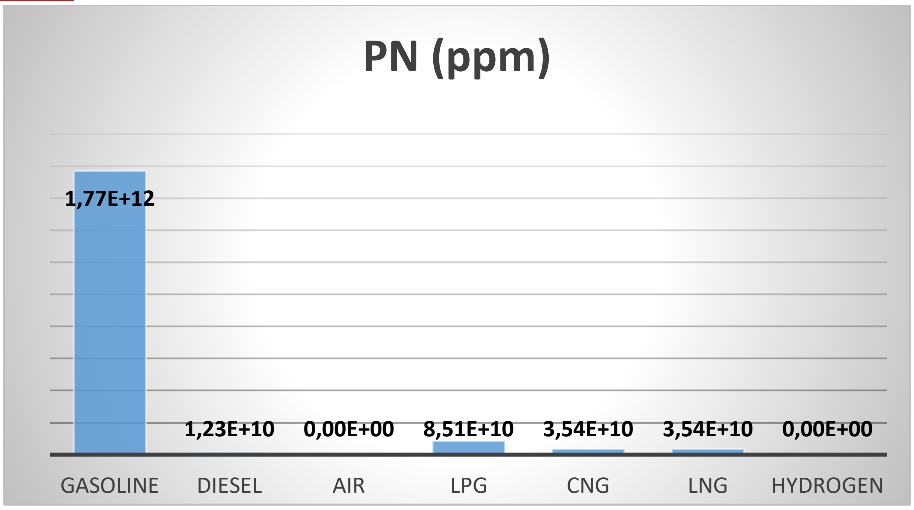
5.3 Pollution

The next and last part of the comparison will be on the pollution. On this part will be compared the amount of CO_2, CO, NO_x, and Particles (the principals responsible of traffic pollution) emit by cars, but also the amount of CO_2 emits during the production of the fuel.

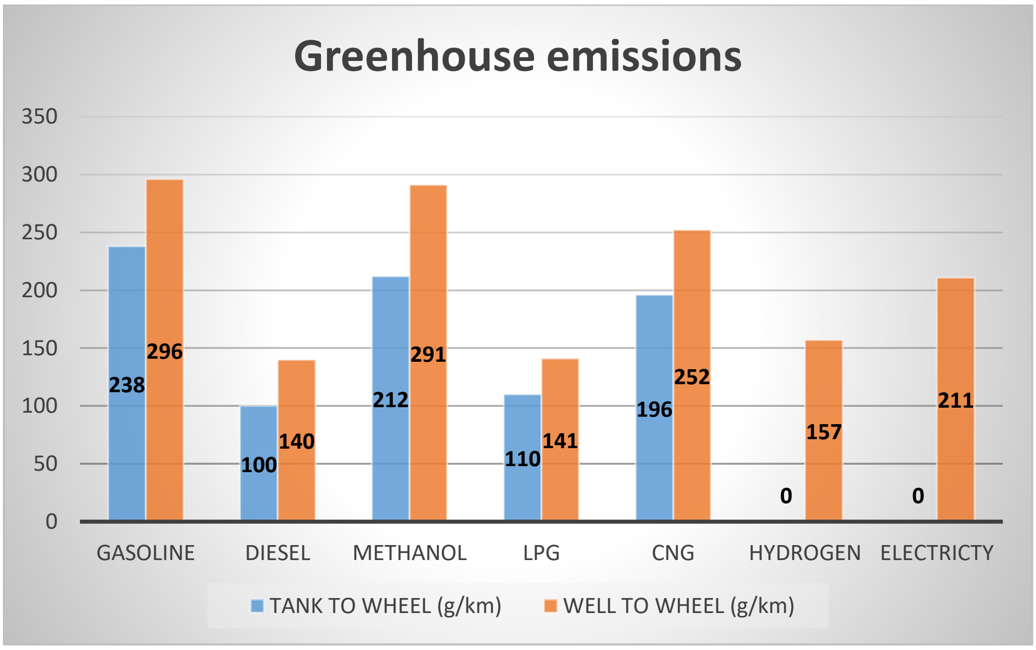
					Greenhouse emissions	
	CO2 (g/km)	CO (g/km)	NOx (g/km)	PN (ppm)	TANK TO WHEEL (g/km)	WELL TO WHEEL (g/km)
Gasoline	121	1,845	0,011	1,77E+12	238	296
Diesel	100	0,037	0,463	1,23E+10	205	217
Methanol	84,5				212	291
Air	0	0	0	0	0	0
LPG	110	0,777	0,009	8,51E+10	110	141
CNG	96	0,46	0,046	3,54E+10	196	252
LNG	96	0,46	0,046	3,54E+10		
Hydrogen	0	0	0	0	0	157
Electricity	0	0	0	0	0	211







On this graph we can notice that, in opposition of what we can think because of the diesel gate, Gasoline engine can emit 100 times more particles than a diesel engine.



Thanks to this comparison on these three principal points, it is possible to choose which fuel seems to be the best option for our future. But here, it is important to take in account the adaptability of this fuel to Finland. And, by taking in account all this different points, Natural Gas (like methane) seems to be the best option. Indeed, this fuel can give a lot of power for a pretty affordable price and by polluting relatively little. And it can be found and produce pretty easily in Finland.

To sustain this comparison, a testing part could have been done, but unfortunately we didn't have the time and the means to do it. Indeed, a software was found to make a simulation, however the IT department of NOVIA, was unable to get the licence to use this software.

6. CONCLUSION

This study could be used as a first step. This report contains a lot of data on several alternative fuels. Today, humanity starts thinking about a solution to save the planet as quickly as possible. So, all this data could be used to choose a solution to global warming in different cases.

During this study, Natural Gas was define as the best option for the fuel of the future in Finland, thanks to the amount of available organic material to produce biogas and biomethane for example. Another advantage is that natural gas is already used in Finland's traffic such as the current existing natural gas grid and filling stations. Nowadays, natural gas stations are easily affordable in the south of Finland but it is more difficult to find one of these in the north of the country. To really be the fuel for the future it has to be available for everyone and everywhere so the distribution system need to be improve. A benefit is that Finland's gas companies and biogas plants work on the expansion of the CNG and CBG filling stations. In 2026 should be exist in total 59 filling stations, that is almost a plus of 50% of the in 2019 existing 40 stations. Also of course the production system must be increase to satisfy the need of a whole country. Furthermore engines running on natural gas are reducing the engine noise in comparison with a diesel engine. This could be a smart solution for a quieter city centre, like the city of Vaasa and Helsinki with their CNG buses shown.

When all these increments will be done, Methane will probably be the best option as a fuel to preserve the planet and our health. But this solution is only available for cars. What about planes? Nowadays planes are using Kerosene.

ENERGY CONTENT TABLE		
Caracteristics	Unit	Value
Energy per Volume	MJ/m^3	35303
Density	kg/m^3	821
Energy per Mass	MJ/kg	43
LHV	MJ/kg	43
HHV	MJ/kg	43
Self-Ignition Temperature	°C	220

POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/L	2520
CO	g/L	1,48
NOx	g/L	1,89

"TANK TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	

"WELL TO WHEEL" POLLUTION TABLE		
Caracteristics	Unit	Value
CO2	g/km	

Picture 107 - Information about Kerosene

Kerosene is the best fuel for plane because it can give more energy than other fuels. But Kerosene pollute a lot so it will be important to find a solution at this problem in a near future.

Indeed, in approximatively 50 years, the Earth will run out of petrol.

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