MSc Program
Engineering Management

Actual and potential new fuel types in Europe and Austria

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 26.02.2020

Affidavit

I, **CHRISTOPH TATZBER, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ACTUAL AND POTENTIAL NEW FUEL TYPES IN EUROPE AND AUSTRIA", 98 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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i. Table of Content

ii. Abstract

The present of this master thesis is concerned with the usage of fuel types in their actual and future form. It should provide a big overview of actual technologies that are available on the market and outline different potential future scenarios.

The future deployment of fuels in our daily life can change. Several technologies gained increase public attention like hydrogen, battery powered vehicles (BEV), hybrid technologies and more. There are several different fuels that have the potential to decrease the humans carbon footprint in this world.

The main goal of the thesis is to provide the technical and theoretical background of fuel types in their actual form and their potential usage in the future. The history of fuels is outlined that provides the foundation for the actual mobility situation on earth. Basic chemical compounds that build the base for actual fuels are treated. Since the development of fuels, the efficiency in the combustion process has been improved several times, as example the adding of a turbo changer can be named, this and potential increasing efficiency methods outlined by technicians are investigated. Biofuels are one big topic that influenced the mixture of conventional fuels the last years, therefore this topic is covered. New upcoming technologies like nanotechnology in the context of biofuel production, biorefineries, fuel cells and other potential scientific inventions are investigated and explained. In the potential future scenarios, the progression and their effects of the different fuel types is investigated. Actual limits of the realization process are outlined and the total cost of ownership is investigated. The emissions of different fuel powered vehicles are covered in the future scenario chapter.

Keywords: actual fuel types, petrochemistry, future fuel types, hybrid technologies, hydrogen, future fuel scenarios

1. Introduction

1.1. Scope of the work – structure of the thesis

This master thesis should outline the actual fuel production and the potential of new fuel types in Europe and Austria. The major energy resources that are used to produce this amount of fuels are investigated. In special the origin from crude oil to a finished fuel is depicted because today 97% are made out of conventional petrochemical fuels. The supply chain for the natural resources are explained and the production process of crude oil is investigated, this is from special interest because the European Union has not enough natural resources to cover the needed amount. Several publications from the European Union provide a good overview of the actual fuel and primary energy situation, these scientific papers are one information resource for the thesis. The complexity of primary energy resources and fuel processing are connected in several ways, therefore the primary energy situation in the EU is also described shortly. (i.e. relation to electrical driven cars)
Information that build the base know-how for the energy and oil processing is covered and outlined in the first chapters. Afterwards the composition of oil that is responsible for the outcome of the refining process is investigated further. The differentiation of fuel sorts and European standards that are the foundation in the production process are investigated. The main chapters of the thesis cover the actual fuel types that are used on the market. These different fuel types are described and possible alternative sources are explained in the end.

Afterwards the fuel consumption and the actual situation in the European Union and in Austria is depicted. Several statistics confirm the actual fuel situation and cars powered by fuel type.

The outcome of this scientific work is to get an overview of the actual and possible future fuel situation. Future technologies that could change the common way of fuel production are investigated in several chapters and compared with conventional fuels. Trends like reducing CO2 emissions, increasing the biofuel components in fuels and other measures are observed. The goal of big fuel producing companies is to see and interpret these trends to have a new alternative income source.

2. General Introduction

Several products from our daily life are made out of crude oil, a life without it would not be possible in the industrial countries. Energy, traffic, hygiene articles, that we need every day, are only a few of them that are made out of it. It is by far the largest single commodity in the international trade market in the world. Political issues and wars were in the past and are still in nowadays the outcome because of power over oil reserves.

The organic chemistry is dealing with the part of chemistry that is based on carbon. Crude oil consists of carbons and other organic compounds with a mixture of sulfur, nitrogen and oxygen, it varies depending on the sort of the crude oil. Coal, oil and gas are named fossil fuels and are used for heating and for the production of fuels.

This thesis especially focuses on the actual fuel production technology, that is very linked to crude oil, the composition of it, the different fuel types and afterwards the regulations that influences the processing and possible alternatives are presented.

The petrochemical industry has a big lobby and therefore big influences in several decision-making processes. This situation is due to the large profit that is made out of the dealing with natural and finished oil products. In the actual modern world humans require oil for several processes that are life essential like pharmacy and energy.

A lot of countries have not enough resources to cover their demand needed for the local society therefore countries that have enough natural resources export products to others and gain political power and money. The political influence because of enough oil reserves is often stated in news around the world i.e. the Russian crisis with Ukraine, influences the gas supply of the European Union and is viewed very critically from other states. Austria has enough gas storage for nearly one year but not enough resources to fill them up.

The next chapter shows the actual primary energy situation in Europe because oil is a big part of it and has influence on the supply and demand situation of it.

2.1. Primary energy resources in the European Union

The European Union has according to Eurostat in 2016 a total primary energy production of 755,4 million tonnes of oil equivalent (toe)[1]. This includes the production of nuclear energy, solid fuels, natural gas, crude oil and renewable energy resources. Austria is contributing to this statistic with an input of 12,3 toe.

The total production is decreasing since 2006 as major factor Eurostat states the exploitation of limited resources becomes more uneconomical and the raw materials gets exhausted. According to Eurostat all European Member states are net importers of energy due to the fact of decreasing production in coal, nuclear energy and the aftermath of the global financial crisis in 2008/09. In figure 1 the total production of primary energy, EU28 based on 2016 statistics is depicted. [1]

Around 10% of total primary energy is coming from crude oil, this fact depicts the interdisciplinary connection between primary energy resources and fuel consumption.

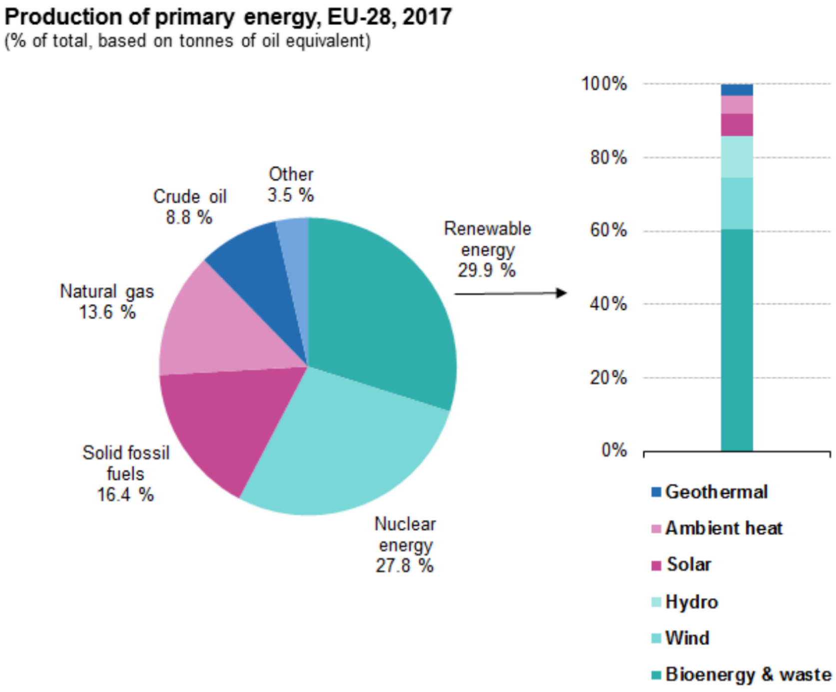

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Figure 1 Production of primary energy, EU28, 2017 (1)

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[1] 1 tonne of oil equivalent (toe) = approx. 42 gigajoules or 11.630 kilowatt/hours

In the EU the crude oil imports are mainly coming from Russia (31,9%), Norway (12,4%), Iraq (8,3%), and Saudi Arabia (7,8%) as it is illustrates in table 1. [1]

	Import Oil sorted by countries %										
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Russia	33,8	33,7	31,8	33,6	34,7	34,8	33,7	33,7	30,4	29,1	31,9
Norway	15,4	15,0	15,0	15,1	13,7	12,5	11,2	11,8	13,1	12,0	12,4
Iraq	2,9	3,4	3,3	3,8	3,2	3,6	4,1	3,6	4,6	7,7	8,3
Saudi Arabia	9,0	7,2	6,8	5,7	5,9	8,0	8,8	8,7	8,9	7,9	7,8
Kazakhstan	4,6	4,6	4,8	5,3	5,5	5,7	5,1	5,7	6,4	6,6	6,8
Nigeria	3,6	2,7	4,0	4,5	4,1	6,1	8,2	8,1	9,1	8,4	5,7
Azerbaijan	2,2	3,0	3,2	4,0	4,4	4,9	3,9	4,8	4,4	5,2	4,5
Iran	6,2	6,2	5,3	4,7	5,7	5,8	1,3	0,0	0,1	0,0	2,9
Algeria	2,5	1,9	2,5	1,6	1,2	2,6	2,9	3,9	4,2	4,2	2,8
Others	19,7	22,4	23,3	21,8	21,6	16,1	20,9	19,7	18,7	19,0	17,0

Table 1 Main origin of crude oil imports in %, EU28, 2006-2016 (1)

Another very important fact is, that the consumption of crude oil as primary energy resources is constantly decreasing since 2006, as shown below in figure 2.

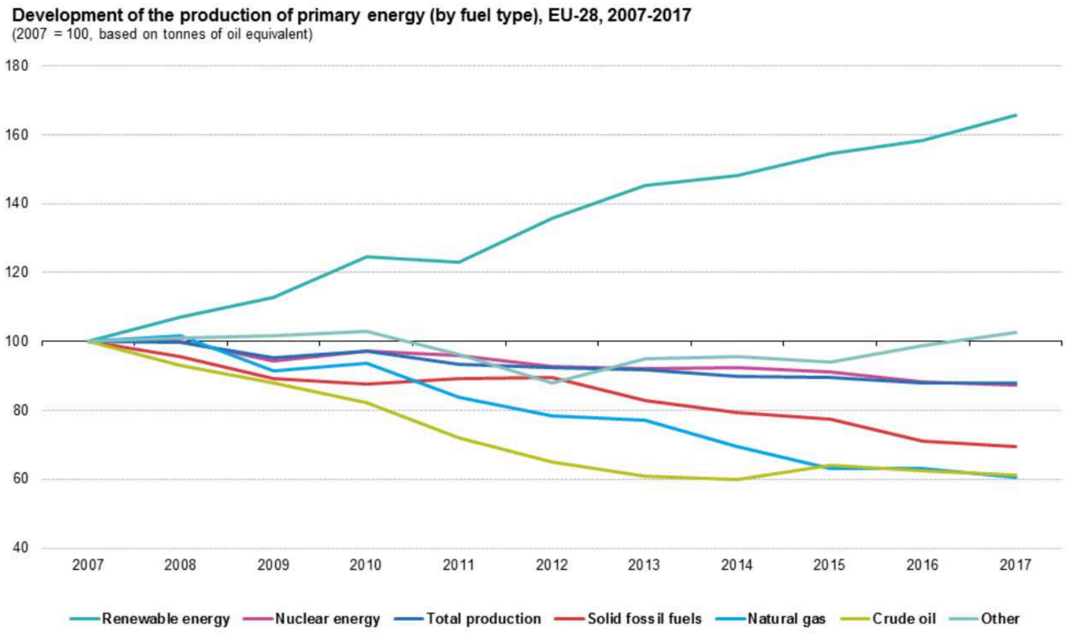


Figure 2 Development of the production of primary energy (by fuel type), EU-28, 2007-2017 (1)

These are important facts for the investigation of the thesis. The decreasing crude oil production for primary energy and increasing dependency on important countries from the European Member States can be one factor that influences the political decision makers in their daily business.

2.1.1. Primary energy consumption by end user

In 2016 according to Perdoldi et.al. [6] in the EU-28 around 33% are consumed by the transportation sector around 25% by the industry, around 25% by the residential, around 14% by Services and the rest is consumed by agriculture, forestry and others. The trend shows that the industry is since 2000 reducing their final energy consumption and the transportation sector increased their consumption since 2000 by around 3%.[2]

The tertiary sector represents around 70% of the EU-28 GDP and is responsible for approximately 14% of the total European energy consumption. In this sector the energy consumption increased very high. [3] One cause could be the economic growth and the availability of cars for nearly every person.

2.2. Fuel & oil consumption in the European Union

According to FuelsEurope Report 2019, FuelsEurope is an association from several fuel producers across the European Union, in the year 2016 around 14% of the global oil production is consumed in the EU28 countries. In figures that are around 618,52 Mtoe[1].

Another important fact is, that in Europe the demand for refined products is bigger than the supply of it. Around 762 Mtoe of refined products are needed in the European market in 2017 and only around 90% are covered by the domestic industry, that mean around 10% has to be imported from third countries. [4]

In the European Union there is a decreasing demand for oil products since 2008. The biggest loss is caused by the decreasing demand of fuel oil and gasoline, while diesel/gasoil and kerosene only decreased very slightly. According to the OECD the main output of refineries in Europe is diesel/gasoil with 39,8%, gasoline with 18,3%. For the complete information from the publication have a look at figure 3.[5]

[1] Mtoe = Million tons of oils equivalent

Source: OECD/IEA

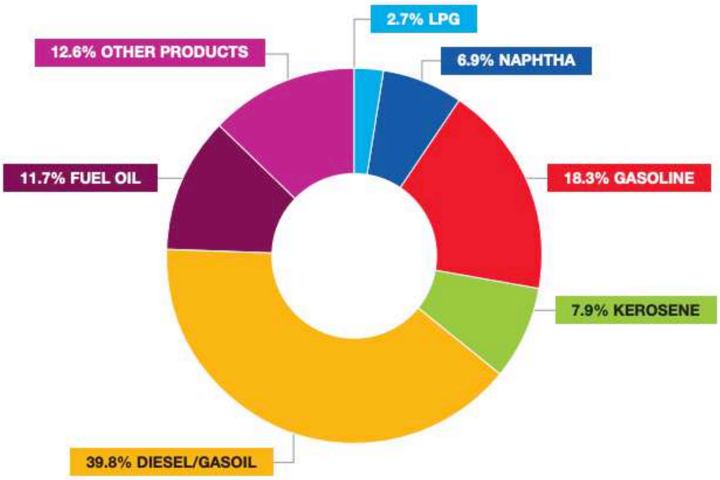


Figure 3 Refinery Outcome Europe - fuel consumption in OECD Europe (2)

In the EU the refineries producing also special products like bitumen, petroleum coke, lubricants. The tax incentives for diesel contributed in the EU to a change in the consumption behavior across the countries. The demand for fuels changed because the demand for diesel increased from 2000 to 2017 by around 1,5 % and the demand for gasoline decreased by that number. [5]

In the European Union according to Eurostat there is a significant trend for net gasoline export and an increasing demand for jet fuel. A few information about the consumption of oil and finished refined products in the EU 28 countries. Around 48% are for road transportation, 14% are for non-energy use, 9% are for aviation and only 5,6% are for the energy sector.[6]

Since the finance crisis in 2008 there is a significant decreasing trend for oil products in the EU. Since the last 8 years an average loss of 8% is the consequence. Since 2005 the global marine fuel was split up into fuel oil and by gasoil, consumption has increased. In the European Union the consumption of marine fuel decreased since 2005 by around 11% and shifted from fuel oil to gasoil. One reason is the established limits for Sulphur in regions especially in the middle sea. The emissions from exhausts reduced by over 60% because of continuously cleaner diesel fuel, advanced engines and effective emissions control technology. In figure 4 the total amount of fuels and their demand in Europe since 2008 is depicted. [7]

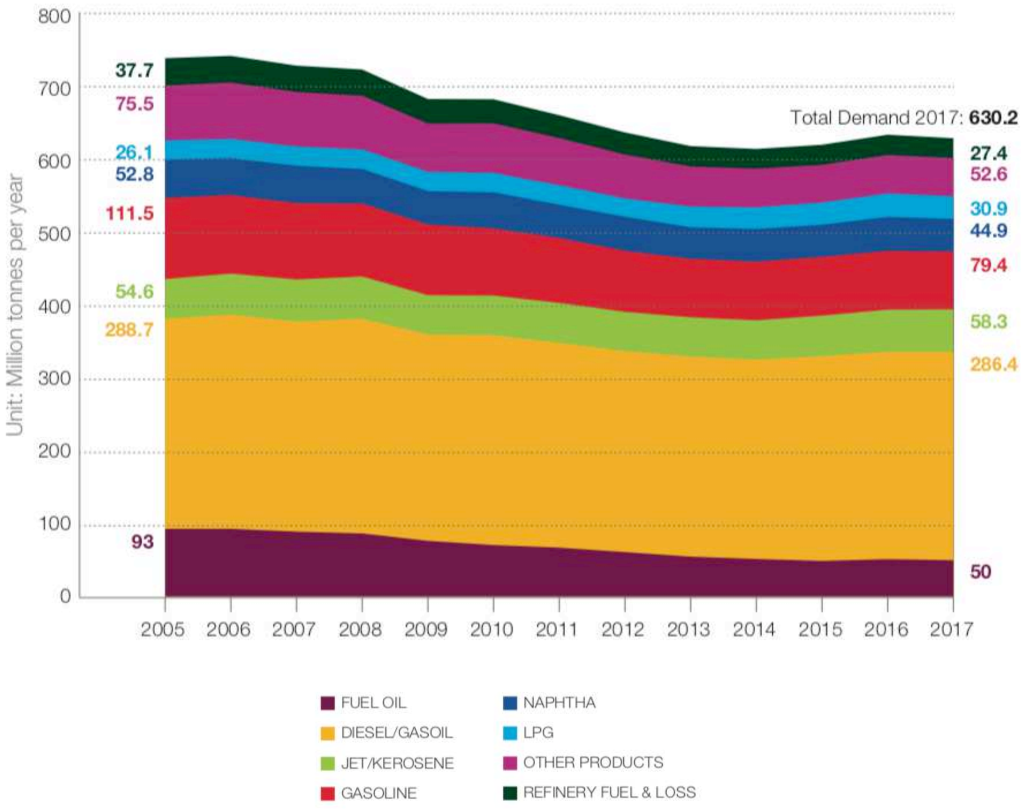


Figure 4 Demand of oil products in the Europe (3)

According to Zacharof et. al. the fuel consumption in the transport sectors is depending on several factors, there are several variations including seasonal change, regional change and policy change of the government. The fuel composition is changing during the year depending on the season because of the influence of cold temperatures on the combustion process. [8]

The overall fuel consumption is a complex topic that depends on several factors and is influenced by governments through tax incentives.

3. Origin of Petroleum

3.1. The History of petroleum and fuel

According to Maugeri [9] oil has a very long history. Already the old ancient Mesopotamia used petroleum for lighting. It was only used in places, where it was easily available through a thin surface. At that time there was no drilling method and the oil was carried by hand. It really emerged in modern history in the 1850s. In that time several scientists from USA and Europe tried to refine oil to use it as a fuel. Abraham Gesner, a Canadian scientist patented as the first one 1854 a new refined product, kerosene it should be used for illuminating or other purpose. One major step stone in history occurred in 1859, when Edwin Drake first succeeded in extracting oil with a drilling machine in an underground prison. He used a method that was already used in Azerbaijan in 1847, but he advised his workers to put a tube in the hole and drill inside of it, so that water and other loose material cannot come into it. [9]

The barrel has his origins around the 1850s, in Pennsylvania a forty-two-gallon (around 159 liters) wooden barrel were used to transport the oil, before it was mainly used in the whiskey production. In 1861 the first oil refinery was established and the first cargo was exported from USA to London. After the initial operation of the first pipeline the “Black Gold Rush” began. At the start of the exploration oil age in America the operators got soon a problem, because the rush of oil on the market pushed down the prices and many of them got bankrupt. High fluctuations in the oil price became the daily business and in the years 1860 and 1861 the oil price changed between 10cents and 10 dollars. [10]

John D. Rockefeller is one of the famous mans from the origin of oil history in America, nearly 90% of all refineries worked at a structural loss. Rockefeller observed the situation and saw that the competition and the uncertain amount of processing crude brought not enough profits. He bought 62 out of 65 refineries in Cleveland and build up a big industry that made refining profitable. The road transportation, which consist of the vast majority of tank cars and rail cars were bought by Rockefeller, because of this fact he had nearly a monopoly position in that time. [11]

In 1900 the Standard Oil Company (founded by Rockefeller) had a hard competition against the Shell Transportation and Trading Company, that has pumped a lot of money in establishing infrastructure and ships to conquer the position of Standard Oil. In that year around 430.000 barrels per day were produced (Russia 200.000bpd, USA 165.000 bpd). In 1905 USA reached twice of the Caucasian production and reached the 370.000 barrels per day border.[12]

By 1900 oil was not anymore used only for lighting. New technologies came up to use the stored energy in kerosene, gasoline or diesel for other applications like petroleum wax for pharmaceuticals, fuels for stoves and internal combustion engines. Nearly 200 products out of crude oil were recorded at that time. 1860 the first patent by a Belgian mechanic was registered. German inventors like Karl Benz, Gottlieb Daimler and Rudolf Diesel came up with new models. The first car-like vehicle was registered at 1901 by Mercedes. A few years later Henry Ford developed in the USA the Model T (1908) and founded Ford corporation in Detroit. The idea that is today still valued is the standardized production in car manufacturing, in which every car is manufactured the same way and is not a unique part. In 1927 Ford corporation already sold 15,4 million cars of the Model T, this means a lot of owners needed fuel for the driving machines. Around 50% of the world's automobile production was accounted by Ford. [13]

In 1910 gasoline sales surpassed the sales of kerosene and oil in USA. Another driver for the research in gasoline and other fuels was the military, they wanted to use the fuels in big vessels and ships. Oil had several advantages over coal and was established as a very good fuel in the world war II. Coal was harder to store than oil and also oil ships could travel more distance because of the higher energy density. There was a big political issue because of that transformation. The United Kingdom provided nearly half of the worldwide traded coal and held a monopoly position. The problem was that they had not any domestic oil reserves not in their island and in their colonies. Therefore, they founded an Oil Company (later BP) that held a very big amount of oil concessions in the Persian room. The first venture contract like the one of former BP and the Persian monarchy built up the base for the next five decades of venture oil

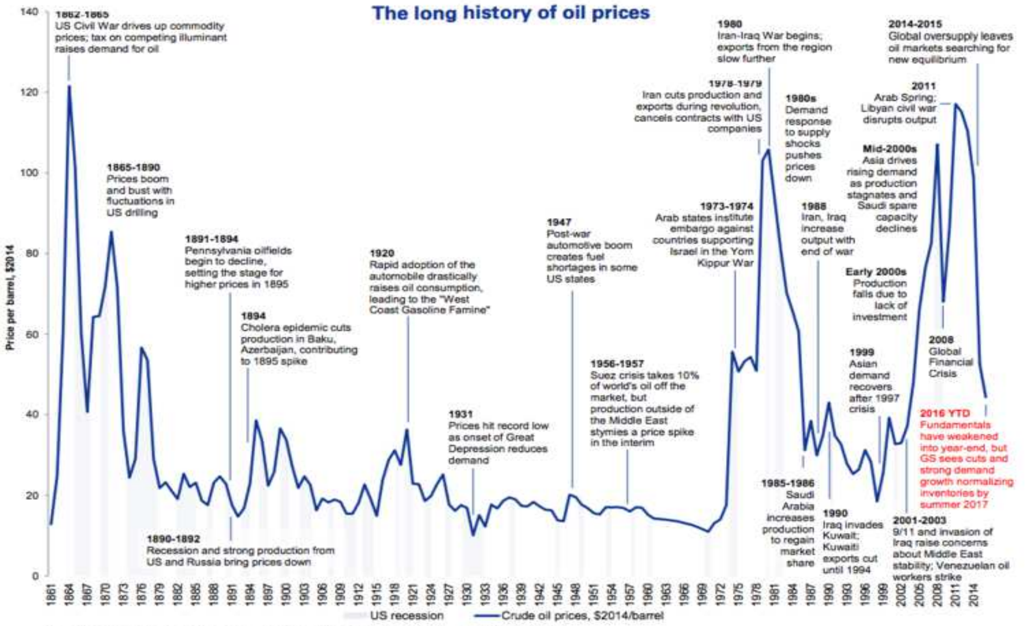
contracts. At the beginning the former BP exhausted a lot of money in establishing infrastructure a big refinery and a pipeline which brought them into financial problems and nearly bankruptcy. Winston Churchill, the former prime minister of the UK, thought that there is a link between oil and national security and successfully acquired BP in 1914. He therefore was arguing 1913 in front of the skeptical parliament:
"If we cannot get oil, we cannot get corn, we cannot get cotton and we cannot get a thousand and one commodities necessary for the preservation of the economic energies in Great Britain."[13]

In World War I and World War II Naphta, gasoline and diesel were used for moving people, armies and airplanes through the world. In the 1920's scientist shows that pressing gas into an oil reserve increases the oil outcome. In the middle of the 1920's all oil companies have become highly visibly because of the logo on their widespread network of petrol stations. In the 1930's a lot of research was done due the fact that less than 50% of a barrel crude oil could be used for finished products like kerosene, gasoline, diesel and so on. In 1935 the National Industrial Recovery Act (NIRA) was created in the US and build an architecture to control the oil production and the trade of finished oil products on the market to manage the oil price in a sufficient area. Texas Railroad Commission had a big influence on the US oil price because a lot of oil was imported from the so called "Black Giant", the biggest oil reservior in Texas. The regulatory system engaged by the government of USA build the base for the former OPEC institution. After World War II oil had an important role of modern economies as well as in military strategy but coal still supplied 80% of world's energy needs. The Cold War readied the fears for less oil supply in the countries. At that time US, Middle East and the Soviet Union were the biggest oil producers in the World. [14]

In the time between 1948 and 1973 the so called "Golden Age of Oil" was reached, at that time the oil consumption grew more than six-fold. In 1948 9,3 million barrels and in 1973 already 56 million barrels were consumed. The major part of the oil success path was the mass motorization because nearly everyone in industrialized states needed fuel. The number of vehicles grew all over the world and grew more than four-fold from 1950 to 1973. In 1960 the Organization of Petroleum Exporting Countries was established, members were Venezuela, Saudi Arabia, Iraq, Iran and Kuwait. In

1973 the first oil shock occurred and the declining of prices ended rapidly. Several factors like the OPEC resolution from Lybia and the US Nixon Doctrine and further decisions of the former US president had influence on the oil policy in the world and created a situation where the oil price reached high bounds. The oil price increased by a factor of ten in only a few months.[15]

In the 1970s the OPEC countries controlled around 55 % of the world crude production so the organization decided gain power to control the oil price. Due to the lack of influence and internal critics the organization gained not the influence it wanted to. In 1975 the organization cuts the production by 35% of total capacity. The political instable situations in the middle east caused a dramatically increase in the oil price that lead to the second oil crisis with a record fuel price of 1,42$ per gallon and 42$ per barrel oil. After the mentioned historical events several other factors like the first gulf crisis, the soviet breakdown and others occurred that influenced the oil price and the supply in the world. [16]



An earlier version of this chart appeared on pg. 16 of Top of Mind Issue #52: OPEC and Oil Opportunities.
Note: 2016 price shown is YTD average as of Dec. 19, 2016.
Source for data: BP, NBER/Federal Reserve Bank of St. Louis, Haver Analytics.
Source for annotations: ©James Hamilton, "Historical Oil Shocks," University of California, San Diego, February 2011; various news sources; Goldman Sachs Global Investment Research.

Figure 5 History of oil price (based on 2014 US Dollar); Source: Business Insider (4)

3.2. Formation of petroleum

The state-of-the-art theory about the formation of petroleum is the interaction of biological microorganisms and physical reactions. Microorganisms like algae, dinoflagellate, cyanobacteria and so on are called phytoplanktonic because of their photo synthesis. These organisms bring in the most important part of petroleum. Around 90% of the biomass in the sea is out of phytoplanktonic and the composition of these organisms provide a very good base material for petroleum. The favorite habitat is in the upper 30 meters in the sea, especially in coast closeness areas because of the presence in nutrients like nitrogen, iron and phosphorous. Dead cells decompose and fall down to the seafloor. Creatures riffle the seafloor and increase oxidation, which provides not the best circumstances for the production of petroleum. The less oxygen available, the better and faster the oil production. [17]

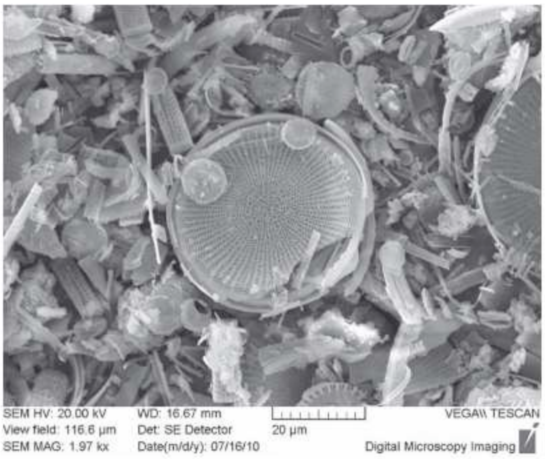


Figure 7 Figure 6 Diatomeen - phytoplanktonic microorganism; Source (5)

Figure 6 Algae in front of the south coast of UK; Source (5)

One of the best environments for the formation of petroleum is the seafloor of the black sea because of the high salt anodic water layer. Most organisms cannot life in such conditions especially because of the sulfur dioxide that is produced by a special group of bacteria. The sapropel that builds up on the ocean bed contains around 35% of organic material, that is a perfect material for black mudrock and in further consequence for petroleum. Formation of petroleum is a complex process that has good conditions in waters, which have less availability of oxygen on the ground. If there is a high consumption by organisms and less water circulation then lakes can provide such conditions too. [18]

Around two thirds of all oil reserves in the world were formatted in jurassic and cretaceous time period because of the hot greenhouse climate conditions and the chemical decomposition process on land, in which enhanced the fertilization of the sea. If the sediments are deposited on a good base material (mother rock) for petroleum depends on the biological activity and on the time in that the substances were mined. The concentration of organic substances in sediments is expressed in the TOC value (total organic carbon). A black shale can have up to 20% total organic carbon, a normal mudrock around 2% and a carbonate rock around 0,3%. When the sediments are covered the process of formation begins. In the layer living creators like Archaeen transform organic molecules into methane, water and carbon dioxide. In general, the methane is released into the environment with the exception in the Siberian area. In that area methane was stored as a big part of the natural gas deposits. In sedimentary rocks the insoluble organic matter is called kerogen. It has no specific chemical formula and during heating it converts into liquid and gaseous hydrocarbons. In science the kerogen is categorized into four groups, kerogen I to IV. The types differ by the involvement of different organisms in the formation process. [18]

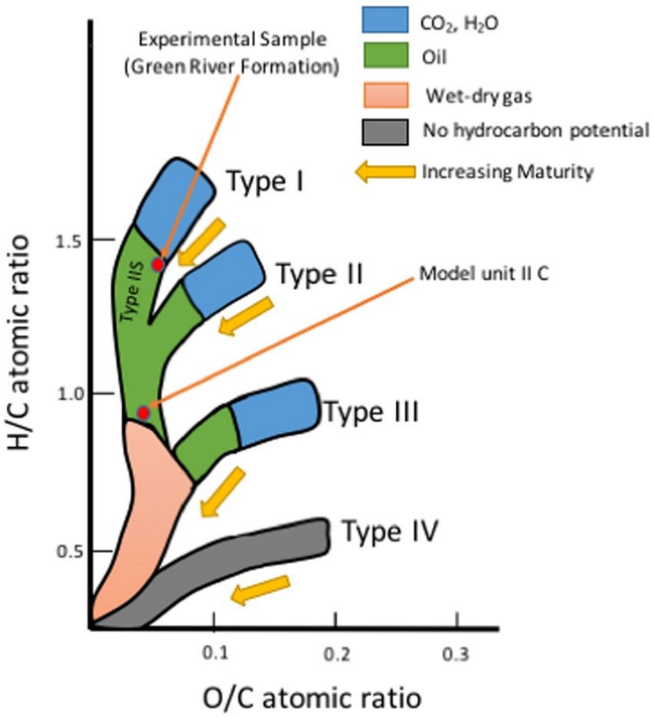


Figure 8 Van-Krevelan-diagram depicting the 4 kerogen types (6)

In figure 8 a Van-Krevelen-diagram is depicted that shows the structure of the different kerogen types.

During diagenesis process especially carbon dioxide and H_2O will be released.

Type I kerogen contains mostly oil, type 2 oil and gas, type 3 almost only gas and type 4 almost nothing of them.

In depths, Kerogen is cracked into Oil and Gas and the stone got often very compressed. A lot of the oil resources consists out of fine-grained stone, that often holds back the oil and gas in the pores. Conventual sites of fossil preservation have coarse-grained neighbor stones like sandstone. If there is no way for the oil and gas to get into coarse-grained stones it is not possible to pump up the oil. The process that the oil passed to get from fine-grained into a coarse-grained stone is called primary migration. The direction of the oil has not to go up it can also go down if the stone is there coarser. The less permeability a stone has, the heavier it is for oil, other fluids and gas to flow out of it. Mud rock and especially carbonate rock imply the oil very good in the pores. To pump out the oil from such sites of fossil preservation the companies using the fracking method. The method faces a very controversial public opinion. If the oil mother stone is a limestone rock it could be possible that the originated acids and carbonic acid has increased the permeability of the stone and made the access for the pump-up process easier, otherwise only diffusion can be a cause for the primary migration. If hydrocarbons are diffused in stones and arrived in coarse-grained one, the secondary migration starts. In that process oil floats up in the water that is saved in the rock layer. The hydrocarbons can travel several kilometers or even up to several hundred kilometers. If methane is also available in such sites of fossil preservations it depends on the pressure environment if there is a dissociation of methane and oil. In the worst-case oil flows up till the surface of the earth and is not useable anymore, in the best case the oil flows up and, on some point, there is an impermeable stone layer, normally out of salt, shale or anhydrite, which holds back the oil.[19]

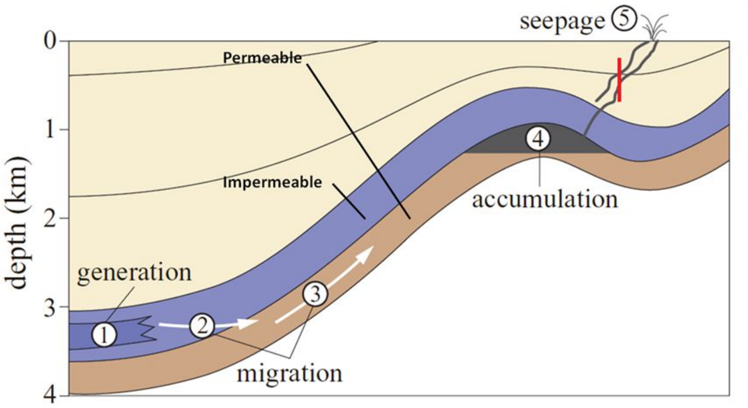


Figure 1. 1) petroleum generation in source rock. 2) primary migration. 3) secondary migration. 4) accumulation in a reservoir trap. 5) seepage of petroleum at the Earth's surface as a due to fracturing of the cap rock.

Figure 9 Primary and secondary petroleum migration process (7)

4. Exploration of petroleum

4.1. Strategy of exploration

At the beginning of the oil history, oil was stored in very high located oil reservoirs and people had the chance to easily explore it, therefore a lot of drilling derricks were located in the same place and pumped up oil from the same reservoir. This occurrence had the consequence that the pressure in these sites of fossil preservations dramatically decreased and a big part of the stored oil could not be pumped up anymore. Today the earth is explored by special sensors that creates a 3D or 4D model on the computer. Afterwards a strategy is created, that allows the companies to explore the oil storage as economical as possible. This special process has the consequence that a lot of oil reservoirs can serve more oil than ever before in history. In the last time not a lot of reservoirs were found but the factor of petroleum exploration increased. There are several strategies, like to explore by several small derricks or in the opposite direction to have only one big derrick. The location of the drilling rig, that dig into the reservoir is also one point that influences the exploration amount. It makes a difference if it is drilled perpendicularly or horizontally. At the beginning of the oil exploration time, there existed a lot of oil reservoirs that had such an overpressure that they even destroyed the drilling rig. A lot of reservoirs had enough pressure that oil flow out by itself from the site of fossil preservation. [19]

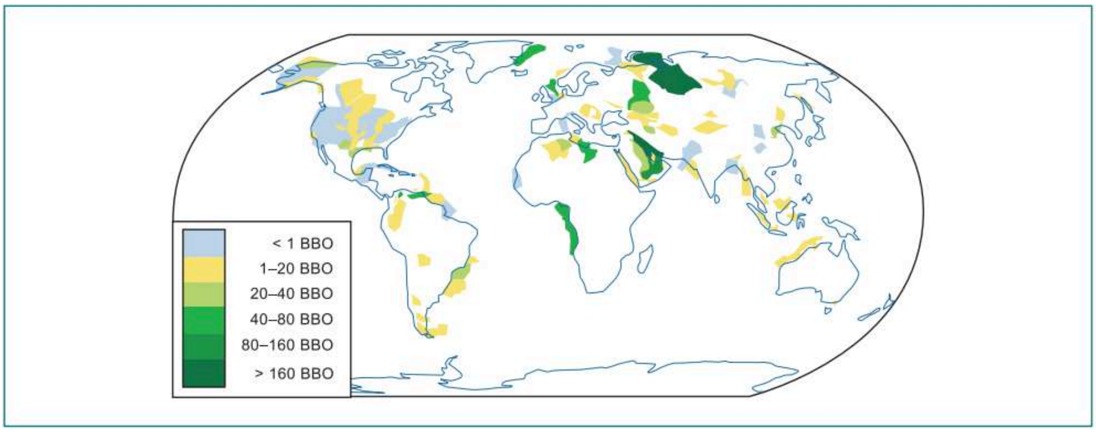


Figure 10 Conventional oil reservoirs according to USGS World Petroleum Assessment; Source (8)
BBO = Billion barrels of oil

4.2. Conventional Exploration

In conventional petroleum explorations the rotary-drilling-process is used. A rotating rig is used that is extended by pipes. A special drilling fluid is used to bring out the particles that come inside the drilling hole. The pipes are driven by a motor that is pending on the top, also named “top drive”. At the bottom of the drilling pipes there is the so called “drilling bit”, that squelch the rocks below. In the pipes the drilling fluid is injected and the fluid is pressed up with the mud. The upcoming water mud mixture is cleaned and used again as drilling fluid. Another special task of it, is that it prevents the oil from an uncontrollable outcome (“Blowout”). The flushing has therefore been always adapted to the correct density. This special fluid is used to cool down the drilling head and decrease the friction of rocks on the pipes. Several different “drilling bits” exists, everyone has a special characteristic and is used in different mother stones. In conventional oil exploration, the drilling hole is at the top around one meter wide and at the bottom around one decimeter, in special explorations even smaller. The drilling hole is lined with casing tubes, that prevents the hole from dismantling rocks. In former times the drilling direction, was often a problem because the drilling bit was directed into another direction by very hard stones. In modern drilling bits there is a high-tech electronic unit in it with that the direction can be controlled from a control unit. It is possible to direct the drilling bit in the desired direction. The new bits are equipped with a lot of sensors, that measures exactly the direction, important environment parameters, and also geophysical parameters that play an important role in the development of an oil field. The data transfer is done via a pulsed signal in the drilling fluid or with cables, but to inject a cable in the drilling bit is more complicated. A special term is used for such high-tech drilling bits, it is called MWD – measurement while drilling, this method allows the drilling crew to bypass complicated rock layers, that can have influence on exploration process. [20]

The drilling process has been always adapted to technological innovations. At the beginning of oil explorations humans were advised by oil leakage at the earth surface, in nowadays high-tech sensors allow companies to build up 4D models of the oil and gas reservoir.

In figure 11 a on-shore drilling rig (derrick) with all required equipment is depicted, and in figure 12 a conventional off-shore drilling rig is depicted.

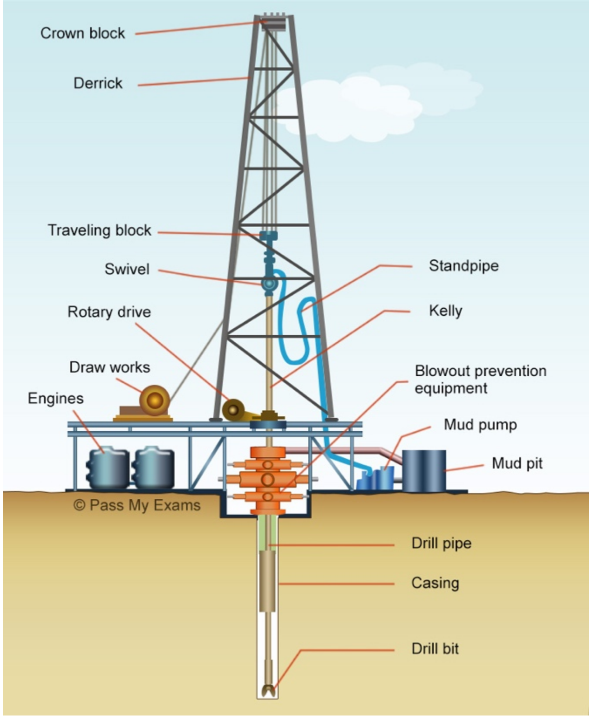


Figure 11 On-shore drilling rig; Source (9)

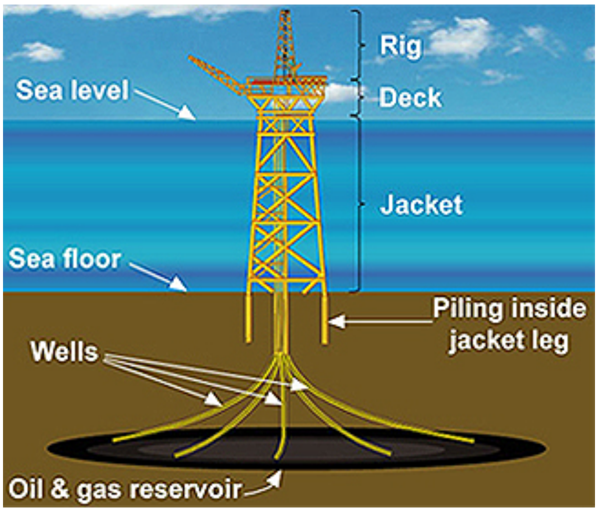


Figure 12 Off-Shore drilling rig; Source (10)

4.3. Unconventional Exploration

In modern oil exploration, there is a shift to unconventional hydrocarbon exploration. The methods of exploration are changing from single layered reservoirs, to multiple layers and from on-shore to off shore exploration. According to Caineng Zou et. al. [21] there is also a trend into unconventional exploration of hydrocarbons, that denotes a process in which oil and gas is produced out of non-conventional processes, like tight oil, shale oil, bacterial gas / oil, gas hydration and so on.

In figure 13 the difference between unconventional and conventional oil and gas stores is depicted.

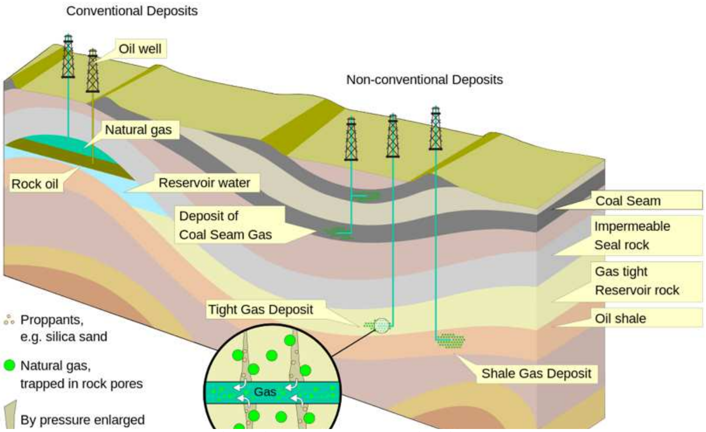


Figure 13 Conventional and unconventional oil reservoirs; Source (11)

Unconventional gas and oil reservoirs have a widespread continuous distribution. An unconventional oil reservoir has according to Caineng Zou et al. [22] several characteristics:

- The trap like in conventional oil reservoirs is not existing or there is no clear definition for it, because it was continuously distributed in the stone layers.
- There are no uniform liquid fluid contacts or pressure systems.

Pore throats with a diameter of 100 to 500 nanometer dominates in such unconventional oil and gas deposits. Conventional exploration technologies and methods cannot be applied for unconventional exploration. [22]

In unconventional exploration holes are drilled in stone layers in that oil and gas is stored in fine-grained pores. Under high pressure a fluid (“fracfluid”) is injected into a geological stone layer that breaks up the pores in the stones. In the reservoir several horizontal holes are drilled that opens up a broad oil or gas horizon in the reservoir. The pressure is decreased and the water mixture flows back to the injected hole but the used additive mixture consists out of several components like sand and chemicals that opens up the pores in the stones. The oil and gas are getting out of the pores and is pumped up with the water. The components of the injected additives are very controversial discussed because companies do not publish the mixture of it. The problem with this chemical can be the pollution of drinkable water, that has dramatically influence on the public. The “flowback”, the part of the fracfluid that is pumped up is stored and has to be afterwards disposed and cleaned, in the USA the water is often disposed in open lakes, that is not allowed in Europe. [23]

Fracking gas and oil have a big impact on the economic in countries, a good example is USA. The country is one of the biggest exporters of natural liquid gas that is produced out of unconventional exploration. Europe and Japan are big consumers of that unconventional gas, because of the supply and demand equation. On the one hand fracking gas has a better CO2 balance than coal and oil, but this cheap natural resource prevents the economy from scientific exploration of natural CO2 neutral resources, like photovoltaic and so on.

5. Composition of Crude oil

The composition of crude oil is very important for the manufacturing process. Refineries have to adjust their plants and the outcome products are depending on the oil sort and the quality of the different parameters. Every oil region has several special properties, like there are oil sorts with a big outcome of gasoline and sorts with a big outcome of asphaltene. The oil composition has influence on the oil price, like Brent oil is traded differently than WTI oil (Western Texas Intermediate).

5.1. Crude oil trading

Crude oil is traded on the stock market like other commodities. In general, oil is like mentioned above differentiated into two big groups Brent and WTI. Brent Crude is a mixture of several crude oils like Brent, Forties, Osberg and Ekofisk, they are together named BFOE. In general, they are lifted in Europe, especially in the North Sea. WTI is lifted in the USA, especially in Louisiana, North Dakota and Texas. [24]

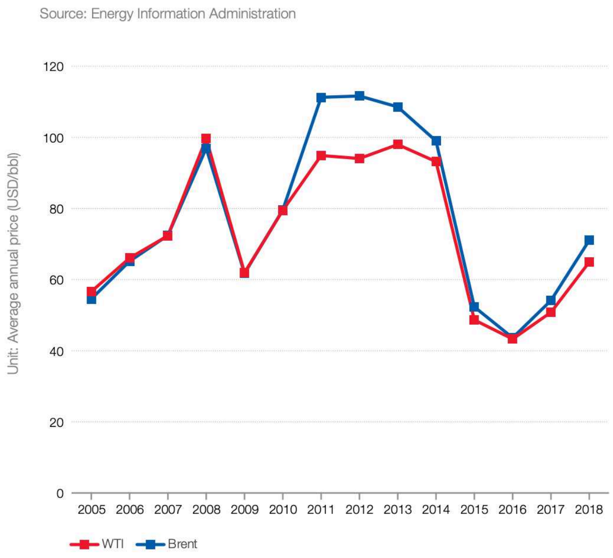

Source: Energy Information Administration

Figure 14 Brent vs. WTI Crude Oil price; Source (12)

A special lifting process made it possible to gain oil out of shale, that made it possible to gain enormous amounts of oil in the US. The biggest influence on the price has the production and demand level in the market.

World's leading oil producers are situated in the middle east, a region that is often influenced and shocked by political tensions and violations. A lot of countries rely on crude oil to balance their fiscal budget. The OPEC organization (Organization of petroleum exporting countries) consists of nations that rely on that commodity. The member states produce around 40% from the total lifted crude oil and have around 1/3 of oil reserves in the world. The middle east situation influences the Brent price, because a lot of oil is exported into Europe. The WTI price is mostly influenced by the lifting rate and the reserve rate in the US. Another important aspect is the composition between the two oil sorts. WTI has a Sulphur content of around 0,24% and Brent of around 0,37%, the lower the sulfur content, the easier to refine. Another difference is the API gravity, this stands for American Petroleum Institute gravity. If a liquid has less than 10 on the API scale than sinks down in water, if it is higher it floats on water. The API term has no scale but is measured in degrees using a hydrometer instrument. In general, a big part of petroleum liquids will be categorized between 10 and 70. There are several classes: Light crude oil, medium crude oil, heavy crude oil and extra heavy crude oil. [24]

In figure 15 there is a comparison of different crude oil sorts in relation to sulfur content and API gravity. The sourer (higher sulfur content) and the heavier the oil is the cheaper and the lighter and sweeter it is the more expensive, this stands in relation to refining costs.

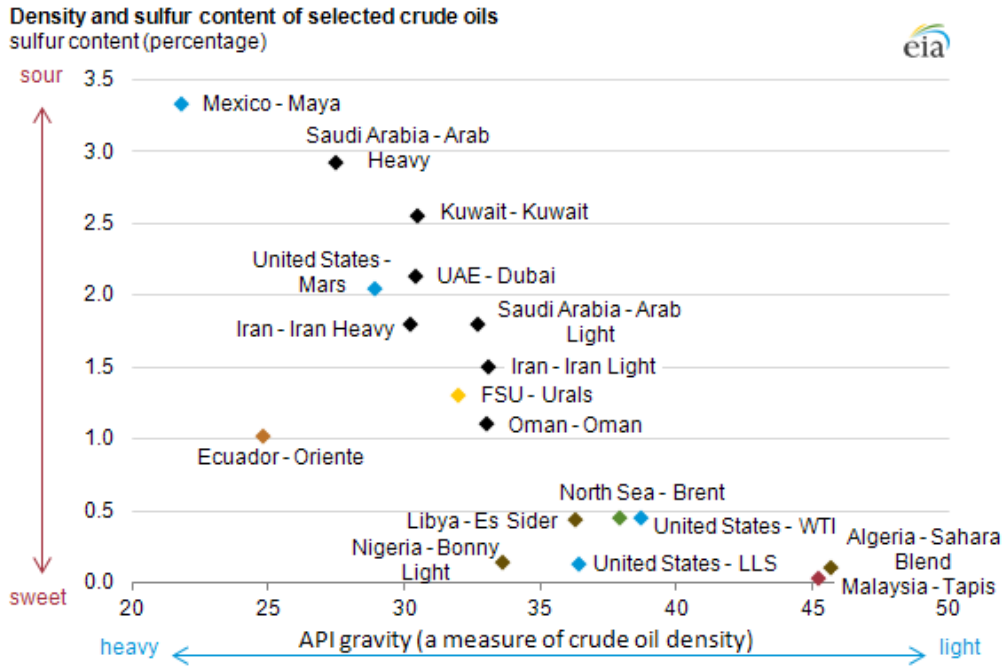


Figure 15 Density and sulfur content of crude oils (13)

Summary of WTI vs. Brent Trading

	WTI	Brent
Location of Extraction	North America	North Sea
Geopolitical	Not as sensitive to geopolitics	Sensitive to geopolitics
Content/composition of the oil	0.24% Sulfur and 39.6 API	0.37% Sulfur and 38 API
Where are the oils traded	NYMEX	ICE
Difference in price and benchmark	Trades at a discount to Brent	Trades at a premium to WTI

Table 2 Summary of Brent vs. WTI Source (12)

5.2. Chemical compounds in crude oil

Petroleum consist out of a mixture between different molecules like carbon. In general, it consists out of 85% carbon, 13% hydrogen, 1,5% sulfur and 0,5% oxygen. Major part of crude oil are single bond carbons, and aromatic carbon bonds. Unsaturated carbon bonds are not existing in crude oil because they are highly reactive and decompose in a normal crude oil environment. Alkanes, cycloalkane (naphthenes), aromatics are the major groups of chemical connection groups in crude oil. Alkanes are saturated carbons and are in lower connection bonds gaseous (methane, ethane, octane, …) and in connection bonds starting from five bonds, they are liquid (pentane, hexane, heptane, …). Cycloalkanes are called naphtenes in the petrochemical industry.[25]

Crude oil is a fluorescent, viscose fluid with an intense smelling. The chemical composition is varying from the sort of crude oil. Like Pennsylvanian Petroleum contains mainly alkanes, crude from Romania contains mainly cycloalkanes and crude from Indonesia contains up to 40% of aromatic hydrocarbons. [26]

5.2.1. Alkanes

Alkanes often called paraffin, are single carbon bonds. Two major groups of alkanes exist, branchless alkanes and branched alkanes. In chemistry there is a systematic way of naming the different alkanes. Important representatives of this groups are methane, ethane, propane and butane. Alkanes have the possibility to exist in several ways, in a normal bond and in an isomerization bond. There is a difference in the chemical behavior and in the structure but they have the same sum formula. In Alkanes the C-H bond and also the C-C bond are nonpolar, therefore no dipoles are existing, which causes their bond connections in fluids or crystals only by dispersions force. The increase of the dispersions force increases the melting and boiling temperature. The first four alkanes (methane, ethane, propane, butane) are gaseous at room temperature, till n-Hexadecane (C_{16} H_{34}) liquid and all others are solid. The density of alkanes is increasing by the length of chemical compounds until a certain maximum value is reached. Methane, the first alkane representative, is beside ethane, propane, and butane the major part of natural gas (average compound: 86,3% methane, 9,6% ethane, 3% propane and 1,1% butane). In oil n-alkanes are the major part of alkanes in it. It is a complex compound. The alkane molecules are non-polar and therefore have no site of attack for charge carrier. Alkanes are therefore declared as slow responding or poorly reacting molecules in the context of ionic mechanism, because it is base material for a lot of petrochemical substances. [27]

5.2.2. Cycloalkanes / Naphtenes

Cycloalkanes or Naphtenes are saturated monocyclic carbons and are important constitution part of crude oil. Cycloalkanes and all derivations of it like cycloalkenes and cycloalkines are pooled in term alicyclic compounds. The term “naphtenes” is often used in relation to petrochemistry, therefore in the thesis the author will name them also naphtenes. There are several combinations and bonds of carbons and hydrogen in that elements. The type of bonds is decisive for the name of the chemical molecules. The most important representatives of this groups are cyclopropane, cyclobutene, cyclopentane, and cyclohexane. The physical behavior of naphtenes is very similar to the behavior of alkanes. They are hydrophobic, they do not mix up with water and they only dissolve unipolar and weak polar substances. The melting and boiling temperature is a bit higher than the ones of alkanes with similar C-atoms. Naphtenes react also very similar like alkanes. Cyclopentan, Cyclohexan and cyclorings with higher carbons are very stable, everything below is reacting easier. [28]

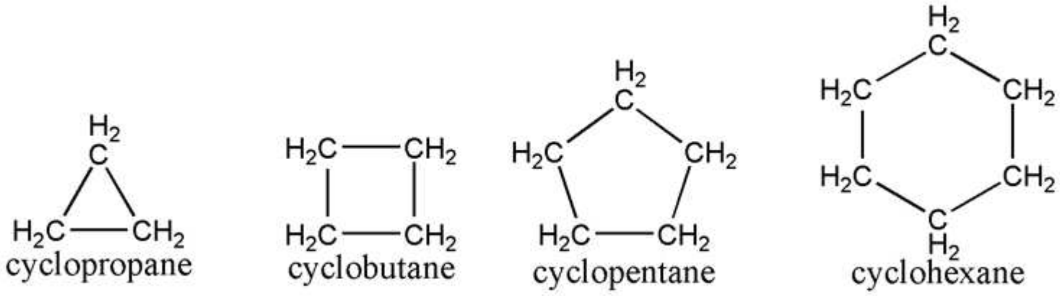


Figure 16 Chemical representation of naphtenes; Source (14)

5.2.3. Aromatics

Aromatic compounds are bonds that have a π-electron around the complete cyclic system. The name aromatics comes from the special smelling of the chemical compounds, but they do not let them classify through smelling because of higher molar mass or polar substitution there is no smelling noticeable. Aromatics have always a cyclic double bond. The most famous representative of this group is benzol. Several benzol derivations are from special interest in the chemical and colour production process. [29]

5.2.4. Asphaltenes, waxes and resins

Asphaltenes, waxes and resins are big molecules in aromatic rings or alkane chains. They often contain sulfur, nitrogen or oxygen ("NSO-bonds") or other metals like nickel or vanadium. There are also molecules that are very similar to chlorophyll in different amounts in petroleum. [30]

Asphaltenes are the most mysterious component in crude oils. There is a special concern to attempting the characterization of this chemistry in crude oils. A scientific expert in the field of asphaltenes is Professor Teh Fu Yen, he studied this type of chemical compounds in detail. The various types of structures and the hierarchical structure of asphaltenes have been termed by the Yen model. [31]

5.3. Measurement qualities of crude oil sorts

Santos et. al. investigated crude oils with different API (American Petroleum Institute) gravities on a molecular level and classified crudes in different categories by several properties. The output of that scientific work is one part of that chapter. Hydrocarbons, with and without heteroatoms, like nitrogen, oxygen and sulfur are the major compounds in crude oils. The polarity, volatility, specific gravity, viscosity and the molecular weight are varying from sort to sort. The highly complex chemical composition is crucial for the refining process and has to be investigated before. [32]

General acknowledged parameters of crude oils are boiling-point distribution, American Petroleum Institute (API) gravity, viscosity and density. [33]

The API gravity is mainly the most important property of a crude oil, because it is giving a great overview of the oil and determining the market price of the natural resource. For the further process a lot more research about the crude oil has to be done, the API gravity measurement is only a preliminary measurement. Analyzations with gas chromatography/mass spectrometry (GC/MS), gas chromatography-flame ionization detector (GC-FID), comprehensive two-dimensional gas, chromatography (GC × GC), infrared spectroscopy (IR), ultraviolet spectroscopy (UV), and thermogravimetry (TG) are state-of-the-art and give an overview of the complex composition and their derivatives. [34,35]

In the last years, a new device is used to characterize crudes and their derivatives, this is especially important because scientists see a correlation between crude composition and chemical composition of fossil fuels. The success is attributable to ultrahigh resolutions and accuracies in mass spectrometry's. There are several special measurement processes that are now possible with that high accuracies like Fourier transform mass spectrometry and ion cyclotron resonance. [32]

Another important fact that Santos et. al. studied is that one crude sort can varying in different layers. In their article they described a case that three samples from one crude oil source was taken, and that every sample had a different API gravity and therefore also different densities and other features. [32]

5.4. Crude oil sorts and their properties

In this chapter the author demonstrates the different properties of the crude oil sorts. As an example, a few crude oils that are processed in a local refinery are explained and further investigated. In table 3 below, several crude oil types and their properties are depicted.

Sort	Origin	Density at 15°C [g/cm³]	Pour Point [°C]	Viscosity at 10°C [mm²/s]	Sulfur [% mass]	Carbons [% mass]	Hydrogen [% mass]
OMV A	AUT	0,917	- 50	175	0,2	83	13,5
OMV P	AUT	0,876	+ 15	30	0,2	85,9	16
Sahara Blend	Algeria	0,804	- 40	4	0,3	85,3	14,5
Brent	GB	0,834	0	7	0,3	86,4	14,9
Brega	Libia	0,816	+ 2	9	0,4	84,5	15,2

Table 3 Several Crude oil sorts and their properties; Source (15)

The crude oil composition is for several purposes important:

- the price is defined by the quality criterias
- the refining output products are directly correlating (shown in figure 18)
- the purchase of different sorts defines the processing parameters, because the oils have to be treated different
- the supply is depending on the political stability, that is different for the sorts

In literature crude oil is often divided by their API gravity into several groups:

10 > API	extra heavy crude oils
10 < API < 20	heavy crude oils
20 < API < 25	medium crude oils
API > 25	light crude oils

Crude Oil Sort	Saturates (%)	Aromatics (%)	Resins (%)	Asphaltenes (%)
Light Crude	92	8	1	0
Medium Crude	78	15	6	1
Heavy Crude	38	29	20	13

Table 4 Crude oil sorts and composition; Source (16)

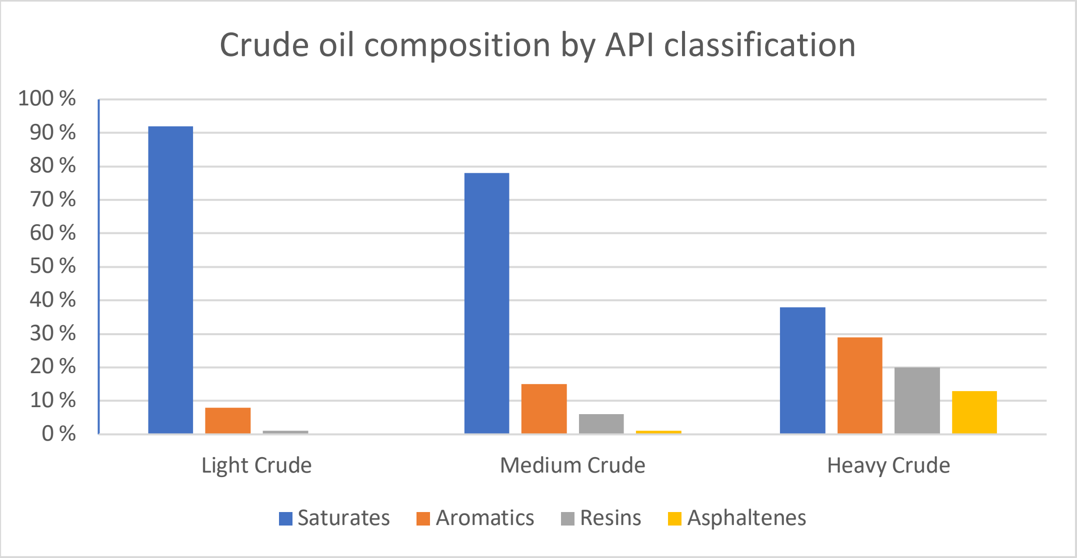


Figure 17 Data source for the diagram from table 4; Source (16)

Another approach to categorize crude oils by their properties is done by EPA (US Environmental Protection Agency):

- ***Class A:***
  These light oils can penetrate porous surfaces and are clear or almost clear. They have a strong odor and flammability. Since they are thin and highly fluid, they mix well with other liquids. Most high-quality light crude oils and refined petroleum products fit into this class.
- ***Class B:***
  These non-sticky oils are thicker than those in Class A and have a waxy feel. They adhere better to porous surfaces when in warm temperatures. Paraffin based oils fall into this category.
- ***Class C:***
  With density near that of water, these oils do not usually penetrate porous surfaces, but they do sink in water. They are sticky, similar to tar, and usually black or brown. Medium and heavy crude oils including residual fuel oils fit into this class.
- ***Class D:***
  These oils are not fluid, so they do not penetrate porous surfaces and do not flow freely. They can become more fluid when heated and are usually made up of heavy crude oils or those with high paraffin content.

Source: United States Environmental Protection Agency (17)

Crude oil is used for different purposes, a lot of end-products are created out of it and therefore a widespread concern is the classification for crude oils by contents of end-products. Like outlined in the previous chapters (4.2, 6.1, 6.2) every sort has different chemical compositions and these compositions are used for different output products.

In figure 18 the composition of crude oil sorted by region and their concentration of semi-end-products are depicted. The classification is done by semi-end-products because out of middle distillates and nearly all categories there can be created a lot more end-products like out of middle distillates, diesel or heating oil etc. There is a correlation between the residue concentration and the crude oil price.

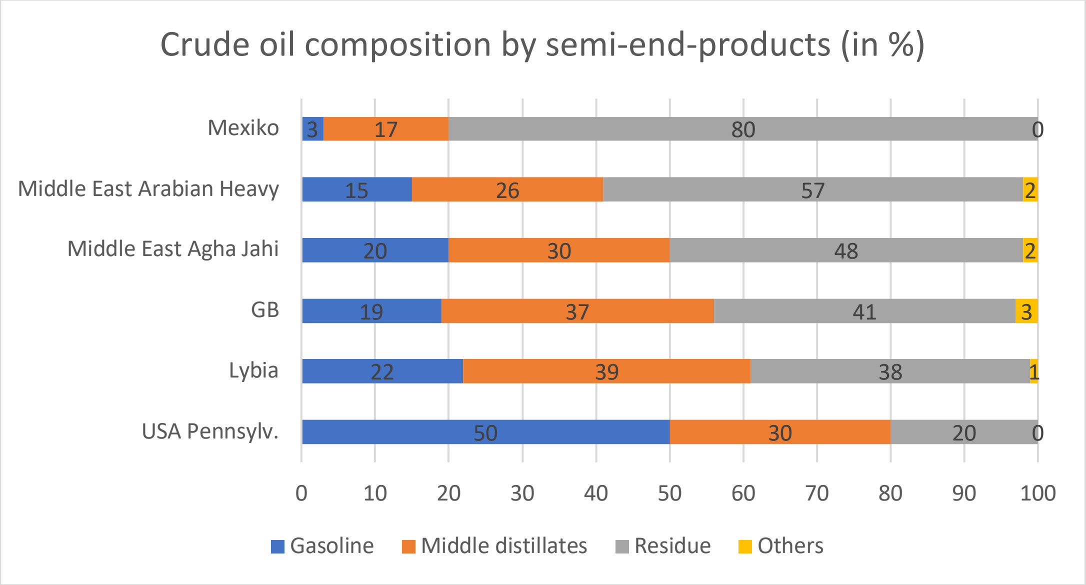


Figure 18 Crude oil composition by semi-end-products; Source (18)

The total composition of crude oil is always summarized in crude oil assays. The assays show different selected chemical and physical properties of distilled fractions or the whole crude oil. In Appendix A such a crude oil assay attached. In petrochemical processing the end-products are often classified by their boiling point or boiling point ranges. Crude Oil traders and planners select different crude oils sorts by their composition and their properties of the refining plants. Traders can also buy off-spec crudes for subsequent trading's. Off-Spec is meant that the crude oil is not in their target range, but can be mixed up with normal crude oil purchases and they are still in specifications. The classification into sour and sweet crude oil is historically shaped because in old days the crude oil was tasted and the sulfur concentration had a big influence on the tasting. The refiner can adjust the range of end-products by adjusting the cutpoints. There is a distillation overlap for naphta, kerosene and gasoil. The swing cut from 150°C to 205°C can be blended into all of these products, depending on the demand for them. [36]

6. Petrochemical Fuels

In this chapter the author gives an overview of available conventional petrochemical fuels and how they are defined.

Modern fuels are a mixture of several compound products of a refinery. Every compound has special properties, these are needed to meet the specification requirements. Every compound has a special boiling range and carbon number. Several Associations publish standards for petrochemical fuels, in Example the ASTM International for America, the Japanese Industrial Standards (JIT) for Japan and the European Union (EU) for Europe. [37]

Today the emissions of carbons and other elements are discussed in political areas because of public interest. The earth heating and other natural occurrences are the causes for more public attention in this way. Therefore, the committees, who are creating the fuel specifications decreases the quantity of harmful or compounds that effect the earth heating. As example the minimization of sulfur, benzene, aromatics and olefin content in fuels can be named. In the European Area the Euro 1-5 gasoline specifications increases the clean fuel quality in every update, like in Euro 1 gasoline 1000ppm sulfur was admissible and in Euro 5 gasoline only 10ppm sulfur was permitted. In Appendix A there is an overview of the different specifications for the updates of the Euro Norm. [38]

In the European Union the fuels are specified in European Norms that are created by the European Committee for Standardization (CEN). In this committee the twenty-seven member states, states that are likely to join the EU and three countries from the European Free Trade Association (EFTA) are represented, this means that the whole European continent is covered.

<u>Overview of fuels and associated norms:</u>

- Gasoline – EN 228 (ATSM D4814)
- Diesel – EN 590 (ATSM D975)
- Jet Fuel - ATSM D1655 (Jet A1 – DEF STAN 91-91)
- Kerosene - ATSM D3699
- Fuel oils - DIN 51603-1 – AUT - ÖNorm C1109 (ATSM D396)

6.1. Automotive Fuels

Since the development of modern cars in 1886, the demand for gasoline as fuel has dramatically increased. In these days the demand for gasoline or generally spoken for transportation fuels (gasoline and diesel) is increasing throughout the world. Traditional markets such as North America or Europe have only a moderate growth rate but emerging markets like Asia or India have a high growth in fuel consumption. [39]

6.1.1. Gasoline

Gasoline is also called petrol (GB), benzin (Europe) or gas (US and Canada). It is a mixture of volatile, flammable liquid hydrocarbons derived from crude oil and is used for combustion engines. In history it was only a by-product, kerosene was the principal product. The ability of being mixed for combustion already in a carburetor made it that famous. Gasoline is a mixture of hydrocarbons below a boiling point of 180°C or at most 200°C. The hydrocarbon structure in that boiling range have four to 12 carbon atoms. The major three general types are: paraffins (incl. branched products), olefins and aromatics. Automotive gasoline contains on an average, depending on crude oil sort, refinery process and product specification, around 4-8% alkanes, 2-5% alkenes, 25-40% iso-alkanes, 3-7% cycloalkanes, 1-4% cycloalkenes and around 20-50% aromatics. [39]

It is not manufactured to achieve a specific distribution of hydrocarbons. It is produced out of several compounds to meet specifications and regulations. In history the “original” gasoline (naphtha) that is present in crude oil is not used anymore in that way. It was discovered that heavier portions of petroleum (that boil even higher than kerosene) would fit perfect to gasoline. At the beginning of the “gasoline” era, there was a storage problem, because gasoline was very instable. The demand for gasoline grew and the industry responded with a solution for the storage problem. With new technologies like thermal and catalytic reforming, catalytic cracking, hydrocracking and polymerization the storage problem was resolved. Gasoline can vary greatly even if the octane number is the same. The constitution of the single chemical compounds has influence on the ignition behavior and on the environmental emission. [39]

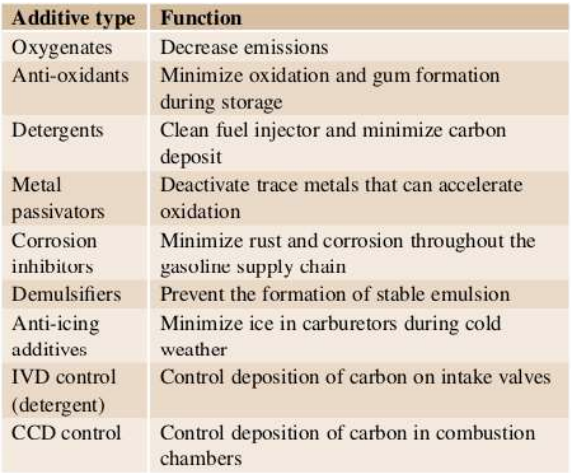
Wittcoff (1987) and Absi-Halabi (1997) et.al. have successfully proven that reformulated gasoline can help reducing the lead content of environmental emission through automotive. As mentioned on the previous page (7.1.1 Gasoline) the octane number is a comparative value that is always prescribed in standards for gasoline (i.e. EN228, ATSM D4814).

In a gasoline ignition-engine, there are some compounds, which already ignite before the piston reaches the top end. This difference causes a so called "knocking" that reduces the power of the motor and increases abrasion on the engine, in special cases it can even cause a total loss of the engine. The octane number is a scale that starts at zero (n-heptane as reference value) and has another reference value at 100 (isooctane). Fuels are normally tested (prescribed by norms) for a research octane number (ROZ) and a motor octane number (MOZ). The ROZ simulates a low speed or city driving load condition and the MOZ a high-speed highway driving load condition. At the beginning of gasoline production, the knocking behavior was not the problem, because if there was a higher demand for power, another piston or cylinder was added to the motor, but there were limits. Some engines even had 16 cylinders. If there was not the possibility to add cylinders then the compression rate has to be increased and that is only possible through a reliable anti-knocking fuel. In the early stage of gasoline development, it seemed unlikely that some gasoline knocked more than others. Therefore, a suitable testing procedure was established that is still the relevant measurement type. The knocking properties are measured by a single cylinder engine under defined conditions. Tetraethyl was the first antiknock component that was discovered. If a small amount was added to the gasoline the antiknock characteristic increased. In nowadays a lot more antiknock components like MTBE (methyl-tertiary-butyl ether), ETBE (ethyl-tertiary-butyl ether) are known. Another very important measure is the RVP – Reid vapor pressure, that represents the vapor pressure of an automobile gasoline at 100°F in a four times liquid volume. It represents the vapor-lock tendency and the start-ignition behavior. The Reid vapor pressure changes over the season because in the summer, when the outside temperature can be high. The RVP therefore has to be low to avoid an overpressure in gasoline tanks that could cause a vapor lock during ignition and to limit emissions. The specification varies from country and climate conditions and switch-over periods exists. [39, 40]

In the modern refinery process, no single stream meets all the gasoline requirements specified, therefore there is always a gasoline blending plant that is mixing up the various streams into a finished product. It is not uncommon that a finished gasoline is made out of six or more streams. A typical summer gasoline, before oxygenate blending, might contain around 40% FCC gasoline, 25% SR-naphta, 15% alkylate, 18% reformate and 0-2% butanes and 0-2% others. This is only an example and can very strongly, depending on the starting product. (crude oil sort, refining process, …) [39,40]

Automotive gasoline needs a few more properties that are not contained in normal petrochemical fuel blending's, thus small amounts of additives are mixed into the gasoline blending. The gasoline-soluble chemical should enhance certain performance characteristics. Typical additive properties are corrosion inhibitors, antioxidants, demulsifiers, anti-icing additives and more. Additives alternate in season, region and retailer.

In general, the desired effect is reached by adding only a few part-per-million (ppm) to the gasoline fuel. Antioxidants are aromatic amines or hindered phenols that prevent gasoline components from reacting with the oxygen in the environment or from peroxides or gums. Gums can plug fuel filters and deposit gums on the engine components. Peroxides can reduce the antiknock-behavior and can wear plastic parts, fuel pumps and other important components for the combustion process. Corrosion inhibitors (carboxylic acids and carboxylats) are used for protecting refinery pipelines, tanks and other metal parts from rusting or corroding. For combustion process they are irrelevant because parts in cars are made mainly out of plastic and rusting free metal. Demulsifiers are used by enforcing the formation of a stable emulsion because of the water-seperating characterstics. Alcohol, glycols and other chemicals are used to prevent the gasoline from freezing in the engine system. [39,40]



Additive type	Function
Oxygenates	Decrease emissions
Anti-oxidants	Minimize oxidation and gum formation during storage
Detergents	Clean fuel injector and minimize carbon deposit
Metal passivators	Deactivate trace metals that can accelerate oxidation
Corrosion inhibitors	Minimize rust and corrosion throughout the gasoline supply chain
Demulsifiers	Prevent the formation of stable emulsion
Anti-icing additives	Minimize ice in carburetors during cold weather
IVD control (detergent)	Control deposition of carbon on intake valves
CCD control	Control deposition of carbon in combustion chambers

Figure 19 Gasoline additives and their functions; Source (19)

In several countries all over the world there are regulations that prescribe the addition of bio components in gasoline. The advantage of the mixture with biocomponents, that are renewable resources, is the saving of petroleum, which is a finite resource. In General, the oil industry uses ethanol (ethyl alcohol or grain alcohol), ETBE, MTBE or TAME (Tertiary-amyl methyl ether) to fulfill the criteria in the case of gasoline.

According to the European Standard EN228 a quota of 5% ethanol can be mixed into gasoline. In Europe especially in the German area, notations like E5, E10 and E15 are common. The "E" symbolizes that ethanol is added to gasoline and the number denotes the volume percent of it. This means E5, that is actually valid according EN228 in conventional gasoline, means that five percent of the blend are ethanol. In the US a gasoline-alcohol mixture is names gasohol and common mixtures are E10 and E85.

The ethanol amount in gasoline has several effects that influences the components of a vehicle. At first it wears all plastic components, because alcohol solves several synthetic materials. Another issue is the different octane number, commercial gasoline has in Europe 95 octanes and alcohol has 102. The fuel value is also different, gasoline has around 32,5 MJ/L and ethanol 22,7 MJ/L, but this can be compensated through the correction control of a lambda probe.

The automotive industry developed especially for that problems a universal engine that allows the owner to drive with different ethanol blends. The term "Flexible fuel vehicle" (FFV) is commonly used for it and they work with gasoline from 0 to 85% ethanol. These cars are very common in brasil and in Sweden. In brasil nearly all fulling stations offer pure ethanol and gasoline with an ethanol blend of 20-25%.

Austria has increased the bio-component amount and therefore a stricter regulation than the European Union. In Austria the bio-component amount in gasoline has to be 5,75%. The legislative basis for that is the EU directive RL2009/28/EG, in which renewable energies have to have an absolute amount of 20% EU wide (34% Austria) and 10% of energy needed in the transportation sector has to come from renewable energy resources like bio-gasoline, electric cars, … [41]

The long-term goal is regulated in the follow-up directive EU2018/2001 (RES II) that prescribes a minimum amount of 14% renewable energy in the transportation sector.

The directive goes hand in hand with the RL2009/30/EG that prescribe that until 2020 the green-house emissions from fossil fuels have to be reduced by 6%.

The EU directive is like all directive part of the so-called secondary Union right and become not law immediately. This means that the nations have to anchor the directive in national law and are not fixed to the published values of the Union. The directive is the foundation but the national law can be even more strict. As an example, Hungary will increase the bio components in gasoline to 15% but claimed are only 10% from the Union.

According to the Austrian "Kraftstoffverordnung 2012" the antiknock components ETBE and MTBE can also be considered as bio components if they are made out of bio ethanol. 37% of ETBE and 22% of MTBE can be considered as part of renewable energy resources. The two ether components are often used to increase the antiknock characteristic of gasoline and are anyway in a gasoline blend, this helps the petroleum industry to reach the bio component goal.

In the last year the supply of so-called premium gasoline products increased. Big petrochemical companies started to advert their "new" product. According to the advertisement of the biggest fuel supplier (20) in Austria, the benefits of premium gasoline are purification, protection, efficiency and power increase and therefore less emissions. These effects should be reached through special additives and an increasing number of ROZ / MOZ. As already mentioned in this chapter, there exist several ways to improve the quality of gasoline. One of them is to increase the antiknock-characteristic. This can be done through adding components, that already have a higher ROZ than normal gasoline. As example, in Austria the normal gasoline fuel has to have a minimum of 95 in the research octane number. If the companies adding compounds that already have more than 95 like MTBE (118 ROZ) or ETBE (117 ROZ) they increasing the anti-knock characteristics of the fuel and therefore gain more power, less emissions. This is only one out of several how a company could achieve the better quality for premium gasolines.

6.2. Diesel

The basic component for diesel is gas oil, therefore it is related to heating and fuel oils. A diesel automotive engine uses heat from adiabatic compression to ignite the fuel/air mixture inside the piston. Diesel engines have several advantages because of the simplicity in design, power, efficiency and durability. Sometimes they are divided into subgroups: low-speed, medium-speed and high-speed engines. They are operating in different revolutions per minute, up to 300 rpm, between 300 and 1000 and above 1000rpm respectively. Nearly all using a four-stroke design, intake, compression, power and exhaust.

Several improvements in the diesel design had been done since the development of the basic principle. Modern engines are always equipped with a so-called direct fuel injection, that has a lot more efficiency than the indirect concept. (It is very similar to the gasoline direct and indirect concept). Another improvement are the Four-Valve cylinder heads that causes high turbulence of the fuel and air in the combustion chamber that results in an increased flame speed that reduces the ignition delay time. The electronic controlled fuel injection timing is another innovation that has several advantages like quitter combustion. Adding a turbocharger, that adds compressed air into the cylinder adds mass to the combustion, that enables the engines to burn more fuel and to increase the power output. [42]

The petrochemical industry and the technical authorities define several major parameters for the diesel fuel specifications:

- Cetane number
- Aromatic content
- Density
- Sulfur content
- Distillation
- Viscosity
- Cold properties (CP, CFPP)
- Flash point (FP)

The cetane number is a figure that defines the ignition delay for a fuel, it is defined through a specific testing method. For this test, two reference fuels are chosen, like the ROZ / MOZ test at gasoline. The first fuel is normal cetane and the second one is an isomer of cetane (heptamethylnonane). The normal cetane is arbitrarily given the number of 100 and the isomer has 15. In the test the cetane number is given by the ignition delay of the test fuel in comparison to the reference fuel. Below the international standard equation for the calculating process of the cetane number is shown. Lower cetane number indicate a longer ignition delay. On the contrary side, higher cetane number indicates a shorter ignition delay, which results in less CO and unburnt hydrocarbons. [42]

$$Cetane\ number\ =\ normal\ cetane\ \% +\ 0{,}15\ x\ heptamethylnonane\ \%$$

There is a slightly non-linear inverse correlation between cetane and octane number. Pure components can differ in context of cetane number significantly to blended components. Another measure is the cetane index that is calculated through the specific gravity and the average boiling point. The cetane number and the cetane index correlate but the index does not require an expensive test. Diesel engines can deal with fuels, having a cetane number between 40 and 55. In the actual diesel standard EN590 Euro 5, diesel fuels must have at least a cetane number of 51. [43]

In the past the emissions of the combustion process had been improved by several measures of the automotive industry. However, in the last years the states defined new regulatory standards to enhance the environmental emissions by diesel cars. The authorities defined a boarder for the level of sulfur in this type of fuel. In diesel sulfur is burned to SO_2 and a little part of it is oxidized to sulfates. In the US a maximum concentration of 15ppm sulfur is allowed and in Europe and the Asian-Pacific region 10ppm. In Appendix A there is a table with a lot of countries and their regulations of maximum sulfur content in diesel fuels. [42]

The fuel has a boiling point between 150°C and 410°C and includes carbon molecules with 8 to 21 length. For automotive use the boiling range is typically between 180°C and 356°C. Another specification is the initial boiling point that is also called the flash point, that has to be greater than 55°C. The regulations use a 95 % boiling point, that mean 95% of the fuel is boiling at that point, to specify the boiling range it has to be less or equal to 360°C. (Euro 5 or ASTM D86). [43]

Additionally, the distillation range has a big influence on the engines power. If the fuel is too volatile the engine loses power and efficiency due the fact of vapor lock in the fuel system or less droplet penetration. In contrast if the fuel is not enough volatile, the engine also loses power and efficiency due the fact of poor atomization of the fuel. There are several boiling points that are often used to specify different properties of diesel, as example the 10% has influence on the engines starting behavior. If this point is too high, the engine will have problems with starting the combustion process. If the 50% point is high the emissions and smell will increase. The higher the boiling point, the higher the remaining carbon compounds in the fuel. This results in less combustion ability and therefore more emissions. [42]

The aromatic content of diesel fuels is very often defined in specifications. Aromatic compounds occur in single-ring, multi-ring and poly-aromatic hydrocarbons. According to Treese. Et. al. there are several studies that shows a contrary picture of reducing aromatic compounds in diesel fuel. [42]

The density has influence on the injection time as a measure it provides information about the particular mass of a volume. That has influence on the fuel amount, as example, the lower the density the more time it takes to deliver the same mass into the cylinder. The lower the injection time, the lower the peak temperatures that results in lower NO_x formations. At high loads the longer the injection time, the more incomplete the fuel is burnt in the combustion process and the more hydrocarbons and CO are exhausted into the environment, this means the density has a significant influence on the emissions of diesel. [42]

The viscosity of a fuel is important for the fuel pump and the injection system. The shape of fuel spray is affected by viscosity. If the viscosity is to less, the injection spray is too soft and will not reach far enough the combustion room in the cylinder. The efficiency and the engines power will suffer from this situation. If the viscosity is too high the fuel will not be enough atomized into the cylinder. Losses in efficiency, power and a poor combustion are the consequences. Especially in this case the high viscosity of the fuel can remove the lubricating film, which causes excessive wear and increased emissions. [42,43]

The Cold properties, in relation to diesel the cloud point (CP), the pour point (PP) and the cold filter plugging point (CFPP) are important measures for several regulations. This type of property defines the fuel behavior in cold weather conditions, due the fact that paraffin, which is a part of diesel, forms crystals in cold conditions. In different areas around the world different measurement methods are used. The cloud point is the point at that waxes begins to flocculate out of the fuel. The longer molecule chains changing their behavior and flocculate. This wax clogs the unheated fuel systems of automotive. In some areas of the world the pour point is used to indicate the lowest temperature at which diesel can be pumped. In general, pour points are 4-5°C lower than cloud points. The cold filter plugging point test has increasing influence on updated specifications because it is replacing or supplementing the cold properties of diesel fuel. The cold filter plugging point is the point at which a special standardized filter is clogged by the diesel fuel. [42,43]

The flash point (FP) is the point at which the fuel produces an ignitable mixture of vapor and air above the surface of the liquid. This property is more relevant for gasoline, but in safety data sheets this point has to be mention. The flash point has influence on the storage of fuels but no influence on the performance and the emission properties. If it is too low, fire or explosion can occur very easily. [42]

The petrochemical industry has various solutions to meet different specifications from the authorities. Adding improvers (additives), using more complex hydro-processing and fractionation are only once of them. As example in modern hydro-processing plants already the low-grade blend stocks from FCC or thermal cracker can be used as basic components of diesel fuel. The creators of regulations have increased the cetane number / index in the last years due the fact that this can be done very easily with additives. A commonly used cetane improver, alkyl nitrate, tends to improve the cetane number linear to the dosage. A standard alkyl nitrate enhances the cetane value of diesel fuel by 2-5 points. The effect is depending on the compounds used for the fuel, because paraffins respond best to the additive. On the other hand, aromatics, that have a low cetane number, have a poorer respond. [42,43]

7. Aviation Fuel

7.1. Aviation Gasoline

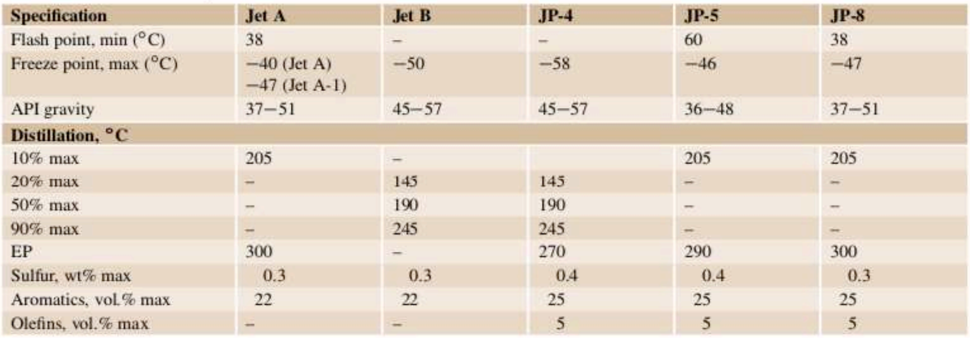
Aviation gasoline has normally a very high concentration of plumb in it and is because of environmental causes therefore in several states prohibited. A special deviation with low plumb concentration is used in small piston driven planes, but this remains as niche market, but it should be mentioned in this thesis. It has very strict specifications and is used for piston-engine-powered aircraft, that has a high-octane number and a low flash point to improve the ignition characteristics. It is a composition of 50-60% (iso-)paraffins, 30-20% naphthene's and a small amount (up to 10%) of aromatics. There is no use of olefins in aviation gasoline because it has the ability to form gum. The usage of aviation gasoline is another than the one of automotive gasoline, therefore the expectations of the components are different. Aromatics, which have a high-antiknock characteristic in rich mixture, but are much like olefins in lean mixture conditions, therefore only a little part of it is blended into AvGas (Aviation Gasoline). It can be classified in JET B or JP-4 category of jet-fuels. The availability of these type of fuel depends very strong on the crude oil consistency and the frictions in it. [39,40]

7.2. Kerosene / Jet Fuel

Kerosene exists in different qualities and is classified by special regulations. In the beginning of the oil age, a lot of kerosene was used for lightning, today the most part of it is used for jet engines and for domestic heaters. The principle of the kerosene, jet combustion process is very well described by C.S. Hsu et.al.:

„At the front of a jet engine, a turbine sucks in air with a fan. The pressure of the air is raised by a compressor, which is powered by a turbine. Fuel is injected, and the air/fuel mixture is burned, generating exhaust gases that push through the fans of the turbine and exit through a nozzle at the back of the engine. As the jets of gas shoot backward, the air- craft is propelled forward. " (Source [44])

Kerosene is the basic material for JET fuels but with different specifications and treatments. The engines of an aircraft can be operated with several fuels. In common refineries classify three grades of kerosene, odorless kerosene, regular-grade kerosene and premium kerosene. Every type has different characteristics and regulations. The important regulations are ASTM D4052, D156, D86, D130. These regulations are mainly for civil purposes, there existing special references for military grades of kerosene. The reason for separated military specification (JP) is that the logistics and the fuel environment is another one. This type of end-user requires higher specifications due the fact of increased challenges. A major different is the different flash point temperature. The IATA (International Air Transport Association) publishes a document called "Guidance Material for Aviation Turbine Fuels Specification", this is a guideline for international use of kerosene / jet fuels. The variety of different aviation fuels is summarized in this document and differs between three kerosene-based fuels: JET A1 meets the regulations of Joint Checklist requirements, JET A meets the ASTM requirements, TS1 meets the Russian GOST requirements and JET B meets the CGSB requirements. The difference between JET A and JET A1 is the freezing point difference, -40°C and -47°C respectively as shown in Appendix A. JET B is also classified as aviation gasoline because of its lower boiling specifications. The fuel specifications are so-called living documents, these means they undergo periodic updates. Another note that should be mentioned is that in these specifications there are often fuel issues addressed in the footnotes, important for all persons that are in contact with these types of fuels. Kerosene fuels includes like others additives that have special properties to enhance the features of kerosene. Like in diesel an antistatic chemical compound is added. Additives for preventing gumming, corrosions, bio-activity and more is added. In figure 20 turbine fuel specifications are shown and in detail in Appendix specifications for different jet fuels are summarized in a table and a comparison of different specification properties of the major civilian jet fuels is depicted. [43,45]



Specification	Jet A	Jet B	JP-4	JP-5	JP-8
Flash point, min (°C)	38	–	–	60	38
Freeze point, max (°C)	−40 (Jet A) −47 (Jet A-1)	−50	−58	−46	−47
API gravity	37–51	45–57	45–57	36–48	37–51
Distillation, °C					
10% max	205	–		205	205
20% max	–	145	145	–	–
50% max	–	190	190	–	–
90% max	–	245	245	–	–
EP	300	–	270	290	300
Sulfur, wt% max	0.3	0.3	0.4	0.4	0.3
Aromatics, vol.% max	22	22	25	25	25
Olefins, vol.% max	–	–	5	5	5

Figure 20 Specifications of tubine fuels; Source [45]

7.3. Fuel Oils

Fuel oil is mainly used for heating purposes. Big diesel engines, power stations and others are often using this kind of fuel because of price-performance ratio. According to Romp [47] fuel oil for heating purpose is categorized into two classes: pure distillates and residue-containing fuel oils.

Pure distillation is often produced in crude oil distillation process under atmospheric pressure or under vacuum pressure.

Residue-containing fuel oils are the side product of a distillation process and contain chemical fractions that cannot be distillated under the temperature of the process and therefore have a very high boiling point.

According to Romp [47] residue-containing fuels cannot be completely burnt without leaving any unburnt heavy ends. In nowadays the most often component is cracked vacuum distillation because of economic benefits. In all of this components asphaltenes are gathers, this are the heaviest part of crude oil and build aromatic compounds. Often fuel oil is blended with diluents to reach the product specifications, but only two to three components are added in contrast to gasoline, that contain around 10 blended components. Highly used blend components are light cycle oil, heavy cycle oil or slurry from fluid catalytic plants. The sulfur content of fuel oils is depending on the crude oil. [47]

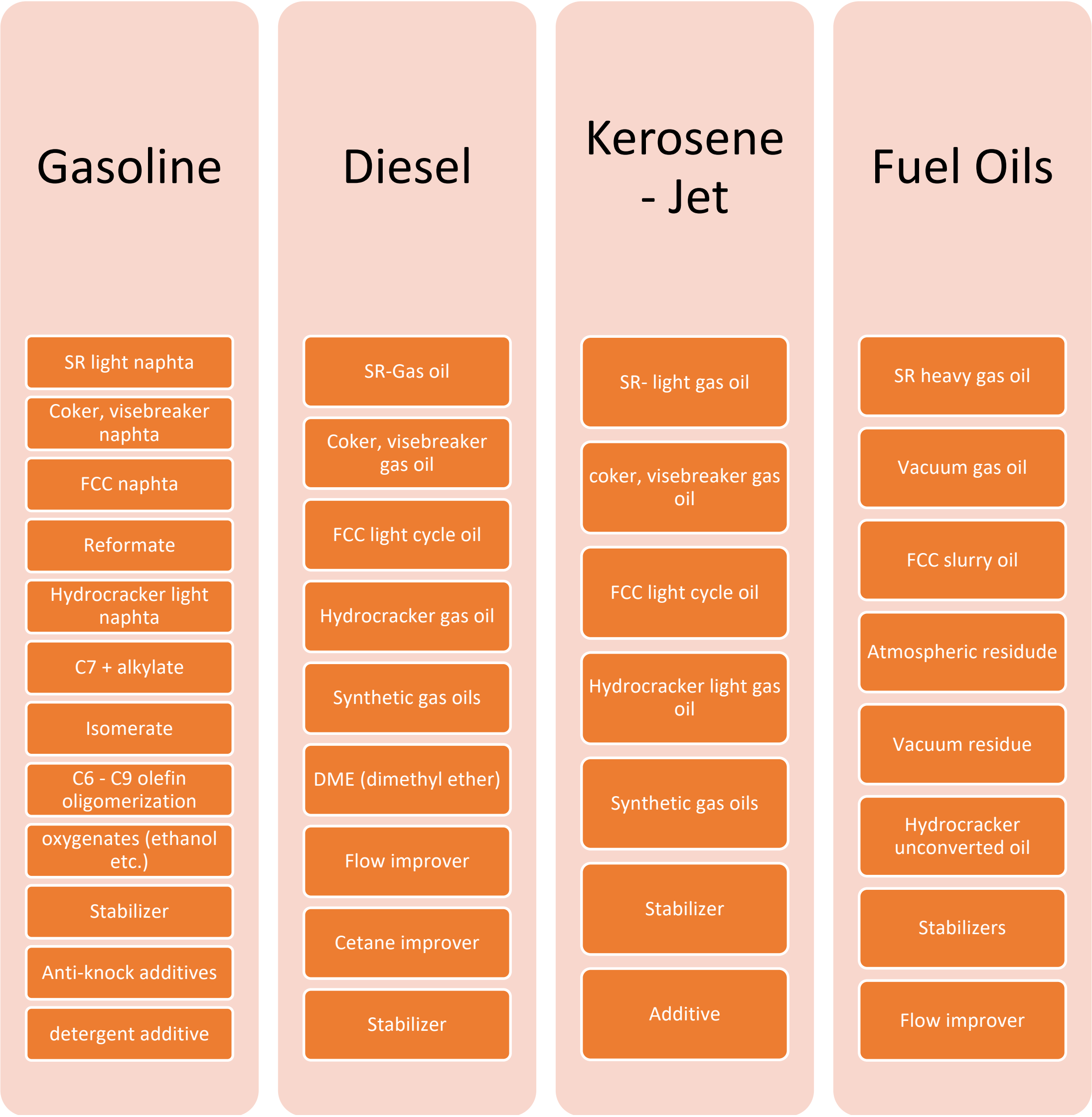
Fuel oil exists in different product specifications and in some sea areas the sulfur content is regulated by the MARPOL 73/78 Annex VI specification. According to Exxon Mobiles Product Description (21) fuel oil is supplied by them in two different qualities: Marine distillate fuel oil and residual fuels. Residual fuels contain very often heavy particles with a high boiling point, that will remain after the heating process as ash.

Marine (Residual) Fuel Oils												
Quality parameter	**Einheit**	**Limit**	**RMA 25**	**RMB 30**	**RMD 80**	**RME 180**	**RMF 180**	**RMG 380**	**RMH 380**	**RMK 380**	**RMH 700**	**RMK 700**
international notation						**IFO 180**	**IFO 180**	**IFO 380**	**IFO 380**			
Density (15°C)	kg/L	Max	0,96	0,975	0,98	0,991	0,991	0,991	0,991	1,01	0,991	1,01
Viskosity (50°C)	mm²/s	Max	30	30	80	180	180	380	380	380	700	700
Water	% (V/V)	Max	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Sulfur	% (m/m)	Max	3,5	3,5	4	4,5	4,5	4,5	4,5	4,5	4,5	4,5
CCR - conradson carbon residue	% (m/m)	Max	10	10	14	15	20	18	22	22	22	22
aluminium and salts	mg/kg	Max	25	40	40	50	60	60	60	60	60	60
flash point	°C	Min	60	60	60	60	60	60	60	60	60	60
Pourpoint, summer	°C	Max	6	24	30	30	30	30	30	30	30	30
Pourpoint, winter	°C	Max	0	24	30	30	30	30	30	30	30	30
Total Sediment Potential (TSP)	%wt	Max	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1

Figure 21 Fuel Oil qualities
Source (20) in personal schematic

7.4. Overview of fossil fuels and possible ingredients

In figure 21 below, there is an overview of nearly all treated fuels and their compounds. It visualizes the ingredients of the different fuels and makes it easier to find the semi-finished products in a refinery schematic. This schematic describes not all possible fuel variations, deviations because of special regulations in countries, quality differences from crude oil variations and different refining processes are only a few causes that can influence the components in different fossil fuels.



Gasoline	Diesel	Kerosene - Jet	Fuel Oils
SR light naphta	SR-Gas oil	SR- light gas oil	SR heavy gas oil
Coker, visebreaker naphta	Coker, visebreaker gas oil	coker, visebreaker gas oil	Vacuum gas oil
FCC naphta	FCC light cycle oil	FCC light cycle oil	FCC slurry oil
Reformate	Hydrocracker gas oil	Hydrocracker light gas oil	Atmospheric residude
Hydrocracker light naphta	Synthetic gas oils	Synthetic gas oils	Vacuum residue
C7 + alkylate	DME (dimethyl ether)	Stabilizer	Hydrocracker unconverted oil
Isomerate	Flow improver	Additive	Stabilizers
C6 - C9 olefin oligomerization	Cetane improver		Flow improver
oxygenates (ethanol etc.)	Stabilizer		
Stabilizer			
Anti-knock additives			
detergent additive			

Figure 22 Overview of compounds in fossil fuels; Source [43] in personal schematic

8. Future Trends

8.1. Renewable Fuels – Biofuels

8.1.1. Introduction

In the last years there is a growing demand for renewable feedstock fuels. The public discussion around greenhouse gas emissions, the limited resource of oil and in consequence to fossil fuel an alternative approach is gathered. The rising CO_2 concentration in the earth's atmospheric causes several national governments to search for solutions of that environmental problem. Like in chapter 8 mentioned several renewable integrities were built to replace fossil fuels. In the case of gasoline, ethanol is replacing several percentages of the fuel. In the case of diesel, FAME (fatty acid methyl ester) is replacing several percentages of it. Fuel produced out of a sustainable and renewable resource is a discussed alternative. In these days renewable fuels are produced out of plants or animals. The feedstocks are named renewable because it can be reproduced in a short period of time. The range of it is from annually to over few decades like in the case of trees. The relation between fossil fuels and renewable fuels is therefore closely because also conventional fossil fuel was built out of plants and animal matters. The difference is that fossil fuel refined out of crude oil needed lots of years to reach a "useable" stage. Fossil fuels or petroleum always contains a lot of elements, like oxygen, alkali, nitrogen, that created the right conditions to form out the finished product and especially this makes the production of biofuel feedstock more challenging. [48]

The usage of biofuels must have a positive CO2 balance, that means over the life cycle the CO_2 emissions have to be lower than the usage of fossil fuels. The life cycle of fossil fuel contains extraction of oil from the earth, transporting to a refinery, refining, transportation to a filling station and the combustion emission of the end-user's vehicle. Similarly, the life cycle of a biofuels starts with the production of energy crop, transportation of the oil-bearing, crop to an extraction plant, extraction and refining the oil, transportation to a filling station and the combustion emission of the end-user's vehicle. [48]

For a long-term success of this type of fuel, the sustainable, clean energy has to make a comprehensive makeover for the billion-dollar industry. The goal should not to radically replace the energy technologies over the time it should be supplement and gain a bigger part of the feedstock for less emissions. The hardest part for this process is the break-down process of the biomass, cost-effectively, into its components so that it could be reformed or upgraded into components of the refining process or into the finishing process. In the last years the petrochemical industry is investing into research and development for alternatives and new perspectives from their classical business way. According to the Department of Energy (US DOE) the future energy mixture should become a mixture of solar, wind, geothermal energy etc. and through the usage of biomass-to-liquids (BTL) fuels that can be used in the current infrastructure. Biomass to liquids and in the end used as fuel can be divided into several unofficial generations:

- 1st generation - nonfood crops
- 2nd generation - nonedible portion of food crops
- 3rd generation – microalgae

[49]

The different generations are treated in the following chapters. There is no general official specification for the different generations, but in literature they are very often classified into them.

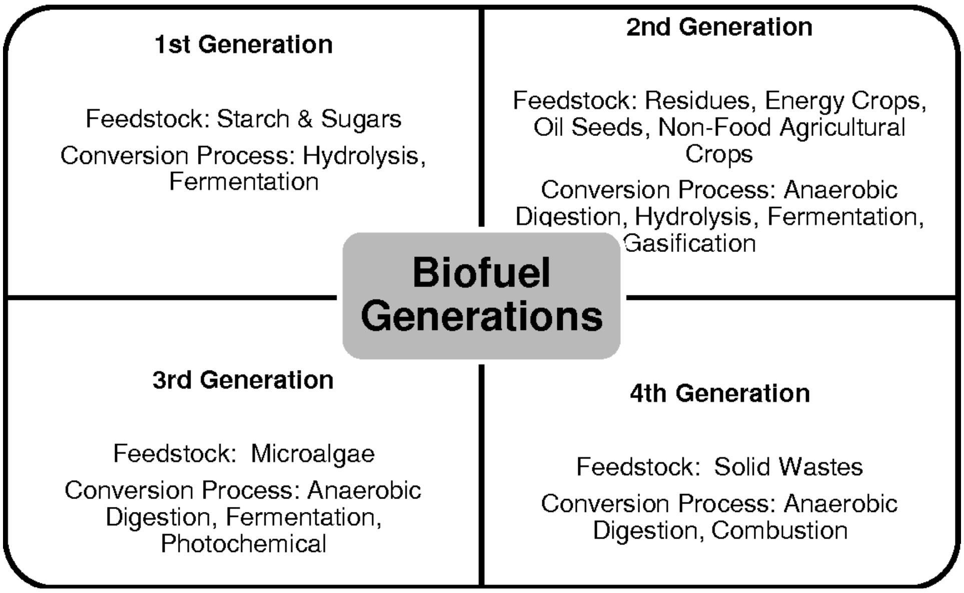


Figure 23 Generations of biofuels in overview; Source (22)

8.1.2. 1st Generation bio fuels

The feedstock of the 1st generation is commonly used in biofuel can be made out of three general forms: starches, sugar, lignocellulosic material and lipid oils (including free fatty acids and triglyceride). Grain and sugar cane are the common resources for sugar and starches that is used as ethanol through fermentation. Ethanol is one of the most used biofuels in the world, especially in Brazil the amount of ethanol in gasoline is higher than in several other states. Lipid oils and triglycerides are gained through the fats from animals or plants, especially from the seeds through extraction. In Wood pulp processing plants tall oil is also used. The fatty acids are converted into FAME (fatty acid methyl ester) via transesterification with methanol. If the triglycerides and free fatty acids are hydro processed the created paraffins make a good blending component for diesel and jet fuel. [48]

The 1st generation of bio fuels achieved already a measurable success. Through governmental subsidies and regulations bioethanol has to be added to gasoline, but there are limits, because the engine would need a customization if the amount of added gasoline is to high. Biobutanol is a new possible compound that can be used similarly to ethanol but it has several advantages.
[49]

The following points have biobutanol over bioethanol:

- Butanol is not as volatile and therefore safer than ethanol
- The energy density is higher
- Butanol makes less cold phase ignition problems because of the smaller vaporization temperature
- Butanol can be blended in higher concentrations to gasoline without adapting the conventional engine
- Butanol can be transported through conventional pipes.

8.1.3. 2nd Generation bio fuels

The 2nd generation of bio fuels is made out of like all others from biomass but especially from the agriculture wastes, municipal wastes, pulp milling by-products, recycled vegetable oils and biomass from forests. A big part of it is used in lignocellulosic form, that form is very environmentally friendly, has low cost and nearly low or near-zero greenhouse gas (GHG) emissions. The good emission balance of lignocellulosic material is from the fact that the CO_2 produced by these fuels can be utilized by the growth of another biomass. This process is still in the early stage and not fully developed but has today a lot of attention in scientific matters. The most used process today is through gasification into hydrocarbons via Fischer-Tropsch or mixed alcohol reactions, pyrolysis to liquids with subsequent conversation to hydrocarbons or by a treatment of a Fluid catalytic cracking plant. The International Energy Agency created the term “biorefining” that is defined as follows: [48,49]

” *Biorefining is the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, and/or materials) and bioenergy (biofuels, power and/or heat)* ”
Source (22)

The second-generation biofuel is having according to several scientific literatures the actual most potential (N. Srivastava et.al 2019, C. Hsu et.al. 2017, S. A. Treese et. al. 2015) to gain more market share. Scientific researchers look for a way to increase the actual efficiency of the conversion process from biomass (in form of lignocellulose) into bioethanol. To gain this efficiency increase, generation of electricity, thermochemical treatment and more can help. This chapter should create an overview of the 2nd generation biofuel process.

The production of biofuel in relation to the second-generation bioethanol conversion process is in detail a very complex procedure. The biggest bioethanol producers are Brazil, China and the United States. In America most of the bioethanol is produced out of maize and cane and in China corn, wheat and sugarcane are mostly used. India wants to get a very high percentage of bioethanol in fossil fuel because of secure energy supply, they published goal is targeted to around 20% of biofuel. The second-generation bioethanol is made out of byproducts from the agro-industry and compromises sugarcane bagasse, rice husks, rice straw, wheat straw and more. Lignocellulose that is the special used in the conversion process is mainly made up of cellulose. Hemicellulose and lignin. The whole process is in literature mainly separated into 4 steps: 1) pretreatment (deconstruction) 2) saccharification 3) conversion of sugar to ethanol (fermentation) 4) purification. [50]

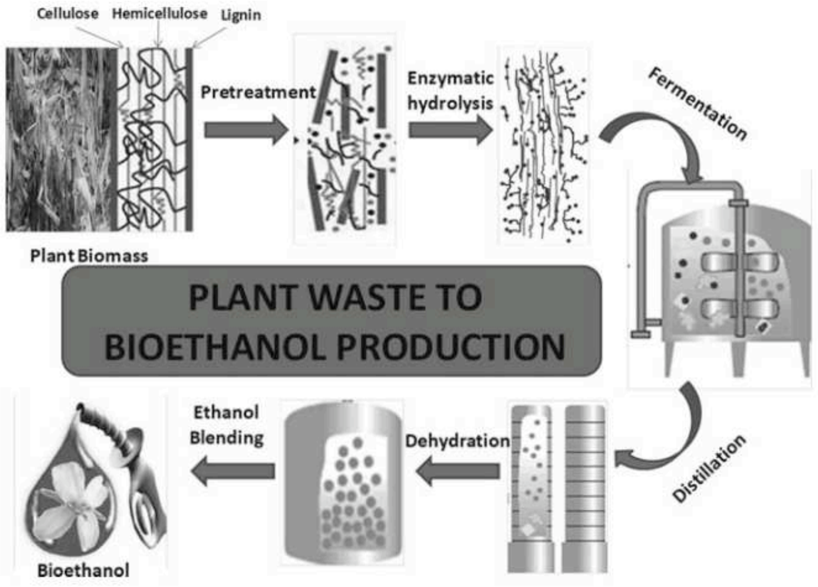


Figure 24 2nd Generation bioethanol process; Source [50]

In state-of-the-art scientific literature (N. Srivastava et. al. 2019) the remaining potential for this process is mentioned as big. The main problems are the sugar recovery, the hemicellulose fermentation, enzyme recycling and the efficiency of microorganisms. In second generation biofuel production the carbohydrates are processed into bioethanol but there is a big amount of protein that is not used in the transformation process and has a lot of potential. If this part of the feedstock could be also used in the production process the technology could decrease the carbon dioxide life cycle, reduce the consumption of synthetic fertilizer and can create an inexpensive feedstock for further processing. In the future this topic should undergo several scientific researches to increase the economical and the energy conversion efficiency. The potential for a higher usage in the petrochemical aspect, like a full integrated biorefinery is only one out of several potential ideas.

8.1.4. 3rd generation bio fuels

3rd generation bio fuels are currently under development but have a high potential in long term view. The state-of-the-art scientific literature (N. Srivastava et.al 2019, C. Hsu et.al. 2017) mention as 3rd generation bio fuels, fuels that are produced from organisms like algae or microorganisms. In terms of algae fuel production, the excess water removal is currently a big problem. The production of fuels out of algae has gained scientific attention because there can be several ways how to reach that goal. [49]

The algae can grow in following systems:

- Open systems – they grow in open air systems
- Closed systems – they are not exposed to the atmosphere and use a sterile source of CO_2
- Photobioreactors – the most expensive system but have a good control

One approach would be to tie the system directly at carbon dioxide emitting areas, like power stations or industry, where there can directly transform it into useable biofuel. This means that no carbon dioxide is released in the air. In the actual research phase, the algae still need a lot of water and big room for growing, this makes the production inefficient and, in this days, not economical or environmental meaningful.

8.1.5. Nanotechnology in context of biofuel production

In 2019 the climate change and the consequences of global warming are a main topic. Around the world protests about the energy policy is done and scientist doing research in the context of greenhouse gas emissions in the transportation sector. In these days' fossil fuels are needed, but the politics is reacting to the public opinion and encourage green ideas. According to Susana Couto (2019) nanotechnology can help to produce biofuel even more environmentally friendly. Like mentioned in previous chapter, one big problem of biofuel production is the conversion process from biomass into biofuel. [51]

Especially in this transformation process nanoparticle can help. The term nanotechnology is used to design materials and phenomena in a very small size (1 to

100nm). Quantum mechanics rules in nanoworld and this is different from those of bulk material. [51]

Nanotechnology can be applied to modify the feedstock of bio fuels. The reaction would improve with a catalyst and this can be made out of nanoparticles. The immobilization of enzymes can make a good conversion from lignocellulose into bioethanol. The usage of Nano-catalysts allows a fast, selective and highly active reaction together with easy recycling of it. Already in 2009 scientists developed a nanotechnology that presented really good results in the conversion process. [51]

The fact that nanoparticles can harm humans and the environment is one big disadvantage of this technology. The consequence is that a lot of research in this topic has to be done before it should be used in practical processes. Researcher tried to apply nanomaterial in the conversion process to save money. The regeneration of enzymes is a cost intensive process and can be accelerated with Nano-catalysts. Green Nanotechnology is in the initial stage but there are a few studies that deals with the conversion from lignocellulose biomass into biofuel. Mahmood an Hussain reported a conversion of spent tea into biofuels by Nano-catalytic gasification followed by transesterification. [51]

8.2. Bio-Refineries

The concept should increase popularity and is created by a task force of the International Energy Agency. The concept integrates the biomass into a refinery process and the renewable feedstock can be used as other crude oil refining’s. According to C.S. Hsu et.al. [48] the feedstock of biomass has the potential to make out of crude oil refining that is currently a monopoly a duopoly. In some scientific environments this concept with several “bio” adaptions in the refining process is called the 4th generation of bio fuels. The processing of feedstocks out of biomass (including vegetable oils, starch and sugar biomasses, cellulosic) by catalytic cracking or by hydrotreating is a promising alternative to conventional fossil fuels. The trillions of dollar worth in infrastructure can be used for another use and can help to reduce the greenhouse gas emissions.

Biomass is or can be made out in big amounts out of waste and this reduces the cost concept in general. A lot of research in biomass conversion and terms of biorefining is done, the number of publications has increased from 200 publications in 2009 to nearly 1600 in 2017. Several chemical conversion processes can be accelerated by different chemicals and catalysts and have similar behavior as normal petroleum therefore the term biorefinery is used in the context of biofuel production. This chapter should bring the reader's attention to the topic of biorefining but this topic by itself could cover a whole thesis. A lot of research in that direction is done and therefore the number of publications will even increase in the next years. [52]

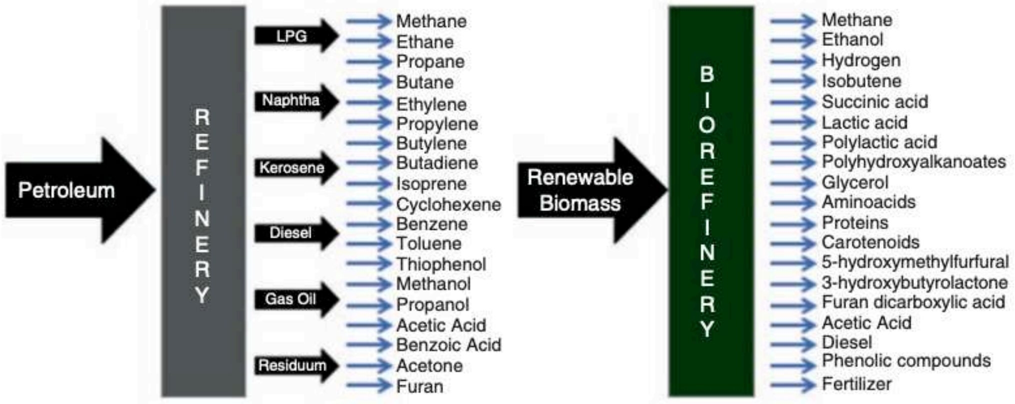


Figure 25 Biorefinery concept; Source [52]

Refining bio material is different than crude oil. According to Treese 2017 et.al. the bio oil is very paraffinic and therefore the wax content has to be reduced by hydrocracking or isomerization. The oils contain olefins and oxygenates that have to be removed before hydrotreating. If the oil is blended to normal crude oil in a mixture of lower <2% the amount of possible side effects is negligible but if there is a higher amount the oil should be treated separately. In scientific literature (N. Srivastava et.al 2019, C. Hsu et.al. 2017, S. A. Treese et. al. 2015, Juan-Rodrigo B. 2019) the focus of biorefineries is more focused on the feedstock, than on the conversion process. [48]

In literature there is sometimes differentiated between "New" and "Old" Carbon. Carbon that is created out of petroleum is called old carbon. New carbon is already at the surface of the earth and can there be found in several processes of plants and creatures. There is a common similarity between all crude oil carbons, because it is entirely composed out of carbon-12 isotope. New Carbon has a greater amount of carbon-14 isotope. In science the analyze of the carbon structure can help to define if the oil is made out of old or new carbon. [48]

8.3. Fossil Fuels vs Biofuels

Fossil fuels have been explored widely from scientists in the last years and the combustion process in vehicles has improved over the last years dramatically. It was the first possibility in human history, where a lot of energy is saved in a small amount of volume. These chemical compounds made it possible that public transportation reached a new era. Despite that, the increasing criticizing of fossil fuel-based energy systems due the concerns of environmental pollution, depletion of resources, rising fuel prices and public demonstrations about the environmental politics. One of the biggest problems according to Sonil Nanda et.al. 2019 is the issue of greenhouse gas emission related to fossil fuel combustion in developed and developing countries. There are other potential techniques that can replace fossil fuels in energy production like hydropower, solar, wind, geothermal, etc. One of the biggest attentions this time from scientist has gained the topic "biofuels" The main advantage is their carbon life cycle balance. [53]

In actual stage of development, biofuels cannot replace fossil fuels due to certain limitations like poor fuel properties, higher production costs, low yield and engine modifications. Different type of fuels emits different amounts of chemicals into the air. In order of CO_2 emission, the following order of fossil fuels can be created: coal > diesel > gasoline > natural gas. The amount of CO_2 emission is depending on the carbon and hydrogen in the fuel. Gas has a lot of potential because it releases the lowest content of CO2 and is therefore treated as the "cleanest" fossil fuel. In this time two different forms of gas as fuels exist: CNG – Compressed Natural Gas, LNG – Liquified Natural Gas. The gas fuel variations will be treated in the next chapters. [53]

8.4. Potential of CNG (compressed natural gas) as alternative fuel

In the future another fuel type can gain big attention: CNG – Compressed Natural Gas. As mentioned in previous chapter, gas is the cleanest fossil fuel, due the fact of less carbon and hydrogen amount and a high methane concentration (around 95%). In a short- or medium-term perspective CNG provides a high potential to replace conventional fossil fuels. High savings in CO_2 and particle emissions but a bad hydrocarbon emission is the consequence. The energy density of methane is around 50MJ/kg and is therefore about 20% higher than from normal fossil fuels (gasoline, diesel 41,9 MJ/kg). Natural gas has in normal form without any compression a low density and is therefore compromised to reach a compared level like gasoline or diesel. Methane has a very high ignition temperature and has good properties for a usage in foreign ignition engines. CNG has a high antiknock-characteristic, that has a positive impact on the efficiency on engines. This type of fuel is stored in steel bottles with a pressure of around 20 MPa. The volume that is needed in comparison to convention fossil fuels like gasoline or diesel is higher. As example the storage tank of a CNG compromised with 20MPa and 250MJ energy has a volume of 300dm$^{3.}$ The volume of gasoline tank with the same energy has only around 80dm^3. [54,55]

Due the fact that methane is a very stable chemical compound, the exhaust emissions cannot be treated as easy as normal combustion engine emissions. Today normal gasoline cars can be modified into CNG and gasoline combustion engines. D. Seboldt. 2019 showed that this can have bad consequences due the problem that porous deposits can be made in the engine. The fact of higher hydrocarbon emissions decreases the effect of CO_2 saving. [54]

Actually, there are three techniques, that can be used to combust CNG in gasoline automotive. Direct injection, mixture formation and injection in the suction tube. Dimitri Seboldt (2019) showed that CNG direct injection compromises several degrees of freedom and improves the hydrocarbon problematic. If the efficiency and the manufacturing process can be improved there is a big potential. [54]

8.5. Potential of LNG (liquefied natural gas) as alternative fuel

LNG is natural fossil gas that is cooled down to around -161°C. At this temperature natural gas reduces the volume from 600 to 1, which mean that in one cubic meter the 600-fold amount of gas can be stored. This special process is used for easier transportation and storage of fossil gas. In comparison to CNG, liquefied natural gas needs 10 to 25% more energy to be in this liquid form. LNG is very often used to transport gas via ship from one country to another one. Qatar is one of the biggest LNG exporters in the world. Since the Russian / Ukraine controversial this form of natural gas is seen in Europe as alternative to Russian gas because it can easily be imported through sea side terminals. [55]

LNG has a high potential as fossil fuel in shipping traffic and for truck fuel on the road. For individual traffic like in cars this type of fuel is not appropriate due the fact that it has to be cooled or a lot of distance has to be passed. According to OMV product page (24) it should have to be 15% less CO_2, 50% less NO_x, 50% less noise, no sulfur dioxide and fine particles in comparison to diesel. The potential for it is big because biogas can be mixed under the LNG gas, which makes the CO_2 balance even better.

The European Union has prohibited a sulfur content higher than 0,5% in shipping fuels. Like mentioned in the chapter 8.3. fuel oils, the fuel of ships has in general a much higher content of sulfur. There are several solutions, one would be to extract sulfur from fuel oil or another one is to use gas as fuel. There are already several ships that have installed an LNG engine, like AIDAnova, AIDAprima and the first container ship CMA CGM should be finished this year. The problem with LNG as truck fuel is the missing infrastructure for it. In the European Union and EFTA countries there are in the year 2016 only around 101 filling stations. (25) Another problem is the missing political support and subsidies from countries. In Austria there is no official statement from the authorities if LNG has to be taxed with the “Mineralölsteuer” or not. The costs for an LNG filling station are around 1,5 million euros. (26)

8.6. Potential of Fuel Cells as alternative

Fuel Cells have a high potential to substitute convention combustion engines and their fuels. The chapter gives a general introduction to fuel cells and illustrates past and future chances in this technology area.

The Carnot processes describes all losses in a conventional energy production cycle, that is often used to depicted the actual efficiency i.e. of a regular steam driven turbine power plant that has an efficiency of around 33%. Fuel cells can offer electrical energy with high efficiencies but today there are still very expensive and have problems with their durability and lifetime. Fuel Cells based on electrochemical reactions and have the possibility to generate and store energy. Fuel cells produce electricity from fuel and an oxidant on the cathode side, that reacts in an electrolyte. A hydrogen fuel cell uses hydrogen as fuel and oxygen and can convert this into electricity by an efficiency of around 65%, which is also the rate of a very modern combined cycle power plant. If there would be enough research the conversion rate can be easily go up to >70%. In these days a lot of different fuel cells are in development. They differ in their electrolyte. The electrolyte is responsible for operating temperature, oxidant, poisons, system designs and more. As example a polymer electrolyte membrane fuel cell (PEMFC) operates between 50°C and 100°C and produces less than 250kW. The fuel and oxidant must be free of CO, carbon monoxide. There are existing several more types of fuel cells like direct methanol fuel cell (DMFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cells (MCFC), …. [56]

In July 2019 around 7000 fuel cell cars are registered in the US and around 3200 in Japan. Toyota, Hyundai and Honda are the most popular producer of this type of driven car. The Zero Emission Vehicle mandate (ZEV) declared that 10% of all new registered cars should be driven by an emission free fuel, after big critics this regulation was passed. [57]

In Japan this fuel cells are used to supply buildings with heating and electricity, this type of supply is called micro combined heat and power. [58]

The potential is high for such type of energy generator, but research and development are still in the early stage and has to be done further, if this type should replace conventional fossil fuels in the transportation sector.

9. Statistics and Market Analysis

In the end of 2018 in the EU, Norway and Switzerland 78 mainstream refineries were operating. (AUT 1, CZ 2, GER 11, F 7, H 1, CH 1) Since 2009 there were 18 refineries closed in Europe. According to Wood Mackenzie in figure 26 the gasoline consumption in Europe stagnates at a level of around 75,000 million tonnes per year since 2013 and the consumption of diesel increased since that time. [59]

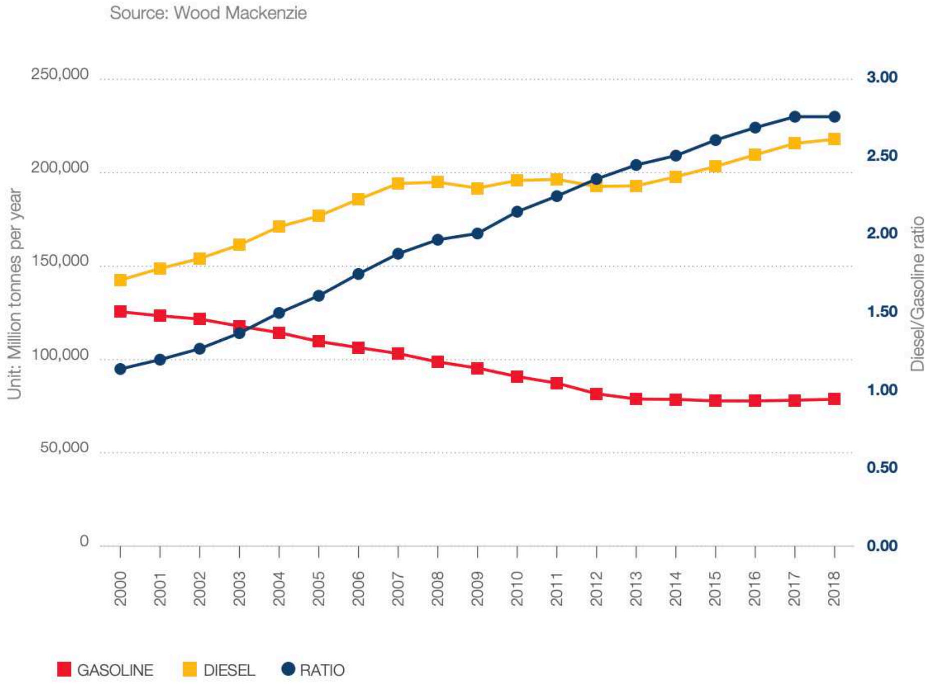

Source: Wood Mackenzie

Figure 26 Road Fuel Demand in the EU; Source (27)

According to the FuelsEurope Report 2019 the European Union exports around 42% of the domestic gasoline production. Around 27% of this overproduction is exported to the USA, 2% to non-EU member states and around 71% to different states in the world. In comparison around 30% of kerosene of the final consumption is imported from abroad. 65% of it is imported from the Middle East, 30% of the Asian pacific area and the rest from different states in the world. The situation is different if there is a few on the diesel / gasoline trading balance because the EU is importing a lot of gasoline from Russia (54%) and North America (20%). [59]

In the next year the limit of Sulphur content of marine fuels in the EU waters will decreased to 0,5%, this can bring a big opportunity for oil companies because there will be a huge demand for it, in the beginning of the next year. The heavy residue consumption will decrease and the higher priced fuel oil with less than 0,5% sulfur content will increase. [59]

In context of new registrated passenger cars the alternative fuel vehicles have a part of 7,3%. From this amount 27,2% were electrically-chargeable vehicles, 52,1% were hybrid electric vehicles and 20,7% other than electric vehicles. The number of electrical vehicles is increasing since 2010. As shown in figure 27 the European Environment Agency depicts the increase of electrical cars and the total amount of electric vehicles. [59]

Source: European Environment Agency

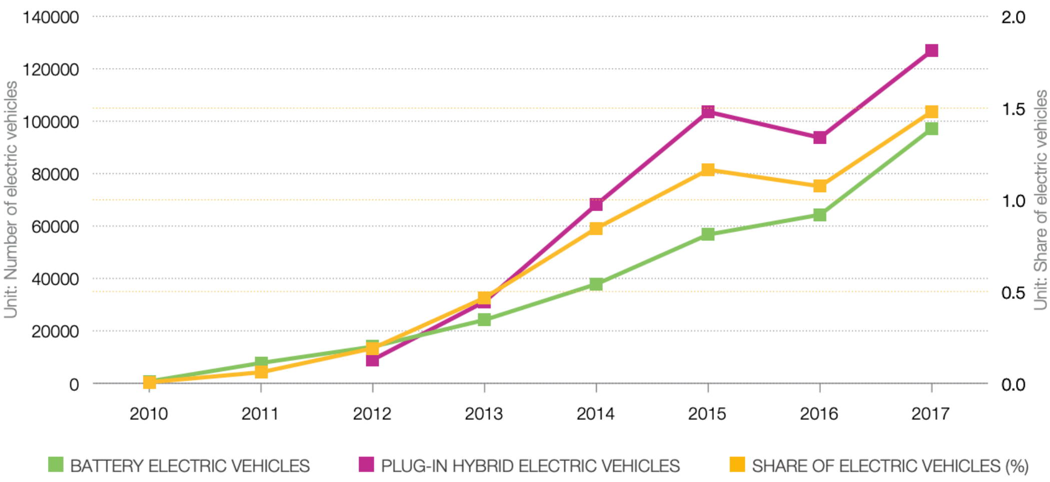


Figure 27 Electric Vehicles in the EU; Source (27)

The trend shows a shift to electric driven vehicles, there are several advantages and disadvantages of this technologies. The main problem is today the range and the charging station network. Another aspect that is still unclear today is the life cycle emissions in comparison to conventional driven cars, because there are existing several calculation methods, that can have significant influence on the balance.

According to the European Automobile Manufacturer Association passenger car fleets are powered by the following fuel type:

	2013	**2014**	**2015**	**2016**	**2017**
Gasoline	57,6 %	56,5 %	55,8 %	53,9 %	49,4 %
Diesel	39,9 %	40,8 %	41,3 %	42 %	44,8 %
Alternative Fuel	2,5 %	2,7 %	2,8 %	3,4 %	5,8 %
Unknown	0 %	0 %	0 %	0,6 %	0 %

Table 5 Passenger Cars by fuel type; Source (28)

The statistics shows a decrease in gasoline powered cars, an increase in diesel and alternative fuel cars. The amount of alternative fuels has nearly increased from 2013 to 2016 by one third but still has a low market share.

A more exact statistic is shown below, the amounts of alternative fuel powered cars divided into their fuel type. In Austria the part of Plug-in hybrid electric vehicles and battery electric vehicles is higher than alternatively powered vehicles, that is vice versa in the whole European Union. The most increase from 2017 to 2018 was in the European Union in hybrid electric vehicles, in Austria in electric chargeable vehicles. The amount of hydrogen driven cars is still very small as depicted in the alternatively powered vehicles. The actual vehicles in use depending on several facts among others subsidies, technology, filling / charging station and more.

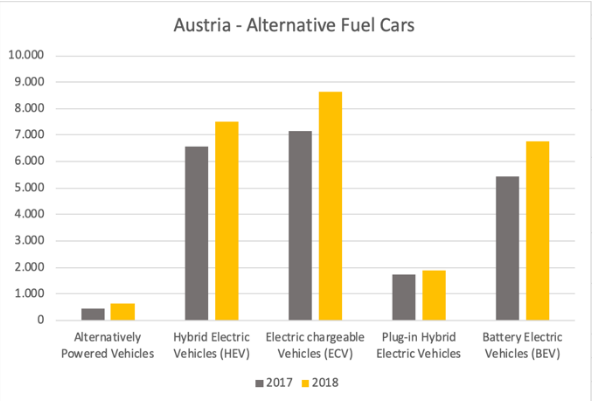


Figure 28 Alternative powered cars in Austria, Source (29)

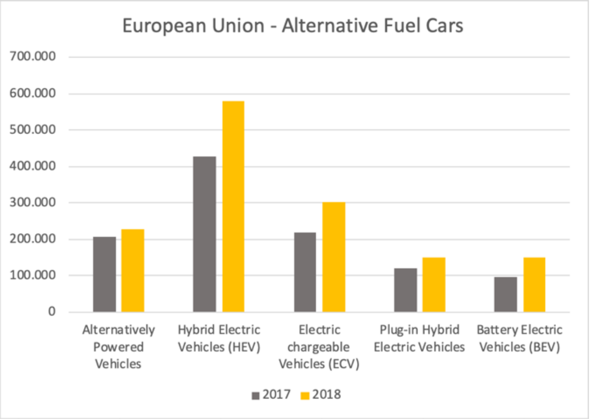


Figure 29 Alternative powered cars in the European Union; Source (29)

10. Conclusion & Interpretation

The primary energy is produced to around a quarter out of petrochemical commodities like natural gas and crude oil but a trend into renewable energy resources is visible. The part of renewable energy already gained a big part of it and should increase further, according to the European climate agreement. Since 2007 this energy resource is steadily increasing and gained more than 70% increase. Nuclear energy that is a very “clean” energy resources, got the last years a bad reputation because of accidents and the disaster in Fukushima. The energy density that is stored in the different energy resources differs and the one of petroleum products is still very high in comparison to other energy resources, therefore it is today needed for several applications.

One major influence on the usage of fuels and the energy resource origin is depending on political decisions and other political measures like funding’s and so on. In Austria and other states, the number of wind turbines increased since the funding of this equipment was established. Another fact that illustrates the funding environment is that wind turbines will often be pushed down after the funding period of 10 years and another new one is built, because then the funding is raised again.

Like the energy production also the fuel consumption depends on political decisions. As example the tax incentives on diesel lead to a shift in the fuel consumption and decreased the gasoline consumption that led to an increased diesel consumption. The global and especially the local economic environment is another factor that influences the usage and consumption of energy and fuels. If the economy is in a recession or depression the energy consumption is also not as high as in economical high profitable years.

Another fact that influences the fuel consumption that should be mentioned is the innovation of new technology that is used in the combustion process. In comparison old cars with the same amount of power have a higher fuel consumption than new once. (Assumed same conditions)

This thesis shows that the market share of fossil fuels is still very high and new cars are still powered by conventional fossil fuels like gasoline and diesel. The resources of fossil fuels are limited, but there are still enough resources for the next years especially if unconventional exploitation methods are included. The USA is already using this method to flood the market with cheap oil and get money into their household budget. The composition of the exploited oil has a significant influence on the further process because of the sulfur and other ingredients. The trend goes into a low or often called ultra-low sulfur fuel, this type of fuel is easier to produce out of "sweeter" oil, like the American one is. The composition of the exploited oil is depending on the kerogen type that was defined a long time ago.

Due to the fact that several states gain a lot of income from petrochemical fuels and therefore also crude oil, especially the Middle East countries, this income has to be substituted by other income if there is a shift in fuel types. Like mentioned in the thesis, the Middle East have high petroleum resources due the good conditions in the formation process. The high sulfur content in the Middle East petroleum needs more after treatment in the refining process than a sweet oil, this leads to higher processing costs. Like in Appendix A depicted there are still a lot of countries that have not high standards for the sulfur content in fuels. The European Union and Austria are showpieces due their high standards. In Europe the most needed fuel type is diesel / gasoil because there are tax abatements in several states and therefore the last years there is a shift occurring to that type.

The amount of kerosene and JET products is increasing due the fact of increasing air traffic. The amount of these products is increasing faster than the one of diesel and gasoline. A lot of people especially in Emerging Countries gained more wealth, which leads to an increased travel behavior. More people than ever in the world history can effort the price for a flying holiday. Foods and other goods are often shipped by plane and therefore the cargo flights increased the last years. According to experts the consumption of plane fuels will still increase the next years.

There are several regulations that try to give a direction into the composition of fuels to emit less CO_2 and other exhaust gases. Several methods like biofuels with a focus on the different generation are described in this thesis. A lot of potential is gained from the emerging technologies. The 2nd Generation of biofuels, from lignocellulose, is very promising, if there are improvements in the production process this type of fuel can be made out of really less CO_2 emitting raw materials.

Alternative fuel types like hybrid electric vehicles (HEV), electric chargeable vehicles (ECV) and more gain a higher market share but still are in a very low level in 2019. The research and development area in such powered vehicles are high, Tesla one of the most famous alternative fuel vehicle car manufacturer (No. 8 BrandZ Most Valuable Global Brands) is investing a lot of money in the research and development area (1,5 billion $) and gained on the exchange market even a higher market capitalization (Tesla 55 billion $) than Daimler or BMW(45 billion $).

10.1. Future Scenarios

In this chapter the author wants to review shortly several possible scenarios than can occur according to the actual technology direction. These scenarios are hypothetic and no claim is guaranteed. Several variances like political decisions, disruptive innovations, catastrophic events and so on can influence the future way of fuels. By the end of 2019 the actual “alternative” techniques are still not capable with the capacity that is required from them, so therefore in some scenarios there is an intermediate solution depicted, like H_2 driven vehicles for the fully electrified future scenario. The order of the scenarios is randomly chosen and has nothing to do with the probability of occurring in the future. The scenarios have in some way an overlapping frame, this mean that techniques can occur in more than one scenario, because today it is already a mixture of multiple techniques like conventional, electrical and hybrid driven vehicles.

The scenarios should illustrate the next 50 to 70 years of fuel. This is a very long-term view, if you keep in mind that diesel / gasoline is now only around 100 years old.

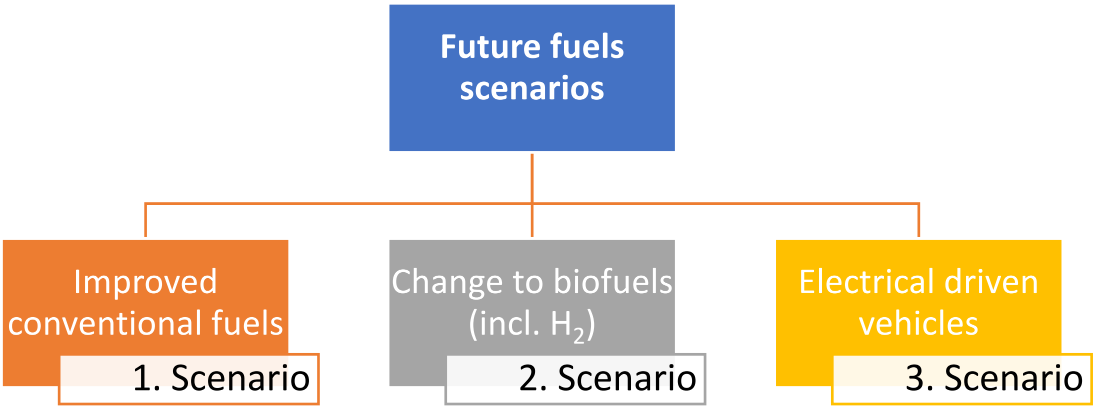


Figure 30 Future fuels and possible scenarios

10.1.1. Scenario 1

In scenario one the conventional fuels will still be used the next 50 to 70 years but under different circumstances. The combustion process will be improved and the efficiency and therefore the fuel consumption of the individual engine will decrease. The European Union and their member states signed a regulation (RED II) that rules the percentage of renewable energy resources in used road vehicles. According to this regulation the percentage of bio fuel will increase, because it is today the easiest solution to reach this target until 2030.

The fuel wastage to reach a targeted power has the last years been improved. Innovations like a turbo charger, high pressure injection valves and more, changed the way of transforming petrochemical fuel into energy. There is still potential for these innovations, as example the pressure of the turbo charger can still be increased, which leads to an increase of the efficiency factor, one limiting factor today is the missing pressure resistance of components in the combustion room. If new or better material components can be used in the engine, the pressure can be increased and therefore the efficiency.

Today around 60% of the fuel is emitted as heating energy from the engine. The last years only the combustion process was improved but today there is another combined approach that also focus on the driving behavior and all connected factors that reduces

the efficiency of a car. The automotive industry is still developing several techniques that can help to decrease the fuel consumption.
A few inventions that would have the potential to reduce the fuel consumption of a car: (in brackets the potential percentage of fuel reduction is illustrated – based on an average golf VI)

- Adaptive cruise control (~ 3%)
- Thermoelectrical generator (~5%)
- Aerodynamic – reduction of the drag coefficient c_d (~3%)
- Tires – reduction of rolling friction (up to 8%)
- Economical acceleration – automatic modus (up to 20% - 2l/100km)
- Usage of heating energy (~2-3%)
- Car bodywork – reduction of weight – alu / CRP (~3-4%)
- Cylinder shutdown (~2-3%)

In sum and under optimal circumstances, where all these innovations deliver their full potential this would generate a fuel reduction of 41%. That would be in case of numbers around 1,558l/100km fuel consumption of an average golf VI (TDI 1.6 BlueMotion, 77kW). If the whole improvement is used in realistic circumstances the savage is for sure not as high, in the eyes of the author around 15-20% would be possible, with such modifications.

Summarized scenario 1 would lead to a future where still conventional petrochemical fuels under different circumstances are used. The today already established blend capacity with biological fuels like ethanol, FAME, … will be increased and lead to a significant reduction of petrochemical fuel. Possible future petrochemical fuel consumption rates of vehicles can be very low if the problems from today can be reduced. The greenhouse gas emission from transportation can be reduced significantly.

Concrete problems today are the energy density and behavior of bio fuels in the combustion process, too less material resistance to increase the pressure in the combustion room and high percentage of emitting heat from the combustion process.

10.1.2. Scenario 2

In scenario 2 an intermediate change to green hydrogen and biological fuels is considered. Green hydrogen is hydrogen that is not produced like conventional hydrogen out of natural gas but rather out of electrolysis from renewable power and water.

In brasil today there is already a 100% biological fuel out of ethanol available. This type of combustion engine requires around 30% more fuel due to less energy density of ethanol in comparison to gasoline. A major change in the world would be the increased need for ethanol or other bio fuels. Today in Austria already 5% of conventional gasoline is substituted by ethanol. The 2nd generation of biofuels is a very promising technology, that produces out of lignocellulose fuel. If this or the following generations of biofuels can be used to produce fuels out of biological material under very low emitting greenhouse gases this technique can reduce conventional fuels. An evaluation of the possibility to produce such amounts of fuels out of biological material cannot be clarified in this thesis because it would exceed the frame of it.

Today big companies and also countries (i.e. Germany) fund the research in hydrogen technology. In 2019 the number of hydrogen cars is very low and therefore also the number of filling stations (Four in Austria). The actual problem is the production of hydrogen. It is produced out of power that comes from coal or other fossil fuel power stations, which are emitting high levels of CO_2 and other greenhouse gases. With the production process of today, there would be no improvements in contrary it would even emit more CO_2, because of the conversion efficiency rate. (Gas / Water --> hydrogen --> combustion)

Another topic that is related with hydrogen cars and is yet not fully developed are fuel cells. If an automotive should be powered by hydrogen the vehicle needs a fuel cells, that converts the hydrogen via chemical reaction. The conversion rate and the process efficiency rate in total is comparable with normal fossil engines, which is around 30% and therefore brings no extra benefit. (Gasoline powered vehicle 22%, diesel 25% and hydrogen car 25%)

In scenario 2 the future fuels will be made out of biological fuels and green hydrogen. One major point is the mass production of biofuels, which will increase dramatically in this scenario. The cultivation area of raw material for the production process must increase, the whole efficiency rate of the production process must improve and the practicability of the production of such amount have to be checked. The amount of needed biological raw material can exceed the capability of our land resources.

Scenario 2 is a mixture with green hydrogen, because these are two technologies that need more R&D because they are still in an early stage. Hydrogen cars are already available today, but with a price of around 80.000€ they are even double as expensive as a conventional middle-class car. The production of green hydrogen is not matured enough yet, and the availability of green power is today even not guaranteed for the amounts needed for the whole changeover to hydrogen driven cars.

One benefit of the green hydrogen scenario is that the power generation should be shifted to renewable energies. These sources have the disadvantage that there are not available 24/7 in the same dimensions. Therefore, the peaks have to be buffered somewhere or compensated by anything. The size of such peaks, that have to be buffered, are hundreds of terawatts, which are far too much to save economically in batteries and it would be tiring for the memories. The intermediate solution could be buffering the power peaks with the production of green hydrogen.

10.1.3. Scenario 3

In scenario 3 the private transportation vehicles are shifted to electrically driven engines. It includes hybrid solutions like they are now available on the market. In 2019 a lot of news deal with the topic electric powered cars. Several big automotive manufacturers want to be one of the first, which are one step beyond.

In general, the process of electric powered cars is very simple (i.e. BEV): Electricity is produced and saved in batteries. An electro motor is producing the power that is needed for the movement. The principle is very old and was already discovered in the 19th century. The development of electrical cars stopped since the cheap availability of oil and fossil fuels increased. The small range in comparison to gasoline or diesel driven is or was already a big disadvantage 100 years ago.

The efficiency rate (~90%) of electric driven cars is very high and is the cause why several experts, scientist and industry branches think this could be one of the possible future solutions. The efficiency is around thrice as high as from conventional engines. The reason for this is the missing reaction or transforming process, electricity directly powers the motor in comparison to conventional engines, where fuel has to be burnt.

Hybrid Cars are like the name already illustrates a mixture out of conventional engines and electro motors. Plug-in hybrid cars can also be powered by power sockets. The battery is powered when the extra power is not needed, or another mode is to use the electro motor as generator and power up the battery again. The mixture of electro motor and conventional engine can enhance the turning moment and lower the consumption rate under certain circumstances. The advantage of hybrid cars can only apply if the electro motor is used often to support the engine, which applies in urban traffic. If a car is mainly used for long-distance routes the hybrid solution can even consume more fuel than conventional vehicles, because of the extra weight from the batteries.

There are several objective goals, that should enhance the vehicles from today to reduce the climate crisis, among others these are: Carbon footprint of the fuel and the manufacturing footprint of the vehicle

The vehicle of the future should be more environment friendly than the cars from today. The vision would be a zero-emitting vehicle. Applied on scenario 3 the emission of vehicles has to be divided into parts. In the manufacturing process which consists of several steps, especially the production of batteries consumes a lot of energy and produces therefore greenhouse gas emission. On the other hand, the production of power also produces greenhouse gases. The origin of the power is the factor that influences how “green” the electro car is. The production of power through coal emits a lot more greenhouse gases than out of renewable energy resources.

Electrically driven vehicles are mainly equipped with lithium-ion accumulators. This type of accumulator has the disadvantages that it lasts very long to power them up, that the ambient temperature has influence on the capacity (optimal temperature 25-45°C), the production consumes a lot of power and they are still expensive (~500€ / kWh). Today scientists are searching for new electrical power storages that do not have these disadvantages. As example batteries with glass, siliceous-air, redox-flow and other possibilities can maybe bring in the future a possible solution to this problem. Illustrating the energy density problem: One-kilogram gasoline has an energy density of around 12 000 Wh and one kilogram lithium-ion accumulator can store around 140 Wh per kilogram. Another problem that occur is the life span of such an energy storage. The average lithium-ion accumulator has to be changed after around 1000 loadings. If one loading is assumed with a distance of 100km the batteries of such a car would last for around 100.000km or around 5-10 years, depending on the usage.

Summarized a lot of potential lies in electrically driven vehicles, but the products still need some time to develop their full potential and be suitable for daily use. The advantages of an electrically powered car can already today used if the driving behavior and the driven distances correlate with the best-use conditions. If a cheap charging station, i.e. the own photovoltaic system, can be used to charge the batteries the greenhouse gas emissions are very low and the operating costs can be very cheaply. The energy mix for powering the vehicle and the energy mix used in the production process influences the well-to-wheel hugely, therefore if the environment thought is in the foreground the car should be powered by “green” current.

10.2. Final Conclusion

The different fuel types have different advantages and disadvantages and should be evaluated in different categories. The columns that intersects the different fuel types are:

- Environment (GHG emissions, raw material used, …)
- Limits of realization
- Total costs of ownership

10.2.1. Environment

In the category environment a useful measurement of greenhouse gas emission from a vehicle is viewed in a special analyzation. There are several possibilities to compare the emission of the different vehicle types. One method is the well-to-wheel (WtW), that includes the raw material, the manufacturing process, the fuel production and the operation of the car. The well-to-wheel is the best comparison method over the complete life-cycle time because in the production of electrical driven cars a lot more GHG gases are emitted than in the production of conventional powered vehicles.

The life cycle assessment approach is still in the early development phase because the last years, the comparison was done on a tank-to-wheel approach. This means that the comparison was done based on the emissions and the fuel consumption in the daily usage. This is especially in relation to the high energy consuming production process of lithium-ion batteries distortive. In figure 31 the different life cycle assessments are depicted.

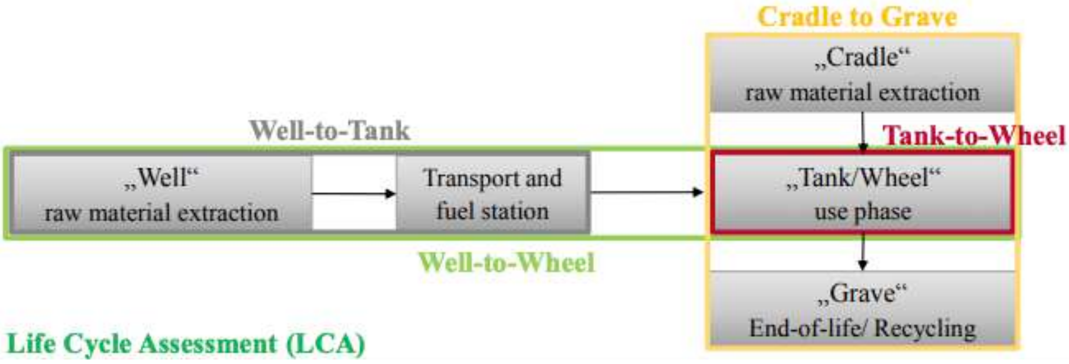


Figure 31 Life Cycle Assessment

In figure 32 below the well-to-whell analysis is depicted. On the X-Axis the energy consumption in kWh / 100km is depicted and on the Y-Axis the well-to-wheel greenhouse gas emissions are depicted.

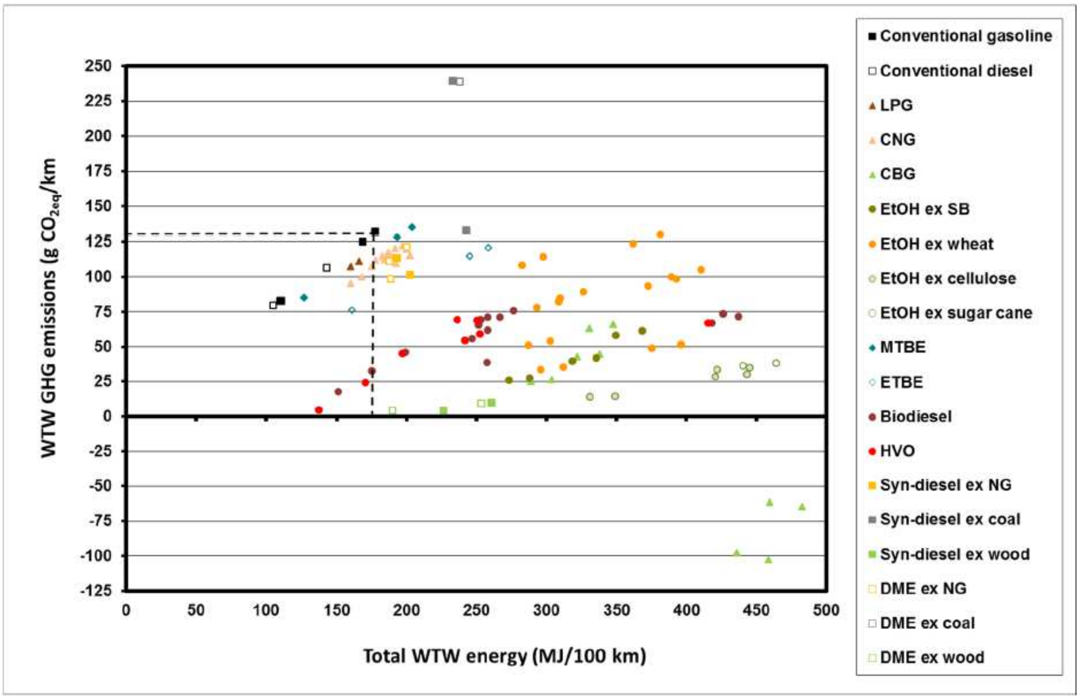


Figure 32 Well-to-Wheel Comparison (30)

Legend for picture 32 – well- to wheel comparison

EtOH	*Ethanol*
MTBE	*Methyl tert-butyl ether*
ETBE	*Ethyl tert-butyl ether*
HVO	*Hydrated Vegetable Oil (biofuel 3rd generation)*
DME	*Dimethyl ether*

The Austrian Environment Agency did 2015 a big comparison of several alternative fuel types. [60] Below the total greenhouse gas emissions of the different fuel types is depicted. In Appendix B the figures from the figure is shown. The Austrian energy has a high number of renewable energy resources (~72%), which has a significant effect on the balance for BEV and PHEV.

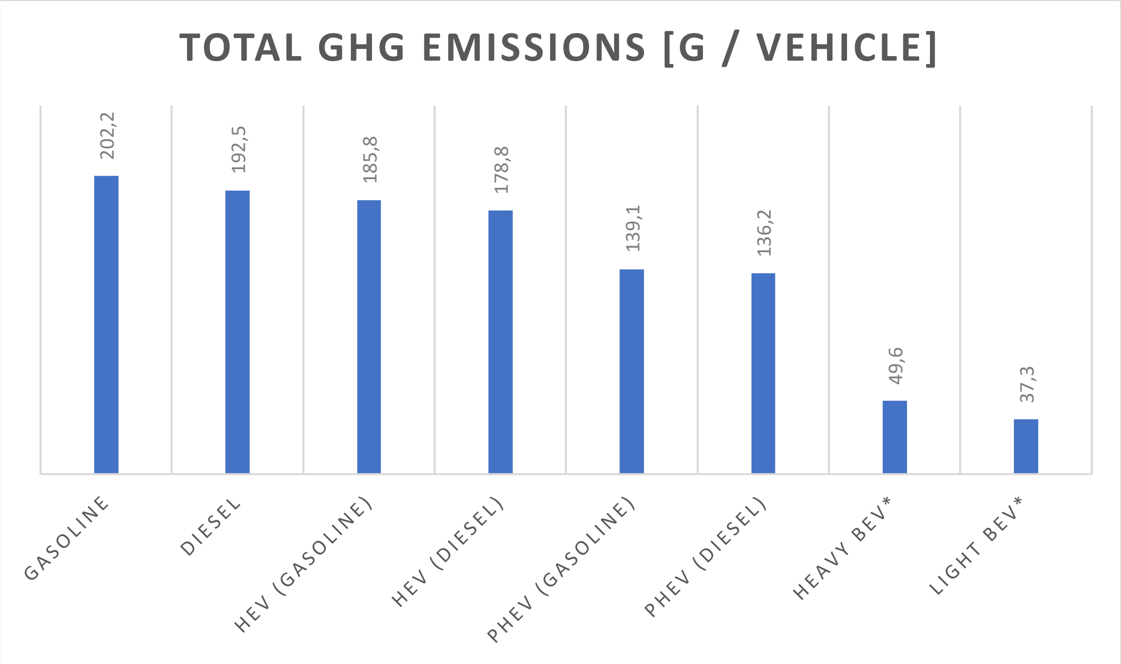


Figure 33 Total greenhouse gas emssions [60]

10.2.2. Limits of Realization

The different fuel types have different physical properties and energy densities. In picture __ below several physical properties are depicted and can be easily compared. For the technical realization of the different fuel types, it is from special interest, how large the storage volume or the storage mass should be. Several aspects from the mass and volume influence the practicability of usage and therefore the limits of realization. Safety aspects, material aspects, country specific costs of the energy carrier, storage- and transformation plants and especially the local infrastructure will influence the distribution of the different fuel types.

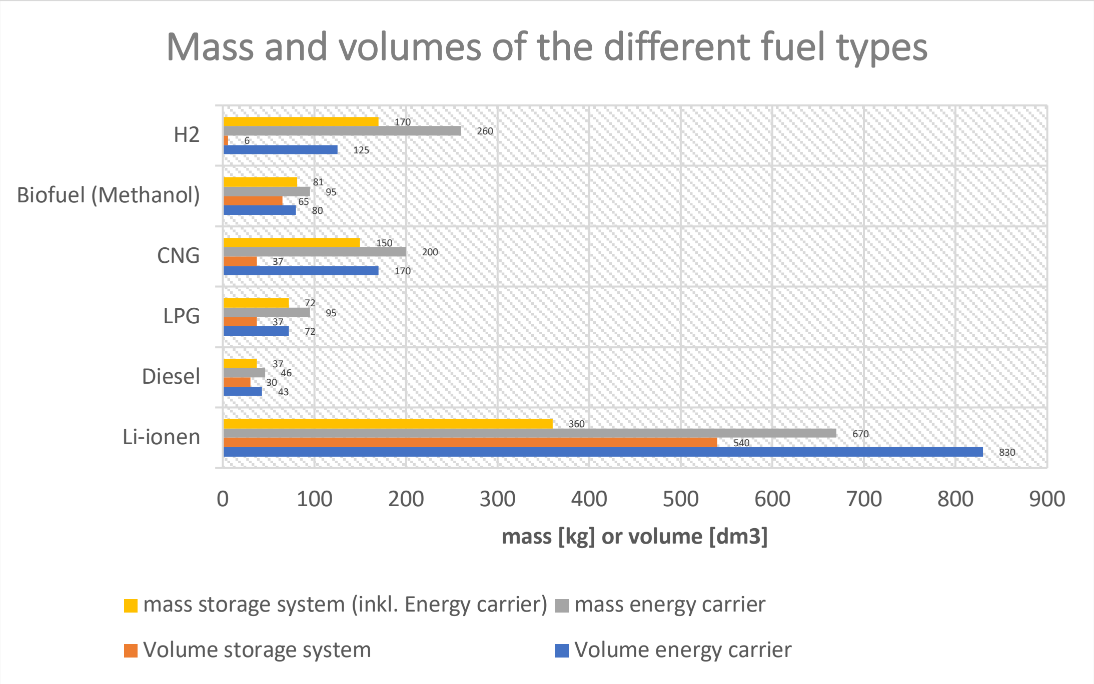


Figure 34 Mass and volume comparison

In the figure above a comparison that gives a conclusion about the different fuel types. The benchmark criteria mass storage system and volume storage system give a pragmatic overview how easy or how difficult it is to store the different fuel types. The comparison is based on 37-liter diesel fuel, which is related to the same amount of gasoline due the fact of more consumption and the lower density in relation to mass. The comparison is based on 37-liter diesel because an average middle-class car can reach around 500km and this should be the actual base for the comparison.

If a car is powered by LPG the volume and the mass of a filled tank is twice as high (72kg) as the one from a diesel car. Methanol as representative for biofuels, has around half of the energy density than diesel, therefore the amount of fuels doubles. The mass including the tank reaches 81kg. CNG needs a special tank, because of the pressure. A 37-liter equivalent in CNG has around 170 kg. The mass of the energy carrier is nearly the same for diesel (30kg), LPG (37kg) and CNG (37kg). Hydrogen has the lowest energy carrier mass 6kg but the mass of the whole system with a filled tank is 125 kg heavy.

The system with the most gap in it, is the storage system with lithium-ion batteries. A fully powered storage system needs around 830kg to reach the capacity of a 37-liter diesel system. If the number one criterion for evaluating the different fuel types the energy storage of an electrically driven car has no chance against a diesel-powered fuel, because the storage system requires nearly the mass of a compact vehicle.

10.2.3. Total Costs of Ownership

The total cost of ownership includes the acquisition costs and the operational costs for vehicles under certain circumstances. This method is used because conventional powered vehicles have less acquisition costs but the operational costs can differ, it depends on the environmental circumstances, like funding’s, taxes on fuel types, insurances and more.

Lebeau et. al. compared several vehicles powered by different fuel types against each other. The study was published in World electric vehicle journal and different classes of cars were compared. Purchasing cost, registration tax, vehicle road tax, maintenance, tires and technical control cost, insurance cost, battery leasing cost, battery replacement cost and fuel or electricity costs were included in their research.

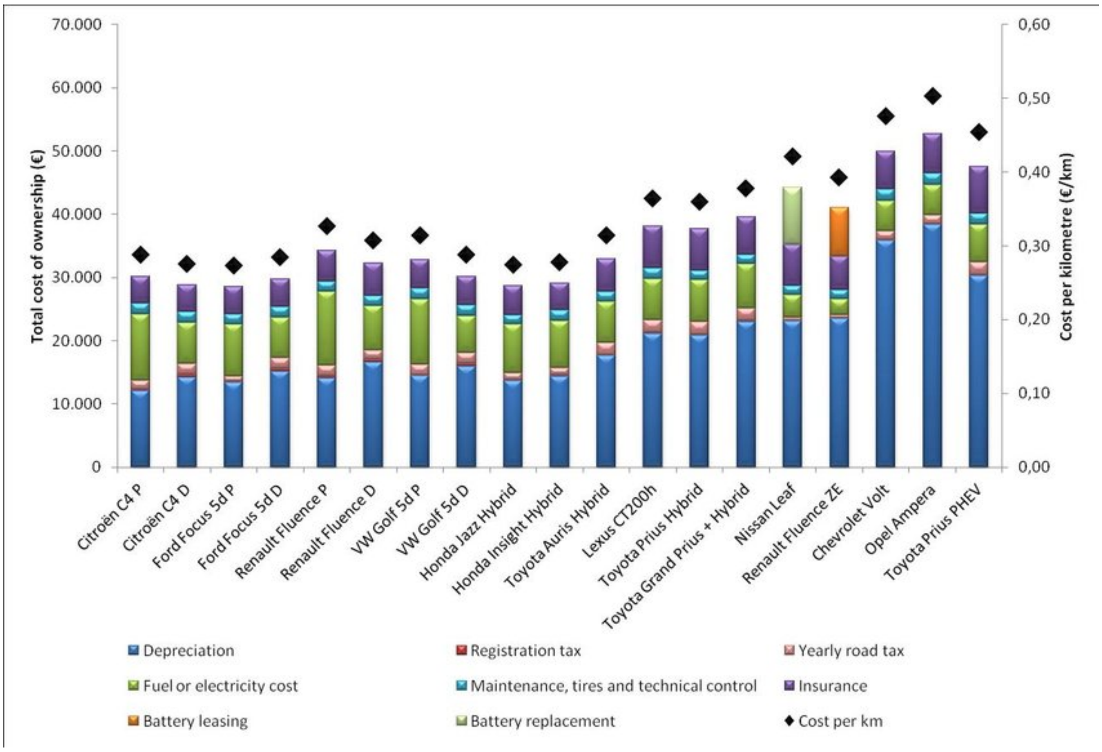


Figure 35 Total cost of ownership of medium class cars (32)

10.2.4. Summary

The final conclusion from the future scenarios was confirmed by the last chapter in which the different fuel types are compared. There will be a broad mixture the next years from vehicle types, every fuel type has his advantages and disadvantages. A big influence on the direction or the local distribution has actually the political representations with methods like funding's, tax regulations and more, as example the past shift from gasoline to diesel because of tax abatements should be mentioned. The actual research, that were presented in the certain topics, shows that electrically driven vehicle and also hybrid solutions have a high potential because of their emissions and the desired future electric situation (high renewable energy from own production – photovoltaic, …). Several indicators promise also good future conditions for other alternative fuel types (CNG, LNG, H2) because the transit traffic cannot be easily economically transformed into electrical driven vehicles. The classical combustion engine provides also enough improvement potential to reduce the emissions and fuel consumption. Overall the study gives a big overview of possible future fuel types and depicts the history of actual fuel types.

Appendix A

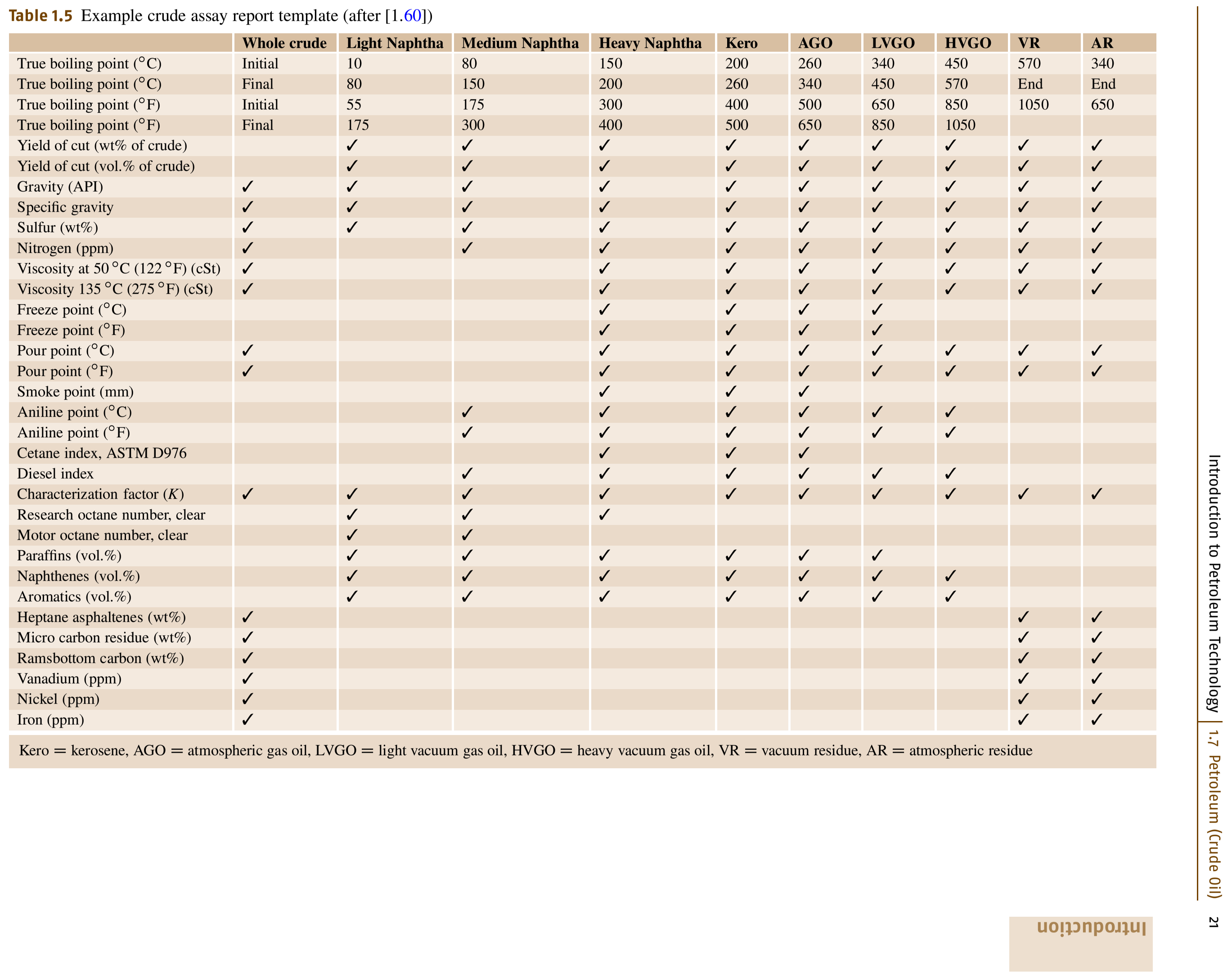


Table 1.5 Example crude assay report template (after [1.60])

	Whole crude	Light Naphtha	Medium Naphtha	Heavy Naphtha	Kero	AGO	LVGO	HVGO	VR	AR
True boiling point (°C)	Initial	10	80	150	200	260	340	450	570	340
True boiling point (°C)	Final	80	150	200	260	340	450	570	End	End
True boiling point (°F)	Initial	55	175	300	400	500	650	850	1050	650
True boiling point (°F)	Final	175	300	400	500	650	850	1050		
Yield of cut (wt% of crude)		✓	✓	✓	✓	✓	✓	✓	✓	✓
Yield of cut (vol.% of crude)		✓	✓	✓	✓	✓	✓	✓	✓	✓
Gravity (API)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Specific gravity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sulfur (wt%)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nitrogen (ppm)	✓		✓	✓	✓	✓	✓	✓	✓	✓
Viscosity at 50 °C (122 °F) (cSt)	✓			✓	✓	✓	✓	✓	✓	✓
Viscosity 135 °C (275 °F) (cSt)	✓			✓	✓	✓	✓	✓	✓	✓
Freeze point (°C)				✓	✓	✓	✓			
Freeze point (°F)				✓	✓	✓	✓			
Pour point (°C)	✓			✓	✓	✓	✓	✓	✓	✓
Pour point (°F)	✓			✓	✓	✓	✓	✓	✓	✓
Smoke point (mm)				✓	✓	✓				
Aniline point (°C)			✓	✓	✓	✓	✓	✓		
Aniline point (°F)			✓	✓	✓	✓	✓	✓		
Cetane index, ASTM D976				✓	✓	✓				
Diesel index			✓	✓	✓	✓	✓	✓		
Characterization factor (*K*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Research octane number, clear		✓	✓	✓						
Motor octane number, clear		✓	✓							
Paraffins (vol.%)		✓	✓	✓	✓	✓	✓			
Naphthenes (vol.%)		✓	✓	✓	✓	✓	✓	✓		
Aromatics (vol.%)		✓	✓	✓	✓	✓	✓	✓		
Heptane asphaltenes (wt%)	✓								✓	✓
Micro carbon residue (wt%)	✓								✓	✓
Ramsbottom carbon (wt%)	✓								✓	✓
Vanadium (ppm)	✓								✓	✓
Nickel (ppm)	✓								✓	✓
Iron (ppm)	✓								✓	✓

Kero = kerosene, AGO = atmospheric gas oil, LVGO = light vacuum gas oil, HVGO = heavy vacuum gas oil, VR = vacuum residue, AR = atmospheric residue

Source:
Chang Samuel Hsu, Paul R. Robinson, „Handbook of petroleum Technology", Springer, 2017, page 21

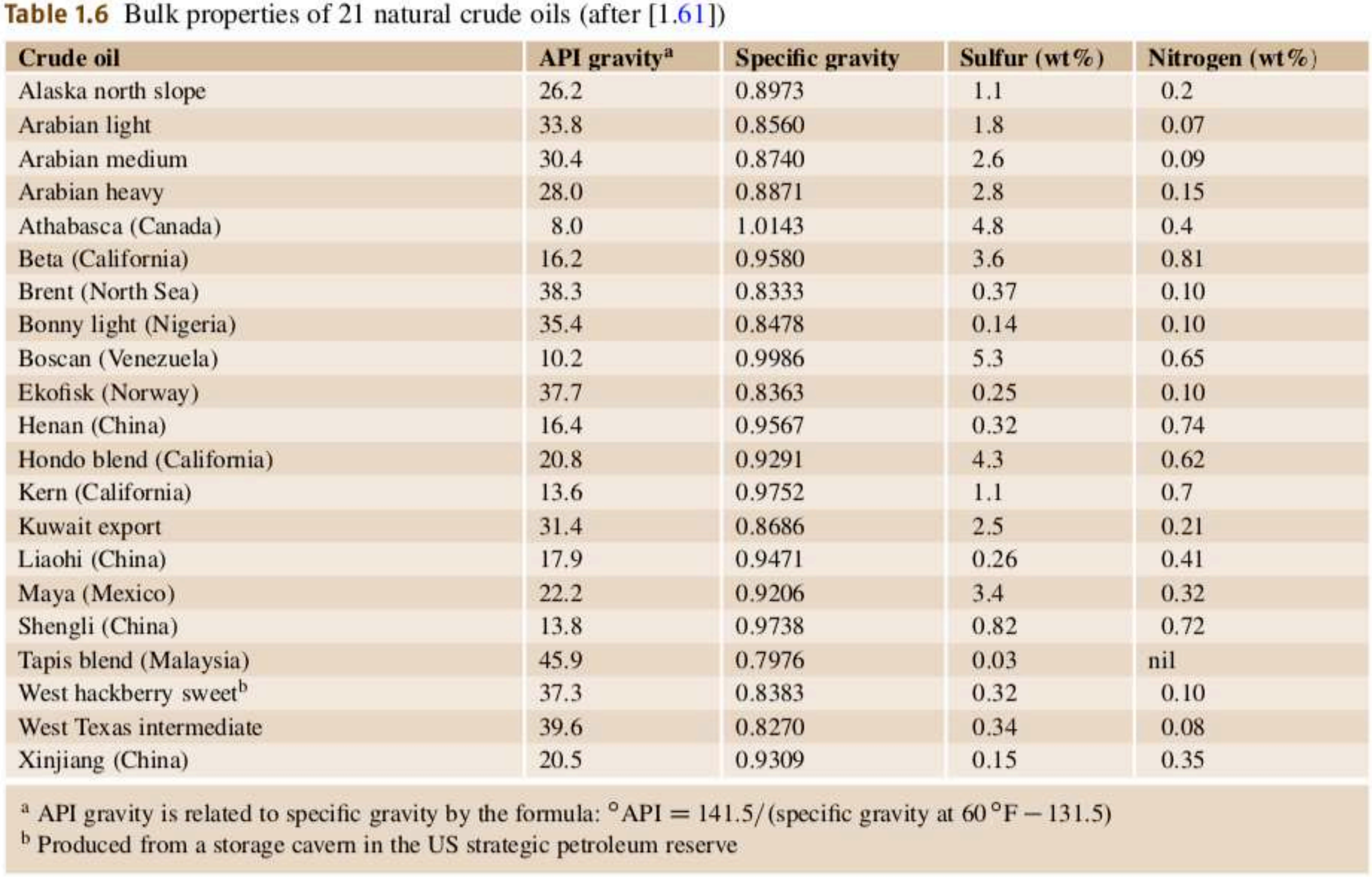


Table 1.6 Bulk properties of 21 natural crude oils (after [1.61])

Crude oil	API gravity[a]	Specific gravity	Sulfur (wt%)	Nitrogen (wt%)
Alaska north slope	26.2	0.8973	1.1	0.2
Arabian light	33.8	0.8560	1.8	0.07
Arabian medium	30.4	0.8740	2.6	0.09
Arabian heavy	28.0	0.8871	2.8	0.15
Athabasca (Canada)	8.0	1.0143	4.8	0.4
Beta (California)	16.2	0.9580	3.6	0.81
Brent (North Sea)	38.3	0.8333	0.37	0.10
Bonny light (Nigeria)	35.4	0.8478	0.14	0.10
Boscan (Venezuela)	10.2	0.9986	5.3	0.65
Ekofisk (Norway)	37.7	0.8363	0.25	0.10
Henan (China)	16.4	0.9567	0.32	0.74
Hondo blend (California)	20.8	0.9291	4.3	0.62
Kern (California)	13.6	0.9752	1.1	0.7
Kuwait export	31.4	0.8686	2.5	0.21
Liaohi (China)	17.9	0.9471	0.26	0.41
Maya (Mexico)	22.2	0.9206	3.4	0.32
Shengli (China)	13.8	0.9738	0.82	0.72
Tapis blend (Malaysia)	45.9	0.7976	0.03	nil
West hackberry sweet[b]	37.3	0.8383	0.32	0.10
West Texas intermediate	39.6	0.8270	0.34	0.08
Xinjiang (China)	20.5	0.9309	0.15	0.35

[a] API gravity is related to specific gravity by the formula: $^\circ\mathrm{API} = 141.5/(\text{specific gravity at } 60\,^\circ\mathrm{F} - 131.5)$

[b] Produced from a storage cavern in the US strategic petroleum reserve

Source:
Chang Samuel Hsu, Paul R. Robinson, „Handbook of petroleum Technology”,
Springer, 2017, page 22

Table 5 Euro fuel specifications

		Directive	EN 228	DIR 98/70	DIR 98/70	DIR 98/70	DIR 98/70
		Year	1993	1996	2000	2005	2009
Euro fuel specifications		Class	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
Aromatics	Vol %	Max	No limit	No limit	42	35	35
Olefins	Vol %	Max	No limit	No limit	18	18	18
Benzene	Vol %	Max	5	5	1	1	1
Oxygen	Wt %	Max	2.5	2.5	2.7	2.7	3.7
Sulfur	ppm	Max	1,000	500	150	50	10
RON		Min	91	92	93	94	95
RVP	kPa		35–100	35–100	60–70	60–70	60–70
Lead	g/l	Max	0.013	0.013	None	None	None

Source: Steven A., Peter Pujado, David Jones, “Handbook of Petroleum Processing”, Springer, 2015, page 238 - 240; ISBN 978-3-319-14528-0

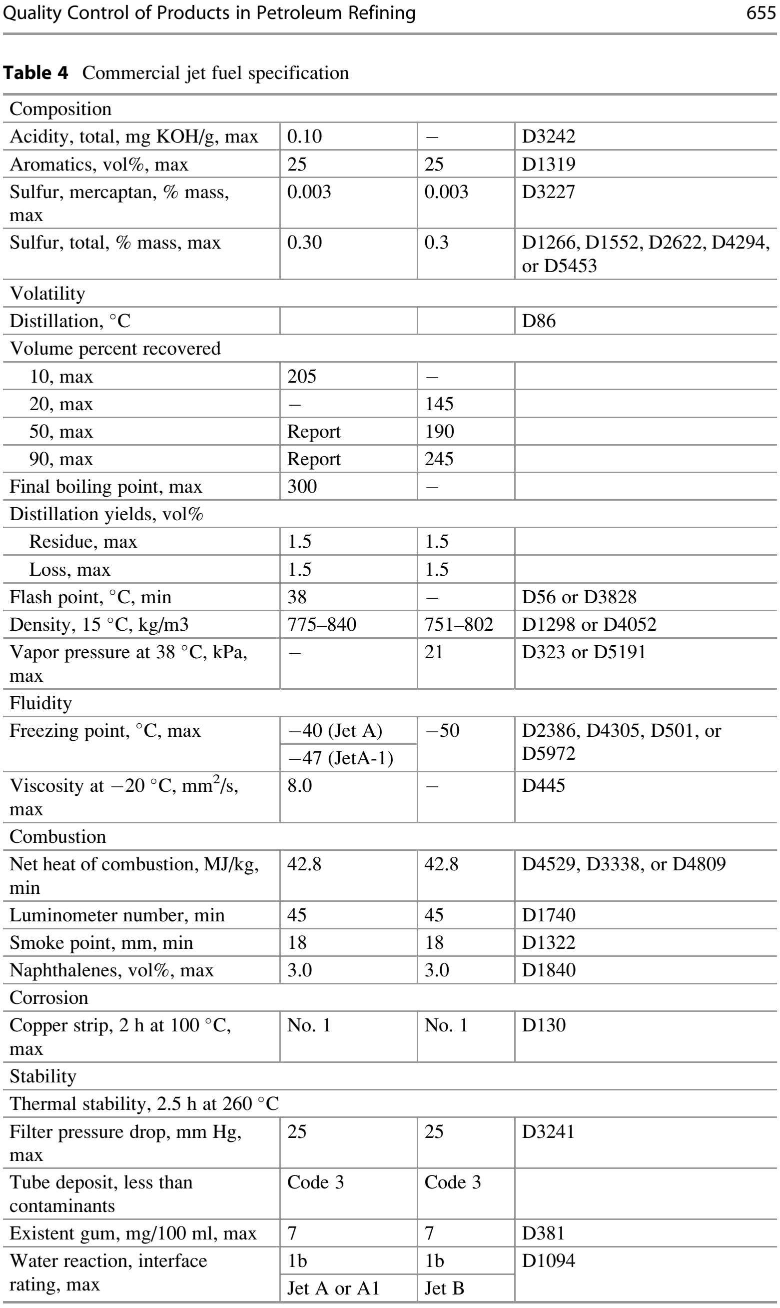


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Table 4 Commercial jet fuel specification

Composition			
Acidity, total, mg KOH/g, max	0.10	–	D3242
Aromatics, vol%, max	25	25	D1319
Sulfur, mercaptan, % mass, max	0.003	0.003	D3227
Sulfur, total, % mass, max	0.30	0.3	D1266, D1552, D2622, D4294, or D5453
Volatility			
Distillation, °C			D86
Volume percent recovered			
10, max	205	–	
20, max	–	145	
50, max	Report	190	
90, max	Report	245	
Final boiling point, max	300	–	
Distillation yields, vol%			
Residue, max	1.5	1.5	
Loss, max	1.5	1.5	
Flash point, °C, min	38	–	D56 or D3828
Density, 15 °C, kg/m3	775–840	751–802	D1298 or D4052
Vapor pressure at 38 °C, kPa, max	–	21	D323 or D5191
Fluidity			
Freezing point, °C, max	−40 (Jet A) −47 (JetA-1)	−50	D2386, D4305, D501, or D5972
Viscosity at −20 °C, mm^2/s, max	8.0	–	D445
Combustion			
Net heat of combustion, MJ/kg, min	42.8	42.8	D4529, D3338, or D4809
Luminometer number, min	45	45	D1740
Smoke point, mm, min	18	18	D1322
Naphthalenes, vol%, max	3.0	3.0	D1840
Corrosion			
Copper strip, 2 h at 100 °C, max	No. 1	No. 1	D130
Stability			
Thermal stability, 2.5 h at 260 °C			
Filter pressure drop, mm Hg, max	25	25	D3241
Tube deposit, less than contaminants	Code 3	Code 3	
Existent gum, mg/100 ml, max	7	7	D381
Water reaction, interface rating, max	1b	1b	D1094
	Jet A or A1	Jet B	

Source: Steven A., Peter Pujado, David Jones, "Handbook of Petroleum Processing", Springer, 2015, page 654; ISBN 978-3-319-14528-0

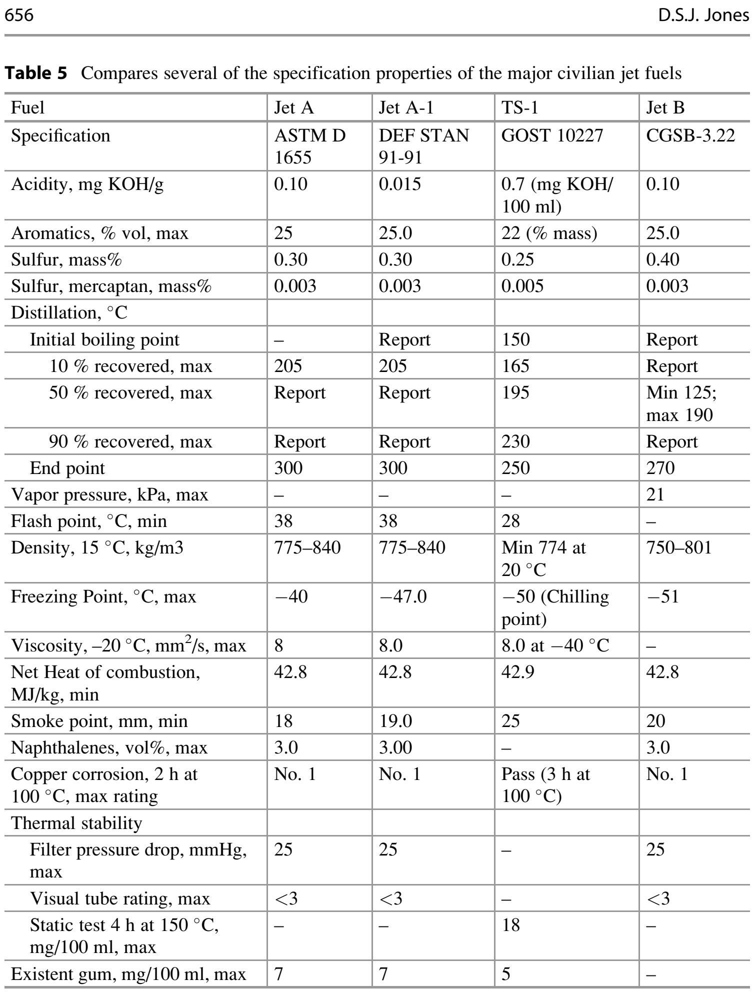

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Table 5 Compares several of the specification properties of the major civilian jet fuels

Fuel	Jet A	Jet A-1	TS-1	Jet B
Specification	ASTM D 1655	DEF STAN 91-91	GOST 10227	CGSB-3.22
Acidity, mg KOH/g	0.10	0.015	0.7 (mg KOH/ 100 ml)	0.10
Aromatics, % vol, max	25	25.0	22 (% mass)	25.0
Sulfur, mass%	0.30	0.30	0.25	0.40
Sulfur, mercaptan, mass%	0.003	0.003	0.005	0.003
Distillation, °C				
Initial boiling point	–	Report	150	Report
10 % recovered, max	205	205	165	Report
50 % recovered, max	Report	Report	195	Min 125; max 190
90 % recovered, max	Report	Report	230	Report
End point	300	300	250	270
Vapor pressure, kPa, max	–	–	–	21
Flash point, °C, min	38	38	28	–
Density, 15 °C, kg/m3	775–840	775–840	Min 774 at 20 °C	750–801
Freezing Point, °C, max	−40	−47.0	−50 (Chilling point)	−51
Viscosity, –20 °C, mm^2/s, max	8	8.0	8.0 at −40 °C	–
Net Heat of combustion, MJ/kg, min	42.8	42.8	42.9	42.8
Smoke point, mm, min	18	19.0	25	20
Naphthalenes, vol%, max	3.0	3.00	–	3.0
Copper corrosion, 2 h at 100 °C, max rating	No. 1	No. 1	Pass (3 h at 100 °C)	No. 1
Thermal stability				
Filter pressure drop, mmHg, max	25	25	–	25
Visual tube rating, max	<3	<3	–	<3
Static test 4 h at 150 °C, mg/100 ml, max	–	–	18	–
Existent gum, mg/100 ml, max	7	7	5	–

Source:

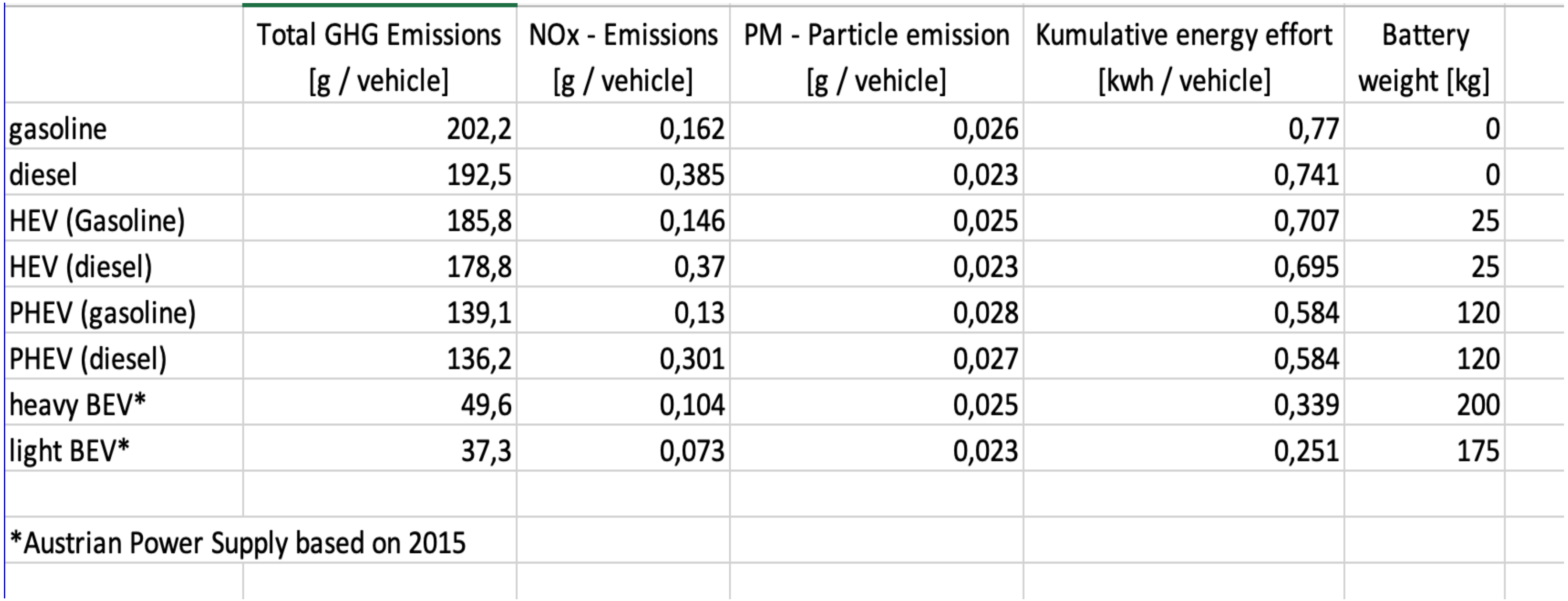
Steven A., Peter Pujado, David Jones, "Handbook of Petroleum Processing", Springer, 2015, page 655; ISBN 978-3-319-14528-0

Sulfur content in diesel fuels – 2013 / 2014

Diesel fuel	<10	<10	<50	<500	>500
Sulfur in ppm	Albanien	Moldawien	Ukraine	Georgien	Armenien
Europe + GUS	Belgien	Montenegro		Kasachstan	Aserbaidschan
	Bulgarien	Niederlande		Usbekistan	Kirgistan
	Dänemark	Norwegen			Tadschikistan
	Deutschland	Österreich			Russland
	Estland	Polen			Turkmenistan
	Finnland	Portugal			
	Frankreich	Rumänien			
	Griechenland	Russland			
	GB	Schweden			
	Irland	Schweiz			
	Island	Serbien			
	Italien	Slowakei			
	Kroatien	Slowenien			
	Lettland	Spanien			
	Litauen	Tschechien			
	Luxemburg	Türkei			
	Malta	Ungarn			
	Mazedonien	Weißrussland			
Australien + Ozeanien	Australien	Neuseeland		Fidschi-Inseln	
	Neukaledonien			Papua-Neuguinea	
Asien	China	Südkorea	China	Brunei	Sri Lanka
	Hongkong	Taiwan	Indien	Indien	
	Japan		Sri Lanka	Malaysia	
	Macao		Thailand	Philippinen	
	Singapur			Vietnam	
Afrika			Marokko	Kenia	Algerien
			Mauritius	Madagaskar	Gabun
			Südafrika	Malawi	Libyen
			Tunesien	Mosambik	Tunesien
				Simbabwe	
				Südafrika	
				Tansania	
Mittlerer Osten	Israel			Bahrain	Jordanien
	Palästina			Libanon	
				Oman	
				Katar	
				Saudi-Arabien	
				Vereinigte Arabische Emirate	
Nordamerika	Kanada	USA			
Lateinamerika	Argentinien		Dominikanisc	Brasilien	Argentinien
	Brasilien		Kolumbien	Costa Rica	Bolivien
	Chile		Uruguay	Ecuador	Honduras
	Mexiko			Guatemala	Trinidad Tobago
				Mexiko	
				Panama	
				Paraguay	
				Peru	

Source: https://roadstars.mercedes-benz.com/ultra-low-sulfur-diesel-landingpages-de

Appendix B



	Total GHG Emissions [g / vehicle]	NOx - Emissions [g / vehicle]	PM - Particle emission [g / vehicle]	Kumulative energy effort [kwh / vehicle]	Battery weight [kg]
gasoline	202,2	0,162	0,026	0,77	0
diesel	192,5	0,385	0,023	0,741	0
HEV (Gasoline)	185,8	0,146	0,025	0,707	25
HEV (diesel)	178,8	0,37	0,023	0,695	25
PHEV (gasoline)	139,1	0,13	0,028	0,584	120
PHEV (diesel)	136,2	0,301	0,027	0,584	120
heavy BEV*	49,6	0,104	0,025	0,339	200
light BEV*	37,3	0,073	0,023	0,251	175

*Austrian Power Supply based on 2015

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