HØJE-TAASTRUP GOING GREEN

GAS

APPLICATION FOR FREIGHT TRANSPORT

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Preface

Today's transport sector is heavily dependent on fossil fuels, which causes significant increases in air pollution. This is in particular crucial in urban areas with high density of transportation. The transition towards alternative fuels is a key factor to fight pollution and to achieve decarbonisation, sustainability and competitiveness of the transport sector.

In Denmark, Høje-Taastrup Municipality is especially concerned and proactive in this area. The project Høje-Taastrup Going Green was launched on 1st of January 2014, where one of the main goals is promoting a fossil free transport sector. Particularly the freight sector is targeted due to the high level of pollution it creates.

A main objective of the project is to create a platform for further use and development of alternative fuels in the freight transportation sector. A special focus is therefore on illustrating the possibilities and perspectives of the alternative fuels: electricity, hydrogen, gas (CNG, LNG and biogas) and biodiesel. At the moment, the application of alternative fuels is not competitive with traditional fossil based propellants. Thus, it is important to prospectively set up the framework and establish the infrastructure to integrate and foster alternative fuels in Høje-Taastrup Municipality.

In line with the project, a set of catalogues of different propellants were developed, focusing on the utilisation of electricity, hydrogen, gas and biodiesel for freight vehicles. Each catalogue analyses the propellant in terms of technology, environmental impact, economics and related policy instruments, in order to point out its applicability and hurdles.

The following catalogue will elaborate on gas driven vehicles.

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1 OVERVIEW

1.1 EU and Danish Goals and Targets

The EU's goal is to reduce emissions by 80 to 95% by 2050 compared to 1990 levels. The transport sector is a significant and still growing source of greenhouse gas (GHG) emissions. Therefore, a reduction of at least 60% of GHGs by 2050 with respect to 1990 is required from the transport sector, which is then followed by a comparable reduction in oil dependency. In order to achieve the target, the EU white paper on transport includes these relevant goals:

- "Halve the use of 'conventionally fuelled'[1] cars in urban transport by 2030;
- Phase them out in cities by 2050;
- Achieve essentially CO_2-free city logistics in major urban centres by 2030". [1]

To strengthen this, Denmark has a challenging goal to reach 100% fossil fuel independence within the transport sector by 2050. Regarding this, almost the entire vehicle fleet needs to become zero-emission.

As a fact, EU transport is 95% dependant on oil and its products. Figure 1 illustrates the final energy consumption in the transport sector in 2011 by type of fuel and emphasise the need of taking actions towards greener transport.

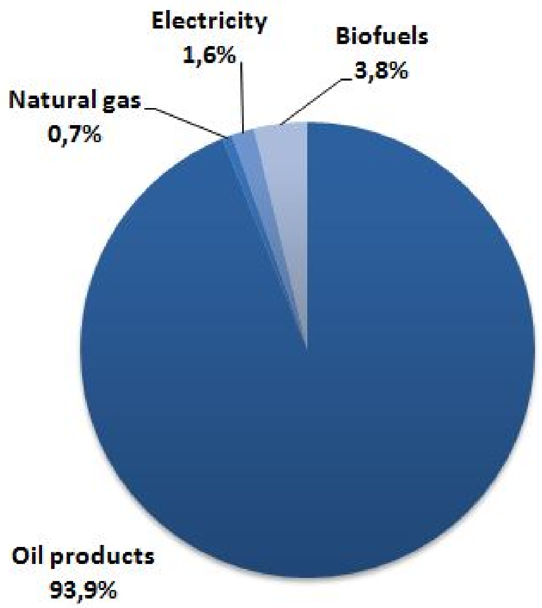

Figure 1: Final energy consumption in EU transport sector by type of fuel

[1] The term refers to vehicles using non-hybrid, internal combustion engines.

1.2 Application of Alternative Fuels

The transport sector cannot rely only on one single type of alternative fuel. In the long run, it should be based on a mix of several different fuels, with respect to the needs of each transport mode. The coverage of travel range by different alternative fuels is summarised in Table 1 for urban, light-duty and heavy-duty vehicles. Biofuels stand for biodiesel and methane stands for CNG/CBG (compressed natural gas/biogas) and LNG/LBG (liquefied natural gas/biogas). [2]

Vehicle							
Range	Urban	Short	Medium	Long	Short	Medium	Long
Electricity							
Hydrogen							
Biofuels							
Methane							LNG/LBG

Table 1: Application of alternative fuels for different transport modes [2]

To conclude, electricity can be applied only for short travel distances, hydrogen and CNG/CBG up to medium distances, and biofuels and LNG/LBG up to long distances. [2]

Electricity, both battery vehicles and fuel cell vehicles, is expected to be applied mainly for the car fleet. Regarding heavy-duty transport, biofuels and methane are prioritised due to the technical reasons. As a result, for the freight transport sector, in particular for long-distance transportation, limited alternative fuels are available. [2]

However, the set of catalogues examines all the different alternative fuels (electricity, hydrogen, biodiesel, CNG/CBG and LNG/LBG) and their possibility to be applied to heavy-duty vehicles.

2 INTRODUCTION

One of the options for the transport sector to meet the abovementioned targets is the application of gas. In particular it is relevant to heavy-duty transport. The topic includes compressed natural gas (CNG), liquefied natural gas (LNG) as well as biogas, which is an emerging form of transport fuel. Transition from fossil fuel based sources to renewable energy implies that, in a long run, biogas has to gradually replace natural gas in any form of fuel (CNG to CBG and LNG to LBG). As an alternative fuel, gas is emphasised to play a significant role in boosting energy security, reducing oil dependency and the carbon footprint, both national and European-wide.

At the moment, there are one million natural gas vehicles in the EU, which represents 0,5% of the entire fleet. [3] In Denmark, in July 2014 there were around 100 CNG and no LNG vehicles on the roads. [4]

2.1 Fuel Production Method and Availability

Gas is a gaseous mixture of hydrocarbons, mainly methane (CH_4), and covers both natural gas and biogas. The methane coming from the ground is known as natural gas and is based on fossil sources, while methane produced from organic matter by biological processes is known as renewable natural gas or biogas.

Natural gas comes from sources formed over millions of years by the heat and pressure on buried organic materials, such as plants or animals. Natural gas occurs in the pores of certain rocks, which is found during geological explorations. It can be then extracted from the subsurface by drilling wells. Natural gas rises to the surface due to its tendency to fill areas with lower pressure. It can also be produced in conjunction with crude oil production. Typically natural gas contains mainly methane with the rest part covered by other hydrocarbons, carbon dioxide (CO_2) or hydrogen sulphide (H_2S). Danish natural gas has 90-97% methane [5]. Once collected, it should go under treatment process to remove impurities, non-methane hydrocarbons and fluids in order to meet the quality to be fed into the grid. [6]

Biogas production is based on biomass, which is mainly liquid manure and organic waste in Denmark. Biodegradable material is decomposed in an anaerobic environment, meaning absence of oxygen, in the fermentation tanks (digesters), where biogas is generated using bacteria ferments. Material has to be constantly heated and stirred to ensure homogeneity and consistent discharge of gas. Raw biogas typically contains 50-80% methane and 20-50% carbon dioxide (CO_2) and other compounds [5]. This gaseous bi-product is then collected to a steel container that cuts off air to the digesters to ensure anaerobic conditions. The rest of non-digestible material from the digester is collected as sludge. [7, 8]

Finally biogas needs to be upgraded to meet the specifications of the natural gas grid (over 97,3% methane with the rest of CO_2). It means unwanted compounds, such as mainly CO_2 as well as water and H_2S, need to be removed to purify biogas. [5] Generally, CO_2 restrains compressibility of gas, lowers the power output while H_2S and moisture can easily cause corrosion. [9]

There are several technologies for biogas upgrading. Water scrubber is the most widely used technology and is applied for the first biogas upgrading plant in Denmark, Fredericia. [10] Unlike some of the other technologies, water scrubbing does not require gas pre-cleaning and heat for the process. It is based on physical absorption of CO_2 and H_2S in water at pressure of up to 9-10 bar, when water is fed to the scrubber from the top to bottom and contacts with biogas coming from the bottom. During this process, around 1-

2% of methane is lost. Finally, the purity of 95-98% of methane is achieved. What is important, both initial and operating costs are lower compared to other technologies and require minimum maintenance. [9] Schematic representation of water scrubber, installed in Fredericia, Denmark, is given in Figure 2.

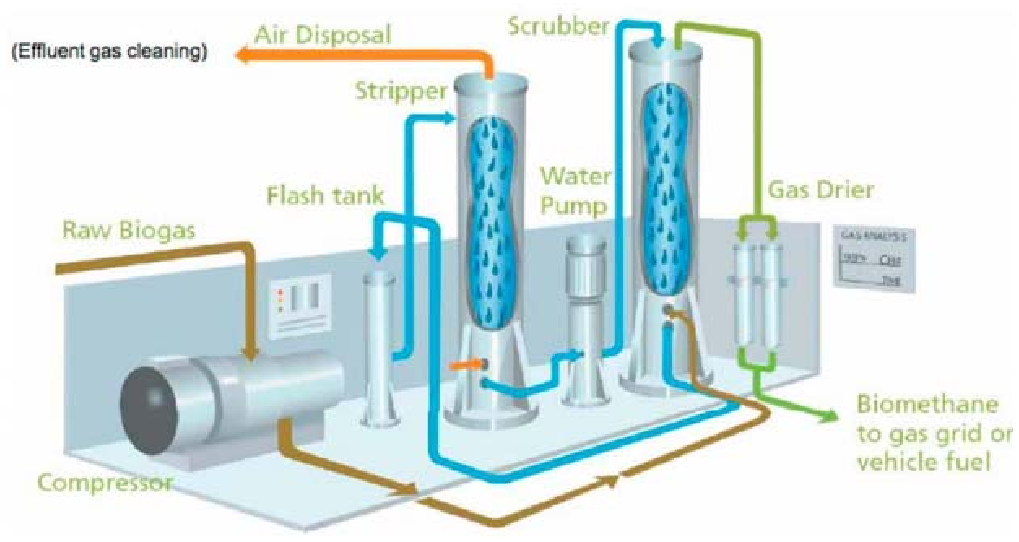

Figure 2: Water scrubber for biogas upgrading [11]

In Fredericia biogas upgrading plant, the raw biogas cleaned from the condense water, is fed into the upgrading plant and compressed under the pressure of 6 bar. The compressed gas is then scrubbed with the water in the scrubber. Since water absorption of CO_2 under pressure is significantly higher than absorption of methane under the same conditions, CO_2, H_2S and other substances bind to water. During this process biogas is purified and reaches a quality to meet the requirements and can be injected into the gas grid. Meanwhile, the process water is fed to the stripper, a device where the pressure is removed and therefore CO_2, H_2S and other substances are stripped from the water. The water is recycled and reused, putting it back to the scrubber. Removed substances are captured from water and the exhaust air is cleaned from small amounts of methane converting it to CO_2 and water. [11]

After biogas undergoes a purification process, it is fed into the natural gas network with no restrictions on blending ratio. If necessary, small amount of propane is added to biomethane in order to reach the same required energy content as for natural gas. [5]

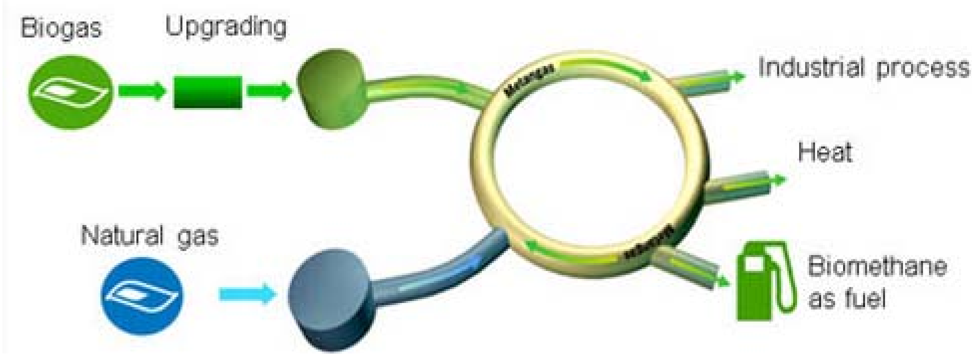

Figure 3: Biogas injection into natural gas grid [12]

A renewable gas certificate is applied to all biogas introduced to the gas grid. For instance, the gas station selling biogas to the consumer has to buy corresponding number of renewable gas certificates. [10] Biogas is an emerging fuel, which production is considered sustainable, renewable and carbon neutral, since it is a part of natural carbon cycle: plants and animals only emit CO_2 they have accumulated during their life time. Both mixing biogas with natural gas and direct replacement help to meet the target of a renewable energy based transport sector. Therefore biogas should gradually replace natural gas under sustainability criteria in order to be in line with the goals towards fossil free future.

Due to the gaseous nature of gas, it should be in a compressed gaseous or liquefied form, CNG and LNG respectively, in order to boost the energy density and apply it to the vehicles. Volumetric comparison between diesel, CNG and LNG, containing the same amount of energy, can be seen in Figure 4.

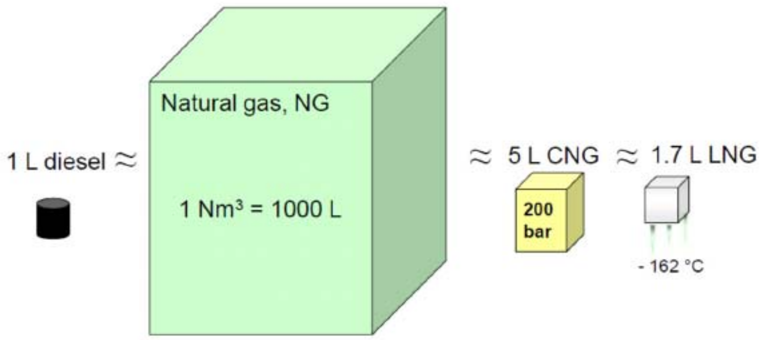

Figure 4: Volumetric comparison of diesel, CNG and LNG

For CNG, natural gas needs to be compressed up to around 200-250 bar to reach less than 1% of the volume it takes under standard atmospheric pressure. [4]

Regarding LNG, methane has to be handled as a cryogenic liquid. For liquefaction, natural gas is cooled down to -160°C at ambient pressure and then kept insulated to avoid temperature losses, which is necessary to keep the liquid state. In contrast to CNG, LNG on-board is stored under low pressure from close to atmospheric and up to 20 bar. Due to its liquid form, LNG has a much higher energy density, which enables LNG to be applied for medium or long distance road transport. However, at the moment, it is mainly applied as propellant for ships, substituting high-sulphur bunker fuel and complying with the requirements for cleaner fuels. Also, Danish ports and shipping companies express an interest in LNG due to its lower SO_2 emissions compared to the conventional fuel for shipping. [2]

2.1.1 Gas Production in Denmark

The first natural gas for the Danish customers came from Germany, until the supply from the Danish gas fields in the North Sea area started in 1984. Today, Denmark is self-sufficient regarding natural gas, which is produced from five fields in the Danish North Sea. The gas grid covers most of the country, except a few islands, including Lolland and Falster. Moreover, the Danish natural gas grid is connected to the European grid and has two natural gas storages, which means that there is a high level of supply security. [5]

Natural gas is transported from ashore to the mainland through two 200 km high pressure transmission pipes under water. In Nybro (western part of Denmark) at a gas treatment plant the gas is purified from liquids and sulphur, the pressure is decreased and gas is ready to be transported to the rest of the country or exported via the transmission network. The transmission system in Denmark has a capacity of 8 billion nm^3 per year. In general, the transmission network has the pressure of 50-80 bar, which is reduced to 50, 40 or 19 bar for distribution network and later on, to up to 7 bar for distribution pipes close to the end consumers. [5]

In 2012 natural gas covered one-fifth of Denmark's gross energy consumption. Natural gas is mainly used for power generation and heating. There is also a significant export of natural gas to Sweden, Germany and Netherlands. [5]

All Danish natural gas comes from the Danish part of the North Sea. Dansk Olie and Naturgas A/S (DONG) and Energinet.dk are responsible for transportation and distribution of gas to customers along with the three regional gas distribution companies: HMN Naturgas, DONG Distribution and Naturgas Fyn A/S. [5]

The Danish natural gas reserves in the North Sea are foreseen to be sufficient with a surplus production until 2025 (see Figure 5). After that year a lower self-sufficiency is expected. However, according to the Danish Energy Agency, gas reserves are expected to increase due to increased exploration and improvements in technological extraction, so that natural gas supply is ensured for a longer period. [5]

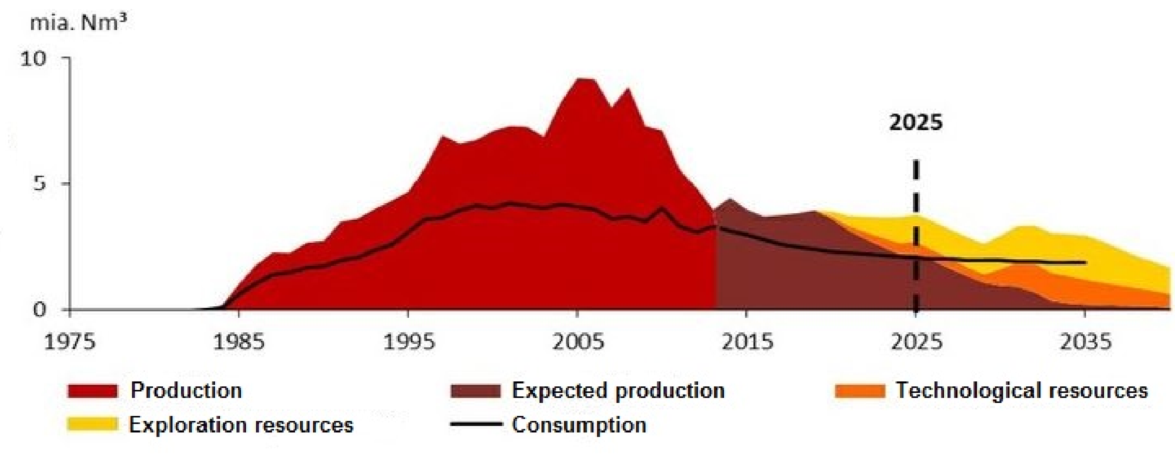

Figure 5: Danish natural gas production [5]

Regarding biogas, Denmark is well known for its wide biogas production and use of this in combined heat and power plants. However, in order to apply it for the transport sector, it should be additionally upgraded before injecting into the natural gas grid. At the moment, there are only a few biogas upgrading plants in Denmark. The first one was established in 2011 in Fredericia, as mentioned before, upgrading biogas produced by the municipality's waste water treatment plant. In the beginning of 2014, HMN Naturgas opened its first upgrading plant near Hjørring, where manure from cows, pigs and chicken are mixed with straw and grass to produce biogas, which is later upgraded to meet the grid requirements. The annual amount of upgraded biogas recently reached 8,2 million m^3. [13]

3 TECHNOLOGY

CNG vehicles are the most common due to the cheaper CNG technology compared to LNG and reasonable refuelling infrastructure. CNG vehicles are prioritised for short and medium distance transport. Whereas LNG is not widespread at the moment, yet it is considered as a fuel for long distance hauling vehicles and especially maritime transport in the future. [3]

3.1 Technology Description

Natural gas vehicles (NGV) use mature technology of traditional internal combustion engine, both converted from conventional vehicle and manufactured by OEMs (original equipment manufacturers). There are three different types of NGVs, as shown in Table 2.

Type	Technology	Mainly used for
Dedicated	- Runs only on natural gas	- Light-duty - Heavy-duty
Bi-fuel	- Two separate fuelling systems - Runs on either natural gas or petrol - Typically, petrol is used for ignition to start the engine - Mainly seen in converted vehicles.	- Light-duty
Dual-fuel	- Two separate fuelling systems - Runs on the mixture of natural gas and diesel - Diesel is used for ignition assistance	- Heavy-duty

Table 2: Types of natural gas vehicles [6]

Light-duty CNG vehicles (dedicated or bi-fuel) are based on spark-ignited engines and work similarly to petrol powered vehicles (see Figure 6). Natural gas is introduced to the high pressure storage tank (B) on the vehicle through the fill valve (A). Natural gas is transferred from the tank to the engine through the high-pressure fuel line (D). The regulator (E) reduces the pressure to comply with the required injection system pressure. The valve (F) allows or shuts down the flow of natural gas. Natural gas mixed with air passes through carburettor and enters the engine, where it is compressed and spark-ignited from a spark plug. Due to the forces created by expanding gases the vehicle is propelled. Element (C) is a manual shut-off valve. [6]

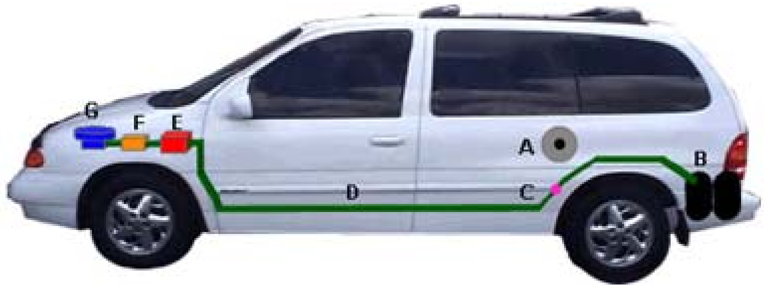

Figure 6: Schematic of natural gas vehicle fuelling system [6]

As mentioned before, LNG is mainly applied for heavy-duty vehicles. Some heavy-duty vehicles can also use spark-ignition systems, but compression-ignition systems are more common. Traditionally, this system is applied for the diesel vehicles, where the combustion process is initiated by the heat which is generated from compression, without any external spark. In case of NGV, a small amount of diesel is injected directly to the combustion chamber under high-pressure in addition to natural gas, which is introduced into the air intake, thereby assisting the ignition process (dual-fuel system). One advantage of LNG vehicle is that it can run on diesel if the gas tank is empty. [6]

LNG vehicle fuelling system, from the tank to the engine, is similar to that of CNG once LNG is vaporised (warmed back to its gaseous status), since the gas fed into the engine needs to be in gaseous form. [12]

Due to the technology, CNG vehicles are suitable for shorter distances, meaning that urban distribution can benefit from CNG, while long distance transportation can rely on LNG. Figure 7 illustrates the driving range which can be obtained by the vehicles with different technology. [14]

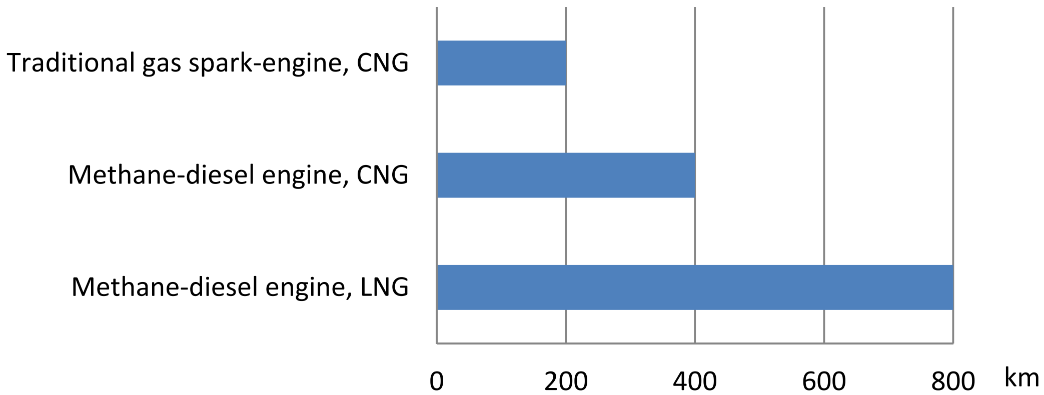

Figure 7: Driving range in relation to the technology [14]

Technology, of both vehicles and filling stations, are already well developed in the neighbouring countries, such as Germany, Sweden or UK. Therefore, Denmark can exploit its knowledge and experience and apply it to Danish transport system in a more economically and logistically effective way. [15]

3.2 Main Characteristics

3.2.1 Fuel

Natural gas mainly consists of methane CH_4, which is the simplest hydrocarbon. It is lighter than air, invisible and odourless. It has a lower energy density compared to petrol or diesel and therefore, the driving range obtained by NGVs is shorter than that of comparable conventionally powered vehicles. [6]

As mentioned previously, natural gas is used in CNG or LNG forms. As a rule, LNG is 2-3 times more energy dense compared to CNG. [6]

The main characteristics of gas as an alternative fuel for vehicles are presented in Annex.

3.2.2 Tank

NGVs require a storage tank for the natural gas. In case of dedicated technology, only one cylinder for natural gas is installed. In case of bi-fuel and dual-fuel technology, an additional conventional fuel tank is installed, resulting in a heavier vehicle and reduced cargo capacity compared to the dedicated NGV technology. On the other hand, it enables to prolong the driving range, as it is possible to continue driving on conventional fuel when running out of natural gas by pressing an automatic switch. [6]

Typically, the driving range of an NGV is comparable to that of conventional vehicle. However, they require larger fuel storage tank to hold the same amount of energy. LNG vehicles though require smaller fuel tank to obtain the same driving range compared to CNG vehicles, since LNG has higher energy density. [6] The needed fuel tank size is determined by the vehicle's duty cycle.

CNG is stored and transported in cylinders or spherical shaped tanks under 200-250 bar pressure. Due to this high pressure, the tanks are made of durable materials with safety controls and require inspection on a regular basis. [16]

Due to the fact that LNG is cooled down up to -160°C, the storage tanks on-board require thermal insulation in order to keep the gas cooled. Double-wall insulated tanks on-board are therefore used. [16] Both CNG and LNG cylinders are usually integrated below the trunk or other parts of the vehicle. [4]

3.2.3 Engine

The engines of heavy-duty vehicles generally have a higher efficiency than passenger vehicles, because their engine is energy optimised for its use. A comparison between the efficiency of different fuel powered heavy-duty vehicles is given in Figure 8, based on the report "Alternative drivmidler" published by Danish Energy Agency in 2013. Natural gas vehicles are slightly less efficient compared to diesel vehicles: 32,8% and 34,8% respectively in 2010. For trucks, gas is the most competitive fuel compared to other alternative fuels. However, public buses running on CNG have lower energy efficiency due to the urban driving conditions, i.e. many starts and stops. This should be taken into consideration when dealing with delivery trucks in urban areas due to similar driving patterns. [17] In the graph, RME stands for rapeseed methyl ester (biodiesel), DME – dimethyl ether (synthetic biofuel).

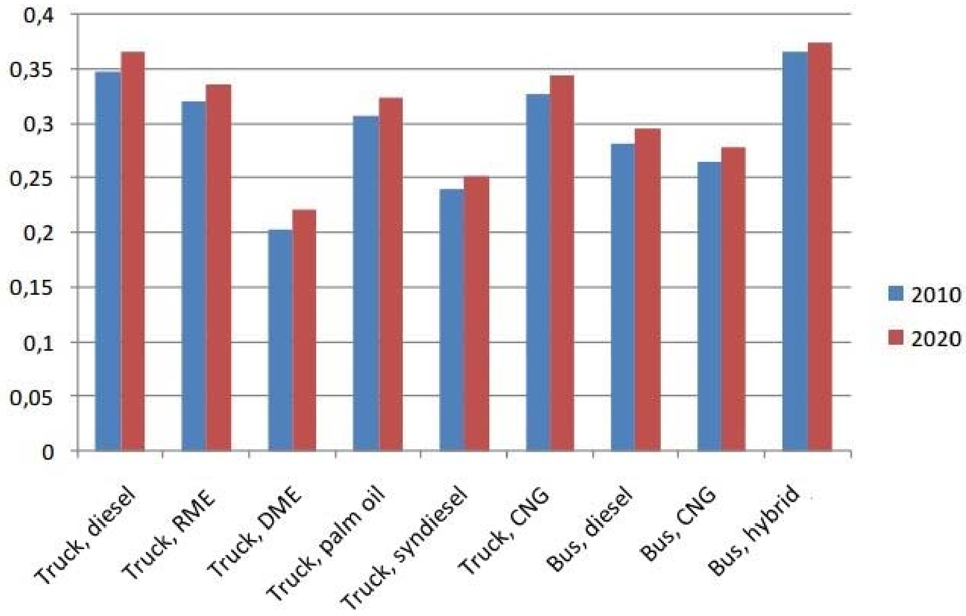

Figure 8: Energy efficiency for heavy-duty vehicles in 2010 and 2020, % [17]

LNG vehicles are not included since it does not exist in the Danish market yet. However, Volvo manufacturer argues that their LNG driven trucks have a 30-40% more efficient gas combustion compared to spark-ignited engines. [14]

Figure 9 compares the torque and power of Scania trucks, powered by gas and diesel. Scania is one of the largest heavy-duty vehicles manufacturers in Denmark. [18] NGVs are competitive with conventional vehicles in terms of power, torque and speed achievements. Dedicated NGVs generally demonstrate better performance and result in lower emissions than NGVs based on other technology. [6]

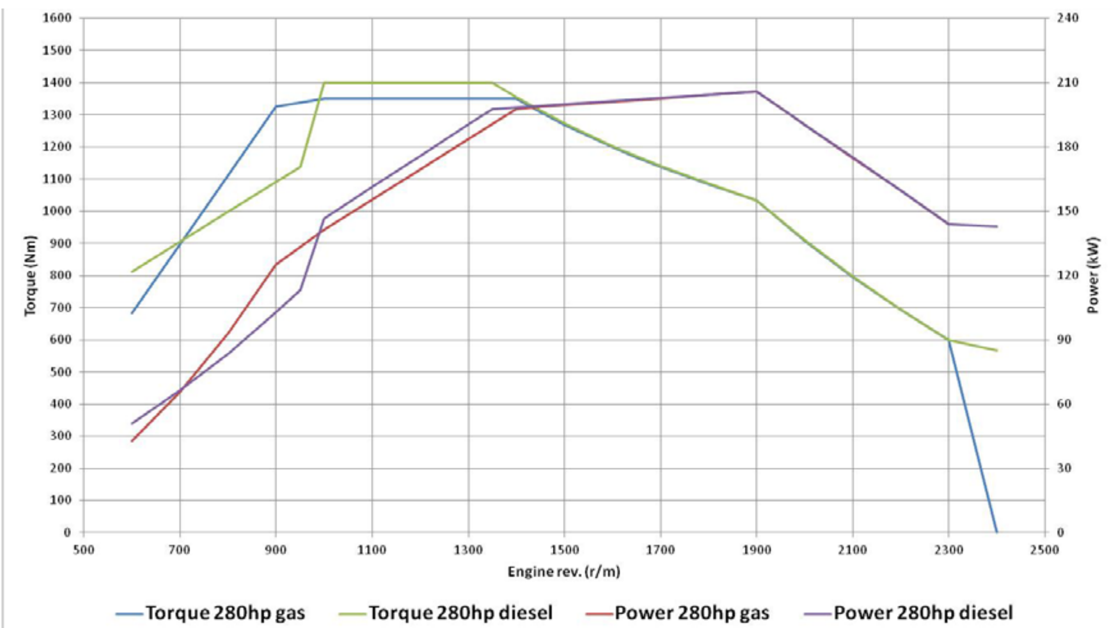

Figure 9: Torque and power of Scania trucks [18]

3.3 Fuelling Infrastructure

3.3.1 Infrastructure & Requirements

CNG fuelling stations require more equipment on site, while LNG stations are less demanding and similar to conventional fuel stations, only with more safety precautions required. [6]

Regarding CNG, natural gas is delivered to the fuelling stations typically by the existing underground natural gas grid. Therefore, no road tankers are needed, in contrast to LNG transportation. For CNG, fast-fill or time-fill station can be chosen. [6]

Fast-fill CNG stations are suitable for quick or random fuelling. Figure 10 illustrates the configuration of the station. Natural gas is taken from the grid at a low pressure and then compressed to a high pressure on-site. Once compressed, it is stored in multiple vessels and ready for a quick fill-up, which is done by the dispenser. CNG in vessels is typically kept under higher pressure than vehicle operational pressure. Due to this, fuel is delivered to the vehicle faster than fuel coming directly from the compressor. Fuelling time at such station is similar to that of conventional fuels. [6]

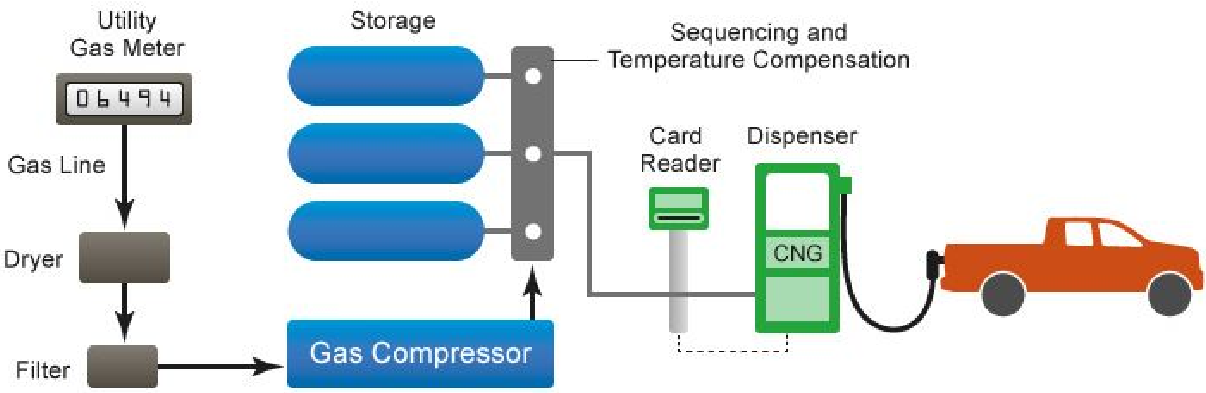

Figure 10: Fast-fill CNG station configuration [6]

Another option is time-fill stations (see Figure 11), which are more suitable for fleets, where fuelling is slower due to the large tanks and can be done over the night. It is an option for the vehicles that are not operated in an extended period of time. The gas is taken from the gas grid at a low pressure and compressed. However, unlike in fast-fill stations, vehicles are fuelled directly from the gas compressor and not from the fuel vessels. The size of the compressor needed is dependent on the demand side. The station also has a buffer tank, which can be used for “top off” of the vehicles if it is needed. The fuelling time depends on the compressor size, amount of buffer tanks and number of vehicles needed to be fuelled. [6]

One advantage of time-fill stations is lower operational temperature and thus fuller fill. In contrast, in fast-fill CNG stations, higher pressure and thereby higher temperature makes the gas in the tank get warmer and expand, thus reducing its energy density. [6] Another option over fast-fill stations is lower costs. Since there are no additional storage vessels, less equipment and space are needed, leading to less maintenance and cheaper operational costs. [19]

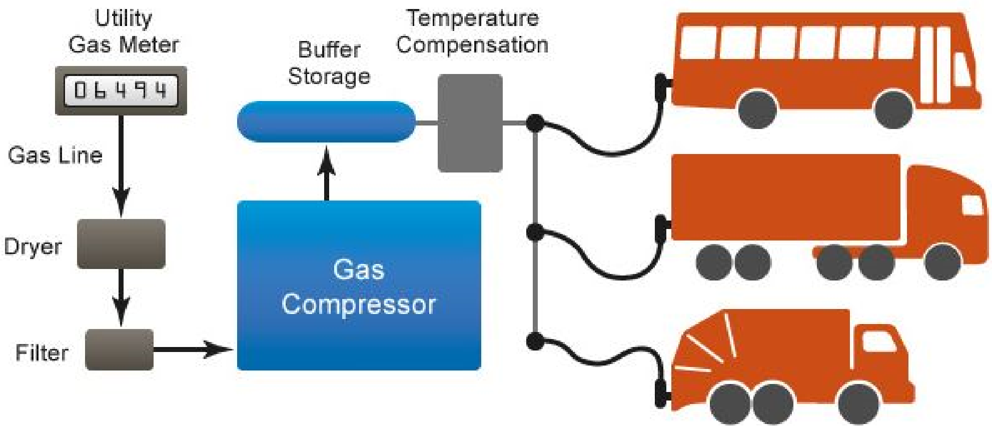

Figure 11: Time-fill CNG station configuration [6]

Regarding the compatibility between the CNG stations and vehicles in Denmark, Nordic Petrol Systems (NPS) develops, manufactures, sells, installs and operates CNG dispensers, payment systems, web facilities, electrical installations on the Nordic market. Dispenser STD 11 D for gas has a capacity of 30 kg/min and can be increased up to 70 kg/min. Dispensers are supplied with electronic temperature compensator including software, which ensures maximum refuelling, which is the issue in fast-fill stations. [20]

LNG stations are structurally similar to diesel or petrol filling stations, both delivering liquid fuel (see Figure 12). LNG is typically produced remotely and then delivered to the filling station by a tanker truck. At the filling stations the LNG is stored in special cryogenic storage tanks. Then the LNG is pumped into the vehicles in similar way as other liquid fuels, by the cryogenic pump. Dispensers deliver fuel to the vehicle under the 2-8 bar pressure. Only more sophisticated fuelling equipment is needed in order to withstand the colder temperatures of the fuel: protective clothing, face shield and gloves. [6]

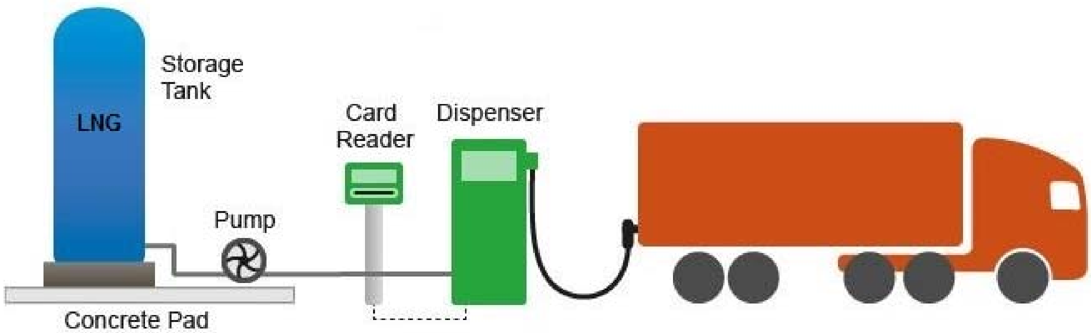

Figure 12: LNG station configuration [6]

For both CNG and LNG, the refuelling nozzle of the dispenser simply clicks onto the inlet in the vehicle and it is ready for filling. The refuelling inlet can be located under the hood or trunk in case of converted vehicles and in the same place as for the diesel vehicle in case of original equipment manufactured NGV. Once the tank is full, the dispenser automatically shuts off. In case of CNG, no extra tools are needed to disconnect the dispenser, whereas for LNG, it is necessary to wear gloves to protect from extreme cold temperatures, which are conducted through the equipment. There is no direct contact with the fuel. One practical advantage of natural gas refuelling is its clean handling, avoiding stains and smells, unlike petrol or diesel. [19]

Liquefied-compressed natural gas (LCNG) station is an innovative type of filling station, offering both CNG and LNG. The station relies on LNG supply, which is delivered by tanker trucks, and has dispensers for both CNG and LNG vehicles. LNG vehicles are fuelled in the same way as at LNG stations, i.e. the LNG is moved from an insulated storage tank by the cryogenic pump through a dispenser. In order to produce CNG, the LNG is vaporised and thereby converted from liquid to gas. The process is controlled to dispense CNG at the right pressure. [16] The configuration of LCNG station can be seen in Figure 13.

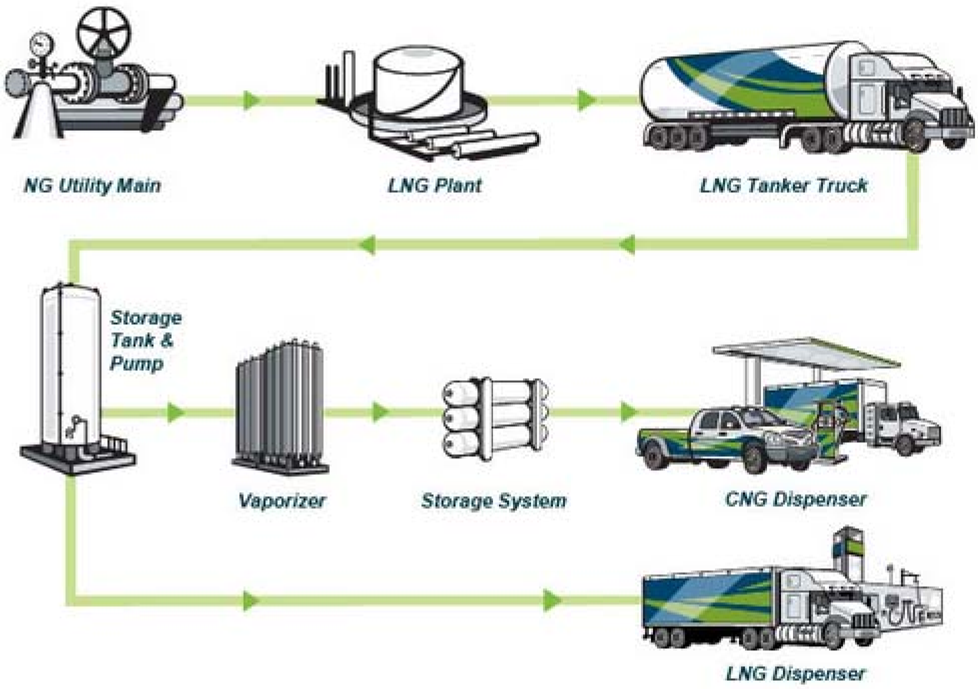

Figure 13: LCNG station configuration [16]

One advantage of an LCNG station is that investment and maintenance costs are lower compared to the case of establishing separate CNG and LNG stations, as less equipment is needed in total. Furthermore, power used for CNG production is lower than a traditional compressor based CNG station. Finally, it can be established in areas without local natural gas network. [16] However, the technology is not matured enough to be widely applied.

3.3.2 Current Situation in Denmark & Suppliers

Natural gas and biogas for transport purposes in Denmark is not well deployed, but there is an increasing interest in the possibilities of the technology. Denmark has a well-developed gas network covering the country, which is a big advantage towards the establishment of gas filling stations, especially CNG. LNG filling stations require better network development. [14]

Naturgas Fyn, HMN Naturgas and E.ON together with the energy company OK are the key players, who have invested in the first CNG filling stations and gas vehicles and are actively working to roll out the market. [10]

Currently there are seven existing CNG stations in Denmark in Tarm, Fredericia, Skive, Odense, Amager, Gladsaxe (Søborg) and Frederikssund. Three more are expected to be opened at the end of 2014 in Holstebro, Aalborg and Frederikshavn (see Figure 14). [13]

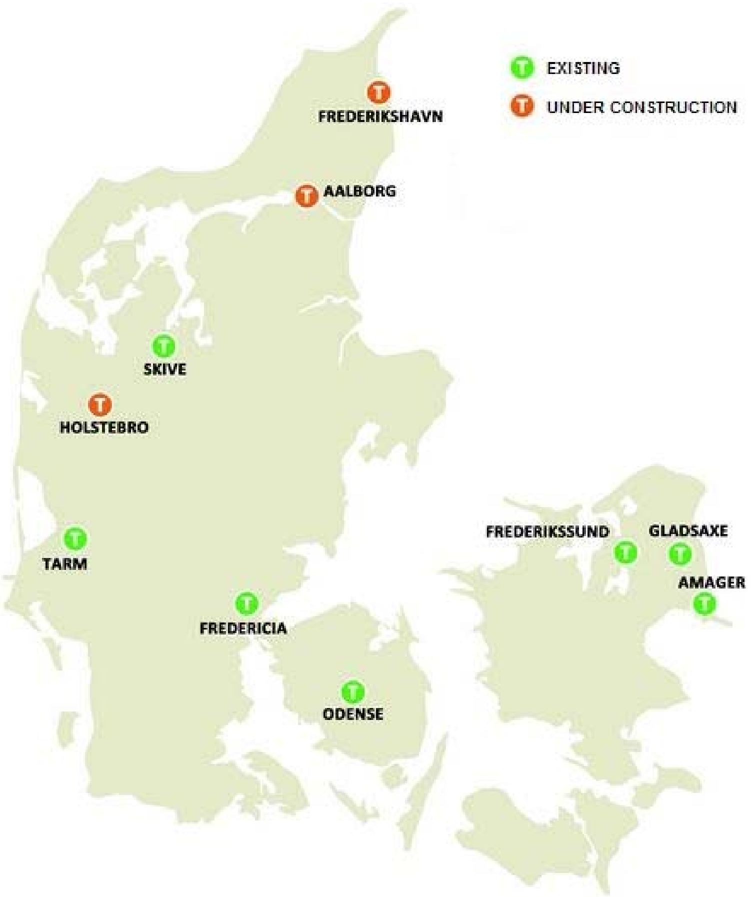

Figure 14: CNG filling stations in Denmark [13]

In 2011, the first 14 gas vehicles were purchased and the first gas filling station was established in Odense. This was done by Naturgas Fyn. Since then, a number of new initiatives have emerged in Denmark. Apart from one filling station in Fredericia, established by Naturgas Fyn, and one filling station in Amager, established by E.ON and OK, the rest of existing stations are owned by HMN Naturgas, so are the stations under construction. [10]

In order to deploy the CNG vehicles, more filling stations should be established all over the country. According to EU's Clean Power for Transport Directive, publicly accessible CNG stations should by 2020 be built up Europe-wide with a maximum distance of 150 km in between. [3]

LNG is currently mainly used to fuel ships, therefore LNG stations for the road transport does not exist in Denmark. In the whole Europe, there are only 38 available LNG filling stations (22 of them in UK). 12 new LNG/LCNG stations are planned to be established under the LNG Blue Corridors project, accompanied by approximately 100 LNG heavy-duty vehicles. As it is laid down in Clean Power for Transport, EU proposes to establish LNG stations every 400 km along the roads of the Trans European Core Network until 2020. Finally, for both CNG and LNG stations, EU proposes to have common fuelling standards. [3]

Any significant penetration requires a minimum refuelling infrastructure available. If a refuelling network was rapidly developed within Europe, the market for natural gas powered vehicles could grow significantly. It could be expected to reach a market share of 5% by 2020, 9% by 2030 and 16% by 2050, considering both light- and heavy-duty vehicles. [21]

3.4 Operation and Maintenance Facilities

NGVs are almost identical to conventional vehicles with internal combustion engine, regarding technology. The main differences are the fuel storage tank and the delivery system. [6] As mentioned before, in particular CNG tanks have to be regularly inspected due to high operational pressure.

One advantage over conventionally fuelled vehicles, due to natural gas properties and absence of particulates, is that NGVs engines' wear and tear is usually reduced. [19]

3.5 Safety

Driving NGVs is as safe as conventionally fuelled vehicles, when complying with requirements for its safe handling. [4]

Natural gas has several safety advantages over petrol or diesel. Since it is gas, in case of an accident and fuel spill, there is no danger of soil or groundwater contamination. Natural gas is lighter than air and therefore rises and disappears in the air, leaving no residue behind. In contrast, petrol and diesel would instead be lying on the ground and create a fire hazard. [4] Regarding LNG, at initial leak it is heavier than air and appears as a fog which should be avoided. Later, it gets warmer, thus lighter than air and disperses. In both cases, CNG and LNG, manual shut-off valve should be closed, if the vehicle is equipped with such and it is possible. [6]

The mixture of methane and air is not explosive in an unconfined environment. An incident resulting in fire could occur only if there is the right concentration of natural gas released in the air (5-15%) together with a source of ignition. [19]

Since natural gas is odourless, in order to detect the leakage, an odorant is added to the CNG, making it recognisable due to a smell similar to "rotten egg". As a result, a leakage can already be noticed if natural gas concentration is 0,3% by volume in the air. It is a far lower level compared to the level of fire hazardous (5-15%), which thus can be avoided. [4] For LNG vehicles, the odorant cannot be added due to the low temperatures. Instead, methane detectors are used. [16]

Natural gas is also not toxic and only moderate concentration of the gas can result in symptoms such as headache, due to the reduced concentration of oxygen. It also does not corrode equipment materials and does not pollute the environment. [19]

Finally, natural gas has higher autoignition temperature than petrol or diesel, meaning that self-ignition in air occurs at higher temperature, indicating a safer substance. [4]

Regarding CNG vehicles, the fuel is stored under a high pressure and has to be dealt with. It is required that CNG cylinders are able to withstand much higher pressure (600 bar) than under normal handling conditions (200 bar). Withstanding fire is also required. Regular qualified inspection is essential for CNG tanks. [4]

LNG is not stored under high pressure and therefore no pressure requirements are applied. Even though LNG stores a large amount of energy, it cannot be released easily enough in the standard environment to cause the explosion related to overpressure. [22]

4 ENVIRONMENTAL IMPACT

4.1 Emissions

Natural gas is a fossil propellant and therefore emits CO_2. However, it is the cleanest of the fossil fuels (coal, oil and natural gas) and its increasing use instead of coal and oil results in significant environmental benefits. [4]

Figure 15 illustrates the composition of methane, which is the main component of natural gas, and diesel. Due to much simpler composition compared to diesel, natural gas results in cleaner burning properties. [16] NGVs can achieve from 10% up to 25% reduction in CO_2 emissions compared to similar conventionally powered vehicles. [12]

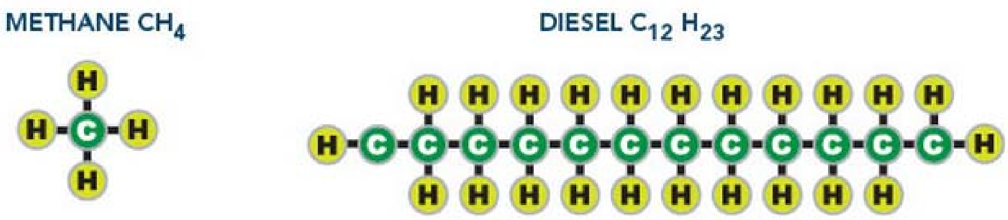

Figure 15: Fuel composition comparison [16]

Moreover, replacing conventional fuel with natural gas reduces the amount of NO_X, SO_2, particulates and other harmful and toxic substances emitted. NO_x and particulate matter is the major issue for air quality and particularly controlled by current emission legislation EURO VI. Furthermore, driving NGVs has no emission of hydrocarbons which contribute to the dangerous ground level ozone formation. [12]

As a result, using NGVs instead of conventionally fuelled vehicles helps to comply with the emission requirements more easily by using less complex filtering equipment, which also results in reduction in costs. [4]

Regarding biogas, it comes from biomass, which is considered a renewable source, and thus is CO_2 neutral. Therefore, produced and upgraded biogas can directly replace natural gas and thus result in even higher CO_2 reductions and benefit the environment. [4]

There is also another aspect of biogas being beneficial for the climate. Methane produced from, for instance, manure can be used for biogas to propel the vehicles instead of leaving it in the fields and letting it vaporise to the air. Methane has a greenhouse effect, which is 25 times larger compared to CO_2. [10]

Figure 16 gives an overview of emissions from trucks powered with conventional and alternative fuels. The emissions of different transport fuels depend on the raw material used for propellant production. Operating CNG truck gives a slight reduction in CO_2 emissions. The reason why the difference is not more advantageous is the fossil nature of CNG and lower energy efficiency of the CNG engine compared to the diesel engine. [17]

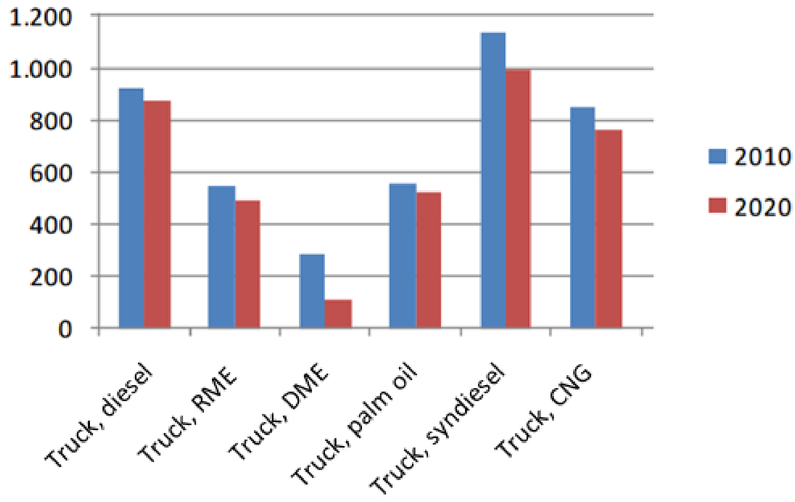

Figure 16: Emissions of trucks in 2010 and 2020, gCO_2e/km [17]

4.2 Smell

Since natural gas is odourless, the problem of smell pollution, in particular within urban areas, is decreased significantly.

4.3 Noise

In addition to reduced emissions, NGVs have also typically lower noise levels. The difference is in particular noticeable when comparing natural gas and diesel heavy-duty vehicles. [4] For instance, 50% lower noise emissions, in comparison to conventionally fuelled trucks, are guaranteed by the manufacturer of Mercedes-Benz Econic NGT (Natural Gas Technology). [23] This decrease of noise pollution is particularly beneficial in urban areas.

5 ECONOMICS

Natural gas is one of the cheapest alternatives to replace oil based fuel in the transport sector. According to the report “Alternative drivmidler”, gas is assessed to be one of the most economically viable alternatives, when comparing the cost per km driven, as shown in Figure 17. [17]

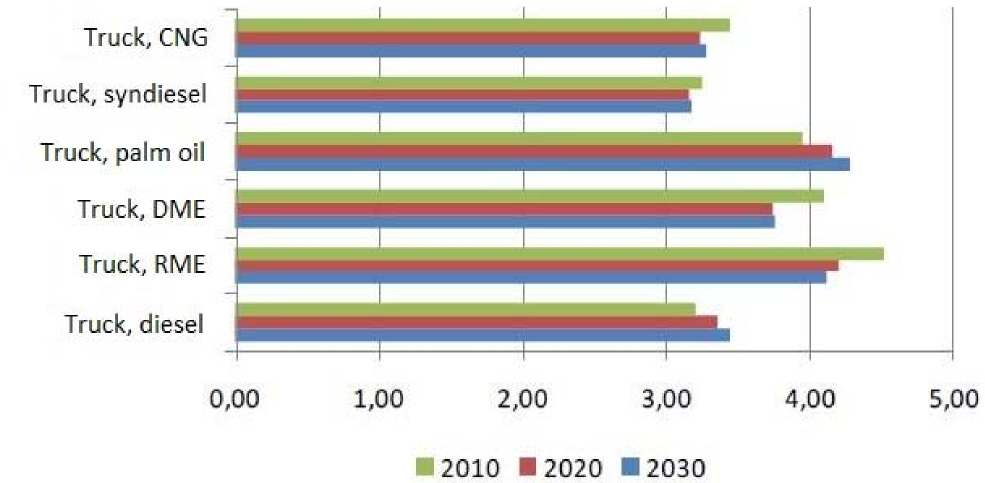

Figure 17: Costs for trucks in 2010, 2020 and 2030, DKK/km [17]

The increase in price of fossil fuel driven vehicles is due to the expected rising price of oil, making CNG trucks more attractive. It is already expected CNG driven heavy-duty vehicles to be cheaper than diesel driven vehicles by 2020 with even bigger difference by 2030. [17]

In more details, the costs mentioned above can be divided into the cost of vehicle, cost of fuel and infrastructure and corresponding cost of emissions and noise. Figure 18 represents the breakdown of the costs for 2020, when CNG is expected to be a cheaper option. [17]

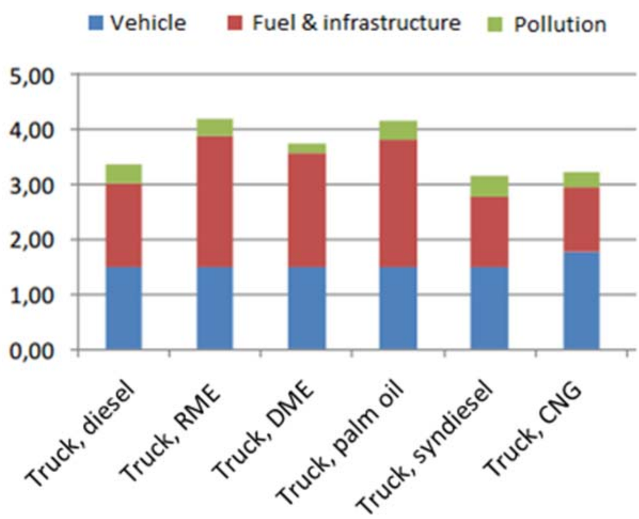

Figure 18: Breakdown of costs for trucks in 2020, DKK/km [17]

LNG is not a widespread fuel for land transport due to its high cost of production and the need for storing it in expensive cryogenic tanks.

5.1 Investment Cost

5.1.1 Vehicles

Regarding natural gas powered light-duty vehicles, the purchase prices are already competitive to those of conventionally fuelled vehicles and are expected to decrease further along with the increase in oil price and enforcement of stricter emission regulations. [21] However, natural gas heavy-duty vehicles are generally 100.000-300.000 DKK more expensive compared to the conventional versions. This is mainly due to the need of a high-pressure storage tank installation, which is expensive. However, due to mass production the cost is expected to fall after 2020 [17]. Also, the initial price is increased due to the existing Danish registration and annual taxes on the vehicles. [15]

In addition, a comparison between Scania's CNG trucks and its counterparts was made. Regarding purchase price, two-axle box-body truck (Scania P280LB4x2) powered by CNG costs 1.050.000 DKK, while the same truck powered by diesel costs 800.000 DKK. Comparing two-axle trucks with three-axle trailer, the one fuelled by CNG (Scania P340LA4x2) costs 1.035.000 DKK, while its conventional counterpart (Scania P360LA4x2) costs 785.000 DKK. It means Scania CNG trucks are around 30% more expensive. [18]

5.1.2 Fuelling Infrastructure

Since CNG stations are more common and more matured in terms of technology, they are therefore cheaper compared to LNG stations. On the other hand, due to the driving range half as long as that with LNG, a greater number of CNG stations should be established.

The cost of infrastructure for public CNG station is considered to be around 200.000-400.000 € (1,5-3 million DKK), considering that natural gas grid exists and only necessary equipment has to be installed, depending on the capacity (normally 300-500 m^3/h). For private station the price can reach 1.000.000 € (7,5 million DKK). [21]

According to E.ON, the gas station is economically viable with the minimum capacity of 600.000 Nm^3/year, which corresponds to 6 GWh of gas. This approximately corresponds to 300 passenger cars, 17 busses or 40 garbage trucks. [28] For instance, in case of garbage trucks, it corresponds to one truck using 15.000 Nm^3/year of gas, which could be covered by 117 full fills for Scania gas truck with 128 m^3 storage tank (described later). This amount of gas enables to run the truck around 100 km/day yearly nominally.

Operation and maintenance cost of the filling station is expected to be around 0,5-2 DKK/Nm^3. This would result in 300.000-1.200.000 DKK/year for the filling station with the capacity of 6 GWh of gas. [28]

LCNG station, based on the fuel supply via fuel tankers, mainly requires installations of stationary LNG tanker, a transfer pump to convert CNG to LNG and dispensers. The cost of the stationary tanker and transfer pump is similar to the cost of the compressor. Therefore, the final cost of LCNG station is expected to be similar to that of a high capacity CNG facility. The maintenance though is expected to be cheaper. [21]

5.2 Operation & Maintenance Cost

It is assessed that the maintenance of CNG trucks costs approximately 15.000 DKK/year more compared to diesel models. [17] Based on the same comparison made by Scania, operation and maintenance cost, including tyres, is 15-20% higher for CNG truck compared to its diesel counterpart. [18]

5.3 Fuel Cost

HMN Naturgas sells both natural gas and biogas, 100% produced in Denmark. The prices offered in gas filling stations, excluding VAT (September 2014), are the following:

- CNG (100% natural gas): 8,26 DKK/m^3
- B25 (25% biogas): 8,33 DKK/m^3
- B50 (50% biogas): 8,39 DKK/m^3
- B100 (100% biogas): 8,51 DKK/m^3 [13]

According to Scania, fuel economy of diesel powered truck and CNG powered truck is around 4 km/l and 3,4 km/m^3 respectively. Based on Scania assess, when diesel price is around 9,40 DKK/l and CNG price is around 8,84 DKK/m^3 (both excluding VAT), the final fuel price to obtain certain distance is slightly (around 10%) more expensive in case of CNG truck. [18]

5.4 Lifetime

Due to the similar technology, natural gas or biogas driven vehicles have similar lifetime as diesel powered vehicles. Heavy-duty vehicles are expected to run around 100.000 km per year and, based on this, have an economic lifetime of around 8 years, meaning 800.000 km. [17]

5.5 TCO Analysis

The purpose of the TCO (total cost of ownership) is to improve decision-making by including all expenses unique to each vehicle. To make the investment on gas driven trucks comparable, both gas and conventional vehicles, available on the market, are taken into account in the TCO. The calculations done by Scania can be seen in Table 3 and Table 4. It is assumed that trucks are leased for 8 years, since the market for used vehicles is not developed in three years. Gas trucks can run both on natural gas and biogas. However, only natural gas price is taken into account. [18]

	Two-axle box-body truck (Scania)		Two-axle truck with three-axle trailer (Scania)	
Model	P280LB4x2	P280LB4x2	P360LA4x2	P340LA4x2
Fuel	Diesel	Gas	Diesel	Gas
Cost of truck [DKK]	800.000	1.050.000	610.000	860.000
Cost of trailer [DKK]	-	-	175.000	175.000
Total cost [DKK]	800.000	1.050.000	785.000	1.035.000

Table 3: Purchase prices of trucks [18]

Leasing yield per month at payment of 0 DKK, 20% scrap value over 8 years with fixed 4% interest rate [DKK]	8.307	10.903	8.151	10.747
Financial cost per year [DKK]	**99.684**	**130.836**	**97.812**	**128.964**
Km per year	90.000	90.000	90.000	90.000
Repair and maintenance, incl. tyres, per month [DKK]	5.000	6.000	6.500	7.500
Repair and maintenance per year [DKK]	**60.000**	**72.000**	**78.000**	**90.000**
Fuel price, DKK/l or DKK/m^3 excl. VAT	9,40	8,84	9,40	8,84
Fuel economy, km/l, km/m^3	4,00	3,40	3,00	2,55
Fuel cost per year [DKK]	**211.500**	**234.000**	**282.000**	**312.000**
Total cost per year [DKK]	**371.184**	**436.836**	**457.812**	**530.964**
Additional costs for CNG [DKK]		65.652		73.152
Additional costs for CNG [%]		18%		16%

Table 4: Results of TCO analysis [18]

According to the TCO analysis for two different Scania models, in both cases CNG trucks are more expensive compared to their counterparts. Additional costs are around 16-18% of the cost running the conventional truck, meaning around 70.000 DKK per year. [18]

6 POLICY INSTRUMENTS

According to the Danish Energy Agreement signed in 2012, 70 million DKK has been allocated to promote the infrastructure for electricity, hydrogen and gas driven vehicles in the period 2013-2015. Out of this amount, 20 million DKK is allocated for the gas filling stations infrastructure and use of heavy-duty vehicles, emphasising application of biogas. [10]

Following the Energy Agreement, a strategic partnership for gas in the transport sector was formed in 2013, consisting of Danish Energy Agency, Public Transport Authority (Trafikstyrelsen) and key stakeholders. Energinet.dk is involved with a number of energy companies, fleet operators, NGOs, research institutions and authorities. The partnership aims to establish a transparent and comprehensive basis for further work on gas in the transport sector. A number of key terms were set as the basis for the partnership and further development of the gas infrastructure:

- Gas is most suitable for heavy-duty vehicles, since for passenger vehicles electricity is prioritised;
- There is a slight reduction in CO_2 effect by replacing diesel with natural gas;
- The goal of CO_2 reduction should be achieved by replacing natural gas with biogas in a long run;
- Significant benefits of deploying gas in the transport sector are supply and price security. [10]

One of the barriers for gas application to the transport sector in Denmark is the taxation system. While electric vehicles and fuel cell electric vehicles are exempted from registration and annual green taxes, the tax structure does not promote and stimulate gas vehicles in this way. [10] Natural gas vehicles are taxed in the same way as petrol or diesel vehicles are, dependent on fuel economy and CO_2 emissions. Moreover, Danish taxes on natural gas as well as biogas are the highest in EU. In 2011, it accounted for 10,97 €/GJ, while the average EU value was just above 2 €/GJ. [15]

However, gas vehicles are promoted by the means of emission restrictions. The environmental zones are established in Denmark with strict regulations. The best example is the majority of Copenhagen and all of Frederiksberg, which has been covered by an environmental zone since 2008. All diesel powered vehicles above 3,5 tons must either meet at least Euro IV emission standard or be improved with an effective filter. All heavy-duty diesel powered vehicles, both domestic and foreign, are required to have an environmental zone label in case they want to enter an environmental zone. It is also implemented in Aarhus, Aalborg and Odense. [24] Due to reduced amounts of pollutants emitted, natural gas vehicles much easier comply with the regulations.

Regarding biogas, its upgrading is subsidised by the Danish government. The subsidy for use of biogas, as renewable energy source, outside the combined heat and power sector is under the approval process in the EU at the moment. [10]

7 EXAMPLES OF GAS VEHICLES FOR DISTRIBUTION

Natural gas vehicles are widely applied for both light- and heavy-duty vehicles. The following examples include CNG trucks which can be found on the Danish market. There are more heavy-duty vehicle models of several manufacturers, such as Iveco, which are not yet on the Danish market.

7.1 Mercedes-Benz Sprinter NGT

Mercedes-Benz Sprinter NGT can be purchased as a van or a flatbed. Table 5 gives an overview of the gas driven van, which can be both with the standard or long axle distance, 3.665 and 4.325 mm respectively. Both manual and automatic gearbox can be chosen, which determines fuel economy. The case of automatic gearbox is given. In addition, the van with a normal, high or extra high roof is available. [25]

Manufacturer:	Mercedes-Benz	
Performance		
Engine: Type Torque Power	 Bi-fuel: CNG or petrol, 4 cylinder, 1.796 cm^3 (Euro IV) 240 Nm 115 kW	
Fuel: Storage Range	 CNG: 208 l Petrol: 100 l CNG: 330 km Petrol: 740 km Total: 1070 km	
	Urban driving	**Mixed driving (urban and highway)**
Fuel economy	CNG: 4,9 – 5,0 km/m^3 Petrol: 5,5 – 5,6 km/l	CNG: 6,8 – 7,0 km/m^3 Petrol: 7,2 – 7,5 km/l
CO_2 emissions	254 – 263 g/km	317 – 329 g/km
	3.665 mm axle	**4.325 mm axle**
Operating Limits: Payload	 1.230 – 1.300 kg	 1.070 – 1.105 kg

Table 5: Main characteristics of Mercedes-Benz Sprinter NGT

Mercedez-Benz Sprinter NGT is based on bi-fuel technology, enabling to run either on gas or petrol. Petrol should be used only to start the engine, which is then followed by the automatic shift to gas. On the other hand, petrol can also be used in case of running out of gas or to prolong the driving range. A shift to another type of fuel can be done manually by pressing a button. A driving range of up to 330 km on natural gas can be obtained. Since gas storage tanks are mounted under the floor, the cargo space is not reduced. [25]

7.2 Mercedes-Benz Econic NGT

The main characteristics of Mercedes-Benz Econic NGT performance can be seen in Table 6. [4]

Manufacturer:	Mercedes-Benz
Performance	
Engine:	
Type	Dedicated CNG (Euro VI), 7,7 litre
Torque	1200 Nm
Power	222 kW
Acceleration:	
Top Speed	90 km/h
Fuel:	
Storage	560 – 700 l at 200 bar
Range	Up to 350 km
Operating Limits:	
Payload	11.500 – 18.500 kg
Total weight	18.000 – 26.000 kg

Table 6: Main characteristics of Mercedes-Benz Econic NGT

Exclusive performance shows Mercedes-Benz Econic NGT competitiveness with its diesel powered counterparts. Moreover, either it runs on fossil based natural gas or renewable biogas, it ensures benefit to the environment due to the engine technology complying with Euro VI standards. Around 20% lower CO_2 emissions are produced in case of truck powered by CNG. [26]

7.3 Scania P Series

Scania takes the largest part of the Danish market regarding heavy-duty vehicles powered by natural gas. In Table 7 several models are presented with a difference in fuel economy and payload capacity. The same configurations are available for the trucks with the 250 kW/1600 Nm engine. [4]

Manufacturer:	Scania		
Model:	P280LA4x2	P280LB4x2	P280LB6x2
Performance			
Engine:			
Type	Dedicated CNG (Euro VI)		
Power	205 kW		
Torque	1350 Nm		
Acceleration:			
Top Speed	120 km/h		
Fuel:			
Storage	128 m^3	128 m^3	128 m^3
Pressure	220 bar	220 bar	220 bar
Range	275 km	325 km	275 km
Fuel economy	2,5 km/m^3	3 km/m^3	2,5 km/m^3
Operating Limits:			
Payload	10.000 kg	9.000 kg	15.000 kg
Total weight	18.000 kg	18.000 kg	26.000 kg
CO_2 emissions	825 g/km	687 g/km	825 g/km

Table 7: Main characteristics of Scania P series

Scania trucks are equipped with automatic gearbox. Trucks have 8 fuel tanks, 4 on each side. Each tank contains 80 l of CNG, resulting in 640 l in total, which is equivalent to 130 l diesel. The tank is made of composite material and is 400 kg lighter than a steel tank. [18]

7.4 Volvo FE CNG

Volvo is about to launch their Volvo FE CNG, which is a counterpart of the conventional FE model. The main characteristics of performance can be seen in Table 8. [4]

Manufacturer:	Volvo
Performance	
Engine:	
Type	Dedicated CNG (Euro VI), 9 litre
Torque	1356 Nm
Power	239 kW
Fuel:	
Storage	Up to 160 m^3
Range	400 km
Operating Limits:	
Payload	19.000 – 26.000 kg

Table 8: Main characteristics of Volvo FE CNG

Volvo FE CNG has 2x4 or 2x3 fuel tanks mounted on both sides of the chassis. Due to the fully automatic gearbox it has similar productivity and driving performance as its diesel FE counterpart. [27]

Finally, it has a spark-ignition engine which is suitable for running short distances with many starts and stops. Therefore, it is being applied for waste collection and urban distribution tasks. [27]

7.5 Volvo FM Methane-Diesel

Even though LNG fuelled vehicles do not operate in Denmark, its market exists in several other European countries. Volvo FM running on LNG or LBG is a huge step towards the liquefied gas roll-out. The main characteristics of performance can be seen in Table 9. [27]

Manufacturer:	Volvo
Performance	
Engine:	
Type	Dual-fuel LNG and diesel (Euro V), 13 litre
Torque	2300 Nm
Power	340 kW
Fuel:	
LNG/LBG storage	280 l (left side)
Diesel tank	150, 240 or 330 l (right side)
Range	>500 km
Fuel economy	2,94 l/km

Table 9: Main characteristics of Volvo FM Methane-Diesel

The truck has a dual-fuel diesel engine of 13 litre and power around 340 kW. Diesel engine gives an increase in energy efficiency of 30-40% and reduces fuel consumption by 25% compared to traditionally powered gas vehicles using spark-ignition engine. On top of that, it can run on diesel when the LNG tank is empty or the gas supply system has problems and thus ensure flexibility and prolong the overall driving range. It is mainly suitable for regional distributions, but unlike CNG vehicles, it has also good economics for long distance operation. [27]

Finally, it has a strong environmental profile and contributes significantly to reducing emissions. Replacing conventional diesel, Volvo predicts 10% reduction in emissions in case of using natural gas and 70% reduction in case of biogas, which is the most preferable. [27]

8 SUMMARY

Table 10 summarises the main findings about gas, both natural and biogas, as an alternative fuel for the transport sector and technology of gas vehicles, with a focus on freight transport. Strengths and weaknesses are found in terms of technology, environment, economics and policy instruments.

	Strengths	Weaknesses & Improvements needed
Technology	Mature technology based on the internal combustion engine LNG has up to 50% greater range compared to CNG and is suitable for long distance hauling transport CNG suitable for shorter distances like city distribution Deployed natural gas production and easy access to gas network is an advantage for infrastructure	Limited current rollout of CNG/CBG refuelling infrastructure LNG production and a new network of filling stations Rollout of biogas upgrading
Environment	Reduced NO_X, SO_2 and particulate emissions Reduced noise emissions Biogas is considered a CO_2 neutral fuel	Natural gas is a fossil based fuel and has a limited reduction in CO_2 emissions
Economics		Purchase price of NGV is slightly higher compared to conventional vehicle Gas price is higher than diesel or petrol High cost of filling stations
Policy	Financial support for the gas filling station infrastructure	No registration or annual tax exemptions

Table 10: Strengths and weaknesses of gas and gas vehicles

In conclusion, technology of gas vehicles is matured, competitive to conventional vehicles and is ready to be deployed. In a short run, they are promoted as the most viable alternative fuel for heavy-duty vehicles with CNG suitability for short distance urban transport and LNG suitability for longer distance hauling vehicles. However, the lack of infrastructure is the hurdle. Even though Denmark is self-sufficient in natural gas production and has a well developed gas network over the country for a number of decades, the network of natural gas filling stations are just now on its way to be developed. Another issue is fossil origins of natural gas, resulting in a limited CO_2 reduction. Therefore, in a long run it is expected to be replaced with locally produced biogas to meet the goal of being fossil-free within the transport sector. Biogas as a renewable source of transport fuel might then be subsidised, thus fostering the roll-out of gas vehicles. At the moment, no policy instruments are applied for natural gas driven vehicles.

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ANNEX: FUEL PROPERTIES COMPARISON

Table 11 gives an overview of the main properties of different alternative fuels, which can then be compared to conventional fuels. These are the following:

- **Physical state**.
- **Feedstock**.
- **Composition**.
- **Gasoline gallon equivalent** is the amount of alternative fuel, which has the same energy content as one gallon of gasoline. This factor is used to compare the energy content of different competing alternative fuels to the conventional fuels. As a note, 1 US gallon is equal to 3,8 litres.
- **Density** is mass of certain substance per unit volume.
- **Calorific value** of the fuel shows the amount of energy released as heat by the complete combustion of fuel (unit of mass or volume).
- **The flash point** of a volatile liquid is the lowest temperature where the fluid evaporates to form a combustible concentration of gas. It indicates how easy a chemical may burn. Chemicals with higher flash points are less flammable or hazardous, making the fuel safer to handle and transport. [29]
- **The autoignition temperature** is the minimum temperature at which gas or vapour spontaneously self-ignites in air without external source of ignition (spark or flame). Higher autoignition temperature typically indicates a safer substance. [29]

The values of the properties are approximate and can differ depending on the fuel composition.

Characteristics	Units	Conventional fuels		Alternative fuels				
		Petrol (gasoline)	Diesel	Electricity	Hydrogen	Biodiesel	CNG/CBG	LNG/LBG
Physical state	-	Liquid	Liquid	Electricity	Compressed gas or liquid	Liquid	Compressed gas	Cryogenic liquid
Fuel material (feedstock)	-	Crude oil	Crude oil	Coal, nuclear, natural gas, hydro, wind and solar	Natural gas, methanol, electrolysis of water	Fats and oils from sources such as soy beans, waste cooking oil, animal fats, and rapeseed	NG: Underground reserves BG: Biomass, sewage, agricultural waste, certain industrial wastes, municipal waste, energy crops	
Composition	-	C_4 to C_{12}	C_8 to C_{25}	N/A	H_2	Methyl esters of C_{12} to C_{22} fatty acids	CH_4 (83-99%), C_2H_6 (1-13%)[2]	CH_4
Gasoline gallon equivalent	-	100%	1 gallon of diesel has 113% of the energy of 1 gallon of gasoline	33,7 kWh has 100% of the energy of 1 gallon of gasoline	1 kg of H2 has 100% of the energy of 1 gallon of gasoline	0,96 gallon of B100 or 0,90 gallon of B20 has 100% of the energy of 1 gallon of gasoline	3,9 gallons (2,6 kg) of CNG has 100% of the energy of 1 gallon of gasoline	1,56 gallons of LNG has 100% of the energy of 1 gallon of gasoline
Density (average)	**kg/m3**	749	851	N/A	40	860-890	175	455
Lower calorific value	**MJ/l**	32,4	35,8	3,6 (MJ/kWh)	4,8	33,4 (B100)	8,2	20,8
	MJ/kg	43,3	42,1		121	38,2	47,1	45,7
Flash point	**°C**	-45	126	N/A	N/A	min. 120	-184	-188
Autoignition temperature	**°C**	257	210	N/A	500	373-448 (B100)	580	580

Table 11: Comparison of different alternative and conventional fuels

[2] Composition of row biogas: CH4 (50-80%), CO2 (20-50%)