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Fuel Handling System for Gas Conversion – Sisu Diesel 420 DWRIE

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ABSTRACT

This thesis was commissioned by Novia University of Applied Sciences. The aim of the thesis was to design a fuel gas handling system for operating on fuel gas in the engine laboratory of Novia to convert a diesel engine to a gas-fuelled engine. The engine is a SISU Diesel 420 DWRIE, this conversion could also be applied to a diesel power vehicle.

To do this, a theoretical study of the most suitable fuel gas for engine conversion has been conducted. CNG was determined to be the most feasible fuel gas for this case, in terms of space, fuel availability, price, safety aspects and impact on the environment. A review has also been made of the fuel system of diesel engines and the adaptations that would have to be made to run on natural gas. By analysing different existing models are all the necessary components for the conversion of the whole fuel system have been determined, costed, and documented.

The final part consists of the calculations of the installation and the proposal of a possible design, as a piping and instrumentation diagram. The findings of the thesis are the design of a fuel management system for compressed natural gas operation adapted to the conversion of the Sisu engine. This work is complemented by another project in which specific modifications are made to the engine. It also provides a basis for future work in which to continue with the engine conversion, simulating and subsequently building the design of the present thesis.

Language: English

Keywords: CNG, gas engine, fuel gas, gas conversion, fuel system, combustion, diesel engine

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Nomenclature

CNG: Compressed Natural Gas

LNG: Liquified Natural Gas

LPG: Liquified Petroleum Gas

RNG: Renewable Natural Gas

NGV: Natural Gas Vehicle

LBG: Liquid Bio Gas

GHG: Greenhouse Gases

ICE: Internal Combustion Engine

1. Introduction

It is estimated that worldwide there are currently about 1400 million internal combustion engine (ICE) powered road vehicles (Saja, 2020). Research suggests that an average diesel vehicle emits about 43 tonnes of CO_2 in its lifetime and about 39 tonnes for a gasoline one (Zhang et al., 2021). Moreover, diesel engines release significantly more pollutants such as NOx and particulate matters than their gasoline engine equivalents (Andre et al., 2020). For these reasons, there has been increasing stringent legislation governing the emission and use and of diesel-fuelled engines, and new alternatives to these engines are emerging. One feasible option in internal combustion engines is natural gas-fuelled engines.

An ICE fuelled by natural gas offers notable emission reductions respect a gasoline engine: a reduction about between 70 and 90% of carbon monoxide (CO), between 50 and 70% of non-methane organic gas (NMOG), between 75 and 95% of nitrogen oxides (NO_x) and between 20 and 30% of carbon dioxide (CO_2) (BioCNG, 2021). Therefore, natural gas engines are the least polluting when talking about internal combustion ones and moreover, this fuel is the cleanest of the fossil fuels (Kontses et al., 2020). As compared to other fossil and biomass fuels, natural gas can be burned effectively to produce heat and electricity while releasing fewer pollution and pollutants at the point of use (EESI, 2016).

There are some different types of fuel gas that can be used in ICE, the most frequently used in these cases are natural gas, as already mentioned, and LPG. LPG or liquified petroleum gas, a gas fuel produced by petrochemical refineries from crude oil and mainly made up of propane and butane (WLPGA, 2021). The issue with this fuel is that is less safe than natural gas. It is difficult to eliminate in case of leakage and the amount of emissions of CO_2 by LPG fuelled engines is larger than natural gas vehicles and close to those fuelled by gasoline (Baumgartner et al., 2019).

The significance of the use of these fuels is on the storage system and the fuel handling system. The liquefied natural gas needs a big and complex system to cool the gas, as well as to prepare it again for combustion. Meanwhile, the compressed natural gas needs a bigger tank as it has a lower density, but it is safer, and the system is less complex than in the liquefied one, more like LPG. Each type of fuel requires one specific design of the fuel system and one of the most important objectives of the thesis will be to choose which fuel will fit best with the current engine characteristics and installations. This decision will affect the whole design of the fuel system as well as the modifications needed to the rest of the engine, as all of them depend on the fuel and its characteristics like the density, the way to ignite it (by spark or compression) and the state of it (liquid or gas). The designed solution may also apply to gas-converted diesel-based vehicle engines, as well as to any kinds of diesel engines.

One reason that makes the natural gas-fuelled engines attractive is that besides that exist dedicated engines for this fuel, it is possible to convert a diesel or a gasoline engine to run on natural gas with a few modifications. Among these, these engines can work with a mixture of natural gas and diesel or natural gas and gasoline or just natural gas. The issue of using gas as a fuel is its low density, so the first handicap is how to store the gas. Currently, there are two different methods available: cooling and pressurizing it. It can be cooled to -162°C to obtain liquified natural gas that it takes up about $1/600^{th}$ (0,167%) the volume of natural gas at standard conditions for pressure and temperature (Lngfacts.org, 2016). Whereas with the pressurization of natural gas at ambient temperature and pressure about 20-25 MPa is obtained compressed natural gas, which can take up about $1/100^{th}$ (1%) the volume of that gas at standards conditions (Pourahmadiyan et al., 2021).

1.1. Aims and objectives

This thesis was commissioned by Novia University of Applied Sciences. The aim of the thesis is to design a fuel gas handling system for operating on fuel gas in the engine laboratory of Novia to convert a diesel engine to a gas-fuelled engine. The engine is a SISU Diesel 420 DWRIE, this conversion could also be applied to a diesel power vehicle.

The objectives of the thesis are:

- Determine and decide on which concept to be used (cooling or pressurizing).
- Analyse the different methods of fuel handling.
- Establish rules and safety concepts.
- Propose a final system design to be built.

1.2. Document structure

The structure of the present thesis is the following: it consists of three main parts that are the research part, the establishment of safety concepts and the purpose of a design. The research part is divided into two parts, the first one is about the fuel gas types (LNG, CNG and LPG) and the second one about what are the fuel handling systems and the comparison between a diesel one with the decided fuel gas (CNG). Then, the establishment of safety concepts part addresses safety in the laboratory, in the filling tank and in the fuel feeding processes as well as in the exhaust gas pipes, where residual CNG can ignite. The last part of the thesis before the discussion and conclusions presents the initial and the final designs purposed by the authors. This part includes a flow diagram, a piping and instrumentation diagram, and its discussion, as well as a summary of all the components needed for the conversion of the diesel engine to a CNG-fuelled engine, including the price and the availability of them.

2. The Sisu Diesel 420 DWRIE

The laboratory where the engine of the present thesis is located is called Technobothnia. It is based in the city of Vaasa, Finland. The laboratory is a facility shared by three universities: The University of Vaasa, Novia University of Applied Sciences and Vaasa University of Applied Sciences and they aim to maximise the quality of the facilities with the coalition of the universities' budgets.

In this engine laboratory, there is a functional diesel engine. The engine is a Sisudiesel 420 DWRIE, with 4 cylinders and 95 kW of power. It has the following features, according to the SisuDiesel Workshop Manual (2013) and the SisuDiesel Operator's Manual (2017):

Table 1. *Sisu Diesel 420 DWRIE technical data (SisuDiesel, 2013).*

Number of cylinders	4
Power	95 kW 2200 rpm
Displacement (dm^3)	4,4
Cylinder bore (mm)	108
Stroke (mm)	120
Compression ratio	16,5/18,5:1
Combustion	Direct injection
Firing order	1-2-4-3
Compression pressure (bar)	24
Weight (kg)	345
Direction of rotation from the engine front	Clockwise
Serial number	J18570
Year of manufacture	1999

This data shows that it consists of a big and heavy engine as it weighs 345 kg and it is intended to be in a fixed installation, not in a vehicle. It was manufactured in 1999 and that means that it is a bit old, the electronic system probably has been added a posteriori and for that reason could be easy to change if necessary.

As the present thesis is focused on the fuel system, the technical data for it is shown in Table 2. This table shows the types of injectors, the filters, pumps, and types of fuels installed on the engine, as well as the pressures at which the fuel passes through valves and pumps.

Table 2. Technical data for the Sisudiesel 420 DWRIE fuel system (SisuDiesel, 2017).

Injection pump	Bosch, in-line type/Stanadyne, rotary type
Fuel	Diesel or biodiesel
Feed pressure, in-line pump overflow valve opening pressure	0,6-1 bar
Feed pressure, in-line pump static	2,7 bars
Feed pressure, rotary type pump static	0,48 bar
Feed pressure, rotary type pump min. pressure	0,20 bar/max. rpm
Injection order	1-2-4-3
Injector	Five-hole nozzle
Fuel filter	Bosch/CAV

This kind of engine is normally used for electricity generation. The one in the engine laboratory is used for academic purposes. Figure 1 shows an illustration of the specific model in the lab.

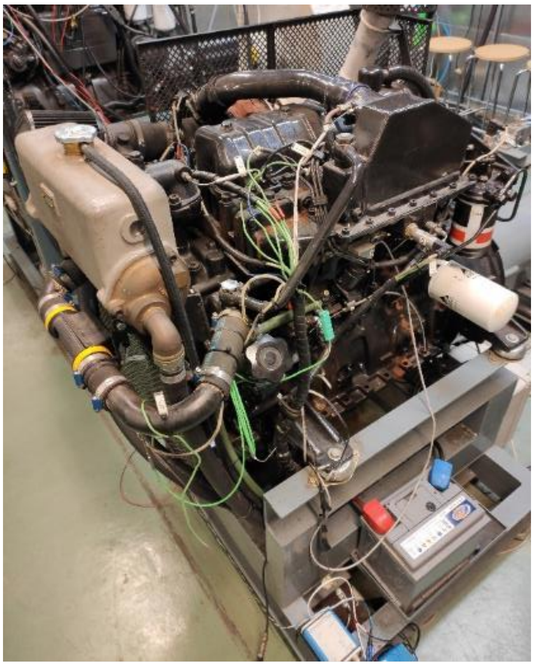

Figure 1. Sisu Diesel 420 DWRIE in Novia Engine Laboratory (2021).

This engine can be converted to a gas natural engine with some modifications. In the present thesis, these modifications are focused on the fuel handling system, the injection, the air-fuel mixing, the exhaust system, and the safety in all the system as well as in the laboratory.

2.1. Engine construction

The construction of the Sisu Diesel 420 DWRIE consists of the following components shown in Figure 2, with its respective legend in Table 3. It is mainly built like most diesel engines.

Table 3. *Legend for Figure 2 (SisuDiesel, 2017).*

Number	Component	Number	Component	Number	Component
1	Thermostat	9	Oil filter	17	Compressor
2	Injector	10	Coolant drain plug (oil cooler)	18	Alternator
3	Intercooler	11	Oil pressure regulating valve	19	Air conditioner compressor
4	Thermostart device	12	Oil dipstick	20	Prefilter
5	Breather pipe	13	Injection pump	21	Starter
6	Fuel filter	14	Timing indicator	22	Fuel feed pump
7	Coolant drain plug	15	Coolant pump	23	Turbocharger
8	Oil cooler	16	Oil filter		

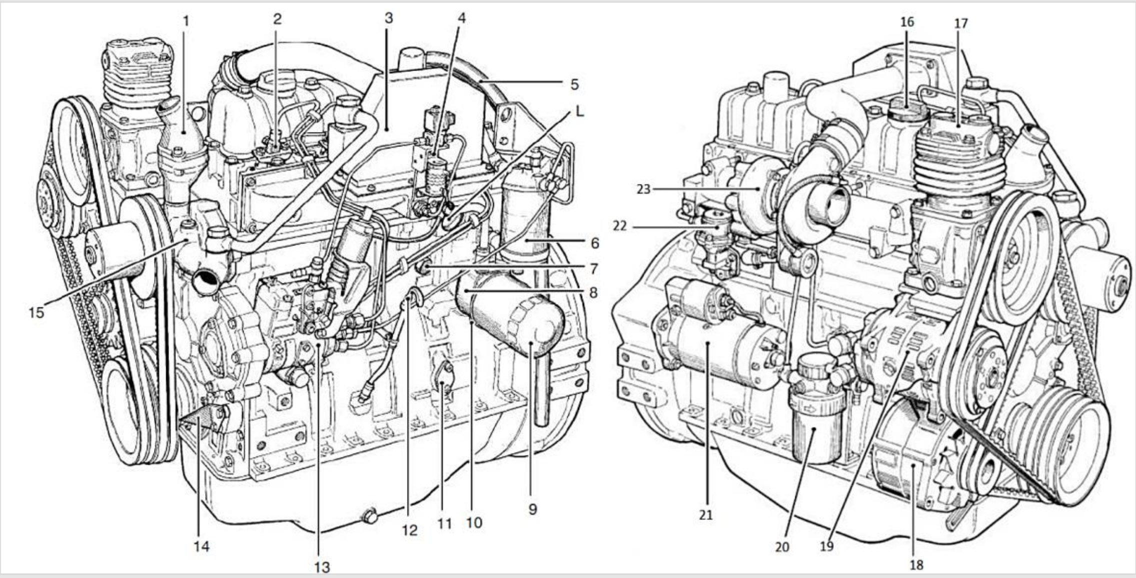

Figure 2. *Sisu Diesel 420 DWRIE illustration from the left on the left and the right on the right (SisuDiesel, 2017).*

The entire system surrounding the engine is part of the air intake system, the fuel system, the lubrication system, the cooling system or the electrical system. The rest is the own engine, which includes the four cylinders and four pistons, the timing belt and the casing of the engine.

2.2. Engine fuel system

In the target engine, the components of the fuel handling system are the following, shown in Figure 3, with its corresponding legend in Table 4. Each part is essential and is intended to work only in diesel fuel.

***Table 4**. Legend for Figure 3 (SisuDiesel, 2017)*

Number	Component	Number	Component	Number	Component
1	Fuel tank	5	Fuel injection pump	8	Glow plug
2	Prefilter	6	Injector	9	Overflow valve
3	Fuel feed pump	7a	Thermostart fuel reservoir		
4	Fuel filter	7b	Magnetic valve		

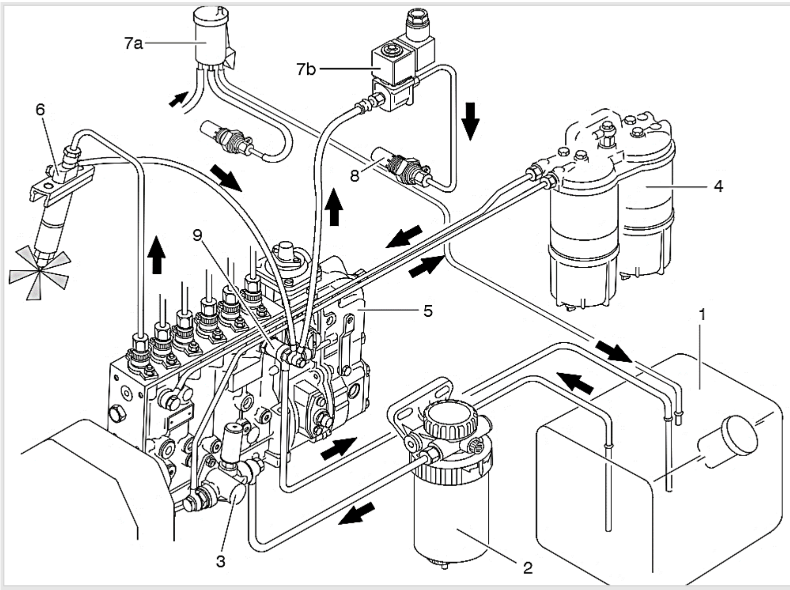

***Figure 3**. Sisu Diesel 420 DWRIE fuel system (SisuDiesel, 2017).*

The functioning of the fuel system is as follows. The fuel feed pump draws the fuel from the tank through the prefilter and then the filter. The fuel injection pump pumps fuel at high pressure through the delivery pipes to the injectors, which inject the fuel into the combustion chamber.

The system includes the Thermostart device, with it, the engine can be used in cold conditions. The glow plug receives fuel from a separate reservoir. Excess fuel returns from the fuel injection pump through the overflow valve to the fuel tank.

2.3. Installation in the laboratory

As mentioned above, the engine is located in the Novia engine laboratory in the Technobothnia building (Figure 4 shows the installation for the Sisu engine, see APPENDIX

1: Engine and installation in Novia Engine Laboratory for more pictures of the installation). In the laboratory, there are two more engines apart from the Sisu. The engines are intended to be used for the production of electricity. In this case, they are only used for academic purposes, such as to see how the motors work and perform.

The exhaust pipes of the engines are connected to a ventilation system that vents the exhaust gases to the outside. There is also a turbine, also connected to the outside that renews the air in the room. In the case of the Sisu, the fuel tank is located in the same room, anchored to the wall. Although space is limited, there is still room to include the gas tanks when the conversion is done.

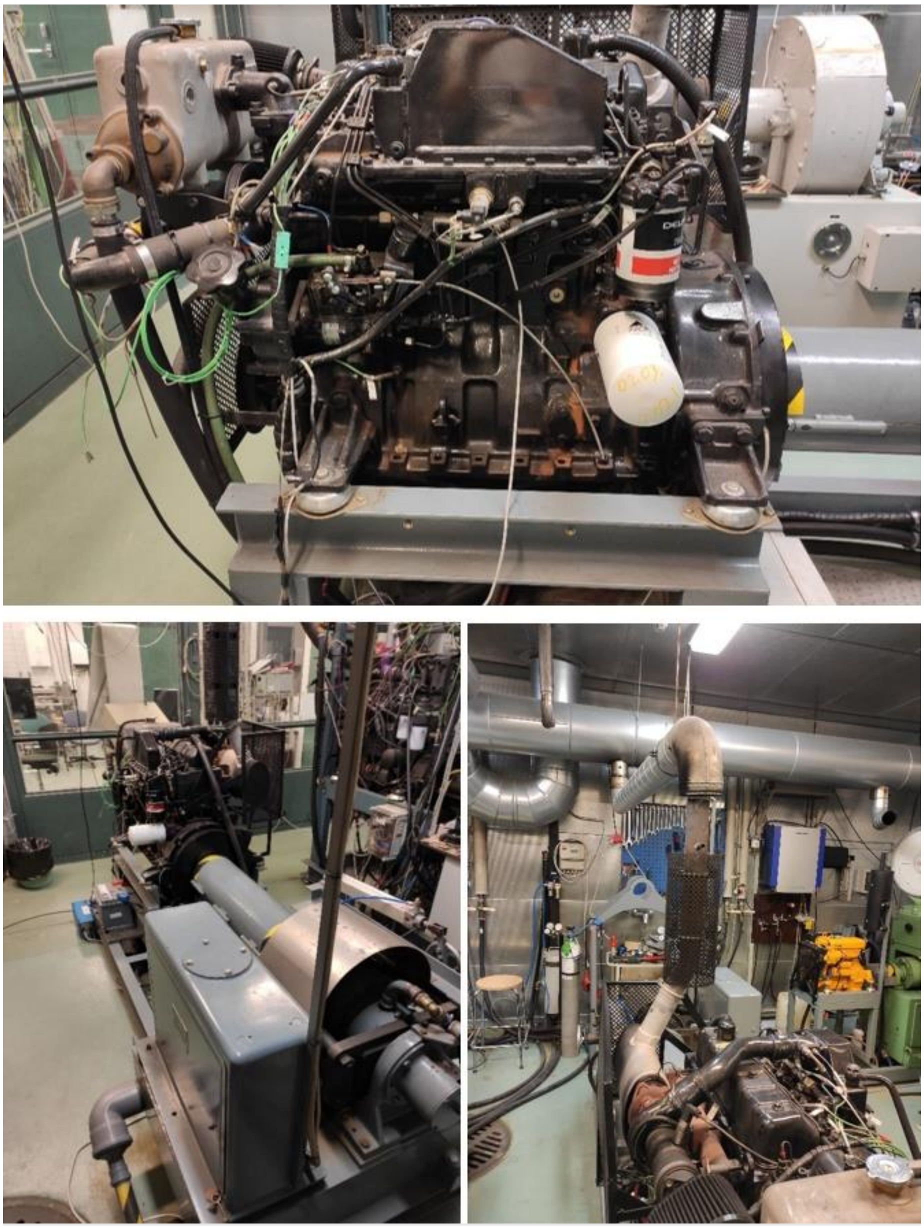

Figure 4. *Sisu Diesel installation in the Novia Engine Laboratory (2021).*

3. Fuel gas in common usage

The research section consists of establishing the theoretical basis for the main concepts of the thesis. Starting with the main types of gas fuels, which are: natural gas, mainly composed of methane, and which has several ways of being produced and stored, and LPG, a mixture of liquefied gases, derived from petroleum and natural gas, mainly composed of butane and propane.

Once the fuel to be used for the engine has been established, the basics of what a fuel handling system is must also be determined. Each type of fuel requires a different design to get the fuel from the fuel tank to the engine. In this case, the existing type (diesel) will be compared with one for the gas fuel chosen for the design.

3.1. Fuel gas types

The types of gases that can be used as fuel are very varied. There are gases such as water gas, a synthesis gas containing carbon monoxide and hydrogen, coal gas, derived from coal, wood gas, syngas made from biomass, etc. The fuels explained below, which are the most used in internal combustion engines, are liquefied petroleum gas and natural gas. This last one can be found in nature or can be produced from organic waste. It can also be stored in liquid form at low temperatures or compressed at high pressure (D'Agosto, 2019).

3.1.1. Natural gas

Natural gas is a fossil fuel that is formed deep underneath the earth's surface composed of different substances, mainly methane, as shown in Table 5 (Eia.gov, 2018). It is a gas formed by organisms that have been decomposing for millions of years. These organisms have been covered by layers of soil, sediments and rocks and this organic matter has been compressed at high temperatures in the earth's crust. (Turgeon et al., 2021).

Table 5. *Composition of natural gas (Uniongas.com, 2017).*

Component	**Formula**	**Range (mole %)**
Methane	CH_4	87,0 – 98,0
Ethane	C_2H_6	1,5 – 9,0
Propane	C_3H_8	0,1 – 1,5
Butane	C_4H_{10}	0 – 0,3
Pentane	C_5H_{12}	0 – 0,04
Hexanes plus	C_6+	0 – 0,06
Nitrogen	N_2	0,2 – 5,5
Carbon Dioxide	CO_2	0,05 – 1,0
Oxygen	O_2	0 – 0,1
Hydrogen	H_2	0 – 0,05

Natural gas, like most fossil fuels, is a non-renewable fuel. It is used as a source of energy for heating, cooking, and electricity production. And as in the present case, it can be used as fuel for vehicles (natgas, 2018). It is likewise utilized in the production of plastics and other economically relevant natural synthetic compounds as a chemical feedstock (Apga.org, 2021). Table 6 shows some properties of natural gas when it is processed. Natural gas is termed rich when it contains more quantities of recoverable higher hydrocarbon gases, otherwise, it is lean (Eswara et al., 2013).

Table 6. *Properties of processed natural gas (Eswara et al., 2013).*

Property	**Value**
Boiling point	-161,5 °C at 1 atm
Freezing point	-182,6 °C at 1 atm
Gas density	0,43~0,47
LNG specific gravity	0,7~0,9 kg/m3
Flammability limits	4~15
Ignition temperature	538 °C at 1 atm
Carbon content	73 by weight
Hydrogen content	24 by weight
Oxygen content	0,4 by weight
Hydrogen/Carbon atomic radio	3,0~4,0
Relative density	0,72~0,8 at 15 °C
Octane number	120~130
Methane number	69~99

About the natural gas environmental impact, it is based on three factors, drilling and extraction, transportation and burning and consumption (Borunda, 2020). Drilling a well can affect local ecosystems and cause earthquakes, transportation involves building a big infrastructure that is a very polluting process and finally the combustion of the gas that produces CO_2 that is emitted to the atmosphere (group.met.com, 2021).

Figure 5 shows the life cycle assessment (LCA) for natural gas about the GHG emissions. This LCA considers the whole natural gas supply chain, from its extraction to the use for electricity production and values the global warning potential in 100 years. As can be seen in the figure, the most polluting processes are the production, the gathering and boosting and the transmission of natural gas and the principal GHG emitted are carbon dioxide and methane. In this case, the N_2O does not contribute significantly to the results (Littlefield et al., 2019).

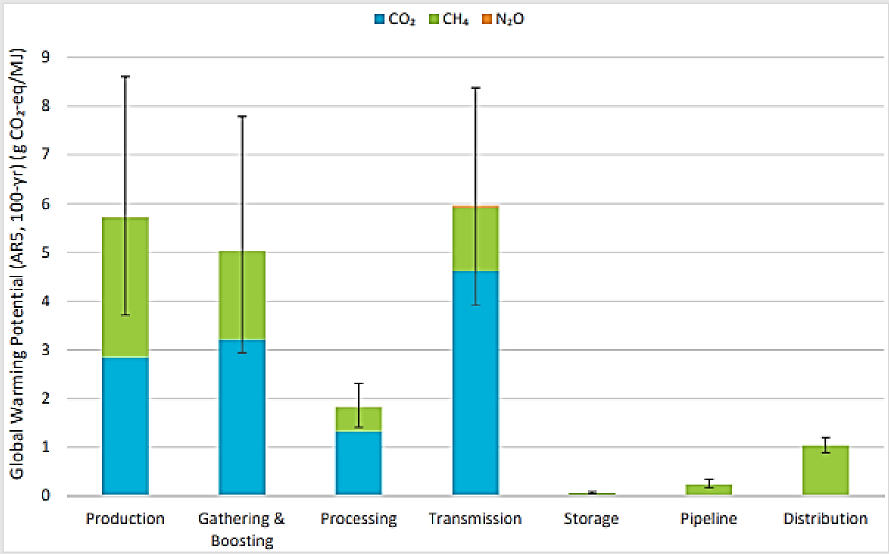

Figure 5*. Natural gas LCA (Littlefield et al., 2019).*

As a fuel for engines, it is intended for use with forced ignition, with a spark plug, as well as a gasoline engine (Wang et al., 2021). Natural gas can be stored as a pressurized gas, that would be CNG, and cooled to a very low temperature as a liquid, that would be LNG.

3.1.1.1. CNG

Compressed natural gas or CNG is natural gas stored at high pressures and is mainly composed of methane. It is mainly kept in a gaseous state to facilitate transportation or storage for use as fuel (Energyeducation.ca, 2018). In order to be used as fuel in vehicles, it is stored in aluminium, steel or some composite tanks (Energyeducation.ca, 2018) at pressures up to 3600 psi, around 25 MPa (Energy.gov, 2021a). In its gaseous state, it is odourless, transparent, lighter than air, non-corrosive and non-toxic at low levels of exposure (Hasan Kinjir, 2021).

Table 7*. Combustion related properties of CNG (Aslam et al., 2006).*

Property	**Value**
Density at 6 MPa (kg/m^3)	45
Density at 25 MPa (kg/m^3)	215
Motor octane number	120
Molar mass (g/mol)	16,04
Carbon weight fraction (mass%)	75
(A/F)s	16,79
Stoichiometric mixture density (kg/m^3)	1,24
Lower heating value (MJ/kg)	47,377
Lower heating value of stoic. mixture (MJ/kg)	2,72
Flammability limits (vol% in the air)	5-15
Spontaneous ignition temperature (°C)	645

Due to its chemical and physical properties, CNG is a great fuel for the spark ignition engine (Nylund et al. 2020). Besides, spark-ignition engines can be converted to CNG fuelled engines easily, with the modification or addition of a fuelling system.

CNG can increase engine efficiency if the engine is designed for specific use with CNG (Aslam et al., 2006). Furthermore, with the help of engine control systems, the engines can emit low amounts of emissions, emitting up to 80% less compared to petrol vehicles (Energyeducation.ca, 2018). Table 7 shows some of the most important combustion-related properties of compressed natural gas.

3.1.1.2. LNG

LNG stands for liquified natural gas. It consists of natural gas that has been cooled to approximately -162°C that the gas is in a liquid state (Chevron, 2018). By this process of liquefaction, the volume of the natural gas is about 600 times smaller than at standard conditions (1 atmosphere and 25 Celsius degrees). This means that the average density of LNG is about twice the average density of CNG at 25 MPa as can be seen in tables 6 and 6. This makes much easy the transportation and storage of this substance (Elengy.com, 2021).

Table 8 shows some of the most important combustion-related properties of LNG.

The process of liquefaction consists of the following steps: first, all the contaminants and impurities are removed, heavier hydrocarbons are removed to avoid equipment damage and the rest of the gas is cooled at –162°C (Dutta et al. 2018). The storage of LNG is done at atmospheric pressure in double-layer tanks made of materials that can bear these low temperatures like nickel-steel, aluminium or other cryogenic alloys and with insulation material in the part between the two layers of the tank, that make it very safe. The LNG is converted to its gaseous state for use in combustion engines by passing through heated pipes by direct-fired heaters or hot water (Saeid Mokhatab, 2016).

Table 8. *Combustion related properties of CNG (Arefin et al., 2020).*

Property	**Value**
Density at 1 atm and -162 °C (kg/m^3)	435
Motor octane number	120+
Molar mass (g/mol)	16
(A/F)s	17,2
Lower heating value (MJ/kg)	49,244
Flammability limits (vol% in air)	5-15
Spontaneous ignition temperature (°C)	540

Talking about safety and pollution, LNG is odourless, colourless, non-toxic and non-corrosive. If LNG spills on the ground or the sea it easily vaporizes and leaves no waste. So, if there is a leakage on the water it has no adverse effects on the biodiversity, which makes LNG safer than other fuels (Lees, 2012). It could be a problem if the LNG vaporizes in an enclosed space because the gas cloud could ignite, but if there are the necessary safety measures, the gas would ventilate and quickly dissipate (Dodge, 2014).

3.1.2. RNG

RNG stands for renewable natural gas, a clean alternative fuel. This product is made from biogas. Biogas is produced by anaerobic digestion; this process consists of the breakdown by microorganisms of different types of biowaste in the absence of oxygen. With this procedure, a mixture of methane and carbon dioxide is obtained. After the removal of the dioxide carbon and the rest of the impurities, it can be obtained a gas containing about 93% methane that can be used as a fuel for combustion engines, therefore the renewable natural gas that can be used as biofuel is biomethane or bio-CNG when it is compressed (Uçkun Kiran et al., 2016). The RNG can be stored in a pressurized tank to a maximum of 30 MPa and used in the same way and the same cases as CNG (Badurek, 2021). The RNG can be also cooled at −162 °C to obtain LBG (Liquid Bio Gas) and is an alternative biofuel for LNG as both are liquid methane, but with different origins (Stormossen, 2021b).

Table 9. *Component comparison between CNG, Bio-CNG and raw biogas (Imran Khan et al., 2017).*

Component	**CNG (volume%)**	**Bio-CNG (volume%)**	**Raw biogas (volume%)**
CH_4	89,14	93	65
CO_2	4,38	4	33
H_2	0,01	0,06	0,02
N_2	0,11	2,94	1,98
C_2H_6	4,05	-	-
C_3H_8	0,83	-	-
Iso-C_4H_{10}	0,28	-	-
Neo-C_4H_{10}	0,66	-	-
Iso-C_5H_{12}	0,09	-	-
Neo-C_5H_{12}	0,28	-	-
C_6H_{14}	0,17	-	-
H_2S	-	20 ppm	500 ppm

Table **9** shows a comparison between the composition of CNG (common natural gas), Bio-CNG (renewable natural gas or biomethane) and biogas as it is obtained from the anaerobic digestion. As it can be seen, raw biogas has a high quantity of carbon dioxide that has to be removed. After the extraction of CO_2 and the impurities, it has an even higher quantity of methane than Bio-CNG (Imran Khan et al., 2017).

3.1.3. LPG

LPG stands for liquified petroleum gas and it is usually referred to in many countries as "autogas". This fuel consists of many mixtures of liquid hydrocarbons like propane (minimum quantity of 85% in volume), propene (with a 5% in volume as max), butene and butene and may contain ethane and ethylene and an added odorant for safety measures called mercaptan (Encyclopedia Britannica, 2021). LPG is produced during petroleum refining and natural gas processing. Figure 6 shows how LPG is isolated from the hydrocarbon mixtures by separation by refining the crude oil, liquefied petroleum gas would be the lightest of the derivatives (González and Lagos, 2021).

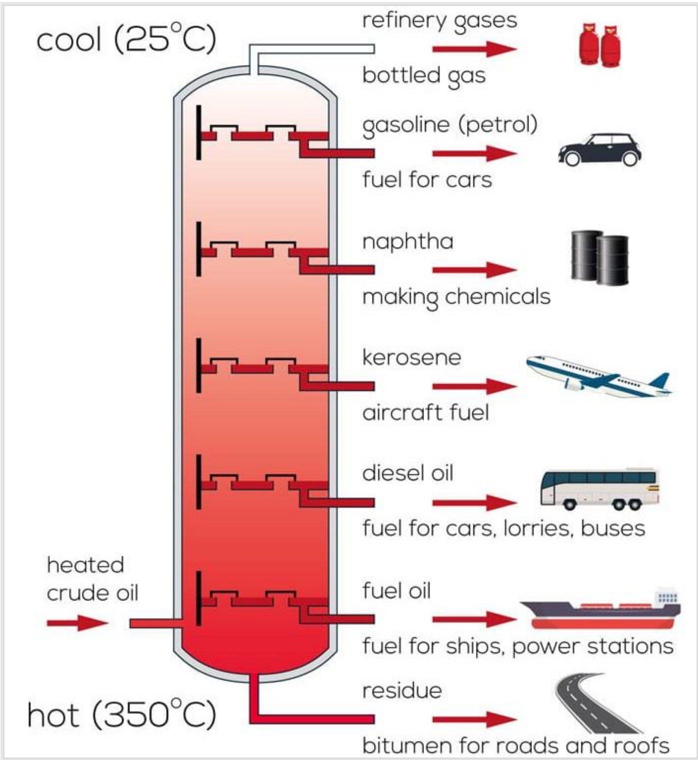

Figure 6. *Petroleum derivatives (González and Lagos, 2021).*

It is normally used for cooking, heating (can also be used as a power source for combined heat and power technologies), refrigeration and of course, fuel for IC engines (Sutar et al., 2020). As well as natural gas engines, LPG is also intended to be used in forced ignition engines, which means that the combustion starts with a spark plug, like gasoline engines (Nolan, 2019). Table 10 shows the principal combustion-related properties of liquefied petroleum gas.

Table 10. Liquefied petrol gas properties (Krishnaiah et al., 2017).

Property		**Value**
Density at 15 °C (kg/m^3)		557
Octane number		103-105
Lower heating value (MJ/kg)		45,7
Stoichiometric air/fuel ratio		15,5
Flammability limits (vol% in air)	Leaner	1,9
	Richer	9,7
Auto-ignition temperature (°C)		488-502
Flame speed (cm/s)		38,25
Stoichiometric A/F (kg of air/kg of fuel)		15,5

LPG has a higher density compared to CNG and LNG, as well as a higher octane number compared to diesel and gasoline but not compared to the natural gas derivatives properties (Krishnaiah et al., 2017).

4. CNG – Selected fuel gas

The chosen fuel gas for the design of the fuel gas handling system for the Sisudiesel in Novia's engine laboratory is CNG as it is the most suitable for this type and size of engines. The three options were CNG, LNG and LPG as these are the most common gas fuels used in gas-fuelled engines. In determining the optimum fuel gas for this engine, a range of selection criteria have been used:

1. Availability of the fuel
2. Safety aspects
3. Viability of designing a fuel system
4. Impact on the environment
5. Price of the fuel and the installation

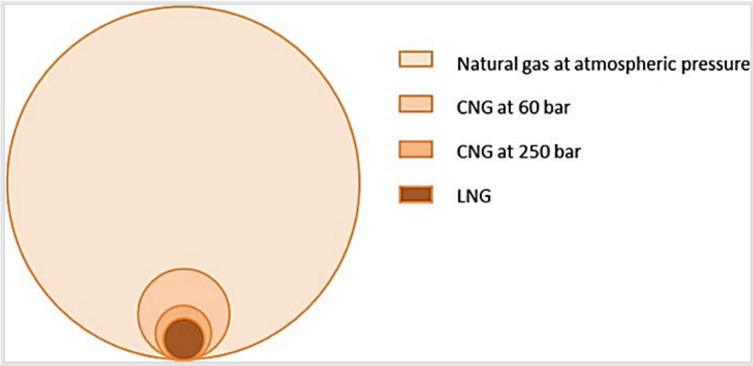

Figure 7. *Relative volumes of one unit of natural gas in different states (Wartsila.com, 2020).*

Foremost, CNG in comparison with LNG needs much less space for the handling system. LNG needs a large space as it has to be cooled at a very low temperature, which includes a bunkering station, the LNG tank, process equipment and control and monitoring system (Wartsila.com, 2020). That makes CNG systems easy to install and cheaper. Figure 7 shows the difference of the volume that would take up the same mass of natural gas in different states, as larger is the density, larger is the energy density of the fuel. It can be seen that LNG is the densest, so it is the state with higher energy density but the difference with CNG at 250 bar (25 MPa, the most usual pressure for CNG storage) is not relevant considering the advantages that CNG entails and that refilling the CNG tank in the laboratory it does not pose a problem.

Furthermore, CNG is the safest of the three. As CNG is very light, in case of leakage, it will quickly dissipate, while LPG and LNG (would it still is liquid) would settle on the ground (UTI Corporate, 2020). It is also the cleanest option. There is not much difference to LNG as both are natural gas, but in comparison with LPG, CNG releases fewer greenhouse gases while LPG combustion emits carbon dioxide (Hahn, 2020). Figure 8 shows how an average vehicle emits fewer pollutants (when it comes to CO_2, CO, NO_x and HC) fuelled by CNG than one fuelled by LPG.

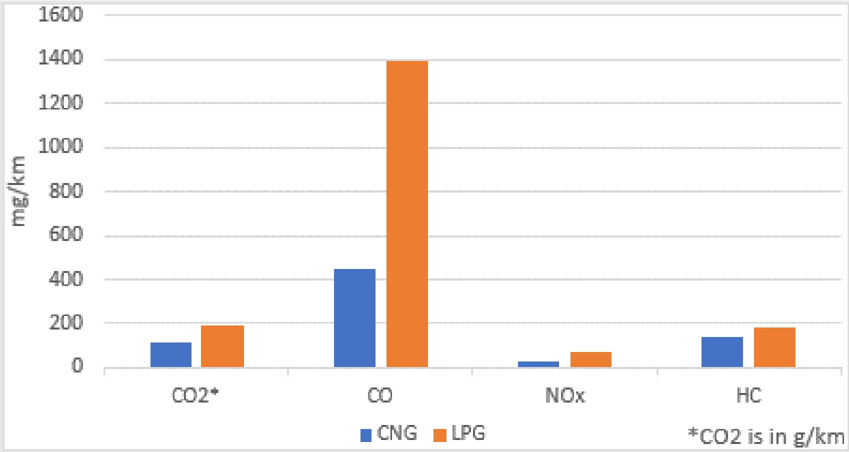

Figure 8. *CNG and LPG emissions comparison for an average vehicle (Imran Khan et al., 2017; Energy.gov, 2021b).*

Another advantage is that CNG can be compressed biomethane. That means that a CNG engine can work likewise with natural gas and RNG as both can be compressed in the same way (Suomen Kaasuenergia, 2017). In that way, it makes this option cleaner and more environmentally friendly.

Ultimately, other facts to consider are the price and availability of the aforementioned fuels. In Finland, there are 41 CNG filling stations and the average price is 1,21€/kg for CNG and 1,34€/kg for compressed RNG (CNGEurope, 2020). There are about 10 LNG filling stations in Finland with an average price of 1,31€/kg (Gasum, 2020) and none of them for LPG as there are no LPG vehicles in use in this country (Mylpg.eu, 2021). The price of the LNG is similar to CNG, but the transportation and storage are what makes this fuel more expensive (fortisbc.com, 2021). Besides, very close to Vaasa, it is based on the company Stormossen Oy, which produces biogas with biodegradable waste (Stormossen, 2021a).

4.1. Natural gas engines

There are four types of CNG engines (Nat-g.com, 2020):

- **Dedicated:** A dedicated CNG engine is the one that is just fuelled with CNG. The fuel handling system transfer the compressed gas at high pressure from the tank and it reduces the pressure to be combusted in the engine (Midwest Energy Solutions, 2021).

- **Mixed fuel:** This kind of engines use a mixture of diesel and CNG but with up to 90% or more of CNG, so it is almost a dedicated engine. They do not work without CNG (Tabar et al., 2016).
- **Dual fuel:** These engines are similar to mixed-fuels ones, but they run on average at 50% of CNG. These can run on 100% diesel. It uses a diesel tank and an additional CNG tank (Prinsautogas.com, 2021).
- **Bi-fuel:** These systems can switch between gasoline and CNG. They have two separate fuelling systems and run just with one of the fuels at a time (Volvocars.com, 2018).

4.2. Fuel handling system types

A fuel handling system involves the storage and the supply of fuel to the engine when it comes to an internal combustion one (Power train, 2018). The fuel is pumped from the fuel tank through the fuel lines until the injector, which injects the fuel into the cylinders of the engine (the fuel is mixed with air after or before this step depending on the injection type of the specific engine) (Burns, 2016). When the fuel is circulating through these fuel lines, it has to go through a fuel filter and fuel pressure regulators (Jay et al., 2012).

4.2.1. Diesel handling system

Each type of fuel needs a different fuel system. Figure 9 shows an example of a diagram for a diesel engine fuel system.

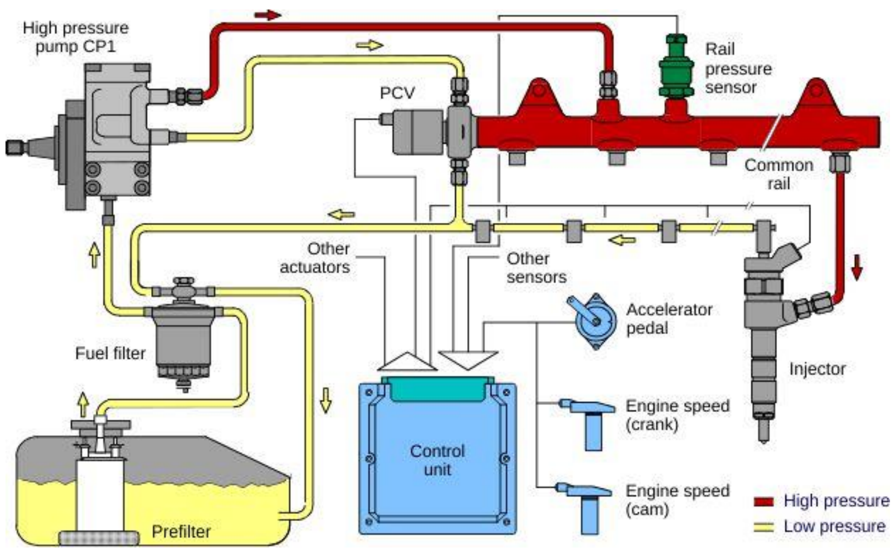

Figure 9. Diesel fuel handling system (Ezoil.com, 2021).

In a diesel engine, the fuel is extracted from the tank by the lift pump and first goes through the primary fuel filter. After that pump, the fuel goes through the high-pressure pump, which pushes it through a secondary filter and then to the injectors. Current diesel engines can have a common rail that doses the fuel to the injectors. Excess fuel delivered by the high-pressure pump is returned to the tank. All parts are electronically controlled by the control unit (Corke, 2020).

4.2.2. CNG handling system

The thesis aims to design a fuel handling system for a dedicated CNG engine. Figure 10 shows an example of a fuel system that uses CNG. This one is designed by Bosch for a CNG car, and it is a similar idea to the design of a fuel system that is the objective of this thesis.

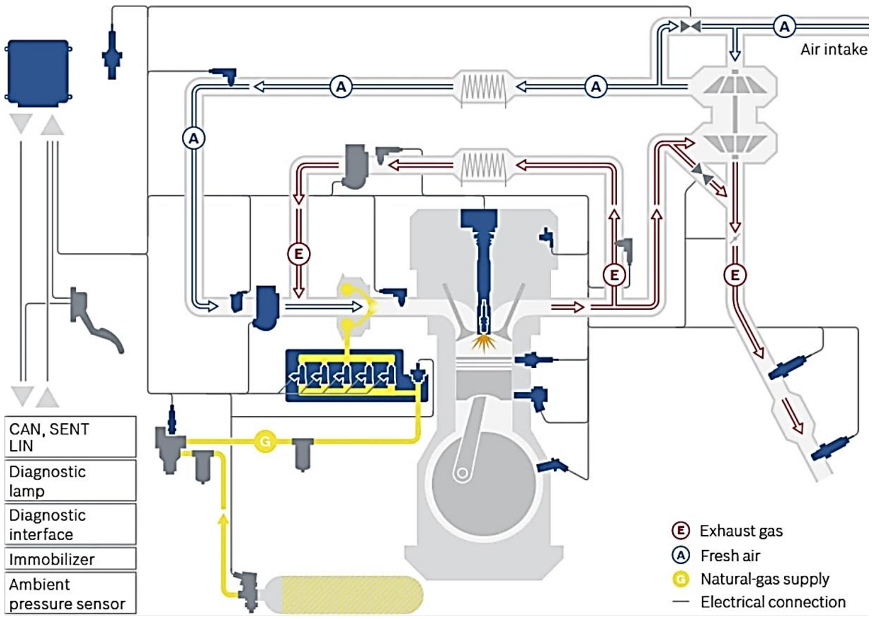

Figure 10. CNG Bi-fuel fuel handling system (Bosch mobility, 2021a).

Generically, a CNG fuel system works as follows. The CNG leaves the tank at high pressure (about 25 MPa) passing through the regulator, which reduces the gas pressure to about 1 MPa. The system has several gas and temperature sensors controlled by an electronic control unit, as well as several safety shut-off valves. Once the gas is decompressed, it passes through a filter and ends up in the common rail, where it is temporarily stored and metered to the injectors, which feed the fuel into the intake manifold. There the gas is mixed with air and ignited by the spark plug (Bosch mobility, 2021a). In the following sections, the version designed for the case in question will be developed.

4.2.3. CNG and diesel comparison

As explained in the previous sections, the fuel handling system of both fuels is different. First of all, diesel is used in its liquid state, while CNG is used in gas. That already makes the tanks different, the CNG tank must be more airtight and safer and withstand high pressures. The rest of the fuel system must also be different. For diesel, pumps are needed to extract the fuel, meanwhile, a CNG system requires a regulator to lower the pressure and several valves to stop the gas flow if necessary.

An important aspect to consider is that a diesel engine ignites the fuel by the elevated temperature of the air due to its compression (Brain, 2021). A CNG engine works like a gasoline one, a spark plug ignites the air-fuel mixture employing a spark (Rouleau et al., 2020). Therefore, a converted diesel engine to a natural gas one, the glow plug must be replaced by a spark plug.

5. Rules and safety concepts

To be marketable and safe, the components of the gas system are subjected to a series of tests. The main component where the greatest danger lies, is the gas tank, on which undergoes the most stringent testing.

Maintaining security inside the university campus is at the heart of this project. In order to ensure this, a series of security measures will be studied for all areas.

5.1. Natural gas and CNG safety

Natural gas has several interesting physical properties, but the most important for its use as a fuel is that it is flammable, so all fuelling and storage systems for natural gas vehicles have to be regulated (Energy.gov, 2021c). This association is a non-profit organisation that aims to eliminate deaths, injuries and property and economic damage due to electrical, fire and related accidents (Nfpa.org, 2021).

Another property that natural gas has is its low density. The relative density of natural gas compared with air is 0.62 (Engineering ToolBox, 2021). When there is a gas leak outside, the gas rises into the atmosphere and dissipates, unlike gasoline and diesel, these in case of leakage have a high potential for contamination soil or water (Hawrot-Paw et al., 2020). In case of being in a closed room, such as a garage or a laboratory, the gas accumulates in the upper part of the room. This presents great danger, as there may not be adequate ventilation and an explosion may occur. To avoid this, a safety measure is taken to facilitate the detection of the gas. Chemicals called odorants, such as mercaptan (Naturgy, 2021), are added to the gas, giving it a distinctive and striking odour, similar to rotten eggs (Energy.gov, 2021c), which allows a human to detect the odour of the gas at concentrations above 1% (Saadatmand et al., 2015). If t is detected, the first step is to close the manual valve on the compressed gas tank. It should also be noted that during refuelling, when connecting and disconnecting the tank from the system, a slight odour may be smelled. This is normal and should dissipate quickly after a few seconds.

In case of leakage and subsequent explosion happen due to the failure of the safety systems, there must be specific conditions for dissolving the gas in the enclosure. For an ignition hazard to occur, the gas must be in air concentrations of greater than 5% and less than 15% (PURA, 2020). At these concentrations, the gas can ignite over temperatures of 538°C (Arun Kishore Eswara et al., 2013). This mix of temperature and air concentration conditions makes the likelihood of an accident inside the enclosure very unlikely.

5.2. Tank

The tank is the main element of the gas injection system. Inside the tank, the natural gas is stored at high pressures. The operating pressure of the tank is between 21 MPa and 25 MPa (Sweet, 2020). Unlike traditional fuels, such as gasoline and diesel, natural gas is stored in gaseous form and is therefore affected by temperature and pressure. If the surrounding temperature varies, the pressure inside the tank will also vary, with the gas expanding as the temperature increases and contracting as the temperature decreases.

The tanks are designed to withstand pressures up to 125% of their maximum capacity, whereby 21 MPa tanks can withstand up to 26 MPa and 25 MPa tanks up to 31 MPa. This safety margin allows tanks to be filled at high pressure on days when temperatures are not very high (Energy.gov, 2021d). This margin allows the fuel to be kept in the tank for a certain period of time, depending on the temperature range of its location.

For the development of the thesis, two design proposals have been considered, one for the inside of the laboratory and one for the outside.

- **Inside the laboratory:** here it will be at a constant room temperature, around 22°C. This will prevent temperature changes, and the pressure inside the tank will remain constant. This allows the tank to be filled to maximum pressure.
- **Outdoor:** if this option is chosen, the temperature changes to which the tank will be exposed throughout the year must be considered. In the last years, the maximum summer temperatures were 25°C and minimum winter temperatures at -30°C (Ilmatieteenlaitos.fi, 2021).

Figure 11 shows the relationship between temperature and pressure in a CNG tank compared to the standard temperature of 20°C.

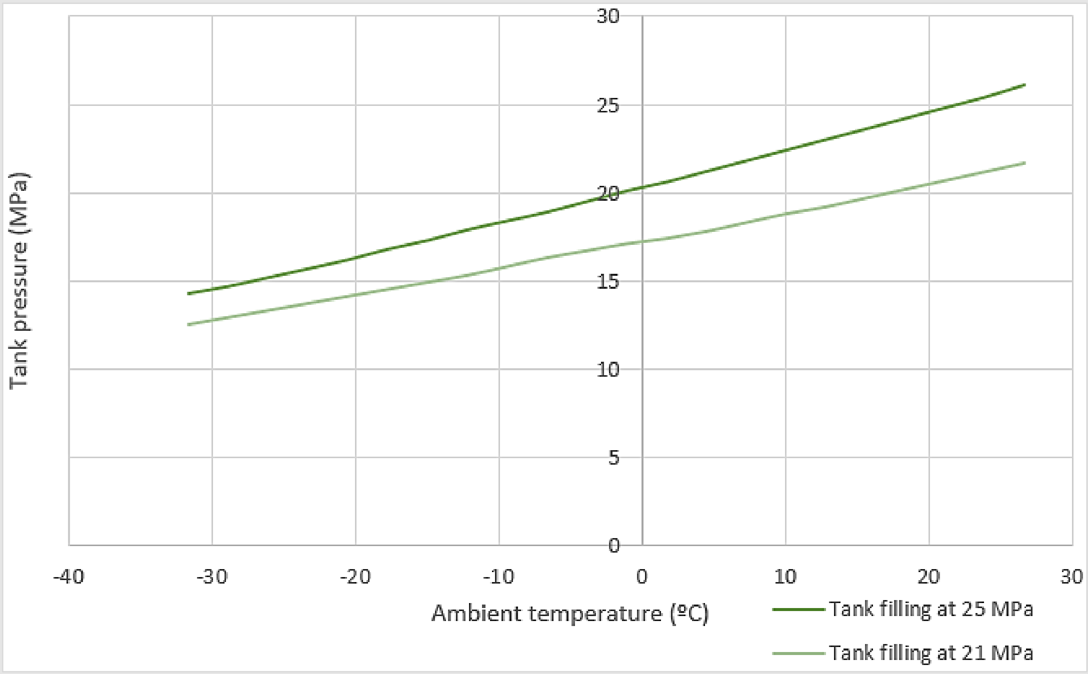

Figure 11. *Tank pressure variation with the temperature (Farzaneh-Gord et al., 2018).*

Figure 11 represents the variation of pressure with respect to the temperature in the range of pressures for which the tanks can be designed, with a minimum of 21 MPa and a maximum of 25 MPa.

From Figure 11 it can be seen that as the temperature increases, the pressure increments increase slightly. The pressure increments have been calculated for every increment of 2.8°C. Between temperatures -29°C and -32°C, there is an increase of 0.4 MPa, while between temperatures 24°C and 27°C, there is an increase of 0.7 MPa. In order to ensure that the pressure rise is not underestimated, having a higher pressure than calculated, the maximum pressure rise of 0.7 MPa is taken. With this increase, it is possible to calculate the maximum temperature increase that the tank will withstand without danger of explosion. With this increase, the minimum temperature that the tank can be filled without being a risk if the temperature increases can be calculated.

In Table 11 the respective calculations are made to obtain the maximum allowable temperature rise. It should be noted that this increase will always be positive, since if the temperature decreases, the pressure will also decrease and will not be a limiting factor.

Table 11. *Calculations for maximum temperature allowable rise.*

Operation pressure (MPa)	25
Maximum pressure allowable (MPa)	31
Pressure increment (MPa)	6
Number of increments	8
Final pressure (MPa)	25+8·0,7 = 30.6
Maximum temperature increase (°C)	8·2.8 = 22.4

Table 11 shows how an increment of up to 22.4°C can be allowed for in the filling temperature. Depending on the time of the year when the tank is filled, this temperature has to be taken into account. To find out if this factor will be limiting for the project, the temperature range of the city of Vaasa is studied.

Taking into account the maximum and minimum temperatures in the city of Vasa, a range of 55°C is obtained, exceeding the maximum allowable increment. With this increment and based on the latest temperatures over the last year, it can be stated that the minimum tank filling temperature without risking safety is 2.6°C. By filling the tank at this temperature, it is possible to keep the gas stored in the tank all year round without endangering the safety of anyone. In the case of filling at lower temperatures, the maximum temperature it can withstand must be considered.

To prevent an accident from happening due to increased pressure, a pressure relief valve can be installed. This valve is used as a last resource and should not be relied upon. This valve has the function of reducing the pressure inside the tank when it reaches its maximum capacity. This valve partially opens when the maximum pressure is exceeded and depressurises the tank to the desired pressure, in this case at 125% of its total capacity.

Another factor that affects tank capacity is tank filling. As the tank is filled, the temperature of the natural gas molecules increases, expanding and becoming less dense, losing energy by volume when the manufacturer's recommended pressure is reached. There are two types of filling, "Fast-filling", which consists of filling the tank in the shortest possible time, and "Time-filling", which is usually a slower process and consists of filling the tank in a determined time. “Time-filling”, although slower, is more efficient, as it allows the CNG molecules to remain in a denser state, avoiding the expansion created by the rapid compression of the fuel by “Fast-filling” (Energy.gov, 2021d). In Section 5.4, the filling procedure that has to be carried out in the two design options is explained in more detail.

Finally, in case the engine has not been used for a long period of time, the tank valves should be closed and the engine started until it is choked (Agility, 2019a). This will allow any residual gas that has remained in the pipes from the cylinder valves to the engine to be consumed.

5.3. Tank safety tests

This section shows the safety tests that the tanks are subjected to ensure their reliability in case of an accident. This type of testing pushes the tank's performance to the limit, as it is subjected to a series of very abusive tests. Other parts of the injection system also have to pass safety tests, such as valves, to prevent leaks and minimise or eliminate the risk of explosion (Minton, 2015).

Table 12. Security tests performed on CNG-3 type tanks shows the tests performed on the tanks. Depending on the type of tank, the tests may vary, so in this section, the most common tanks (CNG-3) have been studied.

Table 12. *Security tests performed on CNG-3 type tanks (Sources – various).*

Hydrostatic pressure burst test	This test is performed with a liquid fluid, usually water. The performance of this test on tanks allows verifying their resistance, structural integrity and hermiticity (Government of Chile, 2017).
Ambient temperature pressure cycling test	The tanks are subjected to failure or up to a minimum of 45,000 cycles, through different pressure cycles at ambient temperature. They must not fail before their specified service life in years per 1,000 cycles (United Nations, 2014).
Environmental test	It verifies that the tanks withstand exposure to the different environments that can be exposed in an automobile or others. The test studies the exposure to different fluids, to analyse the cracking caused by corrosion (United Nations, 2014). The fluids used are usually sulfuric acid, methanol, gasoline, windshield washer fluid, sodium hydroxide, etc (SWANDA, 2014).
Bonfire test	It demonstrates the durability of the tanks in case of fire. It is subjected to a high external temperature of at least 590°C for a certain period of time (United Nations, 2014).
Penetration test	It indicates the resistance of tanks to projectiles. A CNG cylinder pressurized to 20 MPa can not be penetrated by a

	bullet smaller than 7.62 mm in diameter (United Nations, 2014).
Flaw tolerance tests	The finished tank is sectioned longitudinally and the defects in the composite material are checked to ensure that they are less than those specified by the manufacturer (United Nations, 2014).
High temperature creep test	The cylinder is subjected to a temperature of at least 100 °C for a period exceeding 200 hours and pressurized to 26 MPa. During this period of time, the temperature of the resin matrix may not exceed the maximum design temperature of the material by at least 20 °C (United Nations, 2014).
Accelerated stress rupture test	The tank without protective coating is hydrostatically pressurized to 26 MPa and immersed in water at 65 °C. It is maintained in this state for 1,000 hours. Subsequently, the cylinder must withstand a minimum burst pressure of 85% of its design (United Nations, 2014).
Leak-Before-Break (LBB) performance	The tank is subjected to pressure cycles between 2 and 30 MPa, at a rate of fewer than 10 cycles per minute, until failure due to leakage is reached (United Nations, 2014).
Extreme temperature pressure cycling test	Finished tanks without any protective coating are cycled at different temperatures and pressures until they show evidence of rupture, leakage or fibre detachment (United Nations, 2014).

Table 12. Security tests performed on CNG-3 type tanks confirms the number of tests a tank has to pass before it can be placed on the market. This demonstrates the importance of reliability and quality of the product.

5.4. Tank filling

The tank capacity not only depends on the tank itself but also the ambient temperature and the filling rate. The study has been done to a tank of a 25 MPa capacity. In order to analyse tank filling, two extreme filling options have been studied, at -18°C and 21°C, which can occur in the city of Vaasa.

The filling of the tank is differentiated into different time stages, where each stage is characterized by a different phenomenon. The information has been extracted from the Department of Energy of the U.S (Energy.gov, 2021e).

5.4.1. Fast-fill at -18 °C and 21°C

At the start of the filling process, in both cases the natural gas expands in the tank, cooling in the process. This phenomenon is known as the Joule-Thomson effect (Roy, 2002).

From the first minute onwards, the gas continues to enter the tank, raising its internal pressure and temperature. During this process, the gas releases heat. This generated heat energy is called the heat of recompression.

After three minutes, the internal temperature of the tank starts to increase considerably, as the tank is filled quickly and the heat does not have time to dissipate through the walls of the tank. It is at this point that the temperature of the environment begins to affect the process. If the tank is filled at -18°C, the gas molecules move slower than on a warm day, allowing the tank to fill more. If the tank is filled at 21°C, the molecules move faster, resulting in higher pressure and reduced tank capacity.

After five minutes, the tank reaches a certain pressure and the gas supply is cut off. Depending on the ambient temperature, the supply stops at 21 MPa if the temperature is -18°C or at 28 MPa if the temperature is 21°C.

In the last hour, the tank is allowed to cool until the entire gas system and the tank is at ambient temperature. In the case of filling the tank at -18°C, the tank pressure will be reduced to 17 MPa. If the tank is left outside unused for an extended period of time and temperatures rise to 21°C, the tank will be at a pressure of 25 MPa and will not endanger anyone's safety. On the other hand, if the tank is filled on a hot day at 21°C, the tank pressure will be reduced to 25 MPa, which is the rated pressure of the tank. In case of the ambient temperature rises, the tank will hold up to 125% of its rated capacity, so there is no risk.

In Figure 12 and Figure 13 it can be seen the process of fast-filling the tank at different temperatures.

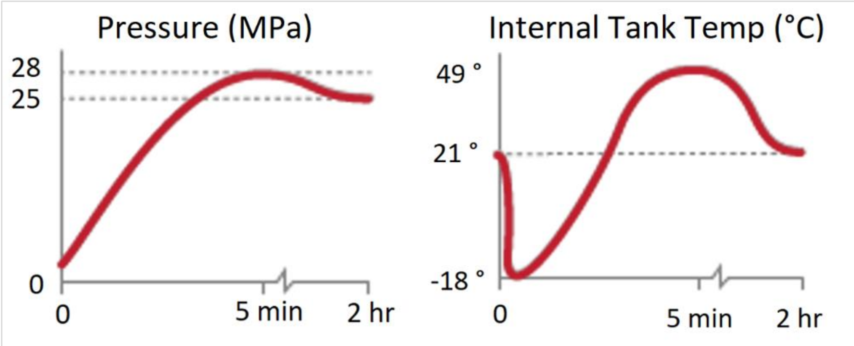

Figure 12. *Fast-fill at 21°C (Energy.gov, 2021f).*

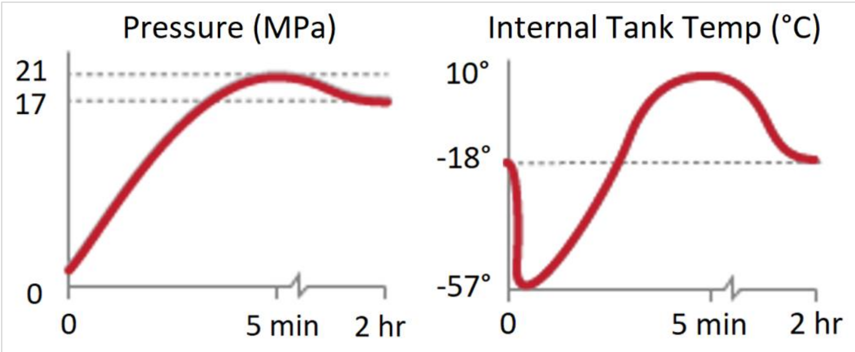

Figure 13. *Fast-fill at -18°C (Energy.gov, 2021f).*

With Figure 12 and Figure 13, the reader can get an idea of the complete process of filling the tank with respect to pressure and temperature over time. The figures show how the tank finally reaches the nominal pressure and the ambient temperature.

5.4.2. Time-fill at -18°C and 21°C

In the first hour, the gas is slowly introduced inside the tank, cooling slightly due to the expansion of the gas.

During the first four hours, the temperature and pressure inside the tank have gradually increased and thermal heat is generated, a large part of which is radiated by the tank walls, reaching a temperature slightly above ambient.

Between the fourth and sixth hour, the gas supply is stopped when a certain pressure is reached. The time is approximate because of the wide variety of factors involved, such as temperature or the maximum pressure that the tank can withstand. In the case of filling at -18°C, the filling of the tank stops at a pressure of 19 MPa. On the other hand, with filling at 21°C, the filling process stops at a pressure of 26 MPa.

In the last hour, the gas will cool down to ambient temperature, reducing the inside tank pressure to 17 MPa and 25 MPa at -18°C and 21°C respectively. In case that the outside ambient temperature rises, the tank will hold up to 125 % of its operating capacity, so that the cylinder pressure will remain within the set safety range.

Figure 14 and Figure 15 show the processes of time-fill at 21°C and -18°C respectively.

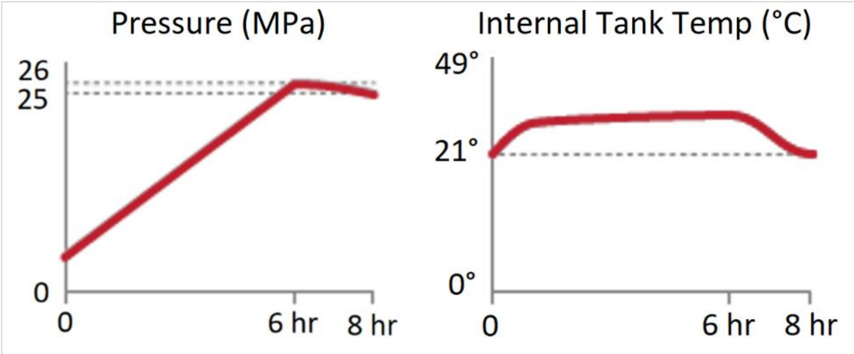

Figure 14. *Time-fill at 21°C (Energy.gov, 2021f).*

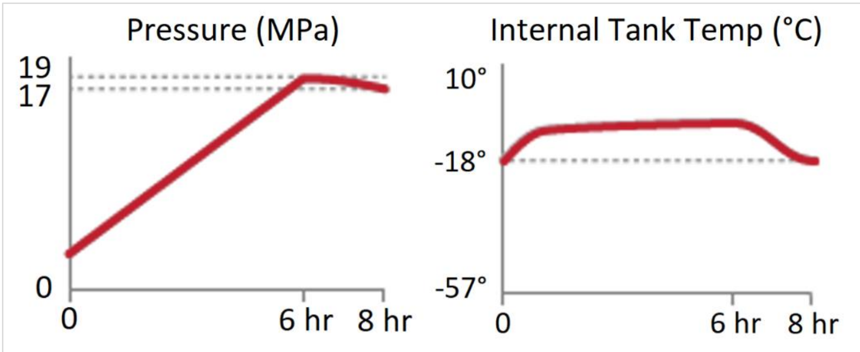

Figure 15. *Time-fill -18°C (Energy.gov, 2021f).*

Figure 14 and Figure 15 show the pressures and temperatures throughout the time. As explained in the text, the final temperature is always the ambient temperature, as the system reaches thermal equilibrium, and the final pressure is always the nominal pressure.

5.5. Maintenance

Unlike systems used for vehicles running on common fuels such as petrol and diesel, CNG systems can pose a safety hazard to people. CNG tanks are designed to have a lifetime of approximately 20 years and to be refilled a total of 1,000 times per service year (European Union, 2011). In the case of this project, the engine will be in an educational facility and may be exposed to corrosive or harmful elements. To ensure that the tank reaches the end of its service life in good condition, several overhauls will have to be carried out.

In the case of a laboratory, there are no regulations that determine the inspection periods, so the same regulations as in a vehicle should be followed to avoid any inconvenience. There are four different types of inspections, the pre-delivery inspection, the quick visual inspection, the general inspection and the detailed visual inspection (Natural Gas Vehicle Institute, 2020).

The pre-delivery inspection consists of inspecting the system before it is put into service. In this inspection, the surfaces, fuel cylinders and components are examined. This procedure ensures that the installation is correct. This inspection has to be carried out by a certified CNG system inspector (Agility, 2019a).

The quick visual inspection is carried out every day the system is used. This consists of a cursory inspection of the entire system, making sure that there is no evidence of any damage or leakage. This can be done by the same person who intends to use the system (NGVAMERICA, 2018).

The general inspection can be performed at any time of system maintenance, such as an air or oil filter change. This inspection checks the entire system, looking for anomalies, but pays particular attention to the cylinder. This is usually performed by a qualified technician (Agility, 2019a).

The detailed visual inspection is carried out after a period of 36 months (Department of Transportation, 2003). During the inspection, all elements are checked, especially those that are subject to high pressures, such as valves or cylinders. The inspection must be done by a CNG inspector (Natural Gas Vehicle Institute, 2020).

During the inspections, the main focus is on the tank. Here, different surface damages, which can be seen with the naked eye, are looked for. Depending on the extent of the damage, they are classified into different levels, with level one being the mildest and level three the most severe (Agility, 2019a).

Other types of damages are cuts, scratches or abrasions. These are caused by an external object rubbing against the cylinder. Vibrations or modifications can also damage the cylinder. The tanks are designed to withstand small impacts, but during transport, installation or refilling, significant damage can occur. This can take the form of permanent deformations on the surface. The ends of the tank, including valves and pressure systems, are where the main danger lies, and where most attention should be paid (Agility, 2019b).

Damage from fire or excessive heat is another important point. Cylinders are designed to use at a maximum temperature of 82.2°C. This surface damage can be observed in the form of darkening or sooting on the cylinder surface. This can lead to fibre loss and is considered the highest level of damage, level three. This implies the replacement of the tank (Agility, 2019b).

Chemical damage is often caused by acids or other chemicals. These can be highly corrosive and can severely damage the tank. Once such damage is detected, a detailed inspection should be carried out to determine whether the chemical has damaged the cylinder structure (Agility, 2019b).

If the tank is located outside is exposed to the elements and can be damaged by a variety of factors. This long-term exposure causes the cylinder to discolour, flake or corrode. Corrosion damage can only occur on cylinders without a protective coating. These types of surface damage are considered to range from mild, level one, which can be fixed by filing the surface (Agility, 2019b), to severe, level three, where the fibres are damaged and end the service life of the tank (Agility, 2019a). To prevent this damage, painted cylinders can be recoated with polyurethane paint. If the cylinder is not painted, an epoxy resin coating can be applied to its surface (Agility, 2019a).

Finally, the revisions are intended to detect any gas leakage. Occasionally, small bubbles can be observed on the surface of the tank. This can occur after the first filling or when the tank is almost empty and is a normal phenomenon. However, it can also be caused by overpressure when the cylinder is subjected to more than 125 % of its capacity. In this case, it is considered level three damage and the cylinder must be removed (Agility, 2019b). Also, an electronic leak detector is used to check for leaks and their location. Once leaks are detected, their location is pinpointed with a methane detection liquid (Agility, 2019a).

5.6. Exhaust pipe safety

To avoid the possibility that residual gas could be present in the exhaust pipes and could cause ignition and explode, a pressure relief device is implemented. It works by allowing gases to escape when there is an unwanted pressure increment (Nationalboard, 2021). This allows that, in case of an explosion in the piping, it can exit through a parallel piping system with a free outlet to the outside, preventing an explosion inside the laboratory and in the exhaust system of the gases.

There are a variety of different types of devices available on the market, such as safety valve, relief valve, safety and relief valve and rupture disc (Nationalboard, 2021). The two most common devices are the safety valve and the relief valve. The main difference between these is their purpose, the safety valve has a purpose of being fail-safe, in order to protect installations and people, while the relief valve has the purpose of keeping the system pressure within its operating parameters to avoid damaging the installation due to overpressure (Tameson, 2021). Putting these two purposes together, the safety and relief valve is created, making it one of the best options for the project. The last option is the rupture disc, these have the same purpose as the safety relief valve. The main difference between the bursting disc and the valves is their lifetime (Cheremisinof et al., 2009). It can only be used once, then it has to be replaced by a new one.

In order to propose the selection of one device, the characteristics of both have been analysed. The main criterion taken into account is the reaction time. A valve takes about 50 ms to open completely, while a bursting disc takes between 2 and 4 ms (Rembe, 2014). It also has to be taken into account that a rupture disc is fail-safe, as it consists of a membrane of a selected material, which depends on the pressure it has to withstand. Valves are more complex systems, with pneumatic, mechanical and electronic systems that can have a malfunction (White et al., 2018).

An explosion is a process that occurs rapidly. In order to ensure the proper functioning of the safety system, it is proposed to implement a pressure disc. The implementation of a pressure disc also simplifies the system and lightens the weight in the pipelines (Rembe, 2014).

The pressure disc is placed inside a disc holder and this is attached to the pipe. Once the disc has been used, it can be exchanged for a new one. In order to know if it is necessary, the disc holder has a sensor that notifies it (Rembe, 2014).

The pressure that the disc will have to withstand is 0.1 MPa, as the gases will be released at atmospheric pressure. In the event of a pressure increment in the piping system, the disc will open and allow the gases to escape. To allow for a safety margin, a burst pressure of 0.125 MPa has been proposed for the disc, with a safety coefficient of 1.25.

5.7. Laboratory safety

Within the laboratory, a new system involving the use of natural gas will be incorporated. This gas was not previously used on the premises, so safety measures will have to be taken to ensure the safety of people and the installation in the event of a gas leak.

To detect the gas, gas detectors will be used. These detect hydrocarbons, hydrogens and gaseous fuels. These sensors can be programmed to detect the concentration of gas in the environment (Status Scientific, 2021). When they detect a concentration above the programmed minimum concentration, an alarm is triggered. The sensor has to be connected to the electronic control unit, which, when it reaches the set concentration, causes the engine to stop. To ensure the safety of the laboratory, two sensors will be installed and connected to the electronic control unit of the engine.

When the gas detector is activated and the engine is switched off, the laboratory will be ventilated. Currently, there is a pipe used to ventilate the laboratory on hot summer days, which is connected to a motor that brings outside air into the laboratory. One option is to take advantage of this pipe to extract gas from inside the laboratory if it is detected. Another option is to add an extension to the exhaust extraction system. In both cases, an electric motor would be added to extract the natural gas from inside the laboratory. This electric motor can also be connected to the control system to be switched on once the gas detector is triggered.

The two options for the implementation of the ventilation system can be seen in APPENDIX 1: Engine and installation in Novia Engine Laboratory, in Figure 4 and Figure 6.

5.8. Tukes regulation

Tukes is the Finnish chemical safety and substance safety agency. Through engineers, toxicologists, and other professionals, it regulates the safety and reliability of services, products and industrial activity (Tukes, 2015a). Its aim is to ensure that all facilities, services, or products comply with established regulations, protecting people, the environment and property.

In the development of this thesis, two options have been proposed to carry out the project, inside the laboratory and outside. As in both cases, piping and storage of natural gas are required, a series of regulations and a subsequent verification by an entity such as Tukes have to be followed to ensure its correct installation.

Before starting with the installation of the system, a licence has to be requested from Tukes, which takes a few months to validate. The aim is to ensure the safety of the site, the equipment used, the construction, and the knowledge of the surrounding area (Tukes, 2015b).

In order to determine whether a licence is required, different scenarios have been studied (Tukes, 2015b). Among those required, the installation of the system involves the addition of gas piping, so a license will be necessary. On the other hand, the tanks will only have a maximum capacity of 98,06 kg or 0.098 tons (calculations are made in Section 6.2), so no permit will be required for the construction of the gas storage.

It may be the case that it is needed to adapt the installation and make any changes, in which case it will have to be notified to Tukes if accomplishes any of the points that they impose, as the piping system modification (Tukes, 2015c).

In order to keep track of the status of the installation, Tukes requests the imposition of a supervisor to take responsibility for ensuring safety and supervising operations (Tukes, 2015d). In the case of this project, the supervisor must monitor the condition of the natural gas pipes and the tank. The university should notify Tukes who is the supervisor of the system. To ensure that there is always one person in charge, more than one supervisor can be assigned.

To ensure the professionalism of the supervisor, three characteristics must be met, they must pass a Tukes examination on natural gas operations, obtain a certificate from a polytechnic institute, technical institute or institute of higher education, and finally have a minimum work experience of two years in the field of natural gas transmission (Tukes, 2015d).

To carry out the installation, qualified operators approved by Tukes are required. Tukes provides a list of candidates who, apart from installation, can carry out maintenance and repairs (Tukes, 2021).

Once the installation is complete, an inspection is required to ensure its safety. This inspection is carried out by a Tukes technician. Periodic inspections of the installation are also carried out every eight years to ensure its good condition (Tukes, 2012).

6. Resultant design

In this part, the design of the fuel handling system is developed. To begin with, the size of the tank must be calculated according to the expected power and running time of the engine. From there, the design of the whole system including all the components of the system from the tank to the engine cylinders must be made. The final design is showed as a piping and instrumentation diagram.

6.1. Diesel to CNG conversion

To convert a diesel engine to a CNG-fuelled one, first, the whole fuel system must be changed, as the diesel is liquid and the CNG is gas. The glow plugs must be replaced by spark plugs and there are also additional parts that must be added, like sensors, ignition controllers, ignitions coils, etc. that are part of the engine itself and not so much part of the fuel handling system (Krishna, 2018).

6.1.1. Conversion steps

The exact steps for the conversion of the diesel engine to CNG are as follows (Ismail et al., 2016):

1. Dismantle the engine.
2. Go component by component to replace the necessary components.
3. Modify the pistons for CNG, as the compression ratio is different.
4. Modify the cylinder head and replace glow plugs with spark plugs.
5. Reassemble the engine and install the injection and ignition system, as well as all the surrounding systems, like the electric and the fuel system.
6. The fuel handling system must be completely replaced, component by component.

6.1.2. CNG components

The components needed for a CNG fuel handling system, from the tank until the engine are the following:

- **CNG regulator.** This regulator has the function of depressurizing the compressed gas and control the pressure. It consists of an electromagnetic valve controlled by the ECU. The CNG is supplied from the tank in the range between 25 and 2,5 MPa, depending on how full the tank is, and the regulator reduces the pressure to match the pressure required in the engine cylinder, about 1 MPa. In case the system uses a gas mixer (or venturi mixer, see below), it can be installed a second regulator to reduce the pressure to the atmospheric pressure (Ventrex.com, 2021).

- **CNG cylinders** (or tanks). There is where the gas is stored. There are CNG tanks of all kinds of sizes. There are four types of CNG tanks.

Table 13. *CNG tank types (National Energy Technology Laboratory, 2018).*

Type	Description	%load contained by metal	%load contained by composite
Type 1	All metal cylinders either steel or aluminium	100	n/a
Type 2	Fiberglass hoop wrap with steel liner	55	45
Type 3	All carbon full wrap with metallic liner	20	80
Type 4	Totally made of fibreglass or carbon. Full wrap with a plastic liner.	n/a	100

The type of cylinder depends on the material. Type 1 cylinders are those that are totally made of metal, as the type increases, the amount of metal and the percentage of load contained by that metal reduces. Then a type 4 cylinder has no metal, and all the load is contained by the composite (Nat-g.com, 2021).

- **CNG shut-off electro valve**. Shut-off valves have the function to safely stop or continue the flow of hazardous fluids, like CNG in this case, without affecting the rest of the system. For that reason, they are installed between the tank and the regulator. They are used to block compressed gas in pipe system (GMS Instruments, 2020).
- **CNG cylinder electro valve**. This valve controls the flow of natural gas out of the tank, and it is also controlled by the electronic control unit (Tomasetto, 2019).
- **CNG filling valve**. This valve controls and regulates the flow of high-pressure gas from the filling station to the tank. This valve opens and closes depending on the gas pressure under rigid safety standards (Mijoautogas, 2015).
- **CNG filter**. This kind of filter is a barrier that removes impurities from CNG like solid particles or water/oil. These filters block these impurities and keep the fuel clean as it enters the engine, which prevents any wear, clogging or problems during the fuel combustion (Filson Filtration, 2020).
- **Fuel rail for CNG systems**. This is a basic component of the fuel injector, it supplies the CNG to the injectors gradually with the required pressure and that makes that the engine reaches high efficiency and performance rates. They can be made of plastic or steel (Toyo, 2021).
- **CNG injector**. This part injects the CNG into the engine intake manifold (there is one injector per cylinder) via electro valves and the fuel rail. They have a nozzle electronically

controlled that can open and close many times in a second and optimize the combustion introducing the needed quantity of fuel. Injectors were a replacement for the old carburettor system (Redex, 2019).

- **Pressure and temperature sensor**: For safety reasons and to have control of the precise dose of fuel at the correct pressure, the system must include this kind of sensor. This sensor is found in the fuel rail. A silicon membrane is used to determine pressure, and its deformation is analysed using a resistance bridge. A negative temperature coefficient (NTC) is used to calculate the temperature. The pressure and temperature signals are sent to the ECU. (Bosch mobility, 2021b).
- **Gas mixer,** or venturi mixer: The use of this device would be an alternative for the common rail and the injectors. A gas mixer has the same function as a carburettor used in a gasoline engine, but instead of mixing a liquid (the gasoline), and a gas (the air), it mixes two gases that are natural gas and air. It mixes the air and the fuel in the appropriate air to fuel ratio, and this mixture goes directly to the engine. This method was used in old gasoline engines, but nowadays, most of them have been replaced by injectors. Despite this, it can be an easier option to implement in diesel to CNG engine conversion as it entails fewer modifications (UTI Corporate, 2020).
- **ECU.** the Electronic Control Unit or Electronic Engine Control Unit is an embedded system in the whole engine system that controls the injection of the fuel and the timing of the spark to ignite it as well as the mixture formation of air and fuel. It controls all the parts of the fuel handling systems, the valves and the injectors and monitors and collects all the data with temperature, pressure, and flow sensors. (Ecutesting, 2021).

The specifications of each component needed in the design of the fuel handling system for CNG to convert the Sisu Diesel engine can be found in APPENDIX 3: Component's data.

6.2. Tank design

To calculate the size of the tank, the features of the engine and the properties of the gas must be considered. As the engine is for academic purposes, the requirement is that at least the engine can run at maximum power for 6h.

Considering the maximum CNG pressure as 25 MPa, the density at 25°C and -30°C in the case the gas cylinders are located outdoors, and the lower heating value for CNG. The data is from Unitrove Limited (2021).

$$\rho_{@25MPa,25ºC} = 215\ kg/m^3$$

$$\rho_{@25MPa,-30ºC} = 276{,}71\ kg/m^3$$

$$LHV_{CNG} = 14{,}53\ kWh$$

And assuming a 40 % efficiency and 6 hours of functioning at the maximum power of 95 kW:

$$V_{@25MPa,25ºC} = 95\ kW \cdot 6h \cdot \frac{1\ kg}{14{,}53\ kWh} \cdot \frac{1\ m^3}{215\ kg} \cdot \frac{100}{40} = 0{,}456153\ m^3\ (456{,}153\ l) \quad (1)$$

$$V_{@25MPa,-30ºC} = 95\ kW \cdot 6h \cdot \frac{1\ kg}{14{,}53\ kWh} \cdot \frac{1\ m^3}{276{,}71\ kg} \cdot \frac{100}{40} = 0{,}35442\ m^3\ (354{,}42\ l)\ (2)$$

With the total volume that the gas will occupy, the weight (m) of the gas can be calculated in the two extreme situations, at 25°C and -30°C. Equations (3) and (4) will help to know whether or not to follow the legal procedures regarding safety.

$$m_{@25MPa,25ºC} = 0{,}456153\ m^3 \cdot 215\ kg/m^3\ \cdot= 98{,}06\ Kg \quad (3)$$

$$m_{@25MPa,-30ºC} = 0{,}35442\ m^3 \cdot 276{,}71\ kg/m^3 = 97{,}81\ Kg \quad (4)$$

Equation (1) considers the density for natural gas at 25 MPa and 25°C and equation (2) at -30ªC. Equation (3) calculates the weight of the gas at 25°C, while equation (4) calculates the weight of the gas at -30°C. Between the two results obtained, the more restrictive weight of 98.06 kg will be followed in order to follow safety standards. The minimum volume of CNG required is 456,2 litres if the tank is inside (or during summer) and 354,42 litres considering the minimum temperature outside in winter as the density of the natural gas varies with the high-temperature difference. For achieving, approximately, these requirements there are about three feasible options considering a mean value due to the consequences of the density variation with the temperature:

- Four tanks of 100 L each.
- One tank of 100 L and one tank of 310 L.
- One tank of 413 L.

The measures of the tanks, according to existing tanks in the market, are the following (see APPENDIX 3: Component's data for cylinder specifications of the chosen ones):

- The 100 L tank has a diameter of 400 mm and a length of 1100 mm.
- The 310 L tank has a diameter of 635 mm and a length of 1524 mm.
- The 413 L tank has a diameter of 635 mm and a length of 2032 mm.

All the tanks chosen are type 3. The reason for this decision is due to the advantages of this type. Because they are made of aluminium, the tank does not need joints that can leak. This material also has a high tolerance to impacts and temperature changes and is resistant to high tautness, allowing the tank to be filled regardless of the ambient temperature. This type is also faster and more efficient when filling. Although it is heavier than type 4, it does not matter as it is a fixed tank in the laboratory. The fact that type 4 is lighter should only be considered if the cylinder is installed in a vehicle, but this is not the case. Furthermore, it is more robust, safer, and cheaper (Worthington, 2021).

6.2.1. Tank installation

In the engine laboratory, there is currently an installation with a pipe and a regulator for gas supply and outside there is a covered and closed space as shown in Figure 16, with enough space for the CNG cylinders, but the pipe was not initially intended for natural gas. The other option would be to install the cylinders inside the laboratory, next to the engine.

Figure 16. *Current fuel tank installation and gas cylinders space outside in the engine laboratory in Novia UAS, respectively.*

Both options proposed are equally viable, but if the two options are studied in more detail, the outdoor option is more convenient in all aspects. Placing the tanks outside reduces the risk of accidents inside the laboratory. Also, there is a dedicated outdoor area with enough space to store the necessary tanks, whereas indoors the space is limited. Finally, the filling process must be considered. To be able to refill the tanks regularly, easy access is needed and having the tanks indoors does not facilitate this process.

6.2.2. Pipe design

To design the pipes of the fuel handling system, the maximum mass flow that will circulate through the pipeline must be calculated. The mass is calculated through the volume and the density (equation 5), and the flow is the mass divided by the time (equation 7).

$$m = V \cdot \rho \tag{5}$$

Where m is the mass, V is the volume and ρ is the density. Taking the maximum volume at the highest temperature, and the maximum density at the lowest temperature to have the maximum theoretical mass flow that could pass through the pipes.

$$m = 0{,}456153\ m^3 \cdot 276{,}71 \frac{kg}{m^3} = 126{,}22\ kg \tag{6}$$

To calculate the mass flow, the mass must be divided by the maximum working time of the engine, which is 6 h. Also, can be calculated the volumetric flow (Q) in equation (8).

$$\dot{m} = \frac{m}{time} = \frac{126{,}22\ kg}{6h \cdot 3600s} = 0{,}005843\ kg/s \tag{7}$$

$$Q = \frac{V}{time} = \frac{0{,}456152\ m^3}{6h \cdot 3600s} = 2{,}11 \cdot 10^{-5}\ m^3/s\ (0{,}021\ L/s) \tag{8}$$

The total mass flow that the pipelines must support is 0,005843kg/s and a volumetric flow of 0,021 L/s.

As said in the safety measures section, the system must have a factor of safety of 1.25. That means that the maximum mass flow and volumetric flow must support 1.25 times the calculated values:

$$\dot{m} = 0{,}005843 kg/s \cdot 1{,}25 = 0{,}0073\ kg/s \tag{7}$$

$$Q = \ 2{,}11 \cdot 10^{-5}\ m^3/s \cdot 1{,}25 = \ 2{,}637\ \ m^3/s \tag{8}$$

6.3. Flow diagram

The first step to start with the design is to make a flow diagram with all the required components of the fuel system and their order. To begin with, a first version has been produced and improvements have been applied until what could be a final version has been chosen.

6.3.1. First version

The initial version considers the tank, all the valves, like the filling valve, the cylinder valve, the relief valve and the shut-off valve, the regulator and the CNG filter. Everything is connected to the Electronic Control Unit and the fuel is supplied to the engine by direct injection, which includes a fuel rail and CNG injectors.

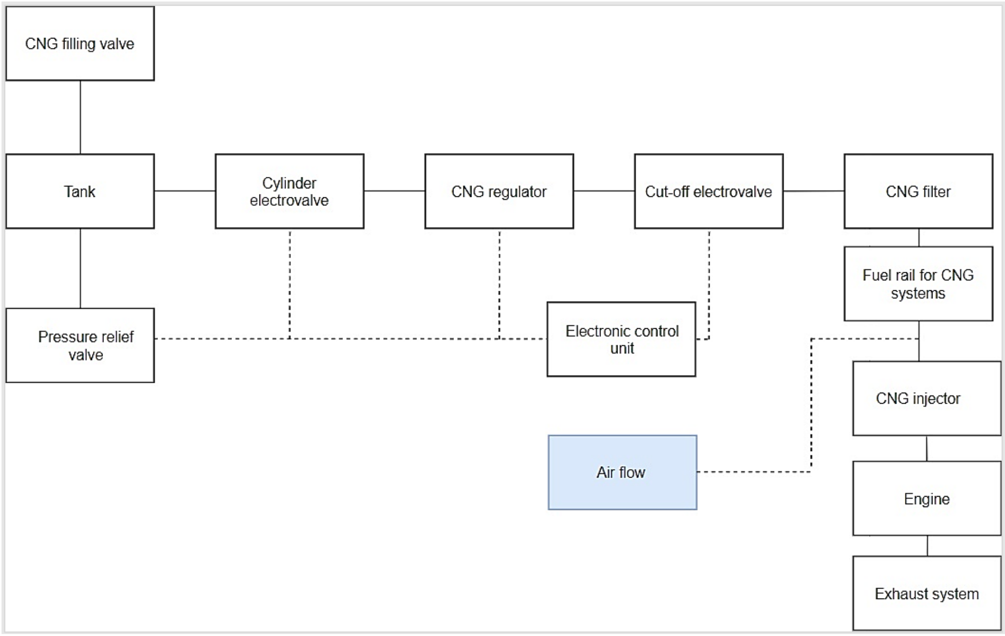

Figure 17. *First flow diagram for the fuel gas handling system design.*

6.3.2. Final design

The final design is an optimised version of the initial one. It differs from the initial version in that a temperature and pressure sensor has been included, also a second pressure regulator that adapts the CNG to be used with fuel and the injection system has been replaced by a turbocharger that supplies the fuel already mixed with air.

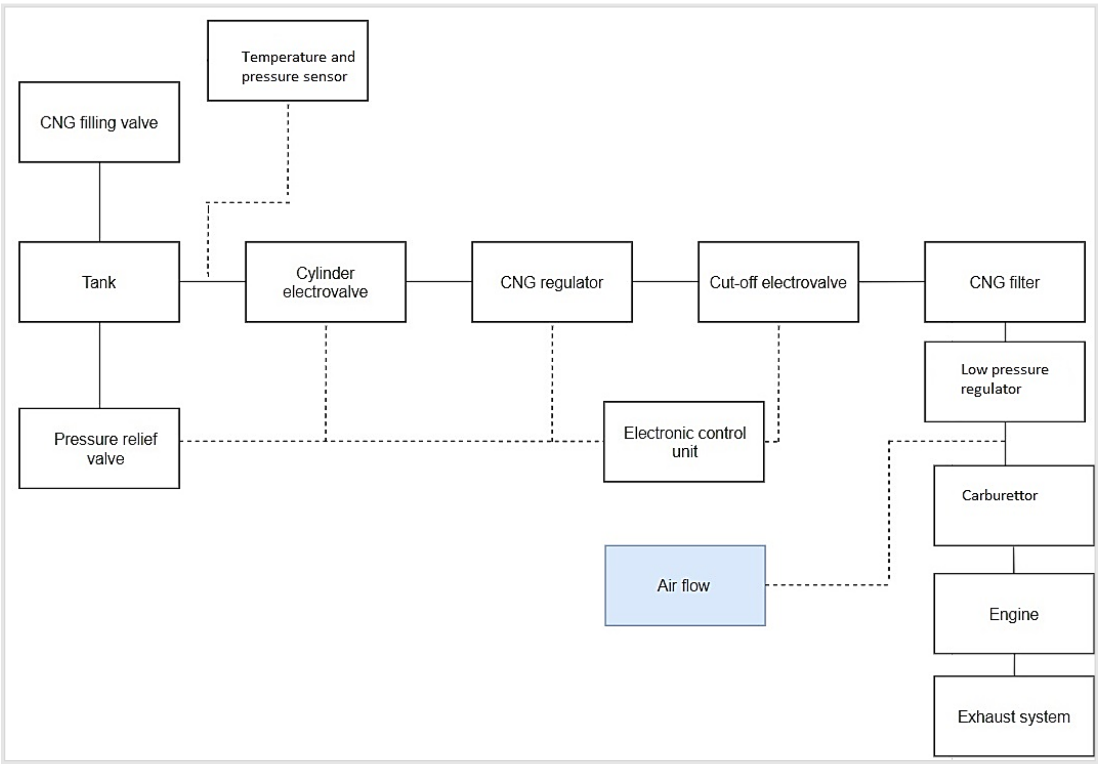

Figure 18. *Final flow diagram for the fuel handling system design.*

6.4. Fuel gas handling P&I diagram

The final design, which is the final product of the thesis, has been presented as a P&ID (piping and instrumentation diagram). There is a first version and a final one made from the flowcharts from the previous section of the report.

6.4.1. First version

The first version was done with online software for diagrams (diagrams.net). It is a simplified version of the system. This one includes just the tank valve and the shut-off valve as safety measures, it just considers one tank and a direct injection system, with a common fuel rail and four injectors. It is only a visual representation and the symbols do not follow any standardised norms.

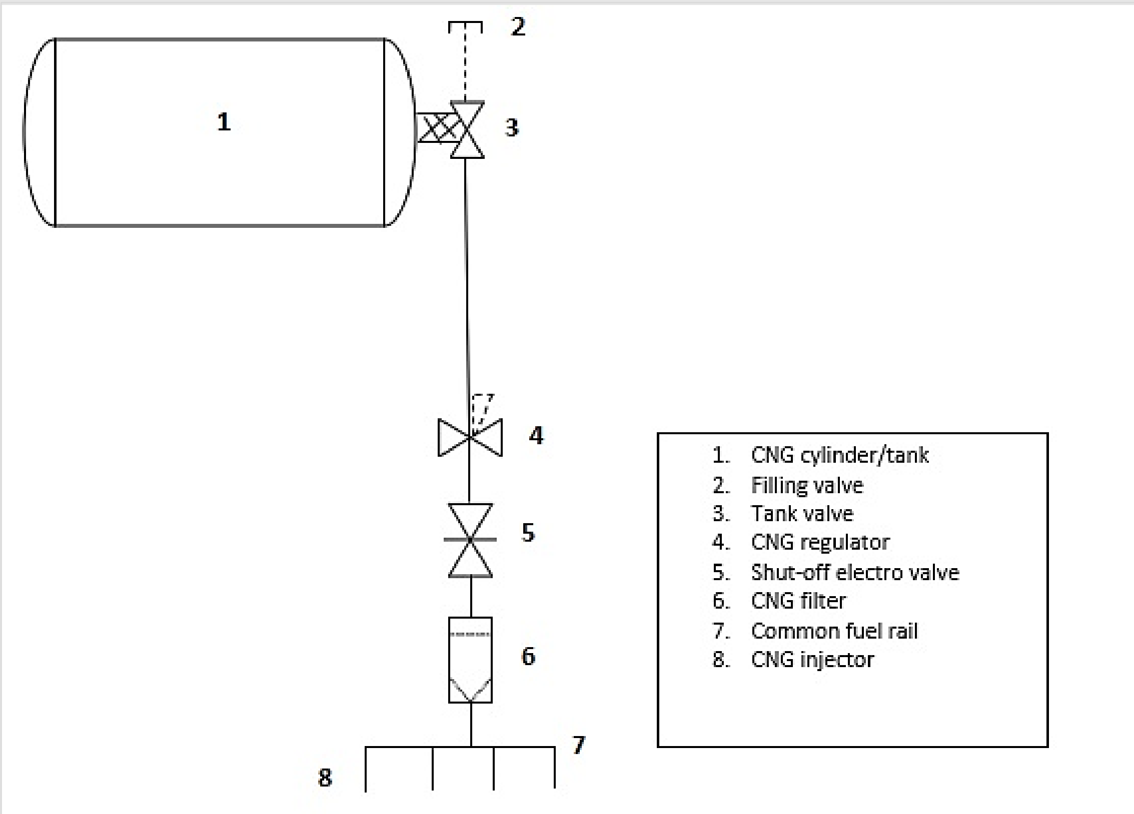

Figure 19. The first design of the fuel handling system for CNG.

In this design, the CNG fuel is stored in the tank (1). This tank has two valves, the filling valve (2), used for refilling the tank, and the tank valve (3), which is the fuel outlet valve for the natural gas to enter the system. After leaving the tank, it passes through a regulator (4) that reduces the CNG pressure from 25 MPa to approximately 1 MPa and then passes through the filter (6). In between, there is a safety shut-off valve (5). After the filter, it goes to the common rail (7) which distributes the fuel to the injectors (8).

6.4.2. Final design

The final design has been done with AutoCAD Plant 3D, the symbols used are according to the ISO standards. This design also considers the four tanks option because this way it is possible to have some cylinders for regular use and some for additional use when the engine has to operate at maximum power. It is also the cheapest option and space it takes up is not a problem. It also has a gas mixer instead of a common fuel rail system with injectors as it is easier to implement. The choice of a venturi mixer instead of a direct injection system is part of the requirements for the design of this fuel system.

In addition, this version includes a temperature and pressure sensor and a tank pressure indicator that shows the pressure in the tank, with that it is possible to know the amount of fuel remaining. See the whole plan in APPENDIX 2: Fuel handling system final design plan.

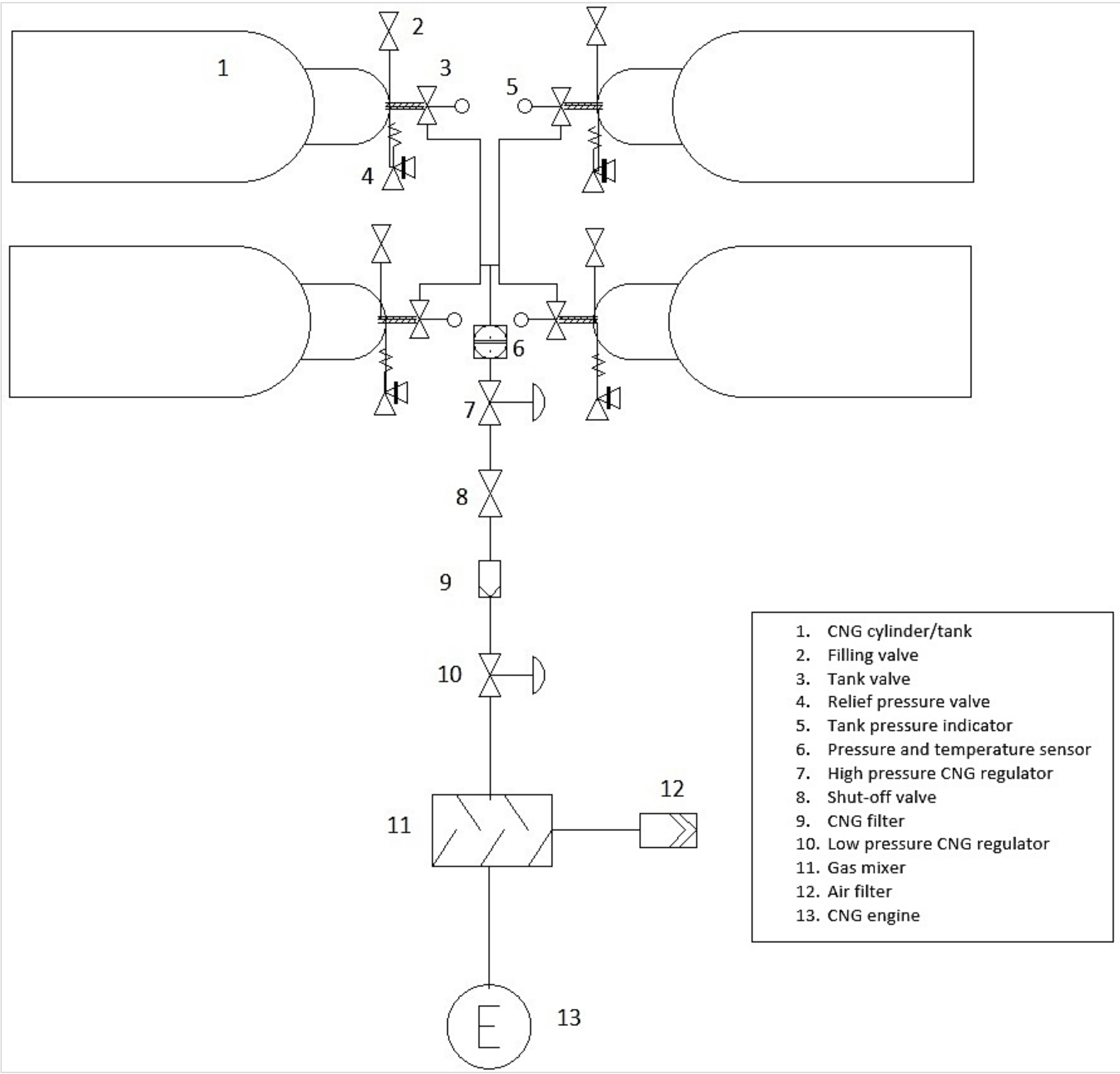

Figure 20*. The final design of the fuel handling system for CNG.*

The functioning of the designed CNG handling system is the following: the gas comes out of the tank (1) at a pressure of about 25 MPa (depending on how full the tank is, which is indicated). There are several valves in the tank. For refilling the CNG fuel there is the filling valve (2), for fuel supply from the tank to the system, there is the tank valve (3) and a relief pressure valve (4) as a safety measure. The tank also has a pressure indicator (5) that shows the fuel level inside the tank. There is also a sensor that measures pressure and temperature (6).

Once it comes out of the tank it passes through the high-pressure regulator (7), which lowers the pressure to about 1 MPa. The gas passes through the filter (9) to remove any impurities and then goes to the venturi mixer (11) where it is mixed with the air, that enters through an air filter (12), to be inserted into the cylinder in the natural gas engine (13), but just after passing through a second regulator (10) which ensures that the natural gas enters the engine at the required pressure. As it passes through a venturi mixer, the pressure has to be the atmospheric pressure, which is approximately 0,1 MPa (Muhssen et al., 2021). There is also a shut-off valve (8) to stop the gas flow if necessary.

7. Discussion

This section deals with the discussion of the objectives proposed before starting the thesis and the validity of the result obtained. It will also compare the proposed design with designs and results of other work that has been done.

- Aims and objectives

The first objective of the thesis was to decide how the gas used as fuel would be stored and therefore also what type of gas. In Section 3 an analysis is made of the possible fuel gas alternatives, among them natural gas and the two main ways of storing it. After that, it is argued why CNG is finally chosen considering the main factors, such as availability, price, space occupation, usefulness, etc.

The next objective was to analyse the types of fuel handling systems. Finally, since each type of fuel requires a different system and studying all of them was not relevant for this work, it has been chosen to analyse the system of diesel, such as the Sisu, and compare it with an existing design of a CNG engine system installed in a car.

Another highly relevant objective of the project was the establishment of safety concepts for both the engine and the handling of natural gas. This part is indispensable and has been very well developed, trying to cover all possible aspects.

The last of the objectives was to propose a design of a fuel handling system for the Sisu Diesel once it has been converted to gas. For this purpose, a possible system has been designed in the form of a schematic diagram. All necessary components, their availability on the market and their price have also been chosen. This last objective is the most relevant, as it is also the aim of the thesis.

- Comparison with published work

In terms of comparison with other work, most of the studies focus on adapting diesel or petrol engines and running them on bi-fuel or dual-fuel, whereby the engines use both fuels. As for those that focus on the conversion from diesel to dedicated CNG, most of them, although interesting, are very superficial tests and done from a very theoretical point of view. The published works can be summarised in the following two types. Likhanov and Lopatin (2020), in their article focus on the analysis of natural gas and their design, are conceptually, they do not talk about what components or devices are needed to carry out the conversion. On the other hand, Krishna (2018), in his work, does talk about the steps and components needed but does not present a final design or how to assemble all these components.

The result obtained can also be compared with CNG engine models currently on the market. Scania (2021) is a heavy-duty vehicle manufacturer, which also manufactures gas-powered vehicles and designs the engines for them. Their design is very similar to the one proposed except that they use a gas mixer to inject the already blended fuel into the engine, the final product of this thesis uses a venturi mixer, which has the same principle. A very important addition to the CNG fuel management systems of Scania engines is the leak tester, which is a safety measure in case of gas leakage, which warns if it detects an uncontrolled pressure difference, which would indicate that there has been a gas loss.

- Limitations during the thesis execution

During the thesis, there have been several problems that have hindered the completion of the thesis. Undertaken during the Covid pandemic, access to resources such as the university laboratories and also hands-on support from supervisory staff, have at times been limited. It was also influenced by the fact that time was tight and that some aspects could not be developed further. These challenges have hindered the completion of the thesis with a design not as optimised as it could be.

- Consistencies and inconsistences

As a strong point, it is worth highlighting the in-depth analysis of alternative fuels in the form of gas and the development of a design for handling from scratch. At the same time, the inconsistency of the work is also the design itself, which is not fully optimised, and the final product consists of presenting the design in schematic form, without a final version presented in 3D or in any other more professional way.

8. Conclusion

This thesis considered the possibility of converting a Sisu Diesel 420 DWRIE engine for possible use on fuel gas alternative. On completion of the project, conclusions have been reached.

Firstly, it was determined feasible to convert this engine from a diesel to fuel gas alternative. It was concluded that CNG was the best fuel gas option for this design for it offered the least impact on available space, ease of accessibility and also for lower environmental impact. The components were found to be not excessively large or expensive. Safety concepts and documentation for both the engine and the handling of CNG were developed. Finally, a piping and instrumentation diagram according to ISO standards was developed as a proposal of a possible fuel handling system for the CNG conversion of the Sisu Diesel. The resultant design also included the specification of all the necessary components, their availability on the market and their price.

This thesis can be continued in future work. For future projects on this fuel handling system, an optimization of the design could be carried out, also by creating a 3D design or simulating it with specific software for this purpose. The next step would be to build the design and convert the engine and then test the whole system, optimize it, and implement improvements until it gives efficient results. In addition, this work considers different options for the number of tanks to be installed, the size of the tanks and where to place them, something that could be addressed in the continuation of this work by other engineers or engineering students.

In summary, the realization of this thesis has been an interesting and enriching challenge. A feasible and simple design has been made that would be easy to implement and gives rise to the continuation of the work in future projects.

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APPENDIX 1: Engine and installation in Novia Engine Laboratory

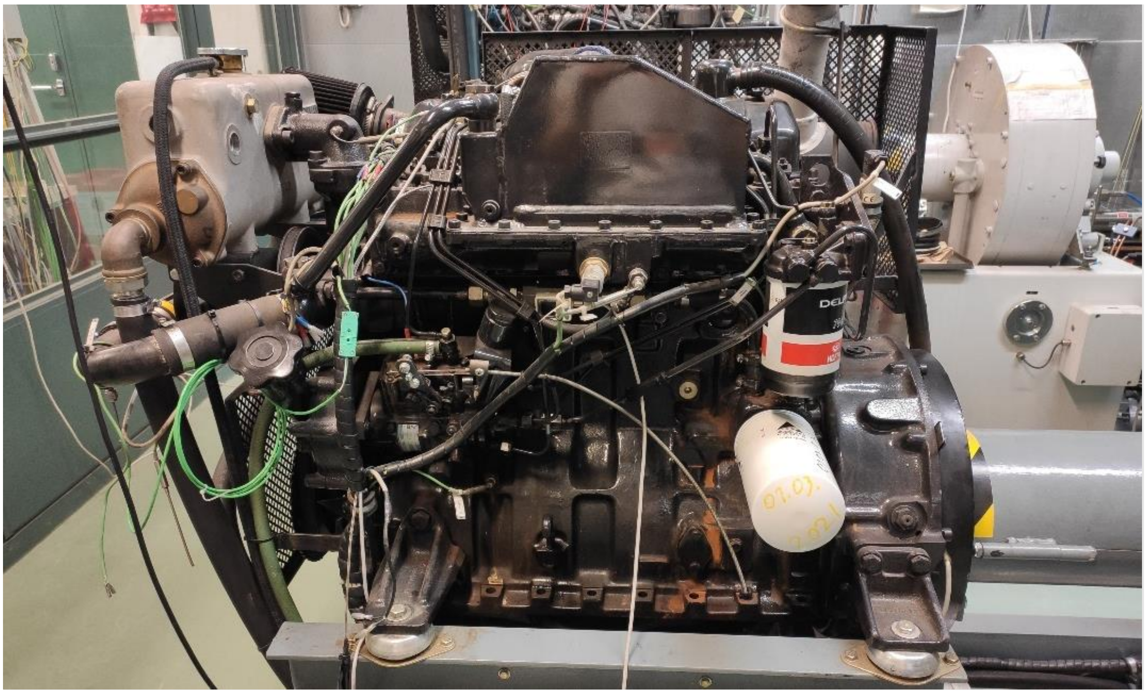


Figure 1. *Engine with fuel system.*

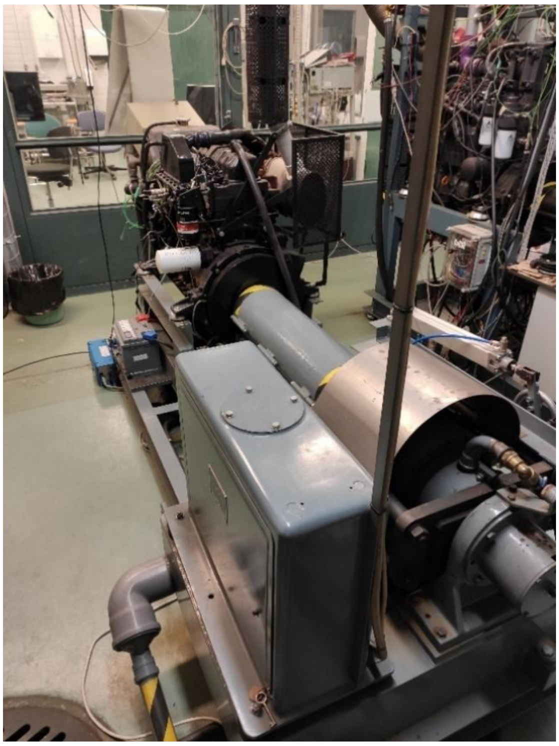


Figure 2. *Sisu Diesel 420 DWRIE with the reducer.*

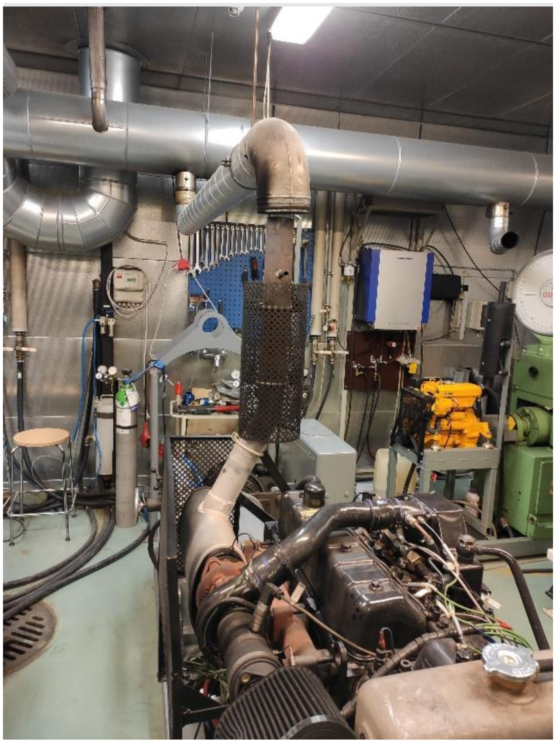


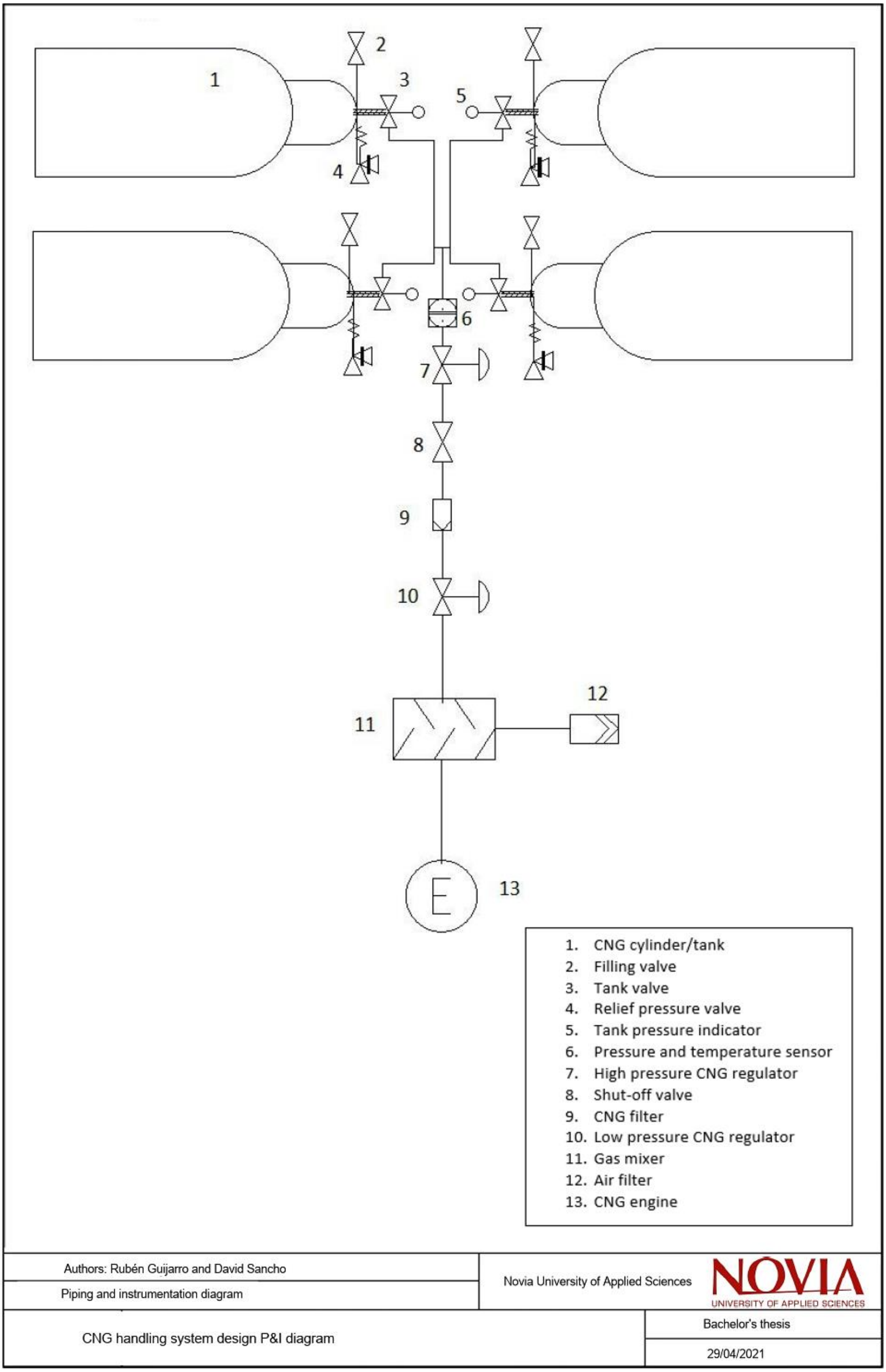
Figure 3. *Exhaust gases installation in the engine.*

Figure 4. *Exhaust pipe connected to the ventilation.*

Figure 5. *Diesel tank.*

Figure 6. *Turbine of the ventilation system.*

APPENDIX 2: Fuel handling system final design plan



APPENDIX 3: Component's data

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	LINK	IMAGE
Electronic Control Unit	Bosch	EGC10 Control Unit	This device controls the injection of the fuel and the timing of the spark to ignite it as well as all the valves, sensors and the injectors.	350€	https://www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/powertrain-systems/compressed-natural-gas/motronic-electronic-control-unit-for-cng-systems/	
CNG regulator	Rotarex	Galaxy Y443	This valve decompresses the CNG coming from the tank at high pressure and adjusts the pressure so that it can be used as fuel.	10€	https://rotarex.com/products/galaxy	
CNG shut-off electro valve	Gasitaly	APUS CP	This valve has the function to safely stop or continue the flow of CNG without affecting the rest of the system.	45€	http://www.gasitaly.com/en/product/tomasetto-cng-solenoid-valves/omb-cng-solenoid-valves/cng-valves/omb-cng-solenoid-cut-off-valve-apus-cp-1191	
CNG cylinder electro valve	Tomasetto	VM05 Automatic	This valve controls the flow of natural gas out of the tank.	55€	https://www.tomasetto.com/en/products/cng-valves/cng-cylinder-valves/vm05-automatica-2	

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	LINK	IMAGE
CNG filling valve	Mijo Autogas	MRV03.NGV	It controls and regulates the flow of high-pressure gas from the filling station to the tank. It opens and closes depending on the gas pressure.	40€	https://mijoautogas.co.in/cng-valves.htm	
CNG filter	Parker	Racor FFC	It is a barrier that removes impurities from CNG like solid particles or water/oil. These filters block these impurities and keep de fuel clean.	10€	https://ph.parker.com/us/en/compressed-natural-gas-cng-filters	
Fuel rail for CNG systems	Horizon	IG3 4CYL	It supplies the CNG to the injectors gradually with the required pressure.	90€	https://www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/powertrain-systems/compressed-natural-gas/fuel-rail-for-cng-systems/	
CNG Injector	Bosch	NGI2K	Injects the CNG into the engine intake manifold (there is one injector per cylinder) via electro valves and the fuel rail.	65€x4	https://www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/powertrain-systems/compressed-natural-gas/injector-for-cng-systems/	

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	LINK	IMAGE
Gas mixer	Motortech	VariFuel2	It is a high-tech variable Venturi type air/gas mixer that can constantly adjust to any fuel changes and allows the engine to operate at its most efficient point.	3000 €	https://www.motortech.de/products/airfuel-ratio-control-systems/varifuel2varifuel2-airgas-mixers.html	
Sensor	Bosch	PS-HPS4	This sensor is attached to the rail and it measures the pressure and temperature of the CNG to make the dosage of the fuel more efficient and for safety measures.	100€	https://www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/powertrain-systems/compressed-natural-gas/medium-pressure-and-temperature-sensor/	
Cylinder 100 L	Luxfer	CNG Cylinder Luxfer with EMER Valve	One of the tank options: a type 3 one with a 100 L capacity. It is made of an aluminium alloy. The service pressure is 25 MPa and the measures 1100 mm x 400 mm.	600€	https://www.lpgshop.co.uk/100-litres-composite-type-3-cng-cylinder-luxfer/	
Cylinder 310 L	CNG United	4473	Type 3 tank with 310 L capacity. It is made of an aluminium alloy. The measures are 1524 mm of length and a diameter of 635 mm.	4000€	https://www.cngunited.com/shop-cng-tanks/cng-tanks-type-3/cng-tank-type-3-o-d-25-length-60-g-g-e-28-7-gallons/	

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	LINK	IMAGE
Cylinder 413 L	CNG United	4470	Type 3 tank with 413 L capacity. It is made of an aluminium alloy. The measures are 2032 mm of length and a diameter of 635 mm.	5000€	https://www.cngunited.com/shop-cng-tanks/cng-tanks-type-3/cng-tank-type-3-o-d-25-length-80-g-g-e-40-8-gallons/	
Pressure relief valve	Grainger	3PYW9	Its function is to protect the equipment in case of overpressure by releasing the necessary amount of gas.	500€	https://www.grainger.com/product/KUNKLE-VALVE-Aluminum-Safety-Relief-Valve-3PYW9