LNG Handling System

A FEASIBILITY ANALYSIS

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1 Abstract

A feasibility study of the use of Liquid Natural Gas, LNG, to fuel a 100 kW engine, for analysis in the laboratory of Novia University of Applied Science, operating for 6 hours. Design and investigation of two methods of teaching. The initial design using LNG to power an engine. A secondary design for use as a teaching aid and proof of concept using Liquid Nitrogen, LN_2, as an alternative gas. Designing of a viable piping and instrumentation diagram for each proposed application. Analysis of components required for each design including parts list and budget report. Handover documentation to ensure the research is continued and a prototype can ultimately be constructed.

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2 List of Frequently Used Symbols and Abbreviations

SYMBOL	UNIT	PROPERTY
LNG		Liquid Natural Gas
NG		Natural Gas
BOR		Boil Off Rate
BOG		Boil Off Gas
P&ID		Pipes and Instrumentation Diagram
MAWP		Maximum Allowable Working Pressure
V	m^3	Volume
V	litres	Volume
P	Kg/m^3	Density
$\dot{Q}$	W	Heat exchange
L	J/kg.	Latent Heat of Vaporisation
M	kg	Mass
$\dot{m}$	kg/s	Mass flow rate
η		Efficiency

3 Introduction

3.1 Mission

The mission of this project is to develop a fuel gas system for LNG fuelled internal combustion engines. The system designed must provide enough fuel to power a 100 kW engine for a duration of 6 hours, for use within the engine laboratory of Novia UAS.

3.2 Vision

The vision is to research and design a LNG fuel powered handling system to modify an existing engine for simulation and analysis of fuel in the Novia engine laboratory. This will be achieved by researching existing designs from major players in the LNG marketplace. The plan is to create a line of contact with Wärtsilä and work with another EPS team to gain a greater insight into the storage and transport of LNG. From the research conducted and insights gained, a P&ID scheme shall be designed and the system shall be dimensioned to regulate the fuelling of the engine from an LNG tank with the specified conditions.

4 Meet the Team

4.1 Introduction

As a team, there are many different backgrounds of study within the engineering discipline. This diversity will allow the team to approach this project from multiple angles and use each specialty to solve potential challenges that may arise throughout.

4.1.1 Euan Slevin – Project Manager

Age: 20
Nationality: Scottish
Area of Study: Computer–Aided Mechanical Engineering
Year of Study: 3rd Year
Place of Study: Glasgow Caledonian University
Hobbies: Hillwalking, Climbing, Cycling.

4.1.2 Gerard Vidal Espada – Project Secretary

Age: 21
Nationality: Catalonian
Area of Study: Industrial design and develop of the product engineering
Year of Study: 4th Year
Place of Study: Escola politècnica superior d'enginyeria de Vilanova I la Geltrú (EPSEVG-UPC)
Hobbies: Human towers, sports, drums, climbing.

4.1.3 Andrew Bruce

Age: 20

Nationality: Scottish

Area of Study: Mechanical Systems Engineering

Year of Study: 3rd Year

Place of Study: Glasgow Caledonian University

Hobbies: Rugby, Fishing, Football.

4.1.4 Sam Gevers

Age: 24

Nationality: Belgian

Area of Study: Electromechanics

Year of Study: 3rd Year

Place of Study: Thomas More Kempen Geel

Hobbies: Volleyball, Squash, Socialising

4.2 Belbin Results

4.2.1 Team Roles

The Belbin theory consists of nine team roles. Any individual may tend towards one team role very strongly or have a more generic spread within the Belbin Test. Common results show one predominant role within a member of a team as well as conforming to a secondary role. The different team roles are as follows:

Resource Management

A resource manager investigates of their own accord bringing fresh ideas back to the whole team. These tend to be outgoing driven individuals using initiative. The weakness that a resource manager may experience is due to impulsive interest, once the initial enthusiasm is gone leads may not be followed up. (Belbin.com, 2017)

Team Worker

A team worker helps the team to work in harmony, this will sometimes involve doing work on behalf of the team. Usually quite diplomatic and cooperative, will listen to the views of the whole team and attempt to avoid hostility. A disadvantage to this cooperative outlook can cause the team worker to be indecisive, especially in crisis scenarios.
(Belbin.com, 2017)

Coordinator

A coordinator is mature, confident and focusses on the work load and delegates between the team tasks that are required, by identifying talents within the team. This delegation however can be viewed as devious and could lead to the coordinator offloading unwanted tasks on other members of the team. (Belbin.com, 2017)

Plant

A plant is very 'free-thinking' and tends to be extremely imaginative and approaches problems from innovative directions. This can cause a plant to struggle to communicate with the wider team as they are too focused on the challenges they are currently facing. (Belbin.com, 2017)

Monitor Evaluator

A monitor evaluator provides logic to a situation with impartial decision making, considering all the team's options before making a decision. This view can prove a challenge however as this can cause the monitor evaluator to be overly critical of the team members and lose motivation for the task at hand. (Belbin.com, 2017)

Specialist

A specialist has a detailed knowledge of a specific subject, very single minded and self-motivated. The weakness of being specialised means that there is a very limited range in which they can provide expertise and often reside on specifics.
(Belbin.com, 2017)

Shaper

A shaper provides motivation and drive to ensure the team stay on target and achieve the goals laid out. They are very dynamic and thrive under pressure, pushes the team to overcome obstacles. This motivation can occasionally be misconstrued as incitement and can offend people. (Belbin.com, 2017)

Implementer

An implementer needs to strategically plan the project and efficiently work through it, very practical and turns concepts into results, this frame of thinking can cause an implementer to be slightly inflexible about new ideas presented that are not in line with the initial strategy. (Belbin.com, 2017)

Completer Finisher

A completer finisher can be effectively employed near the end of projects to refine, scrutinise and perfect. Tends to be anxious about results, actively seeks out errors and have a high standards of quality assurance. The anxiety can be a challenge however can cause unnecessary worry and avoid delegation. (Belbin.com, 2017)

4.2.2 Euan Slevin

From the data gathered during the Belbin evaluation it can be seen in Figure 4.2.1 that the predominant team roles are Finisher and Shaper, with a smaller influence from Coordinator.

From the Finisher team role, it can be derived that there is a real eye for detail. The member will spend a great deal of time reviewing the completed work, tidying and refining to ensure the greatest level of accuracy. This however causes the member to struggle to delegate, a challenge to overcome in a Project Manager. The Shaper team role works well under pressure, this can cause problems within a team however, as it can cause offence.

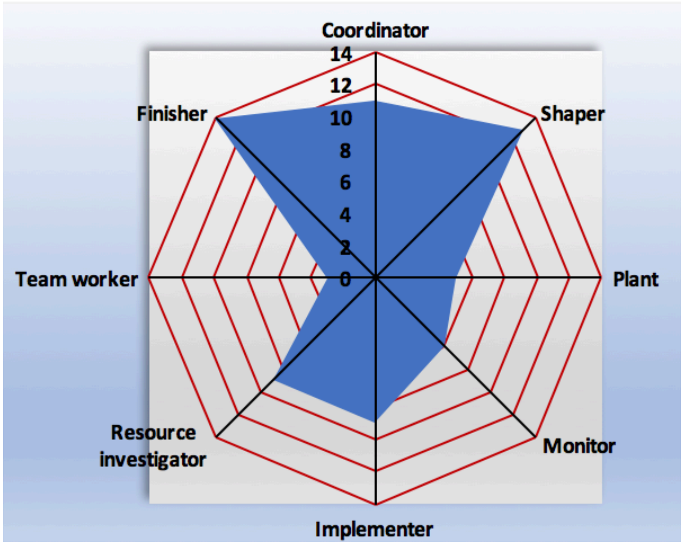

Figure 4.2.1 Belbin Results of Euan Slevin

The combination of these team roles means that towards the end of a project the member would wish to review the project and oversubscribe themselves, putting themselves under pressure. This is something that is a challenge to overcome as the wider team must also be involved.

4.2.3 Gerard Vidal Espada

In completion of the Belbin test, it can be defined the role is equilibrated with stronger attributes on Plant and Team Worker, with weaker scores on Monitor, Implementer and Finisher. These characteristics, according to the test definition are positive attributes, as a plant is creative and imaginative with a capacity to solve difficult problems. A team worker is cooperative, mildly perceptive and diplomatic.

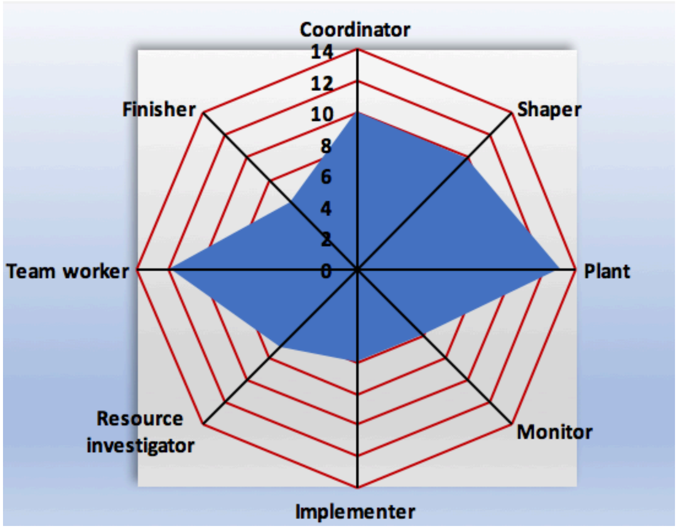

Figure 4.2.2 Belbin Results of Gerard Vidal Espada

According to this attribute care must be taken as weaknesses are to ignore incidents and become too preoccupied to communicate effectively. A team worker, can be indecisive in crunch situations.

4.2.4 Andrew Bruce

The Belbin diagram, which was attained by answering the Belbin questionnaire, suggests creativity, unorthodox thinking and flourishing when solving difficult problems as a strong trend to Plant and to Shaper is shown. This suggests a challenging and dynamic contributor who thrives on pressure within a team, with a “Just do it!” work mentality –this presents an “allowable weakness” in being prone to provocation and hurt other team member’s feelings.

An equally high score in the Team work, Resource investigator and Monitor aspects of the questionnaire suggests cooperation, communication and diplomacy – yet also sober, strategic and discerning.
These qualities combined make an excellent team player.

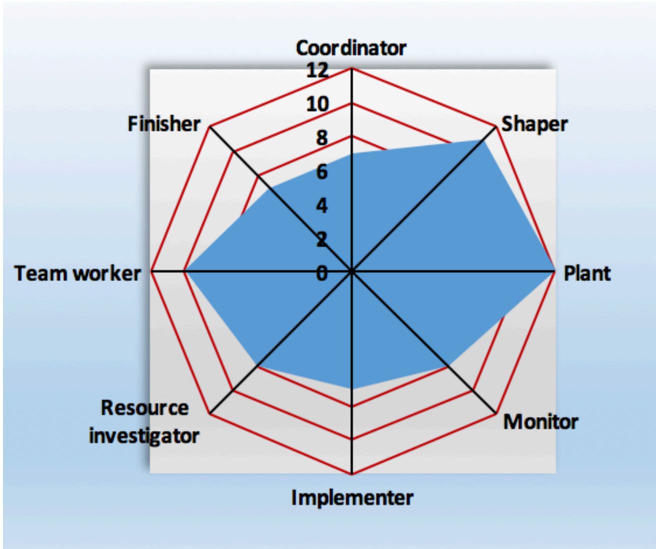

Figure 4.2.3 Belbin Results of Andrew Bruce

4.2.5 Sam Gevers

Looking at the Belbin diagram, there are two roles fulfilled by these results. A Team Worker, meaning cooperation with other people. Attempting to be as diplomatic as possible and analyse issues others perspective.

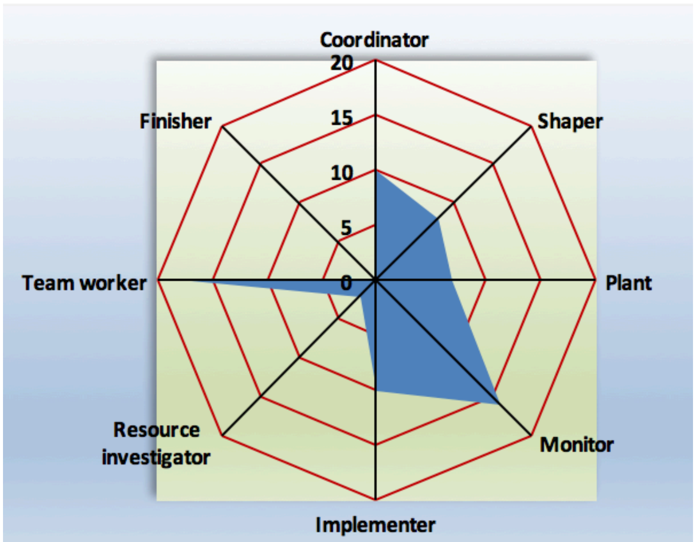

Figure 4.2.4 Belbin Results of Sam Gevers

The other role is that of a Monitor Evaluator. This allows an objective view of a situation. This shows an ability to make rational decisions at a time when tempers can run high.

4.2.6 Conclusion

After cumulating the results of the team members, a conclusion can be drawn about what type of team is formed. This is not a perfect system however it does provide a general idea.

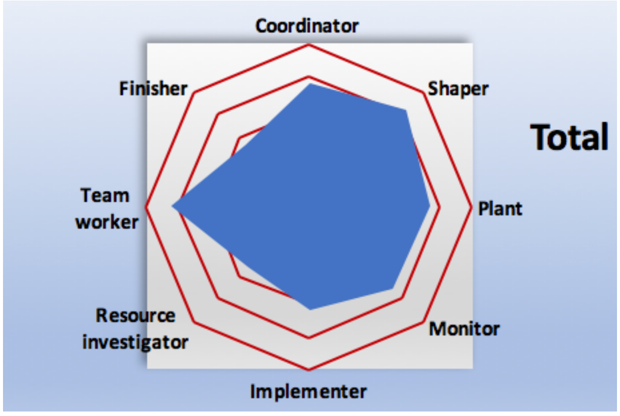

Figure 4.2.5: Team Belbin results

Characteristics the team exhibit are Team Worker and Shaper. The highest score in Team Worker is positive as a team works better if they have a similar outlook on a task. Struggles within a team can easily harm productivity. As a team, there is a risk of becoming indecisive in a moment of crisis if there is a lack of leadership. The role of coordinator is sufficient within the team that somebody will take control. A high score in Shaper implies the team is driven and will thrive under pressure.

The lowest scores for the team are Finisher and Resource Investigator. Finisher is a weakness across many of the team. Though as this is one member's major role, this should be counteracted. This member will play an important role near deadlines in perfecting the reports and presentations.

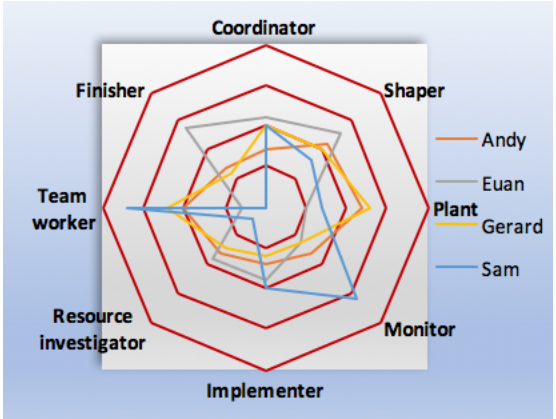

Figure 4.2.6: Team Belbin Results Breakdown

The low score on Resource Investigator should not result in any issues since most the team members have a respectable score in this characteristic. In conclusion, it is a well-rounded team that should work well together to complete the project in a timely manner.

5 Scope

5.1 Objectives

The aim of this project is to design a fuel gas handling system for Liquid Natural Gas, LNG, fuelled Internal Combustion Engines by 16th of May to be presented to a jury.
LNG is a gas mixture, of mainly methane and ethane and some other impurities, that has been cooled down to a temperature of -162°C and is stored in a cryogenic tank. There are a few advantages to LNG as opposed to diesel. The ecological impact is greatly reduced since LNG is much cleaner burning fuel, producing less nitrates and other pollutants. This means it is easier to comply with emission laws. Long term there can be a cost advantage in certain applications, e.g. ships and heavy duty vehicles.

The main stages of interest for us are:

- LNG storage
- Regasification
- BOG (Boil Off Gas)
- Process control

5.2 Stakeholders

There are multiple stakeholders in this project. There are the four team members, all motivated to do the best to finish this project with a successful outcome. The supervisor of the project is Kaj Rintanen, a Senior Lecturer of Mechanical and Production Engineering at Novia University of Applied Sciences. A major support to the team and aid the team throughout the course of the project. The EPS coordinator, Roger Nylund, supervises all the projects and helps and advises the participants.

Another important stakeholder in the project is the engine laboratory of Novia. The completed final design of the fuel gas handling system is to be installed onto an existing test rig for analysis of fuel consumption. There is scope for cooperation with another EPS project team that are tasked to model the whole LNG cycle in the Nordic countries.

5.3 Deliverables

The project has been divided into specific deliverables to give a clearer view of the main goals that need be achieved. There are compulsory deliverables that must be achieved by every EPS team however there are also potential deliverables that may be possible dependant on the course of the project.

- EPS: Compulsory deliverables defined within the course
    - Mid-term report
    - Mid-term presentation
    - End report
    - End presentation
- Project management: Including all planning and monitoring of the project.
- Research report: There is much research required for this project. Existing designs need to be evaluated to give a base knowledge of how this project could proceed. Research must be conducted into sensors, actuators, and various other components could be used.
- System design: This includes the 3D-model and the P&ID scheme.
- User manual: This will guide the end user of the product through operating the design
- Designer manual: This allows a designer to see the method the design follows in operation.

5.3.1 Exclusions

In the project, it is necessary to determine what will be done and what will not. The project exclusions have been defined as: the prototyping of the LNG system requested, the price, though an approximate budget report is within scope, and the adaption of the system to a practical product.

5.4 Responsibility Assignment Matrix

A responsibility assignment matrix, RAM, is used within the project to ensure each task has a member of the project team overseeing its completion. There are many different methods of RAM developed over the years but the method implemented in this project is one of the first, PARIS. This describes the different roles each team member can take in the completion of each task.

- Participant
- Accountable
- Review Required
- Input Required
- Sign-off Required

When developing the project plan each task within the WBS has a team member 'Accountable' for its completion and depending on the challenge and level of difficulty, of said task more resources may be allocated. This is shown in Appendix 1.

5.5 Risk Analysis

There are many risks associated with the Regasification of Liquid Natural Gas to power an engine and the project in its entirety; this section will discuss and analyse the specific risk and probability of said risk occurring including the impact it could have on the project.

5.5.1 Team member related

- Language barriers within the group (3/4 native English speakers)
- Loss of motivation and/or laziness of team members
- Team members leaving the project
- Poor planning of the project and scheduling of time
- Conflicts within the group

5.5.2 Collection and collation of information

- Missing knowledge; no previous knowledge of the subject
- Lack of time

5.5.3 External risks

- Illness of one or more of the group
- Lack of support and guidance from the supervisor

5.5.4 Risks explained:

- Language barriers should not be a challenge to overcome as 3 of 4 team members are native English speakers, however there could be some information misunderstood not only through a language barrier but also through differing accents and pronunciation

- Motivation loss and laziness has potential to become a risk to the project as most of the project is open ended. Keeping all team members properly motivated throughout the 15 weeks is an essential part of the project

- Team member(s) leaving the project poses a potentially critical risk to the outcome of the project. Steps shall be taken to ensure all group members remain happy and to keep frictions within the group to a minimum. Eliminating the risk of a team member leaving the group due to internal frictions. However, some factors cannot be mitigated such as ill health or family problems

- Poor planning and project scheduling pose a significant risk as the group could end up not producing work to the best of their ability as they are two time critical deliverables at the end of the project

- Conflicts within the group could potentially lead to certain members not working to the best of their ability, hence steps must be taken to ensure harmony within the group

- Missing knowledge poses a great risk to the project as none of the team members have taken on a project of this magnitude relating to LNG and many of the other technologies concerned within it

- Lack of time could mean that potentially the project may not be finished before the May 16th deadline

- Lack of support and guidance from the supervisor, Kaj Rintanen, could allow the team to go down the wrong avenue leading to a non-working LNG system

Table 5.1 below highlights the probability of impact that each of the risks could have on the project were they to occur. The risks are given a score out of 10 regarding the probability of it occurring and then another score out of 10 based on the impact on the project. The total risk is then obtained by multiplying both values by each other. The last two columns detail whether the risks were prevented from occurring or if steps were taken to actively reduce their impact on the project.

Table 5.1: Risk Assessment Matrix

Risk	Probability/10	Impact	Total risk	Impact reduced	Prevented
Language barriers	2	3	6	x	
Motivation loss/laziness	5	4	20		x
Member leaving	1	6	6		x
Poor planning	3	5	15		x
Conflicts within group	2	4	8		x
Missing knowledge	4	6	24	x	
Lack of time	3	7	21		x
Illness	3	5	15		x
Lack of support	4	5	20		x

5.6 Work Breakdown Structure

A work breakdown structure is a means of displaying deliverables and tasks of a project within a hierarchal structure. It shows tasks and subtasks of a project in a tree structure and assists in presenting the importance of tasks. The approach of the WBS for this project shows deliverables as the highest priority broken down into several tasks which, if required, are further broken down into subtasks. The WBS can be viewed in Appendix 2. (A guide to the project management body of knowledge (PMBOK guide), 2008).

5.7 Gantt Chart

A Gantt chart is used to display deliverables and tasks within a project with respect to time. (Gantt.com, 2016). It summarises the tasks to be completed and when they are to be completed, this representation allows for easy viewing of the order in which tasks must be accomplished while also showing the dependency of the task upon others. This means that it can be viewed in a Gantt chart what tasks can be worked upon simultaneously allowing for a critical path to be defined. The critical path is the longest path the project could take based upon the task dependencies within the project (Gantt.com, 2016). The Gantt chart for this project can be found in Appendix 3.

5.8 Corporate Identity

To define a corporate image for the project team, the subject of the project is chosen. First the name of the team is selected with the aid of a brainstorming session of ideas for possible names. The session resulted in the selection of a name, a mix of LNG + Engineers = LNGineers.

A picture of the brainstorm in Figure 5.8.1.

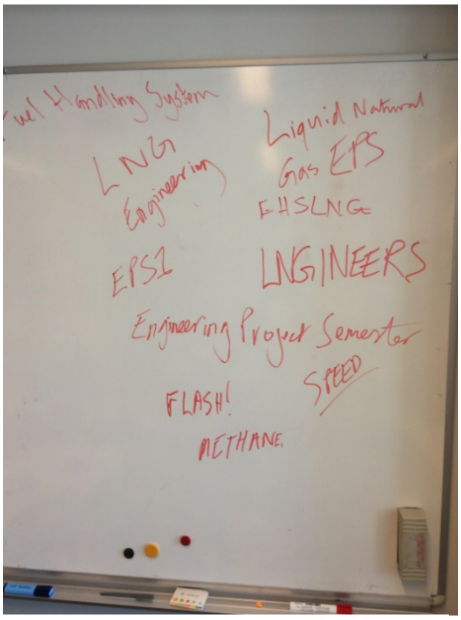

Figure 5.8.1: Brainstorming results

The purpose of designing a logo, to be used as part of the corporate image, is to be recognisable without a name. As with the name, a brainstorming session was carried out to generate some ideas. The initial designs incorporate the name of the company which blurs to gas to symbolise regasification. This is shown in Figure 5.8.2.

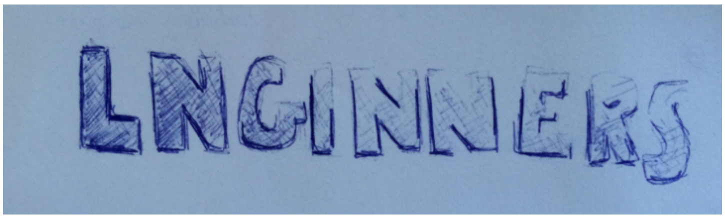

Figure 5.8.2: Initial Logo Design

Finally, a combination of a flame which represents the LNG and a gear that represents engineers was selected, Figure 5.8.3.

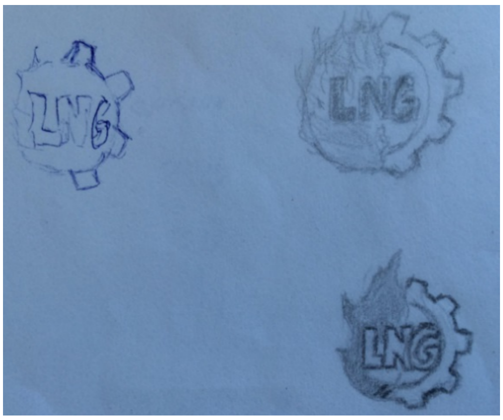

Figure 5.8.3: Initial gear designs

After deciding upon this concept, variations on the design were made. Eventually the decision was made to change the flame to a leaf because LNG is one of the most environmentally friendly fuels available and the flame could be associated with fossil fuels and would not create a good company image. The final logo design is pictured in Figure 5.8.4.

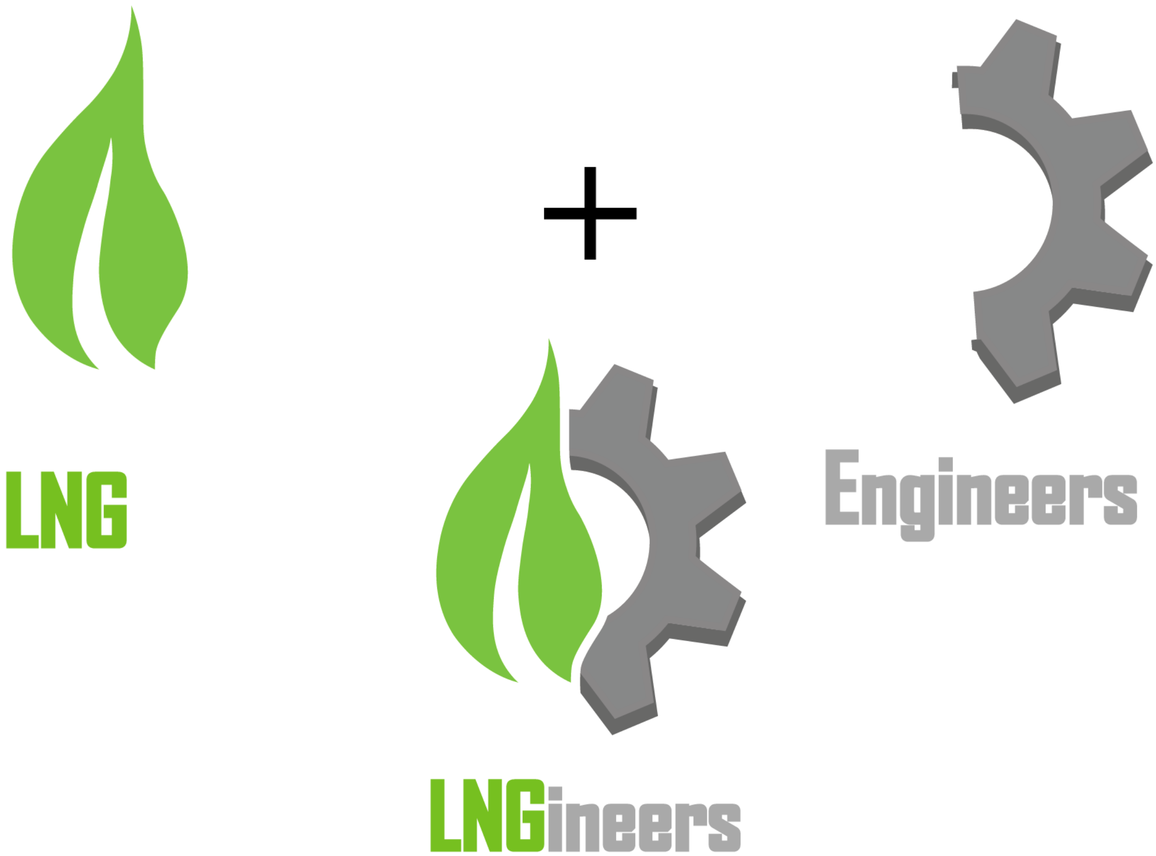

Figure 5.8.4: Final Logo Design

The result is a logo that allows the leaf and the gear and the word 'LNGineers' to be used separately as an Isotype and a logotype. The green colour of the leaf represents the environmentally friendly product and the grey of the gear is a neutral colour that brings structure to the logo. A monochrome style could be used for some corporate documents.

Figure 5.8.5: Monochrome Logo

For the monochromatic logo, Figure 5.8.5, the green of the leaf and the grey gear has been changed to black in the isotype sector. On the logotype, in the "LNG" the body of the text is white with borders black to ensure readability, "ineers" is in black to show contrast between parts of the name.

6 Research

To wholly understand the engineering behind the goal of the project, an extensive period of research is undertaken, not only to define the project but to find out whether it would be possible to engineer such a system. Focus is placed on the different components of the system, developing a working P&ID and investigating existing LNG systems, including but not limited to Locomotives, Boats and Power Plant systems. Alternative fuels must also be investigated, such as whether splitting the fuel used in the system from 100% LNG to a mix with diesel, as it is unclear whether the LNG system is too dangerous to be housed and utilised within Novia University of Applied Sciences. There are many sources consulted throughout this research and various consultations with tutor Kaj Rintanen and Mathias Jansson of Wärtsilä.

6.1 What is LNG?

Natural Gas has long been a popular energy resource and has increased in popularity over the last 20 years (Mokhatab et al., 2014). This is due to the reduced Carbon Dioxide, CO_2, emissions when Natural gas is burned. When natural gas is cooled to around -162°C at atmospheric pressure the gas occupies 600 times less volume and is known as Liquefied Natural Gas, LNG (Engblom, 2017). The decrease in volume allows for the ease of transportation of LNG by ship and truck. This therefore drastically decreases the cost of transporting natural gas reducing the requirement for expensive pipelines and allowing for smaller areas of natural gas to be cultivated (Mokhatab et al., 2014).

6.2 Composition of LNG

LNG is a mixture of Hydrocarbons, predominantly methane, which typically ranges between 87 mole % and 99 mole %, the remainder of the mixture is an array of other small chain hydrocarbon from C_2 to C_4 (Mokhatab et al., 2014).

Finally, some nitrogen and Sulphur may be present. Typical compositions of LNG are shown in Table 6.1.

Table 6.1: Typical Composition of LNG from various Liquefaction Plants (ILEX Energy Consulting, 2003)

Component, mole %	Nigeria LNG	Arun LNG	Brunei LNG	Oman LNG	Atlantic LNG	Kenai LNG
Methane	87.9	88.48	89.4	90	95	99.8
Ethane	5.5	8.36	6.3	6.35	4.6	0.1
Propane	4	1.56	2.8	0.15	0.38	0
Butane	2.5	1.56	1.3	2.5	0	0
Nitrogen	0.1	0.04	0.2	1	0.02	0.1

LNG must comply with a specific code from the International Organisation of Standards, ISO 15403, which details the composition of LNG when used as a "compressed fuel for vehicles". This composition is shown in Table 6.2.

Table 6.2: Natural gas compositions for use in vehicles (ISO 15403)

Gas component	Limit
Methane	≥ 96%
Carbon dioxide	≤ 3%
Oxygen	≤ 0,5%
Total sulphur	≤ 120 mg/Nm³ (1)
Mercaptan (2)	≤ 15 mg/Nm³
Hydrogen sulphide	≤ 5 mg /Nm³
Water	≤ -10 bis -30 °C pressure dew point (depending on local conditions)
Dust	technically free (≤ 1 µm)
Oil	100 – 200 ppm

(1) mg/Nm³: The N refers in normal conditions

(2) Mercaptan: Named thiol too (R-SH) radical with toxic impact to humans

The typical composition of LNG used in Finland is shown in Table 6.3 this follows the ISO 15403 and therefore is an ideal composition to be used in the designed system.

Table 6.3: Composition of LNG used in Finland.

Property	Units	Range	Comments
Methane	%	96 - 99	
Ethane	%	0.5 -1.5	
Higher hydrocarbons	%	< 0.5	
Inert gases	%	< 1.5	
Gross calorific value	MJ/m^3	36.8 - 37.7	
	kWh/m^3	10.2 -10.5	
Net calorific value	MJ/m^3	33.1 - 34	
	kWh/m^3	9.2 – 9.5	
Gross Wobbe Index	MJ/m^3	49.2 – 49.9	
Net Wobbe Index	MJ/m^3	44.3 - 45	
Sulphur content	Mg/m^3	<1	
Dew point	°C	< -5	in winter at a pressure of 40 bar
	°C	0	in summer at pressure of 40 bar

LNG is odourless, colourless and noncorrosive at atmospheric pressure. When heated back to natural gas and burned it produces drastically lower Carbon emissions than any other fossil fuel (Mokhatab et al., 2014), this and the low levels of sulphur and nitrogen oxides make LNG an extremely clean fuel.

6.3 LNG Storage Solutions

There are two main methods of storing LNG. One method is a 'bullet tank', which is a smaller scale solution and the second is a large insulated concrete tank, which is more suited to large scale or industrial storage (Engblom, 2017).

6.3.1 Bullet Tank

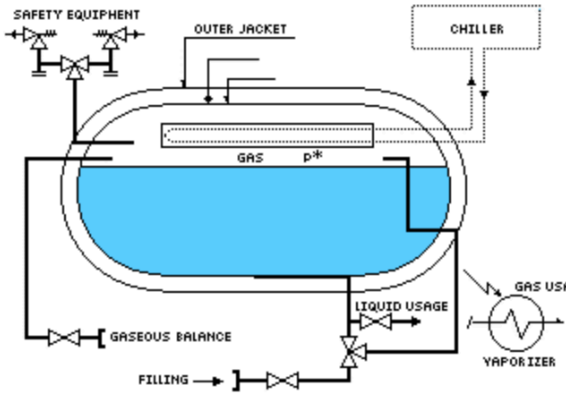

Figure 6.3.1: Vacuum insulated storage tank (Centralwelding.com, 2017)

A vacuum insulated tank has been a standard of storing LNG for many years. The principle of a vacuum insulated tank is one vessel containing the LNG, housed within a larger tank. Current designs have a vacuum insulation of around 250 – 300mm between the two vessels. The internal tank is designed to house the LNG pressure with a tolerance of 1 bar, whereas the external tank is designed to withstand the vacuum. Figure 6.3.1 shows a standard application of a vacuum insulated bullet tank, this design can be easily applied to an LNG storage system. When LNG heats within the tank, it turns into a gas. This increases the pressure within the tank and this increase in pressure can be used to pump the liquid from the tank. The gas could also be immediately removed from the tank and used as fuel. The disadvantage of using a bullet tank as a means of storage is the pressure may not build up too much, meaning that some of the fuel must constantly be used.

6.3.2 Insulated Tank

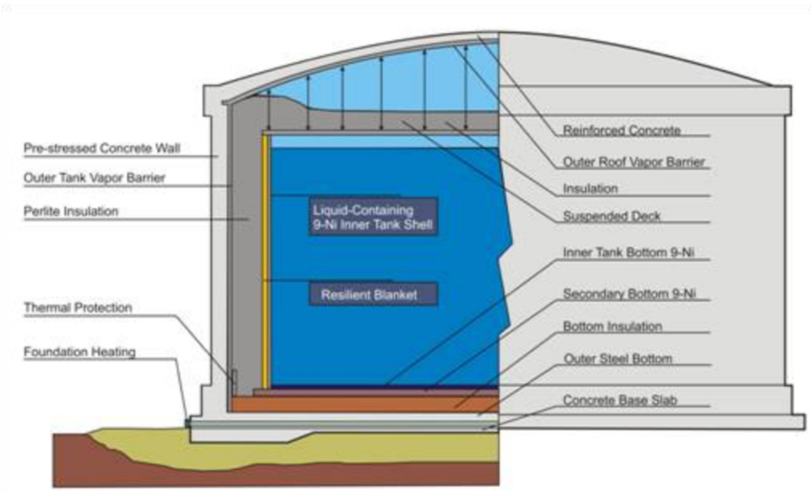

Figure 6.3.2: Insulated LNG Storage Tank (Epd.gov.hk, 2017)

A method of storing large volumes of LNG is an insulated concrete tower as shown in Figure 6.3.2. The insulation is loosely packed and surrounds the inner tank which is usually made from a Nickel based alloy. The domed roof of the tank and the walls are manufactured from pre-stressed and reinforced concrete for structural integrity should the inner tank fail. A layer of thermal insulation is also necessary above the concrete base to ensure that no heat is gained from the ground, this is shown in Figure 6.3.2.

6.4 Existing Designs

6.4.1 Wärtsilä

A Natural Gas fuelled engine offered by Wärtsilä is the Spark-ignited(SG) lean-burn Otto cycle gas engine. In the system, the gas is mixed with air just before the inlet valves, during the intake period natural gas, NG, is fed into a pre-chamber where the NG is rich compared to the cylinder. Once compressed the NG/Air mix in the pre-chamber is ignited by a spark plug. The subsequent flames emerge from the nozzle of the pre-chamber igniting the NG/Air mixture in the main combustion chamber. After each phase the cylinder is emptied of "exhaust waste" and the process begins again (Wärtsilä, 2017).

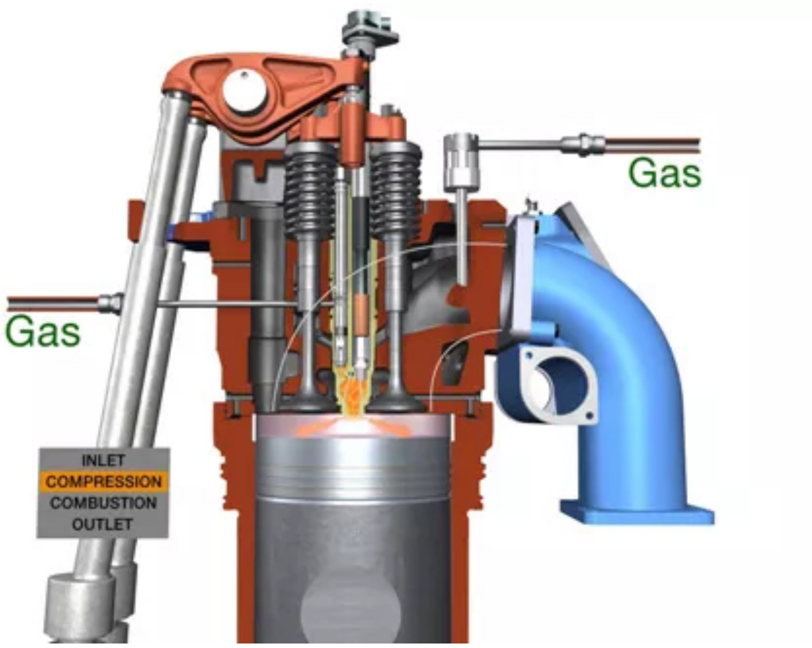

Figure 6.4.1: Wärtsilä Spark-Ignited Lean-burn gas engine.

6.4.2 Locomotive Industry

Liquid Natural Gas is quickly becoming the prime area of fuel development in locomotive industry. Two companies, Electro Motive Diesel (EMD) and General Electric (GE), are leading the way in the exploration of using LNG as the principal fuel source in locomotives. Both companies have developed a LNG fuel tender sandwiched between two high horsepower, six axle AC-traction locomotives which has completed two months of intensive testing, utilising testing equipment which simulated a locomotive hauling 100 cars of coal on the FAST (Faculty for Accelerated Service Testing) loop in Pueblo, Colo (Vantuono, 2017).

EMD's LNG set consists of two SD70ACe units, and the GE set of two ES44ACs. Both Engines use a legacy fuel tender with a cryogenic capacity of 20,000 gallons – LNG gasification occurs within the tender. Both locomotives are *dual fuel* engines meaning that should the situation demand it they can switch to 100% diesel operation. The LNG delivery systems utilized are both low pressure and operate with either a 60%-40% LNG to diesel mix (EMD) or 80%-20%(GE). The engines do not operate on 100% LNG as this requires spark ignition and thus involves many of modifications to the prime-mover (Vantuono, 2017).

Figure 6.4.2: LNG fuelled Locomotive

For widespread adoption of natural gas to occur in locomotive transport, three main areas for development must be satisfied to make it economically viable. The engine and fuel tender technology must be further developed as although Liquid Natural Gas has a vastly lower cost per unit energy in comparison to diesel, the technology needed to ensure wide spread success for LNG's locomotives is not developed far enough. Therefore, AAR's Natural Gas Fuel Tender Technical Advisory Group is working on a standardised design for a LNG fuel tender. There is also the option of an International Organisation of

Standards, ISO, tank approach to refuelling that involves swapping out a spent ISO LNG tank for a fresh unit at a mobile refuelling site.

Fuel infrastructure is also needed for success, as LNG cannot be stored long term safely without continuous cooling to roughly -162°C.

The Dynamic Gas Blending (DMG) approach taken by EMD, that employs a dual fuel mix of LNG – Diesel (maximum 60% LNG), involves introducing natural gas into the engine early in the combustion cycle. A computer-controlled valve opens adjacent to the lower liner air intake ports, feeding a mixture of natural gas and air into the cylinder which is subsequently compressed. Diesel is then introduced once the piston almost reaches the top of its stroke and the ignition of the diesel causes the Natural Gas to ignite.

Since the pressure in the engine air intake system is relatively low, high pressure is not required for the gas to flow into the engine. However, early-cycle introduction of natural gas presents a challenge due to the tendency for the mixture to pre-ignite because of its temperature in the cylinder as it compresses, limiting the amount of gas that can be substituted for diesel fuel. Typically, dual-fuel engines using this method provide 50% to 60% substitution of gas for diesel fuel on a duty-cycle basis. Engine modifications such as reducing the compression ratio may improve operation with natural gas and increase the substitution rate. However, such changes may reduce the efficiency of the engine when operating on 100% diesel, and the engine may be more difficult to start when cold.
(Vantuono, 2017)

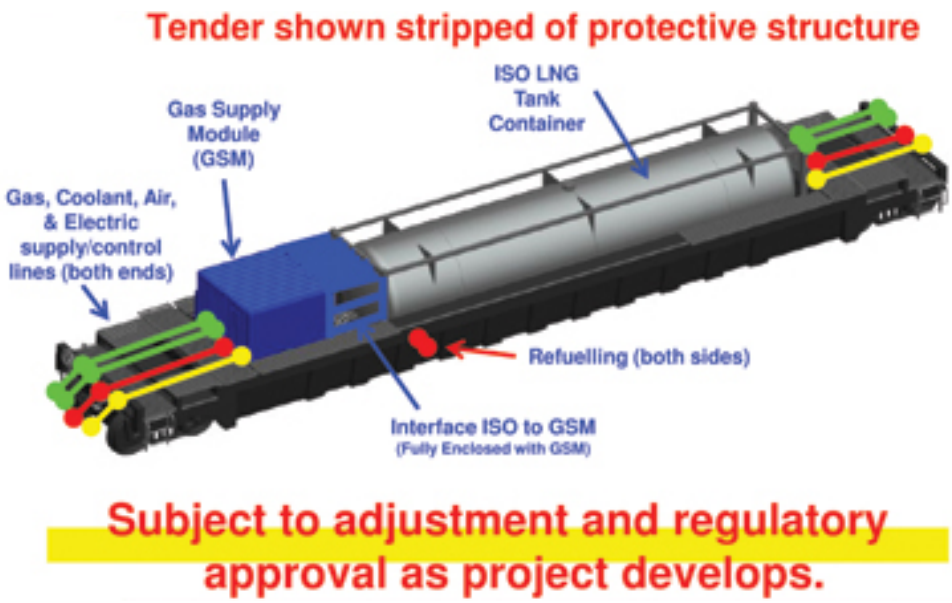

Figure 6.4.3: LNG fuel tender

In contrast to this, a High-Pressure Drive Injection (HPDI) LNG system developed by Caterpillar and Westport (Caterpillar is EMD's parent company) injects natural gas far later in the compression cycle as this eliminates the risk of pre-ignition occurring allowing the engine to run like a diesel engine. The Natural Gas in injected under high pressure, because the LNG must overcome cylinder pressure and the injection must occur quickly, using an injector that provides a 95% natural gas to diesel mix for ignition. EMD say that full power can be generated in its 710-engine using 95% substitution with High Pressure Direct Injection, HPDI, and furthermore significantly lower levels of emissions are produced in comparison to similar 100% diesel systems.

Safety is naturally a concern with LNG. Methane detectors are used to identify any natural gas leaks on the locomotive and alert the control system to shut off the gas supply.

6.4.3 Siemens LNG solutions

The next company which will be looked at will be *Siemens LNG solutions***.** Siemens LNG operate two forms of Liquid Natural Gas fuel systems one of which is the Classic LNG system.

The Classic LNG Plant Systems, which operate using gas turbine driven compressors, typically have an operational efficiency well below 40%. Subsequently the systems flexibility is wholly proportional to the plants maintenance schedule, mainly the gas turbine compression drivers, and the overall reliability of the system.

Figure 6.4.4: Olympian 100kW engine

The other LNG system is a concept which operates using electrically driven compression, eLNG, in addition to a Combined Cycle Power Plant, CCPP, this concept system offers a system output of 50% and a greater operational flexibility while also minimalizing the environmental impact of the system. The main potential downfall of an eLNG system is that for the system to have sufficient strength it must be connected to a large electrical power supply. However, a study carried out on the dynamic frequency response, following outages of generation or compression by Siemens found that it is a viable option to have the system rigged to an “islanded” power supply. So, it would be possible to have the LNG system developed here at Novia while working without being connected to a large power supply – meaning that the electrically driven compression within the system could be powered using a generator so that the system is isolated from the national grid. ("LNG: A Natural Choice")

Olympian 100kW

Olympian 100kW is a Ford manufactured natural gas powered 3-phase engine generator which produces 208V and 347AMPS at. The dimensions are 122” L x 48” W x 60”H with an overall weight of 5000lbs. This is like the LNG engine hoped to be developed throughout the project (Dieselserviceandsupply.com, 2017).

Figure 6.4.5: Olympian 100kW engine in housing

6.5 Regasification

Since LNG is stored at -162°C in liquid form it needs to be returned to its gaseous state before it can be used in a combustion engine. This process is referred to as regasification. Regasification is achieved by heating the LNG. This heat can be supplied from different sources such as seawater, the air or the liquid coolant from an engine.

Some of these methods are impractical, the most efficient method is using engine coolant as less energy is lost. A large amount of energy is required to cool natural gas to its liquid state so it more economical to reuse the energy rather than lose it to the environment.

The most common method of achieving a heat transfer between two fluids is a heat exchanger. There are a few different designs of heat exchangers but the principle remains the same. The basic principle of a heat exchanger is passing two fluids within close proximity of each other with the intention of transferring heat from one to the other. In the case of LNG, it absorbs the heat from the engine coolant and returns to its gaseous state from which it can be used to fuel an internal combustion engine.

6.5.1 Shell and Tube Heat Exchanger

A shell and tube heat exchanger is comprised of enclosed tubes within a shell, this is shown in Figure 6.5.1. Applied to an LNG system, LNG would flow through the tubes and the liquid coolant surrounding the tubes within the outer shell. Considering the design, a large contact surface is available for cooling due to the small diameter and long length of the tubes. This maximises the heat energy absorbed by the LNG, causing the LNG to revert to its gaseous state. Baffles are placed strategically within the outer shell to direct the flow over the tubes multiple times, further increasing the heat exchanged.

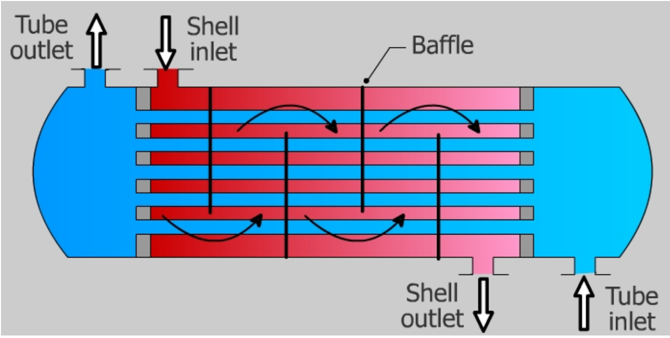

Figure 6.5.1: Shell and Tube Heat Exchanger (Faculty.kfupm.edu.sa, 2017)

6.5.2 Plate Heat Exchanger

The plate heat exchanger increases the contact surface between the two fluids. Within a plate heat exchanger there are multiple plates stacked in parallel to allow the fluids to flow between, as shown in Figure 6.5.2, the fluids alternate between each layer. This increase in surface area allows the heat exchanger to be smaller and additionally causes a significant pressure drop due to the high turbulence within the exchanger.

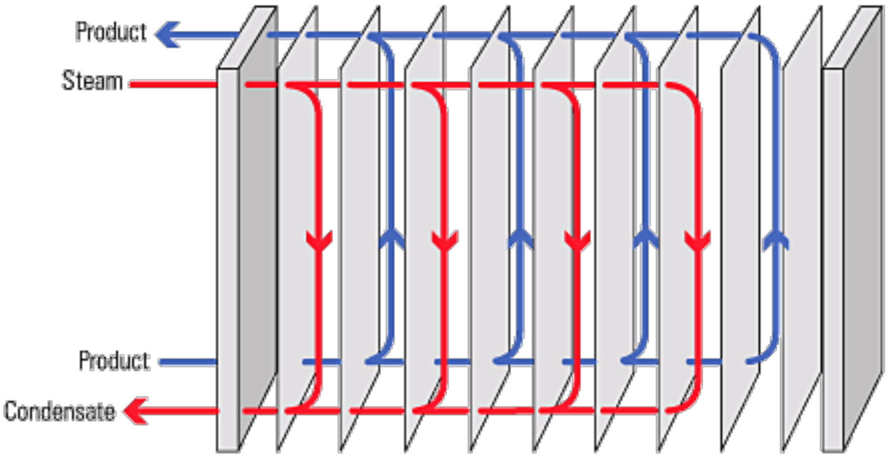

Figure 6.5.2: Plate Heat Exchanger (Pointing.spiraxsarco.com, 2017)

6.5.3 Plate Fin Heat Exchanger

As with plate heat exchangers, the plate fin heat exchanger consists of multiple parallel plates layered together through which the fluids alternate. The advantage is that between the plates there is a layer of corrugated metal resulting in more efficient heat transfer, this can be seen in Figure 6.5.3. The corrugated metal also increases the structural integrity of the heat exchanger and therefore plate fin heat exchangers can be utilised at higher pressures. A disadvantage however is due to the narrow interior it is a great deal more susceptible to fouling, increasing maintenance expenses.

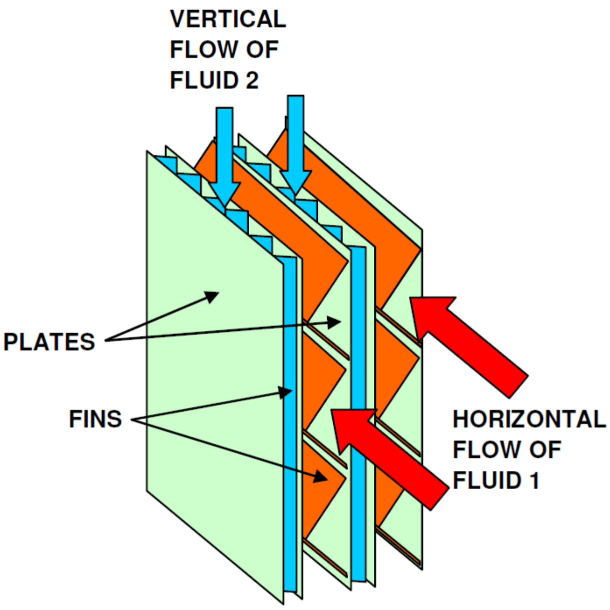

Figure 6.5.3: Plate Fin Heat Exchanger (EnggCyclopedia, 2017)

6.5.4 Spiral heat exchanger

A spiral heat exchanger consists of two chambers, separated by a metal sheet, that are wound around each other in a spiral as seen in Figure **Error! Reference source not found.**. Because of this there is a large contact surface between the two. The flow of the two liquids is counter current which results in a highly efficient heat transfer.

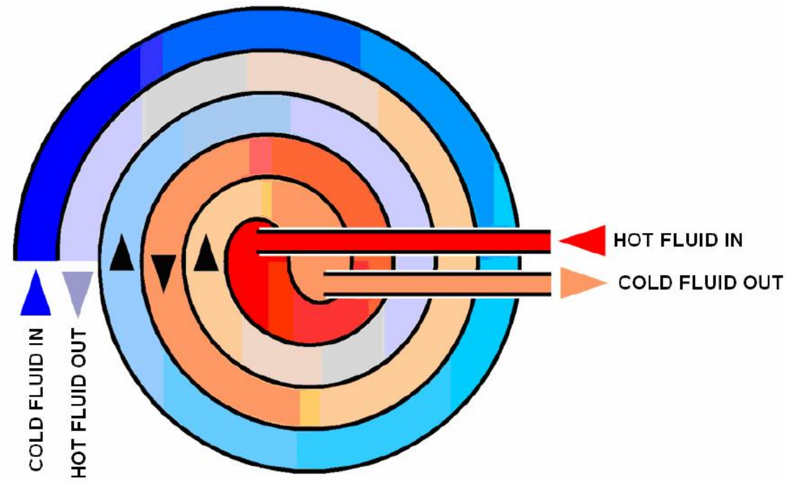

Figure 6.5.4: Spiral Heat Exchanger (EnggCyclopedia, 2017)

6.6 BOG Liquefaction

The LNG is kept at cryogenic temperatures (-162°C) and although the tank is insulated, the environment will cause it to heat up. This temperature rise will in turn cause some of the liquid to evaporate into Boil of Gas, BOG. To reduce the BOG, the storage tanks have multi-layered insulations that minimise the heat transfer. Due to a large difference in temperature between the inside and the outside of the tank, the heat finally leaks into the LNG through the walls, roof or floor of the tank as is seen in Figure 6.6.1.

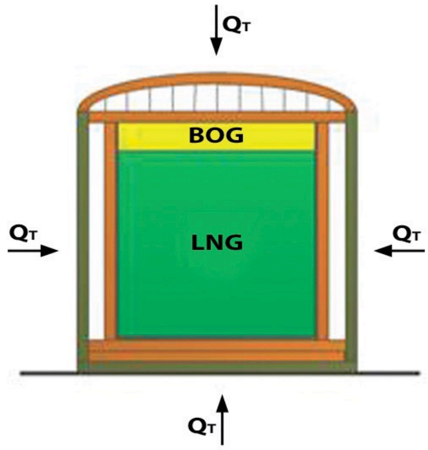

Figure 6.6.1: Large scale BOG storage tank

6.6.1 Measurement

The BOG is measured by the amount of vapour per unit time that boils, boil-off rate, BOR. It can be measured in absolute terms (kg or litres) or relative terms (%). Generally, the relative boil-off rate is used. The boil off rate is used to calculate the duration the cryogenic fluid can be stored in its specific container.

The tanks are designed to reduce the ingress of heat, so the boil-off rate is less than 0.05% per day but it can vary between 0.02-0.1% (British Petrol and International Gas Union, 2011). The boil off rate of a tank it can be calculated by the following expression:

Equation 6.1: Boil Off Rate

$$BOR = \frac{V_{BOG} * 24}{V_{LNG} * \rho} = \frac{\dot{Q} * 3600 * 24}{\mathrm{L} * V_{LNG} * \ \rho} * 100$$

BOR= %/day

V_{BOG} Volume of BOG (m^3)

V_{LNG} = Volume of LNG (m^3)

ρ= density of LNG (kg/ m^3)

$\dot{Q}$= heat exchange (W)

L= latent heat of vaporisation (J/kg.)

6.6.2 Solutions

When the LNG boils off, it raises the pressure of the tank. This pressure can reduce the efficiency of the system as well as damage the tank if it increases excessively. For this reason, there are some solutions to reduce the pressure.

One is to vent the gas from the tank to a fuel station where it will be re-liquefied and redeposited into the tank. Another option is to use it as fuel, some systems use the BOG to refrigerate the tank by means of evaporation. Finally, if there are problems with the previous systems, the last solution is to vent it to the atmosphere (in small quantities).

6.7 Environmental Impact

As with most proposed industrial projects, the environmental impact must be considered. It is necessary to qualify the impact of LNG and to analyse the impact in comparison with other fuels.

6.7.1 Environmental Impact Potential of LNG

As previously outlined the main component of the LNG is methane (CH_4) meaning this is the focal factor to be considered when quantifying the impact LNG has on the environment. There are impurities within LNG that have a detrimental effect on the environment; Carbon Dioxide (CO_2), Hydrogen Sulphide (H_2S) (Burgess et al., 2017) and heavy hydrocarbons including aromatics all exist within and LNG and must be considered when evaluating the effect the fuel has on the environment. Methane produces less pollution from combustion compared to other fuels since it has a small chemical structure, shown in Figure 6.7.1, containing only one Carbon atom and four Hydrogen atoms. The process of combustion of methane is shown in

Equation 6.2: Combustion of Methane.

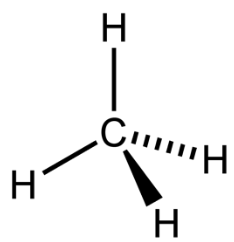

Figure 6.7.1: Chemical Structure of Methane

Equation 6.2: Combustion of Methane

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Although the burning of LNG produces less CO_2 than other fuels, methane has a Global Warming Potential, GWP[1], of 25 meaning any methane released to the atmosphere has a high impact. From existing research conducted it is defined the combustion of 1kg LNG produces 2.750 kg of CO_2 (Practical guide for the emissions calculations of global warming gases, 2011). Another advantage of using natural gas is there are very few sulphurous gases produced during combustion, which is a major cause of acid rain (Economic Commission for Europe, 2013)

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6.7.2 LNG vs Other fuels

The advantages and disadvantages of using LNG in comparison with other commonly used fuels for similar applications are shown in Table 5.1. As presented in the table, the fuel that produces the most CO_2 is gasoline. Although it is not specified in the table, combustion of gasoline produces many more contaminants like sulphites that are not produced when burning LNG. One of the disadvantages of using LNG compared to other liquid fuels is that it requires a larger volume to produce the same amount energy.

[1] GWP: (Global Warming Potential) Relative scale of the impact to the atmosphere compared with CO_2

Table 6.4: LNG Properties vs Other Fuels

	Gasoline	Diesel	Biodiesel	Propane (LPG)	CNG	LNG	Hydrogen	Electricity
CO2 Emissions (kg CO2/kWh)[1][2][5]	0.274	0.263		0.234	0.202	0.202	--	0.222
Chemical Structure[1]	C4 to C8 and ethanol <10%	C8 to C25	Methil Esters of C8 to C22 fatty acids	C3H8	Majority CH4, C2H6 and inert gasses	Majority CH4 (<85%), C2H6 and inert gasses	H2	
Feedstocks[1]	Crude oil	Crude oil	Oils and fats,	A by-product of petroleum refining or natural gas processing	Underground reserves and renewable biogas	Underground reserves and renewable biogas	Natural gas, methanol and water electrolysis	Coal, nuclear, hydroelectric, solar, wind, others…
Lower heating value (kWh/kg)[1][3]	12.2	11.74	10.42	13	13	14	33	
Higher heating value (kWh/kg)[1][3]	13.02	11.97	11.16	14	15	15	39	
Gasoline gallon equivalent	1,02-0.98	0.880	0.96 or 0.90 depending on kind of diesel	1.247	----	1.536	0.997kg	33.70 kWh
Physical state[1]	liquid	liquid	liquid	Pressurised liquid	Compressed gas	liquid	Gas	
Density[5][6]	0.71-0.77 kg/l	0.83 kg/l	0.82-0.9 kg/l	0.5-0.58 kg/l		0.46		

Sources:

1. (Afdc.energy.gov, 2017)
2. (Quaschning, 2015)
3. (Hydrogen.pnl.gov, 2015)
4. (PRACTICAL GUIDE FOR THE GREENHOUSE EMISSION CALCULATION 2017)
5. (Cálculo automático de emisiones totales en relación a los consumos energéticos de sus instalaciones 2017
6. (LNG density calculator, 2017)

6.8 General security terms with LNG

Natural gas is a hydrocarbon which burns when ignited in the presence of Oxygen. The LNG does not burn easily due to the lower levels of Oxygen present. Natural gas, methane, requires 5-15% of natural gas in air to ignite. LNG is not explosive while in its gaseous state as it only burns with the correct oxygen concentration.

The LNG is a cryogen so it must be stored and distributed in specialised tanks and equipment to keep it in its liquid state.
In case there is a leak of LNG, it forms visible white cloud due to condensation of the water in air. Since LNG is a cryogen contact with skin could result in burns caused by the cold temperatures however it does not have toxic effects. In case of an exposure in an enclosed space it can cause asphyxia caused by an oxygen deprivation.

6.9 Sensors

Figure 6.9.1 Rosemount 5900S (Emerson.com. 2017)

A crucial part of the system is being able to measure the amount of liquid natural gas within the fuel tank. This is not a simple task as the LNG is stored at -162°C. Radar technology is suitable for this task as the measurement systems are mainly outwith the tank only the antenna is within the tank, meaning the component will not freeze at cryogenic temperatures. The Rosemount 5900S Level Gauge, as seen in Figure 6.9.1, provides instrument accuracy to ±0.5 mm. The Rosemount 5900S is also normally combined with high precision multi spot temperature sensors meaning that highly accurate net volume calculations can be carried out. One of the main benefits of using radar level and temperature technology is that there are no moving parts and no contact with the Liquid Natural Gas giving an increased reliability and fewer potential interruptions (Emerson.com, 2017). The roof type that the gauge will be fitted to also does not matter as it can be either fixed or floating. “2-in-1” gauging is also present meaning that there can be simultaneous level measurement and alarm functionality that will alert if there is a fuel leak or if the fuel level is too low.

Figure 6.9.2 Rosemount 2240S

The level is calculated using Frequency Modulated Continuous Wave technology (FMCW) – microwaves are transmitted towards the liquid surface with a precise linear frequency variation, around 10GHz. When the signal is received back from the liquid surface it has a slightly different frequency compared to that transmitted. The difference in frequency is measured and is directly proportional to the distance to the liquid surface.

Figure 6.9.3 Rosemount 599

Rosemount 2240S Multi-Input Temperature Transmitter seen in Figure 6.9.2 is a suitable device for measuring and transmitting the temperature within the LNG storage tank when used in conjunction with a Rosemount 566 Multiple Spot temperature sensor for cryogenic use (Figure 6.9.3). The temperature sensor is composed of multiple temperature sensors so it can measure the different temperatures at different heights within the tank to provide a tank temperature profile and an average temperature. The temperature range of the sensors are from -170 to +100 ºC. The sensors are enclosed in a stainless-steel tube which is filled with Argon gas to prevent condensation of water within the sensors at low temperatures.

Figure 6.9.4 Rosemount 3051S (Emerson.com, 2017)

It is necessary to have a constant and consistent pressure reading from within the LNG storage tank and so a pressure sensor must be selected. The Rosemount 3051S Coplanar Pressure Transmitter is an ideal pressure sensor as it provides the temperature to an accuracy of 0.025% (Emerson.com, 2017)
. The pressure is turned into an electrical signal and if the pressure within the storage tank was to drop or rise then an alarm will be triggered. This is shown in Figure 6.9.4.

6.10 Internal Combustion Theory

Though internal combustion engines follow mechanical cycles rather than thermodynamics cycles of ideal gases, the cycle is defined by the movement within the engine its self. It is very useful to compare internal combustion engines to ideal standard air cycles, this is because the main working fluid, Nitrogen, remains a constant throughout (Stone, 1999).

6.10.1 The Otto Cycle

This standard air cycle is used for spark ignition engines with a high speed; it contains four non-flow processes (Stone, 1999). The compression and expansion within the Otto cycle are adiabatic, reversible and therefore isentropic (Stone, 1999).The Otto cycle is shown in Figure 6.10.1. The processes involved are as follows:

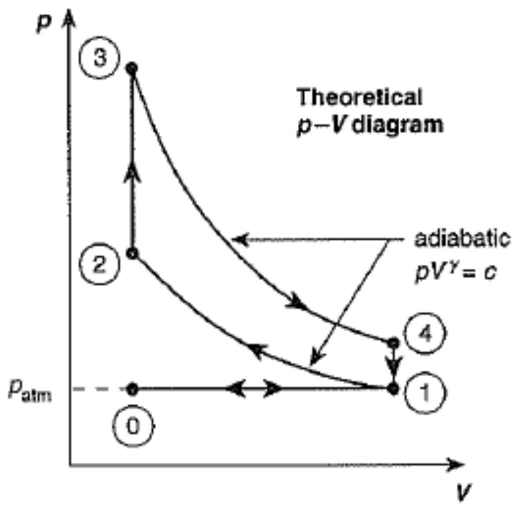

Figure 6.10.1: Ideal Air Standard Otto Cycle (Learn Easy, 2013)

1-2 isentropic compression of air through volume ration V_1/V_2, compression ratio r_v.

2-3 addition of heat Q_{23} at constant volume.

3-4 isentropic expansion of air to the original volume.

4-1 rejection of heat Q_{41} at constant volume.

Considering air as the ideal gas used in the cycle, there is a constant specific heat and mass of air, the heat transfers are

Equation 6.3: Heat Transfers of Otto Cycle

$$Q_{23} = mc_v(T_3 - T_2)$$
$$Q_{41} = mc_v(T_4 - T_1)$$

therefore, the efficiency of the Otto cycle is defined as

Equation 6.4: Thermal Efficiency of Otto cycle (Stone, 1999).

$$\eta_{otto} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

Since internal combustion engines operate in a mechanical cycle, not a thermodynamic cycle the PV cycle is slightly different as shown in Figure 6.10.2.

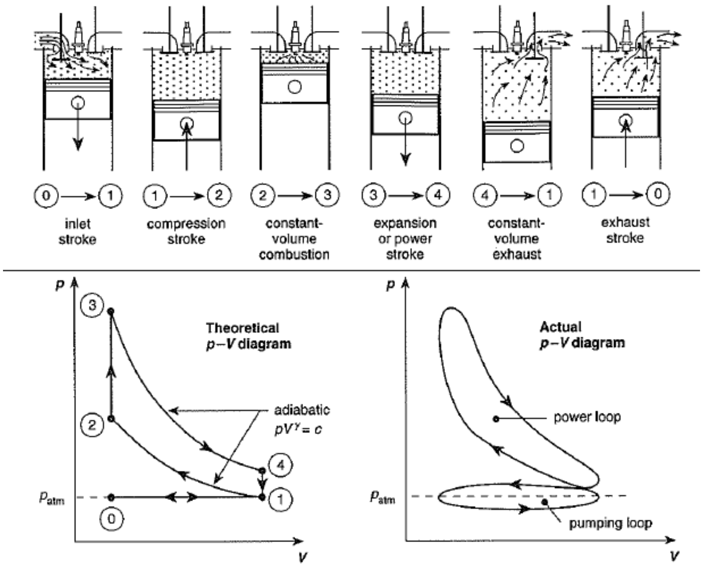

Figure 6.10.2: Thermodynamic and Mechanical Cycle comparison (Learn Easy, 2013)

6.10.2 The Diesel Cycle

The Diesel cycle addition of heat takes place at a constant pressure rather than constant volume as is the case with the Otto cycle (Stone, 1999). The high compression ratio causes the fuel to self-ignite. As with the Otto cycle the Diesel cycle consists of four non-flow processes as shown in Figure 6.10.3.

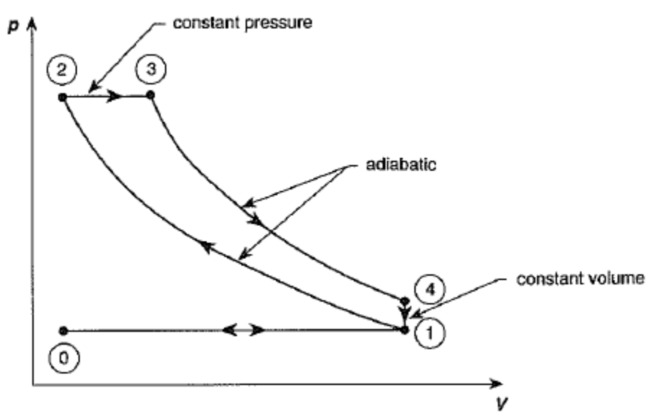

Figure 6.10.3: Ideal Air Standard Diesel Cycle (Learn Easy, 2013)

The processes within the cycle are all reversible as follows

1-2 isentropic compression of air through a volume ratio of $V_1/V_{2,}$ compression r_v.
2-3 addition of heat Q_{23} at constant pressure while the volume expands.
3-4 isentropic expansion of air to the original volume
4-1 rejection of heat Q_{14} at constant volume.

Considering air as the ideal gas used in the cycle, specific heat capacities and the mass of air, the heat transfers are

Equation 6.5: Heat Transfers of Diesel Cycle

$$Q_{23} = mc_p(T_3 - T_2)$$
$$Q_{41} = mc_v(T_4 - T_1)$$

therefore, the efficiency of the Diesel cycle is defined as

Equation 6.6: Thermal Efficiency of Diesel Cycle (Stone, 1999).

$$\eta_{Diesel} = 1 - \frac{1}{\gamma}\frac{T_4 - T_1}{T_3 - T_2}$$

6.10.3 LNG Fuelled Engine

An important benefit of using LNG in an engine is the improved ecological effects, this is due to fuel igniting at lower temperatures. For this reason, it is more suited to the fuel to use a spark ignition engine that would follow the Otto cycle thermal combustion engine, as the efficiency is dependent on temperatures and using this cycle it is possible to keep temperatures down and therefore lower emissions.

7 Design

7.1 Tank Specifications

To define the system the next step is to start making an approximation of the tank which will contain the LNG. As requested, there has to be enough to fuel a 100 kW engine for 6 hours. To start designing, several things are needed: the heating value, the density and the efficiency of the engine.

As previously seen, LNG has an upper heating value of 15 kWh/kg and a lower heating value of 14 kWh/kg. For the calculation, the lower heating shall be used to assure enough fuel. The density of the used LNG is 0.46 kg/l (LNG density calculator, 2017). A gasoline engine bares the closest properties to a natural gas engine therefore a 30% efficiency can be assumed (Wartsila.com, 2017). With this information, the necessary volume can be approximated with the equation shown below.

Equation 7.1: Tank volume in litres

$$100kWh * \frac{1kg\ LNG}{14kWh} * \frac{1l\ LNG}{0.46\ kg\ LNG} * \frac{100}{30} * 6hours = \mathbf{310.56}\ \boldsymbol{litres}$$

Over dimensioning by 40% is applied for safety reasons, in theory 310.56 litres of fuel would be used, but in these calculations, the BOG is not accounted for and there is a possibility that the efficiency of the engine could be reduced. For these reasons for the security coefficient of 1.4 is chosen to approximate the volume of the tank.

Equation 7.2: Tank volume applying Factor of Safety

$$310.56 * 1.4 = \mathbf{434.78}\ \boldsymbol{litres}$$

To define the heat exchanger and piping dimensions the mass flow rate must first be calculated. To calculate the mass flow rate the mass of LNG in the tank must first be defined, this is shown in Equation 7.3.

Equation 7.3: Mass of LNG in Storage Tank

$$mass, m = volume, V \times density, \rho$$

$$m = 434.78 \times 0.46$$

$$m = 200Kg$$

To calculate the maximum mass flow rate in kg/s the mass must be divided into the number of seconds in the 6-hour period the engine is required to operate.

Equation 7.4: Mass Flow Rate of System

$$\dot{m} = \frac{200kg}{6\times60\times60}$$

$$\dot{m} = 0.00926\ kg/s$$

7.2 Initial Design

7.2.1 P&ID Scheme

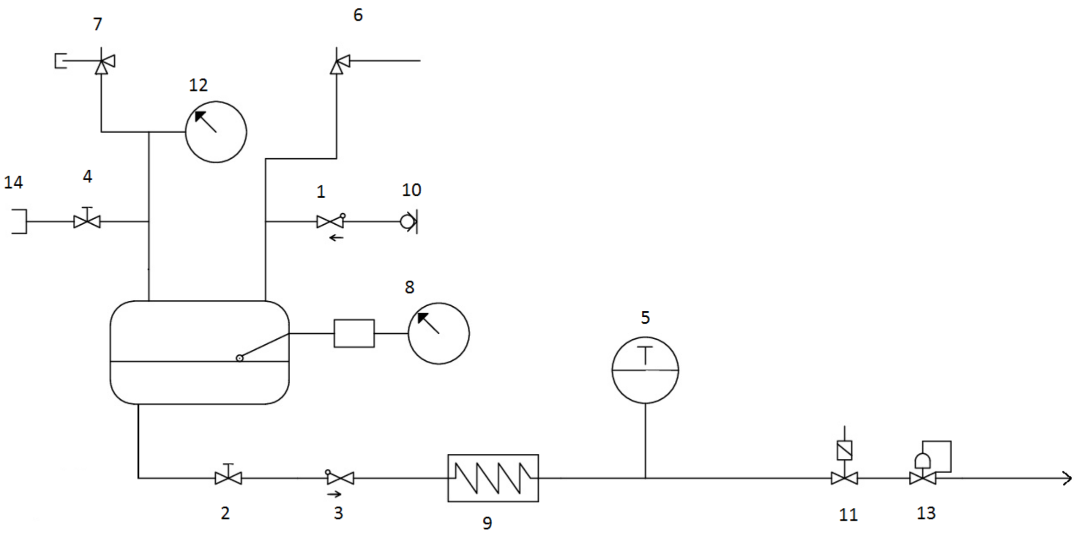

Figure 7.2.1: Initial P&ID Design

7.2.2 P&ID description:

To design the system a P&ID scheme is needed to show how the system functions and to evaluate if it will work correctly.

As can be seen in Figure 7.2.1, the tank is filled via the fill fitting (10). The liquid enters the tank, and flows through the fuel shutoff valve (2) and to the heat exchanger (9) where it reverts to its gaseous state. When it has returned to its gaseous form it enters the engine passing through the automatic fuel shutoff valve (11).

Since there is boil off gas inside the tank a system is needed to release the pressure or the system could get damaged. The first part of the system to avoid overpressure of the NG is the vent connector (14); once the BOG has caused the tank to reach a pre-set pressure the vent connector will send the gas to be used elsewhere or be re-liquefied. The vapour shutoff valve is set to open at this pressure.

Often it is not possible to take the boil off gas from the tank through the vent connector. To avoid issues caused by overpressure there are security controls for example the tank pressure gauge (12) that make sure that the pressure in the tank remains below the maximum pressure. In case that happens the primary relief valve (6) shall open to vent the gas to the atmosphere. For security reasons, there is a second relief valve (7) that would be activated in case that the primary has failed.

A system that utilises gas must be carefully controlled to ensure the security of the system. First the tank pressure gauge controls the pressure of the tank, though if the pressure reaches the maximum rated pressure it activates the relief valves. There is also a temperature controller after the exchanger to ensure that the temperature of the LNG that enters the engine is correct. There are other security systems such as the fill check valve (1), which is a non-return valve on the LNG entrance, and the excess flow valve (3).

7.2.3 Component Function

1. Fill Check Valve:

The main function of the fill check valve is to prevent back flow of LNG during filling. It connects the top fill line inside the tank.

2. Fuel shutoff valve

The fuel shutoff valve is used when service and maintenance operations are required. It is a manual valve with the function to shut off the flow of LNG.

3. Excess flow valve

The function of the excess flow valve is to cut off the fuel flow if it exceeds the limits. This protects the fuel line between the tank and the heat exchanger against uncontrolled fuel release in case of an accident.

4. Vapour shutoff valve

The function of this valve is to shutoff of the vapour. The valve is connected to the top of the tank on the vapour withdrawal line. During normal operation of the system the valve stays closed.

5. Low temperature signal device (LTS)

This is a security device which measures the temperature of the fuel after the heat exchanger. In case of a malfunction, the fuel could be too cold which could damage the engine.

6. Primary relief valve

The function of the primary relief valve is to vent LNG to the atmosphere in case the pressure rises above the maximum allowable working pressure (MAWP) of the tank.

7. Secondary relief valve

This valve is set to 1.5 times the MAWP. Its function is to vent the gas into the atmosphere like the primary relief valve, but in this case, it also prevents a catastrophic failure in the tank in case the primary release valve malfunctions.

8. Fuel contents gauge

The function of the fuel contents gauge is to show the contents of the tank. It is mounted to the inside of the tank and create an electronic signal of the tank level.

9. Heat exchanger

Every LNG system needs a heat exchanger to revert the LNG to its gaseous state so it may be burned as fuel in the engine.

10. Fill fitting

This valve allows filling of the storage tank.

11. Automatic valve

The function is to shut off fuel to the engine when the ignition is switched off or when is activate by a limit sensor. It is mounted on the warm gas outlet of the heat exchanger.

12. Tank pressure gauge

This sensor displays the pressure in the tank.

13. Overpressure regulator

The engine may not operate at the MAWP of the fuel tank. The overpressure regulator reduces the pressure of the fuel before it enters the engine. It is mounted in the engine fuel line downstream of the heat exchanger and the automatic shutoff valve. It works with the pressure control regulator of the tank to keep the correct pressure throughout the system.

14. Quick disconnect valve

This is the valve allows the venting of the gas when it is on the fuel station.

7.3 Final Design

After discussion with Mathias Jansson of Wärtsilä amendments were made to the initial design to include a pressure build-up heat exchanger (Jansson, 2017). The finalised design is shown in Figure 7.3.1. The component list is featured in Table 7.1.

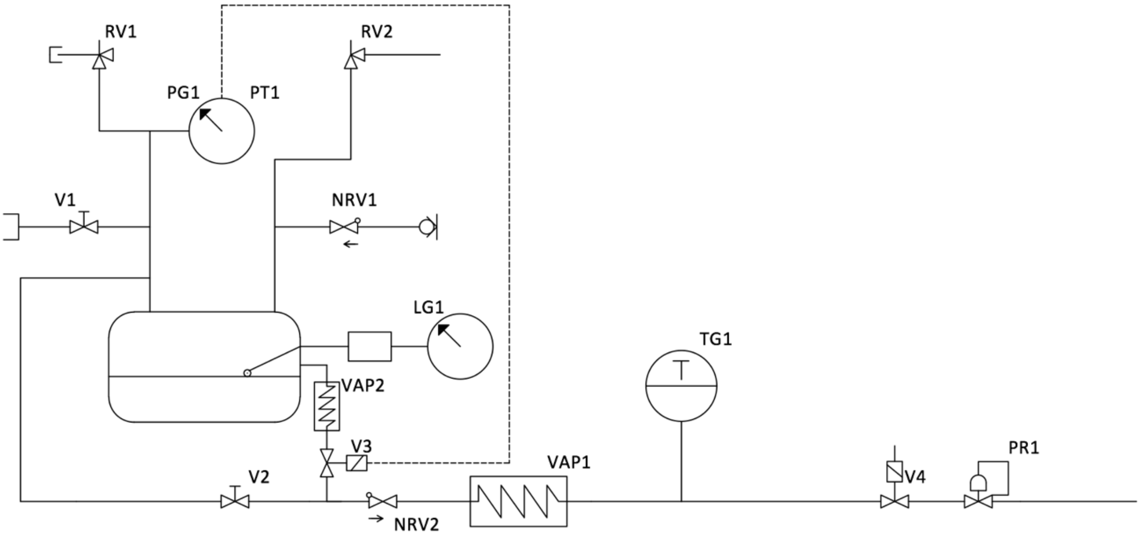

Figure 7.3.1: Final P&ID Design

Table 7.1: P&ID Component List (Agility Fuel Systems, 2017)

Component Code	Component	Description of component
RV1	Secondary release valve	Set to 1.5 times the maximum allowable working pressure, prevents failure if the primary relief valve fails.
V1	Vapour Shut off valve	Manually operated fuel shut off valve
PG1	Tank Pressure Gauge	Tests the tank pressure
PT1	Tank temperature gauge	Tests the tanks temperature at multiple points
RV2	Primary release valve	Vents gas if it exceeds the maximum allowable working pressure of the tank
NRV1	Fill Check Valve	Prevents back flow through the fuel line. Relies on tank pressure to seal.
LG1	Level Gauge	Provides a reading of the fuel level within the tank.
V2	Vapour Shut off valve	Manually operated fuel shut off valve
V3	Vapour Shut off valve	Solenoid operated fuel shut off valve
VAP2	Pressure Build Heat Exchanger	Builds the pressure of the LNG within the tank.
NRV2	Fill check valve	Prevents back flow through the fuel line. Relies on tank pressure to seal.
VAP1	Heat Exchanger	Transforms the NG in a liquid state to gaseous for combustion.
TG1	Temperature Gauge	Tests the temperature of the NG after it leaves the heat exchanger.
V4	Vapour Shut off valve	Solenoid operated fuel shut off valve
PR1	Pressure Relief Valve	Releases excess pressure before the fuel enters the engine

8 Feasibility of LNG Engine Design

When designing a fuel gas handling system for an engine, three aspects of the system must be considered; the pressure of the fuel as it enters the engine, the temperature of the fuel as it enters the engine. The pressure of the fuel supplied to the tank. The importance of these three parameters is the difference in pressure and temperature is the purpose of the system.

From an interview with the head of Marine R&D at Wärtsilä, most LNG engines operate within a range of between 6 and 16 bars pressure (Jansson, 2017). Since a small-scale engine is required for testing in a lab environment, 6 bar is initially assumed. Through discussion with Kaj Rintanen this value is still high. Further investigation with contacts at Volvo showed that a LNG engine would only require a pressure of 1-2 bar. This simplifies storage within the university as the LNG from source is deposited between the range of 1-2 bar. This removes the necessity within the system to have a separate line, known as a pressure build-up heat exchanger, to increase the pressure within the tank to the operating pressure of the engine (Jansson, 2017).

It is difficult to find an operating temperature of an LNG fuelled engine. After discussion within the team and a meeting with the supervisor, it can be assumed that the fuel must reach a temperature of between 20-50°C (293-323K) upon entering the engine.

8.1 Tank Specification

Due to a lack of use of LNG as a fuel in Europe, it is a challenge to source LNG storage tanks that comply with European regulations. Most tanks operate within US regulations. Enquires made to several European companies revealed a challenge finding a LNG storage tank on a laboratory scale. Finally, a suitable tank is found, sold by *Wessington Cryogenics* (Scott, 2017). The PHV-XX Range suits EU regulations for LNG storage. Since the design requires a minimum tank size of 435 litres. The PHV-600 suits specification. It also accounts for fuelling costs, ensuring that the tank is not too small meaning it could potentially be less economical to fill.

Upon eventually sourcing a suitable storage tank a significant discovery was made. Due to safety regulations when selling a tank for these purposes it requires a handling system which in this case, almost matches the initial design. This is shown in Figure 8.1.1.

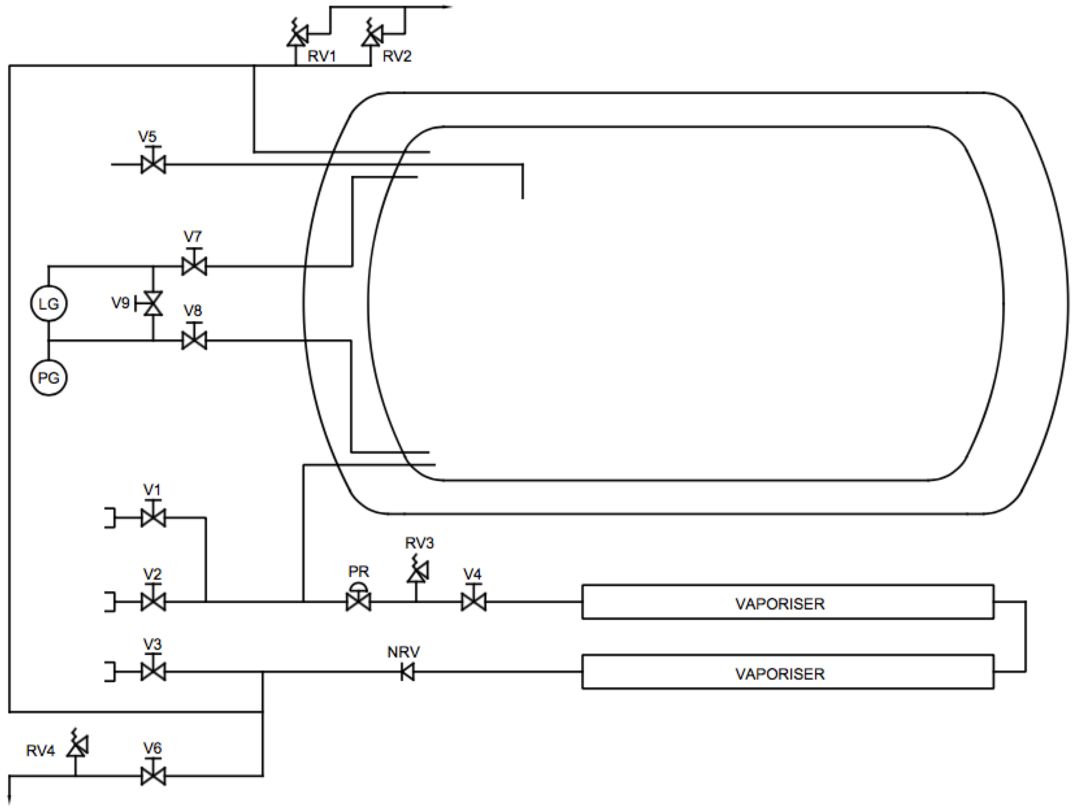

Figure 8.1.1: PHV-XXX Range Schematic Diagram. (Scott, 2017)

8.2 Heat Exchanger

The size of the tank was calculated to contain enough LNG to power a 100 kW engine for six hours. This means that the maximum mass flow rate is calculated as 0.00926 kg/s in Equation 7.4.

Equation 8.1: Mass flow rate

$$\dot{m}_{max} = \frac{\rho V}{t}$$

This is the maximum flow rate required by the engine. This means a heat exchanger needs to be found that is suitable to transfer the correct amount of energy to the LNG to heat it from -162°C to its optimal temperature of 50°C. To heat the LNG back to its combustible state there are three stages it must go through. First, it must be brought to its boiling point. Once it has reached this state it must boil off back into its gaseous state. Finally, the natural gas needs to be heated to the optimal temperate. Since the LNG is so close to its boiling point the amount of energy required to heat to this point can be neglected.

Since the composition of LNG is predominantly methane the following calculations are made using the specific values of methane. This means the results will not be entirely accurate but will yield results that can be used to outline specifications the heat exchanger will demand.

At the boiling point of liquid methane additional heat is added to revert it to a gaseous state. This is called latent heat. The latent heat, L_{meth}, of methane at atmospheric pressure, 1 bar, is 510,000 J/kg. This means to convert 1kg of liquid methane to its gaseous state 510,000 J of heat energy is needed. After it has evaporated it needs to be heated further. The heat capacity of methane is used to calculate the amount of heat needed. Since the heat capacity changes in relation to temperature an average shall be used. The value chosen for heat capacity, $C_{p,meth}$, is 2.121 kJ/kgK. Using these values the power of the heat exchanger can be determined.

Equation 8.2: Heat Exchange for LNG

$$\dot{Q} = \left(L_{meth} + C_{p,meth} * \Delta T\right) * \dot{m}_{max}$$

$$\dot{Q} = (510000 J/kg + 2121\ J/kgK * 212\ K) * 9.26 * 10^{-3}\ kg/s = 8.89\ kW$$

This result means that the heat exchanger must be able to transfer a maximum of approximately 9 kW of heat energy.

8.3 Valve Selection

When defining the valves the major parameter is the working temperature. Since LNG is a cryogen there are valves that are not equipped to function under these conditions. Ensuring the valve suits our specification can be a challenge as many of the valves on the market are made with larger diameters for industrial sized applications. Sourcing a price and data sheets for the valves can prove difficult as most of the companies do not provide the price or dimensions.

9 Feasibility of N_2 Storage Teaching Aid

There are challenges associated with storing LNG in a university lab environment; volatility of the fluid and lack of space. Therefore, the idea was proposed that a possible alternative could be to use a similar cryogenic liquid to simulate the storage and handling of LNG without the volatility or environmental hazard. After analysis of very few options, Liquid Nitrogen, LN_2, was selected. Use of LN_2 is low risk; the major risk associated with Nitrogen is breathing Nitrogen rich air, as this could cause asphyxiation. This is solved by releasing fumes into the atmosphere and the installation of Nitrogen detectors within the lab.

There are other positives when using Nitrogen over LNG. One is ease of sourcing the constituent parts used in the handling system. As Nitrogen is frequently used within lab environments, sourcing storage tanks and valves meeting EU regulations is simpler.

9.1 Tank Selection

When considering tanks *Wessington Cryogenics* appear to be an optimal supplier as the list price includes delivery of the tank. There are multiple product lines that are designed for the storage of LN_2.

The two that are considered as part of this analysis are the LT-XXX line and TPV-XXX line. When considering tanks for a proof of concept the limitations of the tank size is removed. Reducing cost and optimizing space in the lab are the prime objectives when selecting a tank. The LT-301 is the first tank to be considered as it is the smallest tank in the LT range (Wessingtoncryogenics.com, 2017). It has a stock price of *"£7824.00GBP plus packaging and delivery"* (Scott, 2017). This fits the low-cost specification however as can be seen in Figure 9.1.1, the LT-301 is a horizontal tank and therefore does not effectively utilise space within a lab.

Figure 9.1.1: Wessington Cryogenics LT-301

In an attempt to meet all the ideal specification for the tank the possibility of the TPV-XXX line is also investigated. This tank, as seen in Figure 9.1.2, is vertical and therefore occupies a smaller footprint in the lab. It is also more desirable from a budget perspective as it is cheaper than the LT range equivalent. *"The TPV 300 has a list price of £4795.00GBP plus packaging and carriage" (*Scott, 2017). This makes the TPV-300 the storage tank of choice when designing the LN_2 handling system.

Figure 9.1.2: Wessington Cryogenics TPV-300

9.2 Heat Exchanger

Since feasibility needs to be checked for a system handling liquid nitrogen, the same method can be used to calculate the heat exchange if nitrogen is the working fluid. The assumption can be made that the mass flow rate is identical. LN_2 is stored at -196°C and has a boiling temperature of -195.8°C. Latent heat of liquid nitrogen, L_{N2}, at atmospheric pressure is 199,000 J/kg and the specific heat capacity of LN_2, $C_{p,N2}$, is 1040 J/kgK.

Equation 9.1: Heat Exchange for LN_2

$$\dot{Q} = \left(L_{meth} + (C_{p,meth} * \Delta T)\right) * \dot{m}_{max}$$

$$\dot{Q} = (199000 J/kg + (1040\ J/kgK \times 245.8\ K)) * 9.26 * 10^{-3}\ kg/s = 4.21\ kW$$

This means that using the same mass flow rate of LNG for LN_2, the heat exchange needed is approximately half for nitrogen. Since the heat exchanger must be able to transfer a maximum of 8.89 kW the same one could be used to vaporise both liquids providing it could operate at a temperature of -196°C.

9.3 Valve selection

As this is intended as a teaching aid to prove the concept of LNG storage the valves selected for the LNG application may also be used for the LN_2 design, provided they comply with the operating temperature. For this reason, the same valves are listed in the parts list and budget. This can be seen in Appendix 7.

10 Conclusions

10.1 Management and Team

In conclusion, the management of this project initially was excellent. Though as the research progressed and challenges revealed themselves, culminating in modifications to the original scope, the management began to breakdown. The change in the preliminary scope caused the project to follow a different path meaning deliverables and goals diverged. In the wake of the mid-term report the task and Gantt chart was revisited to ensure that the workload and labour was distributed equally among the project team. This change in the scope meant that the teams workload and eventual goals became confused and time needed to be regained in the final weeks of the project.

10.2 Research

In conclusion, the research undertaken was the critical aspect of the project. The time initially dedicated to gathering knowledge was underestimated, as there was no existing knowledge on this subject within the team. The initial research and design phase would have benefitted from a consultation with Wärtsilä at an earlier date. This further extended the research portion of the project as additional areas needed explored before the design could be finalised. This aspect of the project was however efficient because there was an open dialogue and the workload was distributed evenly between members of the team.

10.3 Feasibility

To conclude, the feasibility studies found that this system could be implemented within Novia, with either the LNG fuelled system or the Liquid Nitrogen teaching aid. The finalisation of the P&ID was delayed due to challenges during the research portion. This caused a change in scope and feasibility studies became the final deliverables of the project. Late in the project when sourcing components for the LNG application it was discovered that there are legal issues with providing a tank without the accompanying handling system. This further proved the final design as there are many similarities between each. From these feasibility studies, it should be possible for another project team to implement and improve a final design.

10.4 Hand Over of the Project

The initial scope of this project was not achieved within the time frame available. However, to ensure completion of this project, documentation has been created for another EPS team to continue the research. The team that continues this project will hopefully be in a strong position to build and analyse a prototype with little need for research into the system design. This documentation consists of a folder containing all the relevant resources used and results structured in an easily navigated system. Parts lists and budgets for each system design.

The documentation is attached in the Appendices, Section 13.8.

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12 Acknowledgments

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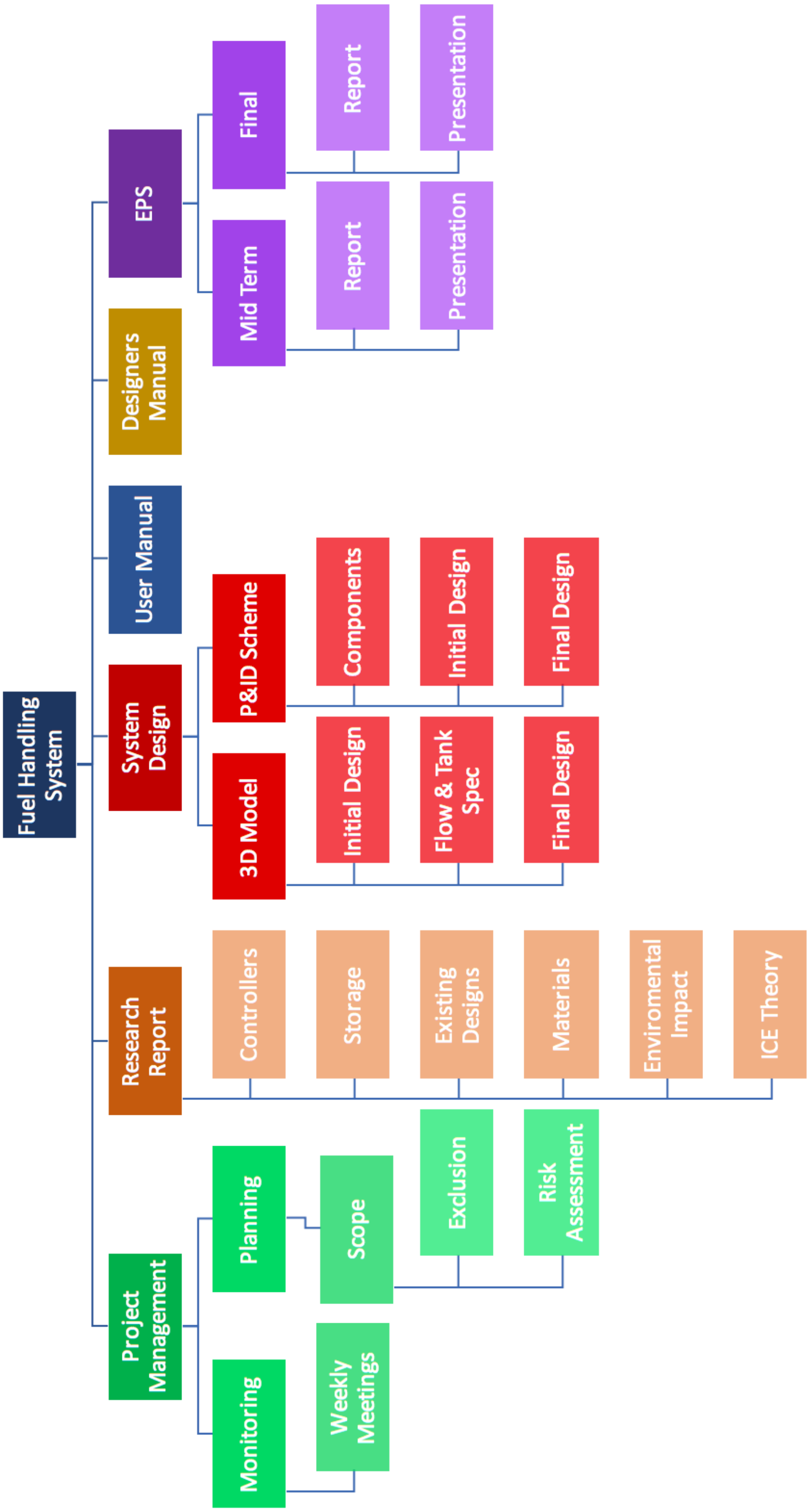
13 Appendices

13.1 Appendix 1 – Responsibility Assignment Matrix

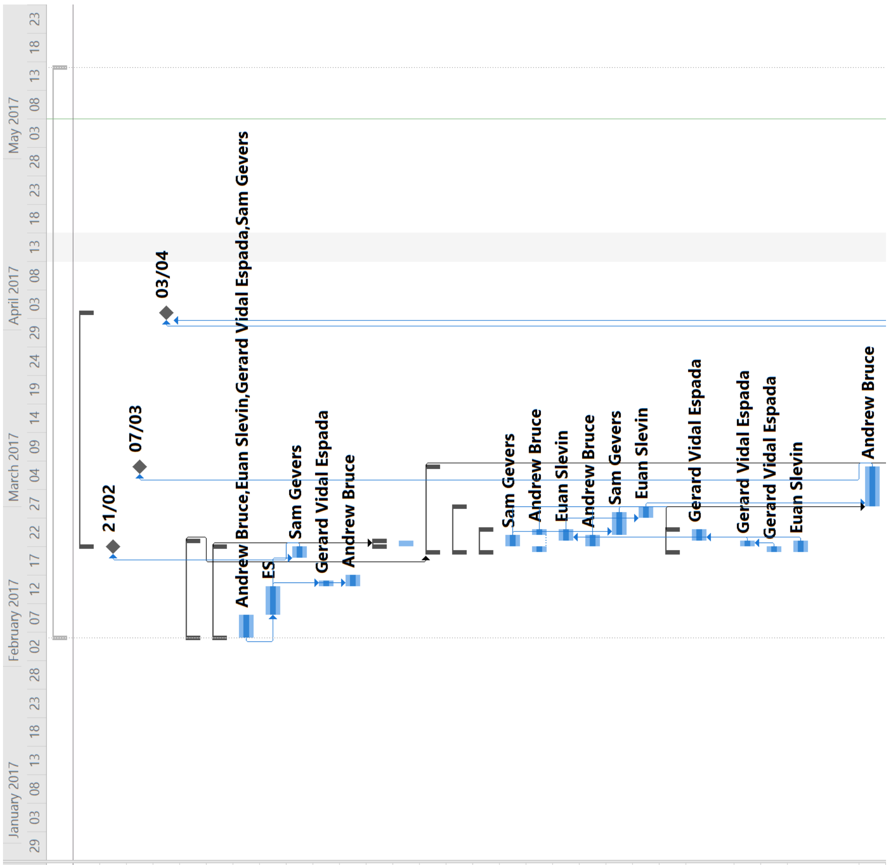
Task	WBS Code	Euan Slevin	Gerard Vidal	Sam Gevers	Andrew Bruce
Project Management	2				
Planning	2.1				
Lectures	2.1.1	I	I	I	I
Project Planning	2.1.2	A	I	I	I
Scope	2.1.3	R	I	A	I
Exclusions	2.1.4	I	A	I	I
Risk Analysis	2.1.5			R	A
Monitoring	2.2				
Weekly Meetings	2.2.2	A	P	I	I
Research Report	3				
Research	3.1				
Controllers	3.1.1				
Actuators	3.1.1.1			A	I
Sensors	3.1.1.2			I	A
LNG Storage	3.1.2	A	R	R	R
Existing Designs	3.1.3	R	R	R	A
Regassification	3.1.4	R	R	A	R
Materials	3.1.5	A			I
Enviromental Impact	3.1.6		A		
Climate Impact	3.1.6.1		A		
LNG vs Other Fuels	3.1.6.2		A		
LNG Biproducts	3.1.6.3		A		
Internal Combustion Theory	3.1.7	A			R
Write Report	3.2	P	P	P	A
System Design	4				
3D Model	4.1				
Initial Design	4.1.1	A	P		
Tank Specification	4.1.2	P	A		I
LNG Flow Calculations	4.1.3	A	P	I	
Final Design	4.1.4	P	A		
P&ID Scheme	4.2				
Initial Design	4.2.1			A	P
Component Selection	4.2.2			P	A
Material Selection	4.2.3	I	I	P	A
Final Design	4.2.4			A	P
User Manual	5	R	R	A	P
Designers Manual	6	R	R	P	A
EPS	7				
Mid Term	7.1				
Report	7.1.1	I	I	I	A
Presentation	7.1.2	I	A	I	I
Final	7.2				
Report	7.2.1	A	I	I	I
Presentation	7.2.2	I	I	A	I

13.2 Appendix 2 – Work Breakdown Structure

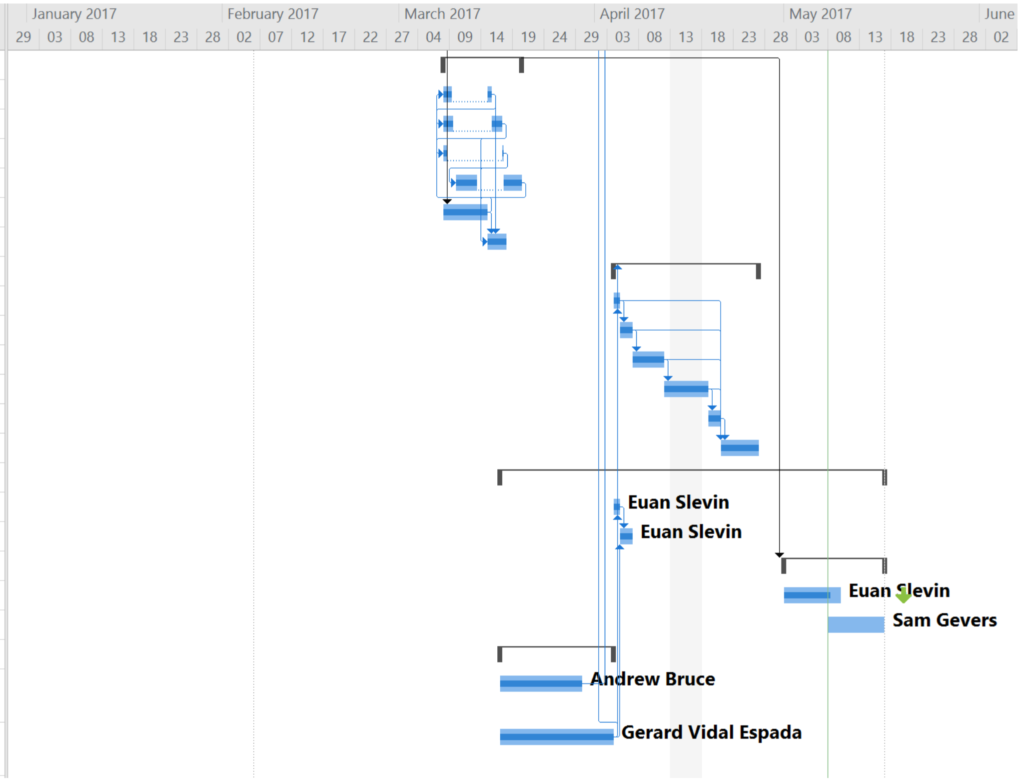


13.3 Appendix 3 – Gantt Chart

	Task Mode	Task Name	Duration	Start	Finish
0		**Fuel Handling System**	**69 days?**	**Mon 06 Feb**	**Tue 16 May**
1		**Milestones**	**29 days**	**Tue 21 Feb**	**Mon 03 Apr**
2		Client Needs	0 days	Tue 21 Feb	Tue 21 Feb
3		Research Report	0 days	Tue 07 Mar	Tue 07 Mar
4		Mid Term Report	0 days	Mon 03 Apr	Mon 03 Apr
5		**Project Management**	**13 days?**	**Mon 06 Feb**	**Wed 22 Feb**
6		**Planning**	**12 days**	**Mon 06 Feb**	**Tue 21 Feb**
7		Lectures	4 days	Mon 06 Feb	Thu 09 Feb
8		Project Planning	3 days	Fri 10 Feb	Tue 14 Feb
9		Scope	2 days	Mon 20 Feb	Tue 21 Feb
10		Exclusions	1 day	Wed 15 Feb	Wed 15 Feb
11		Risk Analysis	2 days	Wed 15 Feb	Thu 16 Feb
12		**Monitoring**	**1 day?**	**Wed 22 Feb**	**Wed 22 Feb**
13		Weekly Meetings	1 day?	Wed 22 Feb	Wed 22 Feb
14		**Research Report**	**11 days**	**Tue 21 Feb**	**Tue 07 Mar**
15		**Research**	**6 days**	**Tue 21 Feb**	**Tue 28 Feb**
16		**Controllers**	**4 days**	**Tue 21 Feb**	**Fri 24 Feb**
17		Acctuators	2 days	Wed 22 Feb	Thu 23 Feb
18		Sensors	2 days	Tue 21 Feb	Fri 24 Feb
19		LNG Storage	2 days	Thu 23 Feb	Fri 24 Feb
20		Existing Designs	2 days	Wed 22 Feb	Thu 23 Feb
21		Regassification	2 days	Fri 24 Feb	Mon 27 Feb
22		**Materials**	2 days	Mon 27 Feb	Tue 28 Feb
23		**Enviromental Impact**	**4 days**	**Tue 21 Feb**	**Fri 24 Feb**
24		Climate Impact due to design	2 days	Thu 23 Feb	Fri 24 Feb
25		LNG VS other fuels	1 day	Wed 22 Feb	Wed 22 Feb
26		LNG Substances	1 day	Tue 21 Feb	Tue 21 Feb
27		**Internal Combustion Cycle Theory**	2 days	Tue 21 Feb	Wed 22 Feb
28		Write Report	5 days	Wed 01 Mar	Tue 07 Mar



	Task Mode	Task Name	Duration	Start	Finish
29		**System Design 1**	**8.34 days?**	**Wed 08 Mar**	**Mon 20 Mar**
30		Tank Specification	2 days	Wed 08 Mar	Wed 15 Mar
31		LNG Flow Calculations	3 days	Wed 08 Mar	Fri 17 Mar
32		P&ID Scheme	1 day?	Wed 08 Mar	Fri 17 Mar
33		Components	2 days	Fri 10 Mar	Mon 20 Mar
34		Initial Design	5 days	Wed 08 Mar	Tue 14 Mar
35		Finalised Design	3 days	Wed 15 Mar	Fri 17 Mar
36		**System Design 2**	**14 days**	**Tue 04 Apr**	**Wed 26 Apr**
37		Initial Design	1 day	Tue 04 Apr	Tue 04 Apr
38		Tank Specification	2 days	Wed 05 Apr	Thu 06 Apr
39		Flow Calculations	3 days	Fri 07 Apr	Tue 11 Apr
40		Components	2 days	Wed 12 Apr	Tue 18 Apr
41		P&ID Write Up	2 days	Wed 19 Apr	Thu 20 Apr
42		Final Design	4 days	Fri 21 Apr	Wed 26 Apr
43		**EPS**	**40 days?**	**Fri 17 Mar**	**Tue 16 May**
44		Buisness Card	1 day	Tue 04 Apr	Tue 04 Apr
45		Web Page	2 days	Wed 05 Apr	Thu 06 Apr
46		**Final**	**12 days**	**Mon 01 May**	**Tue 16 May**
47		Final Report	7 days	Mon 01 May	Tue 09 May
48		Final Presentation	7 days	Mon 08 May	Tue 16 May
49		**Mid Term**	**12 days?**	**Fri 17 Mar**	**Mon 03 Apr**
50		Write Mid Term Report	7 days?	Fri 17 Mar	Wed 29 Mar
51		Write Mid Term Presentation	10 days	Fri 17 Mar	Mon 03 Apr



13.4 Appendix 4 – Time Statements

13.4.1 Euan Slevin

Timesheet

	Date	Day	Description	Start Time	Duration	End Time
1	06/02/2017	Monday	Project Management	08:30	07:30	16:00
	07/02/2017	Tuesday	Project Management	08:30	04:00	12:30
	08/02/2017	Wednesday	Project Management	08:30	06:00	14:30
	09/02/2017	Thursday	Project Management	08:30	08:30	17:00
	10/02/2017	Friday	Microsoft Project	09:00	08:30	17:30
	11/02/2017	Saturday			00:00	
	12/02/2017	Sunday			00:00	
2	13/02/2017	Monday	Belbin Test/team building	09:00	07:00	16:00
	14/02/2017	Tuesday	Belbin Test/team building	09:00	06:30	15:30
	15/02/2017	Wednesday	Lapland		00:00	
	16/02/2017	Thursday	Lapland		00:00	
	17/02/2017	Friday	Lapland		00:00	
	18/02/2017	Saturday	Lapland		00:00	
	19/02/2017	Sunday	Lapland		00:00	
3	20/02/2017	Monday	Internal Combustion Research	12:00	05:00	17:00
	21/02/2017	Tuesday	Internal Combustion Research	08:30	08:30	17:00
	22/02/2017	Wednesday	Internal Combustion Research	08:30	08:30	17:00
	23/02/2017	Thursday	Internal Combustion Research	08:30	08:30	17:00
	24/02/2017	Friday	LNG Storage	09:00	07:30	16:30
	25/02/2017	Saturday			00:00	
	26/02/2017	Sunday			00:00	
4	27/02/2017	Monday	LNG Storage	08:00	06:00	14:00
	27/02/2017	Monday	LNG Storage	15:45	01:15	17:00
	28/02/2017	Tuesday	LNG Storage	10:20	05:40	16:00
	01/03/2017	Wednesday	Internal Combusion Write Up	09:30	06:00	15:30
	02/03/2017	Thursday	Mission and Vision & Group meetings	09:30	06:30	16:00
	03/03/2017	Friday	LNG Storage Write Up	11:30	05:30	17:00
	04/03/2017	Saturday	BOG Research	16:00	01:30	17:30
	05/03/2017	Sunday			00:00	
5	06/03/2017	Monday	ECT Coursework 1	10:00	07:00	17:00
	07/03/2017	Tuesday	ECT Coursework 1	10:00	07:00	17:00
	08/03/2017	Wednesday	Knowledge Consulation	12:00	05:00	17:00
	09/03/2017	Thursday	ECT Coursework 1	09:00	08:00	17:00
	10/03/2017	Friday	Wärtsillä Meeting - Research Report	07:30	09:30	17:00
	11/03/2017	Saturday			00:00	
	12/03/2017	Sunday			00:00	
6	13/03/2017	Monday	Mid Term Report - first draft	09:00	08:00	17:00
	14/03/2017	Tuesday	Mid Term Report - first draft	09:00	08:00	17:00
	15/03/2017	Wednesday	Mid Term Report - first draft	08:00	09:00	17:00
	16/03/2017	Thursday	Warstilla Meeting + Consolidation of knowledge	07:30	09:30	17:00
	17/03/2017	Friday	Mid Term Report - first draft		00:00	
	18/03/2017	Saturday	Mid Term Report - consolidation	10:00	06:00	16:00
	19/03/2017	Sunday			00:00	
7	20/03/2017	Monday	Mid Term Report	09:30	06:30	16:00
	21/03/2017	Tuesday	Mid Term Report	12:00	09:00	21:00
	22/03/2017	Wednesday	Mid Term Report/UK Travel	00:00	02:00	02:00
	23/03/2017	Thursday	UK - Mid term Report	11:00	06:00	17:00
	24/03/2017	Friday	UK - Mid term Report	11:00	06:00	17:00
8	27/03/2017	Monday	UK		00:00	
	28/03/2017	Tuesday	UK		00:00	
	29/03/2017	Wednesday	UK - Interview		00:00	
	30/03/2017	Thursday	UK - Mid term Report Finalisation	10:00	09:00	19:00
	31/03/2017	Friday	UK - Mid term Report/ Travel	08:00	02:00	10:00
	01/04/2017	Saturday	Mid Term Presentation	10:00	08:00	18:00
	02/04/2017	Sunday	Mid Term Presentation	10:00	04:00	14:00
9	03/04/2017	Monday	Mid Term Reports	08:00	09:00	17:00
	04/04/2017	Tuesday	Website Design	10:00	05:00	15:00
	05/04/2017	Wednesday	Website Design	10:00	05:00	15:00
	06/04/2017	Thursday	Website Design	10:00	05:30	15:30
	07/04/2017	Friday	Buisness card	12:00	02:00	14:00
	08/04/2017	Saturday	ECT Coursework 2	12:00	04:00	16:00
	09/04/2017	Sunday			00:00	
10	10/04/2017	Monday	CSR + Website Design	09:00	08:00	17:00
	11/04/2017	Tuesday	ECT Coursework 2	09:00	08:00	17:00
	12/04/2017	Wednesday	CSR+ ECT Coursework 2	08:00	09:30	17:30
	13/04/2017	Thursday	ECT Coursework 2	08:00	12:00	20:00
	14/04/2017	Friday	CSR	10:00	06:00	16:00
	15/04/2017	Saturday	CSR	12:00	07:00	19:00
	16/04/2017	Sunday			00:00	
11	17/04/2017	Monday	Mid Term to Final Report Ammendments	16:00	06:00	22:00
	18/04/2017	Tuesday	CSR	09:00	08:00	17:00
	19/04/2017	Wednesday	CSR +Group Meeting +English	08:00	11:30	19:30
	20/04/2017	Thursday	CSR + Supervisor Meeting + Flow Calculations	09:30	07:00	16:30
	21/04/2017	Friday	Fluid Dynamics	09:30	06:30	16:00
	22/04/2017	Saturday			00:00	
	23/04/2017	Sunday			00:00	
12	24/04/2017	Monday	CSR + Swedish	08:00	10:00	18:00
	25/04/2017	Tuesday	Fluid Dynamics + Group Meeting + ECT Revision + CSR Diary	09:00	11:00	20:00
	26/04/2017	Wednesday	ECT Revision	09:00	12:00	21:00
	27/04/2017	Thursday	ECT Revision	09:00	09:00	18:00
	28/04/2017	Friday	Exam + Project work	08:00	08:00	16:00
	29/04/2017	Saturday			00:00	
	30/04/2017	Sunday	CSR Diary + English	17:00	06:00	23:00
13	01/05/2017	Monday	Project work	12:00	04:00	16:00
	02/05/2017	Tuesday	Feasability of N2 finishing, Final Repo	09:00	07:00	16:00
	03/05/2017	Wednesday	Final Report First Draft	09:00	07:00	16:00
	04/05/2017	Thursday	N2 Feasibility	09:00	08:30	17:30
	05/05/2017	Friday	Final Report First Draft	11:00	05:00	16:00
	06/05/2017	Saturday	Final Report First Draft	14:00	06:00	20:00
	07/05/2017	Sunday	Final Report First Draft	12:00	06:00	18:00
14	08/05/2017	Monday	Final Report First Draft	09:00	11:30	20:30
	09/05/2017	Tuesday	Final Report First Draft & Video	09:00	07:30	16:30
	10/05/2017	Wednesday	Final Report Ammended Draft & Vide	09:00	12:00	21:00
	11/05/2017	Thursday	Second/Final Draft &Video	09:00	12:00	21:00
	12/05/2017	Friday	Report Submission and Presentation	09:00	05:00	14:00
	13/05/2017	Saturday	Presentation		00:00	
	14/05/2017	Sunday	Presentation		00:00	
15	15/05/2017	Monday	Presentation		00:00	
	16/05/2017	Tuesday	Final Presentation		00:00	

Week 1	34.5
Week 2	13.50
Week 3	38.00
Week 4	32.42
Week 5	36.50
Week 6	40.50
Week 7	29.50
Week 8	23.00
Week 9	30.50
Week 10	50.50
Week 11	39.00
Week 12	56.00
Week 13	43.50
Week 14	48.00
Week 15	0.00
Total	**515**
Average	36.8

13.4.2 Gerard Vidal Espada

Timesheet

Date	Day	Description	Start Time	Duration	End Time
06/02/2017	lunes	Project Management	08:30	07:30	16:00
07/02/2017	martes	Project Management	08:30	04:00	12:30
08/02/2017	miércoles	Project Management	08:30	06:00	14:30
09/02/2017	jueves	Project Management	08:30	07:30	16:00
10/02/2017	viernes	Microsoft Project	09:00	08:30	17:30
11/02/2017	sábado			0	
12/02/2017	domingo			0	
13/02/2017	lunes	Team building + Microsoft Proje	09:00	09:00	18:00
14/02/2017	martes	Team building + English + Belvin test	09:00	07:00	16:00
15/02/2017	miércoles	Belvin test	10:00	06:00	16:00
16/02/2017	jueves	General research LNG + English	11:00	05:00	16:00
17/02/2017	viernes	General research LNG	09:00	08:00	17:00
18/02/2017	sábado			0	
19/02/2017	domingo			0	
20/02/2017	lunes	Enviroment impact LNG	09:00	09:00	18:00
21/02/2017	martes	Enviroment impact LNG	10:00	07:00	17:00
22/02/2017	miércoles	Enviroment impact LNG + English	09:00	07:30	16:30
23/02/2017	jueves	LNG composition + English	10:00	07:00	17:00
24/02/2017	viernes	LNG composition	10:00	06:00	16:00
25/02/2017	sábado			0	
26/02/2017	domingo			0	
27/02/2017	lunes	LNG normatives +Security terms	10:00	08:00	18:00
28/02/2017	martes	LNG vs Other fuels	09:00	07:00	16:00
01/03/2017	miércoles	LNG vs Other fuels	09:30	07:00	16:30
02/03/2017	jueves	LNG vs Other fuels	11:00	06:00	17:00
03/03/2017	viernes	LNG vs Other fuels	10:00	06:00	16:00
04/03/2017	sábado			0	
05/03/2017	domingo			0	
06/03/2017	lunes	Report enviroment impact + BOG research	09:00	09:00	18:00
07/03/2017	martes	Leadership + Report enviroment impact + BOG research	10:00	08:00	18:00
08/03/2017	miércoles	Leadership + English +BOG research	09:00	07:30	16:30
09/03/2017	jueves	BOG research	10:00	05:00	15:00
10/03/2017	viernes	Wärtsillä Meeting - Research Report	08:00	07:00	15:00
11/03/2017	sábado			0	
12/03/2017	domingo			0	
13/03/2017	lunes	Leadership P&ID research	09:00	09:00	18:00
14/03/2017	martes	P&ID research	10:00	07:00	17:00
15/03/2017	miércoles	P&ID definition	09:00	07:30	16:30
16/03/2017	jueves	Warstilla Meeting + Consolidation of knowledge	07:00	08:00	15:00
17/03/2017	viernes	Firsts drafts Logo + name team	10:00	06:00	16:00
18/03/2017	sábado			0	
19/03/2017	domingo			0	
20/03/2017	lunes	Firsts drafts of the logo + P&ID	10:00	08:00	18:00
21/03/2017	martes	Final Logo+ P&ID report	09:00	07:00	16:00
22/03/2017	miércoles	Learning Adove ilustrator + Final logo	09:30	07:00	16:30
23/03/2017	jueves	Learning Adove ilustrator + Final logo	11:00	06:00	17:00
24/03/2017	viernes	P&ID report	10:00	06:00	16:00
25/03/2017	sábado			0	
26/03/2017	domingo	Pirates of the baltic sea		0	
27/03/2017	lunes	Pirates of the baltic sea		00:00	
28/03/2017	martes	Pirates of the baltic sea		00:00	
29/03/2017	miércoles	Tank calculations	12:00	04:00	16:00
30/03/2017	jueves	Corrections midterm report	09:00	06:00	15:00
31/03/2017	viernes	Modification of the logo + corrections mid term report	09:00	08:00	17:00
01/04/2017	sábado	Mid term presentation		0	
02/04/2017	domingo	Mid term presentation		0	
03/04/2017	lunes	Mid term presentation	08:00	10:00	18:00
04/04/2017	martes	General research of vehicles with LNG	11:00	06:00	17:00
05/04/2017	miércoles	Trucks with LNG	09:30	07:00	16:30
06/04/2017	jueves	Trucks with LNG	11:00	06:00	17:00
07/04/2017	viernes	Real parts of the system	10:00	06:00	16:00
08/04/2017	sábado			0	
09/04/2017	domingo			0	
10/04/2017	lunes	Real parts of the system	09:00	09:00	18:00
11/04/2017	martes	Leadership report	10:00	07:00	17:00
12/04/2017	miércoles	Leadership report	09:00	07:30	16:30
13/04/2017	jueves	Leadership report	10:00	08:00	18:00
42839	viernes			0	
15/04/2017	sábado	Easter holiday		0	
16/04/2017	domingo			0	
42842	lunes			0	
18/04/2017	martes	Leadership presentation	10:00	07:00	17:00
19/04/2017	miércoles	Leadership presenations	09:00	07:30	16:30
20/04/2017	jueves	Swedish study	07:00	08:00	15:00
21/04/2017	viernes	Leadership presentations + Swedish study	10:00	06:00	16:00
22/04/2017	sábado			0	
23/04/2017	domingo			0	
24/04/2017	lunes	Swedish exam	09:00	09:00	18:00
25/04/2017	martes	Detail research P&ID valves	10:00	08:00	18:00
26/04/2017	miércoles	Detail research P&ID valves	10:00	08:30	18:30
27/04/2017	jueves	Detail research P&ID valves	10:00	05:00	15:00
28/04/2017	viernes	Russia trip		00:00	
29/04/2017	sábado	Russia trip		0	
30/04/2017	domingo	Russia trip		0	
01/05/2017	lunes	Russia trip		00:00	
02/05/2017	martes	Russia trip		00:00	
03/05/2017	miércoles	Russia trip		00:00	
04/05/2017	jueves	Russia trip		00:00	
05/05/2017	viernes	Logo report	11:00	07:00	18:00
06/05/2017	sábado			0	
07/05/2017	domingo			0	
08/05/2017	lunes	Logo report+ Valves for the system	09:00	09:00	18:00
09/05/2017	martes	Datasheets	10:00	08:00	18:00
10/05/2017	miércoles	Datasheets	09:00	09:30	18:30
11/05/2017	jueves	Datasheets	10:00	05:00	15:00
12/05/2017	viernes	Video + final corrections	12:00	08:00	20:00
13/05/2017	sábado	Presentation		0	
14/05/2017	domingo	Presentation		0	
15/05/2017	lunes	Presentation		00:00	
16/05/2017	martes	Final Presentation		00:00	
17/05/2017	miércoles			00:00	
18/05/2017	jueves			00:00	
19/05/2017	viernes			00:00	

13.4.3 Sam Gevers

Timesheet

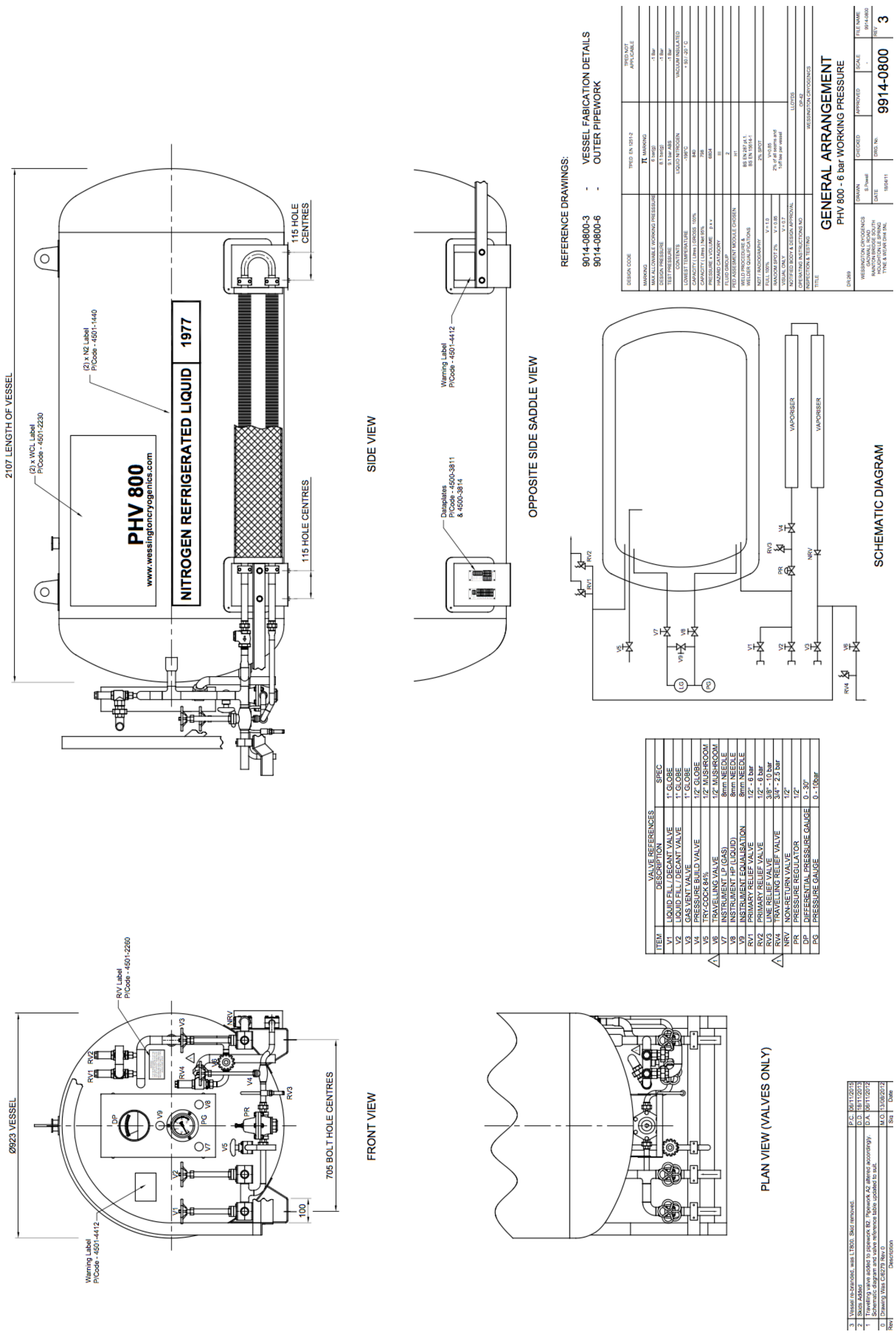
Week	Date	Day	Description	Start Time	Duration	End Time
1	06/02/2017	Monday	Project Management	08:30	07:30	16:00
	07/02/2017	Tuesday	Project Management	08:30	04:00	12:30
	08/02/2017	Wednesday	Project Management	08:30	06:00	14:30
	09/02/2017	Thursday	Project Management	08:30	08:30	17:00
	10/02/2017	Friday	Microsoft Project	09:00	08:30	17:30
	11/02/2017	Saturday				
	12/02/2017	Sunday				
2	13/02/2017	Monday	Microsoft Project + Teambuilding	09:00	07:00	16:00
	14/02/2017	Tuesday	Microsoft Project + Teambuilding	09:00	07:00	16:00
	15/02/2017	Wednesday	Scope	09:00	07:00	16:00
	16/02/2017	Thursday	Scope	10:00	07:00	17:00
	17/02/2017	Friday	Scope	09:00	07:00	16:00
	18/02/2017	Saturday				
	19/02/2017	Sunday				
3	20/02/2017	Monday	Scope	10:00	07:15	17:15
	21/02/2017	Tuesday	Belbin + write up	09:00	07:00	16:00
	22/02/2017	Wednesday	Research actuators	09:00	07:00	16:00
	23/02/2017	Thursday	Research actuators	10:00	06:00	16:00
	24/02/2017	Friday	Research actuators	09:00	07:00	16:00
	25/02/2017	Saturday				
	26/02/2017	Sunday				
4	27/02/2017	Monday	Research actuators	09:00	08:15	17:15
	28/02/2017	Tuesday	Actuators Write Up	10:00	07:00	17:00
	01/03/2017	Wednesday	Actuators Write Up	09:00	07:00	16:00
	02/03/2017	Thursday	Research regasification + Meeting Roger	10:00	07:00	17:00
	03/03/2017	Friday	Regasification	09:00	07:00	16:00
	04/03/2017	Saturday				
	05/03/2017	Sunday				
5	06/03/2017	Monday	CSR + Regasification	09:00	08:15	17:15
	07/03/2017	Tuesday	CSR + Regasification	09:00	07:00	16:00
	08/03/2017	Wednesday	Work home uni	09:00	08:00	17:00
	09/03/2017	Thursday	Work home uni	09:00	08:00	17:00
	10/03/2017	Friday	Wärtsillä Meeting - Research Report	09:00	07:00	16:00
	11/03/2017	Saturday				
	12/03/2017	Sunday				
6	13/03/2017	Monday	CSR + Research report	09:00	08:15	17:15
	14/03/2017	Tuesday	CSR + Research report	08:00	08:00	16:00
	15/03/2017	Wednesday	Research report	09:00	07:00	16:00
	16/03/2017	Thursday	Warstilla Meeting + Consolidation of knowledge	10:00	07:00	17:00
	17/03/2017	Friday	Mid Term Report - first draft	09:00	07:00	16:00
	18/03/2017	Saturday	Visit Tampere			
	19/03/2017	Sunday	Visit Tampere			
7	20/03/2017	Monday	Regasification	09:00	08:15	17:15
	21/03/2017	Tuesday	Regasification	09:00	07:00	16:00
	22/03/2017	Wednesday	Regasification write up	09:00	07:00	16:00
	23/03/2017	Thursday	Conclusion	09:00	07:00	16:00
	24/03/2017	Friday	Helsinki			
	25/03/2017	Saturday	Helsinki			
	26/03/2017	Sunday	Pirates of the Baltic sea			
8	27/03/2017	Monday	Pirates of the Baltic sea			
	28/03/2017	Tuesday	Pirates of the Baltic sea			
	29/03/2017	Wednesday	CSR + midterm report	10:00	11:00	21:00
	30/03/2017	Thursday	Midterm Report	09:00	15:00	24:00:00
	31/03/2017	Friday	Midterm Report	00:00	02:30	02:30
	01/04/2017	Saturday	Midterm Presentation	12:00	06:00	18:00
	02/04/2017	Sunday	Midterm Presentation	10:00	08:00	18:00
9	03/04/2017	Monday	Midterm presentations all teams	08:00	09:15	17:15
	04/04/2017	Tuesday	Resting day		00:00	
	05/04/2017	Wednesday	Future planning	13:00	04:00	17:00
	06/04/2017	Thursday	Heat exchangers	09:00	07:00	16:00
	07/04/2017	Friday	Heat exchangers + Girlfriend arrives	08:00	05:00	13:00
	08/04/2017	Saturday			00:00	
	09/04/2017	Sunday			00:00	
10	10/04/2017	Monday	CSR + Heat exchangers	08:00	09:15	17:15
	11/04/2017	Tuesday	Ill		00:00	
	12/04/2017	Wednesday	Ill		00:00	
	13/04/2017	Thursday	Easter			
	14/04/2017	Friday	Easter			
	15/04/2017	Saturday	Easter			
	16/04/2017	Sunday	Easter + CSR	14:00	04:00	18:00
11	17/04/2017	Monday	Easter + CSR	15:00	05:00	20:00
	18/04/2017	Tuesday	CSR	09:00	06:00	15:00
	19/04/2017	Wednesday	CSR presentation + Girlfriend leaves	08:00	04:00	12:00
	20/04/2017	Thursday	Research Heat exchangers	09:00	08:00	17:00
	21/04/2017	Friday	Research Heat exchangers	09:00	08:00	17:00
	22/04/2017	Saturday				
	23/04/2017	Sunday				
12	24/04/2017	Monday	CSR + Research Heat exchangers + Exam Swedish	10:00	06:00	16:00
	25/04/2017	Tuesday	Research Heat exchangers	09:00	07:00	16:00
	26/04/2017	Wednesday	Research Heat exchangers	09:00	08:00	17:00
	27/04/2017	Thursday	Research Heat exchangers + Parents arrive	10:00	03:00	13:00
	28/04/2017	Friday	Research Heat exchangers	09:30	03:30	13:00
	29/04/2017	Saturday	Parents + Helsinki			
	30/04/2017	Sunday	Parents + Helsinki			
	01/05/2017	Monday	Drive back from Helsinki			
	02/05/2017	Tuesday	Calculations of heat transfer	09:00	07:00	16:00
	03/05/2017	Wednesday	Calculations of heat transfer	09:00	07:00	16:00
	04/05/2017	Thursday	Heat exchanger	10:00	07:00	17:00
	05/05/2017	Friday	Heat exchanger feasibility	10:00	07:00	17:00
	06/05/2017	Saturday				
	07/05/2017	Sunday				
	08/05/2017	Monday	Heat exchanger feasibility	09:30	07:30	17:00
	09/05/2017	Tuesday	Heat exchanger + final report	10:00	08:00	18:00
	10/05/2017	Wednesday	Final report	09:00	11:00	20:00
	11/05/2017	Thursday	Final report + video	09:00	12:00	21:00
	12/05/2017	Friday	Final Presentation	09:00	05:00	14:00
	13/05/2017	Saturday			00:00	
	14/05/2017	Sunday			00:00	
	15/05/2017	Monday			00:00	
	16/05/2017	Tuesday	Final Presentations		00:00	

13.4.4 Andrew Bruce

Timesheet

Date	Day	Description	Start Time	Duration	End Time
06/02/2017	Monday	Project Management	08:30	07:30	16:00
07/02/2017	Tuesday	Project Management	08:30	04:00	12:30
08/02/2017	Wednesday	Project Management	08:30	06:00	14:30
09/02/2017	Thursday	Project Management	08:30	08:30	17:00
10/02/2017	Friday	Microsoft Project	09:00	08:30	17:30
11/02/2017	Saturday			00:00	
12/02/2017	Sunday			00:00	
13/02/2017	Monday	Belbin + Team buildin	09:00	07:00	16:00
14/02/2017	Tuesday	Belbin + Team buildin	09:00	06:30	15:30
15/02/2017	Wednesday	Belbin + Team buildin	09:00	08:00	17:00
16/02/2017	Thursday	Risk Analysis	09:00	08:00	17:00
17/02/2017	Friday	Risk Analysis	09:00	08:00	17:00
18/02/2017	Saturday	Weekend		00:00	
19/02/2017	Sunday	Weekend		00:00	
20/02/2017	Monday	Risk Analysis	09:00	08:00	17:00
21/02/2017	Tuesday	Risk Analysis	09:00	08:00	17:00
22/02/2017	Wednesday	Risk Analysis	09:00	08:00	17:00
23/02/2017	Thursday	Risk Analysis	09:00	08:00	17:00
24/02/2017	Friday	Risk Analysis	09:00	08:00	17:00
25/02/2017	Saturday	Weekend		00:00	
26/02/2017	Sunday	Weekend		00:00	
27/02/2017	Monday	Past company designs	09:00	08:00	17:00
28/02/2017	Tuesday	Past company designs	09:00	07:00	17:00
01/03/2017	Wednesday	Past company designs	10:00	07:00	17:00
02/03/2017	Thursday	Past company designs	10:00	17:00	17:00
03/03/2017	Friday	Past company designs	10:00	07:00	17:00
04/03/2017	Saturday				
05/03/2017	Sunday				
06/03/2017	Monday	ECT Coursework	09:00	10:00	19:00
07/03/2017	Tuesday	ECT Coursework	09:00	07:00	17:00
08/03/2017	Wednesday	ECT Coursework	10:00	07:00	17:00
09/03/2017	Thursday	Past company designs	10:00	07:00	17:00
10/03/2017	Friday	Wartsila Meeting	10:00	17:00	17:00
11/03/2017	Saturday				
12/03/2017	Sunday				
13/03/2017	Monday	Sensors	09:00	08:00	17:00
14/03/2017	Tuesday	Sensors	09:00	07:00	17:00
15/03/2017	Wednesday	Sensors	10:00	07:00	17:00
16/03/2017	Thursday	Sensors	10:00	07:00	17:00
17/03/2017	Friday	Sensors	10:00	17:00	17:00
18/03/2017	Saturday				
19/03/2017	Sunday				
20/03/2017	Monday	Research Report	09:00	08:00	17:00
21/03/2017	Tuesday	Research Report	09:00	07:00	17:00
22/03/2017	Wednesday	Research Report	10:00	08:00	17:00
23/03/2017	Thursday	Research Report	09:00	07:00	17:00
24/03/2017	Friday	Research Report	10:00	17:00	17:00
25/03/2017	Saturday	Pirates of The Baltic Sea			
26/03/2017	Sunday	Pirates of The Baltic Sea			
27/03/2017	Monday	Pirates of The Baltic Sea			
28/03/2017	Tuesday	Pirates of The Baltic Sea			
29/03/2017	Wednesday	Mid term report	10:00	07:00	17:00
30/03/2017	Thursday	Mid term report	10:00	13:30	01:30
31/03/2017	Friday	Mid term report	10:00	12:00	22:00
01/04/2017	Saturday	Mid term presentation	10:00	07:00	17:00
02/04/2017	Sunday	Mid term presentation	10:00	07:00	17:00
03/04/2017	Monday	Mid term presentatio	10:00	07:00	17:00
04/04/2017	Tuesday	Change in scope	10:00	07:00	17:00
05/04/2017	Wednesday	Team meetings	10:00	07:00	17:00
06/04/2017	Thursday	Past company designs	10:00	07:00	17:00
07/04/2017	Friday	Valves	10:00	07:00	17:00
08/04/2017	Saturday				
09/04/2017	Sunday				
10/04/2017	Monday	CSR + Project	10:00	07:00	17:00
11/04/2017	Tuesday	Valves	10:00	07:00	17:00
12/04/2017	Wednesday	St Petersburg ESN + ECT Coursework 2			
13/04/2017	Thursday	St Petersburg ESN + ECT Coursework 2			
14/04/2017	Friday	St Petersburg ESN + ECT Coursework 2			
15/04/2017	Saturday	St Petersburg ESN			
16/04/2017	Sunday	St Petersburg ESN			
17/04/2017	Monday	St Petersburg ESN			
18/04/2017	Tuesday	Valves	09:00	08:00	17:00
19/04/2017	Wednesday	Valves	09:00	08:00	17:00
20/04/2017	Thursday	Valves	09:00	08:00	17:00
21/04/2017	Friday	Valves	09:00	08:00	17:00
22/04/2017	Saturday	Swedish studying			
23/04/2017	Sunday	CSR presentation			
24/04/2017	Monday	Swedish exam and CS	09:00	08:00	17:00
25/04/2017	Tuesday	Trapping	09:00	08:00	17:00
26/04/2017	Wednesday	Fuel tank sensors	10:00	07:00	17:00
27/04/2017	Thursday	Fuel tank sensors	10:00	07:00	17:00
28/04/2017	Friday	ECT Examand project	09:00	08:00	17:00
29/04/2017	Saturday				
30/04/2017	Sunday				
01/05/2017	Monday	P&ID component tabl	09:00	08:00	17:00
02/05/2017	Tuesday	Conclusions	09:00	08:00	17:00
03/05/2017	Wednesday	Handover document	10:00	07:00	17:00
04/05/2017	Thursday	Handover document	10:00	07:00	17:00
05/05/2017	Friday	Handover document	10:00	07:00	17:00
06/05/2017	Saturday	Brothers visit			
07/05/2017	Sunday	Brothers visit			
08/05/2017	Monday	Final report	09:00	08:00	17:00
09/05/2017	Tuesday	Final report	09:00	08:00	17:00
10/05/2017	Wednesday	Final report	10:00	07:00	17:00
11/05/2017	Thursday	Video and finalisation	10:00	07:00	17:00
12/05/2017	Friday	Final report	10:00	07:00	17:00
13/05/2017	Saturday	Presentation preparation			
14/05/2017	Sunday	Presentation preparation			
15/05/2017	Monday	Presentation preparat	10:00	07:00	17:00
16/05/2017	Tuesday	Presentation Day	08:00	09:00	17:00
17/05/2017	Wednesday	Freedom			
18/05/2017	Thursday	Freedom			
19/05/2017	Friday	Freedom			

13.5 Appendix 5 – PHV-800 Technical Drawings



13.6 Appendix 6 – Parts List & Budget LNG Design

LNG Feasibility

Part	Manufacturer	Cost Per piece	Cost per piece (€)	Number of pieces	Total Cost	No. Required	Ideal Cost
PHV-600	Wessignton Cryogenics		Awaiting price	1			
Flat Plate Heat Exchanger with Ce B3-014b	ZEC Trade Industry	$ 19.00	€ 17.29	20	€ 345.80	1	€ 17.29
2016 Hot Sales gas LNG/CNG Fuel pressure relif valve	Tefalok	$ 100.00	€ 91.00	10	€ 910.00	2	€ 182.00
316 Stainless Steel Quick Closing Check Valve	Naco	$ 13.00	€ 11.83	2	€ 23.66	2	€ 23.66
DL-06A1 Brass Cryogenic Excess Flow Valve for LNG Vehicle	Danyang Feilum Gas Valve co. Ltd	$ 32.00	€ 29.12	100	€ 2,912.00	1	€ 29.12
Manual Globe valve shut-off valve LNG	Mayflower Precision Machining	$ 25.00	€ 22.75	100	€ 2,275.00	2	€ 45.50
DJK-25A Stainless Steel Filling Port		$ 120.00	€ 109.20	1	€ 109.20	1	€ 109.20
LNG Normal open solenoid Valve	Yongjia Welldone machine co.		Awaiting price	2		2	
Rosemount 5900S	Rosemount		Awaiting price				
Rosemount 566	Rosemount		Awaiting price				
Rosemount 3051S	Rosemount		Awaiting price				
				Total	€ 6,575.66		€ 406.77

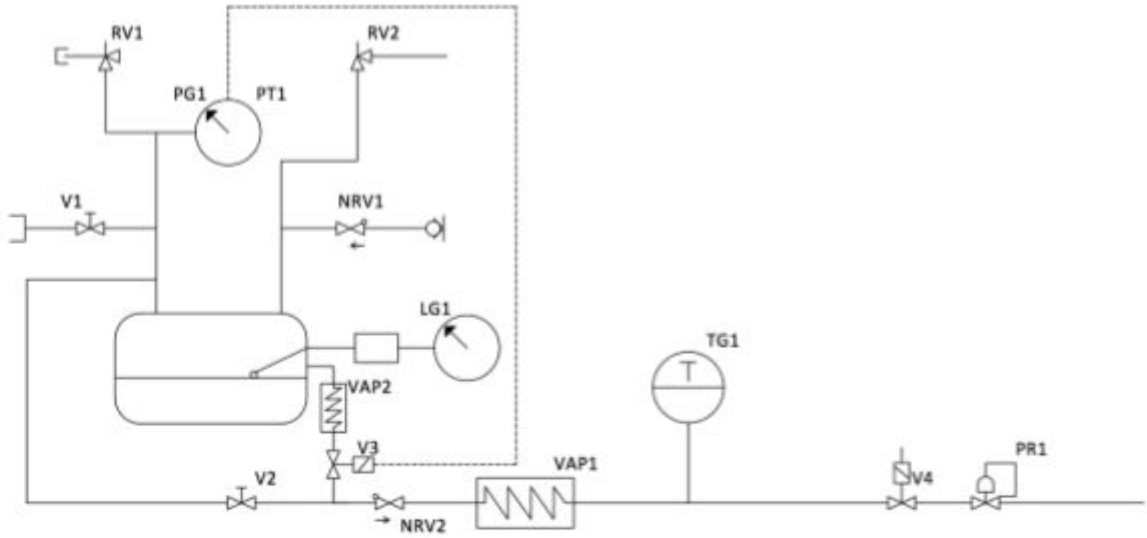
13.7 Appendix 7 - Parts List & Budget LN_2 Design

Nitrogen Feasibility							
Part	**Manufacturer**	**Cost per piece**	**Cost per piece (€)**	**No. of Pieces**	**Total Cost**	**No. Required**	**Ideal Cost**
TPV 300	Wessignton Cryogenics	£ 4,795.00	€ 5,658.10	1	€ 5,658.10	1	€ 5,658.10
Flat Plate Heat Exchanger with Ce B3-014b	ZEC Trade Industry	$ 19.00	€ 17.29	20	€ 345.80	1	€ 17.29
2016 Hot Sales gas LNG/CNG Fuel pressure relif valve	Tefalok	$ 100.00	€ 91.00	10	€ 910.00	2	€ 182.00
316 Stainless Steel Quick Closing Check Valve	Naco	$ 13.00	€ 11.83	2	€ 23.66	2	€ 23.66
DL-06A1 Brass Cryogenic Excess Flow Valve for LNG Vehicle	Danyang Feilum Gas Valve co. Ltd	$ 32.00	€ 29.12	100	€ 2,912.00	1	€ 29.12
Manual Globe valve shut-off valve LNG	Mayflower Precision Machining	$ 50.00	€ 45.50	100	€ 4,550.00	2	€ 91.00
DJK-25A Stainless Steel Filling Port		$ 120.00	€ 109.20	1	€ 109.20	1	€ 109.20
LNG Normal open solenoid Valve	Yongjia Welldone machine co.		Awaiting Price	2		2	
Rosemount 5900S	Rosemount		Awaiting Price				
Rosemount 566	Rosemount		Awaiting Price				
Rosemount 3051S	Rosemount		Awaiting Price				
				Total	€ 14,508.76		€ 6,110.37

13.8 Appendix 8 - Hand-Over Documentation

P&ID Scheme

The final P&ID scheme that the group settled upon is displayed below with an attached component description sheet. It can also be found as Figure 6.3.1: Final P&ID Design in the final report.



Component Code	Component	Description of component
RV1	Secondary release valve	Set to 1.5 times the maximum allowable working pressure, prevents failure if the primary relief valve fails.
V1	Vapour Shut off valve	Manually operated fuel shut off valve
PG1	Tank Pressure Gauge	Tests the tank pressure
PT1	Tank temperature gauge	Tests the tanks temperature at multiple points
RV2	Primary release valve	Vents gas if it exceeds the maximum allowable working pressure of the tank
NRV1	Fill Check Valve	Prevents back flow through the fuel line. Relies on tank pressure to seal.
LG1	Level Gauge	Provides a reading of the fuel level within the tank.

V2	Vapour Shut off valve	Manually operated fuel shut off valve
V3	Vapour Shut off valve	Solenoid operated fuel shut off valve
VAP2	Pressure Build Heat Exchanger	Builds the pressure of the LNG within the tank.
NRV2	Fill check valve	Prevents back flow through the fuel line. Relies on tank pressure to seal.
VAP1	Heat Exchanger	Transforms the NG in a liquid state to gaseous for combustion.
TG1	Temperature Gauge	Tests the temperature of the NG after it leaves the heat exchanger.
V4	Vapour Shut off valve	Solenoid operated fuel shut off valve
PR1	Pressure Relief Valve	Releases excess pressure before the fuel enters the engine

Tank Selection

A bullet tank was selected to contain the LNG. It is a vacuum insulated tank, i.e. a tank containing LNG sealed within the vacuum of an outer tank. As the LNG heats within the tank the pressure increases. This change in pressure can be used to propel the LNG out of the tank and into the system. It could also be removed from the system and used as fuel.

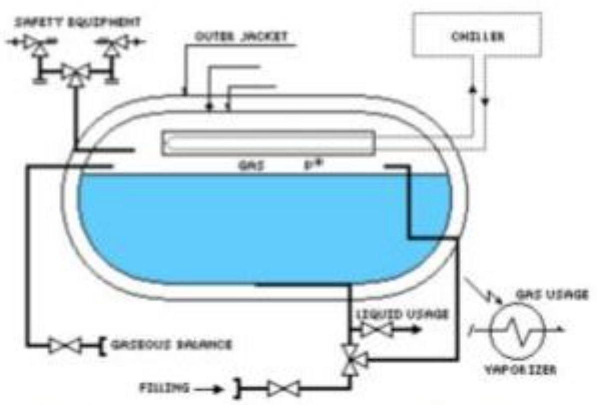


Figure 5.3.1: Vacuum insulated storage tank ("Central Welding Supply - Bulk Gases", 2017)

Budget

The preliminary budget can be found in the handover documentation folder attached, it is an excel file.

Heat Exchanger

A heat exchanger is necessary to return the LNG back to its gaseous state before combustion, this process is called regasification. The basic principle of a heat exchanger is passing two fluids within proximity of each other with the intention of transferring heat from one to the other. The heat exchanger chosen which fulfils the demands of the system is a Flat Plate Heat Exchanger with Ce B3-014b.