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"Regulatory coupling of large and small scale LNG terminals in the light of the newest European clean fuel energy strategy"

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

NOVEMBER 2014

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Abstract

This dissertation was written as a part of the MSc in ICT Systems at the International Hellenic University. Here goes a summary of the dissertation.

In the last few decades the European indigenous production of fossil fuel has been decreased and unfortunately there are not enough new sources to cover the energy needs. European Union has to find new energy sources in order to secure its energy supply. For this reason recently it has be given much attention to the imports of liquefied natural gas (LNG). EU aims to reduce by this way the dependence on pipeline gas and at the same time to diversify its natural gas sources. Also, LNG imports enhance competition which is indispensable for effective gas-market liberalization and the same time buyers have the possibility to choose their LNG supplier. Moreover, LNG is a clean fossil fuel which practically helps to reduce carbon dioxide (CO_2) emissions in a short term and to enhance EU's long term decarbonisation targets. This reduction in greenhouse gases has also to be achieved by the ship sector and heavy road transport sector. Due to all aforementioned parameters there is an increase regarding LNG regasification terminals in the EU. According to the latest news there are already 20 LNG import terminals connecting the EU with the world gas market and there are under discussion and/or construction further 32. For this reason there is an increased need of small scale LNG distribution. GLE has revealed in June 2014 the ''Small Scale LNG Map 2014-Exiting & Planned Infrastructure for Sea-Road-Waterways Transport''. In this map are represented all the operational small scale LNG infrastructures and also all these infrastructures which are under construction, or they are going to be built or what it has been announced to be built.

Taking into consideration the increased need of LNG and especially the small scale LNG infrastructures in EU, this dissertation will provide the basic information regarding the infrastructures which are needed for transforming LNG to natural gas and distributed after to the pipeline system. Moreover, it is analyzed the LNG supply chain and the ways of LNG transportation in small scale; like small LNG ships and trucks. A closer analysis is being done also to the bunkering procedure of LNG; Ship-to-Ship, Truck-to-Ship, Ship-to-Shore. Finally, attention is be given to the satellite LNG plants which are found in remote areas and cover the needs of energy supply where pipeline system is not operational.

AIKATERINI VARAGKA

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Contents

1. Introduction to LNG

The last two decades natural gas has proved the fastest growing energy source due to high conversion efficiencies in power sector and also due to low greenhouse gas emissions. For more than one century natural gas is transported safely to the final consumers through pipelines. Pipelines have served the supply and market needs of the twentieth century ideally, since all large natural gas reservoirs were found in accessible areas. This provides stability and security of energy supply as long as there are available large natural gas reservoirs. However, the last decade it has proved that there are significant quantities of natural gas in areas that are not easily accessible. These large natural gas reservoirs which are more isolated and technically more difficult to be approached have trigger the attention. A significant number of techniques have been developed in order to facilitate the exploit of natural gas. On the other hand, over the past three decades only liquefied natural gas (LNG) industry has managed to facilitate the energy needs of remote areas. Nowadays LNG is gaining more and more ground since it has diversify its supply chains and can compete equally the pipeline gas suppliers, providing security of energy supply for many consumers breaking geographical and political constraints.

Due to rapidly growing energy demand, decrease of available oil sources, the no-flaring regulations, the increase of oil prices and the imposed limits for the greenhouse gases it has appeared the request for transporting stranded gas over long distances. During the past decades many technologies have been developed in order to transport natural gas in long distances. The below figure 1 illustrates the different methods of transporting natural gas to the market. The only fully commercial and mature technologies are pipeline and LNG transportation between remote natural gas suppliers and major natural gas markets.

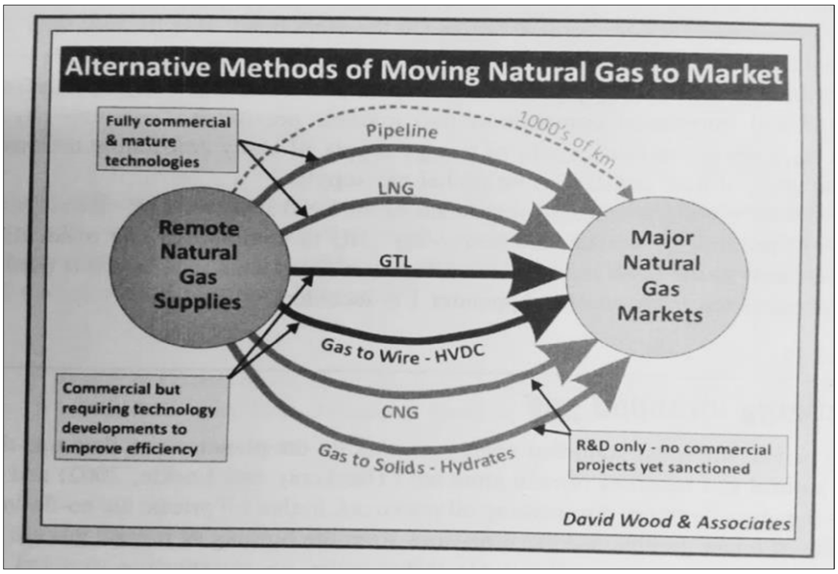

Figure 1: Technologies available to transport natural gas long distances, Chapter 1-LNG Fundamentals, Handbook of Liquefied Natural Gas, Saeid Mokhatab et al., First edition 2014.

The selection of the best fit technology has to do with the transportation distance of the natural gas. Until now 70 percent of the natural gas that is traded internationally is exported by pipeline and 30 percent is transported in the form of liquefied natural gas.

As it is shown in figure 2 the transportation of natural gas through pipelines it is recommended only for small distances approximately up to 2000 km, whilst the liquefied natural gas can be transported to areas which are found from 1000 km to 5000 km. Also, the gas field production rate (bcm / year) from liquefied natural gas is increased as long as the distance is being increased due to economic reasons.

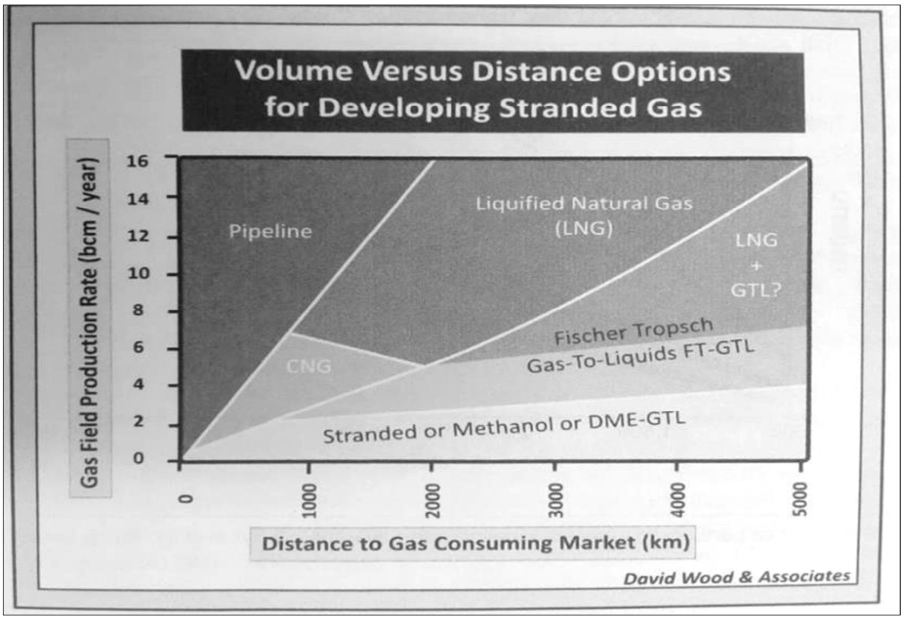

Figure 2: Production volume versus distance to market framework for gas technologies, Chapter 1-LNG Fundamentals, Handbook of Liquefied Natural Gas, Saeid Mokhatab et al., First edition 2014.

In figure 3 it is showed one diagram with the gas transportation costs. The comparison is being done between offshore pipeline, LNG, onshore low pressure pipeline and onshore high pressure pipeline. The results show that for onshore distances transportation of LNG is not recommended since it is away from economic interest. For these circumstances it is suggested to be used pipelines. LNG can be competitive for onshore transportation at the breakeven point of 2,200 miles. LNG is preferred to be used for long distances like those crossing oceans or long stretches of water since the construction costs for pipelines are very expensive. For offshore usages LNG can be competitive when the offshore pipeline is less than 700 miles. [1]

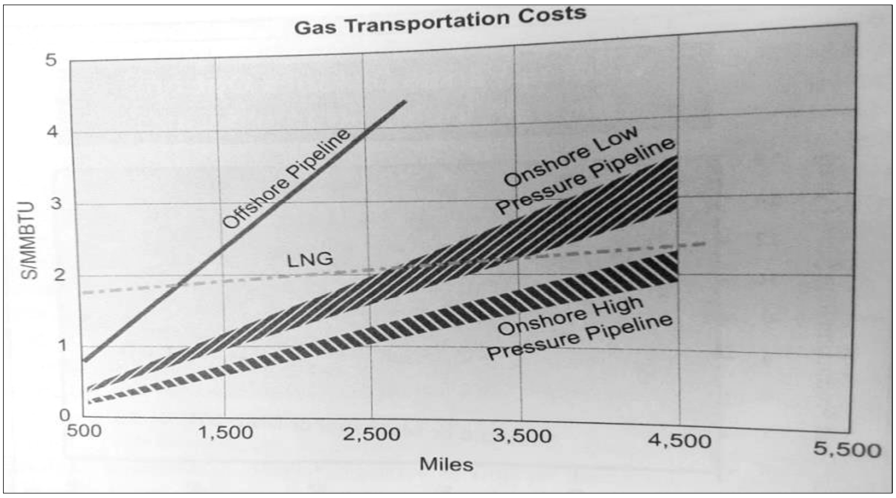

Figure 3: Comparison of the cost of transportation gas via pipeline and LNG; for 1 tcf/yr and including regasification costs, Chapter 1-LNG Fundamentals, Handbook of Liquefied Natural Gas, Saeid Mokhatab et al., First edition 2014.

1.1 Value Chain of Liquefied Natural Gas

When natural gas is cooled down to the point that becomes its condensation then it passes from gas phase to liqued phase. This point is at temperature of -162˚C and under atmospheric pressure. By cooling down the natural gas it is achieved the reduction of storage volume approximately 600 times and this makes it economically feasible for transportation especially for long distances which include also ocean voyages. The major steps for the usage of LNG include many procedures. These procedures form the LNG value chain which is consisted of the following:

- Exploration includes all the operations which are needed to extract natural gas from earth's crust and treatment of this gas in order to be used from the final consumers. The discovery of natural gas is being done most of the times when extraction companies are looking for oil reservoirs. According to the BP Statistical Review of World Energy June 2014 report the proved reserves of natural gas at the end of 2013 were 6557.8 trillion cubic feet or 185.7 trillion cubic meters. The distribution in percentage among the continents is: 43.2 in Middle East, 30.5 in Europe and Eurasia, 8.2 in Asia Pacific, 7.6 in Africa, 6.3 in North America and 4.1 in South and Central America. The production of natural gas including also the quantity of natural gas which is produced for Gas-to-Liquids transformation is 3369.9 billion cubic meters for 2013 (including data from Cedigaz). In 2013, the leading countries producing natural gas and selling it to world markets in the form of LNG were Malaysia, Australia, Algeria, Qatar, Trinidad & Tobago and Russian Federation. There are also other counties which produce and export LNG but in smaller quantities like Norway, United Arab Emirates, Nigeria, Indonesia.
- Liquefaction is the procedure where natural gas is converted to liquid for transportation purposes. Natural gas from the point of its extraction is transferred to the liquefaction power plant in order to be transformed to LNG. A very important procedure before the

transformation is to be removed all the contaminants which are found inside to the natural gas in order to be avoided the corrosion phenomena in the piping. The liquefaction process can purify the LNG almost to 100 percent. When the natural gas is cleaned then refrigerants are being used in order to cool down the feed gas. The liquefaction point is at -162˚C. By cooling down the natural gas its volume is being reduced at $1/600^{th}$ of the space required for a comparable amount of gas to be stored at room temperature and atmospheric pressure. LNG is characterized as a 'cryogenic' liquid which means that it is found in very low temperatures. LNG is a liquid with density about 45 percent the density of water. The storage of produced LNG is being done in specific cryogenic tanks. These tanks are double- walled tanks. Practically it involves the construction of a tank inside to another tank. The inner tank has to follow specific construction characteristics according to identified specifications. The materials of the inner tank include 9 percent nickel steel, aluminum and pre-stressed concrete. The outer tank is made either from carbon steel or pre-stressed concrete. Between inner and outer tanks it is installed insulated material.

- Shipping of LNG is being done with special vessels. These vessels are double-hulled in order to prevent any possible leakage or rupture in case of failure. The cryogenic conditions which have to be maintained inside to the vessels are kept constant due to insulation material which is being used. The storage conditions are at -162˚C and under atmospheric pressure. The type of LNG tankers can be: spherical, membrane design and prismatic design. In 2002 it has been recorded from Maritime Business Strategies that 52 percent of LNG ships used spherical type tanks. However, in 2011 it has been recorded from the same organization a shift towards membrane tanks; 68 percent of LNG fleet containment system followed membrane design, 30 percent spherical design and 2 percent other types. It has been foreseen that between periods of 2011 until 2016 the usage of membrane design tanks will reach 94 percent. One typical LNG carrier has capacities from 125,000 to 138,000 cubic meters (m^3) which can be correlated to 2.6-2.8 billion standard cubic feet (BCF) of natural gas. The sizes of these ships are most of the times 900 feet in length, 140 feet in width and 36 feet in water draft.
- Storage and Regasification are two main procedures which target to the receiving of transported LNG to the terminals in special cryogenic vessels and after the transformation of LNG through regasification procedure to natural gas in order to be distributed to the pipeline system or to be used directly for energy production in remote power plant. Since LNG arrives at the terminal is pumped under atmospheric pressure inside to LNG storage tanks, after is pumped under high pressure through parts of the regasification terminal causing increase of its temperature. The warm up of LNG is succeeded due to the use of heaters. The type of heaters can be either direct-heated or seawater heated or through pipes which are heated with water.

The vaporized natural gas is regulated to its pressure and after is ready to be distributed to the pipeline system.

The usage of LNG is also to serve the needs during high demand periods where there is a peak of natural gas need from system, especially in remote areas. Implementation of this procedure saves a lot of money invested in pipeline infrastructures where capacity commitments are very expensive. [2, 3]

1.2 Composition of Natural Gas

In order to understand better the process of LNG handling and transportation it is a prerequisite to be familiar with its physical and chemical properties. The knowledge of some basic characteristics of LNG ensures the safe operations and actions during an accident like a potential leakage. The properties of LNG are directly connected to the natural gas source and its processing/fractionation history. Natural gas is composed mainly from methane which is found in 82 percent of its entire composition. The rest 19 percent includes ethane, nitrogen, propane, carbon dioxide, butane and pentane. Also, it can be found small quantities of water. For the liquefaction process is demanded some components to be removed from the natural gas like water and carbon dioxide and the reason is to prevent them from forming solids when natural gas is cooled down to -162˚C. The composition of liquefied natural gas is based mainly to methane which is almost 95 percent and only 5 percent of other components like higher hydrocarbons (C2 or C4), sulfur trace or nitrogen exist as well. LNG in normal conditions is odorless, colorless, non-toxic and noncorrosive cryogenic liquid. When LNG is vaporized to natural gas it has the advantage that the generation of particle emissions and carbon dioxide emissions is very low compared to other hydrocarbon fuels. When LNG is combusted the products which are produced contain very small portion of sulfur and nitrogen oxides.

The boiling point of LNG is approximately -162˚C. The densities can vary between 430 kg/m^3 to 470 kg/m^3. For this reason LNG is spilled on water, floats on top and is being vaporized more quickly than the water. When LNG vapors come gradually in contact with the surroundings and reach temperatures of -110˚C, then the density of vapors is lighter compared to that of air and vapors become buoyant. The LNG vapors which have temperature less than -110˚C are gathered at low level areas and when they warm up they transferred to the upper parts. In case that LNG is being released inside to an enclosed space then it has the tendency to displace the surrounded air and making the area hazardous for breathing.

Vapors which are released from LNG are going to be mixed with the surrounding air and due to their temperature differentiation will be guided downwind causing a vapor cloud that may become flammable and explosive. The flammability limits are 5 and 15 percent by volume of air. The methane/air mixture outside of these limits is not flammable. When LNG is stored inside to a closed storage tank the vapor concentration is almost 100 percent methane, if LNG concentration is below the lower flammability limit it cannot be burned. For example in a well-ventilated area the LNG vapors rapidly mixture with air and dissipate to less than 5 percent concentration which is below the flammability limit. The required conditions in order to be produced an unconfined vapor cloud explosion of natural gas is not present in case of LNG facility, for this reason explosions cannot be considered as potential hazard. [1, 3]

1.3 LNG Safety

LNG sector has proved one of the most reliable areas regarding the safety records. There are several parameters which contribute to that high safety results. Firstly, it is given high importance to the safety rules and actions from the engineering phase until the construction and operation. Secondly, the physical and chemical properties of LNG are understood very well from all the parties including engineering personnel until operational staff. Thirdly, there are many standards, codes and regulations that have been developed for LNG purposes and they continue to be updated all the time. LNG is considered one of the cleanest fuels and this makes it environmentally favorable compared to other fuels. The hazards which are associated with LNG handling are ignition and fires, vapor cloud explosions (VCE), cryogenic effects like cryogenic freeze burns, embrittlement of metals and plastics, confined space hazards and chemical hazards. All these hazards have been analyzed and studied very carefully and can be well mitigated with careful actions and estimations of the hazards. Safety features are an inherent part of each LNG facility. The safety features of an LNG facility are: primary containment, secondary containment, plants safety system, LNG unloading operations, insulation standards, instrument and electrical standards, separation distances which have to be followed, safe features of LNG ships and LNG trucks. Moreover, the safe processing, storage and transportation of LNG are the essential parts for the growth and sustenance of the entire industry. LNG marine transportation industries, onshore LNG plants and onshore LNG transportation facilities follow the below paths of safe operations:

- Strictly implementation to the codes and standards designed especially for LNG operations
- Establishment of Process Safety Management (PSM) system for each one operation. The concept of this system is to establish and to follow closely the best industry practices, to adapt and use innovative measures and to obtain the best risk/reward ratio taking into consideration their budgets. The meaning of risk is defined as the probability, consequence or frequency of one hazard to happen and for this reason are taken measures which can reduce these phenomena. [1]

1.4 LNG Implications

In the last few years many concerns have been immerged in the EU energy market regarding the increased fuel prices and the security of energy supply. Temporary cutbacks in pipeline gas supply system from Russia have shifted EU interest towards liquefied natural gas (LNG) as an alternative solution to mainstream shipment through pipelines. EU adopts many policies and frameworks regarding handling and transportation issues of LNG in order to accelerate its penetration between the periods 2020-2030. The main considerations are the security and diversity of gas supply, affordability of LNG, energy efficiency of LNG, reduction of greenhouse gases (GHGs), quality of LNG and supply of LNG though ships.

- Security, Diversity and Affordability of Natural Gas Supply

Increased energy prices and sudden cutbacks in supplies of natural gas from Russia have affected the concerns regarding security, diversity and affordability of natural gas supply inside EU. EU it is very vulnerable to such unexpected changes because according to the latest researches the proved reserves of natural gas for European Union are 0.8 percent at the end of 2013. Proved reserves are those quantities that both geological and engineering information reveal that it can be recovered in the future from known reservoirs under existing economic and operation conditions. Moreover, according to BP Statistical Review of World Energy 2014 the production of natural gas for EU is 146.8 billion cubic meters (bm^3) at the end of 2013. Comparing this value to the production rate of natural gas at the end of 2012 there is a decline of -0.5 percent. On the other hand, natural gas consumption inside EU at the end of 2013 was 438.1 billion cubic meters (bm^3) which has be declined a little bit compared to the values of 2012, this change is at the rate of -1.1 percent. The difference between consumption and production of natural gas inside EU is covered with natural gas imports and the basic supplier is Russia, almost 40 percent of natural gas comes from Russia. The basic limit to the EU natural gas diversification is the fact that approximately 85 percent of natural gas imports are being done through pipelines. This impose to much stretch to the EU and for this reason EU-policy makers consider different ways to alleviate this, through common energy policies, energy efficiency measures, alternative energy sources, the use of liquefied natural gas (LNG) etc. According to BP Statistical Review of World Energy 2014 the trade movements of 2013 as liquefied natural gas to Europe and Eurasia is 51.5 bm3, with the main importers to be Spain, France, Italy Belgium, United Kingdom. When it is mentioned Europe and Eurasia are included European members of the OECD plus Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Former Yugoslav Republic of Macedonia, Gibraltar, Malta, Romania, Serbia, Montenegro and Former Soviet Union. World LNG production between 1975 and 2007 was 8 percent of world natural gas production. It has been estimated that until 2030 global demand for natural gas will be increased 2.1 percent. Also, it has been estimated that inside Europe LNG trade volumes will be 220 bm3 until 2020 and 254 bm3 until 2030. The basic LNG suppliers to Europe by the end of 2013 have been recorded Trinidad & Tobago, Peru, Norway, Oman, Qatar, Yemen, Algeria, Egypt and Nigeria. Apart from the security and diversity of LNG supply another issue is also the affordability of LNG infrastructures. According to the latest release of ‘‘The Global Liquefied Natural Gas Market: Status and Outlook 2003’’ by the Energy Information Administration of United States costs among LNG value chain have been declined. The Gas Technology Institute (GTI) liquefaction costs have dropped from 50 percent to 35 percent in the last 10 years. Plant capital costs from US$500 per ton of annual liquefaction capacity decreased to US$200. Also, the costs which are needed for the construction of LNG storage tanks have also dropped from US$280 million to US$155 million by the end of 2003. Moreover, regasification costs have fallen to the values of US$100 million up to US$2 billion. It is difficult to implement a specific formula for the economic analysis of all LNG industries since they are many parameters that have to be considered like the location of the project, the characterization of the project as greenfield (built in a new location) or brownfield (an expansion of an existing plant).

- Energy Efficiency and Greenhouse Gases

Natural gas can be transported either through pipeline or in the form of LNG. The main differences between these two processes are pointed in the processing, transportation, storage and handling. These differences affect consequently the results of energy efficiency and estimated greenhouse gases released from these two paths. In figure 4 it is showed the primary energy consumption that is needed for delivering natural gas to the final consumers through pipeline infrastructures and LNG.

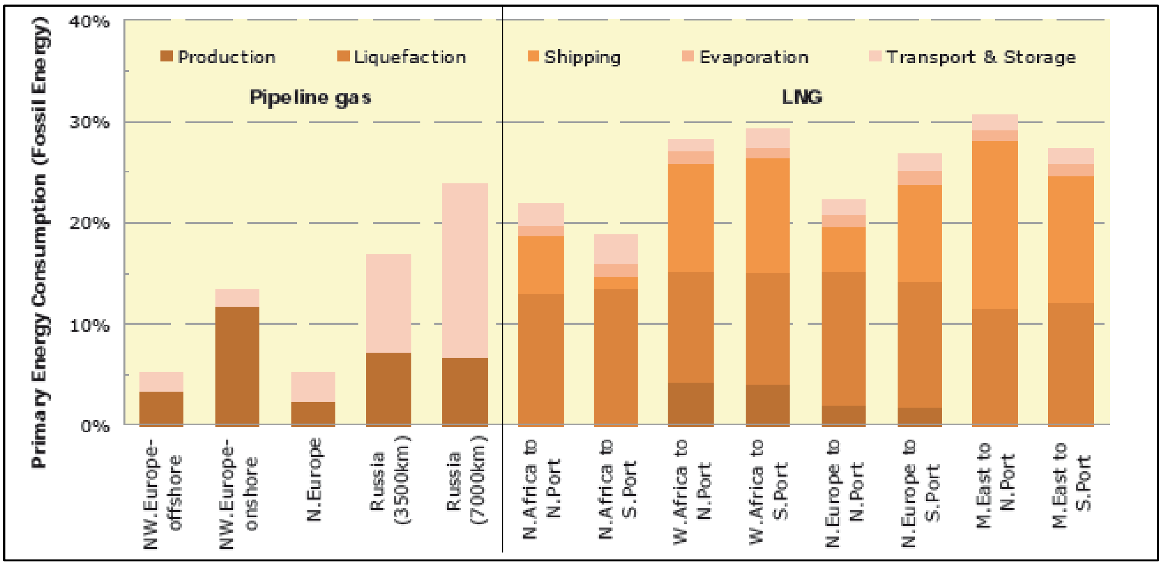

Figure 4: Primary energy consumption to deliver extracted gas by LNG and pipeline pathways [%, primary fossil energy12 consumed along the chains / total energy employed (energy of the extracted natural gas and energy consumed from other sources), all on Net Calorific Value /NCV/ basis], JRC Reference Reports, Liquefied Natural Gas for Europe – Some Important Issues for Consideration, 2009.

The primary energy consumption for delivering natural gas through pipeline is approximately between 12 to 16 percent with an efficiency of 85 to 90 percent, whilst for LNG is 20 to 25 percent with an efficiency of 75 percent. This difference is not so obvious when transportation of natural gas exceeds 7000 km, then energy costs for pipeline transportation is 28 percent versus 24 percent for LNG. In real terms LNG will be a more energy-intensive option than pipeline deliveries of natural gas. It has been proved that almost 18 percent of energy consumption is saved in case that LNG is trucked directly to the refueling station and then vaporized and compressed on site, than if LNG is regasified and then transported through pipeline to the same refueling station. Regarding the greenhouse gas emissions it has been estimated that LNG pathway is inferior to pipeline routes. This is represented more realistic in the figure 5 where it is showed the GHG emissions which are released in order to transport a unit of energy by LNG and pipeline.

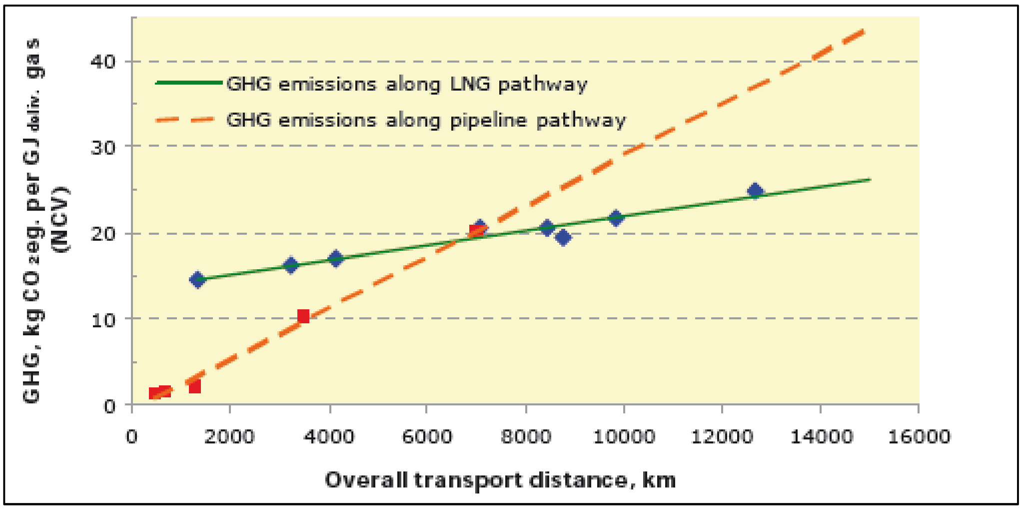

Figure 5: GHG emissions to transport a unit of energy by LNG and pipeline Pathways, JRC Reference Reports, Liquefied Natural Gas for Europe – Some Important Issues for Consideration, 2009.

The break-even point of GHG performance between pipeline and LNG pathways is reached in much shorter distance compared to the break-even point of energy efficiency. The break-even point is approximately at 6500 km transport distance with GHG emissions at 19kgCO_2/GJ for EU.

- LNG Quality Parameters

Natural gas is composed mainly from methane (CH4) but there are also some components in small quantities like heavier hydrocarbons, hydrogen sulphide and inerts. In order to be produced LNG all these impurities have to be removed. This practically means that LNG is composed almost 90 percent of methane. The rest 10 percent is ethane, propane and butanes. All these contribute to the overall energy content of LNG. Due to the processing of LNG slight impurities are found to its composition compared to pipeline natural gas. On the other hand, LNG does not include carbon dioxide (CO_2) and the existence of nitrogen amounts is very small. LNG may be considered as a superior quality fuel to pipeline gas. In figure 6 is represented the chemical composition of pipeline natural gas and LNG in EU, supplied from different sources. Pure methane is found in the top-right corner. The relative size of bubbles indicates the methane concentration. Also, from this figure it can be seen the different groups of LNG suppliers to EU. Generally, the concentration of non-methane hydrocarbons and inerts (N_2 and CO_2) are more pronounced in the pipeline natural gas if someone looks to the left-hand side of figure 6 whilst these impurities are less in the LNG composition which is showed to the right-hand side.

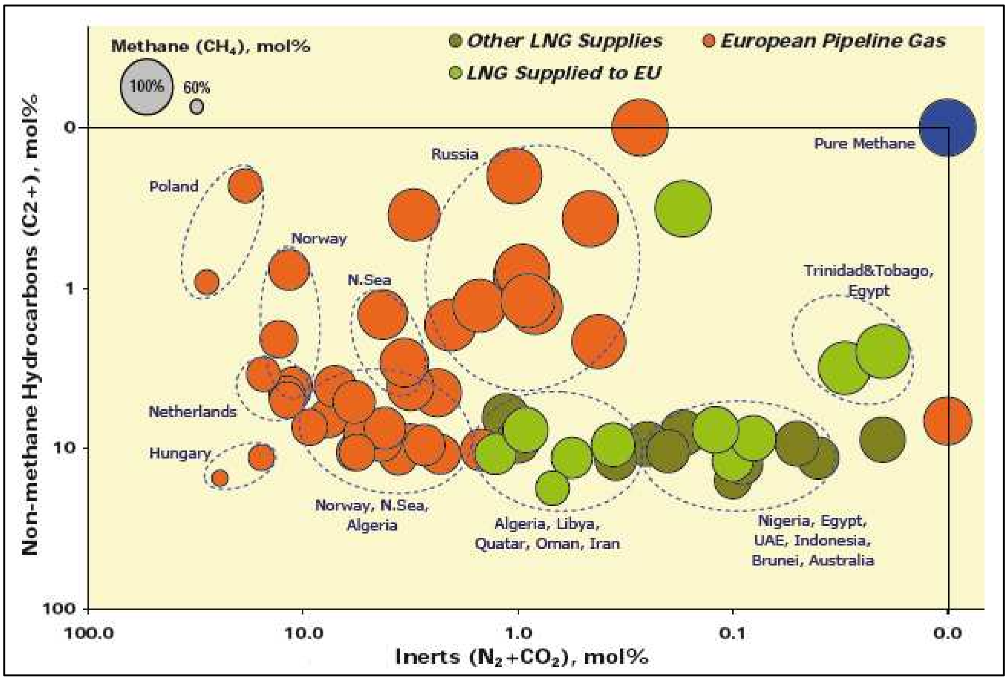

Figure 6: Composition of European pipeline gas and LNG (the relative size of the bubbles indicates the methane content), JRC Reference Reports, Liquefied Natural Gas for Europe – Some Important Issues for Consideration, 2009.

The issue that facing many European countries and also many countries outside EU is how they can manage and control the variation in natural gas quality in order to ensure not only security of energy supply in reasonable costs but also to maintain the integrity of utilization equipment. The basic characteristics regarding the quality of natural gas are the gross calorific value (GCV), the Wobbe Index and the density of gas relative to air. The LNG which is supplied to EU from Nigeria and Libya has a gross calorific value approximately 44 MJ/m^3 and its Wobbe Index is 53 MJ/m^3. The different markets of natural gas are not likely to reach in a consensus agreement regarding the quality standards that have to be followed. However, inside EU, European Commission has already given the mandate to CEN to structure a harmonized standard on gas quality by 2010, and this standard has to follow the EASEE gas specifications. This will allow the free trade of natural gas inside EU and also will increase the flexibility of importing LNG. Countries inside EU like France and Poland are thinking to convert their low calorific value networks to high calorific value networks in order to allow LNG trading system to work more freely. Due to the wide spread use of LNG the forthcoming regulations are going to adopt the LNG quality to their gas supply regulations. In that case large LNG industries may use directly LNG in order to secure energy supply. At that moment large chemical and petrochemical industries cannot benefit from direct use of LNG. Finally, delivering LNG by road trucks and trailers is an alternative option for areas which have poor natural gas quality or for remote areas. This is a promising market to the EU.

- Shipping of LNG

It has been noticed an increase in the world LNG fleet, regarding both transported cargo capacities and number of LNG vessels. It has been estimated from the Ocean Shipping Consultants Ltd., that in year 2007 the number of LNG fleets were 250 with a total cargo capacity 31 million m^3. Analysis results show that by the year 2030 the LNG cargo carrying capacity will be increased to 110 million m^3, while the number of fleet will be increased to 730 units. In this case it is assumed that the average vessel size is 150,000 m^3. Currently are used mostly LNG carriers with cargo capacities of 100,000 to 150,000 m^3 with an increased interest for larger vessels of 160,000 to 170,000 m^3. There are also bigger vessels with cargo capacities about 200,000 to 250,000 m^3. This is a new generation of LNG vessels called Q-Flex. The name comes from the word ‘Qatar’ since these vessels are used mostly to the exporting ports of Middle East and particularly in Qatar. Due to the high needs of LNG carriers already have been constructed the Q-max vessels with cargo capacities over 250,000 m^3. The ‘Q’ series of vessels are used mostly for exporting purposes in large ports. In EU there is a plan of building new LNG receiving facilities, which will served by smaller LNG vessels. In below figure 7 it is depicted the world’s projected LNG fleet capacities and the number of vessels.

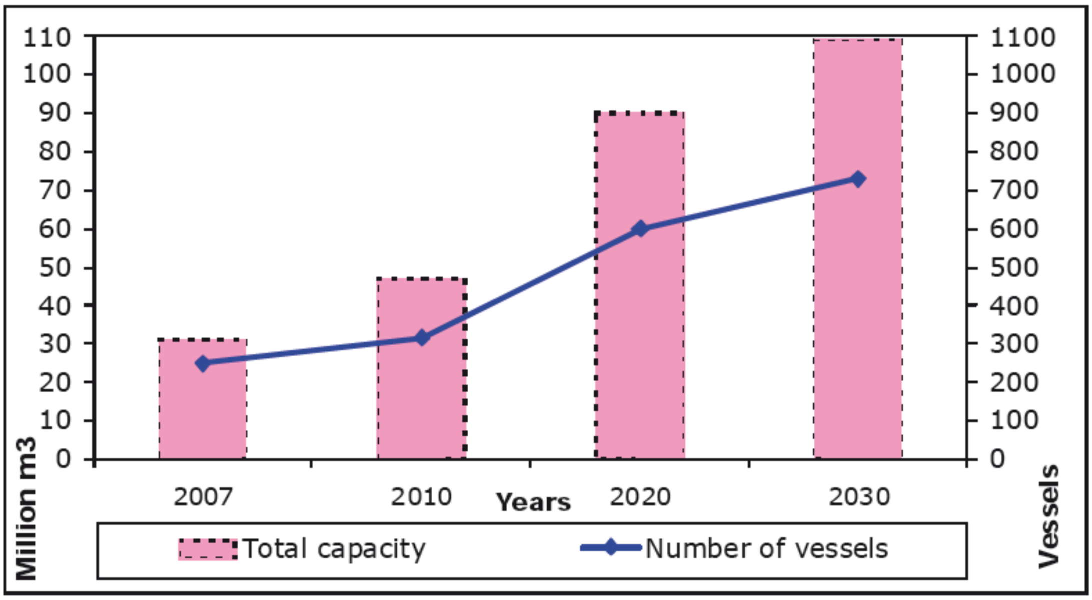

Figure 7: Current (2007) and projected (2010, 2020,2030) capacity of world LNG fleet (million m3) and number of LNG carriers (based on an average vessel’s capacity of 150,000 m3), JRC Reference Reports, Liquefied Natural Gas for Europe – Some Important Issues for Consideration, 2009.

The above aforementioned LNG carriers use liquefied natural gas as fuel oil for their propulsion system. LNG fuelled gas engines have proven to be reliable during operation and also they are environmentally friendly due to the low-sulfur fuel content. Emissions like SO_x and particular matters (PM) are almost negligible, and the NO_x emissions are below the Tier III limits for Otto cycle engines. In order to promote more the use of natural gas ships, it has to be adopted a number of policy measures which will be included also to the limits of Emission Control Areas (ECAs). European industry is a step forward since it has developed already a proven know-how in ‘‘green’’ shipping technologies. The International Maritime Organization (IMO) decided after the Convention in 2008 that the global sulfur content must be reduced to 3.5 percent by 2012 and 0.5 percent by 2020. In areas like the Baltic Sea and North Sea are imposed stricter emission rules. These areas belong to the so called Sulphur Emission Controlled Areas (SECAs). From the beginning of 2010 the sulphur content for these areas was below 1 percent and it has to be reduced up to 0.1 percent by the end of 2015. Regarding NO_x emissions, SECAs areas have to reduce them by 80 percent in order to meet the emission constraints of Tier III. European Commission also tries to impose stricter rules regarding ship emissions, and for this reason it has been adopted the EU Directive 2005/33/EC. This directive includes for example limits regarding sulphur content at 1.5 percent for marine fuels used by passenger vessels and 0.1 percent for marine fuels used by ships on inland waterways and at berths. In below figure 8 is illustrated the emissions regarding an alternative Baltic Sea cargo ship.

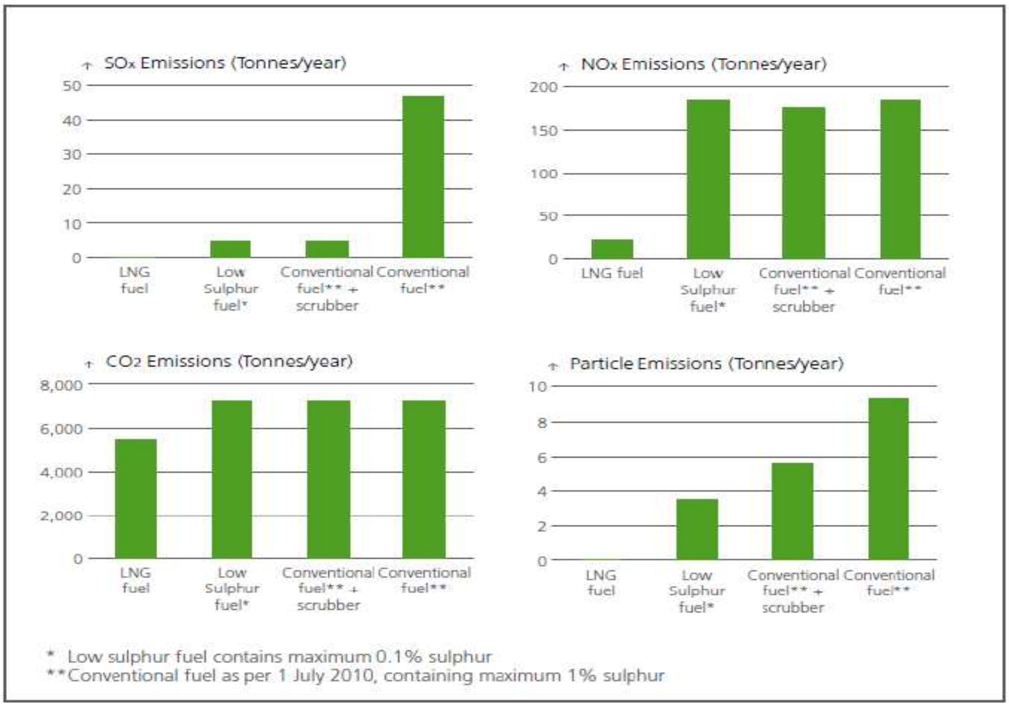

Figure 8: Environmental emissions for alternative concepts for a typical Baltic Sea cargo ship, Source: DNV Det Norske Veritas AS, GLE Position paper: GLE's views on Small Scale LNG, 2011.

This alternative solution provides 0 SO_x emissions for an LNG fueled ship. NO_x emissions are estimated near to 20 ton/year, CO_2 emissions approximately near to 5,800 ton/year and particle emissions (PM) almost 0 ton/year. At that moment European Commission is thinking to submit a proposal which will be in alignment with the IMO Convention. [4, 5, 6]

2. Study of LNG Storage Tanks and Surroundings

In this chapter will be analyzed the requirements regarding the area at which LNG storage tanks are going to be built in. Also, it will be represented the different types of LNG storage tanks.

2.1 Study of Installation Area and its Surroundings

It is very important for an LNG company to include to its safety assessment the functional description of the terminal installation. In order to be achieved this target a series of steps have to be followed. First of all it is very important to be explored thoroughly the site at which the infrastructures are going to be built in. To begin with, a soil survey has to include geological investigation where scientists will try to understand how this area has been formed during the past and which are the potentialities of seismic activities, also they will record the presence of possible salt deposits, soil liquefaction, gypsum, swelling clays, existence of ground water tables etc. This geotechnical search will facilitate the characteristics of the subsoil one of the most predominant characteristics for the LNG terminals topology since unstable phenomena are forbidden under the tank or the equipment foundation. Otherwise it has to be proved that the aforementioned phenomena can be detoured with appropriate measures and potential problems to be overcome. Apart from the soil survey more studies can be done regarding the investigated area. For instance marine aquatic access and marine aquatic environment, study of flooding and shock waves, study of sea water temperature, quality and possibility of tidal, a survey to the surrounding vegetation in order to predict the possibility of fire risks, enhance the communication of the surrounded industrial companies. Studies which will include manoeuvring areas and safety distances for the LNG carriers which transit within the port and those who are at berth. Apart from the site study climatic study has to be done as well. It is very important the scientist to investigate the temperatures of the area during the whole year, the range of barometric pressure, the wind direction and strength, the frequency of rainfall, snow and icing, the relative humidity and the substances of the air since it can be very corrosive to the infrastructures. One of the most important studies which have to be done is the seismology study of the area. The size of the area which are going to be investigated is depends of its nature, its geological and tectonic conditions taking also into consideration the soil survey, for this reason scientists may include also a wider research area which historically has be proved that can affect the site conditions. Generally this area is around 320 km from the site but if the area is characterized as potential seismic then a wider area can be searched. An earthquake is characterized by its vertical and horizontal acceleration of the ground and scientists try to predict their frequency as well as their amplitude. The selection of the relevant data helps scientists to establish the Safe Shutdown Earthquake (SSE) and the Operating Basis Earthquake (OBE). The former is the earthquake which produces the maximum vibratory ground motion for which infrastructures and/or systems are designed to remain functional. It is based upon the evaluation of the maximum earthquake potential taking into consideration the topology of specific area, the seismology and geology characteristics. The latter is the earthquake which is based on the local topology, geography, geology and seismology characteristics as well as the characteristics of the subsurface materials. The estimation of that earthquake ensures the safe operation of the site without undue risk to the safety and health of the public. Finally, parallel with the above-mentioned studies project site location assessments have to be done in order to ensure the suitability of the site location taking into consideration parameters like neighbor industrial and residential development, transportation infrastructures and sensitive developments. When the site will be determined a detailed site assessment has to be published and revised frequently and include all the needed information regarding the location of the project, the scope, the hazardous material which are found in this area, the possible future developments and the conformance with the local and national regulatory laws. [7]

2.2 LNG Storage and Retention System at Terminals

The design of the LNG tanks is accordance to the European Standard EN 1473:2007. The basic principle for the construction of these tanks is to maintain safely the liquefied natural gas at cryogenic temperatures. It is also very important to allow the safe filling of the tanks as well as the removal of LNG. LNG storage tanks have to be structured in such way so as to be possible to withstand leakages due to internal and/or external factors. They have also to maintain stable internal conditions of air and moisture except as a last resort to prevent unwanted vacuum conditions in the vapour space. Moreover, these tanks have to be able to endure the number of filling and unloading (emptying) cycles and the number of cooling and warming operations during the predicted life cycle of the equipment. The aim is to operate safely between the minimum and maximum pressures, permit the boil off gas and minimize the rate of heat leak.

During the normal operation of the tank everything has to be gas and liquid tight. The LNG storage tanks consist of a primary and a secondary container. The primary container generally is consisted either by a membrane, or by continuously welded plate. It is also very usual to be structured with cryogenic concrete pre-stressed with cryogenic reinforcement. The secondary LNG storage container has also to be tight in order to maintain any possible leakage or spillage and for this reason this can be either a continuous welded plate, or concrete tank or any other proven suitable material. The surface of the tank which can be metallic or concrete and it is exposed to the atmosphere has to be designed and constructed in such way in order to minimize any possibility of water penetration in any form, for instance rainwater, surface water, humidity. The existence of moisture can cause severe corrosion problems to the equipment, impairment of insulation material as well as to concrete.

The design of LNG tanks has also to consider the internal and external piping which is directly connected to the loading procedure of the liquefied natural gas. For this reason the fluid and the gas pipes which penetrate to the LNG tank are not allowed to found neither to the primary and secondary container base or walls. It is very important the penetration not to give rise to any heat input and stable conditions to be maintained. If for any reason penetrations cause thermal expansion and contraction then it is necessary internal connections to be strengthened as well as external connections so as to transit piping loads to a thermal piping compensating system. It is very common between the inner tank and the outer containment to exist some connections which are related to the feed of nitrogen and the removal of it when commissioning face is going to take place. Also, these connections serve to purge out LNG after emptying the tank for maintenance purposes.

Another parameter which has to be included to the design of LNG tanks is the insulated materials. It is crucial the design and selection of these material to be done carefully in order to prevent any corrosion and /or damage to the pressure containing components due to the existence of undesirable contaminants. In order to minimize the heat transfer from the ground insulation is implemented beneath the foundation base of the primary container. It has to be considered also the thermal expansion of the components. For instance when the insulation material of the primary container is made of expanded perlite, it is necessary to be protected from settling. This can be done if glass wool padding is implemented. If LNG is stored inside to a spherical tank then the insulation has to be implemented to the outside area of the tank and no prevention to mechanical and/or hydraulic actions should be formed. Furthermore, insulation materials have to be strongly non-flammable. Apart from the proper selection of the insulation material it has to be considered also the proper thickness of it. For this reason many parameters have to be considered like the atmospheric conditions, soil conditions and so on. Regarding the quality of the insulated material it has to be considered that no single point of the external envelope of the container will be below 0°C with air temperature above or equal to 5°C.

Moreover, the design of the LNG tanks has to include also a combination of many possible actions. For example initial warm up to atmospheric temperature and cool down, filling and emptying cycles, the maximum rate of temperature changes, maximum differential pressures that can exist. [7, 8]

2.3 Types of LNG Tanks

There are several types of LNG storage tanks varying from the function, the site characteristics, the safety restrictions and from the results of soil as well as seismic study report. The categories which can be classified for that purpose are:

- Single Containment (Cylindrical metal tank).
- Double Containment (Inner cylindrical metal tank and outer cylindrical metal or concrete tank).
- Full Containment (Inner cylindrical metal tank and outer cylindrical metal or concrete tank).

- Membrane Containment (Cylindrical concrete tank covered from inside with a metallic membrane).

Depending on site's requirements other types of LNG storage tanks can be built as well. For instance there is one type named Cryogenic Cylindrical Concrete Tank which is similar to the aforementioned tanks and it is constructed from an outer pre-stressed concrete tank and a similar internal tank. Another type is the Spherical Tank. The deferent types of LNG tanks will be described below. Generally, the tanks can be placed directly on the ground but most of the times it is preferred to be installed semi buried or in ground or in pit. The foundation at which LNG tanks are placed in has to follow specific requirement and to be in accordance with the seismic studies. [9,10]

2.3.1 Single Containment

This type of tank is consisted only from one containment tank (primary liquid container) made from steel. The shape of the tank is mostly cylindrical and it is self-supporting. There is also an outer steel shell which is not responsible for containing any possible leakage. The purpose of it is to protect and retain insulation only. As it mentioned above the tank here is placed on the top of a concrete foundation, which has also the possibility to maintain the temperature of the tank due to the installed heating system. Between the primary container and the outer steel shell there is also loose filled insulation. The foundation and the tank are found inside to a bund wall. The roof of the primary tank can be separated into two deferent types regarding the capture of the produced vapours. The first scenario is a simple structure of a steel dome roof were vapours are kept inside whilst the second scenario includes an open top cup where a gas-tight metallic outer tank enclosing the primary liquid container. With the second scenario products vapours are kept inside and insulation is protected. In figure 9 are depicted two examples of Single Container tanks. [9,10]

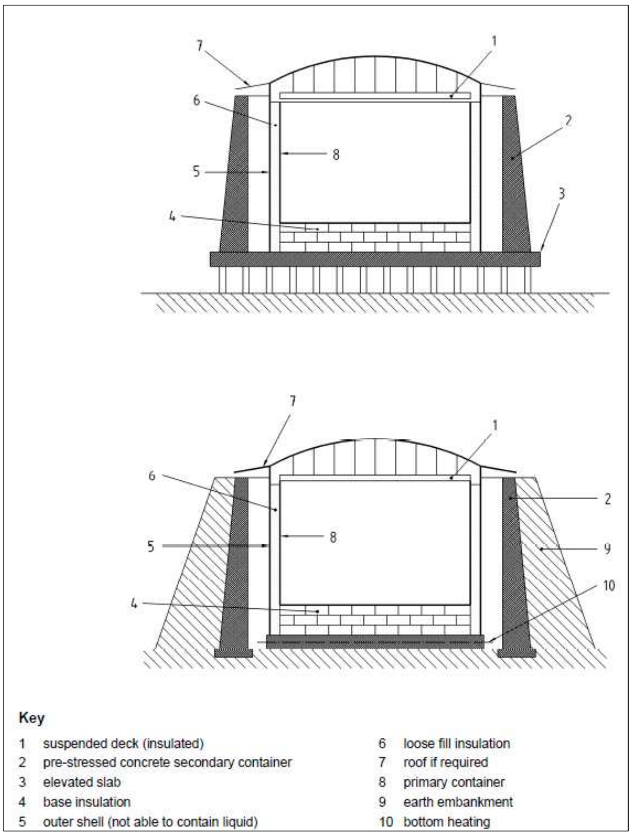

Figure 9: Example of single containment tanks, British Standards, BS EN 14620-1:2006, Paragraph 4: Concept Selection.

2.3.2 Double Containment

Double type containment is consisted of an inner tank made from steel which is reliable to maintain both the vapours and the liquid and an outer tank made from concrete and it is responsible to capture any possible spillage. The secondary container is designed in such way in order to be able to maintain all the quantity of primary container's liquefied natural gas in case of leakage accident, the container does not maintain the vapours as well. The annular space between the two containers shall not exceed six (6) meters. Due to this gap between the two containers it is constructed a shield which prevents the entry of rain, snow, sand. Also, to this type of LNG storage tank there is a concrete foundation which is insulated and a heating system helps to maintain stable the desired temperatures. It is very common procedure instead of building a concrete base to place above the primary and secondary container to build in the ground both containers, an earth embankment is made for this purpose. It is existed also here two possible scenarios for the roof just like the case of single containment type. In figure 10 is showed the drawing of a Double Containment tank. [9,10]

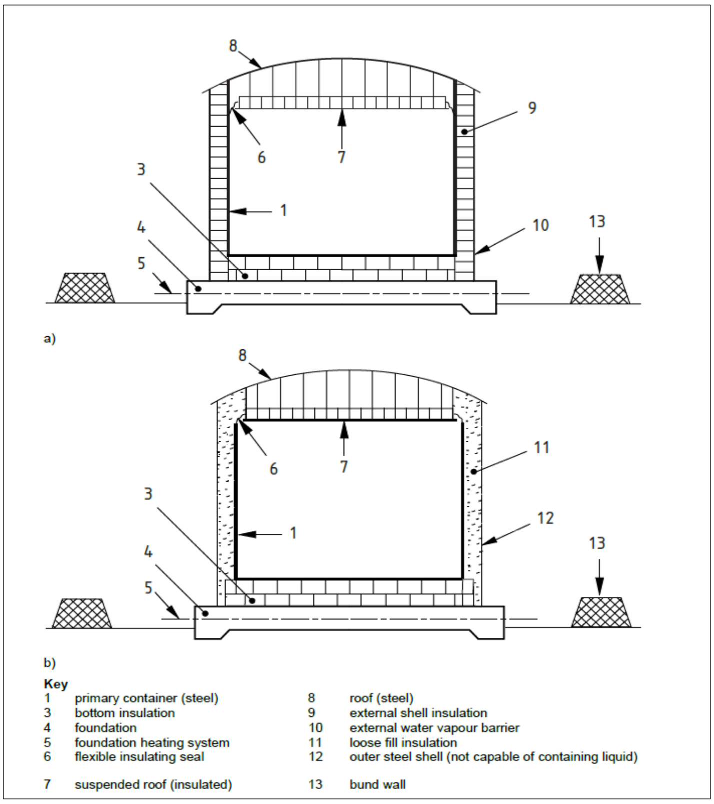

Figure 10: Example of double containment tanks, British Standards, BS EN 14620-1:2006, Paragraph 4: Concept Selection.

2.3.3 Full Containment

The design of a full containment tank includes a primary and a secondary containment which together consist an integrated LNG storage tank. The primary tank withholds the liquefied natural gas whilst the outer tank is responsible for retaining the insulation and in case of primary tank's failure to be able to keep both the liquid natural gas and the vapours. The primary containment can be either open at the top or it can be closed, at this case a dome roof is constructed and keeps inside the LNG vapours. Moreover, primary containment is constructed from steel and it is a self-standing structure. The secondary containment is also a self-supporting steel or concrete construction and it has a roof, made from the same material. The purpose of the secondary containment in the case of an open primary containment is to preserve natural gas vapours and hold thermal insulation of the primary container. If the primary containment is shielded at the top then the aim of the secondary containment is to withhold any spillage occurring due to failure of primary containment. More specific is responsible to maintain not only the liquid but also the vapours of natural gas. There is the case where venting release can be acceptable but it has to be done very carefully. In the normal operation the secondary containment is responsible to keep the thermal insulation of the primary's containment and at the same time to reserve vapours. If both the primary and secondary container is made from steel then the space between them which is approximately two (2) meters is filed with insulated material. The same is done also when the primary container is made from steel and the secondary is made from pre-stressed concrete. In figure 11 is showed the drawing of a Full Containment tank. [9,10, 11]

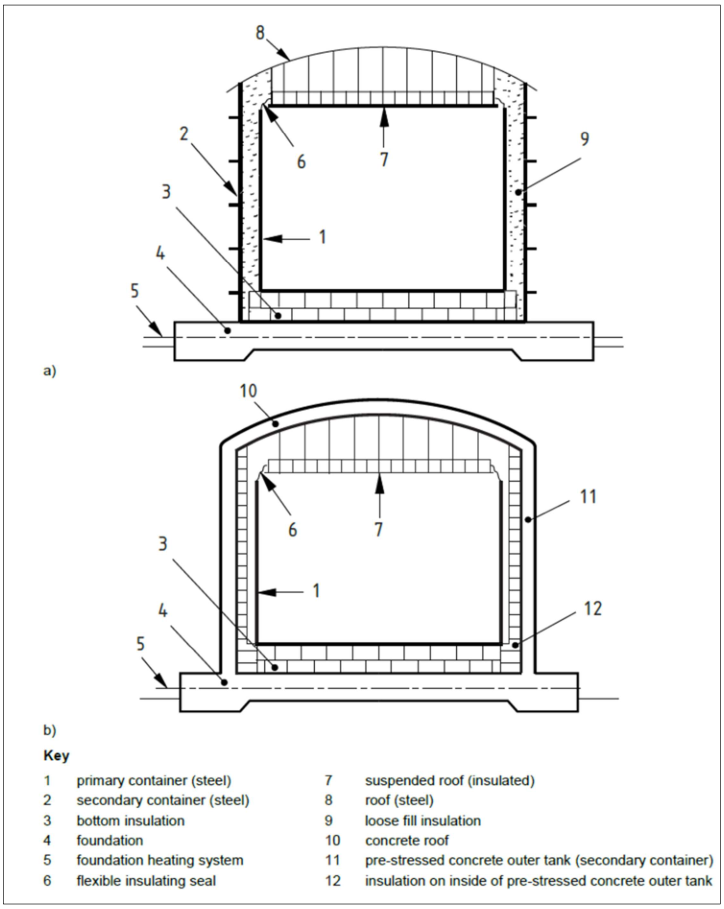

Figure 11: Example of full containment tanks, British Standards, BS EN 14620-1:2006, Paragraph 4: Concept Selection.

2.3.4 Membrane Containment

Membrane containment is another type of LNG storage tank. It is consisted of a primary steel container which is very thin (~1.2mm) and for this reason is called membrane. Most of the times it has a corrugating shape. There is also a secondary containment made from concrete which purpose is to maintain both liquid and vapours in case of leakage and provides hydrostatic stability. Between the two containers exists insulating material, its thickness is 40cm. It is very important this insulated space not to come in touch with vapour space. For this reason there is adjusted on this space a nitrogen breathing system which monitors the methane concentration and keeps the pressure within normal values. Moreover, this nitrogen system it can be used to purify the insulation space in case of a leakage. At the top there is closed, hemispherical, concrete roof and behind this there is an insulated suspended deck which is made from aluminum and fiberglass. A detailed drawing is given in below figure 12.

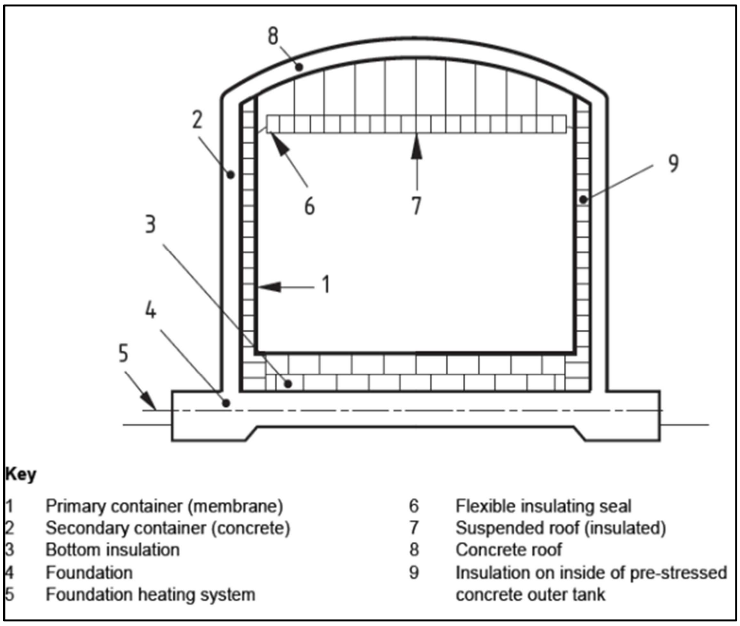

Figure 12: In the left hand an example of membrane containment tank, British Standards, BS EN 14620-1:2006, Paragraph 4: Concept Selection.

Among the four types of LNG storage tanks there is one common characteristic. In all the circumstances below to the foundation of the tank there is foundation heating system. The reason of this is to prevent expansion forces which may lift the tank and damage either the tank itself or parts of the tank for example tank's bottom connections. These expansion forces which are produced are due to temperature differences between tank's bottom and soil. If the soil which is found under the tank becomes too cold then frost penetrates into the ground and form ice lenses. As time goes by these ice lenses are growing and cause expansion forces to the tank. In order to prevent undesirable phenomena it is used a self-regulating on-off heating system which automatically starts and stop keeping the tank foundation between a temperature range of +5˚C to +10˚C. This is the desirable temperature among to tank's foundation. In some areas it may be observed higher temperatures but this does not cause any problem. It is suggested a frequently monitor of the heating system performance because it can reveals any information about tank leak. If a leak is appeared then the controller which is found near to the leak it shows a sudden drop of the temperature. For this reason it is recommended a daily inspection to the system. Another indication that there is a possible tank leak is the change of heating power consumption because it is produced a change in on-off time. The normal activation of the system is 40% to 60% of the total heating operating time. If this suddenly changes to 100% activation this directly indicates an abnormal operation of the system which is very possible to be linked with a leakage problem. [9,10, 11]

3. LNG Supply Chain

In this paragraph the supply chain of the LNG will be described. This includes all the paths from natural gas extraction until the end-use consumption. The first step of the supply chain is the exploration of the source; this includes drilling, well preparation and closure. Most of the times, the recovery of natural gas is accompanied with oil recovery. The main composition of natural gas is methane, but also contains ethane, propane, butane and heavier hydrocarbons. It can be found also small quantities of carbon dioxide, oxygen, sulfur, nitrogen and water. All these components have to be removed and especially the non-methane components like water, carbon dioxide. This is done because during the cool down of natural gas (-160˚C) there is the possibility to be formed solids. The natural gas is processed until to reach very high purity most of the times the purity is 95% methane and only 5% other components. The next step is the liquefaction process. This includes cooling of the cleaned feed gas by refrigerants. By liquefying the natural gas it is achieved the decrease of volume by a factor of 600. Practically, this means that liquefied natural gas uses the 1/600th of the space required for a corresponding amount of gas at room temperature and atmospheric pressure. After the liquefaction process the LNG either is loaded aboard a ship or is stored in specific double-walled tanks at atmospheric pressure. The transportation of LNG is being done with double-hulled ships. These ships follow specific design criteria and codes so as to be in accordance with safety rules. There are different types of LNG ship carriers depending to the construction criteria but also to the loading capacity. After the transportation, LNG is discharged at specific receiving terminals. In these terminals LNG is pumped to double-walled storage tanks at atmospheric pressure. From this point LNG can be transformed again to gaseous phase through regasification process. From the atmospheric pressure storage tanks LNG is pumped at high pressure and after it is warmed by passing through pipes. The heating of pipes can be done either directly by fired-heaters or seawater, or through pipes that are in heated water. The gaseous natural gas can be either transported by pipelines or it can be used for power generation. Apart from regasification process LNG can be transported by trucks. The trucks can carry 40 to 80 m^3 LNG depending from the permitted transported size of trucks in each country. LNG transported by trucks it is proved less cost effective compared to ship transportation if the volumes of LNG involved are sufficiently large over a period of time. The recommended distance for LNG transportation by truck is 600 km approximately. The purpose of LNG transportation by truck is multiply. It is transferred to specific terminals for end-user consumption to LNG vehicles. Liquefied natural gas can be transformed to compressed natural gas which can be used by CNG cars. Also, LNG truck distribution aims to cover energy needs for large industries, energy demand during peak loads (at this case LNG is stored to cryogenic tanks until it is needed, then it is transformed to natural gas) and for remote end users with no access to pipeline infrastructures.

In the below figures are illustrated the different supply chains of LNG that can exist. The choice of LNG distribution depends on commercial as well as technical conditions such as the size of the terminal, the frequency of customer visits etc. Here it is worth mentioned that every additional step to the supply chain may affect the quality of LNG because there is the possibility of temperature increase. This is done due to pumping from one part of supply chain to another part. In the below figure 13 is showed one possible scenario of LNG use.

Figure 13: LNG Supply Chain No 1.

Many power plants in order to ensure their productivity they build LNG storage tanks and use them as backup fuel, depicted supply chain at figure 14.

Figure 14: LNG Supply Chain No 2.

Figure 15 shows the LNG supply chain by truck which is going to be used for transportation purposes. The loading capacities can vary between 50 to 80m^3 of LNG. The exact amount of transported LNG depends on two parameters the maximum load and the length of the vehicle, which directly is connected on its country authority legislations. Figures 15, 16 & 17 show how the LNG trucks can be used for other purposes as well. [12, 13]

Figure 15: LNG Supply Chain No 3.

Figure 16: LNG Supply Chain No 4.

Figure 17: LNG Supply Chain No 5.

4. LNG Regasification Process

In this area it will be analyzed the process of LNG regasification. In remote areas LNG is transferred by ships into the port, after it is unloaded and stored in cryogenic tanks. For the regasification process it is needed some basic equipment, which includes: LNG arms, LNG pumps, Boil-off gas Recondenser System, Vaporizers. Each one will be analyzed separately below. [1]

4.1 LNG Arms

When an LNG ship anchors to port they are used LNG arms in order to transfer LNG from ship to onshore LNG tanks. These arms consist of one riser pipe, the inboard arm and the outboard arm. There are different diameters of arms for instance it is very common 16 in arm, but it can be found also until 24 in arm. Between each pipe segment it is installed a swivel joint which facilitates the movements between the onshore and the ship components. Very careful operations have to be done during the process for this reason there are many monitoring systems like quick connect and disconnect coupling, position monitoring and emergency release systems. When LNG transfer from ship to onshore tank is finished nitrogen purge takes place. This is done before the disconnection between the two systems in order to ensure completely drainage of the arms. A typical port has two or three loading arms, one vapor arm and one spare arm in case it is needed, this arm is common for liquid and vapor. The capacities of arms varies between 4,000m^3/hr until 6,000m^3/hr. [1]

4.2 LNG Pumps

LNG pumps are one of the main characteristics of regasification process. LNG pumps are submerged inside the LNG storage tanks with their motor as well. One very common motor pump is the submerged electric motor pump (SEMP). Liquefied natural gas is a dielectric fluid for this reason there are not safety problems with the submersion of motor and electric cables inside the liquid. One more advantage with the aforementioned pumps and motors is that there is no need for tank penetrations and mechanical seals. LNG pumps can be classified into two main categories the Low Pressure (LP) sendout pumps and the High Pressure (HP) sendout pumps. The former are used inside the LNG storage tanks to force LNG to regasifier and some time there is also the possibility to by-pass it to high pressure pumps, the latter is used to boost LNG to vaporizers. [1, 16]

4.2.1 LP Sendout Pumps

These pumps as it is mentioned before are used for LNG transfer, they are installed inside a vertical pump well and after they submerged inside to the storage tanks. The installation is done from the top of the tank since they are retractable. Pump's column is purged with nitrogen to ensure safety. The main components of an LP in tank pumps are: suction valve seal plate, suction valve seal, helical inducer, suction valve springs, inlet house, wear rings, impeller, main bearing, axial diffuser vane, shaft bushing, motor housing, discharge ports, suction valve, motor housing, submerged electric motor (stator and motor), one-piece solid shaft, coolant return lines, upper bearing, end bell housing, in-tank feed thru, catch screen, terminator cover, in-tank power cable, lower support plate, support cable, lifting cable, customer column.

These pumps are designed to discharge at 8 to 10 barg pressure. The maximum pump's efficiency is when the operation is near to design flow, for example 80% efficiency can be achieved approximately with pump flow 400m^3/h. If pump is operated under the minimum flow, this will lead to efficiency drop and discharge temperature of the liquid will be increased. This can cause problems to the BOG (Boil-Off Gas) recondenser. During the turndown of the pump there is the possibility of shortage of LNG Cold for BOG recondensation, this can result to BOG carryover to High Pressure (HP) sendout pump and cavitation problems. The usage of BOG recondenser is during the startup of the pump where the minimum flow valve opens and the pump's heat generates boil-off gas.

Apart from supplying LNG to HP pumps and to the recondenser, LP pumps are also responsible for circulating cold LNG to the jetty because this process keeps cold the unloading lines. Finally, these pumps include an inducer (an axial flow impeller) to the lowest possible level of the tank so as to improve NPSHR (Net Positive Suction Head Required). This allows operators to lower as much as possible the LNG storage tank level. [1, 14, 15]

4.2.2 HP Sendout Pumps

The usage of High Pressure (HP) pumps is to take suction from the BOG recondenser to increase the pressure from 8 barg to 80-120 barg and to boost LNG to vaporizers. The type of these tanks is vertical canned with submerged motor which drives the close-coupled, multistage pump. When pump operates near to its design flow the efficiency is approximately 70% with flow 510 m^3/h. A typical motor has 1500 to 2000kW power.

The basic components of a HP pumps are: spiral inducer, impellers, thrust equalization mechanism, shaft / rotor assembly, motor, stator, suction nozzle, discharge, electrical penetration, seals. The inducer of the pump reduces the NPSH requirement for operation. During the motor operation heat is generated, this heat is removed by the sensible heat of the inlet LNG. A small portion is vaporized, for this reason it is important to vent the casing of the pump periodically. This vent vapor is sent to the BOG recondenser. Very careful design of the piping system and estimations of the BOG recondenser elevation has to be done, in order to ensure sufficient NPSH available for the pump operation. This is one of the most critical parts to the regasification process and it has to be included in all cases, like startup of the system, shutdown, holding positions, ship unloading procedure. [1, 14, 15]

4.3 Boil-Off Gas Recondenser (Reliquefyer)

During the process of pumping heat is produced and additional with solar radiation causes one fraction of LNG to pass from liquid phase to gas phase. This vapor flow can vary significantly between ship unloading and onshore holding operations. This gas it is called boil-off and it has to be removed from the storage tanks in order to maintain low pressure levels inside them. For this reason these vapors are compressed, removed and condensed in specific equipment called Boil-Off Gas (BOG) recondenser. Vapor flow which takes place is a contribution of many parameters, like the heat input of the operational pumps, the heat gains from the unloading lines, heat leaks from storage tank, volume displacement from the tank by the unloaded LNG from ships. When the ship is not at port vapor flow is much lower approximately 0.05% per day. This quantity of BOG is produced mainly due to heat leaks of the storage tanks. The noticeable here is that when the system is working at high sendout ratios the BOG is reduced so much that it can get even negative, at that times in order to maintain the system stable makeup vapor from the natural gas sendout system can be used for balancing. A typical amount of vapor flow rate is 4 to 40 MMscfd (Million Standard Cubic Feet per Day). The process goes as follow:

Vapor flows guided through piping to the BOG compressor, compressed and sent after to the BOG recondenser where they condensed using a slip stream of the cold sendout LNG. The BOG recondenser has a triple role to the process:

- Maintain the pressure of storage tanks at low levels by condensing the boil-off gas.
- Receives the compressed boil-off gas from the BOG Compressor.
- BOG recondenser operation looks like a drum's operation, where liquid and vapor phase exist together.
- It is used as a suction drum to the high pressure (HP) sendout pump.
- Maintains a constant suction pressure and an adequate NPSH for the HP pump, in order to work normally.

A typical BOG recondenser process line follows the next steps. From an LNG storage tank low pressure (LP) pumps boosts the liquid to the BOG compressor. LNG is compressed about 8 barg. There are two different types of compressors. One is centrifugal and the other is reciprocating. In order to fulfill turndown requirements of BOG it is used three or more, depending of the volume, reciprocating compressors with automatic unloaders. When boil-off gas is compressed then opens the valve and it is allowed the vapor flow from the BOG compressor to the BOG recondenser. The BOG recondenser is separated at two compartments, one consisted of a packed column and the other consisted of liquid level. The packed section is used to maintain the vapors. In order to be produced saturated liquid it has to be provided sufficient LNG. LNG which is cold supplies the needed temperature for the condensation of BOG and the formation of saturated liquid. Primary (LP) pumps from the storage tank send liquefied natural gas to the BOG recondenser. At the same time compressed boil-off gas is guided also there. The sendout flow is balanced with the condensate from the packed column in the lower section of the recondenser and the mixture is send to the high pressure sendout pumps. It is crucial the system of BOG recondenser and HP pumps to be designed and controlled in order to ensure not only a stable flow to the HP pumps but also to provide inadequate cooling and NPSH for the HP sendout pumps. For this reason many actions can be taken as precautions.

First of all it is important to maintain a constant liquid flow to the packed column. A flow ratio controller is used based on the feedback which gets from the boil-off gas flow rate and from the pressure transmitter found on the inlet of recondenser. Second, it is important to keep liquid level on recondenser between some limits. For this reason a level transmitter is used. This instrument gives an alarm when the liquid level increased too much and is close to the packed column. The level should be lower in order to allow all the packing to be available for heat transfer. Moreover, a level controller installed near to the bottom of recondenser ensures that sufficient liquid exists at the outlet of the recondenser which feeds the HP pumps. As it is mentioned before periodically HP pumps have to be vented in order to prevent cavitation phenomena. The vent from the aforementioned process is rerouted to the top of recondenser and it is drained by gravity to the bottom of recondenser going back to the suction of the HP pumps. The recirculation flow of the HP pumps also is rerouted back to the top of BOG recondenser, for this reason recondenser must be designed with surge volume. Finally, during the design phase elevation differences have to be taken into consideration. This is important because it has to be provided the needed NPSHR of the HP pumps for all the circumstances, like startup of the system or turndown of the system.

When liquefied natural gas passes through the BOG compressor and BOG recondenser it is boosted to HP sendout pumps and from there to the vaporizers. [1, 16]

4.4 Vaporizers

The choice of LNG vaporization system is a combination of many parameters, including terminal's location, site environmental conditions, operational issues, energy efficiency measures and regulatory obligations. Also, vaporizers selection has to meet the target of minimization industry's life cycle costs. For this reason economists analyze the project expenditures in order to achieve higher net present value (NPV) and at the same time to be in guidance with emission regulations. Today's LNG regasification terminals target to cover natural gas needs in remote areas. These regasification terminals use mostly Open Rack Vaporizers (ORV) around 70% of them, 25% use Submerged Combustion Vaporizer (SCV) and 5% use Intermediate Fluid Vaporizer (IFV). There are also other types of vaporizers like Direct Air Vaporizers (DAV), Ambient Air Vaporizers (AAV), Shell and Tube Exchange Vaporizers (STV) which are used mostly in small regasification terminals and peak saving facilities. Today, LNG regasification terminals used more and more because they are flexible and they can provide gas where there is shortage. As it is already mentioned above the choice of vaporization depends in a great amount of site environmental conditions. For this reason the countries at which are built regasification terminals can be classified at two categories. The first ones are equatorial countries, these countries have stable site conditions and temperatures do not follow below 18˚C (Mexico, Brazil, Indonesia, Philippines). The second ones are sub-equatorial countries where temperatures can fall below 18˚C at winter months (China, Chile, Spain, UK, France). The selection of the proper vaporization system is a matter of project and site specific parameters and should be evaluated on a case-by-case basis. For the selection of the right vaporizer the below factors have to be considered mainly:

- Plant location
- Site environmental conditions
- Capital costs
- Operating costs
- Supply – demand curve
- Regulatory restrictions (environmental restrictions for seawater and air pollution)
- Vaporizer capacity and operating parameters
- Safety precautions [1, 17]

4.4.1 Open Rack Vaporizers (ORV)

Open rack vaporizers are used widely in the existing regasification terminals and most specific at subequatorial countries. The regasification power plants are constructed usually near to the open sea in order to allow access to ships. The most available source for heat is sea water. For this reason ORV used as heat exchangers taking advantage of the available seawater. It is proved that seawater temperature above 5˚C provides better efficiency results.

An ORV is a construction of tubes which are arranged in panels. These panels are connected between them through the LNG inlet pipe and the degasified product outlet piping manifolds and hung from a rack. Seawater is very corrosive and for this reason ORV are made from finned aluminum alloy tubes which externally are protected with specific zinc paints. The selection of this material tubing is based on two parameters. The first one is to provide mechanical strength to the tubing in order to withstand cryogenic temperatures and the second reason is the high thermal conductivity which appears. Higher thermal conductivity increases ORV efficiency. The design of these units is made based on safety precautions and easy access to the equipment, because it demands regular maintenance. Moreover, the operation of this system can be adjusted through isolating sections of the panels and vary the load of the unit. This provides the opportunity to operators to conform to any changes regarding gas demand, seawater temperature or gas outlet temperature. The advantage of ORV is that there is no possibility for explosion because there is no ignition source to the system and any gas leakage can be detected very easy.

An open rack vaporizer is a system which works with seawater, heat exchangers of this type during the design phase have to consider many parameters that affect the operation. For example, it has to be analyzed the quality of the seawater because this affects the operation of the ORV and also affects the life of the zinc aluminum coating tubing. Also, from seawater analysis it can be detected the concentration of suspended solids and the amount of sand. This is important because it can be appeared sedimentation phenomenon causing jamming of the water through piping. This can be treated with proper infiltration system preventing solids, sea life and silts reach pumping system. Designing an ORV heated by the seawater creates great concerns for the ecosystem of marine life. The destruction of the system when it is in operation has to be as lower as possible, seawater discharge has to be in guidance with local regulations and chemical usage must be minimized (chlorination of seawater is a method which is used widely for the prevention of marine life growth). Other parameter that has to be considered as well is the site environmental conditions. In very cold climates in order to maintain stable the temperature of gas outlet an external heating system is used. At this case it is very common technic the usage of boil-off gas created at storage tanks as a heating fuel. Furthermore, it has to be considered as well the available backup system in case of failure of ORVs. Taking into consideration the aforementioned parameters and many others a case study has to be done before the final decision. In the below figure 18, is showed an outline of the composition of panel tubing arrangement. [1, 17, 18]

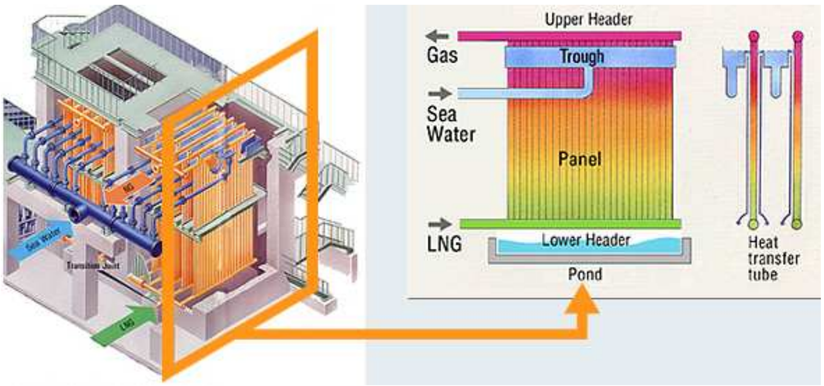

Figure 18: Bird’s-eye view of the ORV, construction company Tokyo Gas.

4.4.2 Submerged Combustion Vaporizers (SCV)

It is one of the most used vaporizer in areas with very stringent emission limits, or within areas where there is no other available heat source and because it can be used to utilize boil-off gas. A typical SCV is composed from a water bath in which there is construction of stainless steel tubing. LNG flows through this tubing. Inside to water bath there is also a submerged gas burner. This burner heats directly the surrounded water with hot flue gases. A distributor which is located under the heat transfer tubes is used in order to dispense the gases into the water. The sparging action creates turbulence through the tubes resulting in a very high thermal efficiency (over 98%) and high heat transfer rates.

Because the system works under constant temperatures leads to high thermal capacities, giving an advantage to sudden load changes, startups and shutdowns.

Due to the combustion process which takes place it is produced carbon dioxide (CO_2) which is condensed in the water casing acidic environment. In order to protect tubing from corrosion it has to be adjusted the pH, for this reason are used chemicals like sodium carbonate or sodium bicarbonate. The excess combustion water before to being discharged to open sea it has to be neutralized. Following up environmental restrictions regarding NOx emissions many SCV units are consisted of NOx burners. These burners limit NOx emissions to 40ppm, this value can be reduced further if selective catalytic reduction units will be used. Then the NOx values can be reduced even to 5ppm.

The design of a SCV is capable to handle a maximum output of natural gas of 200MMscfd. SCV are very reliable during their operation and it is very easy to be detected any possible gas leakage. Also, it does not take enough time for the unit to shutdown in case of emergency. Moreover, the possibility of explosion is very low due to the fact that the temperature inside the water bath is very low compared to the ignition temperature of natural gas. Another advantage of SCV is that they do not demand large tracts of real estate since they are very compact. There are two disadvantages regarding SCV. The first one is the regular maintenance of the system which is demanded due to the complexity of the system (piping, air blowers, and burner). The second one is that SCV system requires 1.5% of the total vaporized LNG as fuel that is a significant operating cost to regasification terminals. In the below figure 19 an SCV system is depicted. [1, 17, 18]

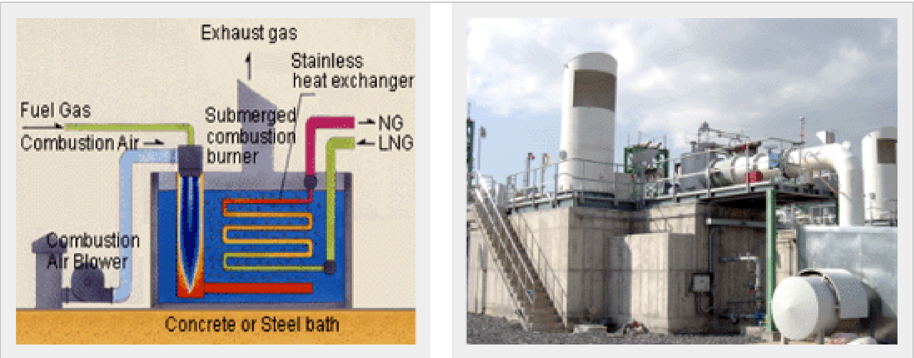

Figure 19: In the right is depicted a Submerged Combustion Vaporizer. Courtesy of Wonil T & I and Sumitomo Precision Products.

4.4.3 Ambient Air Vaporizers (AAV)

Ambient Air Vaporizers is another type of vaporizers which use air as heat source. The choice of using an AAV is due to strict environmental rules which exist in some countries and seawater as heat source cannot be used. Compared to ORVs and SCVs, AAVs are more environmentally friendly and cost competitive. On the other side, the number of vaporizer units is much higher and it is required larger construction area. In areas where the climate is hot and humid fog is formed to the outlet of the system which may be a problem to the surrounding area.

There are two types of ambient air vaporizer for LNG terminals; direct air vaporizer and indirect air vaporizers that use an intermediate fluid. Direct air vaporizers are vertical heat exchangers used mostly in peak shaving plants in small LNG terminals. During their operation ice is formed to the external part of tubing and for this reason it is demanded periodically defrosting. Automatic switching valves are installed that allow automatic defrosting; their operation is based on timers.

A typical ambient air vaporizer is consisted of long, vertical direct contact exchange tubes that expedite downward air draft. Ambient air as enters vaporizer is warmer and less dense, for this reason is found on the top, contrariwise colder denser air being at the bottom. Ambient air vaporizers utilize air in natural or forced draft arrangement. The outlet of exchanger is a mixture of cold, dried air and condensed water; this can be used as source of potable and/or service water.

For the normal operation of the AAV it is needed a periodically deicing or defrosting in order to avoid ice formation to the tubing. This is done every 4 or 8 hours depending on the operating hours of the heat exchanger, as longer as it works more defrosting time is demanded. Defrosting process can be done even naturally or by forced draft air fans. The use of forced draft air fans can save time from non-operational hours but requires additional horsepower. However, it is proved that the aforementioned defrosting technic can be marginally faster because ice layers that are formed in the surface of tubing work like insulation and heat transfer is done slowly. Most of the times the choice of using forced draft air fans is done in order to minimize the fog which is generated because they disperse it. The formation of fog is a natural phenomenon due to the contact of cold air coming from the outlet of exchanger and the warm, moisture air of surroundings. The formation of fog depends on many parameters like the outside temperature, relative humidity, wind conditions, the distance between the units and the quality of LNG inlet. Ambient air vaporizers are preferred mostly in hot climate equatorial regions where ambient temperature is high all year round, whilst in subequatorial regions in winter time may be required supplementary heating system. In figure 20 is represented a typical Ambient Air Vaporizer. [1, 17]

Figure 20: Thermafin™ Supergap™ Ambient Vaporizer. Product of company Thermax Inc.

4.4.4 Glycol-Water Intermediate Fluid Vaporizer (IFV)

There is another type of vaporizers called Intermediate Fluid Vaporizers (IFV). This type of vaporizer uses an intermediate fluid as a heat source to the LNG vaporizers. Heat transfer fluid (HTF) is found in a closed loop and its scope is to transfer heat from a heat source to the LNG vaporizers. HTF most of the times is ethylene glycol, propylene glycol, hot water, hydrocarbon based HTF or any other fluid which has low freezing heat transfer. The choice it depends to the construction company and to the ambient conditions of the area. The main parts of an intermediate fluid vaporizer system are a surge drum, a glycol-water recirculation pump, a heating system for HTF, a shell and tube exchanger.

In this part it will be discussed the IFV which uses as heat transfer fluid glycol-water mixture. The warm glycol-water heat transfer fluid passes through the shell and tube exchanger where liquefied natural gas passes to gaseous phase. The cold glycol-water fluid which exits from IFV is pumped from the glycol-water pumps. Upstream to this pump there is a surge drum which scope is to balance any differences in volume occurring during the startup or shutdown of the system. Glycol-water fluid has to be heated again in order to continue to the IFV. There are many solutions to warm up glycol-water; for instance seawater heater plate and frame exchanger, air heater, reverse cooling tower, waste heat recovery unit or fired heater. Due to high heat transfer coefficient IFV has a very compact design. In the figure 21 there is a schematic approach of the intermediate fluid vaporizer process. [1, 17, 18]

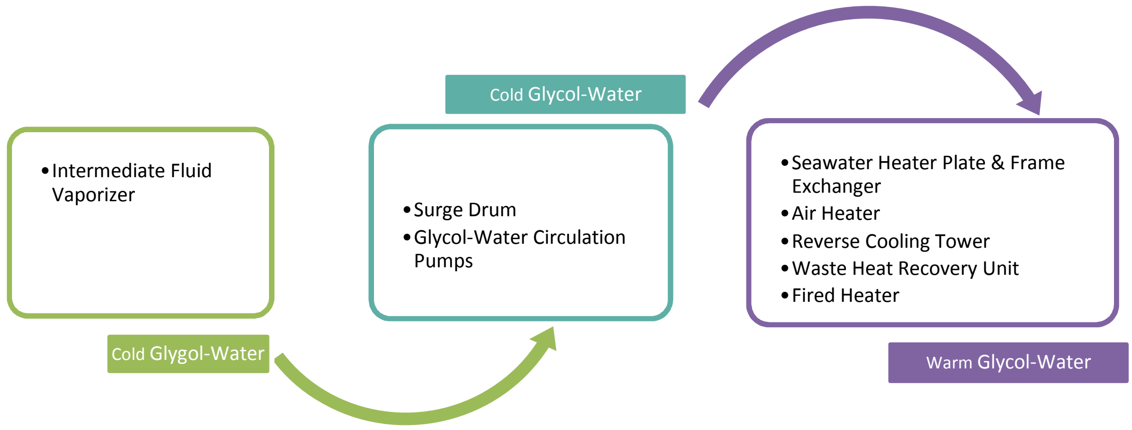

Figure 21: Intermediate Fluid Vaporizer process.

4.4.5 Hydrocarbon Heat Transfer Fluid (HTF)

In many regasification power plants where seawater is used as heat source due to climate conditions, there is the possibility to be encountered freezing problems. For this reason it is very common the use of propane, butane or hydrocarbon refrigerants. The aforementioned refrigerants are used as intermediate heat transfer fluids (HTF) because they allow the usage of seawater at very low temperatures even to 1˚C. At this case in order to transform LNG to natural gas it is used two heat exchanges in series. The process goes as follow:

LNG enters the first heat exchanger which is an evaporator exchanger named LNG Vaporizer. This exchanger uses the latent heat of propane condensation to heat partially LNG. Natural gas exits from the top of LNG Vaporizer whilst from the bottom exits liquid. Downstream to LNG Vaporizer there is an intermediate fluid vaporizer (IFV) circulation pump which boosts preheated liquid natural gas to the second heat exchanger called IFV Vaporizer. This second vaporizer utilizes as heat fluid seawater. Seawater enters to the vaporizer and heats the preheated LNG causing a phase change to gas. Natural gas exits from the bottom of IFV Vaporizer and enters to NG Expander. Afterwards passes from a seawater heater and NG enters to metering station. The second exchanger is used also to vaporize propane which is recycled to the first exchanger. Liquid exits from the top of IFV Vaporizer in the form of High Pressure (HP IFV) vapor and enters to IFV Expander. At the outlet pressure is dropped at low pressure (LP IFV) and goes back to the first heat exchanger. In the below figure 22 it is depicted a schematic picture with the process of an IFV by the company Kobe Steel. In order to protect tubes from erosion/corrosion they use titanium material.

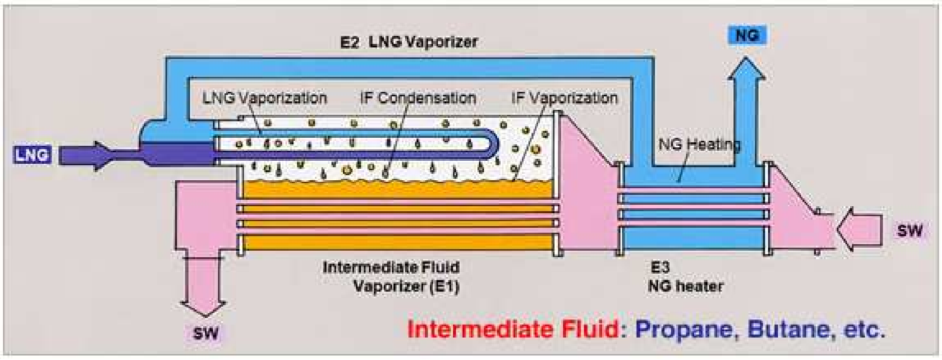

Figure 22: Intermediate Fluid Vaporizer by KOBE STEEL. The symbols represent correspondingly: E-1: Intermediate fluid (shell side) is vaporized by seawater (tube side).E-2: LNG (tube side) is vaporized by the heat from the condensation of the intermediate fluid (shell side). Intermediate fluid is condensed by LNG on the surface of the tubes and dropped to the bottom of the shell. E-3: NG (shell side) is heated by seawater (tube side) up to an ambient temperature.

It has proved experimentally that an IFV heat exchanger can still operate at winter time when it uses as fluid propane. In order to be achieved this seawater temperature is not allowed to go lower than -1.5˚C. Of course, in such circumstances the heat exchanger continues to operate but in reduced rates. When seawater temperature drops down to 5 ˚C the performance of an IFV exchanger is still at the same levels, but when temperature of seawater drops further this concludes that also LNG throughput will also drop. The correlation between LNG throughput (ton/hr) and seawater temperature (˚C) is a linear reduction. At 5 ˚C of seawater LNG throughput is 200 ton/hr whilst at 1 ˚C of seawater LNG throughput is 75-80 ton/hr. [1, 17, 18]

4.4.6 Choice of Vaporizer

The right choice of the suitable vaporizer depends basically to the environmental conditions of the site location. Also, it has to be examined the operability of the system and the frequency of maintenances. For this reason, in warm climates found in equatorial zone the choice of the vaporizer defers from the choice in cold sub-equatorial zones.

In warm ambient locations with temperature above 18˚C during the whole year the most favorable vaporizers are ambient air vaporizers (AAV) and air heated intermediate fluid type vaporizers (IFV). It has proved that both vaporizers can cover the needs of a regasification power plant without the need of trim heating. The first choice of selection is intermediate fluid vaporizer (IFV) using as a heating medium glycol-water/air, the second choice is ambient air vaporizer (AAV) with heating medium air, the third choice is open rack vaporizer (ORV) with heating fuel seawater, the fourth choice is intermediate fluid vaporizer (IFV) using as a heating medium glycol-water/seawater, the fifth choice is intermediate fluid vaporizer (IFV) using as a heating medium propane/seawater and the sixth choice is submerged combustion vaporizer (SCV) using as heating fuel hot water-fuel gas/waste heat. In the final choice of the vaporizer it has to be included as well the space requirements for the construction, the investment cost and operating costs.

In cold ambient locations where site temperature can drop below 18˚C the choice of the proper vaporizer is also important because in this case heating systems which use as a heating medium seawater or air may not be able to conform to vaporization duty. In many circumstances an additional external heating may be required especially in winter months. Because of the cold ambient air temperatures it is preferred the usage of intermediate fluid vaporizers. Taking into consideration the aforementioned the first choice of selection is open rack vaporizers (ORV) combined with submerged combustion vaporizers (SCV) using as a heating medium seawater/fuel gas. The second choice is intermediate fluid vaporizer (IFV) combined with fuel heating vaporizer (FH) with heating medium glycol-water, seawater/fuel gas, the third choice is intermediate fluid vaporizer (IFV) combined with fuel heating vaporizer (FH) with heating medium glycol-water, air/fuel gas, the fourth choice is ambient air vaporizers (AAV) combined with submerged combustion vaporizers (SCV) the heating fluid her is air and fuel gas, the fifth choice is submerged combustion vaporizer (SCV) using as heating fuel how water, fuel gas/waste heat, fuel gas and the sixth choice is intermediate fluid vaporizer (IFV) combined with fuel heating vaporizer (FH) with heating medium propane, seawater/fuel gas. [17]

5. LNG Transportation by Ships

The transportation of LNG requires the construction of specific ships, LNG carriers, due to the need to carry cargo at atmospheric pressure, or under pressurized conditions at cryogenic temperature (-160˚C). The storage tanks are designed to maintain cargo at 0.7 barg, but in normal operation the pressure is 0.3 barg. The design of these tanks in based to the insurance of the hull system, insulation techniques and safety precautions. Insulation is necessary because LNG has to be maintained at low temperature, however they are always some losses and some liquid boils off during the voyage. It has proved that LNG vaporization is not homogenous. LNG is composed from heavier and lighter components. Methane and nitrogen are two LNG components which have very low boiling point and evaporate more easily leaving the heavier components to the bottom. This phenomenon is called ageing and has as a sequence LNG to become heavier and its heating value as well as the Wobbe Index of LNG to increase over time.

Wobbe Index (WI) was introduced in order to characterize the similarities between gas mixtures when combust and release heat. This approach is based on to the correlation between the heat released during the combustion, the heating value of the gas and its density. The index can be calculated by dividing the higher heating value of the gas by the square root of the gas density or molecular weight relative to air ($I_w = \frac{Vc}{\sqrt{Gs}}$). WI is widely accepted as the most guarantee measure of gas interchangeability. The WI is expressed in British Thermal Units (BTU) per standard cubic foot (scf) or it can also be expressed in megajoules (MJ) per standard cubic meter (Sm^3) (1,000BTU/scf = 37.3 MJ/Sm^3). For a typical LNG Wobbe Index is 1,367 BTU/scf. The allowed variation in WI is in the range of 5%. If WI is greater than 5% then vaporized LNG is diluted with nitrogen in order to meet pipeline limits, usually 2 to 3%. As it is mentioned above during the voyage it is common the LNG Wobbe Index to increase due to weathering phenomenon. For this reason regasification terminals in remote areas are equipped with nitrogen or LPG injectors to regulate the sendout gas heating value.

In a daily bases 0.10% to 0.15% of the ship volume must be removed in order to keep ship's tanks at a constant pressure. Depending on the design of the vessel, the produced boil-off gas can be either used as fuel in the dual fuel LNG ship's engines or to be re-liquefied and return back to cargo storage tanks.

An LNG carrier with spherical tanks protruding above the main deck can be recognized from their profile and large size; these carriers are designed with pressurized vessels. Gas carriers which transfer LNG at atmospheric pressure inside prismatic tanks can be recognized by their freeboard. In the below paragraphs it will be examined the design of LNG ships and their capacity. The design is based on Gas Codes and the rules of ship classification societies. The International Maritime Organization (IMO) has introduced up to not three Gas Codes apply to all gas carriers regardless of their size.

- Gas carriers built after June 1986 (the IGC Code)
  International Gas Carrier Code (IGC Code) applies to gas carriers built after 01/07/1986. It is an international standard regarding safe transportation by defining design and construction standards.
- Gas carriers built between 1976 and 1986 (the GC Code)
  Carriers which constructed between 31/12/1976 and 01/07/1986 they have to comply with the Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (GC Code).
- Gas carriers built before 1977 (the Existing Ship Code)
  Gas suppliers that have been constructed before 31/12/1976 have to comply with the Code for Existing Ships Carrying Liquefied Gases in Bulk.

Now the IGC Code is under review and its final report will be published by the end of 2014. [1, 19]

5.1 LNG Carriers Containment System

The basic difference between an LNG carrier and other gas supplier tankers is the cargo containment and the handling system. The categorization can be done as; freestanding solid type containments and non-freestanding (membrane) type containments.

5.1.1 LNG Freestanding Tanks

LNG freestanding tanks are also known as independent tanks because they are self-supporting; meaning that they are not part of ship's hull and for this reason they are not estimated to the calculations of the hull strength. The shape of these tanks can be either prismatic or spherical. The first ones are designed by Conch International Methane Ltd whilst the second ones are designed by Moss Maritime in Norway. Both types of tanks are made from aluminum alloy or 9% nickel steel with layers of insulation at the outside part. There are three categories of independent tanks; Type A, Type B, Type C.

5.1.1.1 Independent Tank Type A

These tanks are designed accordingly to classical ship structural analysis procedure. These tanks are characterized as gravity tanks and have plane surfaces. Here the design vapour pressure P_0 is less than 0,7bar.

Design vapour pressure (P_0) is the maximum gauge pressure (barg) at the top of the tank and this pressure is used during the design phase of the tank. When a cargo tank is lacking of temperature control system and at the same time pressure of the cargo can be dictated only by ambient temperature, P_0 cannot be less than the gauge vapour pressure of the tank at 45˚C. The value of P_0 is directly connected with the temperature of 45 ˚C, however in restricted areas or on voyages of restricted duration or in areas with higher ambient temperature this indicative temperature of 45˚C may be change and accepted by the Society for ships. At these circumstances many parameters have to be considered like insulation of the tanks or P_0 values which cannot be less than the MARVS value (Maximum Allowable Relief Valve Setting). [19]

5.1.1.2 Independent Tank Type B

These types of tanks designed very carefully without making any general assumptions. During the design phase refined analytical tools are used, analytical methods which determine stress levels, crack characteristics and fatigue life. Moreover, many model tests are implemented in order to improve the design of the cargo tanks. Also, type B tanks are gravity tanks where the design vapor pressure P_0 is to be less than 0,7bar. The self-supporting, prismatic type B tanks (SPB) have the advantage over self-supporting, spherical type B tanks (SSB) the usage of the entire available cargo's space. However, they are heavier due to their plates and due to the amount of their bracing; which keep the plates protected from bending. [19]

5.1.1.3 Independent Tank Type C

These type of tanks are called also pressure vessels because they have to comply with pressure vessel criteria which means that they must have design vapour pressure P_0 more than:

$Po = 2 + A \times C(\rho_r)^{1,5}$ [bar] where A stands for $A = 0{,}0185 \times (\frac{\sigma_m}{\Delta\sigma_A})^2$.

In the below table 1 are explained the symbols from the above equation.

Table 1: Explanation of equation's symbols: $\mathbf{Po} = \mathbf{2} + \mathbf{A} \times \mathbf{C}(\boldsymbol{\rho}\mathbf{r})^{\mathbf{1,5}}$. Rules for Classification and Construction Chapter 6, Section 4, Paragraph 4.2.2.4, Edition 2008.

SYMBOL	DESCRIPTION
σ_m	Design primary membrane stress
$\Delta\sigma_A$	Allowable dynamic membrane stress. Double amplitude at probability level Q = 10–8
$\Delta\sigma_A$	55 N/mm^2 for ferritic-perlitic, martensitic and austenitic steels
$\Delta\sigma_A$	25 N/mm^2 for aluminum alloy (5083-0) (Al Mg 4,5 Mn)
C	Characteristic tank dimension to be taken as the greatest of the following: h, 0,75b or 0,45l
h	Height of tank (dimension in ship's vertical direction) [m]
b	Width of tank (dimension in ship's transverse direction) [m]
l	Length of tank (dimension in ship's longitudinal direction) [m]
ρ_r	Relative density of the cargo (ρ_r = 1 for fresh water) at the design temperature.

If the cargo's carriage has relative density greater than 1, then the dynamic pressure differential has to be calculated from the below formula:

$$\Delta_\rho = \frac{\rho}{1{,}02 \times 10^4}\left[a\beta 1 \times z\beta 1 - a\beta 2 \times z\beta 2\right] \text{ [bar]}$$

Where $a_{\beta 1}$ and $z_{\beta 1}$ are the two values which give the maximum liquid pressure $(P_{gd})_{max}$, whilst $a_{\beta 2}$ and $z_{\beta 2}$ are the two values which give the minimum liquid pressure $(P_{gd})_{min}$. For the calculation of Δ_ρ (maximum differential pressure), it has to be evaluated the full range of acceleration ellipse, figure 23 depicts Δ_ρ value. [19]

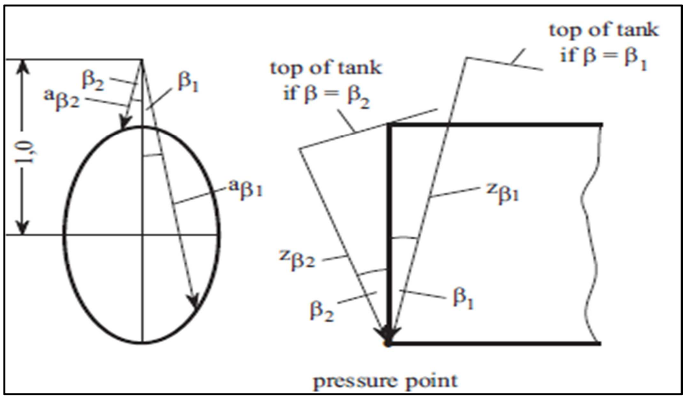

Figure 23: Determination of Δρ. Rules for Classification and Construction, Chapter 6, Page 4-2, Section 4, Paragraph 4.2.2.4,

5.1.2 LNG Non-Freestanding Tanks

Non-freestanding tanks also known as membrane tanks are non-self-supported cargo tanks due to this reason they are surrounded by a complete double hull ship structure which is insulated. These tanks consist of a primary barrier which is a thin layer of metal, after intervene insulation which is followed by a second barrier and the last layer is again insulation material. The design and the construction of these tanks are done in such way in order to prevent any possible thermal or other expansion phenomenon and to avoid stressing of the membrane. Practically the outer tank is the ship's hull followed by insulation material and then a thin layer of membrane is installed inside to retain the liquid. The material which is used for this double hull ships are either high nickel content steel (36%) or a mixture of 18% chrome with 8% nickel stainless steel. The first material is offered by Gaz Transport whilst the second one is offered by Technigaz. Gaz Transport membrane containments are consisted of a grillage structure which is constructed by plywood and filled with perlite, this helps to keep membrane tight as well as insulation. On the other hand, Technigaz follows a different membrane system that includes a double layer system made of reinforced polyurethane foam which is separated by another material called triplex. This construction provides a complete insulation system. Now these two companies have been merged and they formed a new type of containment system called Combined System Number 1 (CS1). This new containment system incorporates characteristic from both previous aforementioned systems and for this reason it includes two membranes and reinforced polyurethane foam as insulation material. The first membrane is made from Invar and it is 0,7mm thick whilst the second one is made from triplex (aluminum-glass fiber). The usage of this containment system is very easy because it is prefabricated and it can be installed very easy onboard.

In this type of containment system the design vapour pressure P_0 in normal operations will not exceed 0,25bar. There is the possibility the design vapour pressure to be increased but many parameters have to be considered, like increase of hull scantlings or increase of insulation supporting system. If these changes are considered then design vapour pressure can be increased until 0,7bar. The standard of the membrane thickness should not exceed 10mm. [1, 19]

5.2 LNG Cargo Containment Design Characteristics

During the design phase of LNG cargo containment many parameters have to be considered. In the below paragraph it will be explained briefly some of them.

- Design Loads

  Tanks with their supports and other fixtures are designed taking into consideration the contribution of various loads like internal pressure, external pressure, thermal loads, sloshing loads, dynamic loads (caused by the ship's movement), tank and support weight, insulation weight, loads related with ship deflection. Very carefully studies are implemented in order to estimate how these loads can contribute to tank's design and operation as well.
- Structural Analysis

  This depends to the type of LNG containment system which will be chosen and defers to each case.
- Allowable Stresses and Corrosion Allowance

  Allowable stress also here depends to the type of LNG containment cargo. For each case separately guidance can be found in ''Rules for Classification and Construction'' by GL (edition 2008). Regarding the thickness of the containment which is a result from the structural analysis that has been done no corrosion is allowed. For pressure vessels which carry no-corrosive substances and their external surface is protected by inert atmosphere or by insulating material then no corrosion allowance is required. Moreover, no corrosion allowance is required when special alloys are used. If the aforementioned conditions are not satisfied then scantlings have to be increased accordingly to the structural analysis.
- Supporting

  Cargo tank is constructed in such way that cargo containment is supported by the ship hull. This structure has to provide stable conditions when tank is under static and dynamic loads and at same time to enable contractions and expansion of the tank when temperature variations exist. The construction of supports has to be in accordance with the largest acceleration and rotational movements of the ship. The design of supporting system has to incorporate also the collision forces which acting on the tank. These are 0,5g in the forward direction and 0,25g in the aft direction.
- Secondary Barrier

  A secondary barrier is provided in order to protect any possible leakage due to failure of primary barrier. This is done when the temperature is below -10˚C at atmospheric pressure. The hull structure can also act as second barrier when surrounded temperature will not go beyond -55˚C at atmospheric pressure. In such cases the material of the hull has to be suitable to maintain any possible leakage and moreover it has to be able to withstand such temperatures without to suffer from stresses problems. In below table 2 there is a schematic presentation of the secondary barriers in relation to the primary barriers.

Table 2: Secondary barriers in relation to tank types. Rules for Classification and Construction, Chapter 6, Page 4-13, Section 4, Paragraph 4.7, Edition 2008.

Cargo temperature at atmospheric pressure	– 10 °C and above	Below – 10 °C down to – 55 °C	Below – 55 °C
Basic tank type	No secondary barrier required	Hull may act as secondary barrier	Separate secondary barrier where required
Integral		Tank type not normally allowed [1]	
Membrane		Complete secondary barrier	
Semi-membrane		Complete secondary barrier [2]	
Independent: Type A		Complete secondary barrier	
Type B		Partial secondary barrier	
Type C		No secondary barrier required	
Internal insulation: Type 1		Complete secondary barrier	
Type 2		Complete secondary barrier is incorporated	

1 A complete secondary barrier will normally be required if cargoes with a temperature at atmospheric pressure below – 10 °C are permitted in accordance with 4.2.1.3.

2 In the case of semi-membrane tanks which comply in all respects with the requirements applicalbe to independent tanks type B, except for the manner of support, the Society may, after special consideration, accept a partial secondary barrier.

- Insulation

During LNG transportation one of the basic parameters that have to be maintained steady is the cargo temperature. When cargo temperature is below -10˚C then the suitable insulation material has to be chosen. This ensures that temperature of the hull structure will not fall below the minimum allowable design temperature, when ambient air temperature is 5˚C and sea water temperature is 0˚C. This is the general accepted conditions but there are some circumstances where the ambient temperatures may deviate, for this reason Society for the ships can make an exception. Specifying the right design temperature is very important because due to this are chosen the construction material for the ships. These temperatures can be found in International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk. Taking into consideration the temperatures of ambient air and sea water as mentioned above there is the approval to be used heating system in order to protect materials from being damaged and not fall below the minimum allowable values. The design and construction of heating system has to be in accordance of the given specification by Society.

- Materials

Materials used for cargo construction must comply with design temperature of equipment. All the parts of the ship like plates, pipes, sections, forgings, weldments, castings, pressure vessels, process piping and secondary barriers are selected according to this. Moreover, insulation material has to comply as well with design temperature of cargo. In the below tables are shown the composition of construction material. Table 3 represents the element composition of plates, sections and forgings related to cargo tank, secondary barrier and pressure vessels which are working below -55˚C until -165˚C. Table 4 depicts the construction material for pipes, forgings and castings for cargo from 0 ˚C to -165 ˚C. In very low temperatures the materials which are used most are aluminium alloys like 5083 annealed, austenitic steels such as 304, 304L, 316, 316L, 321 or 347and 9% nickel steels.

Table 3: Plates, Sections and Forgings for Cargo Tanks, Secondary Barriers and Process Pressure Vessels for Design Temperatures below – 55 °C and down to – 165 °C. Rules for Classification and Construction, Chapter 6, Page 6-5, Section 6, Paragraph 6.2, Edition 2008.

Minimum design temperature [°C]	**Chemical composition [4] and heat treatment**	**Impact test temperature [°C]**
– 60	1,5 % Nickel steel – normalized	– 65
– 65	2,25 % Nickel steel – normalized or normalized and tempered [5]	– 70
– 90	3,5 % Nickel steel – normalized or normalized and tempered [5]	– 95
– 105	5 % Nickel steel – normalized or normalized and tempered [5, 6]	– 110
– 165	9 % Nickel steel – double normalized and tempered or quenched and tempered	– 196
– 165	Austenitic steels (e.g. type 304, 304L, 316, 316L, 321 and 347) Solution treated [7]	– 196
– 165	Aluminium alloys; e.g. type 5083 annealed	Not required
– 165	Austenitic Fe-Ni alloy (36 % nickel) heat treatment as agreed	Not required

Tensile and Toughness (Impact) Test Requirements

Plates Each "piece" to be tested

Sections and Forgings Batch test

Charpy V-notch Test

Plates Transverse test pieces. Minimum average energy value (E) 27 J

Sections and forgings Longitudinal test pieces. Minimum average energy value (E) 41 J.

Notes:

1 The Impact test requirement for forgings used in critical applications will be subject to special consideration.

2 The requirements for design temperature below – 165 °C are to be specially agreed with the Society.

3 For materials 1,5 % Ni, 2,25 % Ni, 3,5 % Ni and 5 % Ni, with thickness exceeding 25 mm, the impact tests are to be conducted as follows:

Thickness [mm]	**Test Temperature [°C]**
25 < t ≤ 30	10° below design temperature
30 < t ≤ 35	15° below design temperature
35 < t ≤ 40	20° below design temperature

In no case shall the test temperature be above that indicated in the table.

The energy value is to be in accordance with the table for the applicable type of test specimen. For materials exceeding 40 mm in thickness, the Charpy V-notch values are to be specially considered. For 9 % Ni, austenitic stainless steels and aluminium alloys, thickness greater than 25 mm may be used at the discretion of the Society.

4 The chemical composition limits are to be approved by the Society.

5 A lower minimum design temperature for quenched and tempered steels may be specially agreed with the Society.

6 A specially heat treated 5 % Nickel steel, for example a triple heat treated 5 % Nickel steel may be used down to – 165 °C upon special agreement with the Society, provided that the impact tests are carried out at – 196 °C.

7 The impact test may be omitted subject to the agreement with the Society.

- Construction and Testing

Due to ship construction the majority of parts are welded. Especially for independent tanks the type is butt weld, full penetration. Nozzle welds are also full penetration type. For all these welding radiographic inspections have to carry out in order to prove the success of welding procedure and their durability. [19, 20]

Table 4: Pipes (seamless and welded), Forgings and Castings for Cargo and Process Piping for Design Temperatures below 0 °C and down to –165 °C. Rules for Classification and Construction, Chapter 6, Page 6-5, Section 6, Paragraph 6.2, Edition 2008.

Minimum design temperature [°C]	Chemical Composition[5] and Heat Treatment	Impact Test	
		Test temperature [°C]	Minimum average energy (E) [J]
– 55	Carbon-Maganese Steel. Fully killed fine grain. Normalized or as agreed [6]	4	27
– 65	2,25 % Nickel steel. Normalized or normalized and tempered [6]	– 70	34
– 90	3,5 % Nickel steel. Normalized or normalized and tempered [6]	– 95	34
– 165	9 % Nickel steel [7]. Double normalized and tempered or quenched and tempered	– 196	41
	Austenitic steels (e.g. types 304, 304L, 316, 316L, 321 and 347). Solution treated [8]	– 196	41
	Aluminimum alloys; e.g. type 5083 annealed		

Tensile and Toughness (Impact) Test Requirements	Each batch to be tested.
Impact Test	Longitudinal test pieces.

Notes:

1 The use of longitudinally or spirally welded pipes is to be specially approved by the Society.
2 The requirements for forgings and castings may be subject to special consideration.
3 The requirements for design temperatures below – 165 °C are to be specially agreed.
4 The test temperature is to be 5 °C below the design temperature or – 20 °C whichever is lower.
5 The composition limits are to be approved by the Society.
6 A lower design temperature may be specially agreed for quenched and tempered materials.
7 This chemical composition is not suitable for castings.
8 Impact tests may be omitted subject to agreement with the Society.

5.3 Selection of LNG Containment System

For the selection of LNG containment system many parameters have to be taken into consideration. Since the design of these containments is done in accordance with specified guidelines, safety requirement and reliable construction techniques the final choice has to include also other parameters. The basic parameter is economic, based on the price, the delivery time, the shipyard expenditures and cargo's availability.

Free standing tanks can be separated into two types; the prismatic and spherical type. The prismatic type containment used in ships has the most operating years of experience and it has proved that up to know any barrier failure happened. The advantage of prismatic tanks is that after the fulfilment of construction works they can be tested and inspected prior to their installation. Their structure is analyzed very thoroughly and this minimizes the failure due to fatigue. Also, when they compared with membrane system they have the advantage that when hull is damaged the possibilities to transfer this problem to the rest of the cargo tanks is very small almost negligible. Also, prismatic tanks make more efficient use of cubic space.

Spherical freestanding tank system is easy to be analyzed structurally and this makes it more reliable. Also, the tank's structure is independent of hull and they leave more free space between hull and cargo tanks. One of the most important advantages that they have is that in case of cargo pump failure can be pressurized in order to discharge the remaining LNG. They provide the safest system in event of grounding or collision.

Membrane tank system is more vulnerable in case that vessel's hull is damaged. It is easier this damage to be transmitted from tank structure compared to freestanding system. Some activities which have to be carry out like inspection or repair activities of membrane and surging of cargo tank can cause damages to the membrane. Moreover, the structure of tank is very difficult to be analyzed and this does not prevent fatigue failures. This consequently can lead to higher repairing costs and demanding time for reconstruction activities. The membrane tank system has gained ground in the last few years because utilizes the hull shape more efficiently leaving less free space between cargo tanks and ballast tanks. Statistical analysis revealed that between the period of 2001-2011 three-quarter of the new LNG ship carriers use this type of tanks because they offer grater cargo capacities and the initial capital cost which is demanded is lower. [1, 19, 20]

6. LNG Carrier Cargo Capacities

LNG ships can be found in many different sizes vary from 19,000 m^3 until 275,000 m^3. Most LNG ships are between 125,000 m^3 and 140,000 m^3 capacity. A typical construction of LNG ship includes five spherical tanks capacity 25,000 m^3 each one. However, in the last decades larger LNG ships are under operation. Q-Flex and Q-Max with capacities 216,000 m^3 and 265,000 m^3 correspondingly are built in order to serve long-distance supply chains. The innovation part of an LNG ship is the propulsion system which uses. New LNG ships use slow-speed diesel engines, which are more efficient, environmentally friendly and easier to operate and maintain them. The problem with boil-off gas in these LNG carriers has been solved due to re-liquefaction system which involve. LNG terminals correspond to the new capacities of Q-Flex and Q-Max carriers and moderate accordingly their facilities.

In the last few years small scale LNG carriers are constructed. This immergence came due to the need of clean fuel power plants in remote areas (industrial or islands), to supply fuel in regions at which pipeline grid cannot reach, to facilitate partial filling and quick replenishment to final consumers when there is peak in energy demand. In year 2003/5 two LNG ships with capacity 2,500 m^3 have been in service in Japan for coastal LNG transportation. Now, is under construction in the same area another LNG ship with capacity 19,000 m^3; it is composed by three spherical tanks. An Australian company develops projects for transportation capacities up to 30,000 m^3. Anthony Veder (NL) Company is building now in Norway a new LNG/Ethylene carrier with capacity 7,500 m^3.

In small scale LNG carriers, the containment system is designed mostly according to independent type C tanks, following the IMO standards and IGC Code. Initially the aforementioned vessels were constructed to carry ethylene and afterwards upgraded to transfer also LNG. The choice of using independent type C tank as containment system is due to:

- Self-supporting pressure vessel
- Tanks are fabricated outside the carrier and this makes them more cost competitive
- Do not required a secondary barrier
- No restrictions concerning partial filling
- Type C is economical for small LNG carriers compared to large carriers [16, 19,20]

6.1 Small LNG Carrier-Ship Arrangement

LNG ships which transfer liquefied natural gas and the same time they use it as propulsion fuel they have to be in accordance with IGC Code and IMO Resolution MSC.285(86). Also, the same two reports have to be taken into consideration during the phase of ship's arrangement design. Any LNG ship with gas-fueled engine should release a risk analysis report in order to ensure the structural strength and integrity in case of an accident. Moreover, the aforementioned report should include instructions regarding construction, installation, operation and maintenance procedures for LNG ships. In below paragraphs will be analyzed the arrangement of LNG ships. [19, 20]

6.1.1 Arrangement and Exact Location of Spaces

The basic characteristic for ship arrangement is to provide the minimum extent of any possible accident related to the hazardous zones of a ship. Machinery spaces, boiler spaces, service spaces, accommodation spaces, drinking and domestic tank spaces have to be separated from hold spaces. Moreover, hold spaces have to be segregate from each other by single bulkheads and very careful selection of construction material has to be done in order to sustain low temperatures.

6.1.2 Machinery Spaces-Gas-Fueled Engines

For gas-fueled engines the machinery station is found in the same level as LNG tank rooms. There are cases where machineries cannot be settled only to one room and there is need for a second one. At this case these two rooms should be designed in such way in order to ensure that any possible leakage or damage caused to one machinery room will not affect the other. Gas explosion has to be contained or vented from the damaged machinery room without affecting the integrity of the other. The system configuration can be separated into two categories: the first one is Gas Safe Machinery Spaces whilst the second one is Emergency Shutdown (ESD) Machinery Spaces. The main difference between these two configurations is that, machinery spaces under abnormal conditions cannot be characterized as safe in the ESD Machinery Space and may become hazardous. When this happens potentially unsafe equipment and machineries automatically turn off. In case of ESD system there are some restrictions that have to be followed, these are:

Electricity engines and propulsion engines have to be separated into two or more spaces which do not have between them any common boundaries. In case that they have, the common boundary has to withstand explosion. The distribution of machineries has to be done is such way in order to ensure 40% propulsion operation and 100% electricity operation in case of shutdown of fuel supply to any machinery space. Also, inside to gas machinery space the piping pressure should be less than 10 bar and a gas detection system is obligatory to operate continuously so as to be able to detected any possible leakage and consequently if necessary to shutdown the system.

6.1.3 LNG Tank Room

LNG tank rooms have to be separated from the machinery station and the distance between them to be as long as possible. In case that the separation is a cofferdam this should be at lease 900mm and insulation class A-60 has to be fitted on the engine room side. The tank's entrance should be at least 300mm high.

The entrance to the tank room has to be completely independent and direct from open deck. In case that the LNG storage tank does not cover all the room's available space, even then the access to this area has to be from the open deck. If this is not possible then air lock system has to be implemented that conforms to the IGC Code regarding air lock system. During the normal operation of the system the access to tank rooms in not allowed unless there is authorization permit.

6.1.4 Gas Piping Requirements

Gas piping which founds inside tanks area has to be protected from mechanical damages and to be able to assist thermal expansions without developing additional tensions. Piping connections are preferred to be done with welding joints and eliminate as much as possible flange connections. The thickness of the piping has to greater to: $t = \frac{t_0+b+c}{(1-\frac{a}{100})}$ (mm). Where:

- t_0 = theoretical thickness
- $t_0 = {}^{pD}/_{(20Ke+p)}$

- p = design pressure (bar)
- D = outside diameter (mm)
- K = allowable stress (N/mm^2)
- e = efficiency factor equal to 1 for seamless pipes and for longitudinally or spirally welded pipes
- b = allowance for bending (mm), $b = \frac{Dt_0}{2.5r}$ (mm)
- r = radius of bend (mm)
- c = corrosion allowance (mm)
- a = negative value which shows the manufacturing tolerance for thickness expressed in percentage (%)

However, there are occasions where piping thickness estimating from the above equation may be higher in order to provide sufficient mechanical strength and avoid phenomena like damages, excessive sag and collapse. Due to very low temperatures (<-110˚C) stress analysis has to be done for each branch of the piping system. The pipes have to maintain a minimum distance from the ship's wall which is 760mm. Gas piping is avoided to be led through other machinery spaces. Also, gas pipes which are related to nitrogen purging procedure should be also marked clearly in the ship's arrangement. Moreover, relief valves have to be provided in specific parts of the piping where liquid gas exists. [19]

6.1.5 Gas Supply System

LNG propulsion systems can use either a combination of boiler and steam turbine engines or slow-stroke diesel (SSD) engines. Dual fuel engines can use gas fuel (boil-off gas) or liquid (diesel) and regarding the circumstances they can switch between both. It is estimated that 1% of diesel fuel is used in order to ignite the gas engine in the phase of startup. On the other hand, single fuel engines which use boil-off gas as fuel are spark ignition engines. The LNG propulsion system can be classified into three categories: the first is Dual Fuel Diesel Electric (DFDE), the second is gas turbine system which uses boil-off gas and the third is high pressure steam turbines.

- Dual Fuel Diesel Electric (DFDE) propulsion system

  This type of propulsion system offers great exchangeability between boil-off gas fuel and diesel fuel for the LNG cargo. The DFDE system has very high efficiency results and due to its electric propulsion system it requires implementation of frequency converters, electric motors and a high capacity switch gear. The maintenance and the operation of such systems require a well performed and qualified staff. During the design of LNG containment system it is considered that a percentage of 0.10% to 0.15% of the tank's capacity (per day) will be transformed to boil-off gas. This amount is collected and is cooled by a LNG spray pipe. Due to very low temperatures liquid droplets may be formed and for this reason it is used a mist separator. The purpose of mist separator is also to remove any heavy components from the boil-off gas which could cause damage to engines. The treated boil-off gas is passed after to low duty compressors where pressure is increased approximately to 5barg. After, the gas is passed directly to engine injection ramp. In some cases (depending from manufacture of engines) the gas before to enter injection ramp is heated up to 20˚C with the help of gas heaters. In case that boil-off gas is in excess then it goes directly to gas combustion units (GCU). There are some cases where boil-off gas does not fulfill the required amount for DFDE system and additional amount is needed, this is called ‘‘forced boil-off gas’’. This is formed when LNG from cargo tanks sent to forcing vaporizers. There vaporization process takes place with the help of ship's steam. When this process finish fuel gas pumps pressurize the gas until to reach 8barg. The result is the production of FBOG which then is led to mist separators and after to gas heaters. At this stage the produced FBOG is mixed with the normal boil-off gas coming out from the low duty compressors.

- Gas Turbine Propulsion System

  Gas turbine propulsion system is a new innovative technology which has many advantages compared to other propulsion systems. It provides low fuel consumption, increased thermal efficiency, low installation costs, easy maintenance, compact machinery which is very light, increased cargo carrying capacity and low vibrations during voyages. The engines which are used mostly in this propulsion system are aeroengines. The main fuel is gas (either boil-off gas or forced gas) and as back-up fuel it is used marine oil gas (MOG). Gas turbine system is mainly driven by an electric propulsion system. Electricity is produced through gas turbine driven alternators and after distributed to high voltage network which with the help of busbars provides power for the propulsion motors.

- Steam Turbine Propulsion System

  Steam propulsion system is the most used system for all the vessels and it is implemented also to the LNG ships. The supplying fuels are boil-off gas and heavy fuel oil (HFO). The system includes two boilers which produce steam which goes to high and low pressure turbines. Through gearbox steam turbines drive a single helix. Also, the purpose of produced steam is to provide heat to fuel tanks and air-conditioning system, drive electrical generators and power other auxiliaries as well. There are also one or two diesel generators that purpose is to manoeuvring LNG ship into the port and to help LNG vessel during the start up when engines are cold. The basic problem of steam turbine propulsion system is the need of very clean water (demineralized water) for the boilers. The demand of such high water quality and the weight of the boiler add extra costs to the system. It has also proved that the fuel efficiency of the produced high pressure steam system is equal to diesel engine system. [19, 20]

6.1.6 Ventilation System

Ventilation system is one of the most basic parts of an LNG ship. Ducts which are used for this purpose should be always separated between hazardous and non-hazardous areas. The ventilation system is designed in such way in order to be operational all the time regardless the outside temperatures during ship voyages. Ventilation system runs through the below systems; gas supply system, bleed vent line, engine rooms and bunkering lines. Electric motors driving fans are used for this purpose and the constructed characteristics differ from area to area. In case that air lose occurs immediately an audible and visual alarm should work. Operation of the fans has to be independent in order to provide the needed capacity for ship operations. Special attention is given to the ventilated areas which are defined as hazardous. At this case the air inlets are taken from areas which are intrinsically safe and are found at least 1.5m away from ATEX areas. Air outlets from hazardous areas have to be in open areas. The estimation of needed ventilation capacity depends entirely to the volume of the room; in some cases due to the complexity of room's design the required capacity may be increased. If a safe area has an opening to a hazardous area, air-lock system has to be provided and ventilation system has to work at overpressure situation. [19, 20]

6.1.7 Relief Valves

The purpose of relief valves is to maintain pressures between operational limits and not exceed the maximum allowable pressure of the gas system which is 7.5barg. According to the Gas Code any LNG tank should have at least two pressure relief valves. There is the possibility to be installed only one is the tank's capacity is lower than 20 m^3. Pressure relief valves have also to be installed along bunkering lines and to each one gas supply unit (GSU). The types of pressure relief valves can be either spring-loaded or pilot operated. Pilot operated relief valves are used mostly in LNG vessels Type 'C'. The relief valves exhaust through the vent header. After, one or more vent riser guideline vapors to the open atmosphere. It is very important these vent risers to be provided with drain, which maintenance has to be done regularly in order to prevent accumulation of rain water and sudden increases of back pressures. All the pipelines which carry liquid and can be either isolated or not, to have relief valves in order to allow thermal expansions of the liquid. If this is not foreseen then collecting pots have to be installed and vents after to be guided to vent risers. [16, 19, 20]

6.1.8 Cargo Pumps

The pumping system of LNG carriers is designed based on centrifugal pumps. There are two different types of these pumps; the first is the deepwell type and the second is the submerged type. The arrangement of pumps is in such way in order to allow the operation only from one pump or a series of pumps. All LNG carriers use submerged motor pumps because they achieve very low discharge levels when they are installed in the bottom of cargo tanks. Both pump and motor are mounted on the same shaft eliminating by this way any need for mechanical seal or coupling. Because this area is characterized as an ATEX area special cabling is used until the motor terminal. The cool down of the pump and the lubrication system of the pump is based on the cargo flow; for this reason is very important to feed a constant flow to the pump. Level switches to the tank, discharge pressure switches and under-current relay can provide this protection.

Pump room as well as compressor room should have a very good mechanical ventilation system, allowing 30 times air flow changing during one hour. The number and the power of the ventilation fans should ensure that capacity air flow levels will not drop below 50% in case of a sudden shutdown and will be operational when pumps and motors are running. In case that ventilation system is lost an audible and visual alarm must work and inform operators who have the responsibility to solve the problem. If this is not possible then all electrical installations have to be disconnected outside the hazardous area and padlocks to be placed. [16, 19, 20]

6.1.9 Inert Gas System

The purpose of the inert gas system is to maintain positive pressures in hold and/or intermediate spaces in order to prevent explosion phenomena. Inerting operation has to be carried out before aerating an area for inspection or drydock. Also, it is used before moving from a gas-free condition to loading condition. It is very important prior to gassing-up to check oxygen levels. Oxygen concentration should not exceed 5 per cent, sometimes lower concentration is demanded but this depends to the loading terminal guidelines. Another basic parameter that has to be checked is the concentration of moisture inside to the inert gas. Due to very cold temperatures any existed moisture will be condensed. This not only can affect negatively the quality of loaded LNG but also it can cause corrosion problems to cargo storage tanks and hold spaces. In order to prevent this drawback inert gas is dried as it leaves the generator.

There are three types of inert gas:

1. Produced inert gas from fuel burning
2. Produced inert gas from shipboard nitrogen system
3. Pure nitrogen from shore

Regarding LNG carriers it has proved that nitrogen production system found onboard cannot cover ship’s inert gas requirements. When it is needed inerting of cargo tank it is used either nitrogen which is produced to the shore or combustion-generated inert gas produced on ship. [16, 19, 20]

6.1.9.1 Produced Inert Gas from Fuel Burning

Gas carriers most of the times prefer the solution of inert gas production from fuel burning because firstly is not costly compared to the purchase of liquid nitrogen and secondly the inert gas capacity is available both at sea and port. During the combustion of fueled liquid attention has to be given not only to the oxygen concentration of inert gas but also to other parameters as well, like sulphur content which has to be as minimum as possible. In the below figure 24 is depicted the flow diagram of an inert gas generator. The same working principle is used for LNG inerting system.

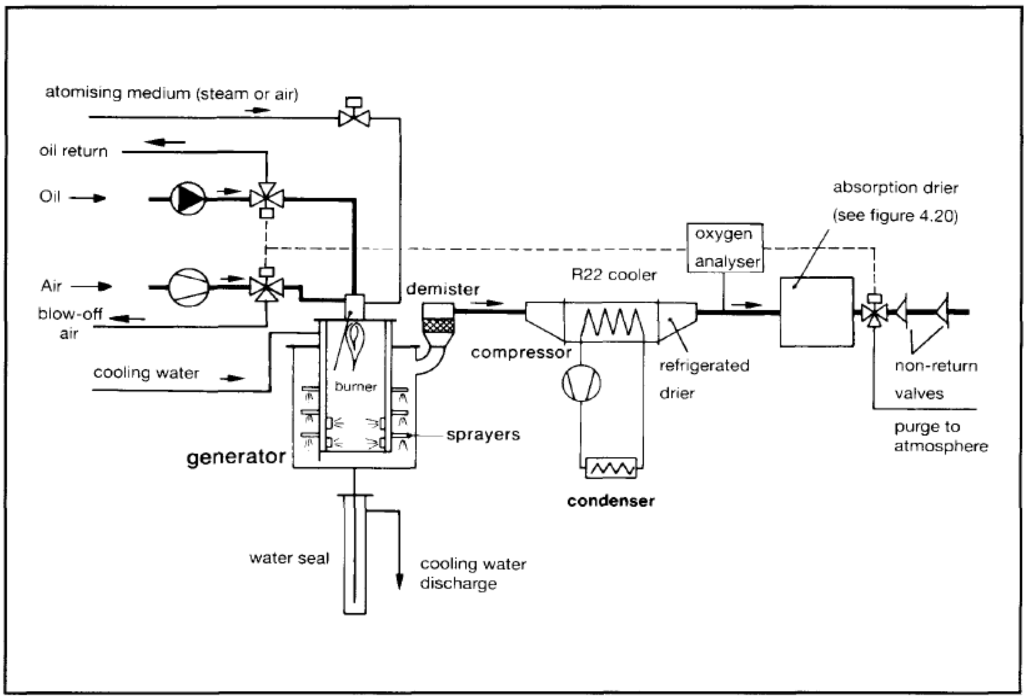

Figure 24: Flow diagram of an inert gas generator, Liquefied Gas Handling Principles, McGUIRE and WHITE, paragraph 4.7.1.

The quality of produced inert gas depends mostly to the manufacturer's instructions for the normal operation of the system. Maintenance procedures have to be followed as planned in order to maintain not only the quality of inert gas in high standards but also to extend the lifetime of equipment. As it is showed in figure 17 the system is composed from one generator (including burner and sprayers), one cooling system, one condenser, one refrigerated drier (which is cooled normally with R22), one oxygen analyzer and one absorption drier. Below will be stated briefly the basic operation procedure of combustion chamber, refrigerated drier and absorption drier.

- Combustion Chamber

  Combustion generators are fitted normally in the ship's cargo engine room. Inert gas is used to fill all the cargo hold positions and also in same cases is piped inside to tank's area. All temporary connections have to be blinded when the system in not in operation. For the main line of inert gas in order to prevent back-flow vapours two non-return valves are installed. When it is not used for inerting purposes regarding fuel loading tanks, inert gas plant is used time to time to fill hold and interbarrier spaces. Inside to the generator chamber it is found the burner, the operation of the burner is designed in such way in order to ensure complete combustion and minimize the possibility to trace high oxygen levels inside to inert gas. For the combustion it is needed also air. Air flow is regulated through valve's openings. After the completion of combustion, inert gas enters the washing section of generator. Due to high combustion temperatures inert gas has to be cooled down. For this reason are installed washing sprayers which use sea water. The purpose of using sea water as a cooling media is also because it can removes acid gases, like sulphur dioxide and oxides of nitrogen. During the reaction are formed solids which have to be removed. The inert gas then exits combustion chamber free of any sulphur content and its temperature is approximately 5˚C higher compared to that of sea water. The only thing that is left is to remove from inert gas water vapours.

- Refrigerated Drier

  After the generator inert gas goes to compressors and then to condenser. The freezing fluid which is used inside to condenser is R22. After the fulfillment of this stage inert gas is guided to refrigerated drier. The purpose of refrigerated drier is to cool down the inert gas in order to minimize the water content. It has proved experimentally that the lower the temperature of inert gas is the less the grams of water per cubic meter. For this reason it is recommended to reach a temperature of 4˚C where saturated water content of inert gas is approximately $6grH_20/m^3$. In the outlet of refrigerator drier it is installed an oxygen analyzer to check continuously oxygen levels of inert gas.

- Absorption Drier

  The inert gas which is coming from refrigerated cooler is driven to two vessels through pneumatic valves. These vessels are filled with activated alumina or silica gel and dry inert gas until to reach dew point equal to -40˚C or below to this value. It is very common these vessels to have at their bottom a layer of sieves in order to improve the dew point. When one vessel is used for drying the inert gas the other vessel can be either in standby mode or to be regenerated. The regeneration process takes place around six hours. During this period the inlet and the outlet valves of inert gas are closed and open only the inlet and the outlet valves of air. The air is heated before to enter the vessel. During the normal operation of the absorption drier there is at the outlet of the vessel one pressure control valve which regulates the pressure changes. This ensures stable pressure conditions along the whole process and at the same time reserves stable combustion conditions inside to the generator. [16, 19, 20]

6.1.9.2 Produced Inert Gas from Shipboard Nitrogen System

A nitrogen shipboard system is a very simple system which operation principle is based to air separation process. Air is a mixture of gases mainly nitrogen, oxygen, carbon dioxide, argon, neon, helium and methane. The separation of nitrogen begins when air passes through air compressors. After, this stage air is guided to filters and then to hollow fiber membranes. Membranes have the capability to capture and separate nitrogen from other gases. The nitrogen which is captured is very clear reaching 95 to 97 per cent purity. The amount of produced nitrogen is a combination of many parameters like; air inlet flow, air inlet pressure and temperature, the number of fiber membranes and finally the demanded nitrogen purity. [16]

6.1.9.3 Pure Nitrogen from Shore

Inert gas is composed mainly from nitrogen. The amount of nitrogen found in inert gas which is produced by combustion is 85 to 89 per cent and the amount which is produced by membrane separating process can be up to 99.5 per cent. Inert gas is not composed only from nitrogen but also from other gases. The quality of inert gas is very important to be kept at high standards because there are very stringent rules regarding oxygen requirements in tank cargoes. For this reason many cargoes are purged with nitrogen coming from shore by trucks. Trucks carry nitrogen in liquid form and for this reason vaporizers are used on board. [16]

6.1.10 Cargo Control Station

All ships have a special room for controlling activities. Control station includes the navigating equipment, emergency source of power, fire recording system. It is prohibited to install a control station inside the cargo area. The purpose of this is to avoid any contact of hazardous gases/vapours in case of piping failure with the controlling machinery. For this reason consideration has to be given in air intakes and openings during design phase and they have to be fitted with closing devices. Regarding the cargo control room this can be installed either above the weather deck or inside to the control station. In the second case same parameters have to be sufficed firstly; like the insurance that control room is a gas safe area and entrances attached to control stations to comply with some design and manufacturing restrictions. [19, 20]

6.1.11 Bunkering Station

The bunkering station of an LNG ship consist one of the most important parts, which is physically and structurally separated from cargo deck and control station. During the loading and unloading procedures the area must be ventilated very well. In case of sudden ventilation loss an audible and visual alarm is energized inside to the bunkering control location. All connections and piping are arranged in such way in order to ensure safe operations during damage of gas piping, avoiding uncontrolled gas discharge. For this reason there is always near to the shore a shutdown valve which works even manually and/or remote. In order to comply with safety regulations it is necessary to be installed under each bunkering connection drip trays. This ensures that any possible spillage or leakage will not contaminate the surrounding area. During the bunkering process operators have to be also in control room and check all the parameters like tank level, tank pressure, overfill alarm etc. [19, 20]

7. Bunkering Procedure

In this section it will be discussed the different types of bunkering facilities, depending on how they store, obtain and bunker LNG to vessels. There are three main bunkering options. The first is bunkering from truck (TTS), the second is bunkering from onshore terminals (TPS) and the third is ship to ship bunkering (STS). There is also a fourth option which is bunkering from container to ship. In the below figure 25 it is depicted graphically all the bunkering solutions which are now under implementation.

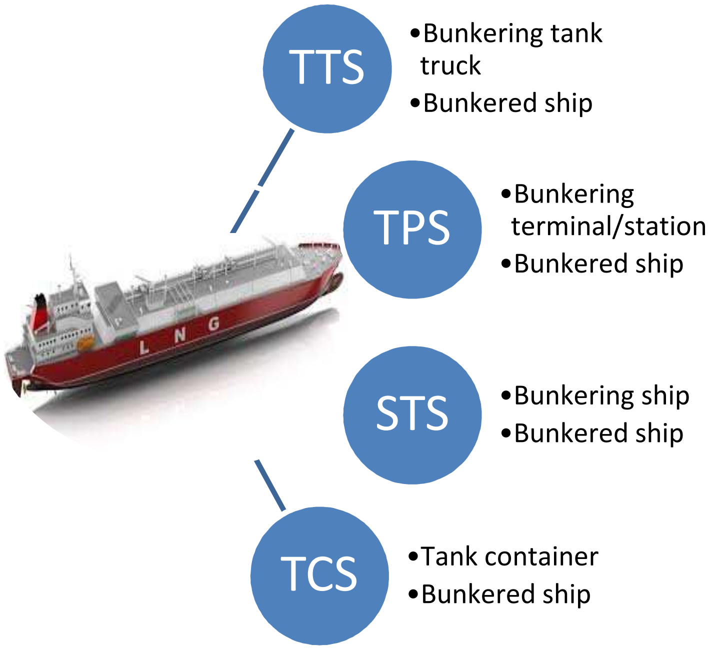

Figure 25: LNG bunkering methods, CLEANSHIP Task 5.6, BUNKERING OF SHIPS THAT USE LIQUEFIED NATURAL GAS OR DUAL FUEL AT KLAIPĖDA STATE SEAPORT.

- TPS Bunkering Procedure

  TPS terminal to ship via pipeline bunkering is the procedure at which LNG ships are fuelled with LNG either from an LNG bunkering station or from an LNG bunkering terminal. TPS bunkering procedure it is used to bunker ships from a permanent bunkering location and in some specific cases to bunker large ships at high intensity. Because of the nature of bunkering, which demands permanent location and high intensity, particular type of LNG ships are used these are linear short-distance ships. In some ports LNG bunkering is used also for bunkering small LNG ships. In bunkering terminals there are different types of LNG tank capacities; this depends on terminal's needs varying from 20 m^3 until 100,000 m^3. The bunkering terminal and the LNG ship are connected between them with connection; like pipes and hoses. The problem which is faced appeared is that these connections are very long burden the bunkering process and increase also the installation costs of the terminals. In order to be solved this problem it is suggested to be installed smaller lengths of connection, and bunkering terminals to be as close as possible to the quays which are used for mooring.

- TTS Bunkering Procedure

TTS tank truck-to-ship bunkering is the procedure at which LNG is bunkered to bunkered ship from LNG tank trucks. This method has the advantage that is very cheap compared to other and for this reason it is used widely in the port quays. In TTS method there is one limitation regarding the volume of bunkered LNG to ships. LNG trucks can carry specific amounts of LNG. These amounts vary from 40 to 80 m^3. For this reason it is recommended to be used for bunkering LNG bunkered ships which have tank capacity from 30 to 200 m^3. It is used widely in small scale LNG ships.

- STS Bunkering Procedure

STS ship-to-ship bunkering procedure is characterized the procedure at which the bunkering ship fills up with LNG the bunkered ship. The conditions at which bunkering procedure can proceed can be either when LNG ship is at the quay, or pier, or in water area (either at the open see or to an anchoring territory). It is recommended that under strong weather conditions; like strong wind, storms, ice etc., to avoid STS bunkering. It is preferred STS bunkering procedure to by exercised by mooring bunkering ship to bunkered ship. The effectiveness of this process is higher when bunkering LNG volumes exceed 100 m^3. The capacities of bunkering ships can vary between 1,000 until 10,000 m^3. In the last years many ports prefer to use bunkering ships with smaller capacities. The opportunity to use LNG as fuel in many different types of ships combined to the advantage of achieving high intensity at high LNG amounts makes STS process very attractive for use.

- TCS Bunkering Procedure

TCS tank container-to-ship bunkering solution is a combination from all the three aforementioned bunkering procedures (TPS, TTS & STS). It can be applied to all types of ships excluding the ships that have large containers. TCS bunkering procedure is the most suitable procedure for bunkering small LNG ships. The application of TCS bunkering procedure is not recommended when ship’s capacities are large enough (1,000 to 1,500 m^3), because these amounts require big storage areas at quays. In order to be covered the above volumes 40 units of LNG tank containers with 35 m^3 capacity per each unit is needed. In order to be transferred the tank container inside to the LNG carrier it is used either crane or container lifter. Cranes can be installed either to the quay side or to be part of ship’s arrangement. Regarding the usage of LNG containers to the TCS tank container-to-ship bunkering solution there are four possibilities.

1) *Usage of LNG containers directly connected to ship engines.*

   This method of TCS bunkering solution has one disadvantage; it minimizes the available space for cargo transportations. When there is a ship which transports cargoes and stores LNG filled tank containers inside to the cargo area it minimizes available transported capacities. Also, there is lack of safety instructions for this method.

2) *Unloading of LNG containers at the quay and their further usage for ship bunkering and filling of LNG tank containers.*

   During the implementation of this method it has to be considered in advance the place at which LNG tank containers will be stored. This is pre-requisite because many different activities have to be arranged to the port, like bunkering of small ships, filling of linear ferries and containers. It has been estimated that this method of TCS bunkering will reduce the traffic of small scale LNG ships in the port. Also, the LNG tank containers which are stored at quays can be hoisted on vehicle transports and transferred to other ports.

3) *The usage of LNG containers in bunkering ships for bunkering of other ships.*

   After the performance of ship bunkering by TCS method, the filled LNG containers can be used as fuel suppliers to other LNG containers or at quays. The remaining empty containers in LNG bunkering ships can be used again after refilling. The refilling procedure can be done from another LNG ship, tank truck or LNG terminal. The advantage of this method is that it is the same to all TCS bunkering types.

4) *The usage of LNG containers in bunkering barges for bunkering of other ships.*

   The same TCS bunkering method which is used for bunkering LNG ships from LNG ship containers which are mounted on ships is also used for ship's bunkering from LNG containers mounted in LNG bunkering barge. The advantage of bunkering LNG containers mounted in LNG bunkering barge, is the usage of small LNG ships and the ability to go sail in shallow waters.

In the below figure 26 it is depicted the advantages as well as the disadvantages of the tree main bunkering solutions; STS, TTS and TPS.

	STS Ship-to-ship	TTS Tank truck-to-ship	TPS Terminal-to-ship via pipeline
Advantages	Flexibility	Flexibility	Availability
	High loading rate	Low costs (investment and operation)	Large bunkering volumes are possible
	Large bunkering volumes are possible		Quick bunkering procedures are possible
	Bunkering at sea (enlarged market)		
Disadvantages	Manoeuvrability in port basins	Small quantities	Fixed to certain quays
	High costs (investments and operations)	Low loading rate	Occupy terminal space

Figure 26: Table 14 Advantages and disadvantages of the different bunkering solutions, from logistical and operational points of view, North European LNG Infrastructure Project: A feasibility study for an LNG filling station infrastructure and test of recommendations, Danish Marine Authority.

Ship-to-ship bunkering solution has many advantages. Its flexibility allows high loading rates and large bunkering LNG volumes for transportation. Moreover, bunkering procedure can take place not only in quays but also at open sea. The disadvantages of this method are the high investment costs and the difficulties in manoeuvring ships at ports. For this reason small LNG ships are gaining nowadays more ground. [6, 21]

7.1 Characteristics of Bunkering Procedure

For the bunkering procedure all companies have to ensure that they follow all the required operations regarding Safety Management System. These procedures should include all the possible risks that may occur and the solutions in order to control them. The following procedures have to be followed by the corresponding company:

- Firstly, communication between supplier and receiver must be finalized before bunkering procedure begins. All open items regarding bunkering procedure and emergency operations have to be clarified in advance.
- It has to be determined that there is adequate space in the receiving tank.
- Loading rates regarding start-up and shut down has also to be decided beforehand as well as tank maximum filling volumes in order to avoid overfilling problems. In case that this happens overfilling arrangement has to be considered.
- All valves related to bunkering procedure have to be checked.
- Ventilation system has to be adequate in order to cover all needs.
- All operations have to be executed by qualified personnel.

The aforementioned bunkering characteristics are the same regarding all available bunkering procedures. There are of course many differences from process to process but the basic idea is to implement bunkering procedure taking into consideration all the needed safety measures. [6, 21]

7.1.1 Characteristics of Bunkering Procedure; Ship to Shore Interface

- Supervision and Control

Regarding communication between ships to shore interface the basic parts are:

- Moorings
- Fenders
- Breasting dolphins
- Hard arms and hoses
- Ship/shore gangways
- Emergency shut-down arrangements
- Ship/shore links, and
- Fire-fighting equipment capability

All terminals around the word have the same arrangement and differ only to the available LNG capacities, both for terminal and LNG ships. LNG projects most of the times contribute contracts of 25 years lifetime. This means that LNG loading terminal, LNG gas carriers and LNG receiving terminal are an integrated part. Safety precautions are the most important issue and for this reason ship and terminal operators have to be familiar with the ship/shore arrangement and operations, the division of each ones responsibility and to ensure a reliable communications between them. These issues are described more detailed in the International Safety Guide for Oil Tankers and Terminals.

Before LNG ships arrive at LNG terminals responsibilities between shipmaster and responsible terminal representative must be separated. This will ensure a safe loading or unloading procedure. Also, before to proceed with any loading or discharge cargo or ballast both ship and terminals representatives have to ensure the readiness to do so. When loading or unloading procedures begin in both sides trained crew must be present and follow the instructions of the responsible officer. It is important to have a continuous watch of tank deck and in case that this is not possible through control room a person has to be arranged only for this job. Terminal staff should watch closely all the loading or unloading procedure until to finish and to check often hosing connections for in possible leakage. In case that this occurs correction actions have to be taken immediately. Finally, stand by requirements related to loading and unloading procedures as well as emergency shutdown system has to be familiar to both parties.

- Design Considerations

Design considerations have to though very carefully for both LNG terminals as well as LNG ships. During the design of a new terminal is established the minimum and the maximum ship size that can cover such needs. When a terminal is ready for operation all the responsible authorities have to be informed; like ship agents, ship-owners associations and port authorities. It is very usual for one terminal to proceed with some modifications due to entrance of new LNG ships which have different characteristics from the originally envisaged. In this case all the modifications have also to be reported to the relevant authorities.

- Communication

Communication between ship and shore begins very early, before the ship to reach its final destination. In order to ensure the compatibility between the ship and jetty information are exchanged betwixt the parties. This information include ship's data like the length of the ship, height of manifolds above the water, ESD system, ship LNG storage capacities, ship's equipment for mooring, hoses connection for shore interface and so on. All these information has to be provided in advance to the terminal's personnel in order to know if the ship can anchor to the terminal. Prior to ship's arrival to the port shipmaster has to inform the responsible person of terminal and to supply all the needed information like; pressure and temperature of cargo, store and bunker requirements, ship's available personnel. Alongside the jetty communication between the two parties has to be performed as well. Both participants have to be in contact and aware of each other actions. The most important part is the ESD (emergency shut-down system) system and its interconnection between the ship and terminal. This system will be energized in case of emergency and relevant shut-down valves will be activated to stop all the ongoing procedures.

Before to start any cargo transfer a meeting has to be arranged between the two parties and to discuss thoroughly all the issues for the ongoing procedure. The basic purpose of this meeting is to ensure a safe loading or discharge cargo operation and to get familiar both parties with the relevant equipment. Any deviations that may exist due to some reason, they have to be discussed and the final resolutions to be written in an official letter. The content of the meeting can include the following issues as shown in table 5:

Table 5: Chapter 6, Paragraph 6.4 Discussion Prior to Cargo Transfer, Liquefied Gas Handling Principles on Ships and in Terminals by McGUIRE and WHITE.

Responsible	**Duty**
Ship/Shore representatives	Provide the names and roles of responsible personnel.
Terminal representative	Checks the implementation of agreed upon issues. Makes inspections to the ship's equipment and tests protocols.
Ship officer	Checks the implementation of agreed upon issues. Makes inspection to the port equipment.
Terminal representative	Check the cargo tank data; cargo quantity, pressure and temperature, tank vapour composition, total quantity of cargo.
Ship/Shore representatives	Agree the quantity and order of unloading cargo. Also, the intended transfer rates, temperatures and pressures as well as the use of return line.
Ship/Shore representatives	Provide the Cargo Information Datasheet to all participants.
Ship/Shore representatives	Review of port and jetty regulations and especially those related to emergency procedures.

- Operational Considerations

For the ship/shore interface the below steps have to be followed:

- Berthing and Mooring
- Connection and disconnection of cargo hoses and hard arms
- Cargo tanks atmospheres
- Cargo handling procedures
- Cargo surveyors
- Gangways and ship security
- Bunkering
- Work permits

In the below figure 27 it is represented a typical Checklist between tanker and shore interface.

Part 'D' Bulk Liquefied Gases – Verbal Verification					
Bulk Liquefied Gases		**Tanker**	**Terminal**	**Code**	**Remarks**
1	Material Safety Data Sheets, or equivalent, are available giving the necessary data for the safe handling of the cargo.				
2	A manufacturer's inhibition certificate, where applicable, has been provided.			P	
3	The cargo deck water spray system is ready for immediate use.				
4	Sufficient protective clothing and equipment (including self-contained breathing apparatus) is ready for immediate use and is suitable for the products being handled.				
5	Hold and inter-barrier spaces are properly inerted or filled with dry air, as required.				
6	All remote control valves are in working order.				
7	The required cargo pumps and compressors are in good order, and the maximum working pressures have been agreed between tanker and shore.			A	
8	Re-liquefaction or boil-off control equipment is in good order.				
9	The gas detection equipment has been properly set for the cargo, is calibrated, has been tested and inspected and is in good order.				
10	Cargo system gauges and alarms are correctly set and in good order.				
11	Emergency shutdown systems have been tested and are working properly.				
12	Tanker and shore have informed each other of the closing rate of ESD valves, automatic valves or similar devices.			A	Ship: Shore:
13	lnformation has been exchanged between tanker and shore on the maximum/minimum temperatures/ pressures of the cargo to be handled.			A	
14	Cargo tanks are protected against inadvertent				

	overfilling at all times while any cargo operations are in progress.				
15	The compressor room is properly ventilated, the electrical motor room is properly pressurized and the alarm system is working.				
16	Cargo tank relief valves are set correctly and actual relief valve settings are clearly and visibly displayed.(Record settings below.)				
17	The operating parameters (opening pressure) of the pressure valves (MARVS) of the tanker have Been considered and agreed.				
18	The (port) authorities have been notified prior to cargo handling, if required.			P	

Figure 27: Part 'D' Bulk Liquefied Gases – Verbal Verification, Appendix 1: Tanker – Shore Safety Check-List, International Safety Guide for Inland Navigation Tank-barges and Terminals, Edition 1 – 2010.

- Fire Fighting and Safety

When the ship is alongside the terminal, fire-fighting measures have already been taken, both on board and shore. Fixed and portable firefighting equipment are in stand-by position in case of emergency and ready to cover ship and jetty manifold area. Hoses attached with their nozzles as well as hoses from fixed dry powder units are laid out. The same also occurs for the firefighting extinguishers. Water spray systems are also available and their availability has to be tested on a regular basis. All personnel including both parties must be trained in order to dial with such circumstances.

Regarding safety precautions check lists are performed in order to assist berth operators and ship operators in their job. Tanker Masters as well as ship operators have to follow strictly these rules as long as the ship is found alongside. The same rules have to be followed as well from terminal representative and shore staff. Both parties have to ensure safe and efficient operations, for this reason they have to collaborate. Inside to these Safety Check Lists are declared each one's responsibilities by ticking the appropriate box, in the end the list is signed from all the parties. This list includes the responsibilities of personnel which are involved to the procedure and all the safety measures that have been agreed between the two parties. In this list there are some responsibilities which belong only to the ship crew whilst other belong only to the shore staff, and there are also some common. The shaded boxes which are included to this list indicate most of the times responsibilities which belong only to one party. The deviation of responsibilities between the two parties does not exclude them from checking that the other part proceeds with the safety measures. In the below figure 28 is depicted the Safety Check List which includes all the main guidelines for completing a safe inspection.

Guidelines for Completing the Safety Check-List					
Part 'D' – Bulk Liquefied Gases – Verbal Verification		**1**	**2**	**3**	**4**
1	**Material Safety Data Sheets, or equivalent, are available giving the necessary data for the safe handling of the cargo.** Information on each product to be handled should be available on board the tanker(s) and/or ashore before and during the operation. Cargo information, in a written format, should include: - A full description of the physical and chemical properties necessary for the safe containment of the cargo. - Action to be taken in the event of spills or leaks. - Countermeasures against accidental personal contact. - Fire-fighting procedures and fire-fighting media. - Any special equipment needed for the safe handling of the particular cargo(es). - Minimum allowable inner hull steel temperatures. - Emergency procedures.	X	X	X	
2	**A manufacturer's inhibition certificate, where applicable, has been provided.** Where cargoes are required to be stabilized or inhibited in order to be handled, tankers should be provided with a certificate from the manufacturer stating: - Name and amount of inhibitor added. - Date inhibitor was added and the normal duration of its effectiveness. - Any temperature limitations affecting the inhibitor. - The action to be taken should the length of the voyage exceed the effective lifetime of the inhibitor. Document should be on board before departure.	X	X	X	
3	**The cargo deck water spray system is ready for immediate use.** In cases where flammable or toxic products are handled, water spray systems should be tested regularly. Details of the last tests should be exchanged. During operations, the systems should be kept ready for immediate use.	X	X	X	
4	**Sufficient suitable protective clothing and equipment (including self-contained breathing apparatus) is ready for immediate use and is suitable for the products being handled.** -Suitable protective equipment, including self-contained breathing apparatus, eye protection and protective clothing appropriate to the specific dangers of the	X	X	X	

	product handled should be available in sufficient quantity for operational personnel, both on board and ashore. -Storage places for this equipment should be protected from the weather and be clearly marked. -All personnel directly involved in the operation should utilize this equipment and clothing whenever the situation requires. -Personnel required to use breathing apparatus during operations should be trained in its safe use. Untrained personnel and personnel with facial hair should not be selected for operations involving the use of breathing apparatus.				
5	**Hold and inter-barrier spaces are properly inerted or filled with dry air, as required.** The spaces that are required to be inerted by the IMO Gas Carrier Codes should be checked by tanker's personnel prior to arrival.	X	X	X	
6	**All remote control valves are in working order.** All tanker(s) and/or shore cargo system remote control valves and their position-indicating systems should be tested regularly. Details of the last tests should be exchanged.	X	X	X	
7	**The required cargo pumps and compressors are in good order, and the maximum working pressures have been agreed between (the two) tanker(s) and/or shore.** Agreement in writing should be reached on the maximum allowable working pressure in the cargo line system during operations.	X	X	X	
8	**Re-liquefaction or boil-off control equipment is in good order.** It should be verified that re-liquefaction and boil-off control systems, if required, are functioning correctly prior to commencement of operations.	X	X	X	
9	**The gas detection equipment has been properly set for the cargo, is calibrated, has been tested and inspected and is in good order.** -Suitable gas should be available to enable operational testing of gas detection equipment. Fixed gas detection equipment should be tested for the product to be handled prior to commencement of operations. The alarm function should have been tested and the details of the last test should be exchanged. -Portable gas detection instruments, suitable for the products handled, capable of measuring flammable and/or toxic levels, should be available. -Portable instruments capable of measuring in the flammable range should be operationally tested for the product to be handled before operations commence. -Calibration of instruments should be carried out in accordance with the Safety	X	X	X	

	Management System.				
10	**Cargo system gauges and alarms are correctly set and in good order.** Tanker(s) and/or shore cargo system gauges should be checked regularly to ensure that they are in good working order. In cases where it is possible to set alarms to different levels, the alarm should be set to the required level.	X	X	X	
11	**Emergency shutdown systems have been tested and are working properly.** Where possible, tanker(s) and/or shore emergency shutdown systems should be tested before commencement of cargo transfer.	X	X	X	
12	**(Both)Tanker(s) and/or shore have informed each other of the closing rate of ESD valves, automatic valves or similar devices.** -Automatic shutdown valves may be fitted in the tanker(s) and/or the shore systems. Among other parameters, the action of these valves can be automatically initiated by a certain level being reached in the tank being loaded, either on board or ashore. -The closing rate of any automatic valves should be known and this information should be exchanged. -Where automatic valves are fitted and used, the cargo handling rate should be so adjusted that a pressure surge evolving from the automatic closure of any such valve does not exceed the safe working pressure of either the tanker(s) and/or shore pipeline systems. -Alternatively, means may be fitted to relieve the pressure surge created, such as re-circulation systems and buffer tanks. -A written agreement should be made between the Responsible Person(s) / Officer(s) and/or Terminal Representative indicating whether the cargo handling rate will be adjusted or alternative systems will be used. The safe cargo handling rate should be noted in the agreement.	X	X	X	
13	**Information has been exchanged between tanker(s) and/or shore on the maximum/ minimum temperatures/pressures of the cargo to be handled.** Before operations commence, information should be exchanged between the Responsible Person(s) / Officer and Terminal Representatives on cargo temperature/pressure requirements. This information should be in writing.	X	X	X	
14	**Cargo tanks are protected against inadvertent overfilling at all times while any cargo operations are in progress.** Automatic shutdown systems are normally designed to close the liquid valves,	X	X	X	

	and if discharging, to trip the cargo pumps, should the liquid level in any tank rise above the maximum permitted level. This level must be accurately set and the operation of the device should be tested at regular intervals. If tanker(s) and/or shore shutdown systems are to be inter-connected, then their operation must be checked before cargo transfer begins.				
15	**The compressor room is properly ventilated, the electrical motor room is properly pressurized and the alarm system is working.** Fans should be run for at least 10 minutes before cargo operations commence and then continuously during cargo operations. Audible and visual alarms, provided at airlocks associated with compressor/motor rooms, should be tested regularly.	X	X	X	
16	**Cargo tank relief valves are set correctly and actual relief valve settings are clearly and visibly displayed.** In cases where cargo tanks are permitted to have more than one relief valve setting, it should be verified that the relief valve is set as required by the cargo to be handled and that the actual setting of the relief valve is clearly and visibly displayed on board the tanker(s). Relief valve settings should be recorded in the check-list.	X	X	X	
17	**The operating parameter (opening pressure) of the pressure valve (MARV) of the tanker have been considered and agreed.** This is the abbreviation for the Maximum Allowable Relief Valve setting on a tanker's cargo tank - as stated on the tanker's Certificate of Fitness / Approval.	X	X	X	
18	**The (port) authorities have been notified prior to cargo handling, if required.**	X	X	X	
19	**If required by the (port) authorities, an external co-ordinator has been appointed and is on board as co-ordinator responsible for the planned cargo handling between the two tankers.**		X	X	

Figure 28: Part 'D' – Bulk Liquefied Gases – Verbal Verification, Appendix 7: Guidelines for Completing the Safety Check-List, International Safety Guide for Inland Navigation Tank-barges and Terminals, Edition 1 – 2010.

- Emergency Shut-Down System (ESD)

It is very important during the cargo loading or discharge operation to be able to stop cargo flow. If an incident happens cargo flow pumps must stop immediately. In most LNG stations, terminal and ship ESD system are linked and work in combination. In terminals at which ship/shore ESD system is not linked directly, more attention has to be given in order to avoid overpressure in connection points. This occurs due to quick closure of isolating valves and reduction of flow. It is preferred during the loading operation of the ship to be energized firstly the terminal's ESD system and after the ESD system of the ship. Whilst, during the ship's cargo discharge is preferred firstly to be energized the ESD system of the ship and secondly the ESD system of terminal. It is recommended ship/shore ESD system to be linked in order to provide more secure operations no matter which party initiates the shut-down. The following figure 29 shows who the ESD system is energized even manually or automatic.

ESD should be initiated by the following EMERGENCIES:	
SHIP	**TERMINAL**
Manual Trip	Manual Trip
Operation of manual trip	Operation of manual trip
Automatic Trip	**Automatic Trip**
Shut-down signal from ashore	Shut-down signal from ship
Overfilling of any cargo tank	Overfilling of receiving tank
Power loss to valve controls	Power loss to arm manoeuvring
Loss of control air pressure	Power loss to ERS
ESD valve moving from full-open	ESD logic failure
ESD logic failure	Fire in terminal area
Fire in cargo area	Loss of electric power
Loss of electric power	Ship movements-pre-ERS
	Activation of the PERC
	High level in surge drum
ESD should initiate the following IMMEDIATE ACTIONS:	
ON SHIP	**ON TERMINAL (LOADING)**
Send shut-down signal to the shore	Send shut-down signal to the ship via the ship/shore link
Trip ship's cargo and spray pumps	Trip loading pump
Trip booster pump	Open spill-back valves
Trip vapor return pressure	Start to close shore ESD valve
Start to close ship's ESO valve	**ON TERMINAL (RECEIVING)**
	Send shut-down signal to the ship
	Start to close shore ESD valve

Figure 29: ESD activation, Paragraph 6.8 Linked Emergency Shut-Down Systems, Liquefied Gas Handling Principles on Ships and in Terminals by McGUIRE and WHITE.

- Terminal Booklet

In terminal booklet it is recorded all the basic information regarding the ship/shore interface. There are information which include data from geographical position of the terminal, weather conditions, safety requirements etc. It is recorded also all the relevant regulations from national and local authorities. Finally, it is recorded all the submitted documentation regarding calculation and planning form of cargo. In figure 30 is denoted the basic form of a terminal booklet. [6, 16, 21, 22]

INFORMATION	REGULATIONS	DOCUMENTATION
▪ Port geographical position ▪ Restrictions on port entry ▪ Ship restrictions at the berth ▪ Weather and tidal data ▪ Preferred mooring plan ▪ Diagram of jetty fire-fighting and life-saving appliances ▪ Procedures for limiting surge pressures ▪ Terminal pipeline and tankage plan ▪ Description of BSD arrangements ▪ Communication methods ▪ Requirements for a ship/shore ESD Link ▪ Cargo pumping limitations ▪ Safety requirements ▪ Emergency procedures	▪ National and port authority requirements ▪ Safety issues	▪ Letter to shipmasters ▪ The ship/shore safety check list ▪ A cargo planning form ▪ A cargo calculation form

Figure 30: Terminal Booklet, Paragraph 6.9 Terminal Booklet-Information and Regulation, Liquefied Gas Handling Principles on Ships and in Terminals by McGUIRE and WHITE.

7.1.2 Characteristics of Bunkering Procedure; Ship to Ship Transfer

Bunkering procedure regarding ship to ship transfer has been developed based on transfer and safety guidelines described by SIGTOO, ICS, OCIMF, IMO IGC Code and IMO IGF Interim Guidelines. These guidelines take into consideration that bunkering procedure and cargo transfer happen at the same time in order not to prolong the ship stay at port. These guidelines include the following:

- Safety instruction during bunkering procedure
- Safety equipment

- Communication between two ships
- Manoeuvring and mooring procedure
- Connection procedure and needed equipment
- Unmooring
- Emergency plan

Figure 31 shows the timeline of bunkering procedure. It is separated in three timing zones. The first is before bunkering process to begin and takes place for 15 minutes. During this period must be fulfilled all checks regarding tank system, available equipment, and exchangeable information between two ships, arrival, mooring and hose connection. After the completion of this stage check lists are returned signed and manual valves can be open waiting for bunkering process to start. The second time zone includes LNG transfer from one ship to other which lasts for 25 minutes. This transfer time is directly connected with the bunkering LNG volume. In this figure it is assumed that LNG transfer rate is $320m^3/h$ which corresponds to 65 tons of LNG (LNG density 500 kg/m^3). When transfer is finished is demanded some time (approximately 10 minutes) for both ships to complete bunkering procedure and after a while to be available again.

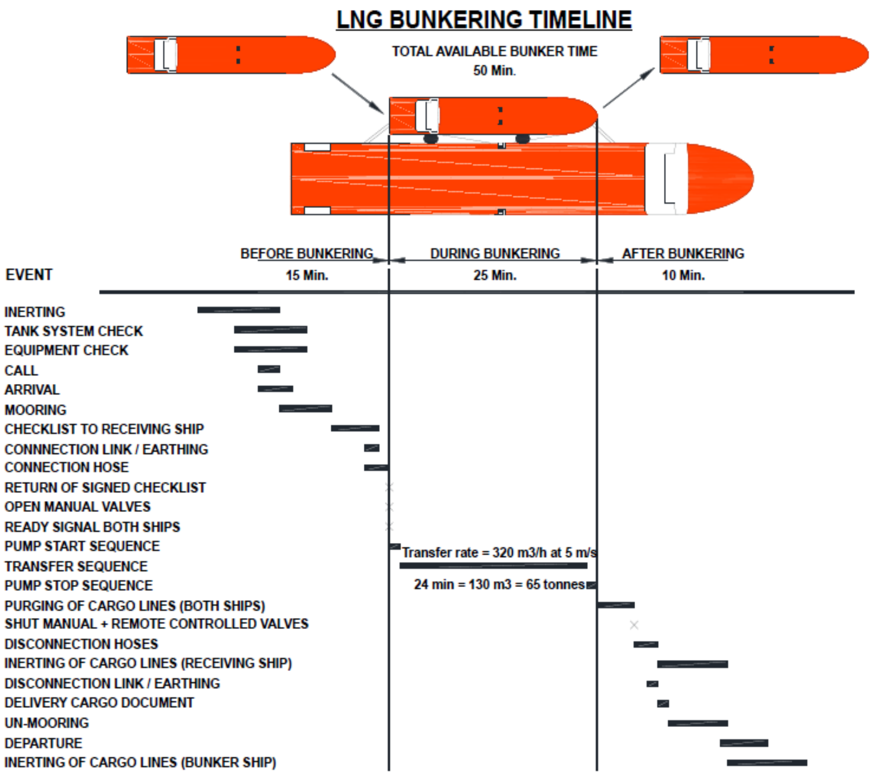

Figure 31: LNG Bunkering Timeline, page 22, LNG bunkering Ship to Ship procedure, Swedish Marine Technology Forum 2010.

Some preconditions have to be finalized in advance before the day of bunkering procedure. It is very important to be closed all the open items in order to be allowed from both parties the LNG transfer. These requisites are:

- Approval of bunker ship: Local authorities have to check if LNG bunkering procedure complies with the local regulations and at the same time to the port regulations. If everything is right then they can release the process.
- Ship compatibility: Necessary equipment regarding mooring and bunkering procedure must be available and compatible between the two ships.
- Transfer area: Port authorities are responsible to define the proper area for bunkering process. At the same time bunker ship has to check the decided area and to evaluate if it is suitable to ship dimensions and operations (like manoeuvring space).
- Weather conditions: It is very important for bunkering procedure the weather conditions to be stable. Also both parties have to agree that bunkering procedure can take place under current situations. Another parameter that has to be taken into account is that due to the complexity of procedure and high safety standards it is preferred bunkering procedure to be conducted during daylight hours.

Since the aforementioned preconditions have been fulfilled bunkering procedure can start. As it is mentioned before ship to ship bunkering it is separated into three stages: operations before bunkering procedure, operations during bunkering procedure and operations after bunkering procedure. In below table 6 are depicted in sequence all the steps which have to be followed before bunkering procedure happens as well as all the additional actions that have to be taken.

- Operations Before Bunkering:

1. Preparations: Before to begin any action it has to be noted in the ‘Before Bunkering Check List’ (figure 25) that the crew of both ships have the proper safety equipment, firefighting equipment has been checked, emergency zones are free of hazards and ESD system in both ships work properly. Moreover, both ships have to check that LNG tanks have the right conditions regarding temperature and pressure because there are cases at which tank temperature is high before bunkering and this can cause an increase in tank pressure when bunkering begins. For this reason it is recommended to reduce tank pressure beforehand. All bunkering hoses which are going to be used have to be checked in order to ensure that they are in good condition and the arrows which show the flow direction are right. The corresponding thoroughly check has to be done also to the mooring equipment like fenders, winches.

2. Check List before Bunker: Bunker ship and receiving ship have already prepared their checklists including all the items which are necessary to be included in the initial inspection. All steps which have to be followed are written very clearly and crew with to follow them strictly.
3. Call: When discharging ship is close to the receiving ship, they make a phone call through the VHF contact channel in order to take the permission for berthing. The receiving ship can ask also the mooring plan of discharging ship in order to know exactly their relative distance and more detailed information.
4. Manoeuvring: Since the discharging ship takes the permission to berth manoeuvring can be commenced.
5. Mooring: As bunker ship approaches the receiving ship two main fenders are rigged alongside. Secondary fenders are placed into extent in order to be avoided direct contact between the two ships. All fenders have to be approved by class. Mooring procedure has been finished when all lines have been connected according to the plan and they are stretched to the desired way. All mooring lines have to be monitored closely during the whole process.
6. Connection Communication Link: No mooring and bunkering procedure will take place before to be ensured that communication between two ships is sufficient. The communication methods which are used commonly are; VHF, vocally, handheld radios or through a cable link containing a wired communication.
7. Connection of Hoses: Connection hoses are delivered in most cases with the help of a hose crane from bunker ship to receiving ship. When transfer of connection hoses to receiving ship has been finished, trained crew receive them and perform the connection with the manifold. Also, they check all the connection hoses to be supported sufficiently. The hoses can be found in different sizes for increased safety measures.
8. Bunker Hoses: The connection between the two ships is completed by two separate hose connections. The first one is used for transferring the LNG whilst the second one is used for vapor return. It is very important these connections to be distinguished clearly and for this reason it is followed different color code. Thorough checks have to be done in advance to all these connections. The hose connections are supported in such way in order to avoid contact with stainless steel gratings and also to avoid any contact with the water.
9. Pre-Transfer Bunker Check List: This is a list which has to be checked very thoroughly from the responsible ship operator in order to be confirmed that both bunker ship and receiving ship are ready for LNG transfer. The items which have to be checked are listed to the following figure 26.

In the below table 6 are depicted all the steps which are included in the operations before bunkering procedure.

Table 6: Operation Before Bunkering, paragraph 5, LNG bunkering Ship to Ship procedure, Swedish Marine Technology Forum,2010.

OPERATIONS BEFORE BUNKERING	
Steps	Further Actions
1. Preparations	▪ LNG tank system check ▪ Mooring equipment check ▪ Bunker hose check
2. Check List Before Bunker	▪ Please refer to figure 25
3. Call	▪ Safe communication ▪ Mooring plan
4. Manoeuvring	
5. Mooring	▪ Fender positioning ▪ Fender type and size ▪ Mooring operation ▪ Mooring line supervision
6. Connection communication link	
7. Connection of hoses	
8. Bunker hoses	▪ LNG bunker hose and vapour return hose
9. Pre-transfer bunker check list	▪ Please refer to figure 26

Both bunker ship and receiving ship must fulfill beforehand their corresponding checklists in order to ensure safe handling. A sample of the form of this checklist is depicted in figure 32.

Name of ship: ……………………………………………

Place of bunkering: …………………………………… Date: …………………………

General checkpoints	Bunker Ship Y	Bunker Ship N	Receiving Ship Y	Receiving Ship N
1. Authorities/Port permission for bunkering?	☐	☐	☐	☐
2. Are ships compatible for bunkering regarding mooring and hose connections?	☐	☐	☐	☐
3. Is the transfer area ok for approach, mooring and bunkering?	☐	☐		
4. Are light conditions satisfactory?	☐	☐		
5. Is the EX-Zone activated?	☐	☐	☐	☐
6. Are earth indicator lights on switchboard/control panel ok?	☐	☐	☐	☐
7. Are main radio transmissions restricted?	☐	☐	☐	☐
8. Are accommodation doors around bunkering area closed?	☐	☐	☐	☐
9. Is the safety zone activated?			☐	☐
10. Are personnel protection equipment checked and ready for use?	☐	☐	☐	☐
11. Is the ESD-system tested and ready for use?	☐	☐	☐	☐
12. Is the mooring equipment checked and ready for use?	☐	☐		
13. Are the fuel transfer hoses visually checked?	☐	☐		
LNG-Tank temperature (˚C)				
LNG-Tank pressure (bar)				

Signature

……………………………………

Figure 32: Appendix A CHECK-LIST BEFORE BUNKERING, page 56, LNG bunkering Ship to Ship procedure, Swedish Marine Technology Forum 2010.

Since the inspection of checklist has finished and no problems exist ship Masters have to make a final review to the list of pre-transfer bunker procedure, which is depicted in figure 33.

Name of ship: ....

Place of bunkering: .... Date: ....

General checkpoints	Bunker Ship Y	Bunker Ship N	Receiving Ship Y	Receiving Ship N
1. Do the weather conditions permit bunker operations?	☐	☐	☐	☐
2. Is the receiving ship safe at berth?			☐	☐
3. Is the mooring plan agreed upon and mooring of the ships carried out in accordance with the plan?	☐	☐	☐	☐
4. Are primary (and secondary if needed) fenders in proper position?	☐	☐		
5. Is safe communication in agreed language established between ships?	☐	☐	☐	☐
6. Are radio transmitter aerials earthed, radars switched off and VHF on low power?	☐	☐	☐	☐
7. Are smoking regulations, naked light and galley requirements being observed?	☐	☐	☐	☐
8. Are emergency signals and shutdown procedures agreed upon?	☐	☐	☐	☐
9. Are firefighting equipment checked and ready for immediate use?	☐	☐	☐	☐
10. Are navigational signals indicating bunkering operation displayed?	☐	☐	☐	☐
11. Are the fuel transfer hoses checked to be of the correct type, in good condition and ok according to the maintenance/replacement system?	☐	☐		
12. Are the fuel transfer hoses properly connected and supported?	☐	☐	☐	☐
13. Are all fuel transfer manifolds, not in use, blinded?	☐	☐	☐	☐
14. Are valves set to their correct position?	☐	☐	☐	☐
15. Are receiving tanks gauged and fuel transfer quantity to be transferred agreed upon?	☐	☐	☐	☐
16. Is the maximum pump rate and the topping up rate agreed upon by the responsible officers on both ships?	☐	☐	☐	☐
17. Are there trained and educated persons on watch at bunker stations, close to the emergency stop, on both ships?	☐	☐	☐	☐
18. Are drip trays in position and ready for use below manifolds in use?	☐	☐	☐	☐

Specific checkpoints for LNG transfer	Bunker Ship Y N	Receiving Ship Y N
1. Are vapour return connections properly connected and supported?	☐ ☐	☐ ☐
LNG-Tank temperature (˚C)		
LNG-Tank pressure (bar)		

Signature by receiving ship

……………………………………

Signature by bunkering ship

…………………………………….

Figure 33: Appendix B CHECK-LIST PRE-TRANSFER, page 57, LNG bunkering Ship to Ship procedure, Swedish Marine Technology Forum 2010.

➢ Operations During Bunkering:

1. Signed Documentation: The pre-transfer bunker check list will be provided to the receiving ship for control and acceptance and after it has to be returned back to the bunker ship. It is compulsory this list to be kept in ship files for at least 3 months. Moreover it is necessary responsible officers for both ships to clarify in advance the transferred quantity of LNG, the transfer rate and pressure in normal operation as well as during the startup and shutdown of the system. In all circumstances maximum and design pressure must be known.
2. Manual Valves Position: Since all documents are checked and signed from both parties, manual valves of bunker vessel can open. A close look to remote controlled bunker valves has to be done in order to be ensured that they are closed.
3. Signal for Startup: When both ships are ready for bunkering procedure, a signal is given by VHF communication. All the personnel stand outside of bunker area and monitor closely the process. When LNG transfer pumps start working trained crew check that connections are ok and no leaks appear. If something goes wrong or if it is detected any possible spillage the procedure shutdown immediately.
4. Bunkering: Since LNG transfer pumps start working the process continues in a controlled manner. Personnel of both ships check all the time the situation of hose connections, manifold connection, and operation of pumps and record the flow rate data.
5. Shutdown of Pumps: When transferred LNG quantity is almost to be reached LNG transfer pumps ramp down to the agreed topping up rate. Always the filling volume of LNG tanks cannot exceed 98% of the total tank volume.

- Operations After Bunkering:

1. Purging of Bunker Hoses: When LNG transfer finishes hoses connections must be drained and cleaned before to be disconnected. The hoses are purged with heated LNG from bunker ship and for this reason all the valves near to manifold connections are open. When purging stops all valves have to be closed. First close the remote controlled valves and after all the manual valves.
2. Disconnection of Hoses: Since purging of hose connections finishes the bunker line and the vapour return line of the receiving ship can be disconnected and all the valves to be closed. Equipped personnel very carefully will drive all the hose connections back to the bunker ship hose crane and they will leave them in the parking position. All hoses are connected to the ventilation mast in case that vapours are captured inside to the pipes.
3. Submittal of Signed Documents: The responsible officer of bunker ship submits to the responsible officer of receiving ship two copies which include the quantity and the quality of transfer LNG. Both parties have to sign them and each one will keep one copy for at least three months.
4. Unmooring and Manoeuvring: After the completion of bunkering procedure and handover of all documents, bunker ship is ready to unmoor. Weather conditions have to be taken into consideration. The responsible officer gives instructions for loosing mooring lines and storing them. Only when the bunker ship has moved away from receiving ship fenders can be removed and stored to the deck.
5. Inerting of Bunker Lines: When hoses are disconnected from the manifolds directly begins the inerting procedure for the receiving ship. Hoses which are related to bunker procedure cannot remain with gas inside and must be cleaned. For the bunker ship inerting procedure is not necessary to start immediately since the hoses are connected to the parking area and they are ventilated. In order not to be forgotten a check list after bunkering procedure has to be fulfilled and additionally an alarm signal is activated from the main switchboard within 60 minutes.
6. Checklist after Bunkering Procedure: Bunker ship and receiving ship have a checklist with all the steps which have to be followed after the completion of bunkering procedure. This list is depicted in figure 34. [23]

Name of Ship: ……………………………… Date: ………………………

Place of Bunkering: ………………………

General Checkpoints	Bunker Y	Ship N	Receiving Y	Ship N
1. Are the fuel transfer hoses purged?	☐	☐	☐	☐
2. Are the remote controlled fuel transfer valves closed?	☐	☐	☐	☐
3. Are the manual fuel transfer valves closed?	☐	☐		
4. Are the fuel transfer hoses disconnected and placed in their parking position?	☐	☐		
5. Are the Transfer Documents signed and delivered?	☐	☐	☐	☐
6. Are the mooring lines retracted?	☐	☐		
7. Are the fenders retracted?	☐	☐		
8. Is the radar turned on?	☐	☐		
9. Are the fuel transfer lines inerted?	☐	☐	☐	☐

Signature

……………………………

Figure 34: Appendix C CHECK-LIST AFTER BUNKERING, page 59, LNG bunkering Ship to Ship procedure, Swedish Marine Technology Forum 2010.

7.1.3 Characteristics of Bunkering Procedure; Truck to Ship Transfer

When a small LNG ship with receiving volume around 200m^3 is mooring at the port, truck can proceed with its bunkering procedure. Tank trucks have capacities between 40 to 80 m^3 of LNG. This means that 3 to 4 trucks are required in order to fill up ship bunker volume. Also, tank trucks can be used to serve the needs of remote areas which cannot connect to the main pipeline system or other ports that want to provide LNG to their LNG vessels. This is an economically feasible solution which can be implemented to areas which are found between 350 and 600 kilometers away from trucks area.

The steps which are followed during the bunkering procedure can be classified into four categories. The first one is the pre-operational checks, the second one is the pre-transfer operations, the third one includes the actions during the LNG transfer and the fourth one comprises all the actions which are taken after the fulfilment of bunkering procedure.

- Pre-Operational Checks:

1. Local and terminal authorities have granted permission for LNG transfer operations for a specified day and time.

2. Terminal and local regulations have to be followed very strictly.
3. All personnel which are involved to this procedure have to be trained in order to be familiar with the procedure.
4. The bunker area has to be free of obstacles and accessible for the LNG supplying tank truck.
5. The area has to be sufficiently illuminated.
6. Gas detection equipment must be available and certified by a credible laboratory.
7. The procedure that will be followed during the bunkering has to be agreed in advance from both parties.
8. All ATEX areas have been recorded beforehand.
9. Firefighting system related to ship, truck and terminal area must be tested and ready for use when is needed.

All the aforementioned steps are shown in the below figure 35. The letter 'A' declares the agreement or the procedure that has to be identified in the Remark column or in another mutually accepted form. The letter 'R' shows all the items that have to be checked again from both parties in a specified period. The letter 'P' indicates that permission has to be granted by the authorities.

	Checks	Ship	LNG Truck	Terminal	Code	Remarks
1	Local authorities have granted permission for LNG transfer operations for the specific location and time.				P	
2	The terminal has granted permission for LNG transfer operations for the specific location and time.				P	
3	Local authorities have been notified of the start of LNG bunker operations as per local regulations.					Time notified: ________ hrs
4	The terminal has been notified of the start of LNG bunker operations as per terminal regulations.					Time notified: ________ hrs
5	Local authorities requirements are being observed.					e.g. Port byelaws.
6	Local terminal requirements are being observed.					e.g. Terminal regulations

7	All personnel involved in the LNG bunker operation have the appropriate training and have been instructed on the particular LNG bunker equipment and procedures.					
8	The bunker location is accessible for the LNG supplying tank truck and the total truck weight does not exceed the maximum permitted load of the quay or jetty.					
9	The bunker location can be sufficiently illuminated.				A	
10	All LNG transfer and gas detection equipment is certified, in good condition and appropriate for the service intended.				A	
11	The procedures for bunkering, cooling down and purging operations have been agreed upon by ship and truck.				A	
12	The system and method of electrical insulation have been agreed upon by ship and truck.					
13	The LNG transfer exclusion zone has been agreed upon and designated.				A	Exclusion zone: ________________ mtr / ft
14	Regulations with regards to ignition sources can be observed. These include but are not limited to smoking restrictions and regulations with regards to naked light, mobile phones, pagers, VHF and UHF equipment, radar and AIS equipment.				A	
15	All mandatory ship firefighting equipment is ready for immediate use.					
16	All mandatory truck firefighting equipment is ready for immediate use.					

17	All mandatory terminal firefighting equipment is ready for immediate use.					

Figure 35: I. PART A: Pre-Operations Checklist, LNG Bunker Checklist, Truck to Ship, Version 3.0, June 26th, 2014, International Association of Ports and Harbors.

➢ Pre-Transfer Checklist and LNG Transfer Data:

1. Travelling conditions have to be checked in advance, like weather and wave conditions.
2. The access and mooring of ship to be secured.
3. Operating equipment to be available on site.
4. Responsible persons both from ship and truck have to be present all the time until to finish the bunkering procedure.
5. Prior to any operation has to be agreed and tested the communication system between ship and truck interface.
6. Security zone has to be established and clearly signed with marks.
7. Material Safety Datasheets (MSDS) have to be available on bunkering area as well as all the needed measures in case a spillage or leakage happens.
8. Availability of instrument and valves as well as their alarm signals has to be checked beforehand.
9. ESD system both on ship and at tank truck must to be tested.
10. Pre-cooling of terminal components.
11. Hoses connections to be in good condition. Grounding cable between ship and quay must exist and also tank truck to be electrically grounded.
12. Moisture and oxygen has to be removed from pipes for this reason inert has to be done with N_2.
13. Because some engines are sensitive to nitrogen it is usual procedure to purge piping with LNG.
14. Since it has been clarified between ship and tank truck responsible the amount of transferred LNG as well as the flow rate, pressure and temperature bunkering procedure can start. The filling begins with a low pumping rate until to reach the maximum allowable working pressure.
15. The pump stops when the pre-agreed amount of LNG is delivered to the final client.

In below figure 36 is found the checklist of pre-transfer operations.

	Checks	Ship	LNG Truck	Terminal	Code	Remarks
1	Present weather and wave conditions are within the agreed limits.				A R	
2	The LNG receiving ship is				R	

	securely moored. Regulations with regards to mooring arrangements are observed. Sufficient fendering is in place.					
3	There is a safe means of access between the ship and shore.				R	
4	The bunker location is sufficiently illuminated.				A R	
5	The ship and truck are able to move under their own power in a safe and non-obstructed direction.				R	
6	Adequate supervision of the bunker operation is in place both on the ship and at the LNG tank truck and an effective watch is being kept at all time.					
7	An effective means of communication between the responsible operators and supervisors on the ship and at truck has been established and tested. The communication language has been agreed upon.				A R	VHF / UHF Channel: _____ Language: ______________________ Primary System: ______________________ Backp System: ______________________
8	The emergency stop signal and shutdown procedures have been agreed upon, tested, and explained to all personnel involved.				A	Emergency Stop Signal: ______________________
9	The predetermined LNG transfer exclusion zone has been established. Appropriate signs mark this area.				A	

10	The LNG transfer exclusion zone is free of unauthorized persons, objects and ignition sources.				R	
11	External doors, portholes and accommodation ventilation inlets are closed as per operation manual.				R	At no time they should be locked
12	The gas detection equipment has been operationally tested and found to be in good working order.					
13	Material Safety Data Sheets (MSDS) for the delivered LNG fuel are available.				A	
14	Regulations with regards to ignition sources are observed. These include but are not limited to smoking restrictions and regulations with regards to naked light, mobile phones, pagers, VHF and UHF equipment, radar and AIS equipment.				R	
15	Appropriate and sufficient suitable protective clothing and equipment is ready for immediate use.					
16	Personnel involved in the connection and disconnection of the bunker hoses and personnel in the direct vicinity of these operations make use of sufficient and appropriate protective clothing and equipment.					

17	Hand torches (flashlights) are of an approved explosion proof type.					
18	The water spray system has been tested and is ready for immediate use.					If applicable
19	Spill containment arrangements are of an appropriate volume, in position, and empty.					
20	Hull protection system is in place.					If applicable
21	Bunker pumps and compressors are in good working order.				A	If applicable
22	All remote control valves are well maintained and in good working order.					
23	Bunker system gauges, high level alarms and high-pressure alarms are operational, correctly set and in good working order.					
24	The ship's bunker tanks are protected against inadvertent overfilling at all times, tank content is constantly monitored and alarms are correctly set.				R	Intervals not exceeding ____________ minutes
25	All safety and control devices on the LNG installations are checked, tested and found to be in good working order.					
26	Pressure control equipment and boil off or reliquefaction equipment is operational and					

	in good working order.					
27	Both on the ship and at the tank truck the ESDs, automatic valves or similar devices have been tested, have found to be in good working order, and are ready for use. The closing rates of the ESDs have been exchanged.				A	ESD Ship: ____________ seconds
28	Initial LNG bunker line up has been checked. Unused connections are closed, blanked and fully bolted.					
29	LNG bunker hoses, fixed pipelines and manifolds are in good condition, properly rigged, supported, properly connected, leak tested and certified for the LNG transfer.					
30	The LNG bunker connection between the ship and the truck is provided with dry disconnection couplings.					If applicable
31	The LNG bunker connection between the ship and the LNG bunker truck has adequate electrical insulating means in place.					
32	Dry breakaway couplings in the LNG bunker connections are in place, have been visually inspected for functioning and found to be in a good working order.				A	
33	The tank truck is electrically grounded and the wheels are					

	chocked.					
34	The tank truck engine is off during the connection, purging and disconnection of the LNG bunker hoses.					
35	The tank truck engine is switched off during transfer.					Unless the truck engine is required for transfer of LNG.
36	The ship's emergency fire control plans are located externally.					Location: ________________________
37	An International Shore Connection has been provided.					
38	The LNG specifications have been agreed upon by ship and truck.				A	e.g. quality, temperature and density of the LNG.
39	Port authorities have been informed that bunker transfer operations are commencing and have been requested to inform other vessels in the vicinity.					

Figure 36: I. PART B: Pre-Transfer Checklist, LNG Bunker Checklist, Truck to Ship, Version 3.0, June 26th, 2014, International Association of Ports and Harbors.

- After Filling LNG-Checklist:

1. Since the filling has finished stripping has to be done in piping and hoses connection, in order to be ensured that no more liquid exist.
2. After is followed purging of pipes.
3. Disconnection of hoses (under atmospheric pressure) and grounding connection can be done after the procedure finishes.
4. Disconnection of grounding cable can be done. In case that the terminal provides the ESD cable to the ship it has to be removed also this.
5. Local authorities to ensure that bunkering procedure has finished.

6. Handover of signed documents from both parties has to be done. These documents will include the quantity and quality of transferred LNG as well as any incident that may occurred.

In figure 37 is illustrated the checklist after the fulfillment of bunkering procedure. [24]

	Checks	Ship	LNG Truck	Terminal	Code	Remarks
1	LNG bunker hoses, fixed pipelines and manifolds have been purged and are ready for disconnection.				A	
2	Remote and manually controlled valves are closed and ready for disconnection.				A	
3	After disconnection the LNG transfer safety zone has been deactivated. Appropriate signs have been removed.				A	
4	Local authorities have been notified that LNG bunker operations have been completed.					Time notified: ________ hrs
5	The terminal has been notified that LNG bunker operations have been completed.					Time notified: ________ hrs
6	Port authorities have been informed that bunker transfer operations have ceased and have been requested to inform other vessels in the vicinity.					
7	Near misses and incidents have been reported to local authorities.					Report nr: ________________

Figure 37: II. PART C: After LNG Transfer Checklist, Truck to Ship, Version 3.0, June 26th, 2014, International Association of Ports and Harbors.

8. LNG Transportation by Trucks

Consumers which are found in remote areas and they do not have access to coastal areas they receive LNG by trucks, road trailers or ISO intermodal cryogenic containers. Liquefaction and trucking procedure in remote areas have been proved an economically solution compared to construction of long pipeline system. If we look it also from the consumer side natural gas prices remain historically in low levels. LNG trucking is a safe and reliable solution for refilling stations, because are used specialized, double skinned vacuum insulated tanks. LNG transportation by trucks serves also the needs of satellite stations, where trucks unload their cargo inside to insulated pressurized storage tanks.

Trucks that carry LNG must comply with European regulations which are the followed:

- European Directives 94/9/EC and 1999/92/EC; regarding explosive atmospheres (ATEX)
- European Directive 97/23/EC; related to pressure equipment
- Trucks have to be designed according to the standard EN 13530 “Cryogenic vessels – Large transportable vacuum insulated vessels”
- In case of vacuum loss or fire the inner vessel of LNG trucks must maintain its integrity in order to avoid sudden increases of pressure
- LNG trucks must have a specific equipment which operation will be to detect if the cargo tank is cooled enough and the level of liquid inside to the tank
- Earth connection is obligatory
- LNG truck carriers must comply with ADR regulations (International Carriage of Dangerous Goods by Road)
- Trucks’ connection has to be in accordance with Liquid Specifications; Messer Griesheim: 794.01837
- Manifolds of trucks have to enable the purge of flexible connections and flushing with nitrogen before to be disconnected from the truck. The customer is responsible to specify the type and size of these connections which will have the characteristic to be adjusted directly to the connection point without the need of adaptor
- Truck have to accommodate ISO 9001
- The driver of truck has to be a qualified person and to be familiar with English language

All the aforementioned requirements for LNG transportation by truck have to be followed strictly without any exception. [25]

8.1 Steps for Approval Procedure

There are four basic steps for the approval of LNG truck to the filling station, these are:

8.1.1 Exchange of Information

Customer must sent in advance all the required information related to its truck like; dimensions of the truck, weight of the truck, design, P&ID, technical data, location of manifold connections and types’ of connections. Also, it has to provide the approval certificates and the documents which are related to cooling down procedure, filling procedure and emptying procedure. Moreover, Customer has to provide a detailed list with the names of participants including truck driver and supporters. All the staff has to be familiar to LNG transportation and handling procedure and also to be certified by an independent body. Customer has to surrender also annual protocols from Ship operators who confirm that LNG transportation has been done safely under all safety precautions. On the other hand, operators from terminal have to provide to Customer the access plan to the area. [26, 27]

8.1.2 Compatibility between Customer and Terminal Operator

Since terminal operator received the request from Customer it has to answer within ten working days if accepts or rejects LNG transportation. During this time operator checks all the submitted documents and studies if there is technical and physical compatibility between the two facilities. There are cases where operator and Customer arrange a meeting in order to clarify some issues. After the approval of LNG transportation, Customer visits the terminal in order to record the area and the faculties that have. [26, 27]

8.1.3 Test Procedure

Before the date of LNG transportation it is performed a test filling. During this day terminal operator records all the data linked to filling procedure and writes down all the corrective actions that may have to be taken. This report will be sent after to the Customer between the next five working days.[26, 27]

8.1.4 Approval of Truck

After the fulfillment of checks terminal operator has to decide if accepts or rejects the request for LNG transportation. If the truck is authorized to perform transportation then Customer will receive a signed approval document which will be valid for the next five years. If the truck does not implement all the pre-requisites then corrective actions have to be taken. Finally, in case that the truck is not authorized to perform any actions to the terminal then the whole procedure will have to be repeated again under the terms of a new request. [26, 27]

8.2 Operational Procedure

With the arrival of LNG truck to the terminal there is a strict procedure that has to be followed in order to be completed the LNG transportation. The below steps describe the basic checks that are used to be done in every LNG terminal. [26, 27]

8.2.1 Entry of LNG Truck to the Station

With the arrival of LNG truck driver to the Station security post is informed. The responsible security officer checks the Operational Schedule of the terminal and confirms the arrival of LNG truck. Also, he crosschecks that arrival time, identity information of trucks' driver and truck details correspond to the prescheduled operations. The driver has to hold and show his valid training certificate for LNG transportation by truck, the approved certificate of LNG transport unit and to live to the security post all the devices (such as mobile phone etc.) which are not allowed to be taken inside to the filling station. Since the security officer performs all the aforementioned checks then he informs the Station Control Room for getting the permission to allow the entrance of truck to the site. Since the truck takes the permission to enter to the site, the responsible person for receiving trucks approached the gate and welcomes the driver and he makes also one final visual inspection (possible broken lights, flat tire, defective thermal insulation, available PPE, MSDS and other documents). [26, 27]

8.2.2 Supervision

From the time that truck enters to the terminal the whole responsibility and inspection has the station officer. Wherever the truck and its driver go, the officer has always to follow. Officer is responsible to guideline the process of tanks' cooling down, loading and unloading procedure and the departure of truck from the terminal. [26, 27]

8.2.3 Cooling Down Trucks' Tank

Stored LNG in terminals is found in very cold conditions, -162°C. In order to be transferred inside to the truck tank a cooling down operation must exist beforehand, unless if the truck has already reached the station in cryogenic conditions. If the truck arrives in 'hot' condition this practically means that it will be demanded longer period for LNG transportation because it has to be avoided the reach of valve set pressure. Also, the evaporation of transferred LNG will be higher and will lead to an increase of normal temperatures, approximately above -120°C. The officer and the truck driver always have to look the pressure and the temperature of the returned Boil-Off Gas (BOG) to the terminal. Checks are performed with the help of specialized instrumentation. The cooling down procedure strictly follows the steps which are described thoroughly inside to the contract. It has been estimated that the average time for LNG transportation to a cooled tank is between 30 minutes to one (1) hour, whilst the average cooling time for a 'hot' tank is approximately one (1) hour. [26, 27]

8.2.4 Trucks' Tank Condition

The tank of the truck when reaches the terminal must be found in natural gas atmosphere or in nitrogen atmosphere. This means that inside to the tank the maximum water (H_2O) vapour content is 1 ppm, maximum carbon dioxide (CO_2) content is 100 ppm and maximum oxygen (O_2) content is 100 ppm. [26, 27]

8.2.5 LNG Loading Procedure

Under the supervision of officer, truck driver drives the truck to the weight station. There is recorded the weight of the truck when it is empty. Then he drives the truck to the loading bay position. Flexible hoses are been connected between the truck and the filling station, fitting and tightening of flanges is carried out as well as opening and closing of truck valves. The maximum loading rate is 100 m^3 LNG/h. The degree of tank filling will comply with the ADR regulation. Normally is 80% filling level. After, the fulfillment of LNG transportation all valves must be closed and checks have to be performed in order to detect any possible leaks. Since this procedure has been finished the truck goes back to weight station in order to be recorded the new weight. The formula which is used for calculating the mass of loaded LNG is:

$$M\ LNG\ Loaded\ (kg) = M\ Truck\ after\ LNG\ loading\ (kg) - M\ Truck\ before\ LNG\ loading\ (kg)$$

And the formula for calculating the volume of LNG loaded is:

$$V\ LNG\ loaded\ at - 160°C\ (m^3) = \frac{M\ LNG\ loaded\ (kg)}{\rho\ LNG\ at - 160°C\ (\frac{kg}{m^3})}$$

When all procedures finish officer handover to the truck driver all transport document required by the ADR and the Loading Certificates. These Loading Certificates include information regarding the quality and quantity of transported LNG. [26, 27]

9. Satellite Stations

LNG plants are small stations where LNG can be stored and vaporized for supply gas to an isolated area or to satisfy the needs in peak saving circumstances. LNG satellites stations are being supplied with fuel by road tankers, barge or rail carriers. The location of these stations is near to remote consumers in order to satisfy their needs immediately. A typical satellite station includes truck unloading system, storage tanks, vaporizers, safety and control system. The type of storage system can be either LNG storage tanks or LNG cylinders. LNG storage tank capacity is between 31.6 to 3,158 m^3 with an effective volume of 30 to 3,000 m^3. Working pressures can be between 2 to 16 bar with a vaporization rate 0.5 to 0.2 % per day. From the other hand, LNG cylinders have capacities from 63 to 526 l with an effective volume of 60 to 500 l. Working pressures have to be below 16 bar with a vaporization rate 2 to 3 % per day. [28]

9.1 Schematic Process of LNG Satellite Stations

In this paragraph will be analyzed the facilities of an LNG satellite terminal and the sequence of processes which take place. The fueling of the terminal is done by trucks. The final purpose is to supply natural gas to the grid system or to vehicles.

1. LNG Trucks approach to the terminal and they unload their cargo. The LNG transportation is being done by pumps from offloading tanker to the storage vessels.
2. During the stage of truck unloading the volume inside to the tank is being decreased gradually, causing misbalances to the trucks' cargo. In order to balance the volume of the pumped liquid a small volume of vaporized through an atmospheric vaporizer. The gases which are produced flow back to the vehicle tank. The flow rate of the gas is controlled all the time with pressure instruments (pressure indicators and/or pressure transmitters) which are found on the vehicle tank.
3. When LNG storage tank is not being filled until its maximum permissible volume the pressure inside the tank is being increased. In order to avoid high pressures the gases which are found inside

to the tank are warmed up through an air heated exchanger and then it can be delivered to the gas grid.

4. LNG from storage tank is vaporized through heat exchanger and after is delivered to the grid.
5. LNG from storage tank also can be pumped in high pressures with the help of piston pumps and to be guided through a heat exchanger. LNG is then vaporized and fed to high pressure tanks of vehicles.
6. LNG from storage tank is supplied also to the refilling stations of vehicles. At this circumstance LNG is found in a sub-cooled liquid state. In order to be achieved this purpose liquid nitrogen is used.
7. Every LNG satellite plant must has its own sub-cooling station consisted of a storage tank with liquid nitrogen. Liquid nitrogen (LN_2) can be used to cool the gas phase of LNG inside to the storage tank.
8. Liquid nitrogen sub-cools also LNG for vehicle tanks and the LNG transfer system.
9. From the LNG truck one small portion is vaporized through a heat exchanger

Figure 38 depicts all the aforementioned steps from 1 to 9. [29]

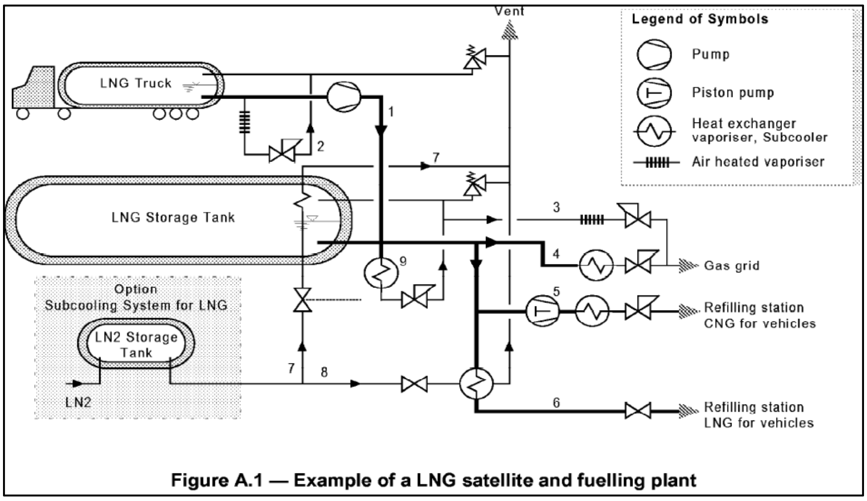

Figure A.1 — Example of a LNG satellite and fuelling plant

Figure 18: A.1-Example of a LNG satellite and fuelling plant, ANNEX A-Schematic description of a process for a satellite and fueling plant, Installations and equipment for liquefied natural gas-Design of onshore installations onshore installations with a storage capacity between 5 t and 200 t, BS EN 13645:2002.

9.2 LNG Satellite Regasification Plant Components

A typical installation of an LNG satellite plant requires firstly central storage tanks where trucks will unload their cargo. The type of tanks can be either vertical or horizontal with storage capacities ranging from 60 m^3 to 250 m^3 and design temperature -196˚C. Another basic component is vaporizers. There are two types of vaporizers, Ambient Air Vaporizers and Hot Water Vaporizers. Ambient Air Vaporizers use the heat from ambient air to sub-cooled liquid. It is an inexpensive way to cover plant needs since there is no need for extra heat energy. Hot Water Vaporizers take advantage of heat transfer between hot water and sub-cooled liquid. Hot water is produced from a gas-fired burner which consumes approximately 2% of natural gas for this reason these vaporizers are more expensive compared to ambient air vaporizers. Pumping system between LNG truck and storage tank. There are two ways to transfer LNG from trucks to storage tanks. The first one is by increasing gradually the pressure inside to the LNG truck tank. The pressure inside to the truck tank can be around 5,5 bar reduced to the outlet to 5,3 bar, until to reach finally 3,5 bar inside to the LNG storage tank. The disadvantage of this way is that the process is slower but requires less equipment on the truck itself. The second way of transfer is by pumping. The pressure inside to the truck tank is approximately 2,5 bar increased with the help of a cryogenic pump to 20 bar concluding to LNG storage tank at 17 bar. This way of transfer provides higher flow rates but it requires more equipment on the truck itself. Monitoring and recording is also another important component of the process. Safety measures including MSDS, personnel protection equipment, fire prevention mechanisms and other have to be taken also into consideration. [28, 29]

9.2.1 Satellite LNG Storage Tanks

Small LNG capacity storage tanks are preferred to be fabricated according to the design of steel pressure vessels. These tanks have spherical shape because its geometry provides strong durability to pressures up to 10 bar and even more. The reason why it is needed this durability is because no matter how good is the insulation of the tank there is always some boil-off gas inside. This amount of boil-off gas can increase not only the pressure but also the temperature inside to the tank. When the tank is not full with LNG more boil-off gas will be created inside. For this reason it is installed a pressure control valve which opens when the pressure inside to the tank is increased too much and this releases the stresses, lowers the temperatures and keeps the container into equilibrium phase. The advantage of using a pressurized tank is the avoidance of use a re-liquefaction system. The boil-off gas which is created will be used afterworlds with the consumption of LNG. Small scale LNG tanks exist in many different types from small ones up to larger tanks with capacities even 1,000 m^3. In order to be achieved the desirable volume it is very common to be used many tanks in parallel position. Pressurized storage tanks are classified in three categories: Single Integrity, Double Integrity and Full Integrity.

- Single Integrity

  A single integrity storage tank is defined this tank where cryogenic liquid is stored inside to an inner tank whilst outside there is only insulation casing which is not possible to withstand the LNG in case of tanks' failure. Code BS EN 13645 describes the design of storage tanks with capacities between 5 tones to 200 tones. In figure 39 is depicted a spherical single integrity storage tank.

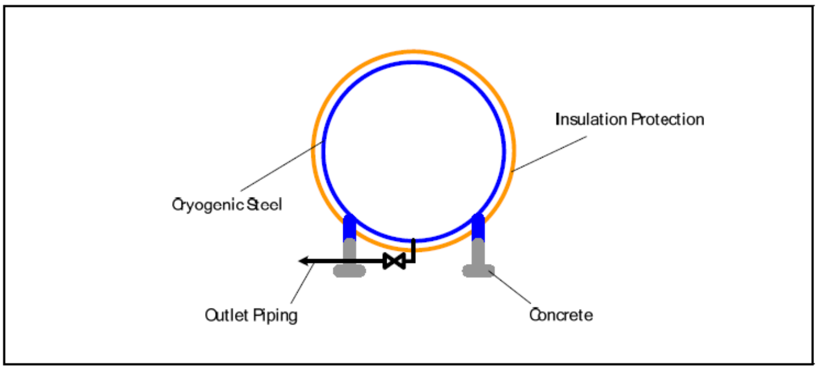

Figure 39: Single Integrity LNG Sphere Design, Comparative Risk Assessment for Different LNG-Storage Tank Concepts, Stefan Path, 2013.

- Double Integrity

  In case to be avoided any possible leakage into the environment a double integrity storage tank is designed. Practically is a single integrity bullet/sphere tank which is installed along with a leakage collection system. The second container can be a containment pool or a collection basin which will gather all the spillages and gravitational will lead them inside to the pool. Bullet tanks are installed in groups elevated above the ground on two supports. Figure 40 shows a horizontal double integrity storage tank.

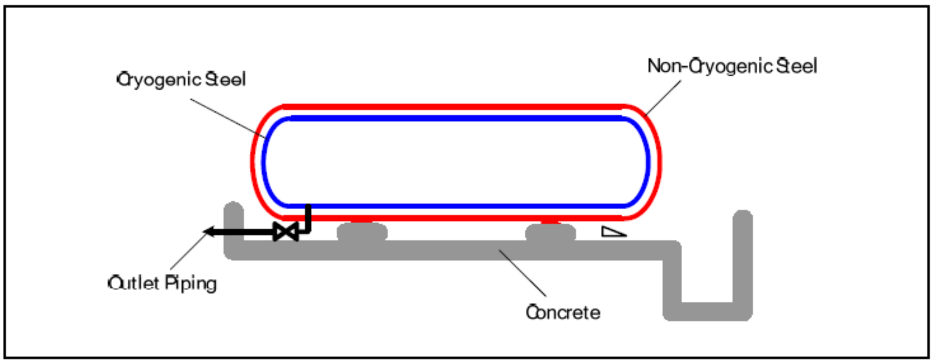

Figure 40: Double Integrity LNG Sphere Design, Comparative Risk Assessment for Different LNG-Storage Tank Concepts, Stefan Path, 2013.

- Full Integrity

  A LNG sphere or bullet tank is characterized as full integrity when inside and outside container are made from cryogenic steel and are both able to maintain any possible leakage. The basic advantage is that in case of inert tank failure outside tank will maintain the LNG without to lose its structural integrity. In figure 41 is showed this type of LNG storage tank. In this figure it is showed also inside to the inert tank one valve. This valve is a shut-off valve which closes automatically from the ESD system in case of export piping rupture.

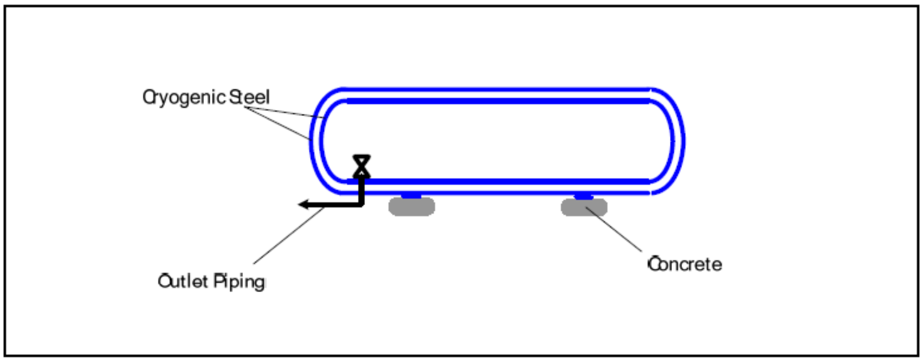

Figure 41: Full Integrity LNG Sphere Design, Comparative Risk Assessment for Different LNG-Storage Tank Concepts, Stefan Path, 2013.

The design of a small LNG storage vessel has to ensure that no surface water penetration or atmospheric humidity will be permeated inside to the tank. The materials which will be used for external thermal insulation will be in accordance with EN 1160:1996. The installation of LNG storage tanks can be either above ground or underground. Depending to the position of the tank different insulation techniques and materials are used. For example the following figure 42 illustrates steel storage vessels with different insulation materials according to surrounded conditions.

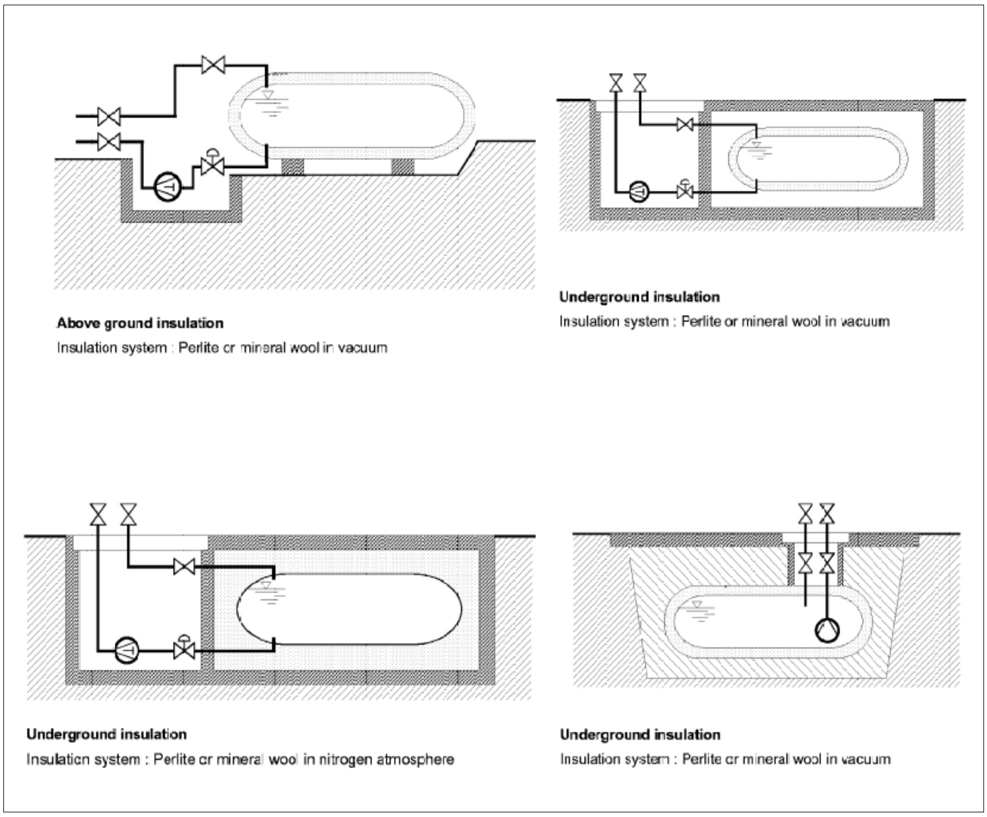

Figure 42: Annex C: Examples of LNG Storage Vessels- Design Concepts, British Standard Institution, BS:EN 13645:2002.

In all cases perlite is used for insulation combined either with vacuum or nitrogen atmosphere. The position of the tank can be vertical or horizontal. Vertical position is preferred when capacity storage volume is between 3 to 50 m^3. For storage volumes from 20 to 250 m^3 is preferred the horizontal position. The same position is also recommended for volumes from 100 to 200 m^3. The boil-off rate is also affected from the design requirements of an LNG storage tank, its storage capacity possibilities, position of the tank and insulation materials. In below figure 43 is represented this combination of all the aforementioned parameters. [29, 30]

Installation	Position	Volume m^3	Insulation concept	Boil-off-rate %/day
Above ground	vertical	3-50	vacuum-perlite	0,2 – 0,5
Above ground	horizontal	20-250	vacuum-perlite	0,1 – 0,2
Under ground	horizontal	20-250	vacuum-perlite	0,1 – 0,2
Under ground	horizontal	100-500	perlite-nitrogen	0,3 – 0,6

Figure 43: Table C.1, Annex C: Examples of LNG Storage Vessels- Design Concepts, British Standard Institution, BS:EN 13645:2002.

9.2.2 Satellite LNG Vaporizers

LNG satellite plants use mostly two types of vaporizers the first one is ambient air vaporizers and the second one is hot water vaporizers. Regarding atmospheric heat exchangers there are two types: direct heat exchangers and indirect heat exchangers. Direct heat exchangers are comprised from a water distribution system, a section which enables the direct contact of working fluid and air, a fan which creates the proper air flow and one basin to recover water and condensate. Indirect heat exchangers consist of a coil section inside which is recirculated the working fluid. In order to be increased the available surface area these coils are fitted with fins. The ambient air is forced down with the help of forced draft fans in order to collect the water/condensate to the collection basin.

- Ambient Air Vaporizers (Atmospheric Heat Exchangers)

  Direct heat exchangers which belong to this category are characterized from the direct contact of air and working fluid while in indirect heat exchangers there is separation between working fluid and air and heat transfer take place. Both systems take advantage of the wet heat transfer procedure since they condense atmospheric moisture and exploit the benefit of latent heat transfer. Direct system takes advantage of heat and mass transfer while indirect system uses only heat transfer. Also, in the indirect system coils and fins are used in order to help heat transfer procedure by increasing the necessary surface area. It is very important during the design phase of both systems to take into consideration parameters like weather and wind conditions. Mass and energy balance also differ in the direct and indirect procedure. In below figure 44 is illustrated a schematic process of the indirect procedure. The mechanisms that participate in this system are: 1. Sensible heat transfer: ambient air → fins → tube wall → to fluid

  2. Latent heat transfer: condensing vapor → film → fins →tube wall → to fluid

3. Sensible heat transfer: ambient air → film → fins →tube wall → to fluid

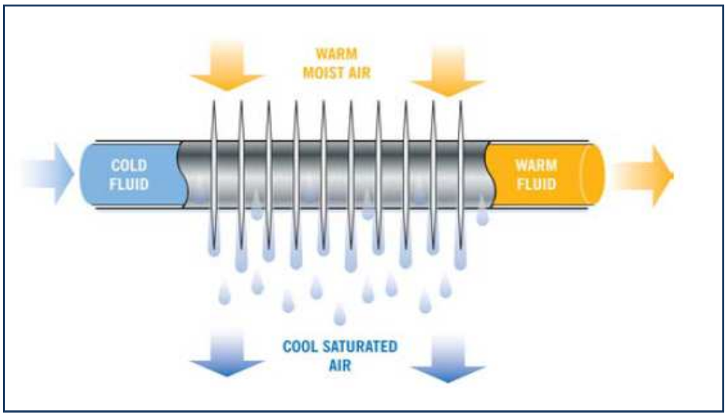

Figure 44: Mass and energy balance, indirect and direct heat exchangers, Utilization of Atmospheric Heat Exchangers in LNG Vaporization Processes, Tom Dendy, 2008.

On the other hand figure 45 represents the mass and energy balance of a direct heat exchanger. The mechanisms that participate to this system are:

1. Sensible heat transfer: ambient air → to fluid
2. Latent heat transfer: condensing vapor →to fluid
3. Mass and Energy transfer: from condensate mixing with fluid

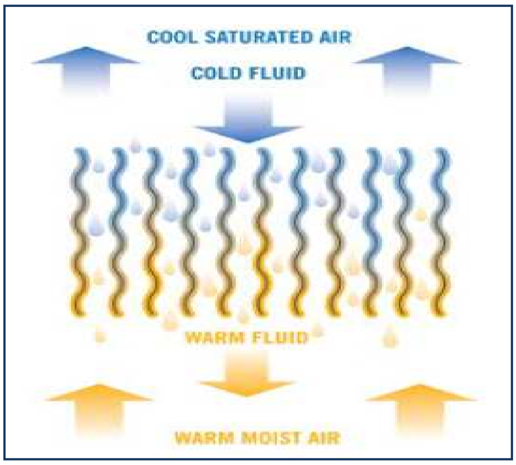

Figure 45: Mass and energy balance, indirect and direct heat exchangers, Utilization of Atmospheric Heat Exchangers in LNG Vaporization Processes, Tom Dendy, 2008.

Since the available heat from the condensate has been transferred to the heat exchanger or to the vaporizer, condensate has to be removed from the system. In the direct heat exchanger this is done upstream to the heat exchanger. There is also the possibility the condensate to be discharged downstream of the atmospheric heat exchanger but it has beforehand to be equalized with the working fluid. Direct heat exchanger transfers more heat than indirect heat exchanger and for a given air rate it seems that less surface area is demanded.

The performance curve of both direct and indirect heat exchangers depends on the inlet air wet bulb conditions and the ambient temperature. Inlet air conditions and ambient air conditions are not always distinct able. Inlet wet bulb temperature for a given air flow and cold fluid temperature affects the outlet fluid temperature. There is linear correlation between wet bulb temperature and outlet flow temperature. When the first one drops the same trend follows the other. Moreover, when the inlet fluid temperature is low this result to smaller size of heat exchangers and q widely range of operating conditions.

- Hot Water Vaporizers (Gas Fired Burners)

  Submerged combustion vaporizers belong to heated type vaporizers where heat source is integral with the exchanger. The operation of these vaporizers is based on the warm up of LNG as it flows through the tube bundles which are found submerged to the water bath. The water which is inside to the bath is heated by the combustion of a small portion of natural gas. Burner and heat exchanger are parts of the tank. Submerged combustion burner during its operation emits hot exhaust gas which directly heats the water bath. The vaporizer consists of the following parts: submerged combustion burner, combustion air blower, concrete or steel bath, exchanger section, inlet of LNG, outlet of NG, fuel gas inlet, flue gas distributor and exit stack.

  The burners of the submersed combustion vaporizers can be either completely immersed to the tank bath or semi-submerged. In the immersed burner the combustion takes place underneath the water surface and the products of the combustion are guided to the opposite direction of the liquid bath. On the tank deck are located two or more downfired high velocity burners, the connection of fuel gas supply and the connection of combustion air. The combustion takes place above the liquid level and it is distributed homogeneously with the help of a common downcomer. The existence of two or more burners provides protection to the system in case that some of them fail to operate. The products of combustion are guided directly to the liquid bath with the help of a water cooled downcomer which includes spargers for uniform distribution. The difference between semi-submerged burner and immersed burner is that in the first case there is only one single burner with large capacity and combustion takes place under the liquid level. Main combustion air is supplied from the top and one supplementary volume is supplied from the bottom. Fuel gas inlet is found on the bottom of the conical combustion section which is cooled by a water jacket. The products of combustion are directly exhausted to the bottom of the liquid bath and with the help of distribution duct are dispensed along the bath. Also, in order to be achieved homogenous conditions there are installed spargers. Due to high thermal capacity of the water bath stable conditions can be maintained stable for a long period and this provides protection in case of a sudden shutdown of the system. During the combustion gases of NO_x are formed and have to be eliminated for environmental reasons. In order to be achieved this it is installed inside to the burner combustion chamber a water injection spray system which mixtures gas fuel with water. Practically this can minimize NO_x emissions but may cause corrosion to the combustion chamber.

Exhaust burner vaporizer consists of a downcomer distribution system whilst semi-submerged single burner vaporizer consists of a distribution duck. In both cases these systems are responsible to collect the hot fuel gas from the burner and to exhaust it inside to the water bath. The exhaustion point is within the weir area and below the process tubing. This is done in order to allow more uniform distribution conditions. The reason of existence of weir is to provide the needed space for water recirculation through the open bottom. After the pass of fuel gas through the tube bundle the exhausts are guided to the stack. The purpose of existence of stack is to achieve good dispersion by dropping the pressure across the burner, distributor and submergence.

From the process inlet which is found on the top of the vaporizer LNG is guided to the bottom inlet header where exchanger exists. There it passes through the exchanger tubes and gradually comes out from the top outlet header in the form of natural gas. Heat exchanger tubes are installed and supported inside to the weir. The type of exchanger tubes are in the form of serpentine. It is recommended to be installed some mixers to the liquid zone of vaporizer tubes in order to ensure liquid contact with tube walls. For this reason the material of tubing is made from stainless steel 304 or 304 L.

The operation of a submerged combustion vaporizer is based on the heat transfer that occurs between water and process LNG. Water is used as heat transfer medium. The first stage of the process includes heat and mass transfer from combustion products to the water bath, the second stage includes only heat transfer from heated water and exchangers' process tubes, and the third stage includes heat transfer between heated tubes and LNG. As it is mentioned beforehand the products of combustion are exhausted to the bottom of water bath allowing by this way a better heat distribution, higher efficiency rates and ensuring safer operations. The LNG enters the vaporizer in sub-cooled conditions.

The efficiency of a submerged combustion vaporizer under normal operations is over 100 percent. This high efficiency results are due to condensation of the combustion water vapour based on the lower heating value. Fuel composition, ambient temperature, water bath temperature and combustion stoichiometry are taken into consideration for the fuel efficiency results. The required amount for fuel consumption (natural gas) is calculated to 1.5 to 2 per cent of the LNG which is vaporized during the process. Concluding, submerged combustion vaporizers are ideal for using them in peak shaving demands, for base load operations, for stand-by operations and in seasonal facilities since they have proved economically feasible and safe during operation. [31, 32, 33]

9.2.3 Nitrogen System

In a satellite power plant it is very common to be found a liquefied nitrogen storage tank in order to cover basic process needs. The usage of nitrogen system can be:

- To cool down the gas phase which exists inside to the LNG storage tank in order to minimize the amount of boil-off gas
- To precool the transfer system between truck and import terminal
- To sub-cool the tank of the receiving vehicle (in case that the terminal is a refilling station for LNG vehicles)
- For piping purging purposes
- Drying and inerting specific part of plant
- Rapid extinction of flares and vents

It is very important the materials of liquefied nitrogen system to be in accordance with recognized codes and proper for cryogenic substances. [29]

9.2.4 LNG Pumps

In LNG services it is commonly used centrifugal pumps. The design, manufacturing, testing and installation and operation of the pumps must to comply with some standards like: EN ISO 9906, EN 12162, EN ISO 13709, EN 61800 and EN 12483. The tests which will be performed regarding pumps can be classified to the following categories: type tests, acceptance tests, strength and tighten tests, performance tests and net positive suction head (NPSH) tests. All the aforementioned tests will be carried out with liquid nitrogen or with LNG. The selection of materials has to withstand cryogenic conditions and for this reason it is recommended to be followed the EN 1160. The suppliers have to demonstrate that the selection of pump materials is proper for their use. During the design phase of LNG pumps and the operational description of the terminal it has to be foreseen the proper maintenance of equipment. For this reason it is suggested isolations valves to be installed in proper areas so as to allow the draining, isolation and purging of equipment. During the operation of the pump the responsible personnel has to take into consideration the pump' curve characteristics in order to setup the pump in its best operational positions. [29]

9.2.5 LNG Piping System

In one satellite power plant the piping system is consisted of the main process system, the auxiliary process system, the utility system and the fire protection system. During the design phase of the power plant some basic rules have to be implemented regarding piping construction. All piping systems have to be in compliance with EN 13480. Dynamic effects have to be avoided like vibrations and for this reason the pipes are designed in such way in order to ensure smooth flows. Pressure drop calculations have to be submitted for correct operation of the pumps. The materials that are used for piping construction and their accessories like supports, pipe joints are be chosen according to the purpose of their use. The specifications for material selection can be found in the EN 1160. Basically there are two categories for materials: the first one is the materials which are used in occasional or permanent contact with LNG and the second one is the materials which come in contact with LNG but in case of an accident due to leakage or spillage problem. This separation is being done because in the first case the materials must follow the cryogenic requirements whilst in the second case the materials are chosen according to the level of a possible accident. In the last case it is used most of the times insulation with suitable material. All pipes have to be tested according to the existed industrial piping codes. In case that there are not sufficient instructions for the pressure test procedure then it is recommended to be done either hydrotest with pressures 150% of design pressures or pneumatic tests as per PED directive. It is suggested in cryogenic equipment the pressure tests to be pneumatic type. In case that it is not feasible pneumatic tests to be done, a hydrotest will be carried out and after all the pipes have to be dried. The water that will be used for the hydrotest has to follow the recommended specifications. If during the pressure tests leakages will appear this is not acceptable. Proper actions have to be taken before to be repeated again the pressure test. [29]

9.2.6 Control and Monitoring System

Control and monitoring system is one of the most important parts of a satellite plant. These systems enable the operator to monitor and control natural gas process, the situation and position of equipment, to have a close look to the site access and egress, monitor and control plant safety, to be accurately informed for any incident that may be caused and to exchange information with site operators and personnel. Monitoring and control system can be separated into three main categories: the process control system, the safety control system and the access control system.

- Process Control System

  This system provides the real situation of the plant position and allows safe and efficient operation of the plant. Some of the equipment has their own individual process shut down (PSD). In case of failure of process control system shall not lead to hazard situations. In order to be avoided this some precautions can be taken. For instance to be designed more data transmission routes, equipment of same functions to be split between different processing modules or to be available spare I/O modules. The system has to record all the data and operator to have access on them. The system chronologically discriminates and stores all information including the initial problem and the relevant actions that have been taken. The system has to present to the operator the minimum amount of data required for safe and efficient operation of the plant and alarms that are not in high importance to be minimized.
- Safety Control System

  Safety control system is designed in order to protect the plant from hazard situations and operators to have the possibility to act in advance. The functions that have to be controlled at least are: gas detection, fire detection, spillage detection, control of normal operation of safety devices, ESD station.

Emergency shutdown system (ESD) is activated by the safety control system. The activation of ESD system is based on the feedback that it gets from the fire system, gas system, some specified local ESD stations and/or ESD central panels. When the ESD system is activated automatically equipment shutdown and ESD valves go to fail close position. ESD valves are also used inside to a sub-fired area in order to prevent release of hazardous materials to the rest of piping or equipment. The plant is separated into two zones; the fire zones and the sub-fire zones in order to escalate the importance of actions. A hazard assessment has to be defined beforehand and it has to be in compliance with the rest of safety control system. The type, number, location, installation position and redundancy of detectors and/or sensors have to be studied very carefully so as to be in compliance with the hazard risk assessment. The philosophy of ESD system is to minimize the release of hydrocarbons and to confine the expansion of the hazard. The typical ESD levels are:

- ESD 1: Plant shutdown with the exception of certain safety items normally powered by the emergency generator or the UPS
- ESD 2: Shutdown of all hydrocarbon processing and transfer operations
- ESD 3: Local plant area, equipment or operation shutdown

The main functions of the safety control system have to be:

- The automatic release of ESD system in case of emergency. The manual activation of ESD system can be done only if it written to the hazard risk assessment and only after the approval of the appropriate authorities
- Automatic activation of the necessary protection equipment
- To inform the process control system when ESD is activated
- To control visual and sound emergency communication devices like siren
- To allow the access of emergency crew and staff when the emergency plant is activated
- The safety control system has to be designed and operate in accordance with the EN 61508-1 [29]

9.2.7 Safety Plant

Every LNG satellite plant should establish its safety plan which will include all the risks and the appropriate appraisal of the consequences. The safety plan is established during the design phase but it will be reviewed when unacceptable risks will be indentified. A hazard and operability study (HAZOP) will be constructed in order to minimize all possible hazards. Safety plan will include also the safety measures and principles that have to be followed by the site operators and the emergency actions that have to be taken. The basic parameters that a safety plant has to include are: collection and data information, threshold values, identification of risks and estimation of the consequences of a gas or LNG release. [1, 29]

9.2.7.1 Collection of Data and Information

The first step for designing a safety plan is to record the data from natural conditions and surrounding integration in order to identify all the possible risks and define the relevant measures. The information of natural conditions will include topography, seismology and seismic characteristics recorded over years. Also meteorological and soil conditions have to be included. The information of surrounding integration will contain data from the nearest fire services, access roads for LNG trucks and other surrounding infrastructures like industrial sites. [1, 29]

9.2.7.2 Threshold Values

There are some threshold values that must be exceeded in order for a certain reaction to be manifested. These are heat radiation from fires, heat radiation from flare and/or lighting of vent and ignition limit of natural gas. In the safety plan it has to be determined in case of fire which are the maximum thermal radiation flux that are acceptable for equipment damages. These values are provided from manufacturers of equipment and also from validated methods which are defined in ENV 1991-2-2, ENV 1992-1-1, ENV 1992-1-2, ENV 1993-1-1, ENV 1993-1-2, ENV 1994-1-1 and 1NV 1994-1-2. For LNG storage vessels the permissible radiation flux has to include to its calculation at least the following: loss of mechanical strength, increase of pressure inside the vessel, relief capacity of safety valves and the temperature of safety valves. There are also some given values for the thermal radiation fluxes regarding areas beyond the boundary. The designer of the system has to confirm that the heat radiation from flare or lighting vent (excluding solar radiation) will not exceed 1,5 kW/m^2 inside buildings, vessels and other equipment. Finally, the flammable mixture range of natural gas and air is given in EN 1160:1996. [1, 29]

9.2.7.3 Identification of Risks

The risks of a satellite LNG plant can be classified into two categories. This risks which are caused due to an internal problem and these risks which are the result from an external origin. Risks which are caused due to an external parameter may be related to LNG supply vehicles, toxic gases, heat radiations or natural phenomena like an earthquake or a flooding. The risks which have an internal origin are related mostly to the parameters which can cause failure of LNG vessels even these vessels are plant vessels or LNG truck vessel. [1, 29]

9.2.7.4 Estimation of consequences in case of LNG release

The consequences of an unexpected LNG release are described thoroughly in the EN 1160:1996. When there is heat transfer between LNG and ground or water phenomena like vaporization take place and this is the result of depressurization. There are already some models which are using data from composition and flow rate of LNG, temperature of ground and atmospheric conditions in order to find out the rate of vaporization. Also, they have been developed models which estimate the rate of the cloud dispersion which has formed due to the LNG evaporation. Moreover, validated models are already used to calculate the over pressure field. Finally, there are calculations which are based on the radiation effect which is caused due to the natural gas vapour ignition. These models can calculate precisely the various distances and elevations of radiation in case of accident.

LNG satellite plants have storage capacities from 50 t to 200 t. In order to ensure safety operation of the plant many calculations and models have been introduced to calculate specific results of phenomena that may exist like pool spreading, dispersion and radiation. These models which have been developed take into consideration many parameters like mass flow rate and flash, vaporization, pool spreading, dispersion, radiation. When LNG comes out of its storage tank there is separation to its phases. There is the flashed vapour which is natural gas; there are the liquid droplets which are entrained in the jet (aerosols); and the liquid that is being disposed to the ground. Aerosols include practically droplets which are not going to be deposed on the ground but they will be transferred to the vapour phase. Rainout is the LNG that comes out from the storage tank and after follows down as droplets. In figure 46 is being depicted one LNG tank and the result of LNG outcome.

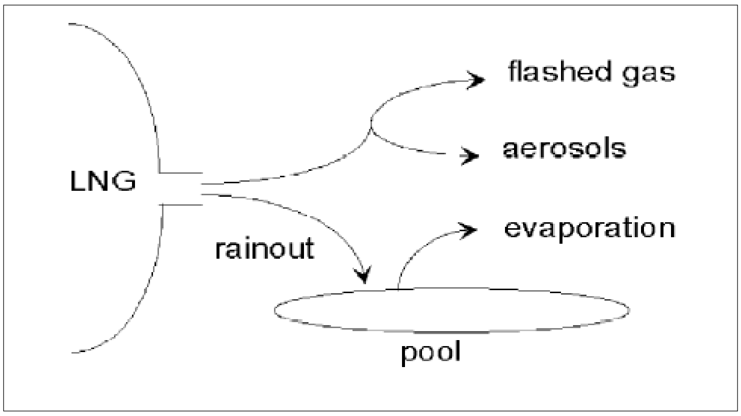

Figure 46: Figure B.1-Description of phenomena, ANNEX B, Examples of safety scenarios and calculations, British Standard, BS EN 13645:2002.

Fluid mechanics are also used here in order to calculate the mass flow rate that comes out from the LNG storage tank. Thermodynamic models are used to calculate the flash phenomenon. Also, it can be estimated the occurrence of rainout based on the following criterion:

- If rainout does not occur all the liquid that will be released will pass to the aerosol phase. The proportion of aerosol and vapour can be calculated by the flash calculations.
- If rainout take place it cannot be estimated the proportion of aerosol and rainout. Then estimation is being done assuming that the mass flow rate of aerosol is equal to the mass flow rate of flashed vapour.

A box type model is used to calculate the pool spreading of the rainout and the evaporation rate of the pool. This model uses time rates in order to estimate the pass from wetted form to the vaporization form. An integral type model is used from the other hand to calculate the dispersion of a pressurized jet of natural gas. Finally, the model which is used to calculate radiation has to take into consideration some parameters like the wind speed, the atmospheric stability, and ambient temperature, the relative humidity, the flame dispersion and the surface emissive power. When all the aforementioned parameters are considered then it can be predicted also the distances and elevations of radiation.[1, 29]

Conclusions

Small scale LNG provides actually two opportunities. The first one the usage as a fuel for heavy transport like ships, trucks, buses and rails. The increasing demand of LNG use in this sector is directly connected to the stricter regulations regarding greenhouse gas emissions (SO_x, NO_x, CO_2) and especially is shipping. Combining the need for reduction of carbon footprint with the necessity to keep fuel costs in low prices, LNG has proved a well promising alternative fuel especially for shipping sector. For this reason EU strengthens the use of small scale LNG as the solution to a cleaner transport sector, considering all the environmental benefits and safety precautions. Moreover, it is trying to adopt a cleaner legislative and fiscal framework in order to attract more players to invest in heavy duty road transport and rail. The second usage of small scale LNG is the distribution of LNG from big import terminals to smaller regional and local regasification terminals inside EU. This is practically the operation of breaking up bulk cargoes and delivering them to smaller market where most of the times the pipeline system cannot support them. LNG import terminals can have varying capacities, from these terminals small LNG ships with cargo capacities ranging from 5,000 to 30,000 m^3 will take care for the LNG distribution to remote areas. Also, trucks with cargo capacities approximately 50 m^3 will distribute LNG to the onshore areas and same procedure can be executed by rails with capacities from 500 to 1,500 m^3. EU aims to connect with this way areas which are not connected to the main European grid system and do not have access easily to the pipeline system. Moreover, small scale LNG ensures security of energy supply, enhances the normal operation of market functioning inside EU and reduces fossil fuel prices.

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