LNG Regasification Terminals

A literature study into the world of LNG

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The Hague,
September 30, 2015

Delft University of Technology

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Sustainable LNG regasification terminals

A literature study into the opportunities of LNG

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A technical feasibility study for constructing a sustainable LNG regasification terminal in Yuzhny, Ukraine

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By

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Contents

1. Introduction

In this report the main subject is the LNG industry. The demands of LNG market are increasing significantly, which makes this study a good opportunity to investigate new opportunities of LNG processes. The research has been divided into multiple sub questions in order to redefine the subject into smaller sections. During the literature study the process of comparing motivations and conclusions of similar thesis reports is done to redefine a new research proposal by questioning motivations and raising questions. Ultimately, a research proposal including a research question for the case study is suggested to the thesis committee.

After the orientation phase, some new chapters have been introduced;

- hazard identification analysis
- PIANC: *Masterplans for the development of existing ports; nr 158 – 2014*
- cold core integration
- LNG flammability range

1.1 Approach and methods

The literature study is the motivational background information about the research. Current literature, reports and journals are analysed in order to focus on a new research question. The applied approach of the literature study is divided in multiple steps:

- Set up a scope
- set boundary limits
- divide subject of LNG industry into multiple subjects
- analyse by comparing conclusions and motivations of the literature
- finalize study with conclusions and recommendations

All data are collected from a variety of sources. All literature, citations or sources are mentioned at the tail of the report within the registry. The data is first filtered and analysed in a separate file and all the relevant literature is treated in this literature study.

1.2 Scope of the literary study

The literary study focusses on the developments of the LNG industry, with respect to general information, LNG market and regasification terminals.

1.3 Goal of the literature study

The main goal is to gather information about LNG. The literature will serve as background information, gaining knowledge and justify the motivations about LNG processes and regasification terminals. The required data about LNG are enlisted below, within this list the first topics are focused on more general topics and further in the report more detailed topics. The treated topics are:

- LNG regasification processes
- LNG regasification terminals
- design approaches
- constructing methods
- standards and regulations
- involved actors
- reference projects

1.4 Document Structure

Set up of the report of the performed literature study is:

1. Introduction
2. Core of the literary report;
    a. Analyse and redefine the main subject.
    b. Determine sources which are expected to supply adequate data.
    c. Determine and execute systematic search profiles and criteria.
    d. Read and analyse the abstracts in order to filter the relevant data.
    e. Analysis and review the filtered data.
3. Results, conclusion and evaluation.
4. Discussion.
5. Recommendation for;
    a. redefined problem
    b. new research question

2. Problem analysis

2.1 Problem description

The main problem is the increasing demand in LNG, therefore regasification terminals are required. This problem can be divided into three sub problems:

1. There are not enough LNG regasification terminals.
2. Terminals are not working as efficiently as possible.
3. Why is the demand of LNG increasing?

In order to give a result to one of these sub-problems some characterisations of the corresponding sub-questions have been formulated. These three classes are General, Global Trade Market, and Terminal Efficiency.

2.2 General information

LNG

- What is LNG?
- What are the required processes for liquefaction and regasification?

Motivation

- Are the motives correct for the increase in LNG demand?

Social and safety aspects

- What are the largest disasters throughout history at LNG facilities?
- What are the major hazards or potential dangers?
- What are the safety standards, design criteria, and regulatory components?
- Is there any risk management in the port?

Miscellaneous

- Are there any reference cases?

2.3 Global LNG Trade Market

Trade market

- Who are the major actors globally?
    - main distribution lines
    - largest exporters/importers
    - stakeholders
- What is the expected growth rate of LNG usage in the future?
- Are there any areas of opportunity/Isolated areas?
- Why is the demand for LNG increasing?
    - energy shortage
    - climate change
    - political
    - improved transport conditions

Transport

- What are the main requirements and processes from port to hinterland?
- Which types of carriers are applied?

2.4 LNG Terminal efficiency

LNG Regasification terminals

- What are the main processes of an LNG regasification Terminal?
- What are the key elements during the design of an LNG Terminal?
- What are the key elements during construction of an LNG Terminal?
- What has been the relevant progress in history?
- What is the expected progress for innovative designs in the future?

3. Research methodology

The different phases within the literature study are:

1 Analyse and redefine the main subject.
2 Determine sources which are expected to supply adequate data.
3 Determine and execute systematic search profiles and criteria.
4 Read and analyse the abstracts in order to filter the relevant data.
5 Analyse and review the filtered data.

3.1 Systematic search profile

1) Orientation within the field of speciality;
   - Define a clear question.
2) Divide total question in multiple independent elements:
   - Determine relevant terms and combination of these;
     - (1) LNG
     - (2) regasification
     - (3) terminals
     - (4) import
     - (5) efficiency
     - (6) distribution
     - (7) companies
     - (8) innovative
   - Not included in search;
     - (1) production
     - (2) liquefaction
     - (3) costs
     - (4) export
     - (5) LPG
3) Apply appropriate search engines;
   - Repository.tudelft.nl
     - (1) Civil Engineering
     - (2) Hydraulic Engineering
     - (3) Mechanical Engineering
     - (4) Transport, Engineering and Logistics
   - scholar.google.com
   - 'Witteveen + Bos' Database
4) Apply as many variations as possible for each of the terms.
5) Execute search action.
6) Assess the results;
   - (1) If not enough → apply different demands.
   - (2) If too much → apply more demands.
   - (3) Too much and irrelevant → apply other terms.
7) Analysis of abstracts and summaries.

4. Results and discussions

In this section all (sub)-questions will be treated per category.

4.1 General information

4.1.1 Liquefied Natural Gas

LNG is a natural gas, (mostly methane, CH_4) that has been converted to a liquid state in order to make it easier to store or transport. This can be done by liquefaction of the gas, by doing so the volume decreases and density increases. The liquefaction process is done by the removal of certain components, dehydrating and freezing of the gas. I.E. Methane can be frozen at cryogenic temperatures of around -162 °C. Production of LNG is done at an LNG plant, where natural gas is liquefied.

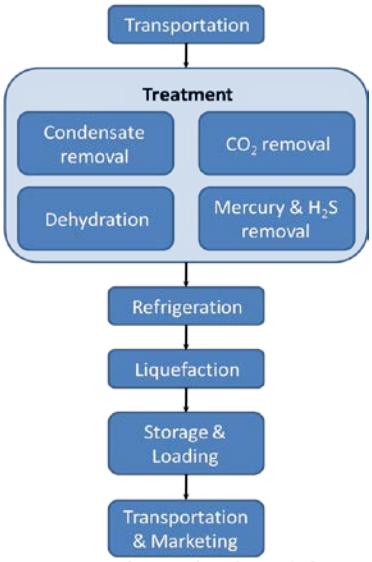


Figure 1 *Schematization of the LNG transport processes,* **adapted from** *open source wikipedia.com* **retrieved** *February 15* **From** *Wikipedia*

The volume of LNG can be reduced significantly more than CNG, which means that LNG is really cost efficient to transport over long distances by specialized vessels from plant to port. The other ways of transportation of the LNG gas is by tanker truck or railway tanker. Figure 1 shows all processes required in the LNG 'Process Chain'.

Regasification is the reversal of LNG at -162 °C to natural gas at atmospheric temperature. There are two types of regasification plants. It can be located on land or on floating barges. Regasification has three distinctive phases;

- LNG is received and offloaded from the LNG carries into cryogenic storage tanks.
- Regasification re-warming the liquefied gas to raise the temperature gradually above 0 °C.
- Gas is treated so it can be transported in the pipeline grid.

Storage of the liquefied gas is in LNG storage tanks these are located in ports and also in ships for transport. These tanks are typically a full containment type, which means that it is prohibited to have any leakages. Figure 2 on the next page shows a schematic view of an LNG storage tank. The figure shows a full containment type of storage tank, in which the main elements are:

- primary inside tank, made of cryogenic material
- insulation
- vapor barrier tank
- outer tank
- domed roof

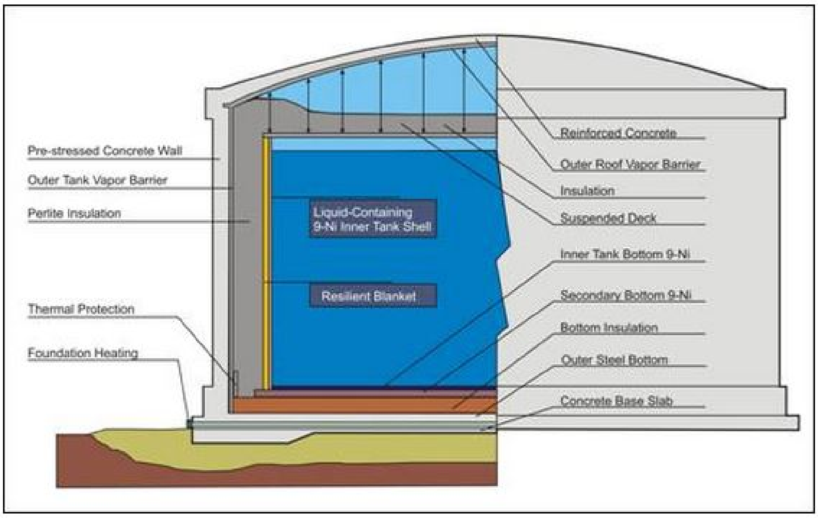


Figure 2 *Schematic view of LNG storage tank*, **adapted from** *EIA,* **retrieved** *February 2015* **from** *http://www.epd.gov.hk/eia/register/report/eiareport/eia_1252006/html/eiareport/Part1/Sec1_3_v2.html © 2015, EIA,* **reprinted with permission**

Applications of LNG are first for motorized uses, such as cars, etc. Secondary it can also be used in gas for household uses, such as heating or gas ovens. Third application is for energy purposes, it is a fossil fuel, yet it is one of the cleanest fossil fuels, as can be seen in figures 3 ,4 & 5 (Huisman S. , 2013).

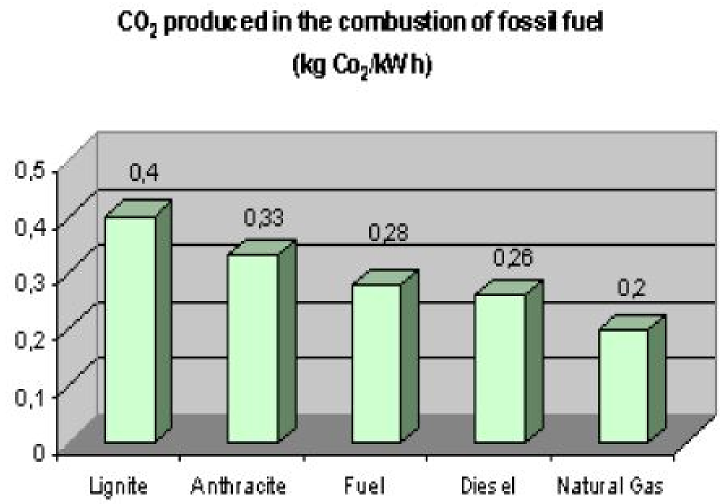


Figure 3 *Carbon dioxide emissions*, **adapted from** *Challenges of developing LNG Terminals* **, retrieved** *February 2015* **from** *UNESCO-IHE © 2013, VOPAK*, **reprinted with permission**

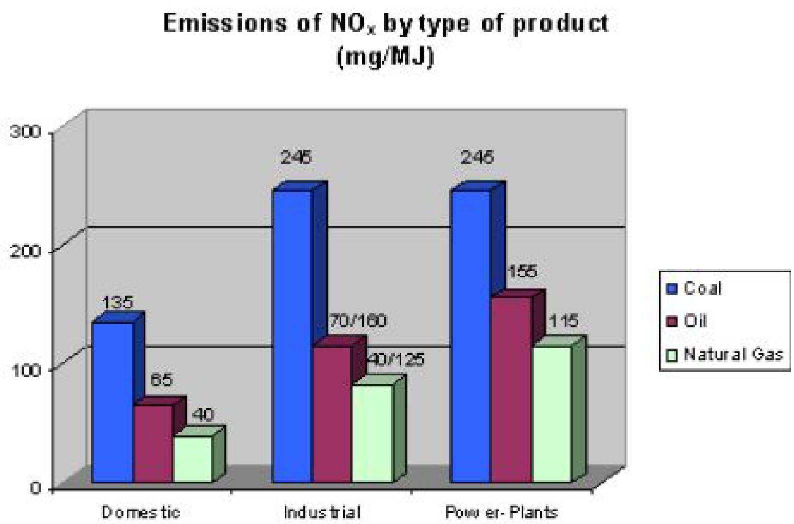


Figure 4 *Nitrogen emissions*, **adapted from** *Challenges of developing LNG Terminals,* **retrieved February 2015 from** *UNESCO-IHE* **© 2013,** *VOPAK,* **reprinted with permission**

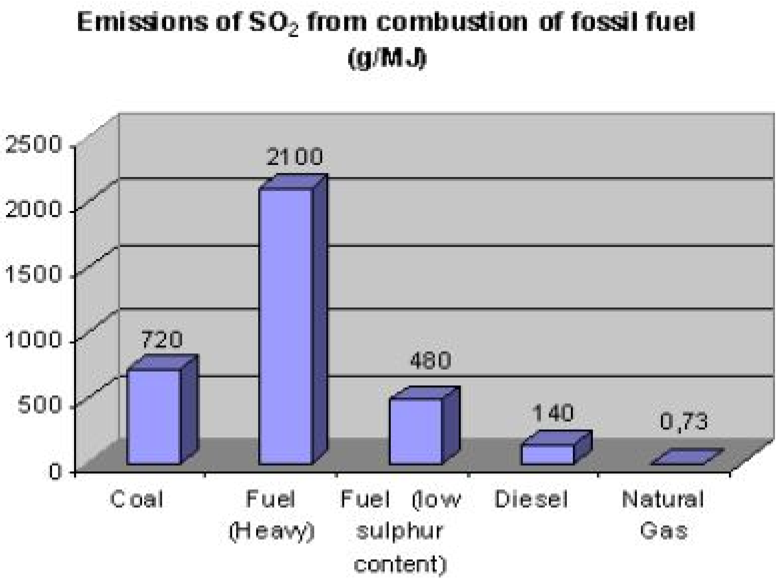


Figure 5 *Sulfur emissions*, **adapted from** *Challenges of developing LNG Terminals*, **retrieved February 2015 from** *UNESCO-IHE* **© 2013,** *VOPAK*, **reprinted with permission**

4.1.2. LNG flammability range

Vapors are released when LNG transforms into natural gas. When this is not properly managed, then these vapors become flammable, and explosive under certain known conditions. Yet safety and security measures contain in the engineering designs and technologies prevent these hazardous situations as much as possible.

For LNG there exists a range of minimal and maximum concentrations of vapor in which are and LNG vapors form a flammable mixture that can catch fire and burn. Figure XX is a schematic view of the upper and lower flammability limit of methane.

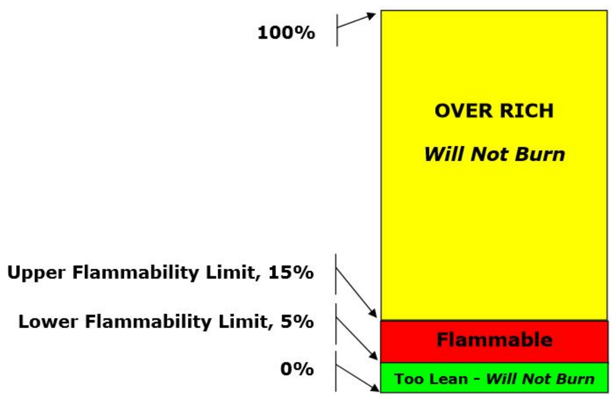


Figure 6 *Methane flammable range*, **adapted from** *LNG safety and security*, **retrieved May 2015 from** *Energy Economics Research © 2012, Center for Energy* **Economics, reprinted with permission**

If the upper limit is exceeded by the fuel concentration, then the mixture will not burn because there is not sufficient oxygen present. Similarly, there is no ignition when the lower limit is exceeded, but now because of the lack of Methane in the mixture. So methane gas will only ignite if the ration of mixture is within the flammability range.

The lowest temperature at which flammable gas vapors ignite spontaneously is called the auto-ignition temperature. Above this temperature the auto-ignition causes ignition after a short exposure of heat, without an external ignition source.

When LNG is spilled on the ground or water and there is no ignition source, then the flammable gas vapor will dissipate and there will be no fire. However, this is only true for ignition sources that do not exceed a spark or source of heat of 540°C.

4.1.3. The necessity of LNG

In the last century the World population has nearly quadrupled. Currently it is about seven billion people, but in 2024 this will already be eight billion. A tremendous change occurred with the industrial revolution, whereas since of the origin of life, it has been around 1800 for world population to reach one billion people, it has now increased to seven times as much. However the annual growth rate per year is reduced, this means that world population will grow in the 21st century, but at a slower rate. The latest United Nations projections indicate that the world population will stabilize at just above ten billion people in 2062.

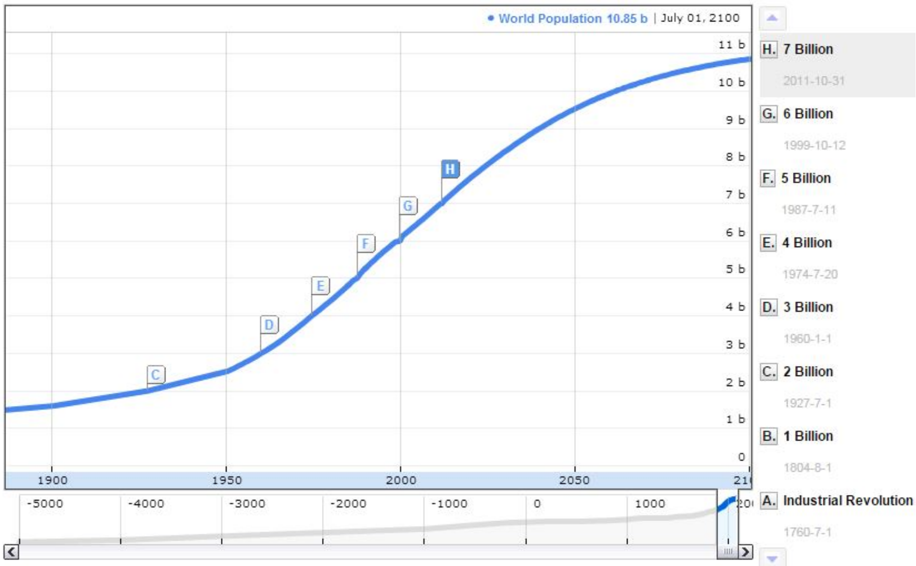


Figure 7 **Expected world population, adapted from** *Worldometers*, **retrieved** *February 2015* **from http://www.worldometers.info/world-population/ © 2015, Worldometers.info, reprinted with permission**

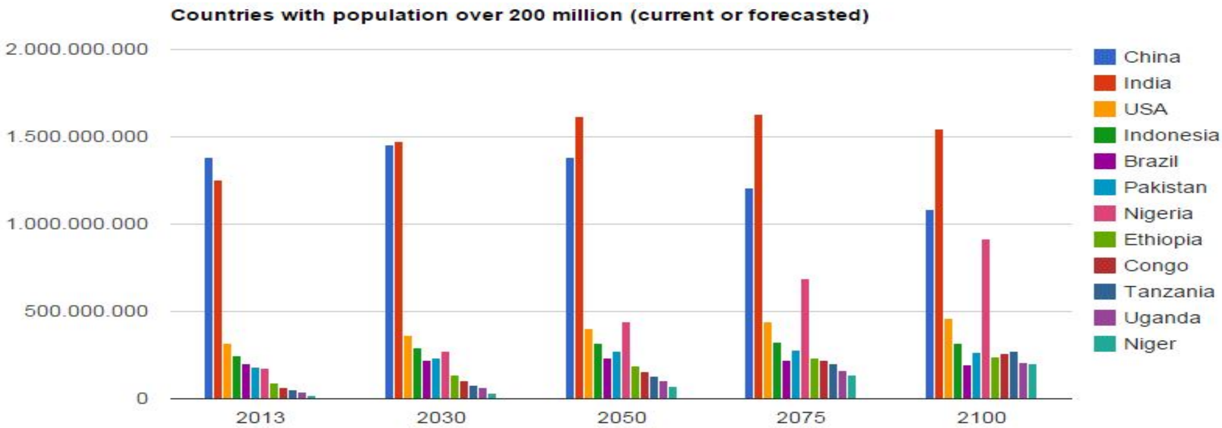


Figure *8 Expected population largest countries*, **adapted from** *Worldometers*, **retrieved** *February 2015* **from** *http://www.worldometers.info/world-population © 2015, Worldometers.info*, **reprinted with permission**

Figure 7 shows the estimated population growth of the countries that will grow over 200 million persons. All these people need housing, food, a safe environment and energy. However, the total availability of non-renewable fossil fuels is decreasing and environmental influences result in a necessity for a different kind of energy source. New methods such as green energy and nuclear power plants are not capable to solve the energy shortage, as stated by (Huisman, 2014) and (BP, 2014).

Green energy resources, such as hydropower, fuel cells, wind, biomass and solar energy, do not (yet) supply enough capacity and stability to all those countries. The growth is very dependent on other influences, such as political standards and also progress made with innovation of current technology. Certain green technologies as, solar, hydropower and onshore wind have a stable continuous growth of output over time, however offshore wind, bio-energy, concentrated solar power, ocean and geothermal technologies are lagging behind, which require more investments and technical improvement to achieve sufficient growth rates (International Energy Agency, 2014).

The image of nuclear power has had a serious fall back, due to the disasters in Fukushima in Japan and Tsjernobyl in Russia. Logically, there has been a declination in global nuclear energy generation, however new innovations of a technology kept some countries still interest in nuclear energy. The transition to Generation III light-water reactors resulted in a reduced decrease. Since nuclear power produces very little greenhouse gas pollution, it works efficiently in order to limit global warming. However, most countries still do not have any concrete plans to solve the nuclear waste problems (International Energy Agency, 2014). When in the future there is a better concept for processing the

So, in the mean while something else is required to supply sufficient energy, which cannot be non-renewable and has to have limited greenhouse gas pollution. Liquefied Natural gas in this case has a high potential in supplying the gap. Natural gas lowers carbon dioxide emissions in two ways, directly by replacing coal and indirectly by providing flexible support for variable renewable resources (International Energy Agency, 2014). To achieve a higher efficient energy generation additional improvements are still required.

4.1.4. Relation between oil prices and gas prices

According to Jensen there is a link between high prices on world oil and LNG prices.

"The sharp increase in world oil prices, which has affected natural gas and other energy prices, as well. The response of demand and the effect on interfuel competition of these higher prices is not well understood. (Jensen associates, 2007)"

Since, Jensen only suggested there is a link between high oil prices and natural gas price, but did not supply any support in his statements. Additional literature on this topic is therefore required. Most of the literature remains quite ambiguous about how the price is determined. However, some publications gave a clear statement about this topic. These are discussed next.

Looking at oil prices and gas prices in history, it becomes clear that these highly correlated. Import and export prices were based on long-term contracts with a lifespan of 20-25 years. Contracts in which the price was determined were built up from three principles (Stern, 2007):

1. Near parity with crude oil export prices
2. To be competitive with final consumer's alternative non gas fuels
3. Reflect historic costs of gas production

Since the price for oil shows large fluctuations, the gas price has to adept similarly, because of the long term contracts. Otherwise, people would have changed between the oil and gas whenever it was in their best interest. Due to these contracts, the difference between oil prices and gas prices was kept small. So large oil and gas companies controlled the market prices and the prices were not influenced by market demand or supply. This statement is supported by (Bock & Gijón, 2011) & (massonnier, 2006). Figure 8 shows the correlation between oil and gas price index where the Henry Hub national gas price only has small fluctuations of the gas price index.

There are three different perspectives regarding oil product-linked pricing. 'DG COMP' sector investigation identified three groups of stakeholders on this topic (DG, 2007);

1. Incumbents and producers, who believe in market power and favour long term contracts
2. Regulations, entrants and traders, who consider the link to be a lack of competition, but still favour medium to long term contracts
3. Entrants, customers and government agencies, who believe in open markets and favor short term contracts.

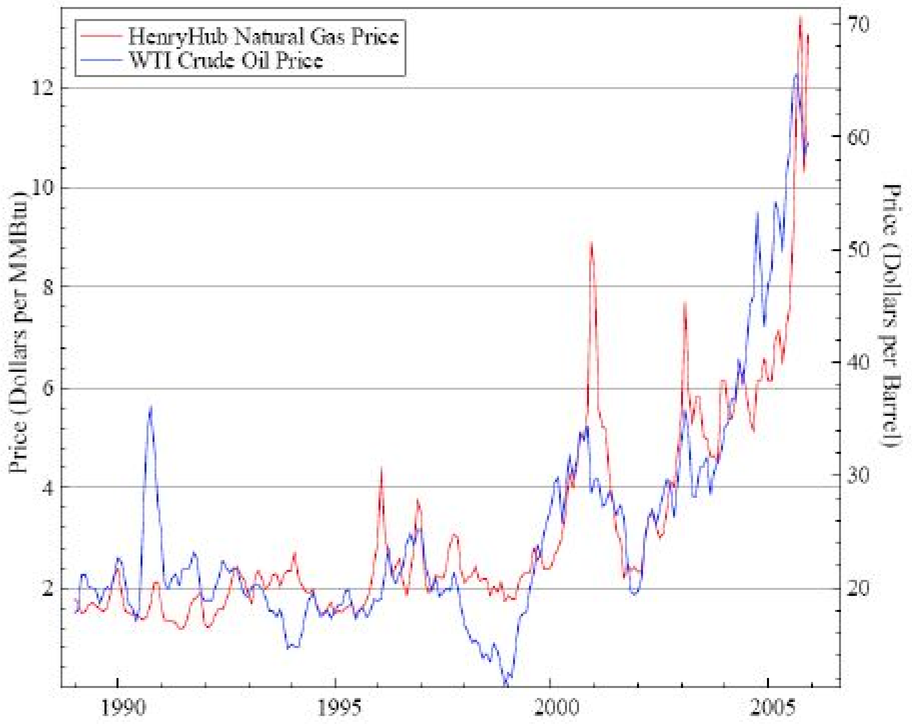


Figure 9 ***Oil-gas prices from 1990 to 2008*****, Adapted from** ***EIA 2006*****, retrieved** ***February 2015*** **from** ***World LNG report 2014 © 2014, IEA*****, reprinted with permission**

Nowadays, there has been a change in the United States. Since the market is deregulated, these long term contracts have adapted in short or medium term contracts. In Europe and Asia the gas price is still based upon the price of crude oil. However even in the deregulated markets, there is still an indirect link (Bock & Gijón, 2011) & (massonnier, 2006). Still, it can be clearly seen that fluctuations of the oil price index influence the gas price index significantly, yet the other way around the fluctuations in gas price index does not influence the oil index.

"In the future oil prices can still be determined by long-term alignment of gas prices, with oil prices, seen in the past will be a good guide to the future. However, short term pricing will create a larger and more competitive gas market which is not influenced by dominant Oil and gas companies. Another hypothesis is that long-term prices will be based on a price band where production and delivery cost define the floor and alternative fuels in the power sector.

Geographical and political influences increase where one country compared to another can have large differences in dependency on gas.

The determinant for gas prices can also be deducted from the market effect. Linkage of the price index of gas and oil will be determined by shortage of surplus in gas. (Stern, 2007)"

The energy supply will shift from gas to oil as the dominant fuel in 2035 (BP, 2014). This can be related to the Kyoto agreement for limiting the Greenhouse gas emissions, where the total amount of emissions will be lowered by 20% in 2020. This agreement includes a lowering in CO_2 and SO_2 emissions, even though most of these emissions are caused by Asian countries. Another influence on the shift of gas is the fact that natural gas is renewable.

In conclusion of this topic, it would be best not to link the gas price index with the oil price index. The value of gas will only increase and oil will lower. In order to get a fair competition there should be an open market so efficiency will be promoted in the future. This resulted in adaptations today, where new LNG regasification terminals should be constructed in such a manner in can compete with the energy demand.

4.1.5. Geopolitical Issues

Application of LNG is very sensitive to public opinion, so political issues are at a high interest, during the life span of LNG facilities. Countries that have to import LNG, in order to keep their energy up, are dependent on exporting countries. Consequently, this creates a strong market position for the exporting countries, which can be misused. These issues with politics are discussed by many, yet according to (Jens Bjornmose ea, 2009), globally seen political issues regarding LNG regasification plants are:

- transnational pipelines are owned by multiple states
- cooperation between member states, so transparency of available capacity
- terrorism
- political dependence on transit routes crossing hazardous countries/parties

Much literature has already been written about the political issues where Russia threatens to shut down the oil supply to Europe. It states that 30 % Europe's gas is supplied by Russia, what are the consequences and are there alternatives?

Ukraine Conflict

As stated by Jon Henley in (Henley, 2014) the consequences will have no large impact. Since Russia has threatened the many times with shutting down oil and gas supply to Europe, there have been preparations. First was started with making countries less dependent just on gas. Second is to construct alternatives to Russia's gas, for instance by making LNG Regassification terminals, and transport the LNG from the Middle East and Norway.

In the Middle East are also risks at stake, such as long transit routes. Which makes these routes vulnerable. Diversification of natural gas limits the risk of losses and increases the energy independence.

Finally it can be stated that Gazprom total gas sales and Russia's total budget revenue are from oil and gas. Russia needs the source of revenue. However where a year ago, it was expected that Vladimir Putin would have stood down, this has not been the case. Also he is still denying any role in the Ukraine fightings. So the gas is currently not coming towards the Eastern countries of Europe, this also implies the new construction of an LNG regasification terminal in Yuzhny ,Ukraine.

New events with respect to the Ukranian Conflict (Arsu, 2015) is that Russia's Gazprom has decided that the new South Stream Transport, which initially went towards Southeastern European countries, is now going to Turkey. Gazprom's chief executive Aleksei B. Miller told:

"There are no other variants possible. Our European partners have been notified of this and their task now is to establish the necessary gas-transporting infrastructure form the boarders of Turkey and Greece."

According to (Micco, 2014), who did a study into the risks of European countries that are too dependable of Russian gas. He states that:

"Ukranian crisis underscored the importance for the EU to diversify its energy sources".

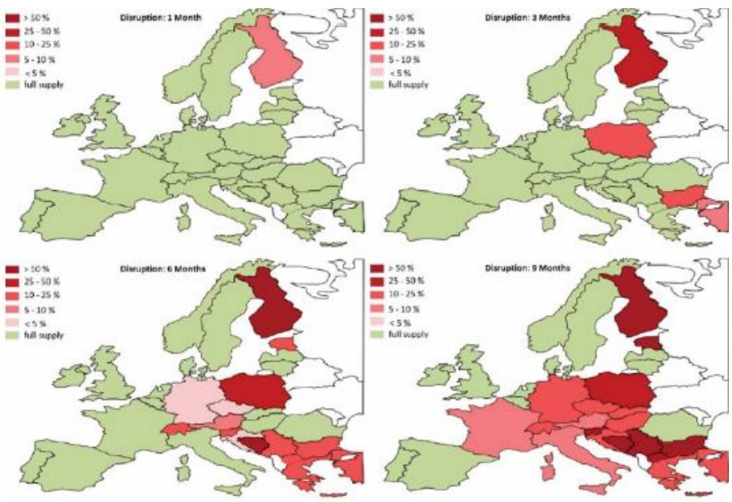


Figure 10 *Supply Shortfalls in European countries relative to their demand,* **Adapted from University** *of Cologne,* **retrieved** *February 2015* **from** *A cold winter to come © 2014, University of Cologne(EWI),* **reprinted with permission**

As shown in figure 10, the dependency on Russian gas at the moment is too much. So E.U. has to diversify, in the longer term, gas supplies from the Asia Pacific region, US, Middle East or Mozambique and Nigeria are a better solution. However, there is a risk of large inflations, and eventually causes the E.U. going into recession, because of contracts between the E.U. and Russia. Even more, the most of these Middle Eastern countries are quite unstable due to religious aspects, which can have similar consequences as Russian gas.

4.1.6. Potential hazards at regasification terminals

The next sections treat topics with respect to safety. First are some major disasters in history, next will be more detailed information about standards, regulations and risk management.

Major LNG disasters in history

Throughout history there have been some major disasters, a variety of disasters have been enlisted by (Hamutuk, 2008):

- Cleveland Accident in Cleveland, Ohio USA in 1944
    - At the peak shaving plant a tank failed and spilled the contents on the street and storm sewer system. The resulting explosion and fire killed nearly 128 people. The tank was built with a steel alloy that had a low nickel content, which made the alloy brittle when exposed to extreme cold of LNG
- Staten Island, New York, U.S.A. in 1973
    - A fire started while repairing the interior of an empty storage tank at Staten Island. The resulting increase in pressure inside the tank was so fast that the concrete dome on the tank lifted and then collapsed down inside the tank killing the 37 construction workers inside.
- Mostafa Ben Bouliad Spill, USA in 1979
    - While discharging cargo at Cove Point, Maryland, a check valve in the piping system of the vessel failed releasing a small quantity of LNG. This resulted in minor fractures of the deck plating.
- Mercury, Nevada, USA in 1987
    - In August 1987 an accidental ignition of an LNG vapor cloud occurred at the U.S. Department of Energy Nevada Test Site during large-scale tests involving spills of LNG. The cloud was accidentally ignited and damaged and propelled polyurethane pipe insulation outside the fence.
- Skikda, Algeria in 2004
    - A steam boiler that was part of an LNG production plant exploded, triggering a second, more massive vapor-cloud explosion and fire. The explosions and fire destroyed a portion of the LNG plant and caused 27 deaths, 74 injuries, and material damage outside the plant's boundaries.
- Ghislenghien, Belgium in 2004
    - A pipeline carrying natural gas from the Belgian port of Zeebrugge to northern France exploded, resulting in 23 known fatalities. The cause of the incident is still under investigation, but it appears that a contractor accidentally damaged the pipe.
- Districts Heights, Maryland, USA in 2004
    - Washington Gas Company-sponsored study released in July 2005 pointed to subtle molecular differences in the imported liquefied natural gas the utility began using in August 2003 as the cause of a house explosion in March 2003.

In the previous list, small failures within a system caused major disasters. A list of the most occurring failure leading to hazardous situations is underneath. LNG's principal hazards result from its:

- cryogenic temperature
- flammability
- vapour dispersion characteristics

Some misconceptions in some of the publications have to be cleared:

- LNG does not explode;
    - Explosions are caused by LNG touching water, these are called Rapid Phase Transition
- Terrorist attacks are not plausible, because of the thick walls of containers (Ditali & Fiore, 2009).

The total amount of disasters in 50 years is quite small compared to other energy facilities. However consequences are usually quite high, therefore it is good to have strict regulations in building regulations and standards. Applying these codes minimizes internal risk of casualties, which is necessary in such a delicate topic. In the case of such a topic as LNG disasters, there is a large political influence by governments, but also socially the impacts of the public are significant. The positive momentum of an LNG facility can easily become negative. The same happened to nuclear power plants after Tsjernobyl and Fukushima.

4.1.7. Safety of LNG industry

A paper has been published by (Foss, 2006), which mentions the requirements for safety and corresponding standards and regulation. The safety of LNG industry is determined by a four layer protection system.

Figure 11 *Critical safety conditions* **adapted from** *Energy Economics research,* **retrieved** *February 2015* **from** *LNG Safety and Security © 2006 ,Center of Energy Economics,* **reprinted with permission**

The four layer containment safety, in figure 11, consists of these aspects;

1. Primary containment is the first safety requirement for the LNG facility is to contain LNG.
2. Secondary containment is the second layer of protection during failure of the first containment by leaks or spilling. The LNG can still be obtained an isolated.
3. Third is the safeguard systems, where the main function is to minimize the release of the LNG and mitigate the effects of a release.
4. Separation distances is the fourth layer of protection. The main requirements of federal regulations are that LNG facilities need to be at a safe distance from adjecent industries, communities and other public areas. .

Industry standards and regulating compliances are required to have an insurance for appropriate operating and maintaining procedures being in place.

Design criteria, regulations and safety standards

The four protection layers plus the standards and regulatory compliances are important to enhance the safety level of LNG terminals. These standards and regulatory for constructing a safe LNG terminal are discussed by (Huisman J. , 2014), (Ditali & Fiore, 2009) & (Wright Marine Technology, 1997).

These design criteria for a safe design of an LNG terminal are stated by (Huisman J. , 2014):

- Vessel traffic Management System (VTMS)
- navigation aids
- pilots
- tugs
- bathymetry;
    - Under-keel clearance = 0.8 m to 2.5m.
    - Include tidal amplitude.
- channel width and lengths (Depending on environmental conditions);
    - Minimum width of dredged and marked fairways is 4 to 6 times beam of design LNG carrier (approximately 200 to 300 m).
    - Minimum distance for free sailing ship at 6 to 8 knots requires 1 nautical mile to come to a stop (approximately 1 km).
- turning areas must be;
    - Two times the overall length of the design vessel.
    - Minimal 1.5 LOA if GPS is available.
- Jetty location never at the end of approach channels or in outer bends

Some of the primary measures are treated by:

- Internal safety distances: Imposed by the LNG Standards such as:
  - NFPA59A (Standard for the production, storage and handling of LNG
  - EN1473 (Installation and equipment for LNG. Design of onshore installations)
    - Distances of 300 -500m for areas with low concentration of people i.e. industrial or port nature.
    - Distances of >1 km for areas with medium concentration of people i.e. housing
    - Distances of >1.5 to 2k m for areas with high concentration of people i.e. schools, offices or hospitals.
  - EN 1160 (Installation and equipment for Liquefied Natural Gas – General Characteristics of Liquefied Natural Gas contains guidance on properties of material commonly found in LNG facility that may come into contact with LNG)
- All LNG piping runs over impounding's, which, in case of a leak, contain the leak and limit radiation of the pool and evaporation.
- Extensive safety measures for extinguishing means.
- Scenarios of catastrophic tank failure are considered.
- Storage tanks are of the full containment type.
  - EEMEUA 147[44] Recommendations for the design and construction of refrigerated liquefied storage gas storage tanks. This document contains basic recommendations for the design and construction of single double and full containment tanks for the bulk storage of refrigerated gases(RLGs) down to -165°C, covering the use of both metal and concrete materials

The safety standards need to be high, due to these large damages, mentioned by (Hamutuk, 2008). Therefore the industry standards such as: [discussed by (Fiore, 2009)]:

> "NFPA 59A, US DOT 49 CFR 193, and BS-EN 1473, CSA Z276-07.
> Several safety studies have been completed or are near completion for LNG risks: Fay (2003), Lehr et al. (2004), ABS (2004), DNV (2004), Sandia National Laboratories (2004). Many earlier safety studies were completed in the 60's and 70's (USCG, 1980)."

Risk management in the port approach

Even though the paper by (Wright Marine Technology, 1997) has been written in 1997, their view on risk limitation during port navigation and cargo operations is still rather accurate. They formulate a variety of criteria for designing and risk management in the port approach. A summary of specific criteria for safe LNG Berth is enlisted below and separated in three main elements:

First are the essential design criteria for a safe LNG jetty:

- Location with a suitable distance with respects to centers of population.
- Provide a safe position, removed from other traffic and wave action.
- Construct mooring points in a sufficient array and strength.
- Apply hard arms for cargo transfer.
- Interlink ship and shore ESD Systems.
- Provide a two stage ERS Systems, linking ESD protocols and PERC operation.
- Fit hard arms with PERCs, together with quick acting valves.
- Fit wind speed and direction monitoring equipment.
- Install load monitoring equipment on mooring line quick release hooks.
- Determine maximum credible spill, gas cloud range and ignition-free safety zones.

Second are the terminal procedures for the LNG carrier alongside

- Set limits on the mooring system for wind speed, wave height and current.
- Set wind limits for cargo stoppage, hard arm disconnection and unberthing.
- Restrict speeds of passing vessels.
- Control visitors and vehicles in safety zone.
- Establish ignition free offshore zones.
- Warning systems with weather forecasts.
- Pilots and tugs available for emergencies.

Third is LNG Port Procedures

- Set up weather limits for closure.
- Set up port controls for approach channels.
- Set up port controls for tugs and escort draft.
- Set up procedures and systems regarding traffic control.

In addition to these criteria human errors and operational factors should be included. The most critical conditions are bathymetry and weather conditions, but the other criteria are flexible applications for a safe design. All these aspects of safety have resulted in very few hazards or disasters. In order to maintain this high safety level all of standards and have to be combined and updated every year (Huisman J. , 2014).

Hazard identification techniques

Several hazard identification techniques are currently identified by (Cozzani, et al., 2011) & (Paltirnieri, Tugnoli, & Cozzani, 2014), namely 'State of the art','DyPASI' , 'HazId and 'MIIMAH'.

The 'State of the art'analysis contains some conventional techniques, whichh are:

- hazard and operability studies (HAZOP)
- failure mode and effect analysis (FMEA)
- event tree methods (ETM)
- fault tree methods (FTM)

"Thus, no specific method was identified. Moreover, the analysis of the current state-of-the-art in hazard identification for LNG plants evidenced the presence of gaps and "grey areas". The key issues identified in the gap analysis concerned the availability of a guided approach to the systematic extension of the consolidated knowledge to innovative design solutions, the assessment of external threats, and the inclusion of "unknown known" hazards from the analysis of past accidents and near-misses. (Cozzani, et al., 2011)"

So, other methods were required for improved hazard identification methods. The improved methods are mostly based upon extending the existing tools and focus it on one of the gaps.

Methodology for the Identification of Major Accident Hazards (MIMAH) is a tool for identifying major accident hazards in the process industry. This technique makes it possible to construct bow-tie diagrams by combining critical events within fault and bow trees. Which can be developed based upon taxonomy and hazard of substances.

Dynamic Procedure of Atypical Scenarios Identification (DyPASI) is an extension of a self-learning model for past events. DyPASI is used for identification of atypical hazards related to safety. Atypical events are described as when it cannot be classified as common events, because it deviates from normal expectations. These potential scenarios are classified as:

- knowns-knowns
- known-unknowns
- unknown-knowns
- unknown-unknowns

With DyPASI a systematic inclusion of atypical events is made, these are mostly low probability event with high consequences or for events with little to no experience. DyPASI procedure steps:

1. pre-analysis
2. identify all hazardous situations
3. Define all critical events
4. Construction of ETM
5. construction of FTM
6. definition of safety barriers

So, DyPASI makes it possible to recognize atypical events early based upon previous events, such as accidents, inherent studies or general concern. It is modelled to support bow-tie diagrams and MIMAH. An atypical event is the result of a sequence of events that do not have to be atypical. This chain of events defined by the DyPASI method is illustrated in shown in figure 12. In this figure the Rapid phase transition (RPT) event in the bow tie diagram is developed using the MIMAH method.

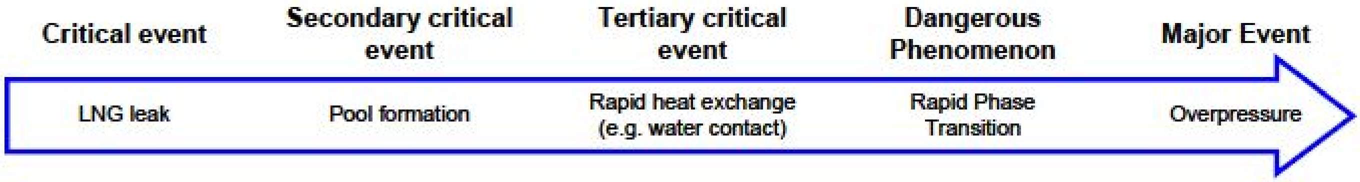


Figure 12 *Chain of events resulting in RPT explosion* **adapted from The Blue book Approach , retrieved** *March 2015* **from** *LNG Safety of LNG regasification terminals © 2011 , AIDIC*, **reprinted with permission**

Hazard Identification of external threats (HazId) is a review technique that is based on brainstorming sessions. With this method classes are determined such as 'internal', 'intrinsic' or 'external' hazards', and enlisted with corresponding guidewords. These guidewords are deducted from Standardized entries, i.e. ISO 17776. Logically, the experience of the team leader and team is of major influence in order to ensure a complete identification of all hazards.

4.1.7. PIANC Masterplan Analysis

Strategic plans with introducing guidelines for competitiveness usually have a timescale of about 10 years. Considerations made within a Masterplan take up a timespan of about 20 to 30 years. Short term planning is referenced as port zoning this typically has a time frame of 5 years. Port zoning defines the layout and the allocated areas for water and land. Masterplan is a document that describes the intended growth rates and adaptations associated with the evolution of demand and/of other various factors. Obviously, port Masterplan's will be discussed within this analysis of the report by PIANC, (World Association for Waterborne Transport and Infrastructure, 2014).

A Masterplan is drafted with three different strategic focuses:

- Multinational level
- National or regional Level
- Local level (similar to port planning)

Processes within the Masterplan are driven by;

- Technical considerations
- Accessibility by land and sea
- Environmental issues
- Economic assessment

Review of existing port facilities and operations of LNG terminals. Productivity and capacity are determined by local circumstances. Capacity indicators are derived, as such:

- Storage capacity total terminal: No. of tanks x capacity [m3]
- Handling capacity total terminal: No. of handling equipment x theoretical throughput [m3/h]

Two design criteria have been introduced as a rule of thumb. First the storage capacity of a tank farm should be at least 3 or 4 times the largest vessel size. Second is that handling capacity should be around 3%to 5% of the annual terminal throughput. Handling capacity is in the order of 8000 m3/ hr. to 14000m3/hr. Typically a maximum pumping rate from a carrier is 10% of the vessel's capacity per hour. Actual discharge rate depends on the size of (un)loading arms, pipeline capacity and length and tank farm system. Tabel 1 shows the current and potential optimized capacity for a liquid bulk terminal.

Table 1 Throughput and productivity calculations by PIANC

Quay productivity	As is situation		Theoretical Maximum (existing equipment		Theoretical maximum	
	Throughput	Productivity	Capacity	Productivity	Capacity	Productivity
Liquid Bulk terminal	Handled m3 p.a.	Handled m3 p.a. per berth	Maximum utilisation(%) x existing handling capacity (m3/h) x 24h x 360d	Maximum capacity per berth	Maximum utilisation(%) x optimized existing handling capacity (m3/h) x 24h x 360d	Maximum optimized capacity per berth

In general the liquid bulk terminal area and overall layout are dependable on:

- Type of cargo
- Volume of cargo
- Variation in cargo types at the terminal
- characteristics of the product (and hazard classification)
- Type of terminal (import, export, tank farm, fuel depot)

Apart from the storage area, an additional approximately 30% of the terminal area is required to allocate the internal roads, buildings, workshops, etc.

Engineering aspects for master planning considers a range of factors that apply specifically to port masterplanning. These aspects, enlisted on the next page, are a pertinent through this thesis report, especially considering port design in the case study in Yuzhny.

Environmental Issues and 'Green Ports'

"The Kiev protocol defines 'Strategic Environmental Assessment' as the evaluation of the likely environmental, including health, effects, which comprises the determination of the scope of an environmental report and its preparation, the carrying-out of public participation and consultations, and taking into account of the environmental report and the results of the public participation and consultations in a plan or program." (World Association for Waterborne Transport and Infrastructure, 2014)

Two important aspects of sustainable port planning are the Environmental Impact Assessment (EIA) and Environmental Impact Statement (EIS). Green design principles are developed in terms of preparing port Masterplan's, during all stages. The issues that should be considered to include the green principles are:

- land and water area use
- modalities and connectivity
- air and noise pollution
- surface water and sediment
- soil and groundwater
- dredging
- climate change and sea level rise
- light pollution
- habitat and species management
- ship related management
- globalization
- sustainable resources management

"A stronger consideration of green design initiatives and considerations of environmental values at and around individual seaports should be central part in Masterplan development. Ultimately, more efficient and sustainable use of resources, resulting in greater port productivity and overall cost savings should be the key drivers of a green approach. (World Association for Waterborne Transport and Infrastructure, 2014) *"*

1. Topography and bathymetry
2. Metocean conditions
3. Geotechnical aspects
4. Material supply
5. Dredging and reclamation
6. Marine access
7. Breakwaters
8. Quays and jetties
9. Utilities
10. Maintenance
11. Safety, security and border patrol
12. Container terminal simulation

Terminal planning associated with LNG cargoes. LNG cargo is classified as a hazardous substance, therefore governing, safety requirements are introduced. Required equipment, facilities and tanks for handling are single point mooring (SPM), loading arms, pipelines pigging system and storing is done in cryogenic or normal gas tanks. The productivity per berth determines the number of berths required; this is shown in equations 1.

Equation 1

$$C_b = P * N * n_{hy} * m_b$$

Where:	C_b	= productivity per berth	[tonnes/year]
	P	= productivity per handling entity	[tonnes/hour]
	N	= number of entities per ship	[-]
	n_{hy}	= number of operational hours per year	[hours/year]
	m_b	= berth occupancy factor	

Equation 2

$$n = C/C_b$$

Where:	n	= number of berths	
	C	= required throughput trough the terminal	[tonnes/year]
	C_B	= productivity per berth	[tonnes/year]

For a single berth the quay length is typically determined by the length of the largest vessel frequently calling at the terminal, plus an additional 15-30 m fore and aft to account for mooring lines.

Equation 3

$$L_q = L_{s,max} + (2 * al)$$

Where:	L_q	= quay length	[m]
	$L_{S,max}$	= maximum ship length using the berth	[m]
	al	= additional length (usually 30 m).	[m]

These equations are all rules of thumbs and only serve as an indication. The accounted safety factors are up for discussion to meet the demands of both governing parties.

4.1.8. Conclusion

The total world population is increasing significantly in the next 50 years, while climate change has to be reduced. So other sources of energy have to be developed in order to limit the greenhouse gas emissions. One way of doing this is applying renewable green energy such as wind, hydropower, solar, biomass, etc. However the current green technology is not enough to supply the large demand. These sources of energy or not sufficiently reliable and efficient enough or have other issues where negative side effects are still in order. In example, hydropower in large reservoirs is leading to high erosion and sedimentation problems downstream and upstream, respectively. The gap in energy demand has to be filled with other resources. Since, the disasters of Fukushima and Tsjernobyl with nuclear plants the public opinion is negative, because safety and environmental consequences were not secured. Natural gas is also a fossil fuel this means that emission rates are not zero, however these emission rates are at such a low rate, it becomes acceptable to use natural gas as an alternative for the energy shortage. When natural gas is applied as an energy source, this will give green energy enough time to develop into a fully sufficient energy source in the future.

The political issues in the world have led to a diversification of exporting LNG terminals, because countries that export LNG have been too powerful the last years. This means an increase in energy independence of a single country.

Large uncertainties about the stability of the gas price index led to long term contracts where the price of natural gas is correlated to the price of oil. This is not beneficial to the market's demand, where companies have become too powerful. However, a good reason to have this correlated price is when the gas price index is unstable. To improve market it should be considered to have small term contracts. With this kind of contract the price of natural gas is not correlated to the oil price index, which results in a more open market with a fair price for gas, where smaller companies can more easily fade in. These small term contracts set the price by the current demand or shortage of LNG, thus based upon the gas price index.

The LNG industry has an excellent history without many disasters compared to other sources of energy. This is a credit of the high applied safety level during the design, construction and operational phases. This high safety level is achieved by setting high standards, regulatory components and an adequate approach in risk management. Also the highly adaptive mentality with respect to previous disasters resulted in more safe designs.

4.2. Global LNG trade market

The global LNG Market is divided into two topics. First is the trade market, and second the transport of LNG. In figure 13 the largest regasification terminals and liquefaction plants of the world in 2010 are shown.

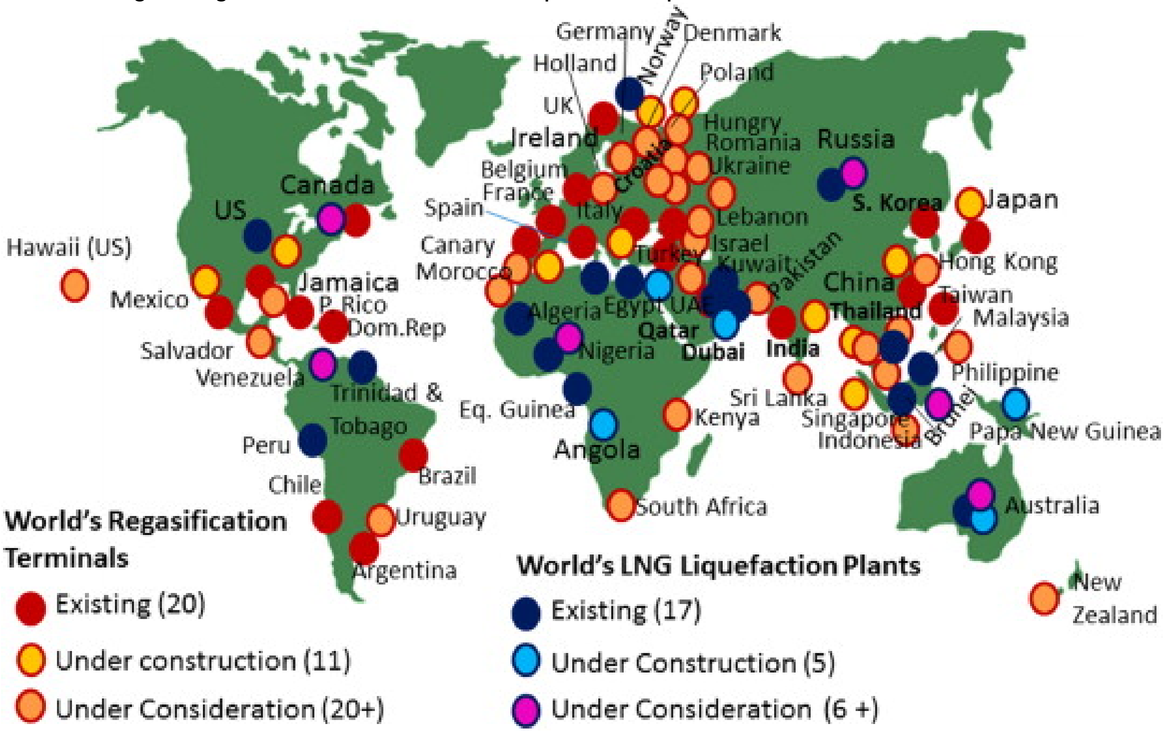


Figure 13 *Largest terminals in the world in 2010* **adapted from** *Current status and future projections of LNG demand and supplies: A global perspective, retrieved February 2015* **from** *Elsevier.com © 2011 Elsevier*, **reprinted with permission**

4.2.1. LNG Market

The total demand of LNG is increasing this is shown by considering the current largest contributors of LNG trade. In order to visualize the LNG trade the largest countries that import or export and the main distribution lines are discussed. According to different institutions, there will be a vast change in the contributing countries and distribution.

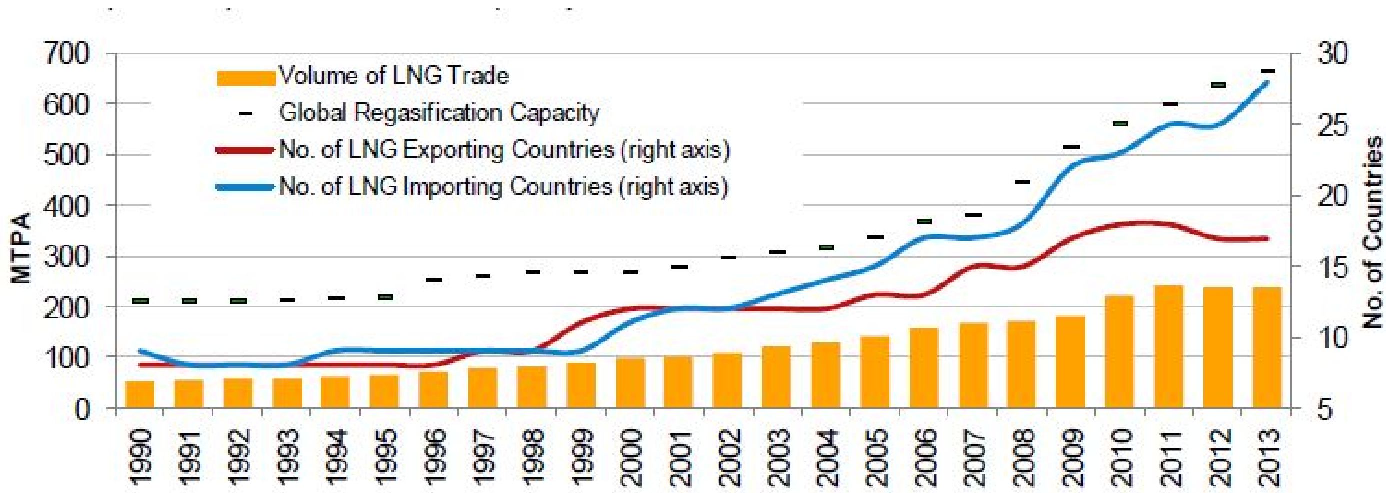


Figure 14 *LNG trade volumes 1990-2013* **adapted from World LNG report, retrieved** *February 2015* **from** *IGU.com © 2014 IGU*, **reprinted with permission**

Figure 14 shows that since 1990 there has been a significant increase in volumes of LNG trade. This can be related to the increased possibilities to transport LNG. The higher gradient for importing country's compared to exporting countries is due to that many countries had natural gas at first, but changed policy or the storage is simply empty. So exporting countries become importing countries vice versa also happens, just not as frequent. US first were an importing country, but now they have large resources of Shale gas and have become an exporting country.

Main distribution lines

All distribution of LNG has to be transported along different transport routes with a variety of LNG terminals in between. A single carrier services several LNG terminals over the world. Some countries only export, some only import or some countries do both. They import when more storage is required and when it is not required they export the LNG once again.

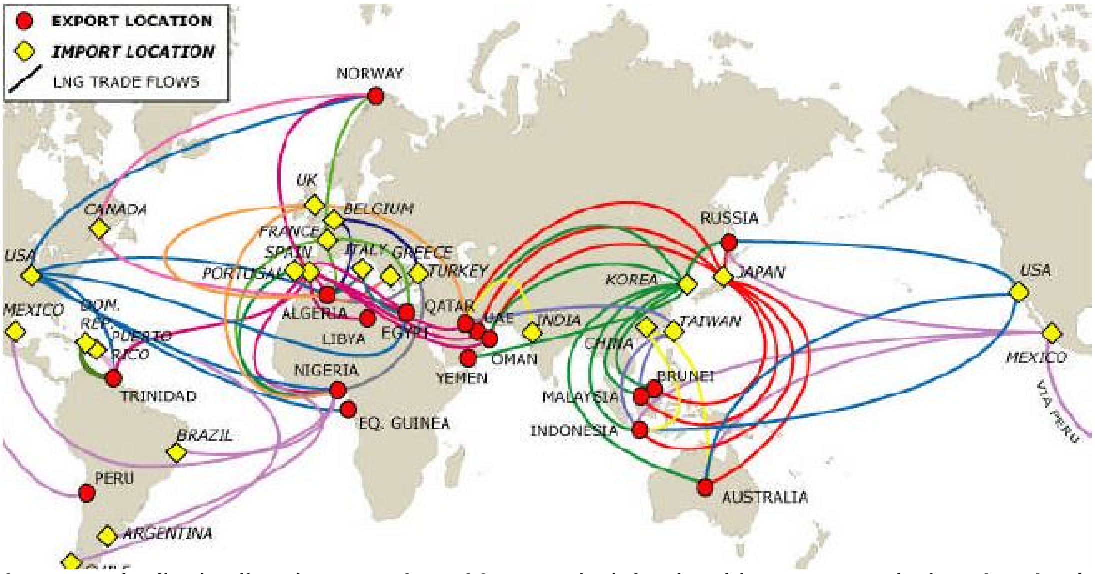


Figure 15 *Distribution lines in 2010*, **adapted from** *Outlook for the Kitimat LNG terminal*, **retrieved** *February 2015 © 2010*, *Poten en Partners*, **reprinted with permission**

Figure 15 shows the relevant export and import locations and the distribution lines in between. It is noted that the main focus is around the Middle East and Asia Pacific for export and for import it is North and South America, Europe and east coast of Asia. According to (Huisman, 2014), the main distribution lines in 2030 are as shown in **f**igure 14**.**

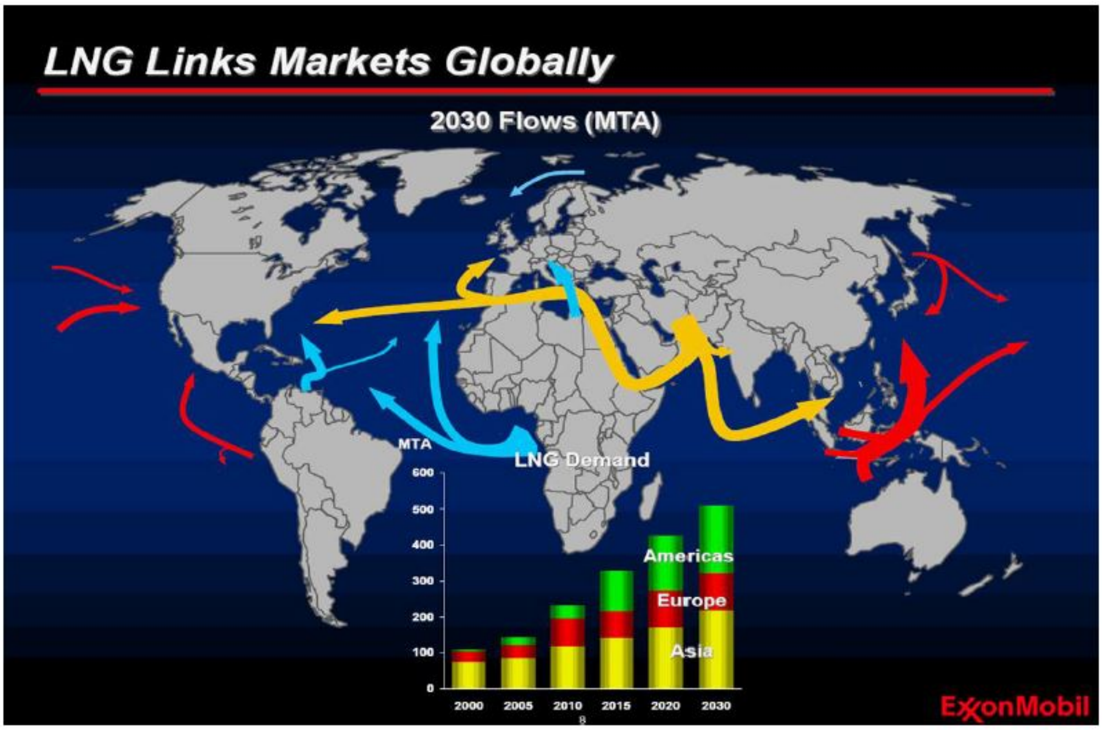


Figure 16 *Main distribution lines according to Exxon Mobil*, **adapted from** *LNG Terminal fuel of the future*, **retrieved** *February 2015 © 2014 Exxon Mobil*, **reprinted with permission**

When figure 16 is compared to figure 15: America, Europe and Eastern Asia are still importing LNG in 2030, while Africa, Middle East and Asia Pacific are still the largest contributors. So the distribution lines and largest contributors are similar in 2010 and 2040, according to (Huisman, 2014) and (Poten & Partners, 2010).

However, due to production of shale gas in Northern America it has become an exporting country. This can be beneficial to Europe, because America is more stable as an exporting contributor compared to the Middle Eastern countries and Russia.

Largest contributing countries for import and export of LNG

According to the report by (International Gas Union, 2014) the largest contributors to the trade of LNG are shown in table 2**.**

Table 2 *Top ten largest contributor of the LNG market*

Largest contributors to the LNG market						
	Export			**Import**		
index	**Country**	**Total Export [MT]**	**Relative change to 2012 [MTPA]**	**Country**	**Total Export [MT]**	**Relative change to 2012 [MTPA]**
1	Qatar	77,2	-0,2	Japan	87,8	0,5
2	Malaysia	24,7	1,6	South Korea	40,9	4,1
3	Australia	22,2	1,4	China	18,6	3,8
4	Indonesia	17	-1,1	India	12,9	-1,1
5	Nigeria	16,9	-3,1	Taiwan	12,8	0,1
6	Trinidad	14,6	0,2	Spain	9,4	-4,9
7	Algeria	10,9	-0,1	UK	6,8	-3,6
8	Russia	10,8	-0,2	Mexico	6	2,4
9	Oman	8,6	0,6	France	5,8	-1,7
10	Yemen	7,2	2,1	Argentina	4,9	1,1

Historically seen the Asia Pacific region has always been the largest contributor of export of LNG in the world. However, these exports have been supplemented and, ultimately, to be surpassed by the Middle East in 2008. Qatar is the most significant reason for this growth development. Figure 17 shows the largest contributors in 2014.

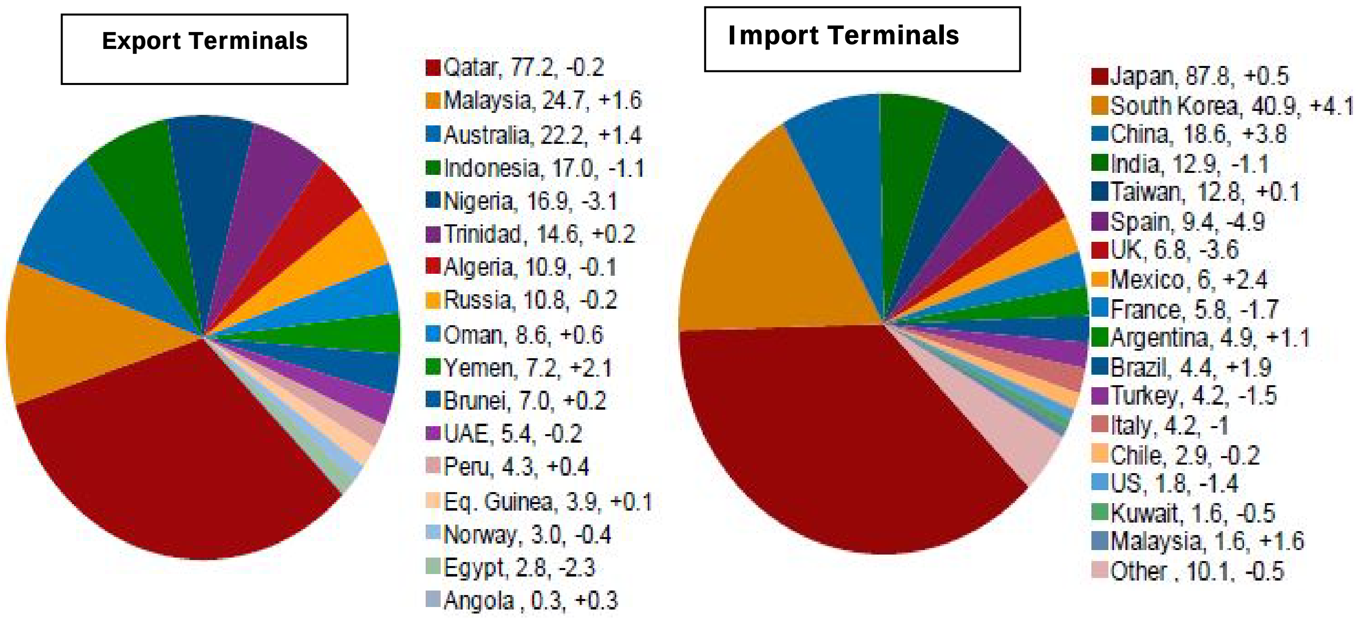


Figure 17 *Import and export terminals worldwide* **adapted from** *World LNG report*, **retrieved** *February 2015* **from** *IGU.com* **©** *2014, IGU*, **reprinted with permission**

Japan has become the largest importer of LNG after the Fukushima disaster. Since 2012-2012 the energy supply of Japan has become fully dependable on LNG. Other countries now use multiple resources for energy and increased their LNG import in order to increase their gas supply security.

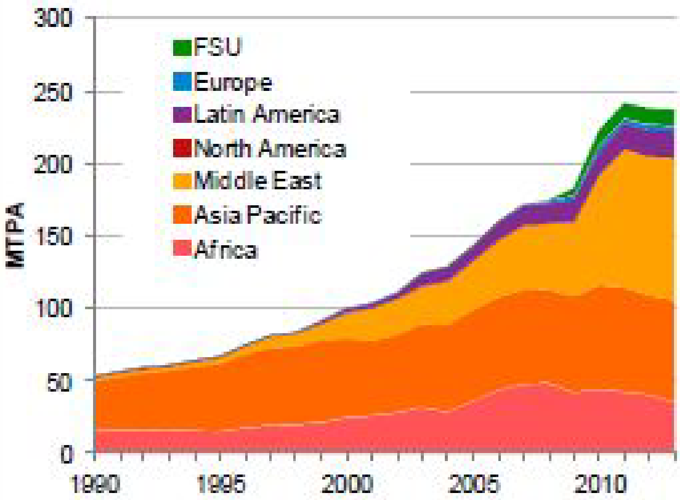


Figure 18 ***Export increase over time per region*** **adapted from** ***World LNG report*****, retrieved** ***February 2015*** **from** ***IGU.com*** **©** ***2014, IGU*****, reprinted with permission**

In figure 18 it can be seen that over the last year the main exporting regions have focused on the Middle East and the Asia Pacific. As well as an increasing use of LNG up to 2011 after this there has been small decrease. This can be explained as, that countries were storing more LNG, instead of importing LNG. In the appendix are all LNG facilities over the world.

Isolated regions/Areas of opportunity

An isolated region is a region in the EU-27 not yet developed or underdeveloped compared to the gas potential. Table 3 is based upon a study performed by (Jens Bjornmose, 2009).

Table 3 Areas of opportunity within Europe

Areas of opportunity in Europe			
Region	**Country**	**Problem**	**Opportunity**
Baltic Region	Finland	Not integrated in the EU Network and not diversified	Interconnector projects establishes a integration into the EU Network
	Estonia		
	Latvia		
	Lithuania		
Central Region	Poland	Too high reliance on coal in the power sector	New climate objectives
	Germany-Poland	No reverse flow	Project establishing reverse flow
Scandinavia	Sweden	Political priorities have been on other energy sources.	The planned BGI pipeline could stimulate competition for supply to Sweden
Islands	Sardinia, Italy	No connection	GALSI pipeline project from Algeria via Sardinia to Italy will supply gas at Sardinia
	Malta		No plans
	Cyprus		Construction of an LNG terminal

Expected growth and changes of the LNG trade market in the medium to long term

Medium to long term expectancy is in the range of 25 to 50 years, where multiple institutions published their expectations in a variety of literature about changes in the LNG Import terminals, such as (BP, 2014) ,(International Gas Union, 2014) & (Jensen associates, 2007) e.a.

Where BP and the IGU agree with each other is that Eastern-Asia will be the highest importer of LNG, once again. Europe will be second, however it should be noted that Europe's growth of population comes to a standstill resulting in a decrease in LNG import around 2065.

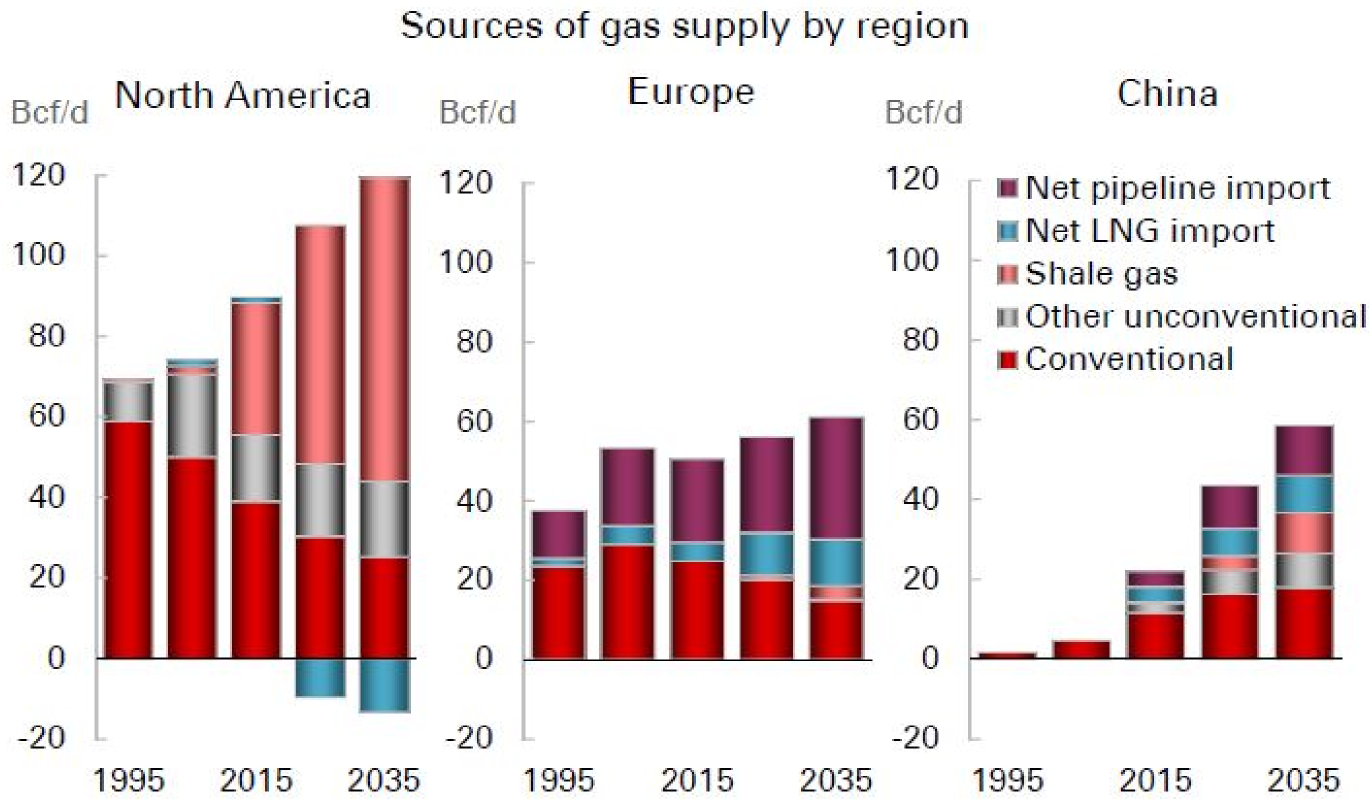


Figure 19 ***Sources of gas supply by region*** **adapted from** ***BP Outlook 2035,*** **retrieved** ***February 2015*** **from** ***BP.com © 2014, BP*****, reprinted with permission.**

When figure 19 is compared to the statement made by the (International Gas Union, 2014):

> *"Japan continues to dominate as the largest regasification market, with 28% of global capacity. This position is not expected to change, particularly as Japan brings new terminals online. It completed the Naoetsu terminal in early 2014 and has another four under construction, for at least an additional 6.5 MTPA of capacity (one terminal has yet to release capacity). Japan usually averages a utilization rate around 50% due to import seasonality; utilization stood at 48% in 2013.*
>
> *Although China is still only the sixth largest regasification market, it is the 3rd largest and one of the fastest growing LNG importers. The country has rapidly expanded its LNG import capacity over the past five years, from 6 MTPA in 2008 to 32 MTPA at the end of 2013. Further, it currently holds 20% of LNG regasification capacity under construction. China also had a much higher utilization than the five largest regasification markets (in terms of capacity), at 94% in 2013.*
>
> *In addition to China and Japan, ten more countries have reached FID on new large-scale LNG import terminals. Of these, three are new to the LNG markets: Jordan, Lithuania and Poland. Most of the remainder are, unsurprisingly, in Asia. However, a few are in highly under-utilized markets in Europe; both Spain and France currently have onshore capacity under construction. "* (International Gas Union, 2014)

Statements of America going from major importer to exporter of Shale Gas are mentioned in (BP, 2014), (Jensen associates, 2007) & (International Gas Union, 2014). However only BP and IGU expect that the main trade center of LNG will be based at Eastern Asia and is larger than the import demand by Europe for import in the long term and export of LNG is produced by Asia Pacific, the Middle East and Nigeria.

(Jensen associates, 2007) expect that the growth of Northeastern Asia is smaller over time compared to Atlantic America, see figure 18.

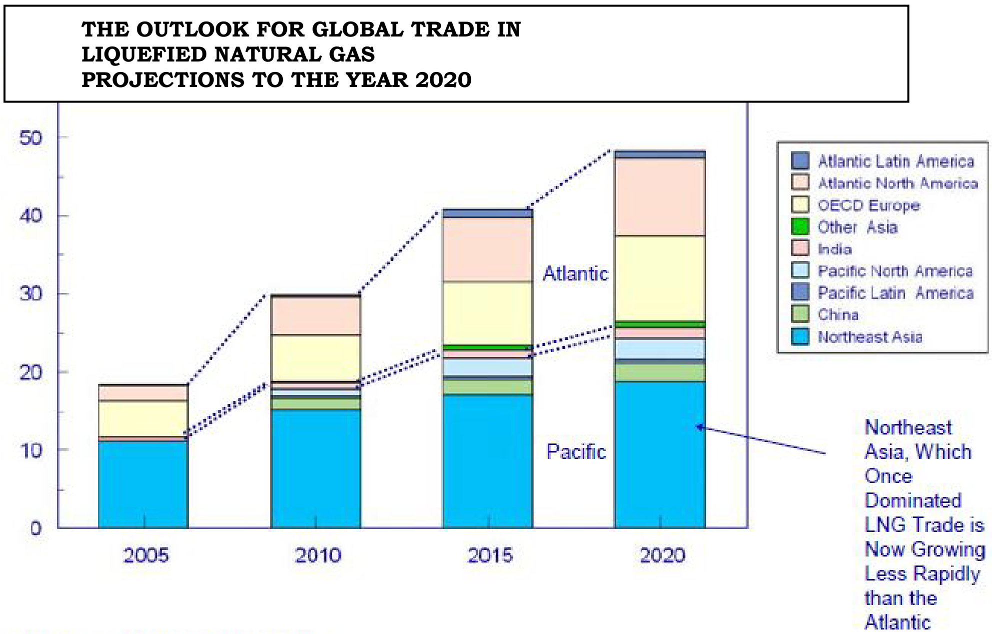


Figure 20 *Base Case Projections of World LNG Demand by Region* **adapted from** *the outlook for global trade in liquefied natural gas projections to the year 2020,* **retrieved** *February 2015 © 2014, Jensen Associates*, **reprinted with permission**

This difference between the two statements is that the statement by Jensen Associates is based upon older data in comparison with the statements made by BP and IGN in 2014. The demand of LNG and any other energy sources is highly volatile and sensitive to public opinion. Therefore it is hard to make adequate long term predictions, because of this.

When figure 7 is reconsidered in combination with the expected energy shortage and the current LNG Market, it should be noted that the countries with population growths over 200 million people, are also on in table 2 as the largest importing LNG countries. The demand for energy by LNG will thus increase drastically the coming 50 years. Therefore it is in the best interest of these countries to set short term contracts in order to have a fair market price, when the total demand will increase. Other solutions are reinvesting in other energy sources and becoming independent of fossil fuels.

4.2.2 Transport of LNG

The supply chain of LNG from production to distribution is shown in figure 21 (Huisman S. , 2013).

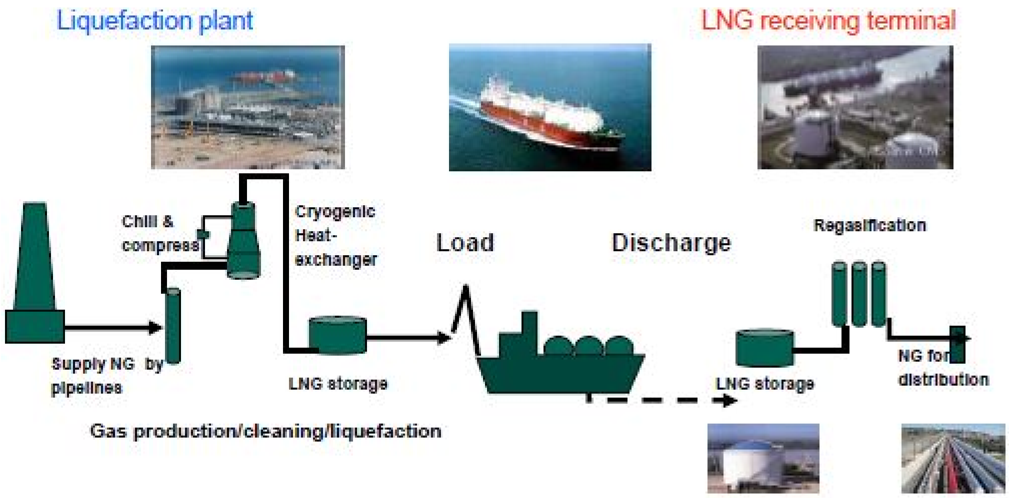


Figure 21 ***LNG Supply Chain*****, adapted from** ***Challenges of developing LNG terminals*****, retrieved** ***February 2015*** **from** ***UNESCO-IHE © 2013, VOPAK,*** **reprinted with permission**

Figure 21 is quite self-explanatory, so it is easy to recognize the three stages of LNG transportation:

1. Liquefaction at the plant, in order to transform natural gas into liquefied natural gas;
    a. supply by pipelines
    b. chill and compress
    c. cryogenic heat exchange
    d. LNG storage
2. Transporting of LNG by carriers;
    a. load
    b. discharge
3. LNG receiving terminal;
    a. LNG storage
    b. regasification
    c. natural gas for distribution

To transport the LNG towards the hinterland after the seaport is done in multiple ways, such as by pipeline, by truck, or by re-exporting with small scale LNG.

LNG Pipeline technology

If LNG flows through the pipeline, this pipeline must be protected with a “Pipe in pipe” design with fully bonded insulation, as an example see figure 22, in which some characteristics are:

- Dual pipe system with cooling i.e. nitrogen in outer pipe
- Bunker pipe system must always be at cryogenic temperature
- Fully bonded flexible insulation system
- Gas free after bunkering
- Gas detection Nitrogen system
- Approved by legislation

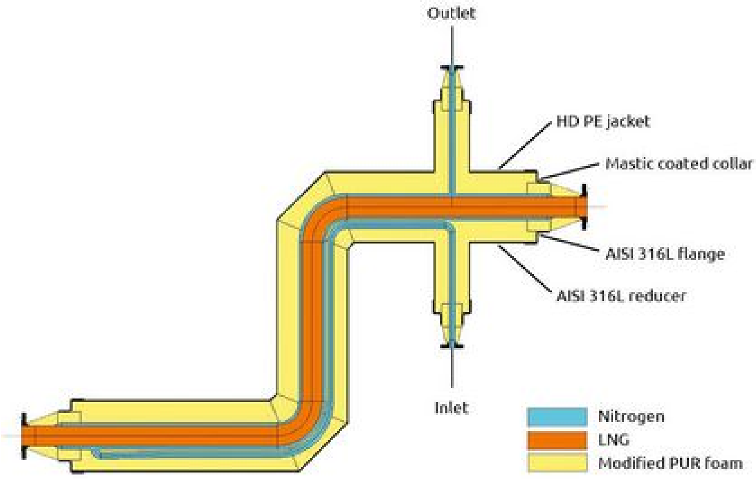


Figure 22 *Exemplary Cryogenic LNG pipe system* **adapted from** *MGIT,* **retrieved** *February 2015* **from** *www.mgit.no/lng-fuel.htm***l © *2010, MGI Thermo & LR Marine AS,* reprinted with permission**

When LNG has been transformed into natural gas, it can be transported with the common pipeline systems. The most used pipe technology is a jetty combined with a vacuum insulated pipe, in which the main function of the vacuum insulated pipe is to keep the fluid cryogenic. This is all above water level.

Another pipeline technology uses ambient pressure insulated LNG Pipeline offshore. With this technology, it is possible to construct pipe sections below water level. It is stated by (Prescott, Zhang, & Brower, that the design uses ambient pressure insulated LNG pipeline offshore, 2005). By applying this sort of pipe it is claimed that the pipeline costs and maintenance requirements are reduced and an increase pipeline reliability. This LNG pipeline technology uses the highly efficient insulation in an ambient environment.

> *“Figure 23 on the next page shows the nanoporous insulation, which is hydrophobic, in figure 21 upper detail, because the pour spaces are than the water molecules, therefore, the insulation does not absorb water. The insulation does not degrade in the presence of water or moisture, an important consideration for thermal efficiency and for operational maintenance. In case of the metallic bulkhead, in figure 21 left bottom detail, at the end effect sealing of the annular space and allow transfer of the contraction-inducted axial compression load. Additionally, non-metallic bulkheads provide additional sealing and water stops and additional load transfer throughout the whole pipeline configuration; see figure 21 right bottom detail. Between these bulkheads and to facilitate the fabrication, non-metallic spacers’ are centralizers provide additional support and structural rigidity.* (Prescott, Zhang, & Brower, New design uses ambient pressure insulated lng pipeline offshore, 2005).

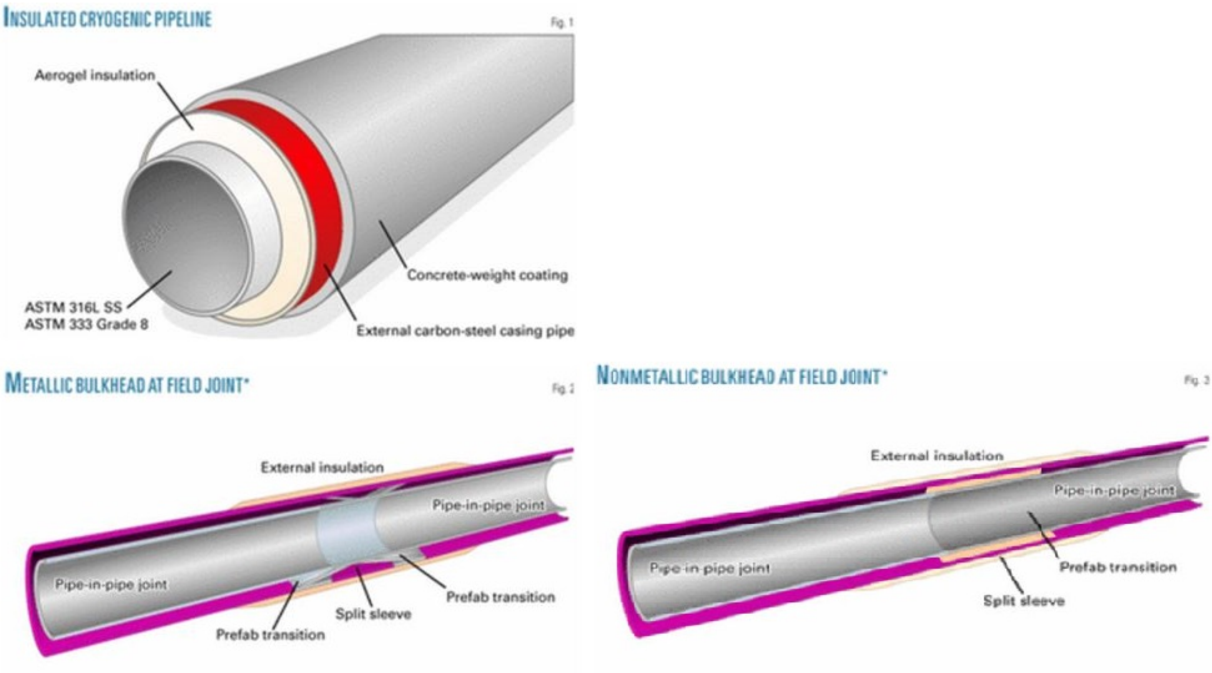


Figure 23 ***Ambient pressure insulated pipeline technology*****, retrieved** ***February 2015*** **from** ***www.ogj.com/articles/print/volume-103/issue-28/transportation/new-design-uses-ambient-pressure-insulated-lng-pipeline-offshore.html © 2005, FLUOR Inc. and Astro Technology INC.*** **, reprinted with permission**

The development of the Subsea cryogenic pipeline technology by (TOTAL, 2015) has resulted in an significant increase in distances of several kilometres that now can be crossed with this new pipe technology. Due to the subsea cryogenic technology, LNG floating Regasification Units can now be located offshore. TOTAL claims that the advantageous are:

- no more trestles
- limited dredging
- decreased visual impact
- improved security

The cryogenic nature of LNG is the largest failure probability, where contraction and expansion due to temperature changes is the most common reason for failure. Figure 24 shows the design with aspects of the Subsea Cryogenic Pipeline technology.

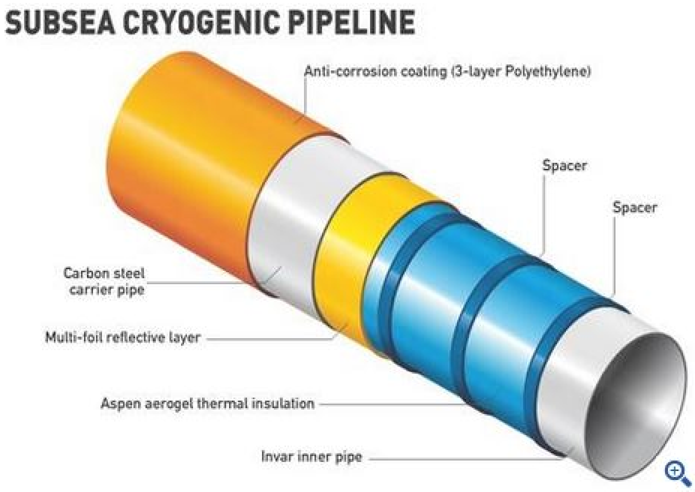


Figure 24 ***Cryogenic LNG pipe technology by TOTAL*** **adapted from** ***TOTAL*****, retrieved** ***February 2015*** **from** ***www.total.com/en/energies-expertise/oil-gas/exploration-production/strategic-sectors/lng/innovation/subsea-cryogenic-pipelines © 2015, TOTAL*****, reprinted with permission.**

Natural gas transportation by pipeline can be done in large distances and under high pressures. Characteristically the under pressure is about 80 bars with a pipeline of about Ø500 mm. Compressor stations combined with measurement stations and regulation stations are along the pipeline in order to initiate flow, measure and regulate flow through the pipes.

Figure 25 shows that for short distances under 2500 miles or below 1000 miles, it is more beneficial to have an onshore pipeline or an offshore pipeline, respectively.

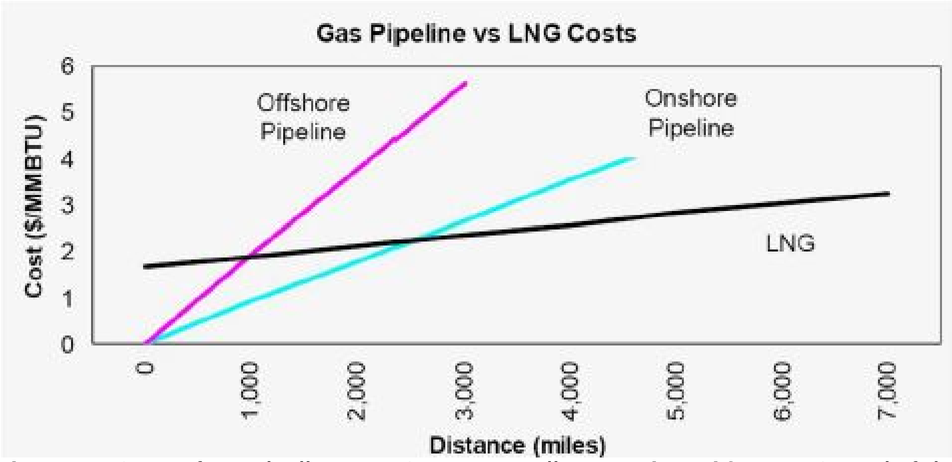


Figure 25 *Costs of gas pipeline vs LNG costs over distance* **adapted from** *LNG: Fuel of the future,* **retrieved** *February 2015* **from** *Delft University of Technology © 2014, TU Delft,* **reprinted with permission**

Some relevant problems with technical background regarding pipeline distributions are mentioned below:

- Reverse flow; by establishing reverse flow possibilities is technically relatively simple, as only the metering stations have to be modified. By having a reverse flow this strengthens the competition and secure supply.
- Energy efficiency; only 5% of the energy is applied for transportation.
- Standardization; if a pipeline goes through multiple states, there are different set of design criteria and daily operations per state.

Interconnectors are important for facilitating the establishments of hubs, where multiple gas flows meet, trading intensity is high and is thereby stimulating competition. The difference between an interconnector and a gas pipeline is that at an interconnector the flow can be reversed. In the case of a crisis, during temporary shortages etc., at an interconnection, thus guarantees supplies to the countries that it connects.

Interconnectors are unidirectional, because of the nature of the demand pattern. By establishing reversible flow makes it possible to improve the security of supply.

An example is during the gas crisis in January 2009, in Germany and Austria there was sufficient amounts of gas, however, in Czech Republic, Slovak Republic and Hungary there was no gas and it could not be transported to these countries because of the insufficiency of the reverse flow system.

Types of LNG carriers

In figure 26, it is clearly visible that in the recent 30 years there has been a significant increase in carrier size and corresponding carrier storage capacity in the years between 1960 to 1972 and 2002 to 2010. This increase in LNG carriers is in line with the total LNG trade in figure 12, which also gradually increases over the years. Especially, in the last decade where the demand for LNG has increased significantly, due to the Middle Eastern countries that have become the largest contributors to the global production of natural gas. This is why the carriers' capacity has nearly doubled in the last decade.

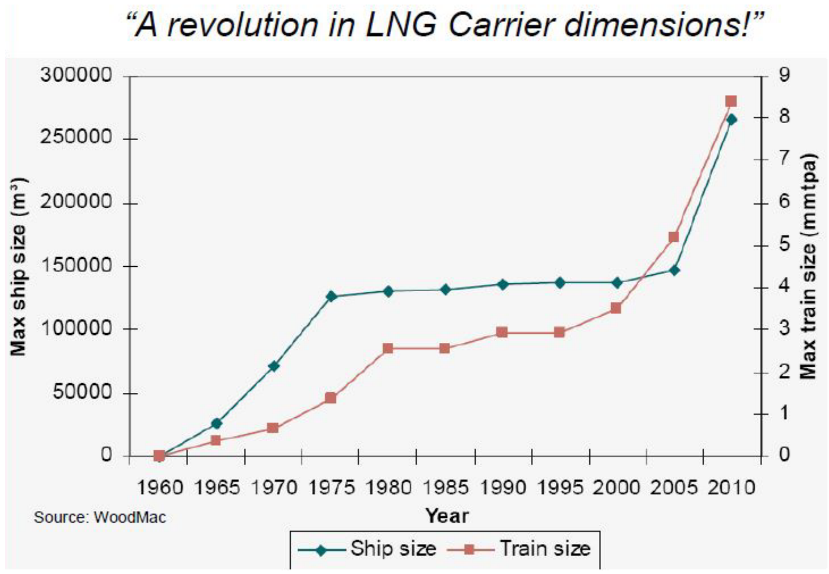


Figure 26 *Increase of LNG carrier capacity size and train sizes over time*, **adapted from** *LNG Fuel of the future*, **retrieved** *February 2015* **from** *Delft University of Technology © 2014, TU Delft*, **reprinted with permission.**

The current average LNGC capacity is around 145,000m^3, with most new-builds now in the 145,000 m^3 to 175,000 m^3 range, and length overall up to 300 m (called "flex carriers"). Qatar has built a fleet of some 25 very large scale LNGCs called "Q-flex" (at 210,000 m^3 capacity), and "Q-max" (approx. 265.000 m^3). These carriers are up to 350 m in length, and pose challenges not only to port designers, as most existing terminals were not designed for these vessels, and they push up the required tank storage capacity to retain a healthy shipping flexibility.

For port designers the following dimensional envelope can be used as a guideline for the LNG carrier class:

- length overall: 270 – 350 m
- beam: 46 - 55 m
- draft: 11 – 12.5 m
- freeboard: up to 25 m (and air-drafts between 40 and 50 m)
- water displacement; Up to 180.000 tonnes (or about 70% of cargo capacity)

These values have been determined by (Huisman J. , 2014). The corresponding image is in figure 25.

Figure 27 *Examples standardizes carrier sizes*, **adapted from** *Challenges of developing LNG terminals* **retrieved** *February 2015* **from** *UNESCO -IHE© 2013, VOPAK*, **reprinted with permission**

LNG Carriers have three different designs for LNG Containment systems:

1. SPN (IHI)
2. MOSS spherical
3. GTT Membrane

Figure 28 shows a clear trend towards membrane for larger carriers over the last forty years.

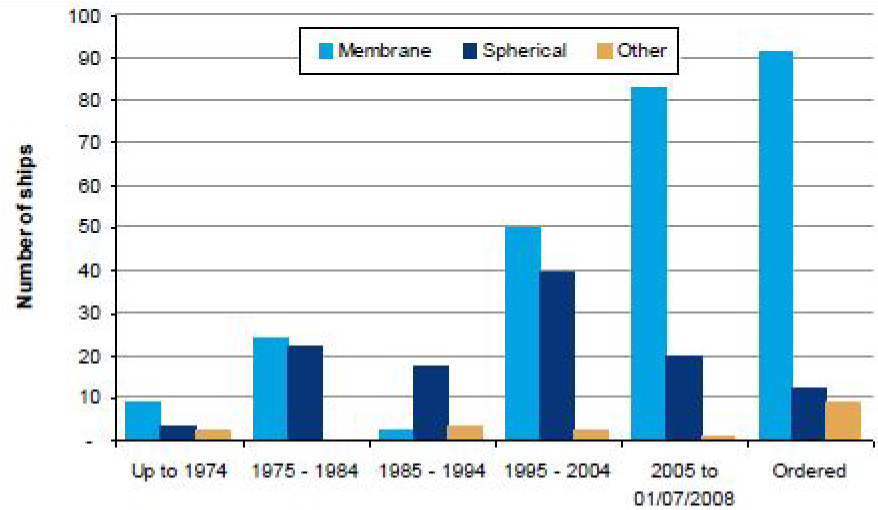


Figure 28 ***applications of different LNGC containment types*****, adapted from** ***Challenges of developing LNG terminals*** **retrieved** ***February 2015*** **from** ***UNESCO -IHE© 2013, VOPAK*****, reprinted with permission**

Small scale LNG facilities

A new development in the LNG industry is SSLNG distribution, in which LNG carriers have a smaller capacity, and a lower draft. So, these carriers can sail at lower depths and transport gas from a main hub LNG terminal towards a smaller regional or satellite terminal. (International Gas Union, 2014) states that small scale LNG facilities as plants with a capacity under 1 MTPA.

This new trend of smaller carriers makes it possible for downstream development of LNG terminals on emerging islands i.e. Vietnam or Indonesia, and remote islands i.e. Philippines and Cyprus. The new development of small scale facilities is positively supported by (Huisman J. , 2014)

Figure 29 shows the locations where new opportunities for development of SSLNG distribution.

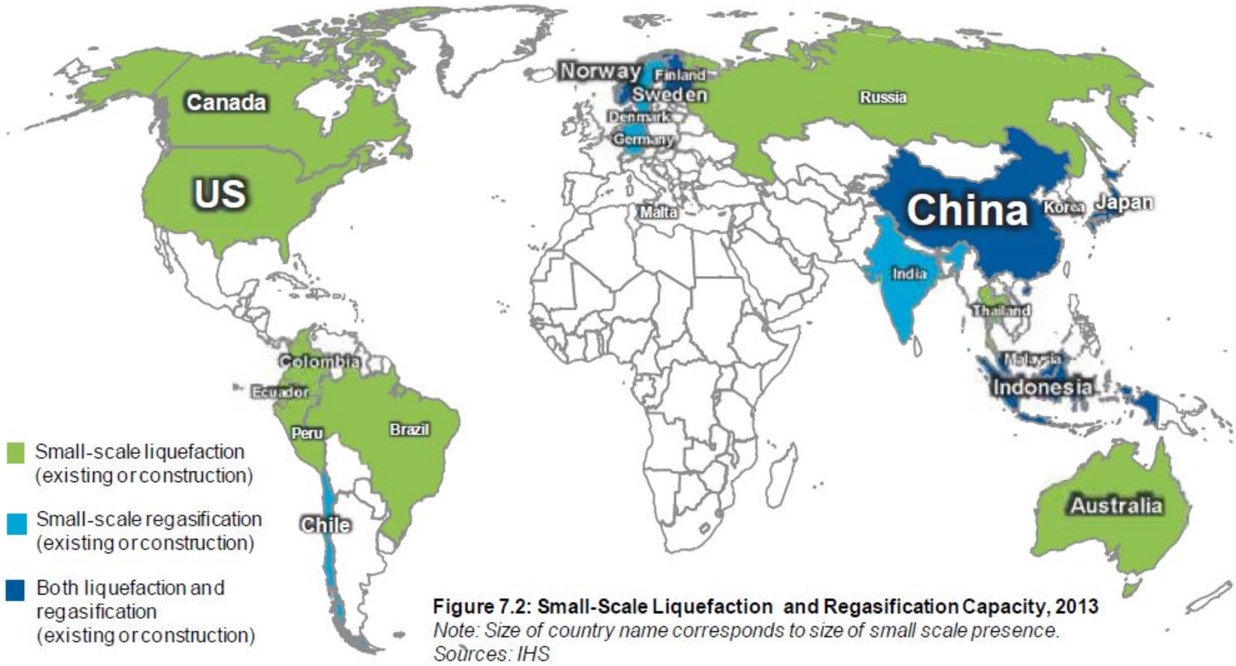


Figure 29 ***Small scale liquefaction and regasification*****, adapted from** ***World LNG report 2014*****, retrieved** ***February 2015*** **from IGU ©** ***2014, IGU*****, reprinted with permission.**

Currently, Japan holds the most existing small scale import terminals, many of which were built as satellite plants. Small scale import functions similarly to floating regasification; their main advantages are primarily:

- lower cost
- speed of construction
- added flexibility
- higher accessibility, because of smaller ship's dimensions

Due to SSLNG the distribution network within Asia has grown in size. In example, at the Scandinavian Region it is beneficial to have one large LNG terminal that distributes the LNG over multiple small import terminals in order to reach every corner in the Baltic Sea. For small scale LNG distribution, there are several different sourcing strategies:

- regional small liquefaction plant → small regasification plant
- international large liquefaction plant → small regasification plant
- global large liquefaction plant → Large import/export hub → small regasification plant

4.2.3. Conclusion of LNG trade Market

The relocation of the LNG main distribution hub towards the Asia – Asia Pacific was to be expected. Since, it has the largest growth in population as well as technical capability and resources, because of this Asia has the most potential. Due to the new developments of small scale LNG carriers and cryogenic pipelines, the potential reach has increased significantly. Offshore import/export hubs can now distribute LNG to the regasification or receiving terminals near shore.

Europe is changing their policy regarding Russia's gas, however, Europe still needs gas from another sources, such as the Middle East, America or Norway. The Middle East is too risky due to potentially funding Muslim extremist institutions. Norway will be one the best scenarios to import LNG, yet this does not solve the energy shortage in the Eastern Bloc countries. A suitable source of LNG for Europe to import from is America, yet the distances are enormous. So, this will be quite expensive, but when transported with the largest LNGC it will be more efficient.

After 1000 miles approximately 1610 kilometers pipeline distributions are not efficient, therefore the ports in of the Eastern European states require another source of LNG. The nearest producing regions are the Middle Eastern region or the Northern African region in order to import from.

There used to be a growing trend in carrier capacity, as was shown in figure 25, where carriers and LNG facilities were increasing significantly. Yet now there is new incentive for small scale LNG distribution. By reducing the carrier dimensions the draft of the ship is less deep, in this way more vacant locations with low water depths can be reached. So new LNG facilities emerged on these locations, where LNG is regasified at small facilities. The LNG can be imported from small, large or international import/export hubs.

4.3 LNG regasification terminal

Over the past decade, there has been a significant increase in regasification terminals and capacity. Due to previous mentioned reasons, such as political issues, energy shortage, greenhouse gas emission limit, etc. LNG demand is increasing drastically. To cope with this increasing trend several new techniques for importing LNG has been developed. In figure 30 is a schematic view of all types of receiving terminals. This chapter starts with the introduction about basic components of an onshore LNG regasification terminal, where later in the report the main processes of regasification of LNG into natural gas are described. Last is the diversity of required phases to construct an LNG regasification terminal.

4.3.1. Introduction into the types of LNG receiving terminals

When a new LNG terminal is designed several key aspects have to be taken into account, according to (Huisman J. , 2014):

- Expected LNG/NG market volume with growth in over-time.
- Likely LNG Supply sources and shipping distances.
- Feasibility of connecting to an existing natural gas pipeline grid.
- Feasibility of locating a suitable onshore site to build the LNG plant.
- Possibility to create an acceptable terminal water-front.
- Prevailing regulatory and environmental regime within which environmental, construction and operating licenses need to be obtained.

If no suitable waterfront is available or exceptionally high construction cost for a new port, then investing in innovative offshore regasification plants is maybe the best solution applicable. Figure 30 shows the multiple LNG unloading methods introduced for the LNG chain.

Figure 30 *Examples of offshore LNG receiving terminals* **, adapted from** *Challenges if developing LNG terminals* **retrieved** *February 2015* **from** *UNESCO -IHE© 2013, VOPAK*, **reprinted with permission**

Figure 31 shows the recent increasing trend for LNG regasification facilities where floating and onshore plants are applied.

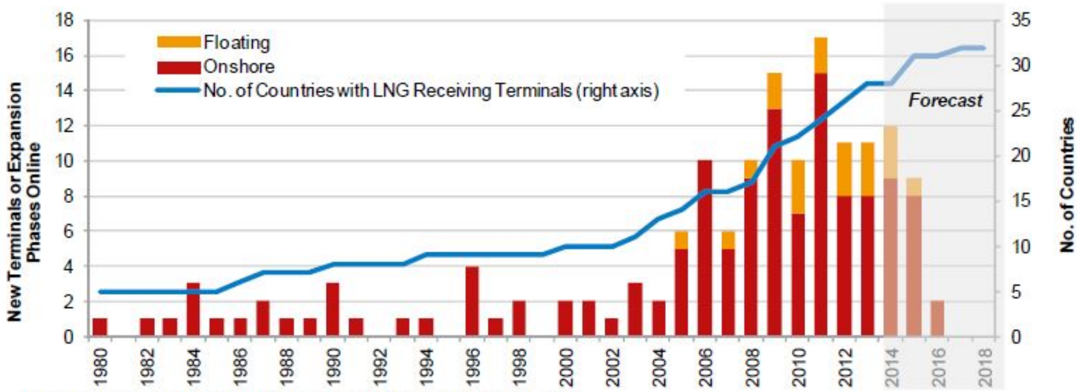


Figure 6.3: Start-Ups of LNG Receiving Terminals, 1980-2018

Figure 31 ***Increasing trend in LNG floating regasification plants*** **, adapted from** ***World LNG report 2014*****, retrieved** ***February 2015*** **from** ***International Gas Union © 2014, IGU*****, reprinted with permission**

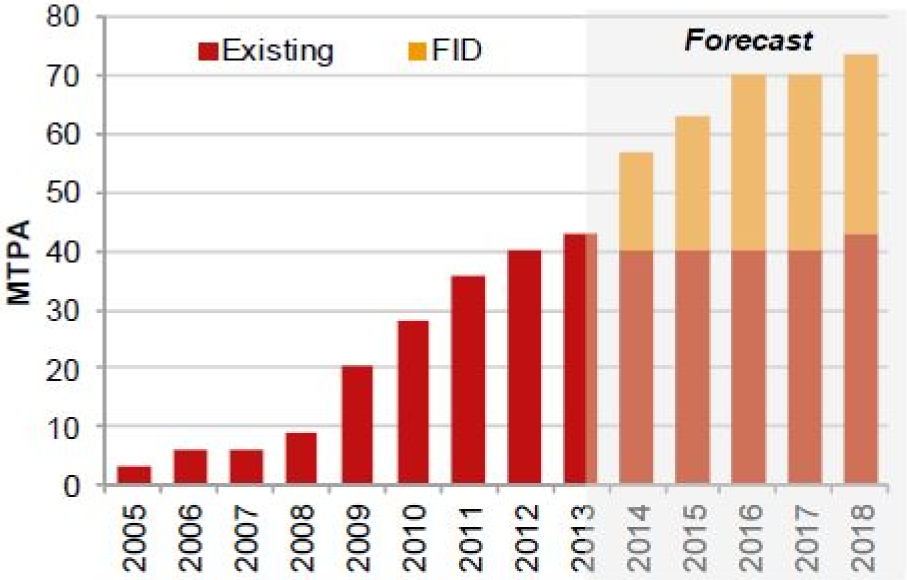


Figure 32 ***Increasing trend in capacity of floating plants*** **, adapted from** ***World LNG report 2014*****, retrieved** ***February 2015*** **from** ***International Gas Union © 2014, IGU*****, reprinted with permission**

Figure 32 visualizes the increase in the unloading capacity of offshore plants per year. An additional 23 countries have now design plans to increase their terminal capacity by expanding with offshore facilities. Two countries already in 2014 have reached the Final Investment Decision (FID). More Floating Storage and Regasification units (FSRU) expected to come in the upcoming years.

Another trend within the regasification terminal sector is the receiving terminal with reloading capability. In 2013 two terminals have been added to the total up to 13 terminals in eight countries. One of these is the 'GATE terminal' in the Netherlands which added reloading capacity as continually low LNG demand in Western European re-exporters France, Spain and Portugal. Beneficiary of reloading capacity is when there is a low demand within a country, but a high storage the country i.e. Netherlands, can sell the LNG to countries with a higher demand.

4.3.2. Main processes during regasification

The different stages during the regasification progress of the 'Gas Chain', according to (Saggas, 2013):

1. LNG is received at a temperature of -160° C. Tankers moor at the unloading quay of the regasification plant and offload the LNG through three arms located on the quay.
2. LNG passes through the pipes that join the arms to the tanks is stored inside them at T= -160° C.
3. The contribution of heat to LNG causes a fraction of this gas to pass the vapor stage. This gas is called Boiled Off Gas (Bogs) and is used for:
    a. Compensating the movement of the shipment that originates from the unloading process of the freighters.
    b. Re-injects in the process due to the re-liquefier.
    c. When the capacity of (a) and (b) are exceeded, the BOGs are burned.
4. The primary pump system allows for the conduction of LNG towards the liquefier that functions as a collector of liquid for the secondary pumps. Simultaneously it allows for the recuperation of the BOGS incorporating it in the gas.
5. The LNG from the re-liquefier is pumped at a high pressure by a secondary pumping system, with a design similar to the primary pump systems, which forces the LNG to the vaporizers.
6. The changeover from liquid to gas is carried out in the seawater vaporizers. In these vaporizers the LNG is heated with seawater with a temperature of 0°C or higher that causes the LNG to vaporize.
7. Natural gas is driven through a container with regulation, measuring and odorizing systems, before it flows into the general network of gas pipelines.

These processes originally were in the onshore regasification terminals, yet, nowadays it can also be designed in FSRU's. This reduces obviously the capacity of the storage to the capacity of a single carrier, instead of a large onshore storage tank. The average capacity size of a carrier is around 145000 m^3.

4.3.3. Design of a regasification plant

Figure 33 is a simplified schematic view of an onshore LNG receiving terminal is given. All the processes required to regasify the LNG into natural gas are included. Therefore the corresponding main components at the plant are:

- unloading jetty and trestle connecting piping to shore
- LNG storage tanks and low pressure pumps(primary)
- boil off gas (BOG) handling and recondenser
- high pressure pumps (secondary) and vaporizers
- process control and safeguarding systems
- general facilities i.e. offices, warehouses or workshops

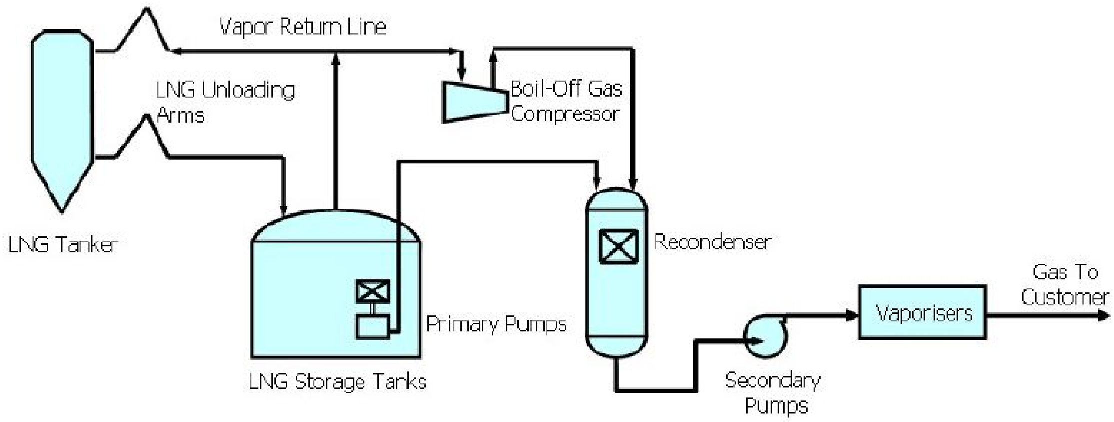


Figure 33 *Typical receiving LNG terminal block flow diagram* **, adapted from** *New LNG Receiving terminals concepts,* **retrieved** *February 2015* **from World Petroleum Congress ©** *2005, (Ertl, Durr, Coyle, Mohammed, & Huang, 2005),* **reprinted with permission**

The unloading system consists of several loading arm which connects to the carrier. Loading lines deliver the LNG to the storage tanks, return displaced vapour and BOG to the ship, which replace the volume of LNG pumped out. These loading lines are connected to the trestle that connects to the shore. In order to ensure safety and efficient operational settings, considerations are made with respect to the management of transient periods such as cool-down and the transition from unloading mode to holding mode. The main unloading lines should be as short as practical, because of the high expenses of the cryogenic design and size that allows (un-)loading of carriers typically within 24 hours. LNG transfer rates vary between 8000 m^3/hr and 14000 m^3/hr.

LNG is usually stored in one to three storage tanks with a range in sizes of about 60000 to 200000 m^3. Typically, the shape of LNG storage tanks is cylindrical, because this is generally the most cost efficient way for costs per volume. Primary pumps are installed in wells within the tanks.

Leaking or spilling of gas from a pipeline is inevitable. To capture these gasses a Boiling off Gasses system has to be installed. A BOG systems eliminates the need to compress the gas from atmospheric pressure to the pipeline pressure most terminals include a recondenser.

The secondary pumps generate sufficient pressure to deliver the LNG, which is vaporised and heated prior to export. There are multiple ways to heat the LNG for vaporisation, including;

- Open Rack Vaporisers (ORV).
- Submerged Combustion Vaporisers (SCV).
- Air heating of an intermediate fluid to evaporation duty in a heat exchanger (IFV).
- Integration with other facilities with a cooling requirement, such as Air separation plants or power plants.

The first two methods ORV and SCV are most commonly applied in an onshore regasification unit. An IRF is applied in an FRSU, yet is has to be adapted in such a manner that sloshing in the tank and vaporizer is prevented.

Vaporizers

Figures 34 to 38 show a variety of LNG vaporizers, such as the ORV, SCV, STV and AAV.

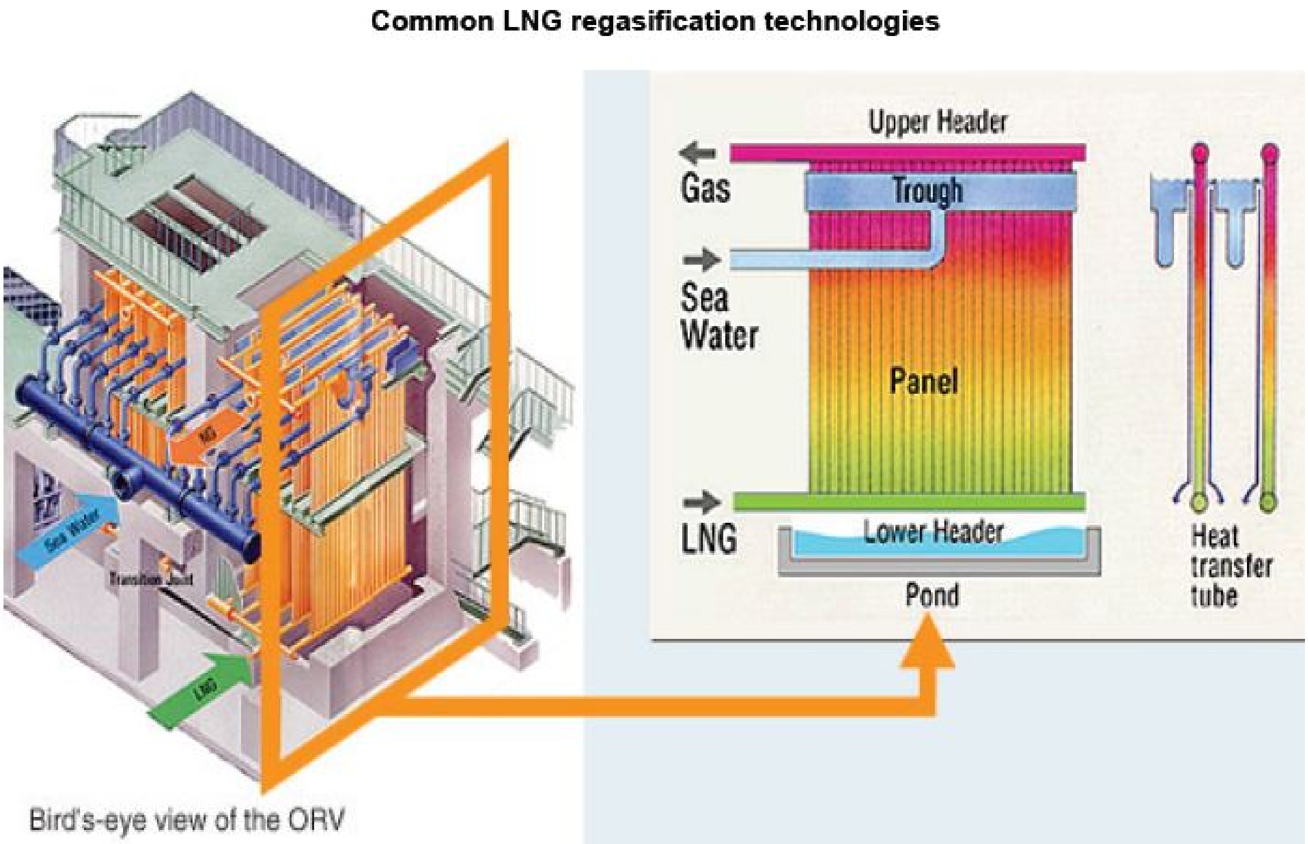
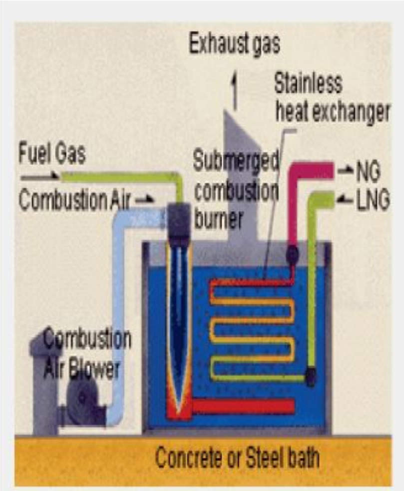


Figure 34 ***Open Rack Vaporizers*, adapted from *Technology evaluation and cold energy utilisation*, retrieved *February 2015* from *Queensland University of Technology © 2012, Randeep Agarwal*, reprinted with permission**



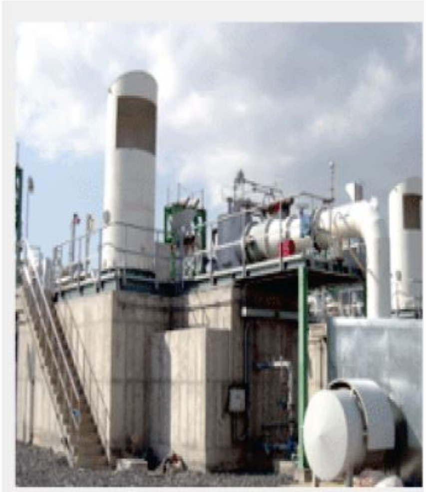


Figure 35 *Submerged Combustion Vaporizers, adapted from Technology evaluation and cold energy utilisation,* **retrieved** *February 2015* **from** *Queensland University of Technology* **© 2012**, *Randeep Agarwal*, **reprinted with permission**

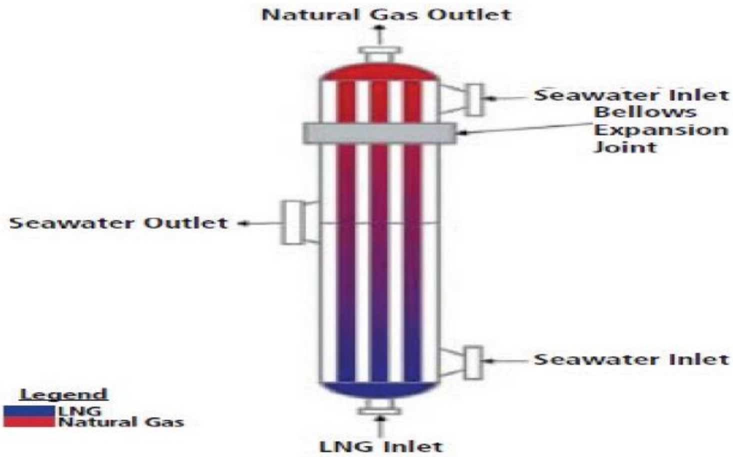


Figure 36 *Shell & Tube Vaporizer*, **adapted from** *Technology evaluation and cold energy utilisation,* **retrieved** *February 2015* **from Queensland University of Technology ©** *2012, Randeep Agarwal,* **reprinted with permission**

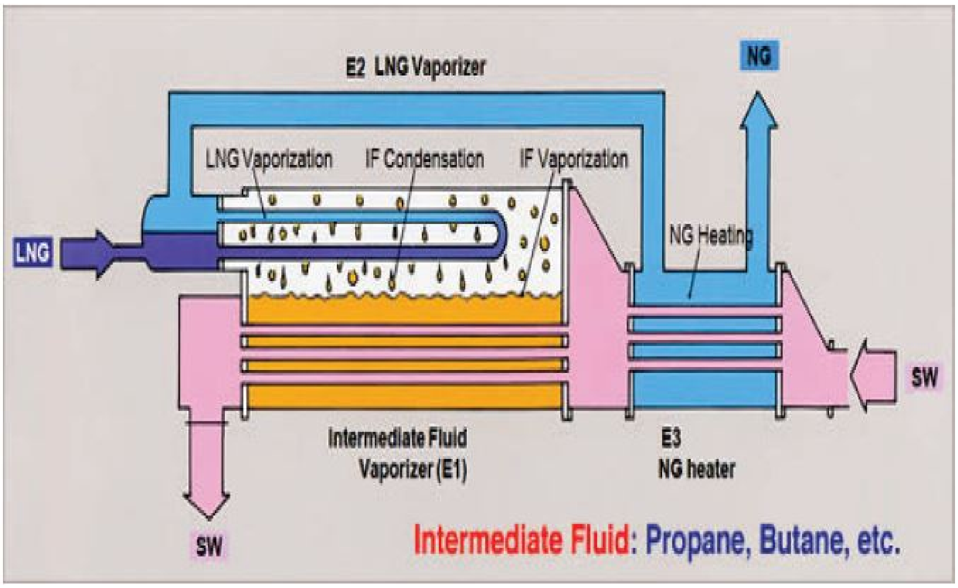


Figure *37 Intermediate Fluid Vaporizers*, **adapted from** *Technology evaluation and cold energy utilisation,* **retrieved** *February 2015* **from** *Queensland University of Technology © 2012, Randeep Agarwal,* **reprinted with permission**

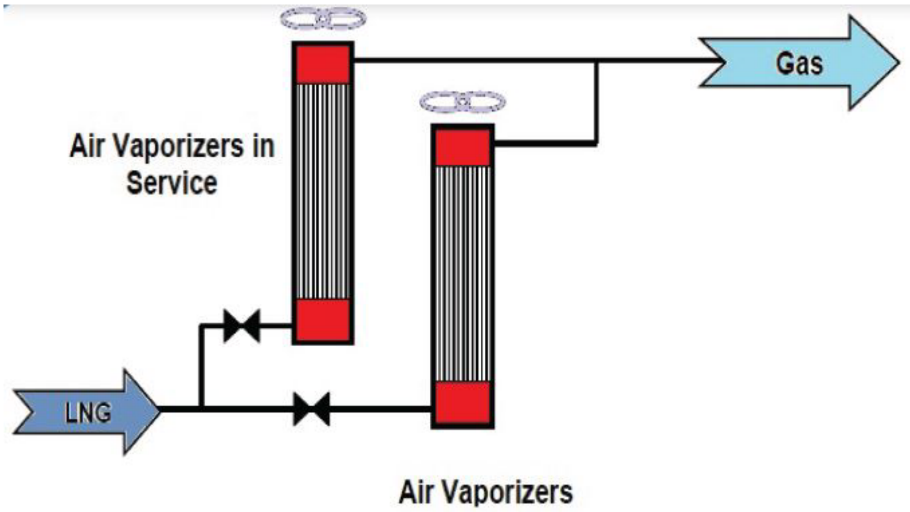


Figure 38 *Ambient Air Vaporizers,* **adapted from** *Technology evaluation and cold energy utilisation,* **retrieved** *February 2015* **from** *Queensland University of Technology © 2012, Randeep Agarwal,* **reprinted with permission**

With ORVs there are some environmental issues, which are the water outlet temperature, water intake velocity and treatment (Ertl, Durr, Coyle, Mohammed, & Huang, 2005):

- Water outlet temperature guideline by the World Bank is that:

  "*The effluent should result in a temperature increase of no more than 3° C at the edge of the zone where initial mixing and dilution is mixing. Where the zone is not defined, use 100 meters from the point of discharge*. (World Bank Group, 1998) "

- The objective of the regulation is to minimize mortality of all types of marine life due to impingement and entrainment of the water intake structures and establishes strict technology-based performance requirements applicable to the location, design, construction and capacity of water intake structures for new facilities.
- Water supply requires chlorination to protect the system against bio-fouling.

SCV's have environmental issues related to combustion emissions and water bath effluent. The emissions caused by the combustion are CO_2, CO and NO_x and volatile organic compounds (VOC). Due to the combustion process the water is condensed in a water bath, therefore the water is continuously produced. The produced water is polluted with Carbon dioxide, which must be neutralized.

Several of the more recent developments in the LNG industry associated with LNG vaporizers are the Fired heater, Reverse Cooling Tower and the Ambient Air vaporizer (Ertl, Durr, Coyle, Mohammed, & Huang, 2005).

- The fired heater is a design where LNG is indirectly vaporized by heating a Heat transfer fluid that is in contact with the LNG though a Shell and Tube Vaporizer, see figure 34.
- The reverse cooling tower applies ambient air flowing through a cooling tower as a heat source. Only in this case the tower cools the air instead of heating. An intermediate fluid transfers heat between the tower and LNG. A standby fired heater is used when temperatures are low.
- Ambient Air Vaporizers have two types which can be used for LNG vaporization. One type is the direct air-to-LNG contact vaporizer which uses air in either a natural or a forced draft vertical arrangement. This type of vaporizer is preferred for peak shaving plants at locations where the LNG vaporization duty and flow rate is relatively small. The second type is the Indirect Ambient Air Vaporizer, which uses an intermediate fluid between a Shell and Tube LNG Vaporizer and conventional fin-fan air coolers to reheat the fluid by ambient air. In figure 36 shows a schematic view of Ambient Air Vaporizer.
- Waste Heat Recovery Vaporizer applies waste heat at a higher temperature of about (±0°) to vaporize the intermediate fluid. The heated fluid is necessary to transform the LNG to NG.

According to the life cycle analysis done by (Ertl, Durr, Coyle, Mohammed, & Huang, 2005), it is stated that in general the AAV requires the highest CAPEX, but the lowest OPEX. The fired heater had the lowest CAPEX, yet the highest OPEX. The highest NPV was achieved by AAV with the highest cost-effective scheme. However, it must be mentioned that the results were sensitive to site-specific values.

Heat integration with other facilities

Most LNG regasification terminals nowadays have vaporized LNG to export the gas into the distribution grid. Heat integration is a method, where the cold from vaporizing the LNG is used to provide chilling in the integrated process. In many cases there is considerable potential for improved thermal efficiency.

At the terminal is a large reservoir of cold energy, which is dissipated into sea or atmosphere. Up to 10% can be used at export terminals in the freezing process to liquefy the gas. Most of this energy is transported to the LNG receiving terminals as 'Cold energy' and is technically free to the receiver as gas is priced on heating the value. Schemes to use this cold energy include:

- cryogenic power generation
- air separation
- CO_2 -solidification
- cold storage/ frozen foods
- cryogenic crushing
- seawater desalination

Opportunities to integrate the terminal with facilities with large sources of continuous low grade heat and high temperature heat sinks. An adjacent industrial facility, such as refineries or power stations, offers excellent opportunities to realize the inherent synergies of integration using established technology.

A power plant must reject heat to condense steam and to cool equipment. Additionally, power output is increased, by cooling the gas turbine air inlet. By increasing the mass throughput and also allowing more fuel to be burnt due to lower compressor discharges. Thermal integration processes required for sustainability are, according to (Ertl, Durr, Coyle, Mohammed, & Huang, 2005):

1. LNG Cold Recovery.
2. Heat recovery from the power plant.
3. Combinations of both heat and cold recovery.

These thermal integration processes are good applications to improve sustainability.

4.3.4. Exergy of LNG regasification process

A study by (Gómez, Garcia, Gómez, & Carril, 2014) discusses the topic of exergy of LNG regasification process. Producing LNG requires a significant amount of energy, 1370 kJ/kg/s of LNG. LNG is transported in low temperature along with high quality chemical energy, both aspects result in a high physical exergy. During the regasification process vaporizers release a significant amount of cold exergy, around 370 kJ/kg/s of LNG,

Definition of exergy is the maximum theoretical work obtainable from a system in disequilibrium with the reference environment. Reference environment is described as the simple compressible systems whose conditions are constant and uniform at atmospheric pressure (1 bar) and temperature (25°C). Exergy contained in LNG is classified as chemical and physical in nature. Physical exergy is caused by an imbalance due to a difference in temperature and pressure. If the distribution pressure is kept low, thermal exergy increases, similarly the effectiveness of LNG physical exergy. If the required pressure of NG is 6 bars, exergetic exploitation is about 75%. The remaining 25% of the pressure exergy is required for the gas distribution process.

This exergy can be applied in several ways, as discussed within the topic 'Cold Energy Extraction'.

4.3.5. Cold energy integration

A study by (Sharratt, 2012) discusses the opportunities of cold energy extraction during the LNG regasificaiton progress. Although most commonly applied vaporizers are the ORV and SCV, but by applying the Shell and tube vaporisers, it is possible to extract cold energy or to alternate heat sources.

Regasification terminals are as close as possible to the point of LNG delivery, similarly cold energy extraction should be adjacent to the LNG import terminal. Possible applications of LNG cold energy integration are;

1. Inlet air cooling to gas turbines for power generation
2. Cold power generation
3. Air separation
4. Chilled water for industry
5. District cooling
6. Niche applications

The methods above are based upon power generation with adaptations to the current regasification progress or by transferring thermal energy via an intermediate system or fluid. For power generation a total potential of 110 MW of cold energy can be extracted at a 5MTPA import terminal. Laws of thermodynamics imply that the lower temperature of the refrigerant supplied, the greater the energy required for providing a unit of that refrigerant.

Inlet air cooling to gas turbines for power generation

Inlet air cooling (IAC) to gas turbine generators (GTG) results in an increased power output from the turbine. The cold formed by vaporising is transferred to the GTG inlet air by a suitable heat transfer fluid. Extra fuel is required to fire the combustion condition and incremental power is then generated from the greater mass of exhaust gas. A schematic view of this system is shown in figure 39. Implementation of IAC systems in one of the concepts will increase the generation of electrical power, but it is still expensive with increased operational and investment cost.

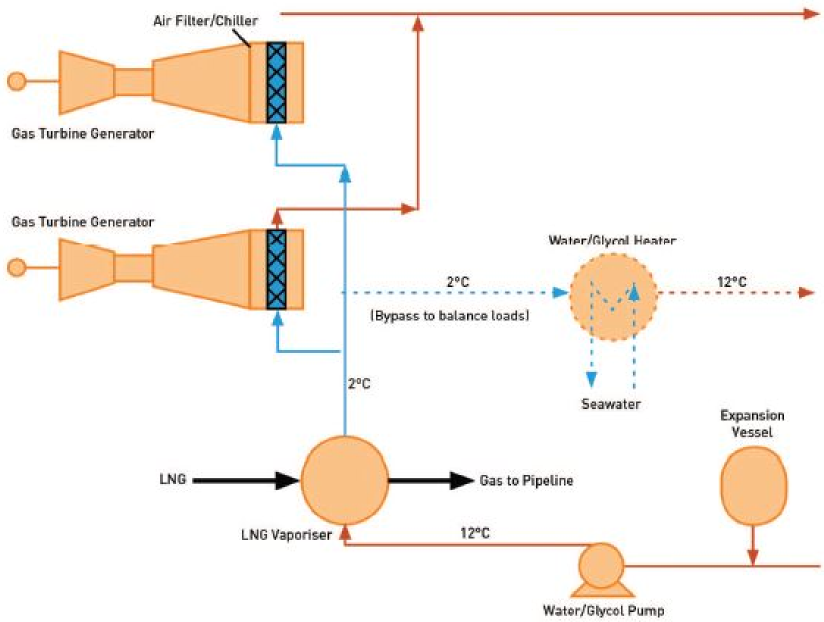


Figure 39 ***Simplified scheme of a GTG IAC integration system*, adapted from *LNG terminal cold energy integration opportunities offered by contractors*, retrieved *May 2015* from *Foster Wheeler Company© 2012, Foster Wheeler AG*, reprinted with permission**

Specifications of the IAC system that need to be considered for application are;

- Heat transfer medium, such as water/glycol, methanol/water or seawater
- During the process additional actions are required, such as:
  - Chilling Coil.
  - Condensed water must be collected and removed from the air stream before the intake of the air compressor.
- Cooling medium supply temperature must be equal or higher than 2°C.
- Operating conditions need to be chilling moisture laden air below around 8-10°C.

Significant operational issue is that the power plant operator and LNG import terminal operator must have 100% perfect collaboration, in order to achieve mutual commercial benefits for both facilities. A successful integration is fully dependent on the two units operating year-round consistently near maximum operating level.

Cold power generation

Generation of cold power creates electricity by the expansion of a working fluid across a turbine linked to a generator. For a 5 MTPA import terminal 35MW can generate without any fuel consumption. Figure 40 shows the Rankine cycle power generation system. This system is also used in the Osaka LNG terminal.

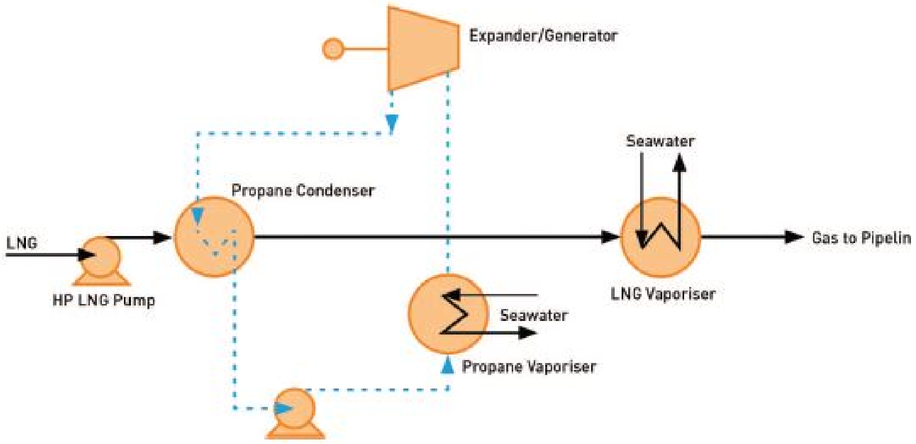


Figure 40 ***Simplified schematic for power generation from LNG cold energy using a Rankine circle,*** **adapted from** ***LNG terminal cold energy integration opportunities offered by contractors,*** **retrieved** ***May 2015*** **from** ***Foster Wheeler Company© 2012, Foster Wheeler AG,*** **reprinted with permission**

For this system to work there must be a sufficient temperature potential between LNG and seawater to condense and vaporize the working fluid. The fluid has to boil at high pressure against sea water and condense at low pressure against LNG. Propane is a suitable working fluid.

Air separation units

Air separation using cold energy from LNG provides liquid nitrogen and liquid oxygen. This is an attractive solution to start synergies with other industrial facilities, because of the low temperature source. By applying integrated air separation units (ASU), power consumption can be reduced significantly, up to 50% compared to initial LNG regasification systems. This method for integrated air separation units is already constructed at multiple LNG import terminals operating in Japan, Korea, Taiwan and France.

Some of the side products of air separation are liquid oxygen, nitrogen and argon, which can be sold to the industrial gasses market or apply the cold energy for cooling other low temperature separations, such as ammonia, ethylene or LPG.

Chilled water

Industrial facilities, such as refineries or chemical plants, globally apply cooling water as low-grade heat sinks. In closed-loop systems or evaporative systems, cold energy from LNG is applied as a heat sink to lower the temperature of the fluid. This is realised by integrating an intermediate refrigerant circuit and a closed water loop to extract all the cold energy from the circuit into the loop to cool the water. Ultimately, this results in a continuous supply of chilled water to industrial facilities for many purposes.

District cooling

District cooling is similar to chilled water, cold water is applied to reduce capital cost and operating cost, but now it is for residential or commercial use. i.e. Cooling water for an air conditioning etc. By integrating closed water systems with cold energy via an intermediate refrigerant circuit, chilled water can be supplied to a whole district.

Niche applications

- Cold storage and frozen food are a logical usage of the cold energy, yet not really effective because only a small amount of the total potential energy is used.
- Cryogenic crushing of an elastic material can transform the structure into the brittle range enabling crushing.
- Seawater desalination is a cheap alternative compared to other desalination systems. However, the total usage of the potential energy is rather low, resulting in low energy efficiency.

4.3.5. Offshore regasification terminals

As the figures showed in the introduction, there is a current trend for designing offshore regasification terminals. If the bathymetry does not allow an onshore plant and also the construction cost for dredging are too high, an offshore terminal is a great opportunity to reach these countries, which were unreachable before. Figure 41 presents a schematic cross-section of an FSRU carrier.

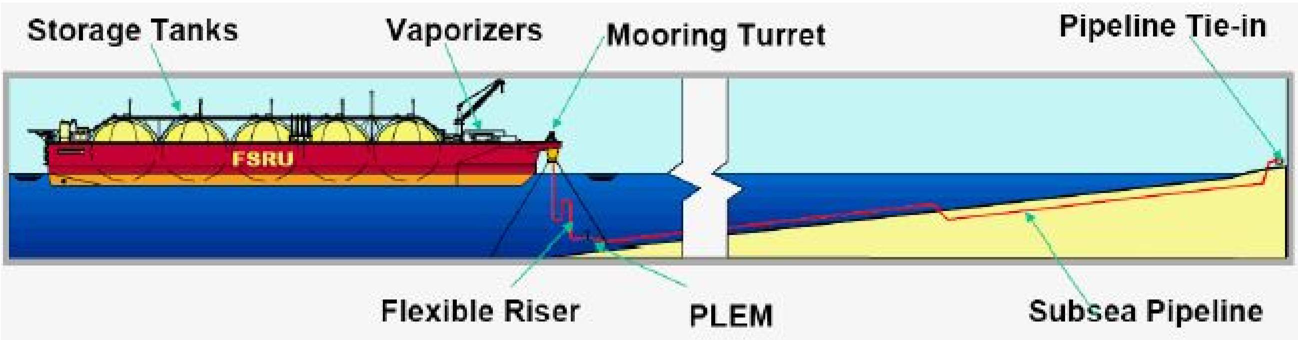


Figure 41 *Cross-section of FSRU*, **adapted from** *Challenges of developing LNG Terminals*, **retrieved** *February 2015* **from** *UNESCO-IHE © 2013, VOPAK*, **reprinted with permission**

Figure 30 showed already a variety of offshore LNG unloading concepts, which were:

- Floating Storage and Regasification Units (FSRU)
- Gravity Based Structures (GBS)
- other concepts

The required technology for designing such offshore terminals is already known, however, the practical experience is rather new. This has a couple of consequences during the design, which are for safety and concept selection.

Since, the LNG industry has such high standards for safety regarding onshore terminals, yet the same or higher safety level is expected for offshore plants as well. This can be achieved by doing more analysis, such as the Quantitative Risk Assessment of offshore installations. More measurements are in order to mitigate the risk of escalation and higher consequences in terms of economic loss.

Concept selection for offshore trends is different for each construction site, because the site conditions are continuously varying over time during the constructional and operational lifespan of the plant.

Floating Storage and regasification units (FSRU)

By applying FSRU's instead of a conventional plant, this drastically increases the flexibility and reduces construction time and damages when failure occurs (Egashira, 2013). Differences compared to the conventional LNG facility are the influence caused by the sea or ocean conditions. Waves force the FSRU in all directions of movement, and in addition the potential for transient non-horizontal periods. The degree of motion is affected by the hull dimensions and dynamics, wave climate and mooring systems. When designing for motion this affects several elements of the terminal design, including:

- Storage tanks, where sloshing has to be limited to a minimum, especially for membrane-type tanks
- Vaporizers, an FSRU requires a process scheme based, due to movements like pitch and roll of the hull of the carrier, the vaporizer has to be designed in such a manner that sloshing is avoided. The IFV is the best type of vaporizer for doing so, according to (Egashira, 2013).
- Measures against pitching and rolling of the hull, this is achieved by increasing the ships dimension. By enlarging the width rolling is decreased and by increasing the total length of the ship pitching is decreased.

Brazil, China and Italy already have some FSRU's in practice.

Future issues for FSRU

These issues have been stated by (Egashira, 2013) of KOBE Steel in 2013, so it is expected that these are recent and quite accurate. The main issue of an FSRU is that space is limited, because it is a transformed LNG carrier. Therefore the spatial footprint of the IFV must be reduced and have less weight. A new trend in demands of an FSRU is that not only a vaporizer has to be on board of the carrier, but also the package supplying of LNG vaporizer equipment including peripheral piping, electrical apparatus and instrumentation and pumps. In order to achieve these adaptations, it is required to further downsize the IFV and modernization of LNG equipment.

Gravity based structures (GBS)

Gravity based structures are caissons positioned in the sea, which are sunk to the bottom of the sea. The new trend is to design and construct LNG regasification terminals on the caissons. Benefits of such a design are a fixed and stable LNG import terminal located offshore, which can regasify the LNG or store the LNG. The GBS is a rectangular structure, which makes it easier to construct and design the layout on top of the caisson. Also this greatly benefits the construction of the membrane containment system inside the tanks for storage. Furthermore, the long side of the GBS acts as a breakwater for the moored LNGC's. Figure 42 is an image of the world first offshore GBS LNG Terminal near Venice in Italy.

Figure 42 *First GBS Adriatic LNG in Italy*, **adapted from** *World's first offshore gravity-based LNG terminal near Venice,* **retrieved** *February 2015* **from** *http://www.pipelineandgasjournal.com/world%E2%80%99s-first-offshore-gravity-based-lng-terminal-near-venice © 2009 Oildom Publishing Company of Texas,* **reprinted with permission**

Major influences on the design are in a hydro-dynamical and environmental sense, where wave climate at sea and salinity have the most impact on the caissons. It is studied by (Loots & Buchner, 2004) if wave run-up and green water on the deck is a problem that needs evaluation, because of the optimized heading of the GBS beam to the dominant wave direction. Their results were that a jet is formed, due to wave run-up and breaking. This jet shoots up against the caisson and falls back again down. It was expected that the jet will reach the deck due to wind, yet this was not so significant. In order to reduce the green water on the deck a deflector on the edge will solve it. These preliminary investigations were insightful, but have yet to be validated.

Other concepts

Currently there is a concept to design a Single Point Mooring System connected to a GBS, with a cryogenic pipeline connection to a remote facility. This way the natural gas can be transported instantly towards the shore and distribution network.

The cryogenic cavern is a concept in which LNG is stored within a mountain/cavern. By storing LNG under high or low temperature, it is possible reducing storage volume. There are already multiple designs with underground storage, such as gas reservoirs, aquifers and salt caverns. A new concept is hard rock storage. In-ground and aboveground storage in insulated steel tanks near the coast is a conventional method for storing LNG worldwide as LNG is transported by sea and is handled in gas terminals (Cha, Bae, Lee, Lee, & Bodin, 2007).

4.3.6. Construction of LNG receiving terminals

The construction of an LNG regasification terminal is separated in multiple phases. Figure 43 shows a typical construction phase chart of a project.

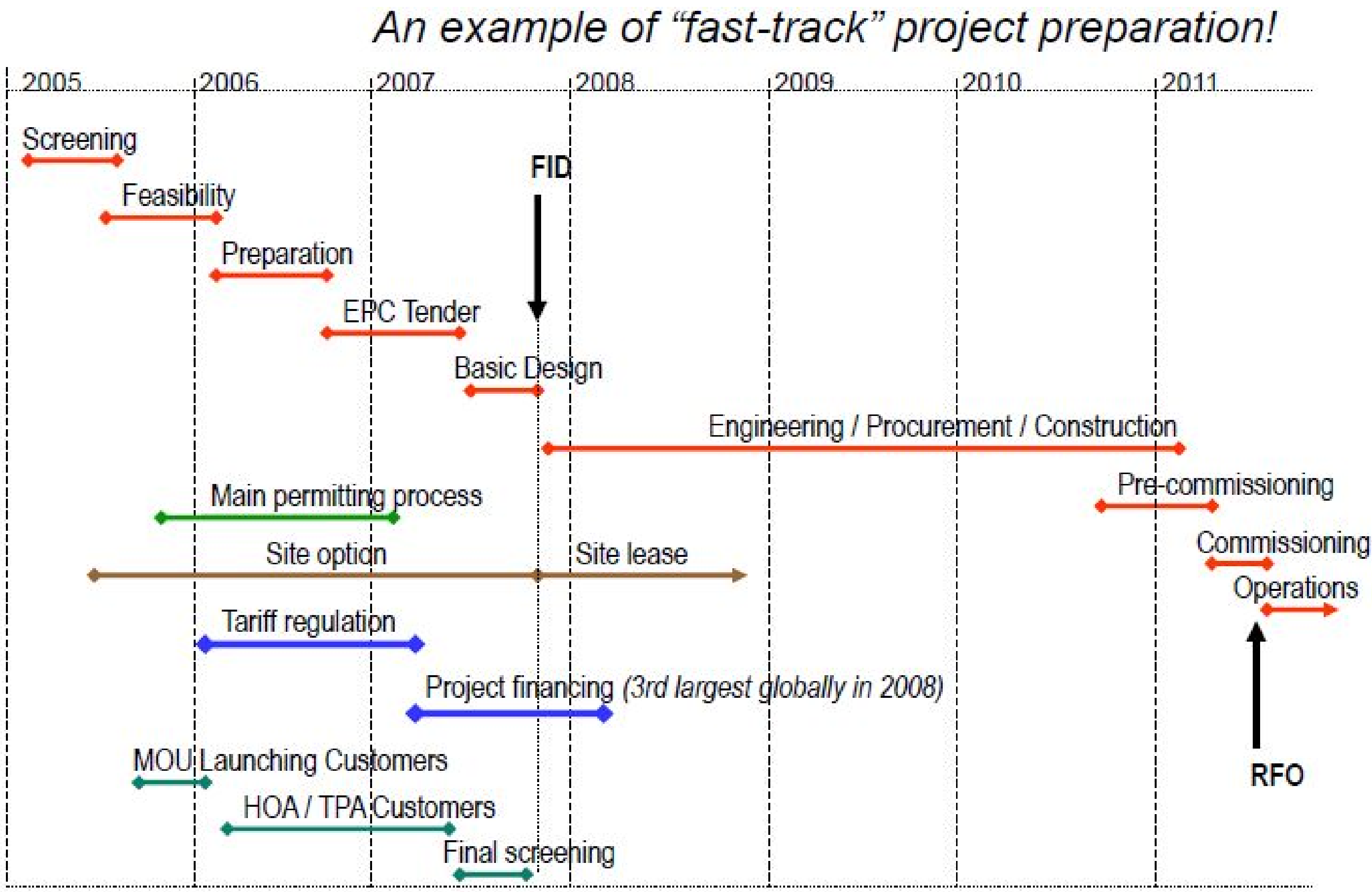


Figure 43 *Phases of construction for an LNG project*, **adapted from** *Challenges of developing LNG Terminals* , **retrieved** *February 2015* **from** *UNESCO-IHE © 2013, VOPAK*, **reprinted with permission**

Onshore vs offshore technical comparison

Large differences occur throughout the lifespan of an onshore terminal, FSRU and GBS. These differences per phase are shown in table 4.

Table 4 *FSRU vs GBA*, **adapted from "***Offshore LNG terminals; Sunk or Floated***", retrieved** *February 2015* **from** *www.gustomsc.com © 2004, Offshore Technology Conference,* **adjusted with permission**

Technical Comparison	Onshore	FSRU	GBS
Design phase			
Permitting	o	o	o
Site selection	-	+	-
Construction phase			
Construction site	+	+	o
Fabrication	+	o	o
Integration	-	+	-
Transport	+	o	o
Site preparation	-	o	-
Installation	+	+	-
Schedule	+	+	o
Cost escalation	o	o	-
Operational phase			
Berthing and Mooring	-	+	o
LNG Transfer	+	o	o
Storage	+	+	+
Vaporization	+	+	+
Send-out	+	o	+
Maintenance	+	o	o
Stability	+	+	+
Operability	+	unknown	unknown
Safety	+	+	+
Future phases			
Expendability and re-use	o	o	o
Decommissioning	o	+	-

Legend
- = Poor
o = Average
+ = Good

The table above is based upon research done by (Wijngaarden, Oomen, & Hoorn, 2004), where they have compared GBS against the FSRU. Both have different benefits, such as a short construction time for FSRU and high accessibility of carriers for the GBS. The first column is an extension based upon the results of this current literature study. Every phase has its inherent key elements. Since, the FSRU and GBS are still relatively new technologies, the long term operability is not yet tested, and therefore it is rated with unknown.

4.3.7 Reference cases

The enlisted cases underneath will be discussed briefly in this section. The selection of reference cases is based upon unique primary functions or layouts per reference case, in this way all areas of LNG regasification plants are treated. The selection criteria are:

1. Conventional terminals:
   1.1. import terminal Zeebrugge
   1.2. import Terminal in Dunkerque LNG terminal
   1.3. re-export Terminal GATE terminal Rotterdam
2. Offshore terminals:
   2.1. FSRU: Klaipeda, Lithuania
   2.2. FSRU: Livorno, Italy
   2.3. GBS: ALNG
3. Small-Scale LNG regasification terminal:
   3.1. Fredrikstad, Norway by SSLNG
   3.2. Sakaide Japan by SSLNG
   3.3. Japan by Small Shuttle Vessels

Conventional terminals

Table 5 shows the characteristics for onshore facilities:

Table 5 Characteristics for conventional terminals

Country	Terminal	Reloading Capability [m^3\year]	Unloading capacity [m^3/year]	Storage [m^3]	no. of jetties	No. of tanks	Constructed in:	Maximum allowable type of LNGC
Belgium	Zeebrugge	5,00E+03	9,00E+09	3,80E+06	1	4	1987	Qflex
France	Dunkerque	NA	1,30E+10	5,70E+06	1	3	2015	Qmax
Netherlands	Rotterdam	2,50E+03	1,20E+10	5,40E+06	2	3	2011	Qmax

The terminal in Zeebrugge has been selected as a reference case, because of a distinctive layout and it is one of the largest re-exporters of LNG of the world together with the GATE LNG Netherlands. Dunkerque is selected as a reference case, because it has the largest regasification capacity of the Europe, which represents around 20% of France and Belgium's annual gas consumption. All three terminals constructed storage tanks above ground level and ORV's. In figures 44 to 46 are shown all three layouts of the corresponding import plants.

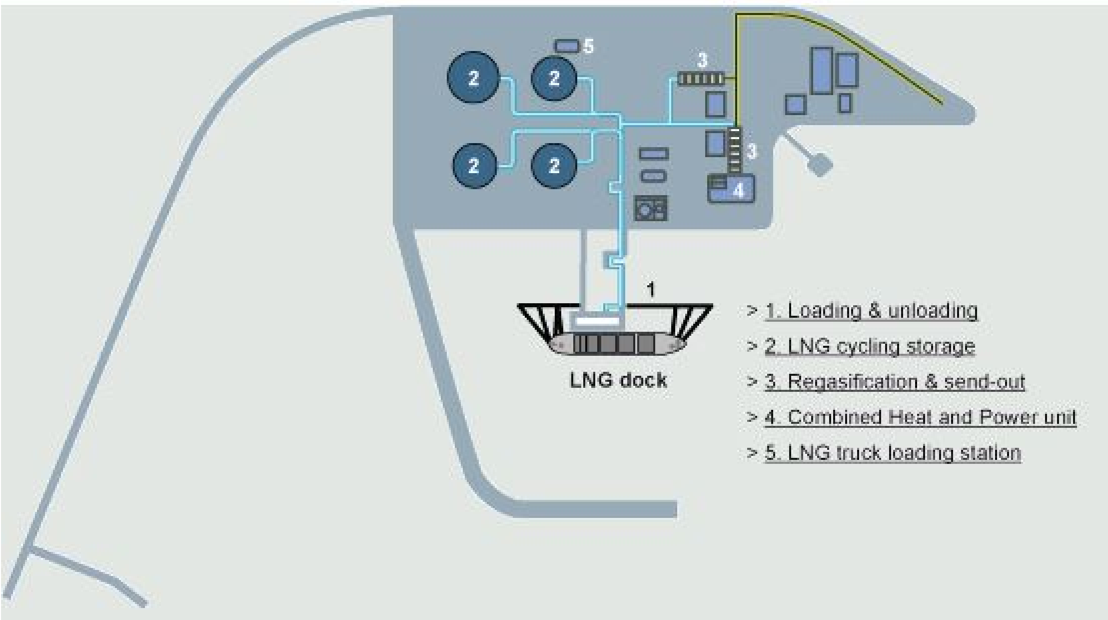


Figure 44 ***Layout Zeebrugge LNG Terminal*, adapted from *Overview*, retrieved *February 2015* from *http://www.fluxys.com/belgium/en/about%20fluxys/infrastructure/lngterminal/lngterminaloverview.aspx* © 2014, *FLUXYS*, reprinted with permission**

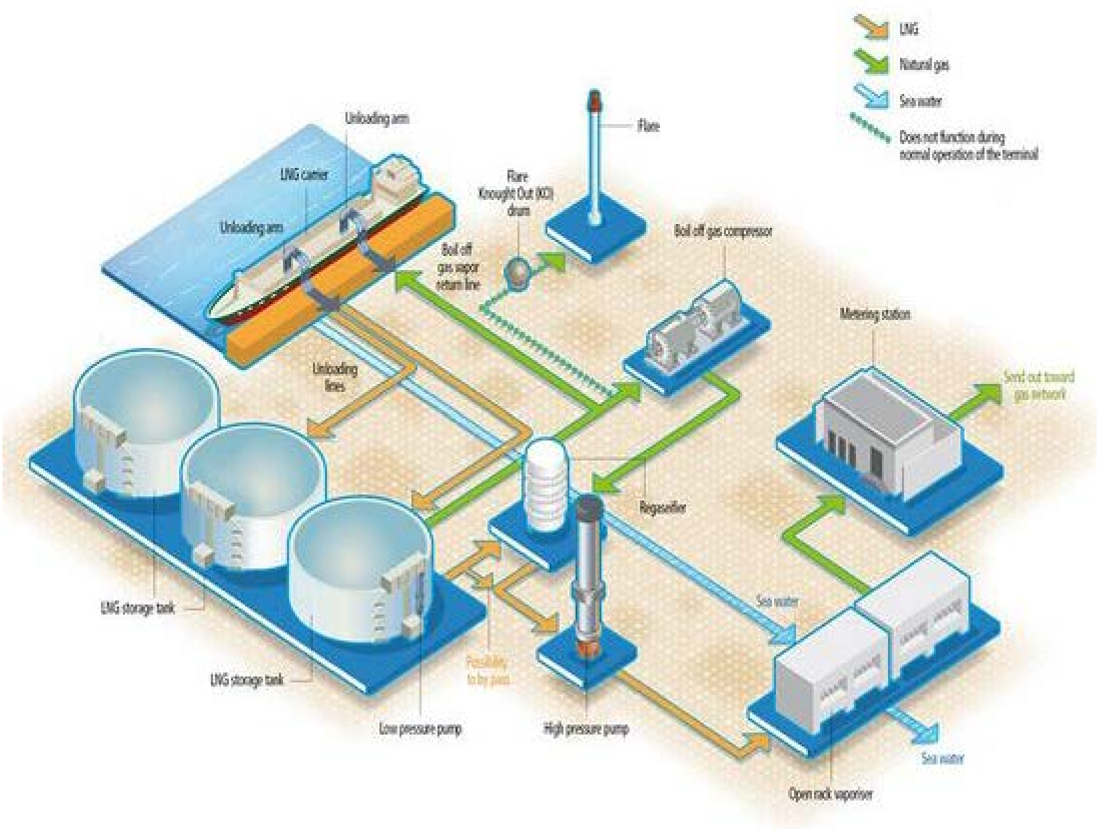


Figure 45 *Birds view of terminal at Port of Dunkerque*, **adapted from** *Dunkerque LNG terminal*, **retrieved** *February 2015* **from** *http://www.vanleeuwen.eu/showcases/dunkerque-lng-terminal/?contentlocale=NL_EN* **© 2014,** *Van Leeuwen*, **reprinted with permission**

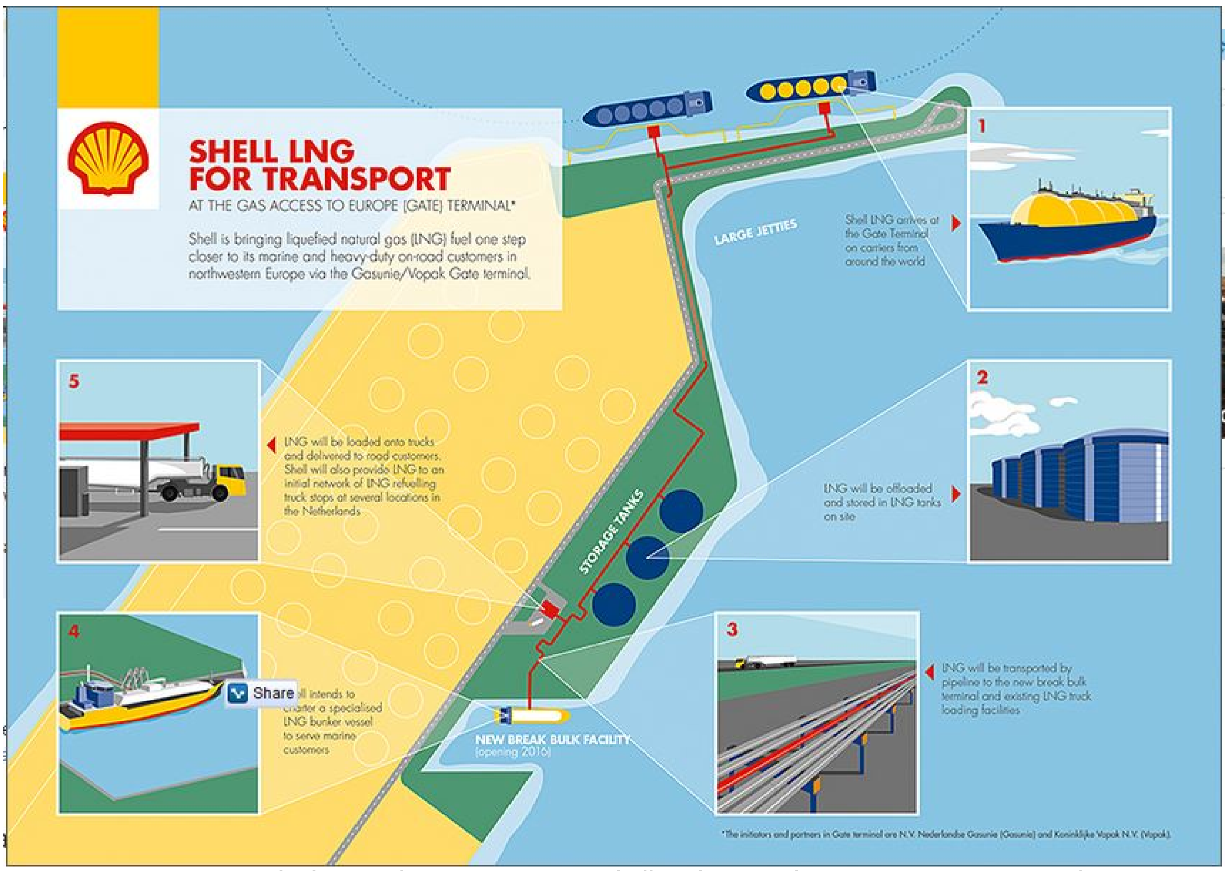


Figure 46 *Gate LNG Terminal Rotterdam*, **adapted from** *Shell Is the Launch LNG Customer at Rotterdam*, **retrieved** *February 2015* **from** *http://hhpinsight.com/marine/2014/07/shell-is-launch-lng-taker-at-rotterdam © 2012-2015, HHPInsight.com, reprinted* **with permission**

The regasification LNG scheme can clearly be recognized in all terminal layouts. Where the LNG has been transported, regasified into NG, and transported into the distribution grid.

Carrier → Storage → Peak shaving plant → Distribution grid

Whereas the location of the storage and jetty is according the standard codes in order to minimize hazardous situations. Due to the size of these ports and allowable maximum size of Qmax, really makes the ports more accessible for diversifying all export locations. When demand is low, the LNG can be re-exported and vice versa when demand is high LNG can be stored in the large full containment tanks.

Offshore terminals

The three reference cases are the FSRU's in Lithuania and Livorno and the first GBS called ALNG in Italy. These three have been selected for various reasons, as will be explained briefly.

Lithuania is selected, because of similar political issues at stake. The Lithuanians imported all their domestic demand for natural gas was coming from Russia via Gazprom's distribution grid, which made Lithuania dependable on the Russians. The newly constructed LNG terminal Klaipeda makes is possible to diversify the LNG import. In total they used to import 3.4 billion m^3 and the capacity of the FSRU is 3 billion m^3 per annum. Thus in the future the terminal will satisfy the demand. Figure 43 shows a scheme of the cross-section of the FSRU and the LNGC which are connected to each other and to a fixed jetty. The design incorporates a fixed jetty of 450 meters, where the LNGC are connected to FSRU. Some characteristics of the FSRU in Lithuania are included in table 5.

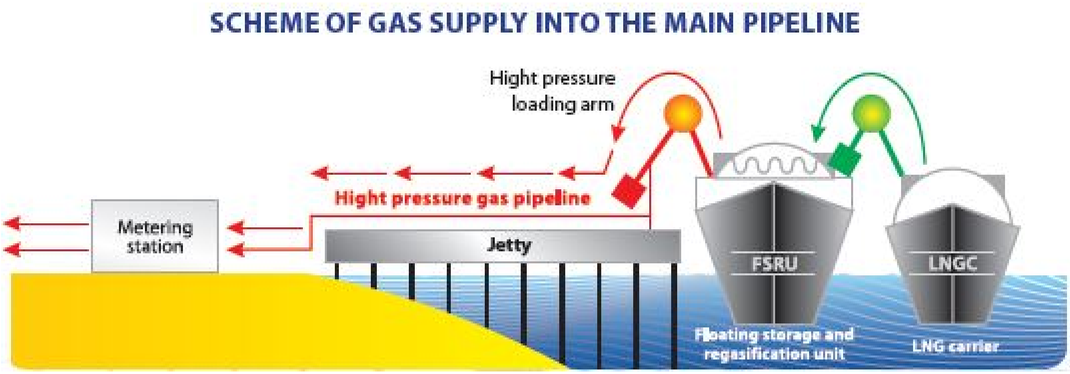


Figure 47 *Scheme of gas supply into main pipeline grid*, **adapted from** *implementation actions of the LNG terminal*, **retrieved** *February 2015* **from** *Port of Klapedia © 2014, Klaipėda State Seaport Authority*, **reprinted with permission**

Livorno LNG terminal in Italy is selected, due to the fact that it will be moored 20 km into the sea at a depth of 120 meters. The FSRU is a conversed LNG carrier, which is permanently moored in the open sea, via a rotating turret. The vaporizers applied in the FSRU are three IFV heat exchangers. The gas resulting from vaporization is sent to shore via an offshore pipeline connected to the national network at Suese, in the Livorno hinterland (Favi, 2014). Between the FSRU at sea and the remote LNG terminal will be a subsea cryogenic pipeline in order to avoid any spillages and any of the other occurring hazards. In figure 48 is the artistic view of the conversed 'Golar Frost'. In table 6 are some characteristics of this conversed FSRU.

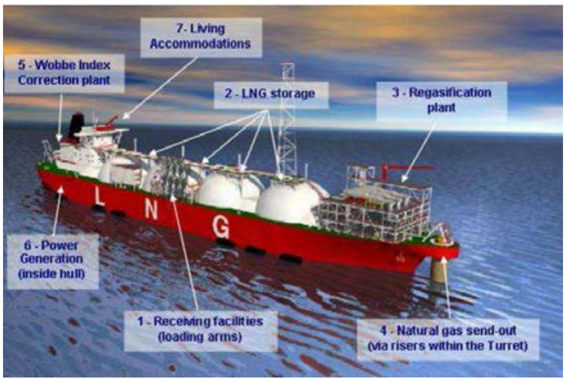


Figure 48 *Artistic view of the FSRU "Golar Frost" at Livorno*, **adapted from** *OLT Livorno FSRU: an innovative solution for the gas industry*, **retrieved** *February 2015* **from** *Saipem © 2014, Saipem*, **reprinted with permission**

Table 6 FSRU Characteristics

Characteristics	Storage capacity [m^3]	Unloading/Reloading capacity [m^3/hr.]	Length [m]	Width [m]	Draught [m]
FSRU Klaipeda	170000	9000	294	46	12.6
FSRU Livorno / Golar Frost	137000	12000	288	48	N.A.

Adriatic LNG is the first GBS ever made in the world in the Adriatic Sea near to the Port of Levante in Italy. The ALNG is designed to transport 8 billion m^3 per year into the Italian distribution grid. The GBS includes two LNG storage tank and regasification facility on the topside. The overall dimensions are 180 m long, 88 m wide and 47 m high, resting on a seabed at 29 m below mean sea level. These storage tanks have a capacity of 125000 m^3 per tank. When designing such a structure seismologic and metocean considerations have to be taken into account. Figure 49 shows the topside layout of GBS.

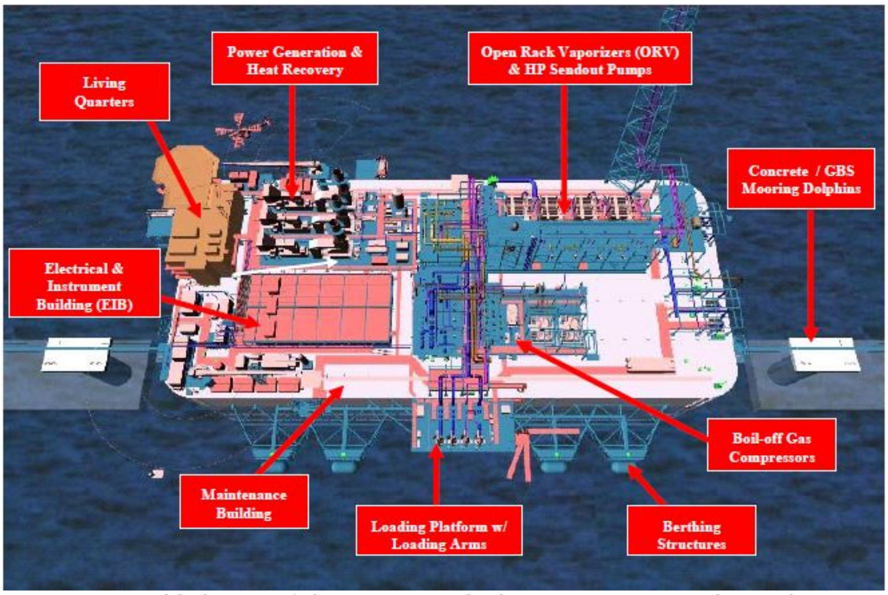


Figure 49 ***Topside layout of the ALNG Terminal*, adapted from *Design and construction of gravity based structure and modularized LNG tanks for the Adriatic LNG terminal*, retrieved *February 2015* from *ExxonMobil Development Company © 2007, ExxonMobil Development Company* ,reprinted with permission**

> "*Major process equipment will include four in-tank LNG pumps, five high-pressure send-out pumps, four Open Rack Vaporizers (ORV's) which use seawater as the heating medium, a Waste Heat Recovery LNG Vaporizer (WHRV) which uses waste heat from the turbine generators, and two Boil off Gas (BOG) compressors. One of the in-tank LNG pumps, one high-pressure LNG pump, and one ORV serve as spare equipment. Three gas turbine generators will provide approximately 31.5 Mega Watts (MW)* (Water, Mueller, Hellen, & Hurst, 2007)"

The 40 km long pipeline, of which 15 km is in sea, 10 km over wetlands and 15 km over onshore/farmlands, transports the natural gas towards Caverzere. At Carverzere meturing station a secondary project is started to transport the natural gas further into Italian mainland towards Minerbio, where it will be transported into the Italian distribution grid. In figure 50 this whole distribution line is shown.

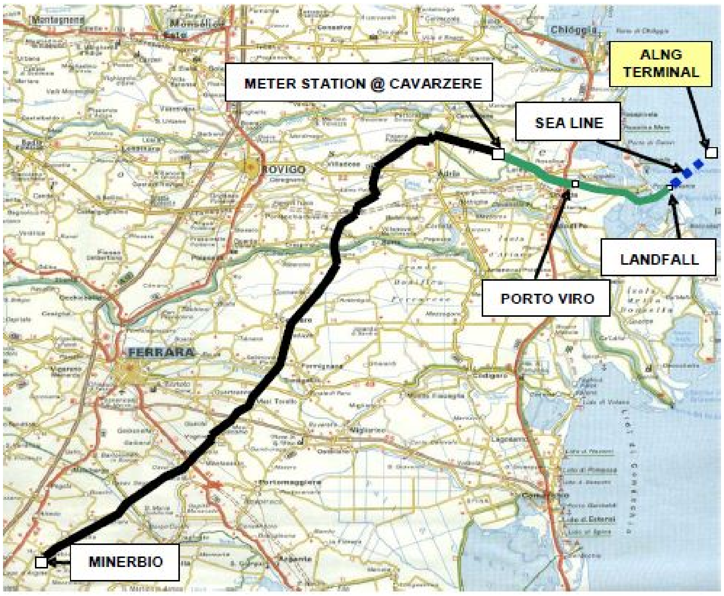


Figure 50 *ALNG Terminal Location and Pipeline Route*, **adapted from** *Design and construction of gravity based structure and modularized LNG tanks for the Adriatic LNG terminal*, **retrieved** *February 2015* **from** *ExxonMobil Development Company © 2007, ExxonMobil Development Company* **,reprinted with permission**

Small scale LNG

Small scale LNG facilities are defined as plants with a capacity of less than 1 MTPA. In addition SSLNG carriers are defined as vessels with a capacity of less than 18000 m3. Figure 51 shows an LNGC to the left and to the right is a SSLNGC.

Figure 51 *SSLNG carriers*, **adapted from** *LNG Terminals fuel of the future*, **retrieved** *February 2015* **from** *Design of liquid bulk terminals © 2014, Delft University of Technology*, **reprinted with permission**

Since the size and load of the ships are smaller, this results in lower drafts of the vessels. Many more new locations can be reached. SSLNG is growing across worldwide, because of the low emission rate and lower investment costs and operational costs. As mentioned in section 4.2.2 about SSLNG distributions, there are three types shown underneath once more, but now with an addition of a reference case:

Small liquefaction → Small regasification i.e. Frederikstad in Norway
Large liquefaction → Small regasification i.e. Sakaide in Japan
Liquefaction plant → Import/export hub→ Small regasification Yufutsu in Japan

These regasification plants serve as reference cases in order to gain information about the feasibility of SSLNG applied to the case study. Table 7 shows some data about these three cases.

Table 7 *Small-Scale Marine-Based Regasification import projects, (***International Gas Union, 2014)***.*

Project	Country	Status	Original capacity [MTPA]	Constructed in	Operator
Fredrikstad	Norway	Existing	<0.1	2011	Skangass LNG
Sakaide	Japan	Existing	0,7	2010	Shikiko Electric
Yufutsu	Japan	Existing	<0,1	2011	JAPEX

A typical design for a small-scale LNG import regasification terminal is shown in figure 52.

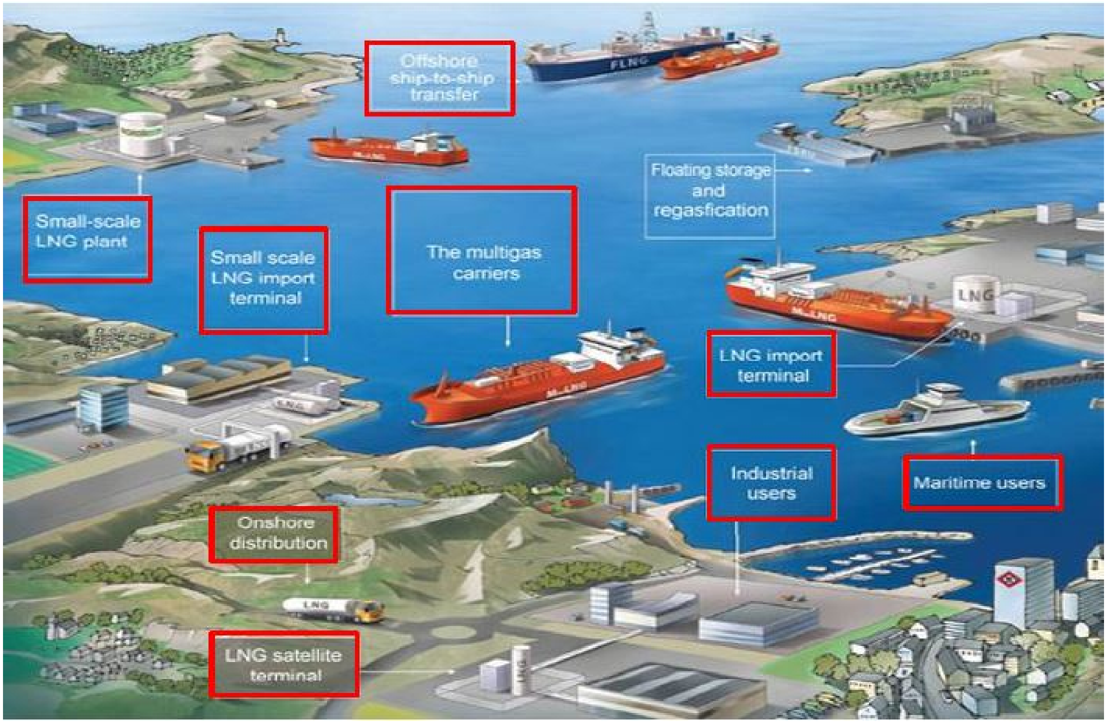


Figure 52 *Schematic view of an SSLNG import terminal*, **adapted from** *MarTech LNG*, **retrieved** *February 2015* **from** *http://www.golng.eu/files/Main/news_presentations/Skangass%20Risavika%2018092013.pdf © 2013, Skangass, reprinted* **with permission**

In the figure above an FSRU and FLNG are importing and exporting LNG, respectively. There are many hinterland connections by pipe or truck, which transport LNG in the distribution network. In the small scale storage tanks is only limited capacity, so LNG can only be stored temporarily, and must be quickly distributed before more import of LNG can occur. The amount of LNG in the terminal is purely based on the local demand.

Reference cost

A study into the total cost per reference case is done to determine a range of total cost for three terminals. Table 8 shows the reference cases with short term and long term value.

Table 8 Reference cases total costs

		Total Cost [$]	Total Cost [€]	Reference
Sabine Pass	CT Additional value	5.60E+09	5.02E+09	(Hydrocarbons Technology, 2015)
Indonesia	CT 5bctpa	8.69E+08	7.79E+08	(Princeton, 1980)
Rotterdam	CT Gate	8.93E+08	8.00E+08	(VOPAK, 2007)
Lithuania	FSRU Klaipeda	1.28E+08	1.15E+08	(Sc KLaipeda Nafta, 2014)
Italy	GBS Adriatic LNG	1.00E+09	9.00E+08	(Locatelli & Mancini, 2009)
Croatia	GBS Adria	1.30E+09	1.17E+09	(2b1stconsulting, 2015)

4.3.6. Conclusion

The LNG industry is highly dependable on the market's demand. Each new project is completely different than the one before. The global demand or by local governments is ever changing, so the LNG industry has to adapt and come up with new innovative designs in order to lower investment costs, emissions rates or to increase the achieve high efficiencies. All these motivations for innovation have led to many new opportunities, such as;

- floating storage and regasification units
- gravity based structures
- small scale LNG facilities

Yet this would not have been possible without innovations in applied vaporizers within LNGC or Subsea Cryogenic Pipelines, conversed LNGC into FSRU's or downscaling LNG facilities and carriers. In order to keep up with the market's demand of LNG these innovations have to keep going. Otherwise the demand of LNG will shift into other resources of energy.

Reference short term total cost indicates that the FSRU is by far the cheapest solution and the GBS most expensive. In between is the conventional terminal, yet this fully varies with additional value created by expanding and synergies, this results in a higher investment costs even exceeding the long term values of the GBS. Since the FSRU and GBS do not provide much or any space for expandability, and site selection of the conventional terminal provides sufficient space for expansion. The cost escalations for the long term value can escalate quickly.

5. Conclusions and Recommendations

There is a global trend for using renewable energy sources to supply the demand of world's energy demand. However, with the current issue for world population growth in combination with climate change, a new source of energy with acceptable greenhouse gas emissions has to be developed. Since, currently Green energy is not sufficiently reliable to supply this enormous demand, so the best alternative has to be selected. Due to the disasters with nuclear plants the public opinion has become negative about nuclear energy. This resulted in the closing of many nuclear plants worldwide. The gap in energy supply before green energy has become sufficient reliable has to be filled. Natural gas is the best alternative as a fossil fuel, because natural gas is a renewable source, emission rates are low and it has really good transport capabilities. Natural gas can be liquefied, by doing so the volume decreases by a factor 1/600 of the original volume.

The market of LNG is shifting towards Asia, because this area in the world where still the most progress can be achieved. Especially, with small-scale LNG distribution many of the Asian countries can now be reached. The Asia-pacific region as one of the most stable LNG exporting countries enforces this trend towards Asia. With the resourcing of shale gas America has become from importing to the exporting country. In Europe the import of LNG will be diversified, because the dependency on Russian gas became too significant, which resulted in conflicts with Russia. Europe is at risk for large inflations, but politically seen, it is better to import from multiple exporting countries.

In order to transport LNG all over the world the LNG industry has to be innovative with their designs and projects. The constant scenarios challenge the designers to be innovative in their designs. The incentives are to reduce the investment cost or increasing the benefits. By locally or globally improve the accessibility of LNG facilities this can benefits the market. Recent trends in LNG industry have been FSRU's, GBA's and small-scale LNG distribution would all not have been possible without innovations in every single aspect of the LNG industry. Table 9 shows the clear, distinctive benefits and cons of the regasification terminals.

Table 9 Benefits and cons of regasification terminals

	Benefits	**Cons**
Conventional	High safety	Limited accessibility
	Experience	Site selection
	High storage capacity	Integration
	LNG Transfer	Berthing and mooring
FSRU	High accessibility	Low practical experience
	Flexible	Send out
	Site selection	Maintenance
	Installation	LNG transfer
GBS	High accessibility	Low practical experience
	High storage capacity	Site preparation
	Send out	Site selection
	Stability	Integration
SSLNG	High accessibility	Low storage
	Less costs	Short distances
	Demand based transport	Only for small demands
	Lower emission rates	No distances shorter than 1000 miles

The excellent history of disasters is credited to the high safety level during the design, construction and operational phases. Such a high safety level can only be achieved with a mentality for a search for developments and innovations. The newest regasification technology has to be just as safe as or safer than the current onshore facilities.

The issues as defined in the beginning of this report are:

1. There are not enough LNG regasification terminals.

   Some countries have been undeveloped with respect to the LNG industry, because of no accessibility or bad pipeline connection. With SSLNG, FSRU's or GBS new locations can be reached.

   Demand is highly volatile, yet construction time remains the same per concept. So, new LNG regasification plants should be constructed in order to even the demand.

2. Terminals are not working as efficiently as possible.

   New developments in vaporizers, pipelines and hinterland connections have increased the efficiency significantly. Still much more research can be done in order to raise efficiency by combining power generation with LNG receiving terminals for instance.

3. Why is the demand of LNG increasing?
   - increasing world population
   - climate change
   - increasing Europe's energy independence
   - incapability of other energy resources
   - acceptable greenhouse gas emissions from LNG
   - renewable fossil fuel
   - high success rate with LNG
   - high safety levels

The literatures in this study are more a gathering of information about LNG, instead of a discussion about multiple hypotheses made in a variety of literature. Most of the literature reviewed in this study did not leave any space for discussion, because it mainly showed new innovations, researches, new projects or it was a study about situations at a specific moment in time. All studies about LNG were informed, but not suggesting a hypothesis, which can be discussed. Yet, some of the statements made with future expectations were not true, but this does not make a significant difference in the final conclusion. At that particular moment these expectations were logical, yet some major changes politically or new developments changed the outcome.

Some of the journals posted about Russia bluffing about shutting down the gas supply were wrong, even so this still proved that Europe currently is too dependable on Russian gas.

(Massonnier, 2006) states that long term contracts for the gas price index should be avoided, because the United states have done this to avoid monopolies. Also the gas price index was stable enough to be self-sufficient to apply an open market system in the US. But in smaller countries where the gas price index is not stable, it is a good way to set a price based upon the oil price index controlled by stable companies.

(Jensen associates, 2007) Jensen states that America will be a major contributor importer of LNG, yet when this was stated, their Shale resourcing was not sufficient enough. Now this has changed where America has become an exporting country.

Ukraine, Yuzhny

Currently, they import natural gas from Russia via a pipeline. Due to the conflict with Russia, Ukraine has now a large energy shortage at hand. With the 'South Stream' redirected to Turkey and no working connection to the Western Europe gas distribution network, another solution has to be developed in Ukraine. By constructing an LNG Regasification terminal in Yuzhny Ukraine can diversify their LNG import to satisfy their demand. The motivations of the project are similar to the LNG receiving terminal in Lithuania.

Since Yuzhny is located at the coast of the Black Sea, it has to be investigated what the best solution is for designing an LNG receiving terminal at this location. This can be done in the various methods discussed within this study. The only entrance way into the Black sea from the Mediterranean Sea is the Bosphurus strait. The passage through the Bosphorus strait is a possible bottleneck that has to be studied. Yet this will be done in the next phase.

6. Additional Literature

Within this section all additional literature which could not be classified within the core of this report.

6.1 Current projects

A list of projects in a variety of phases, those affect the design of current projects.

1. Canal Istanbul

(Jones, 2011)

The project's ideology is the high vessel intensity of the current Bosphorus Strait of about 56000 vessels per year, of which about +10000 vessels with hazardous cargo. All these vessels have to sail through the narrow Bosphorus with a strong surface current and many bends, resulting in dangerous situations. The goal of the new Bosphorus is to minimize the vessel intensity within the former Bosphorus, so this can be applied for water sports and leisure.

The length of the waterway will be 45-50 km with a depth of 25 m. It is 150 m wide at the surface at bed/canal level the width is 120m. Although the precise location is still undefined, the project is planned to be finished in 2023.

Some questions are raised by the Turkish Green political party. They are concerned about the specific and sensitive ecosystem of the Black sea, which can easily be disrupted or destroyed by the new project.

2. New Suez Canal

(Suez Canal Authority, 2015)

Idea of the project is to construct a new canal, parallel to the existing canal, to the increase maximum benefit from the current canal and its by-passes. The project is performed to develop a two way traffic lane and minimizing the transiting vessels. Ultimately, the required results are an increase in numerical capacity of the waterway and accessibility for all vessels. The new construction of the canal will be 72km long, to a depth of 24 m and width of 317m at surface water. The project is due to be finished in 12 months, approximately in 2016.

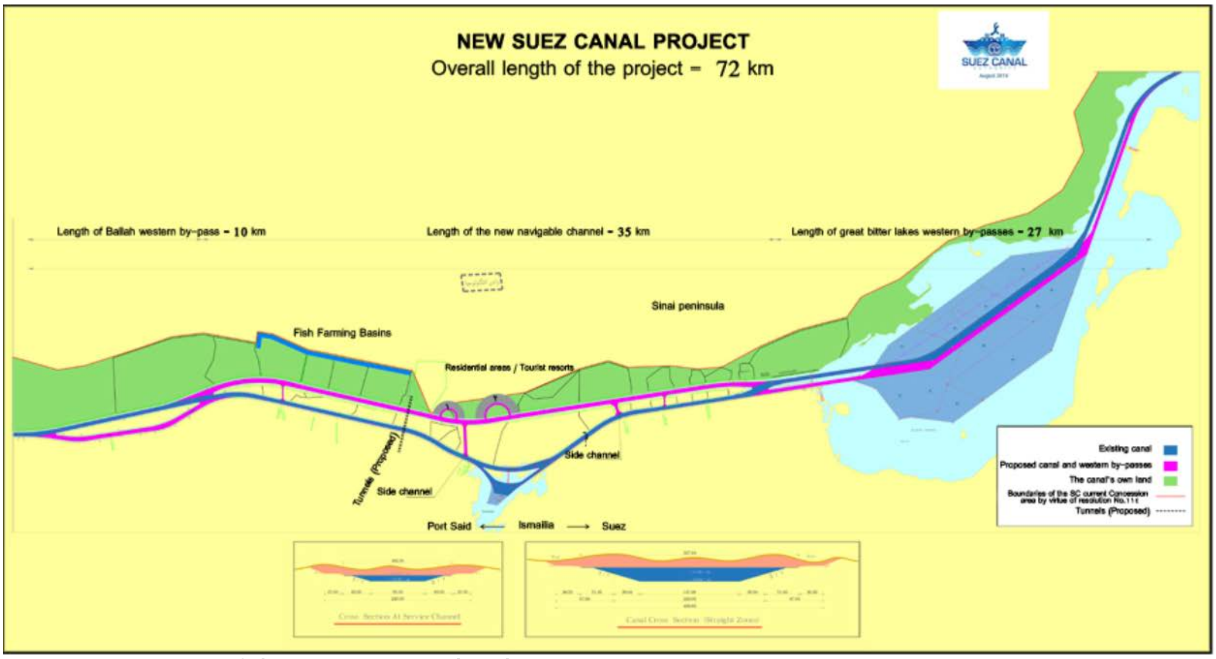


Figure 53 *Map of the new Suez Canal project*, **adapted from** *SCA*, **retrieved** *May 2015* **from** *http://www.suezcanal.gov.eg/sc.aspx?show=69 © 2008, Suez Canal Authority*, **reprinted with permission**

3. Dredging works at the port of Yuzhny

(Amelin, 2015) Is already included within literature study.

7. References

7.1 List of abbreviations

Table 10 List of Abbreviations within this report

Abbreviation	full
AAV	Ambient Air Vaporizer
boe	Barrel of oil equivalent
BOG	Boil Off Gas
FID	Final Investment Decision
FSRU	Floating Storage and Regasification Unit
FSU	Former Soviet Union
GBS	Gravity Based Structure
IFV	Intermediate Fluid Vaporizer
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
MCE	Multi-Criteria analysis
NG	Natural Gas
ORV	Open Rack Vaporiser
SCV	Submerged Combustion Vaporiser
SSLNG	Small-scale LNG
STV	Shell and Tube Vaporizer
VTMS	Vessel traffic Management System

7.2. Units

Table 11 Applied units within report

Unit	Full
bcm	billion cubic meters
cm	cubic meters
km	kilometer
m	meter
mcm	thousand cubic meters
mmBtu	million British thermal units
mmcm	million cubic meters
MT	million tonnes
MTPA	million tonnes per annum
tcf	trillion cubic feet
tcm	trillion cubic meters

7.3. Conversion factors

Table 12 Conversion factors

	←		Multiply by	→		
	Tonnes LNG	**cm LNG**	**cm gas**	**cf gas**	**mmBtu**	**boe**
Tonnes LNG		2,222	1,3	45,909	53,38	9,203
cm LNG	0,45		585	20,659	24,02	4,141
cm gas	7,69E+04	0,0017		35,31	0,411	0,0071
cf gas	2,18E+05	4,80E-05	0,0283		0,0012	2,01E-04
mmBtu	0,0187	0,0416	24,36	860,1		0,1724
boe	0,1087	0,2415	141,3	4,989	5,8	

8. Registry

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8.2. List of figures

8.3. List of tables

9. Appendix A

All LNG terminals, finished or under construction up to 2015. The document is included as a separate file, because there was no proper way to include this, without having to retype the whole document.

(Global LNG Limited, 2015)

10. Appendix B

Relevant standards and guidelines

Relevant British Standards

- BS 6349-1-1:2013, Maritime works. Code of practice for planning and design for operations
- BS 6349-1-2:2013, Maritime works. Code of practice for assessment of actions
- BS 6349-1-3:2013, Maritime works. Code of practice for geotechnical design
- BS 6349-1-4:2013, Maritime works. Code of practice for materials
- BS 6349-2:2010, Maritime works. Code of practice for the design of quay walls, jetties and dolphins
- BS 6349-3-2012, Maritime works. Code of practice for the design of shipyards and sea docks
- BS 6349-4:1994, Maritime structures. Code of practice for design of fendering and mooring systems
- BS 6349-5:1991, Maritime structures. Code of practice for dredging and land reclamation
- BS 6349-7:1991, Maritime structures. Guide to the design and construction of breakwaters

- BS EN 1990, Eurocode- Basis of structural design
- BS EN 1991(all parts), Eurocode 1-Actions on structures
- BS EN ISO 19901-1, Petroleum and natural gas industries – Specific Requirements for offshore structures – Part 1; Metocean design and operating considerations (for definitions, symbols and abbreviations)