Universitetet
i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study programme/specialisation: Petroleum Engineering / Natural Gas Engineering	Spring semester, 2017 Restricted
Author: Kseniia Parygina	…………………………………… (signature of author)

Programme coordinator: Prof. Terje M. Halmø
Supervisor: Espen Brevik

Title of master's thesis:

Key criteria for successful LNG market development to replace LPG in the Scandinavian market.

Credits: 30

Keywords: - LNG - LPG - Market - Pricing mechanism - Supply Chain - Availability	Number of pages: 78 + supplemental material/other: Stavanger,15/06/2017 date/year

i. Abstract

The main goal of the thesis is to perform the comparative study of LNG and LPG markets and to examine key factors for successful LNG implementation on the Scandinavian market on competition with LPG.

It was found that the main competition between LNG and LPG arises in the energy generation for steel, iron and chemical industries. The price of both fuels is found as the main driver for companies to make a decision on switching from LPG to LNG utilization.

LNG market in Europe is expected to be oversupplied as a result of huge shale gas developments and the current narrow Asian-European price spread. LPG availability will also increase as a portion of still expanding shale gas projects in the U.S., but it will always be disrupted by various factors because LPG is a fraction whether of gas processing plant or refinery. Refining margin is established as one of the main parameters affecting LPG small scale market. At the increasing refining margin trend the price for LPG is observed to fall down. LPG price is found to be very fluctuating compare to LNG price.

Another important parameter such as the advent of new environmental policies will also tighten the competition between both fuels.

ii. Acknowledgements

First and foremost, I would like to express my sincere appreciation and gratitude to my supervisor, Professor Terje Martin Halmø. I'm very grateful for his valuable advices, patience, encouragement during the research and opportunities to be involved in very interesting conversations in a friendly atmosphere on a professional and personal level. I have been an extremely lucky student to have such a great supervisor.

My warmest thanks also go to the company's supervisor, Espen Brevik. I'm very grateful for his continued support, important advises, prompt answers and guidance all along my work. It was a great pleasure to work with you.

I must express my gratitude to Thor Abrahamsen, Jorunn S. Rosvoll, Laurent Viguier and Jan Wahlqvist for your extremely important advises, suggestions and support.

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

LNG - Liquefied Natural Gas

LPG – Liquefied Petroleum Gas

SSLNG – Small Scale Liquefied Natural Gas

SSLPG – Small Scale Liquefied Petroleum Gas

GPP – Gas Processing Plant

GDP – Gross Domestic Product

Bcma – billion cubic meters per annum

MTPA – million tonnes per annum

OECD - Organisation for Economic Co-operation and Development

FID - Final Investment Decision

HH – Henry Hub

KPI – Key Performance Indicator

CAPEX - Capital Expenditure

OPEX - Operating Expenses

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background

1.1.1 Global energy trends

In accordance with EIA International Energy Outlook 2016 [1], the global primary energy consumption will grow by 48% between 2012 and 2040. The main driver of the increasing energy consumption is growing population. It is expected that by 2035 the population will increase by 31,6% from the level of 2017, representing 9725 million people [2]. Economic growth is the next contributor to the energy consumption [3]. Energy demand is mostly driven by non-OECD economies, including China and India as the largest contributors to the increase [4]. Energy sources schemes will continue to diversify due to continuously changing environmental policies and new technologies developments [5].

So, all these factors drive the energy consumption. More energy is required to meet the growing demand.

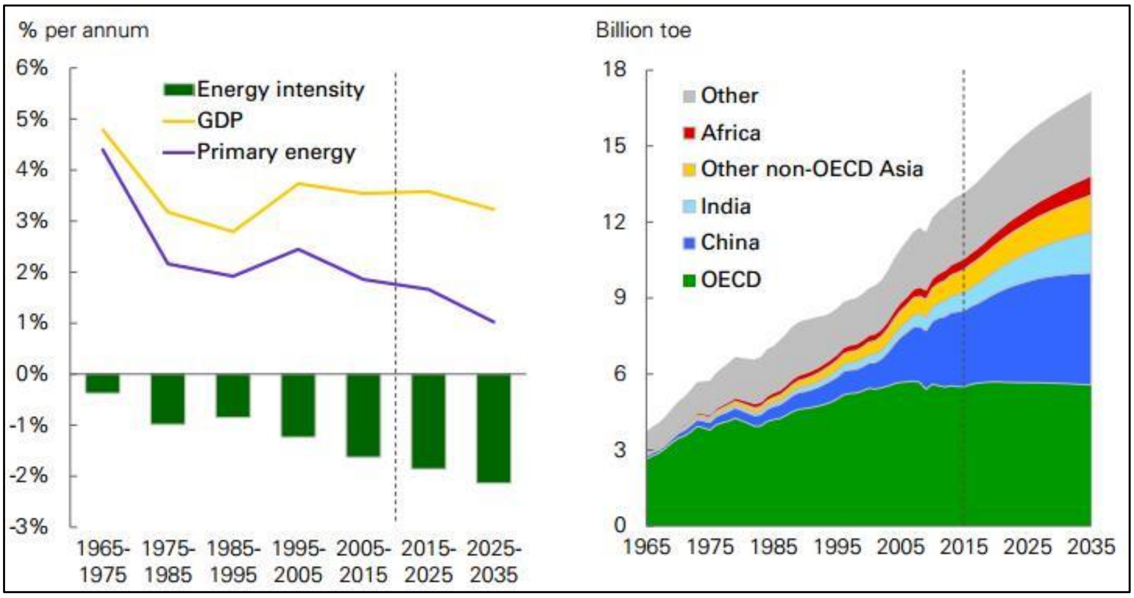

Figure 1-1 Growth in GDP & primary energy and Energy consumption by region [4]

Petroleum and other liquid fuels remain the largest sources of energy. Renewable energy share is going to increase by 2.6% per year and nuclear by 2.3% per year by 2040 [1]. Coal consumption falls down and has the smallest increase in world energy consumption over the next decade. The biggest consumers of coal are China, the U.S. and India which account for more than 70% of the world use. But these countries are on the way to reduce dependence on the harmful coal. With new regulations and the increased shale gas and oil production in the U.S. and China a shift to more clean energy use is predicted [4]. Natural gas has become very successful energy source because of its efficiency and environmental advantages compare to crude oil and coal [6].

1.1.2 *Natural gas in the global energy mix*

The gradual change in the overall energy mix is set to continue with natural gas accounting for the highest increase in world energy consumption over the next decade, Figure 1-2.

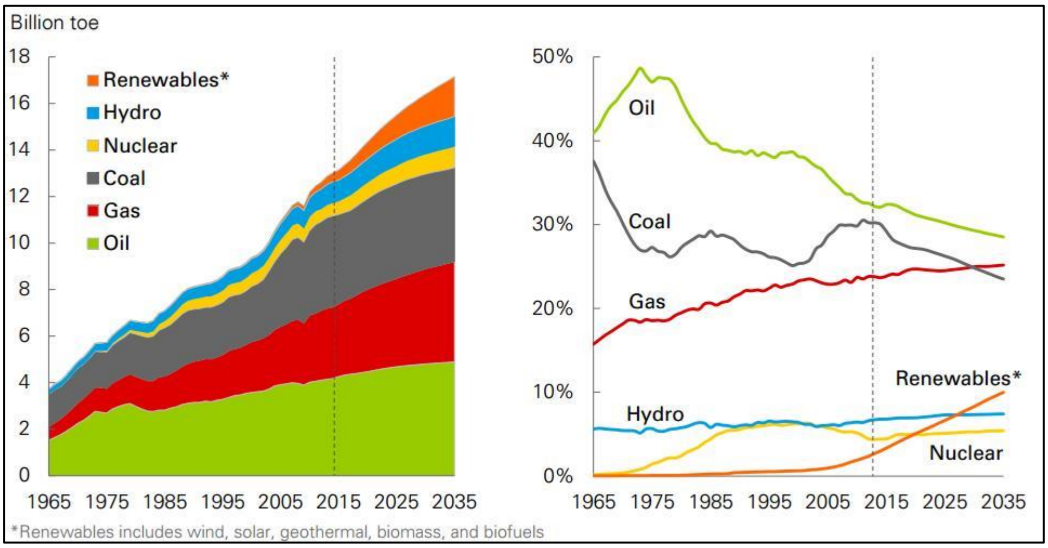

Figure 1-2 Primary energy consumption by fuel and Share of primary energy, BP [4]

In accordance with BP Statistical Review 2016 [3], the natural gas consumption achieved approximately 3468.6 bcma by 2015 where 778 bcma in USA, 391.5 bcma in Russia, 402.1 bcma in Europe, 490.2 bcma in Middle East and 701.1 bcma in Asia Pacific region. According to BP Energy Outlook 2017, by 2035 the gas consumption is projected to reach approximately 4580 bcma [4].

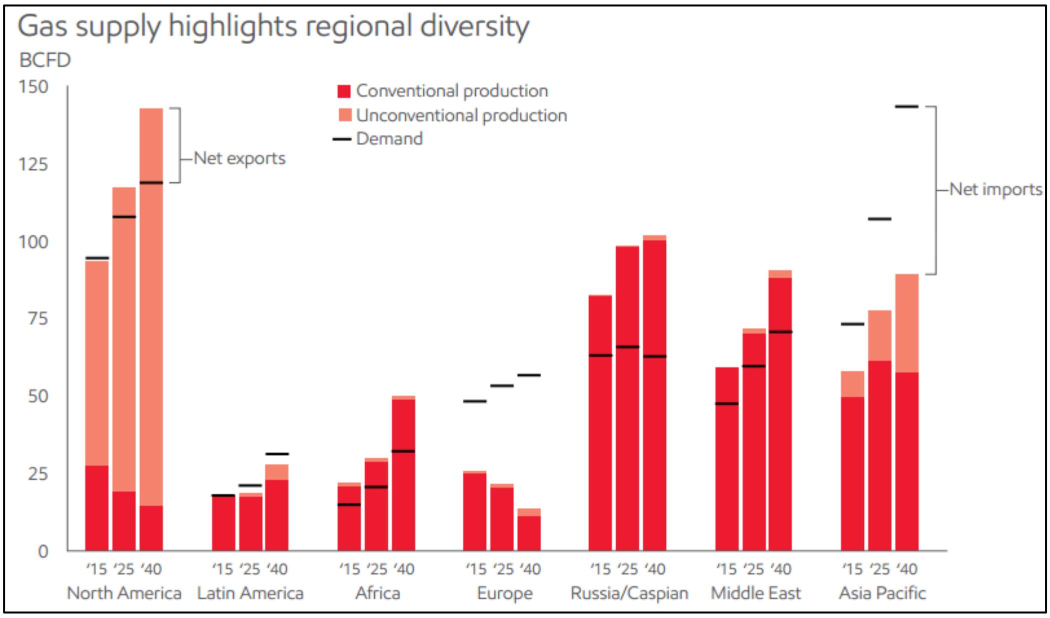

Figure 1-3 Natural Gas Production and Demand by region (1Bcfd ≈ 10bcma), ExxonMobil [5]

The natural gas demanding areas are power, industry and transport. Natural gas is competitive source for electricity and power generation, because of moderate capital cost of plants, fuel efficiency and increasing availability. Moreover, the increasing interest to gas-fired energy generation is driven by world's concern about environmental changes. Many countries introduce new 'green' policies to reduce carbon dioxide emission by substituting coal and liquid fuels.

Natural gas is a mixture of hydrocarbons consisting methane, ethane, propane, butane and some impurities as can be seen on the figure below.

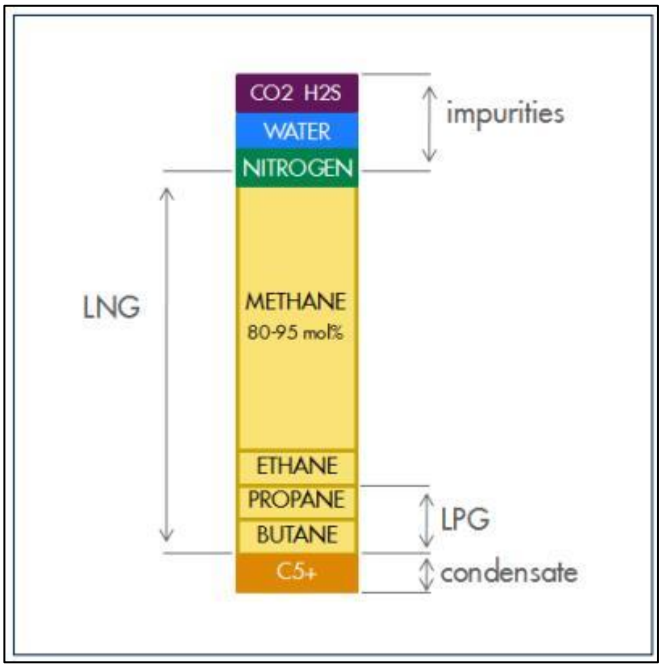

Figure 1-4 Natural gas content, Shell [7]

Low density natural gas transportation was limited by some regions. So, before the development of liquefied natural gas technologies, natural gas have not had a such big international market as it has by 2017 [8]. By 2017, natural gas represents almost a quarter of the world energy demand, and 9.8% of gas consumption is relied on LNG [9].

1.1.3 The role of LNG

The first "experimental" LNG cargo was shipped to UK in 1958, then by 1964 first commercial cargoes were delivered from Algeria to UK and France, and from Libya to Italy and Spain. Europe was looking for flexibility in their supply schemes to decrease dependency on pipeline gas from Algeria [8]. Japan has a special market, it has no own petroleum resources and very depend on import. Firstly, they started to import LNG from the U.S. and Middle East. In order to diversify their supply, the import interest shifted to South Asian countries and Australia [7]. Korea and Taiwan have also increased interest in LNG. So, between 1975 and 1996 Asia-Pacific demand increased on average by 3 bcm from year to year [8]. In 2016 demand of these countries achieved 132 MTPA (approximately 184.8 bcma) which represents a half of the global LNG trade [9].

At the end of 90s U.S. gas production fell significantly and Canadian import could not meet the growing demand so that LNG import became very important for the country mainly from Qatar and Nigeria. Since 2005 the development of shale gas industry in the U.S. has reversed the energy supply schemes, such that huge regasification capacities are being reconstructed to export terminals. Therefore, all volumes intended for the U.S. were redirected to Europe and Asia and caused a new market structure in Europe, continuous energy demand growth in South Asia and new capacities being built in Australia and Oceania.

In accordance with IGU 2017 report [9], the world liquefaction capacity represents 339.7 MTPA (476 bcma) by 2017, while the global regasification capacity by January 2017 accounts for 795 MTPA (1113 bcma). The recent increase in receiving capacity emerged due to new projects in China, India, Japan, France and South Korea [9].

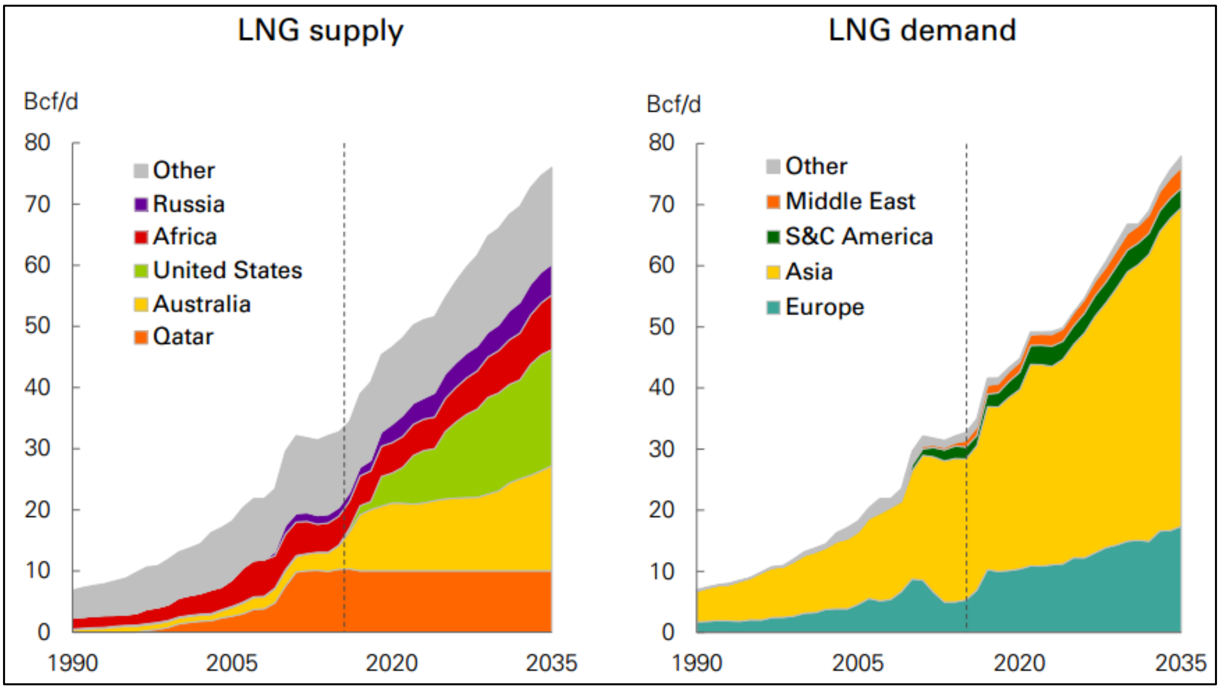

Figure 1-5 LNG supply & demand projection (1Bcfd ≈ 10bcma), BP [4]

1.1.4 Small scale LNG market

In recent years, small scale (SS) LNG became more attractive in a local trade activity. New SS liquefaction capacities are being constructed all over the globe especially in the U.S. and European countries mainly because of the increasing demand in transportation sector. Since a huge number of base-load liquefaction facilities comes online and larger volumes are being shipped, there is a need for small cargoes to provide a flexibility to the market. Such a flexibility can be secured by SSLNG. Moreover, the SS market can provide energy to remote customers or customers who is not connected to a pipeline grid.

However, there are some challenges with the SSLNG, such as security of supply. Since the small scale market just started to gather pace, it has no large competition. Thus, customers are afraid of limited number of supply chains. Moreover, there is a challenge with implementation of regulatory framework and fiscal regime favourable to support high investment decisions [10].

1.1.5 LPG market

Liquefied Petroleum Gas (LPG) is predominantly a mixture of propane and butane, *Figure 1-4*. It’s a side product either of gas processing plant or refinery. The main market for LPG from gas processing plant is petrochemical industry. While refined LPG is mainly sold to residential and industrial sectors. LPG can be in a form of liquid at very low pressure, from 2 to 5 bar that makes it suitable to use in small cylinders. There is a very big bottle market in the U.S., South Europe and Asia.

Global LPG production is growing up with the largest rise in the U.S. to over 66 MTPA in 2016 [11], mostly due to the huge shale oil and gas developments led by new hydraulic fracturing and horizontal drilling technologies [12]. With the improvements of the technology the shale production becomes more economically efficient and encourages the shale developments in other regions such as Canada, China, Europe, Asia and Australia [12]. As can be observed from the *Figure 1-6* the production from shale gas reservoirs will continue to increase [13], that will further increase LPG production.

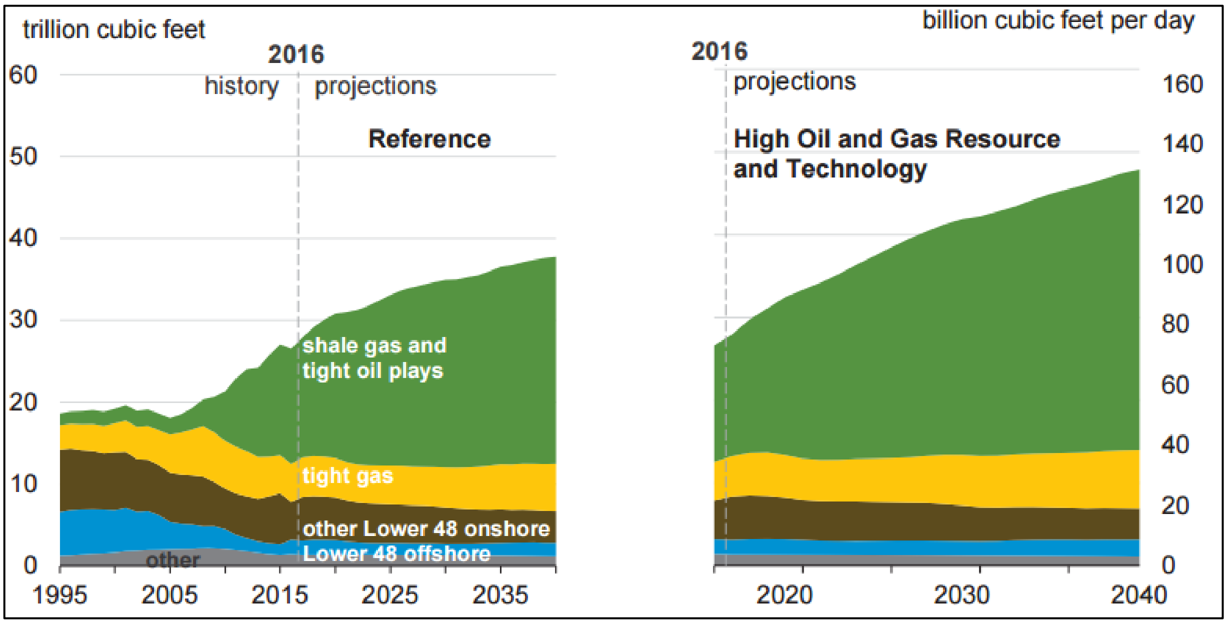

Figure 1-6 Dry natural gas production by type, (1Bcfd ≈ 10bcma), EIA [13]

As U.S. LPG production increased, the export volumes spiked up from 4.17 to 28.94 MTPA by 2016 mainly to Asia [11].

Approximately 47% of the LPG consumption in Europe is LPG produced by GPP, while about 53% of consumed LPG comes from refineries [14].

LPG coming from gas processing plants addresses the large scale market as it sells LPG in very large cargoes mostly to petrochemical industry and to some extend to large LPG distribution companies. In Europe, the main sources of LPG on the large scale are Kaarstoe gas processing plant in Norway, Teeside plant and SAGE St Fergus plant in UK etc. The production from gas processing plants in the region accounts approximately for 10 MTPA by 2008[1] [15].

[1] The value is assumed to be true for the 2016 year, if take into account the fact that there were no large developments in gas processing infrastructure.

As for refineries, they produce LPG in smaller volumes compare to gas processing plants. The quality of refined LPG is not favourable by petrochemicals as it is slightly cracked product. So, this LPG is mainly sold to residential sector and to industries for energy generation.

European refineries suffer challenging time, due to overcapacity. Total, Shell, BP, and ENI are all planning to close or reduce capacities of their facilities. The level of complexity of these plants cannot withstand to more sophisticated refineries from Asian and Middle East countries. Companies invest to improve the refineries complexity to meet increasing demand for light and middle distillates. If the trend for complex refineries is going to continue the EU market will mostly be middle distillate market.

1.2 Literature overview

In the process of doing the comparative study on LNG and LPG markets, a literature study was performed to get inside of both competing fuels sectors and to identify tools for the analysis. The literature review was continuously carried out throughout the whole time of the thesis since there are always some new changes and findings arising on the markets.

As for current trends on the global energy market. Exxon Mobil [16] and BP [4] issue the World Energy Outlooks on the yearly basis. Both agree that the world energy demand grows, where oil, gas and coal are the base of the energy mix. Gas will grow more quickly and it will further increase as portion of the primary energy mix both in actual numbers and in percentage while oil demand will increase in numbers but not in the energy share.

As for LNG. Many reports were read to get the picture of the LNG market globally, and up-to-date information on the current trends. In order to understand the gas/LNG market structure, latest International Gas Union [9], International Energy Agency [17], Gas Strategies [18] etc. Outlooks were investigated. To get the gas/LNG price indexes, shipping costs overview, the ICIS database was used. In accordance with many studies, the LNG market is expected to grow in volumes that will facilitate the changes in price mechanisms. IGU [19] report on gas price says that gas-on-gas competition continuously increasing its share in Europe and due to US LNG and the current surplus the more changes in pricing mechanisms may come in the nearest future. The same opinion is described by Stern, J., in "*International gas pricing in Europe and Asia"* article [20], where it's outlined that the more advanced hub based trade based takes place in Europe while in Asia the switch to the hub trades could require a decade to complete.

As for LPG. There are not many open sources that could get inside the global and European market, but those that were available as for example, DooHo, C. in his article on "*The effect of shale gas revolution on oil industry"* [21], says that with the shale developments in the U.S.A. the production of LPG is increasingly boosted. Also, he writes that the production is expected to increase that will bring the downward pressure on the global prices. As the dominant volumes of LPG come from U.S., the Energy Information Administration reports and articles were examined to estimate the future development of the market. U.S. EIA [22] expects the U.S. LPG production to increase, facilitated by rapid development of the export capacity that will change the global trade picture. To understand the current situation on the market as well as the price development picture, the Argus and Platts services reports were used.

As for the comparison of both markets. Not many studies on the LNG and LPG markets comparison were found, but there are some researches on the prices modelling. There are many hypotheses on prediction of gas prices, some of the articles prove that the price is correlated with oil price dynamics and weather conditions as in the article written by Jan Muller, G.H., Alfred Muller [23], others as Mu, X. [24], has empirical results revealed on significance of the weather changes and storage levels. In the master's thesis on LPG pricing in NWE [25] it was found that the price is correlated with Brent and naphtha price dynamics. Some researches tried to find the relationship between main commodities as oil & gas and LPG price in the U.S. In the work done by Mishra, D.A.K [26], it was found that there is a causality runs from propane return to crude return and from heating oil return to propane return. In another article written by Petter Osmundsen et al. [27], authors outlined that the strong LPG & oil relationship has eroded due to the shale gas boom in the U.S. which facilitated great increase in NGLs production.

1.3 Research goals and questions

The main goal of the thesis is to find key criteria affecting the competing fuels markets development.

To fulfil the purposes, the following research questions are being addressed:

- How markets are presented in Europe/Scandinavia?
- What is the difference between markets?
- What are the parameters influencing both markets?
- What is the point of collision of interest for LNG and LPG markets?
- What are the incentives and constrains for converting to LNG?
- Comparison study of LNG and LPG markets based on established parameters and highlighting the most contributing to the balance between them.

2 ENERGY OUTLOOK

2.1 European energy outlook

The EU import accounts for around 53% of the total energy consumption in the region.

In OECD Europe, consumption of liquid fuels remains stable, largely as a result of improvements in energy efficiency, high taxes on motor fuels, good developed transportation system and slow population growth. The natural gas consumption in OECD Europe growing up from year to year, 1.3% on average [1]. Gas accounts for 23% of the EU primary energy consumption. 15% of the gas is consumed by electricity generation companies and almost a third by residential and industrial sectors. The share of natural gas in power generation segment will increase further mostly because of nuclear and coal-fired units decommissioning and new alternative fuels policies implementation.

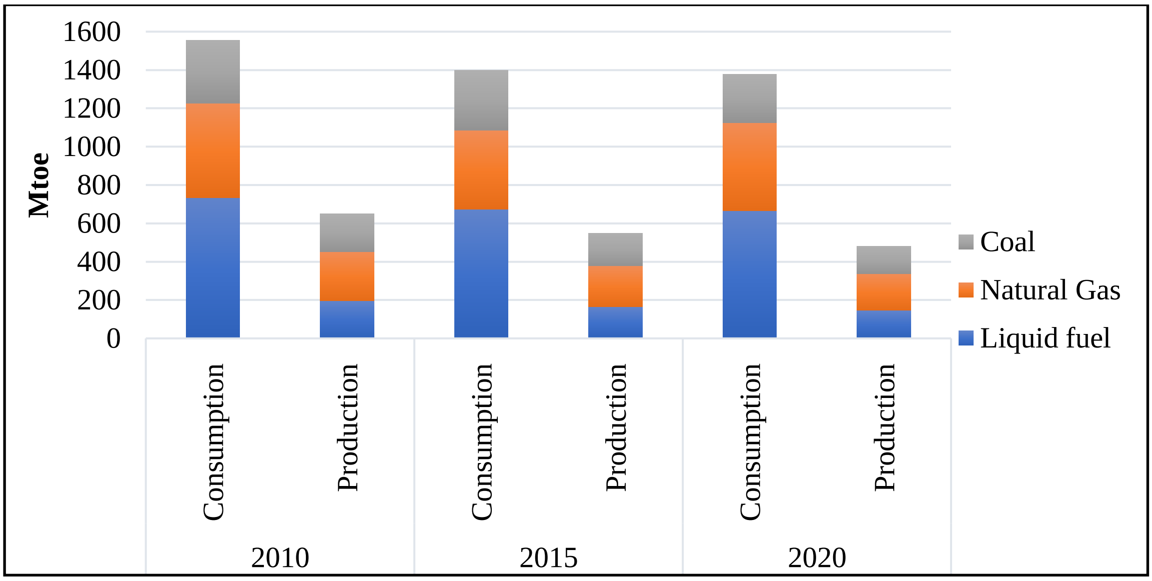

Figure 2-1 Energy consumption & production by fuel type in Europe, Eurostat

The transportation sector accounts for ¾ of the European oil products consumption. Today the situation is different: consumption of oil products is falling down due to improvements in fuels efficiency in maritime sector and high taxes.

European industrial energy consumption grows only by 0.2% per year [1]. Electricity has the highest share of the energy mix used by the sector. With environmental and energy policies targeted at energy security, diversity in supply chains, energy efficiency and decarbonization, the industrial energy offtake is expected to slow further. The trend for decrease in petroleum liquids use in the power generation sector is being foreseen. It may give a room for increase in gas consumption.

2.2 Policy drivers

Europe has agreed new policies on 2030 energy framework. The targets for 2030 are the following:

- 40% reduction in greenhouse gas emissions,
- increase in energy efficiency by 30%,
- increase in electricity interconnection by 15% compared to the level of 1990 [28].

The fuels emission reduction and improvement of energy efficiency can be achieved by switching to LNG which meets the requirement of the International Maritime Organisation (IMO) and regional air quality regulations. LNG has a potential to provide diversification of transport fuels, increase in energy effectiveness and decarbonisation in Europe.

More than 60% of total petroleum products consumption is used for transport purposes. The implementation of LNG can significantly reduce the environmental impact of shipping operations. Firstly, it considerably reduces GHG emissions due to its lower carbon content. For example, use of LNG will reduce GHG emission by 20% compare to Heavy Fuel Oil (HFO).

Secondly, it considerably reduces the SOx and NOx emissions. It produces lower nitrogen oxide emissions up to 85%, almost no visible sulfur and 95% lower particle emissions [29]. In 2015, the IMO introduced new regulation to reduce SOx to 0.1%. As has been reported by AGA, approximately 300,000 vessels pass annually the Baltic Sea which means that strict regulations will largely reduce the carbon and sulphur emissions.

In addition to the above, due to geopolitical challenges of robust fossil fuels supplies, the EU has created the energy securing strategy which is aimed at diversification of the EU’s gas supply. So, in the EU strategy on 16th of February 2016, Europe relies on potential of LNG and gas storage as a key Energy Union providers of a security and resilience. LNG may bring the access to cleaner energy for lock-in areas and competitiveness from international suppliers [30].

As for LPG, it is not an alternative fuel and it’s not allowed to be used in marine engines since it has an explosion risks Chapter 5.1.1.

3 MARKET PRESENCE IN NORTH WESTERN EUROPE

3.1 LNG market

3.1.1 Gas in Europe – pipeline & LNG supply

The European gas market is on the way of undergoing changes. The European Union has approved the development of diversified natural gas supply strategy to reduce the dependency on one type of energy sourcing. The gas in Europe is mainly transported by pipelines, 80-85 % and only 15-20% in the form of LNG, but the percentage of LNG cargoes in Europe is increasing.

Table 3-1 Pipeline flows in Europe, bcma in 2016, BP [3]

	Russia	Norway	Netherlands	Other European countries	Algeria	United Kingdom	Libya
Pipeline	159.8	109.5	40.6	35.7	20.7	13.4	6.5
Total	386.2						

As we see from the table above, still the main suppliers of gas to Europe are Russia and Norway, representing 35% and 24.7%, respectively. The pipeline transportation is an expensive choice of gas delivery. Pipeline infrastructure takes some years to be commissioned [31], as all governments need to agree about transit routes and fees [31], which makes LNG more flexible and attractive mode of transportation [7].

In terms of LNG the main suppliers are Qatar around 56%, Algeria and Nigeria [32].

Table 3-2 LNG flows into Europe, bcma in 2016, BP [3]

	Qatar	Algeria	Nigeria	Norway	Trinidad & Tobago	Peru	Other European countries	US	Oman
LNG	27.8	13.1	7.6	3.1	1.8	1.2	0.2	0.1	0.1
Total	55								

As a result of low LNG prices the import of LNG to Europe increased in 2015 by 15.9% [3] mostly from Qatar and Nigeria. More sourcing facilities are coming on stream particularly from Australia but these volumes are unlikely to reach Europe. Most likely volumes could come from the U.S. due to their huge developments in shale gas, but it will take some time to influence the European market, more details in Chapters 4.1.3.2 and 4.4. According to EIA statistics, for 2016, LNG send out volumes from the U.S. to Europe accounted only for 1.25 bcma. The largest exporter of LNG is Qatar which has lifted moratorium to increase gas production and may produce additional 20 bcma [33]. Qatar is very flexible supplier, it has huge gas resources with low production costs so these volumes can be easily diverted to different places as it happened in 2011 due to Fukushima disaster[17]. Some cargoes are expected to come from Russia which is on the way to increase their presence in the LNG trading world. The 16.5 MTPA (≈ 23.1 bcma) Yamal project is announced to be commissioned in the late 2017 [34]. All LNG volumes have been already sold to Europe and Asia. These cargoes are going to pass Zeebrugge and Dunkirk terminals in Europe for reload during their winter season pathway [35].

3.1.2 Current LNG infrastructure in NW Europe

Regasification facilities.

As a result of low LNG prices and the less reloads at Europe's LNG terminal in Spain the import of LNG in Europe increased in 2015. Higher offtakes were observed in UK, Italy and to some extent in Spain and Belgium [36].

The utilization level in Europe still remains low, approximately 25% [17], so Europe doesn't require investments in new large regasification facilities. As can be seen in the table below, by 2017 only 1 regasification terminals in France are under construction. The slightly increased interest is observed to small scale facilities, 4 out of 6 plants are being built in Europe, particularly in the Nordic region.

Table 3-3 Regasification facilities in Europe,2017, GIE [37]

	Operational	Under Construction	Planned
Large-scale	25	0	23
FSRUs and others	2	0	11
Small-scale	4	4	4
Total	***30***	***4***	***27***
Total capacity, bcma	***224***	***29***	***161***

The map of the LNG regasification capacity in Europe can be observed on the figure below, the detailed information on volumes of the import terminals can be found in the Appendix 1. Europe is set to take a glut of world LNG volumes.

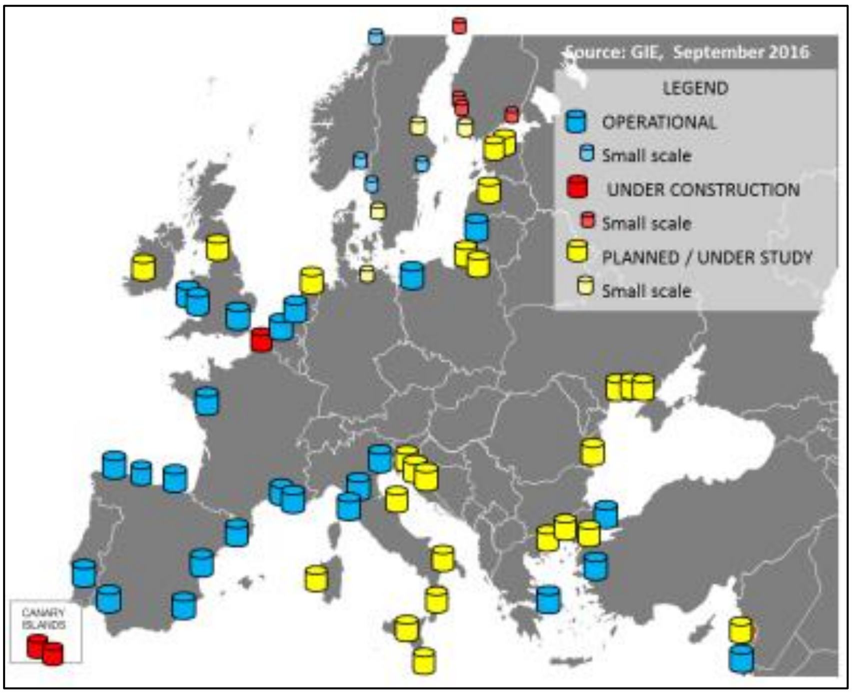

Figure 3-1 LNG import terminal in Europe, GIE [37]

Most of the LNG import facilities in Europe were built as a traditional import terminals where the main purpose was LNG regasification and transportation to a gas network grid. Because of the redirection of huge Qatar LNG volumes in 2008 – 2009 European market became oversupplied and import terminals started to look for new demand in the region by establishment of small scale services such as:

- ship reloading;
- transhipment;
- bunkering;
- truck loading.

At that time EU Commission introduced Third Party Access (TPA) to the transmission infrastructure and reduced threshold for customers to become an “eligible” buyer, Chapter 4.1.3 and this availed even smaller consumers to buy spot volumes at lower prices [7].

Due to higher availability of large scale regasification terminals in the EU there is a great potential for further development of small scale market.

Liquefaction facilities.

Liquefaction capacities in Europe are not likely to expand over the next 5 years due to oversupplied market and consequently low prices which don’t give signals for high CAPEX facilities to be build [38]. New liquefaction projects all over the world have one important feature, they are built to operate base load mostly due to their huge upfront investments and low OPEX. So, these facilities tend to operate at full capacity to reimburse faster their CAPEX. Almost all liquefaction plants sell their LNG to future customers before the construction process is being started. The unit costs for liquefaction facilities has been increased by average 30-50% from the level of 2000-2008 and became $987/tonne in the 2008-2016 period [38]. The most expensive parts of the project are construction, bulk materials and equipment costs. These costs became even higher last decade due to raised competition for engineering, procurement and construction (ECD) services as many projects started up simultaneously [38]. So, later facilities like those in Australia have had higher CAPEX per annual tonne capacity.

There is only one large scale liquefaction plant in Europe which is placed in the Northern Norway, Melkøya with the annual capacity of 4.2 mt. But there is a project on building LNG export terminal in Russia, Baltic LNG with the capacity of 10 MTPA (FID) which serves the possibility to be expanded up to 15 MTPA [39]. In addition to it there is a few number of small-scale liquefaction facilities which are mostly placed in the Nordic countries.

Table 3-4 NWE LNG export terminals, GIE

Country	Terminal	Company	Service	Capacity, tons/year	Year
Norway	Melkøya	Statoil	truck loading 125,000 cm storage	4200,000	2007
Norway	Risavika (Stavanger)	Skangass	reloading, ship loading, 30,000 cm storage	300,000	2011
Norway	Snurrevarden (Karmøy)	Gasnor	reloading, ship + truck loading	21,000	2004
Norway	Kollsnes LNG I	Gasnor	reloading, ship + truck loading	40,000	2003
Norway	Kollsnes LNG II	Gasnor	reloading, ship + truck loading	80,000	2007
Finland	Porvoo LNG satelite	Skangass	truck loading, 2,100 cm storage	20,000	2010

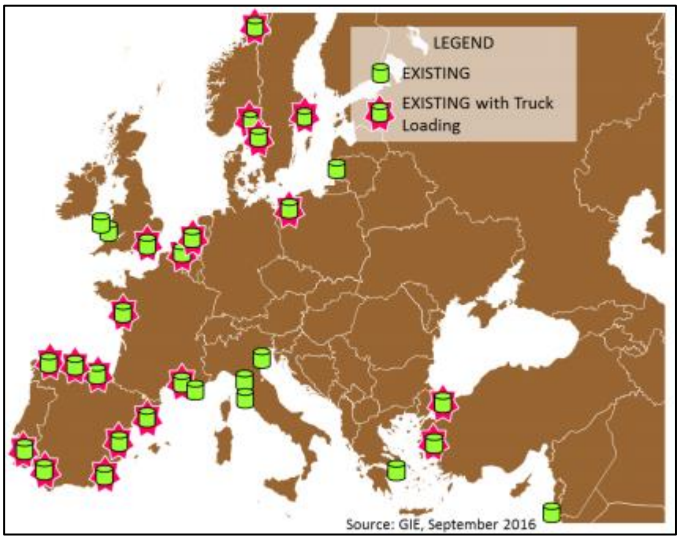

Figure 3-2 LNG terminal offering truck loading service in Europe
**The truck loading at Klaipeda LNG will start in August 2017, GIE*

The Baltic region was strongly dependant on Russian pipeline gas but now it started to be more diversified due to Klaipeda project and Poland import terminal Swinoujscie. But there is a problem with interconnections, still the importing LNG cannot reach neighbouring states. Baltic countries like Estonia and Lietuva are looking for the financial support from EU for the infrastructure development. But there is a progress in the diversification, such as Gas Interconnector Poland – Lithuania project which is going to start in 2019 [40].

3.1.3 Flexibility of the market

Contractual flexibility.

It is always a question, to what extend supply has its destination flexibility.

Traditionally long-term contracts (15-20 years) had take-or-pay clause. The flexibility provided by such contract is that a buyer has a right to take the agreed variety of volumes but if buyer doesn't take these volumes then he is to pay a certain price. In return for that flexibility customers have to agree for a destination clause, restricting the following distribution (reselling) of LNG to the global market that prevents the development of fully flexible market. Also customers may get a reduction of energy cost for approximately 33% [7].

Most of the buyers look for flexible contracts. The average period of the current contracts is about 2-5 years, Espen Brevik, Skangas (Personal communication, December 23, 2016). The most flexible trades can be achieved by contracting LNG based on free on board (FOB) terms meaning that the cargo ownership transfer occurs at the port of loading, so that buyers can divert cargoes from the original destination to a more attractive market.

But Europe has found a way to overcome the bound of contractual constrains. The contractual constrains were greatly achieved by LNG reloading.

Reloading.

Only some of European terminals offers reloading operations. Such countries as Spain, Belgium and France were successful at exporting the reloaded gas to the high-priced markets. Along with the main reloading players, Lithuania has started its reloading operations. On 2d of

January it loaded the Coral Energy, 15,000 cm LNG carrier for Skangas from the FSRU Independence [41].

Recently arbitrage attractiveness of the Asian market as a destination of the traditionally reloaded volumes from Europe disappeared. There were no reloads in March for the first time since the early 2010s. Today the reloading activity can take its position in the small scale market and be a tool of flexibility by providing the opportunity to reload gas to smaller vessels and be a part of the small-scale business.

Table 3-5 NWE LNG terminals offering reloading

Country	Terminal	Reloading capacity, mcm/h
Netherlands	Gate, Rotterdam	10
Belgium	Zeebrugge	4-5
UK	Isle of Grain	Ship - dependant
Lithuania	FSRU	0.09

Storage as a tool of flexibility.

EU's gas storage suppliers traditionally provide seasonal and load fluctuations. The gas storage infrastructure is very important tool to provide flexibility and security of gas market. It responds local shocks in supply: seasonal variations and daily supply fluctuations. For the 2015 year Europe accounts for 108 bcm of working gas volume (WGV) [38] which is 27% of global underground storage. The main owners of storage facilities in Europe are Germany, Netherlands, France, Austria and UK.

The gas storage flexibility for North West Europe is influenced by the outage of the Rough storage site in the UK, which stopped the injection in June 2016. The development of Rough storage facility has two major impacts on the EU gas market such as

- an increase interest to Norwegian gas;
- interest to gas supply via Interconnector UK (Belgium – UK) or via BBL (the Netherlands – UK) [38],

Traditionally the gas balance in Europe relied on Norwegian and Russian pipeline gas but the future gas sourcing is not obvious yet as either pipeline or LNG import could principally replace the declining domestic production of Groningen field, which is now (by 2017) at the half of its 2013 level, producing 24 bcma [38]. The Dutch government has placed a production cap on the Groningen field because further high rate production could lead to seismic activity in the area. But except Netherlands, Norway and Russia will not be able to provide Europe with additional L-gas volumes during cold winter. So, the additional storage facilities will play an important role for delivering peak-level quantities. In the future especially starting from 2020 the L-gas export will start to decline as L-gas market will be converted to H-gas.

The storage capacities were booked by long-term shipper's contracts but now they tend to have only short-term contracts since there is no substantial difference between summer and winter gas prices, and the injection & withdrawal costs are strong, thus shippers don't earn expected margin [38]. Moreover, shippers have a possibility to keep its volumes for some time and put them on the grid only when the price shows good signal to do so, which may have negative impact on storage volumes and vessels availability, (Personal communication, Skangas).

Small scale LNG.

With locally developed small scale infrastructure, LNG could potentially become the way to balance the market, as it takes 3-5 days to get the ship at the destination point (based on own assessment in NWE). SSLNG is a cheap way to distribute gas to areas where there is no local gas pipeline grid infrastructure. It can support a fluctuating consumption and be a valuable tool to meet the short-term upswing demand which can't be provided by base load. The main challenge is only about the development of an efficient and competitive supply chain.

3.1.4 LNG pricing

The increasing LNG volumes to Europe have changed the pricing structure. Higher import has contributed to transformation away from oil indexation to gas-on-gas indexation. Gas pricing based on oil-indexed contracts seems to follow the oil prices while spot deals reflect a supply/demand picture on market.

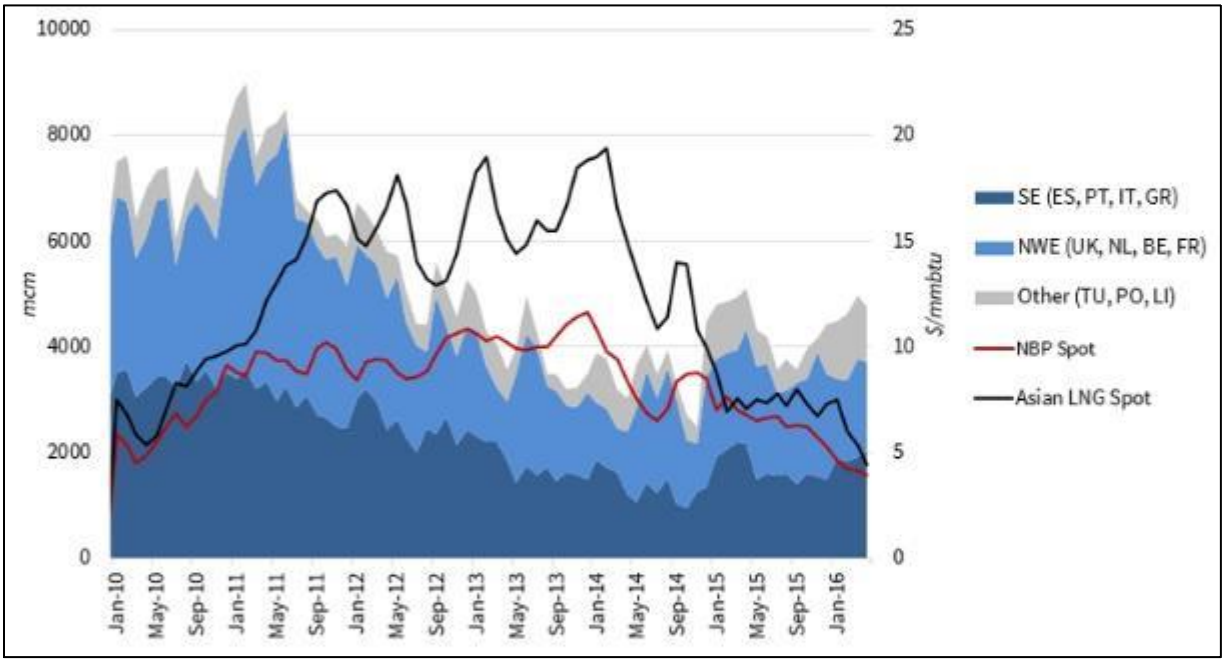

Figure 3-3 LNG price development, Timera Energy

Before diversification of the EU gas market, Russian oil-linked contracts with take-or-pay obligations played predominant role in the pricing mechanism.

Now LNG price on large scale market is currently the same as on the European gas hub which allows LNG to compete with traditional pipeline gas from Russia and Norway. It's expected that EU buyers may reduce TOP contracts and will rather take LNG.

Small scale pricing is the same as large scale LNG price plus a cost of SS supply chain. LNG becomes more competitive choice of energy transportation since sea and to some extend road are cheapest elements in the supply value chain which gives a competition to pipeline transportation choice.

3.2 LPG market

3.2.1 LPG production

LPG has two origins, around 60% of the world LPG is recovered during a natural gas processing and the rest 40% is produced during refining of crude oil.

3.2.1.1 LPG from a natural gas processing plant

The well stream natural gas commonly is a mixture of hydrocarbons such as methane, ethane, propane, butane, condensates and impurities like water, hydrogen sulphide, carbon dioxide, mercury etc. In order to meet specifications, the gas is to be conditioned. The gas conditioning process consists one or several separation processes [7] as are the following:

- Physical separation (removal of sand and solid);
- Mechanical separation (separation of liquid from vapours by various physical barriers; absorption, adsorption and distillation processes).

Associated hydrocarbons, known as natural gas liquids, NGLs are to be also separated in accordance with the specifications for gas in the customer's country. These components such as ethane, propane and butane are independently sold to a market. Cryogenic processing and absorption are the methods of methane separation from NGLs. The turbo-expander is the most effective method of cryogenic process, where the refrigerant lowers the gas steam temperature that enables the NGLs to condensate. The adsorption process implies the use of oil that soaks up the NGLs while gas passes through an absorption tower. The next step of the NGL's processing is the fractionation where the propane, butane, ethane separation takes place. The final stage is the propane and butane treatment. The sulphur and water can be removed by Merox, Sulfrex processes and by adsorption on molecular sieves correspondingly [7].

Unprocessed gas contains around 5-10% of NGLs, and LPG represents a significant portion of the liquid components.

3.2.1.2 LPG from a refinery

Oil refinery is an industrial process plant where crude oil is processed into different products such as light and middle distillates, heavy distillates and residues. Each refinery has an unique configuration [42], which determines its complexity.

There are numerous processes that take place at a refinery, modern refineries may have up to 15 processes [42]. The main stage is the distillation process which is aimed at separation of crude oil into numerous fractions. The products are separated according to boiling points. Distillation column takes out various fractions at different boiling points with the highest boiling components being taking out near the bottom and lightest near the top.

Lighter components, such as gases CH_4, C_2H_6, LPG are recovered at lower temperatures [43]. The next evaporation fractions - light distillates such as gasoline & naphtha and middle distillates such as jet fuel, kerosene and diesel are taking out. At temperatures above 300 °C the heaviest components as residuals are boiled off.

Configuration plays the key role in the yield output of a refinery. There are four main refining configurations, such as topping, hydroskimming, conversion and deep conversion. The simplest refinery has only the distillation unit, for example topping refinery. It simply converts crude oil into light gas, gasoline, naphtha, middle distillates and fuel oil.

Hydroskimming refinery is more advanced type, in addition to the distillation unit it has a catalytic reforming, hydrotreating and product blending units. Catalytic reforming is aimed at naphtha upgrading (increasing its octane number). The main output of this process is the high-octane gasoline blendstock, moreover it produces hydrogen which is further used for diesel production. Then, the hydrotreating process takes place where sulfur, nitrogen and heavy metals are removed. The final stage is the products blending to meet customer's requirement on octane number, sulphur content, boiling point etc [44].

But in order to get the greater value from processing of crude, refineries all over the world started to increase their complexity by introducing cracking units (conversion refineries) [42], for example fluidized catalytic cracking (FCC). Cracking process destroys the long, high-boiling components into smaller once which after further processing can be used for gasoline and other high-value products blending [42]. The cracking of crude oil was originally done by thermal cracking but it was replaced by FCC which produces much large volumes of high octane gasoline [45].

FCC is aimed at production of cracker naphtha for gasoline blending by cracking vacuum gasoil or atmospheric residue, *Figure 3-4*. The process results in high yield of propane/butane and propene/butene as by-products [46]. It is also possible to use specific additives to on-purpose gain even more LPG-components (and olefinic products) than with use of FCC-catalyst only. Many refineries with the FCC unit also have either alkylation or polymerization units downstream of the FCC [46]. Alkylation implies the reaction of light olefins, mainly C_4 and some C_3, with isobutene to produce alkylate. Polymerizing process means polymerization of 2,3 olefins to produce polygasoline. Both alkylate and polygasoline are gasoline blendstocks [46].

The only problem with conversion refineries is the low H/C ratio of refined products which facilitates coke formations. In order to avoid it, the refinery should have an external hydrogen supply or have to continuously remove the coke.

Deep conversion refineries are advanced conversion refineries with the cocking unit. The cocking element is aimed at conversion of vacuum residue or residue into low molecular weight hydrocarbon gases, naphtha, light & heavy gas oils and petroleum coke [42].

Therefore, with more advanced cracking the refinery produces more valuable products out of crude oil and thus gets higher margin.

LPG is a by-product of refinery representing only 3-5% of the overall yield. LPG share in the total output depends on the particular production plan set by a refinery, as such at higher light (gasoline)/middle distillate production, the higher volumes of LPG are extracted.

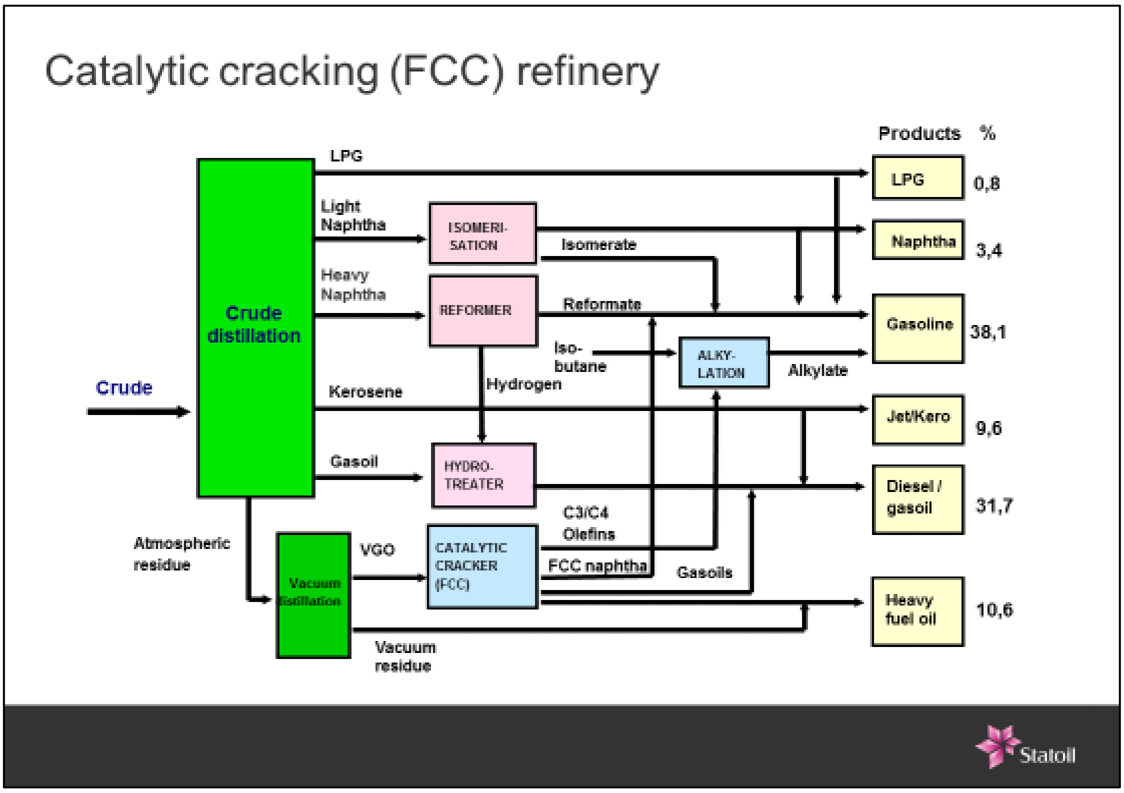

Figure 3-4 Catalytic cracking refinery, Statoil

3.2.2 Main suppliers

The current LPG world production is around 292 million tons per annum, 2015, while global consumption represents only 284 million tons per annum [47], so there is 8 MTPA oversupply on the market. The main supplier of LPG in the world is the U.S. which spiked their export volumes up to 29 MTPA in 2016 due to their shale gas developments. These volumes were directed mainly to Asia [48].

U.S. LPG export to Europe accounts for 2.93 MTPA in 2015 (until August) which represents 10% of the domestic demand. These volumes compete with traditional sources from Russia, North Africa and the Middle East [22]. In 2016, U.S. export to Europe rose by 68% compare to the previous year.

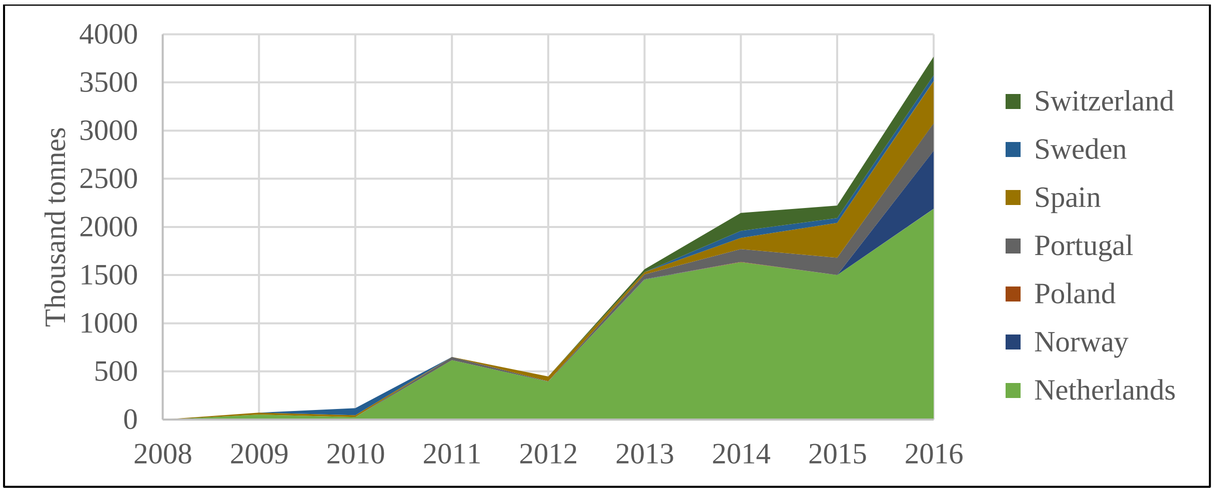

Figure 3-5 U.S. LPG export to Europe [1]

The largest exporters of LPG in Europe are gas processing plants in Norway and UK [49].

Table 3-6 Gas processing plants sourcing LPG

Country	Gas processing plant	NGL capacity, million/day
Norway	Karstoe	10
	Kollsnes	
	Nyhamn	
UK	SAGE St Fergus	2
	Teeside	

The highest LPG consumption in Europe occurs in the petrochemical area. According to Eurostat statistics, 45.4% of total consumption refers to petrochemical industry, 19.3% to transportation and 18.4% to residential & industrial use. With the development of petrochemical industry, LPG draws more attention as a basic raw material for chemical industry. In chemical production, LPG can be converted into light olefins such as ethylene, propylene, butylene, butadiene, etc. and aromatics by steam cracking. Then aromatics and light olefins are used to produce synthetic plastic, rubber, fibre and to produce pharmaceuticals, explosives, etc.

Gas processing plant sells LPG in very large volumes and exclusively to petrochemical industry and to some extend to large LPG distribution companies. For example, Statoil sells LPG to Turkish company which resells it to their large domestic bottle market.

Before 2009 only Teeside terminal in UK was able to load small and large cargoes of LPG. Since 2009 there were problems with storage facilities, so now Teeside loads only small scale vessels (Personal communication, T. Abrahamsen, March, 7, 2017). Only a few ports in North western Europe are able to reload large cargoes of LPG to small vessels, some of them are Stenungsund and Karlshamn in Sweden and Terneuzen in Netherlands.

Thus, LPG from gas processing plant represents the large scale market.

Since refineries are not able to produce the volumes required by petrochemical industry and actually refineries produce slightly cracked LPG which is not favourable by petrochemicals, only straight run LPG from a distillation tower can be applicable. Therefore, refineries are the source of small scale LPG market.

Smaller producers of LPG in Europe are refineries across the EU or EU-neighbours such as Algeria.

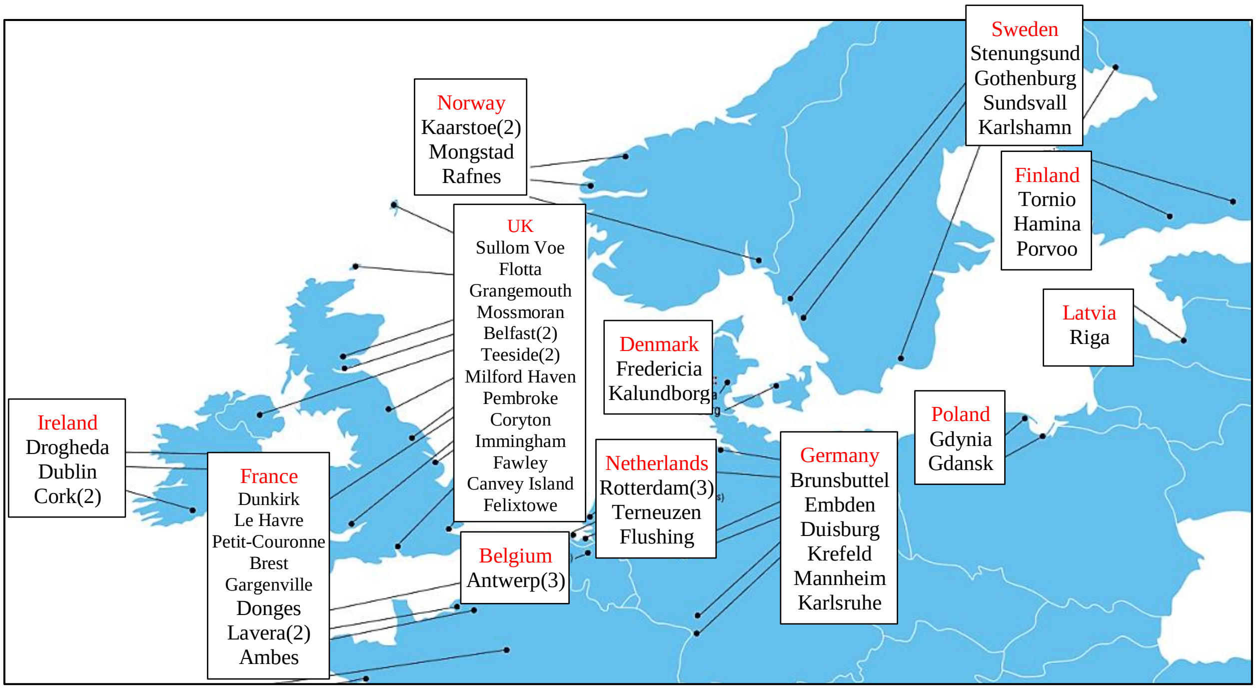

Figure 3-6 Key European LPG import & export terminals, Argus (value means number of terminals)

European refineries suffer difficult time last 1,5 years, low refining margins, underutilization of capacities and switching of ownerships [50]. The most likely refineries which might be closed are less complex refineries especially it concerns the coastal plants, because it exposes to higher competition from other import volumes from Asian and Middle East, while complex refineries and refineries placed inland are more stable and could withstand ongoing challenges [50]. Companies invest to improve the refineries complexity to meet challenges related to the decreasing North Sea production since now refineries are to be able to process different types of crude [50]. If the trend for complex refineries is going to continue the EU market will mostly be middle distillate market.

LPG market is not that flexible as LNG market, because the volumes on the market depend on the other products demand. Moreover, the LPG market cannot be well balanced as there are only few facilities that can reload large scale cargoes to smaller.

3.2.3 LPG pricing in North-West Europe

There are many indexes which are used in LPG pricing. In the thesis Argus and Platts providers of price and analysis services are used to examine the price picture. As has been notices during the research, all indexes are different as they are related to different markets and price mechanisms.

The Argus CIF ARA[2] Large provides propane and butane price data for cargoes moving into and out of northwest Europe. The prices represent the dominant market prices as the LPG cargoes traded based on it are large cargoes up to 85,000 mt. A such big volumes of LPG can only

[2] ARA - Amsterdam, Rotterdam, Antwerp region.

be taken from gas processing plants, and usually are traded as a feedstock to petrochemical facilities for plastics production in competition with naphtha.

There is a level of LPG price which is between 80-90% of naphtha price when petrochemical industry starts actively buy LPG, taking low cost advantage of latter [49]. The LPG price gets close to a certain level and then starts to go up again as demand increases. The switching price level depends on the prices of their produced products.

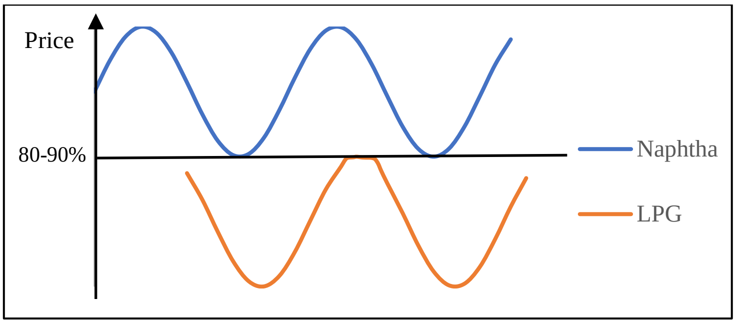

Figure 3-7 LPG & Naphtha price relationship. By March 2017 LPG price was 87% of Naphtha price

Thus, LPG price for the large scale is related to naphtha variation. Since December 2014 until November 2016 LPG price was low due to very large LPG production in the world. The price has periodically fallen even to the natural gas level. Since December 2016, the price recovering process has been seeing, but still propane is approximately 377 USD/ton representing 78% of the naphtha price. So, it's expected that in the next 5-6 months LPG price will reach around 410 USD/ton.

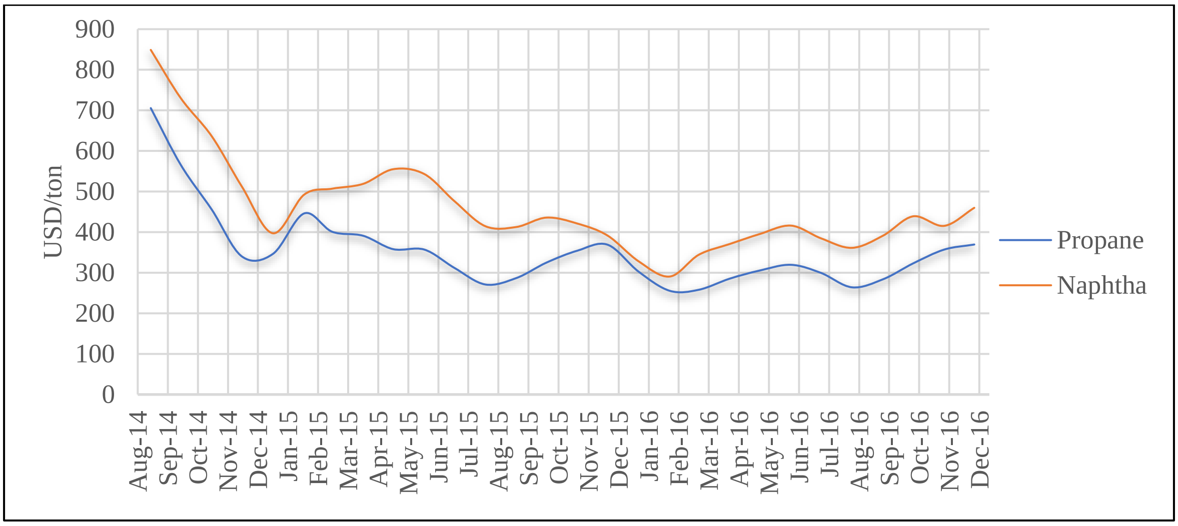

Figure 3-8 Propane vs. natural gas price (Propane price is Argus ARA Large index)

Actually, LPG consumed in Europe is predominantly refined LPG while Nordic region is mostly based on the Norwegian LPG from gas processing plant, around 35% of LPG production comes from GPP. Norway and Sweden are the biggest consumers of LPG from GPP in the region [14]. Therefore, Argus CIF ARA Large can be considered as a representative price index in the region [51].

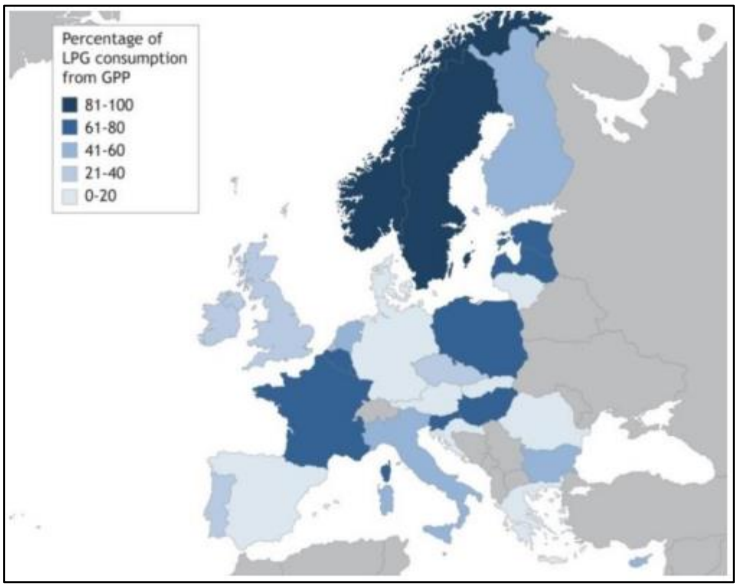

Figure 3-9 Percent of countries which buy LPG from GPP [14]

Platts FOB Seagoing (PMABB00) index refers to NWE coasters with cargoes ex-refineries between 1,000 to 3,600 mt, so the price represents small-scale trading activity where LPG source element is a refinery. The price mechanism for this index will be described in details in the next section.

4 INVESTIGATION OF KEY FACTORS AFFECTING BALANCE BETWEEN LNG AND LPG

The following section will discuss the key driving factors that could influence the balance between LNG and LPG. Based on the history of natural gas market growth and price development, scenario-based analysis was developed. Many factors affecting the balance were investigated such as stagnant gas & oil production, LNG and LPG markets flooding, refining margin and NGLs shortage. For the analysis, among all of the factors three main drivers were considered as the most crucial which are the following:

i. LNG market flooding;
ii. Refining margin;
iii. LPG & Ethane shortage.

4.1 LNG market flooding

4.1.1 Development of LNG capacity globally

As it was shown on *Figure 1-3*, the natural gas demand will increase with population, prosperity and new world climate target and implementation of the Paris Agreement towards significant reduction in the emissions by 2030, so that gas may replace harmful coal from the energy generation sector. Alongside, LNG share will take up the majority of the increase.

The globally traded volumes are increasing, representing 361 bcma (258 MT) in 2016 [9]. As for liquefaction facilities, some new export projects are under construction totalling 160 bcma by January 2017, mainly in Australia and U.S. The current liquefaction infrastructure amounts for 476 bcm [9]. The proposed liquefaction capacity accounts for 1231 bcma but the likelihood that all these LNG projects will get an approval is very low, maybe only one third of them will be commissioned. The half of the expected capacity is going to be built in North America [9].

The receiving capacity reached 1113 bcma in 2017 as projects in China, France, Poland and South Korea were commissioned [9].

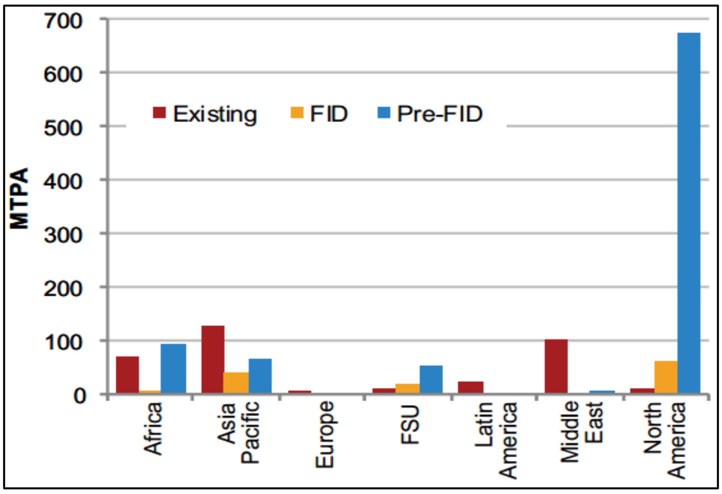

Figure 4-1 Nominal Liquefaction Capacity by Status and Region, as of January 2017 (1MTPA ≈ 1.4 bcma), IGU 2017

The giant expansion of liquefaction facilities in Australia and the U.S. continues to increase. The sizes of these volumes will certainly impact on global prices. As many reports say, the current LNG market is oversupplied but the real situation is slightly different. The outages in the LNG production make significant price signals, for example as it happened in December 2016, due to outages at Australia, Gorgon LNG T1[9] and the maintenance issues at Sabine Pass plant.

Australian LNG export facilities grow unprecedentedly fast, as a consequence of investment decisions made 5-6 years back. The main importer of these growing volumes is Japanese market which is currently diversifying its supply schemes [52] with a larger share of U.S. cargoes.

Table 4-1 LNG projects in the USA

	Project	**Start data**	**Capacity, million tonnes**
Operation/construction	Sabine Pass 1-5	2016	22.5
Projects with Japan involvement	Cove Point	2017	5
	Cameron	2018	13.5
	Freeport	2018	13.2
Under construction	Corpus Christi 1-2	2019	9
Total capacity		**By 2019**	**63.2**

In addition to huge developments of LNG facilities like the U.S. and Australia, East Africa, Qatar and Russian will play significant role.

The large discoveries in East Africa, particularly in Mozambique and Tanzania have caused large proposals for liquefaction facilities in the region, 53.4 MTPA and 20 MTPA correspondingly which are going to become operational in early 2020s. But these projects will require large investments in infrastructure development and new commercial and regulatory frameworks [9] that could postpone the terminals commissioning by 2-3 years more.

Moreover, the market can be balanced by higher utilization levels at terminals in Qatar, Malaysia, Norway, Papua New Guinea, Russia and the UAE as the world utilization level in 2016 was 82%. Furthermore, the new Artic project at Yamal LNG will bring additional 16.5 MTPA by 2019.

So, the global liquefaction and regasification capacity will increase further.

4.1.2 U.S. impact on the global market

Since the U.S natural gas production kicks up, more gas is available for export. On the figure below the projections for future development are shown.

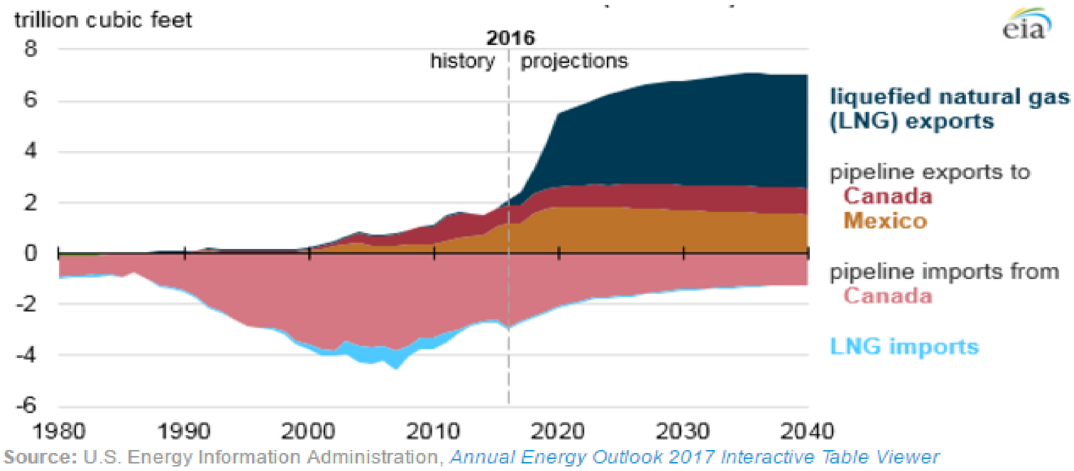

Figure 4-2 LNG export & import volumes projection in the U.S. (1 bcfa = 28.32 bcma), EIA

By 1st of May, 2017 there are 4 pre-filing projects with 5.04 bcfd (52.07 bcma) capacity and one proposed with 1.8 bcfd (18.6 bcma) [53]. Most of the U.S. capacity is aimed at Japanese market as its companies are involved in these projects as investors [52].

Price development in the U.S.

In March 2016, the natural gas price in the U.S. was the lowest, 1.73$/MMBtu since 99th, mostly because of the mild weather. Due to the fact that the gas proved reserves in the U.S. have declined by 16,6% in 2015 representing 324.3 Tcf, (in 2014 388.8 Tcf); and the fact that U.S. energy production decreased in 2016 after a stable increase since 2009 mostly due to fall in coal, petroleum and gas production by 18%, 5% and 2% correspondingly, the Henry Hub prices started to increase from less than 2$/MMBtu in February 2016 to 3.23$/MMBtu in March 2017. In accordance with the EIA, it is expected that the price will continue to increase, mostly because of new export capabilities and growing domestic gas consumption. But if take into account that in 2017 the U.S gas production is expected to increase by 0.8 bcfd (8.3 bcma) and by 4 bcfd (41.3 bcma) in 2018, and the Trump's thoughts about coal [54], the natural gas price is not expected to increase significantly.

If look at the historical forecasts done by EIA, the trend for overestimation of the Henry Hub prices can be observed. From year to year the actual price of HH is lower than the forecasted one, *Figure 4-3.*

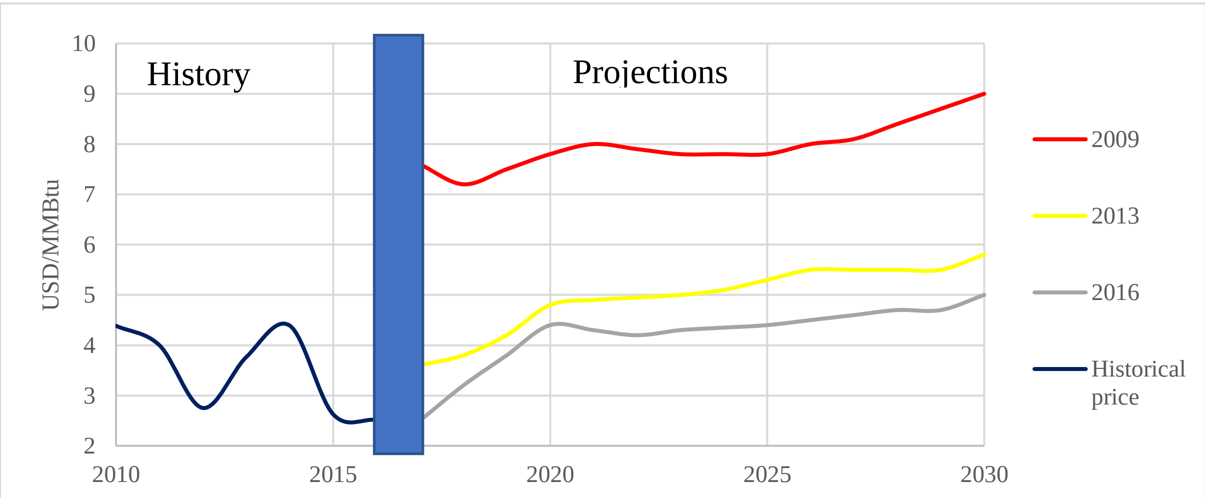

Figure 4-3 Historical Henry Hub price projections in time

The figure above was done based on the EIA projections for the future Henry Hub price. So, from the figure and table below it can be noticed that each projection year the EIA has been changing their forecasts for HH price for 2020 and 2030. Therefore, the declining trend for the HH prices forecasts can be observed.

Table 4-2 Historical Henry Hub price projections

	Projection year		
	2009	**2013**	**2016**
2020	*7.8 $/MMBtu*	*4.9 $/MMBtu**	*4.4 $/MMBtu**
2030	*9 $/MMBtu*	*5.8 $/MMBtu**	*5 $/MMBtu**

* The price was taken for the Reference case which reflects global oil market.

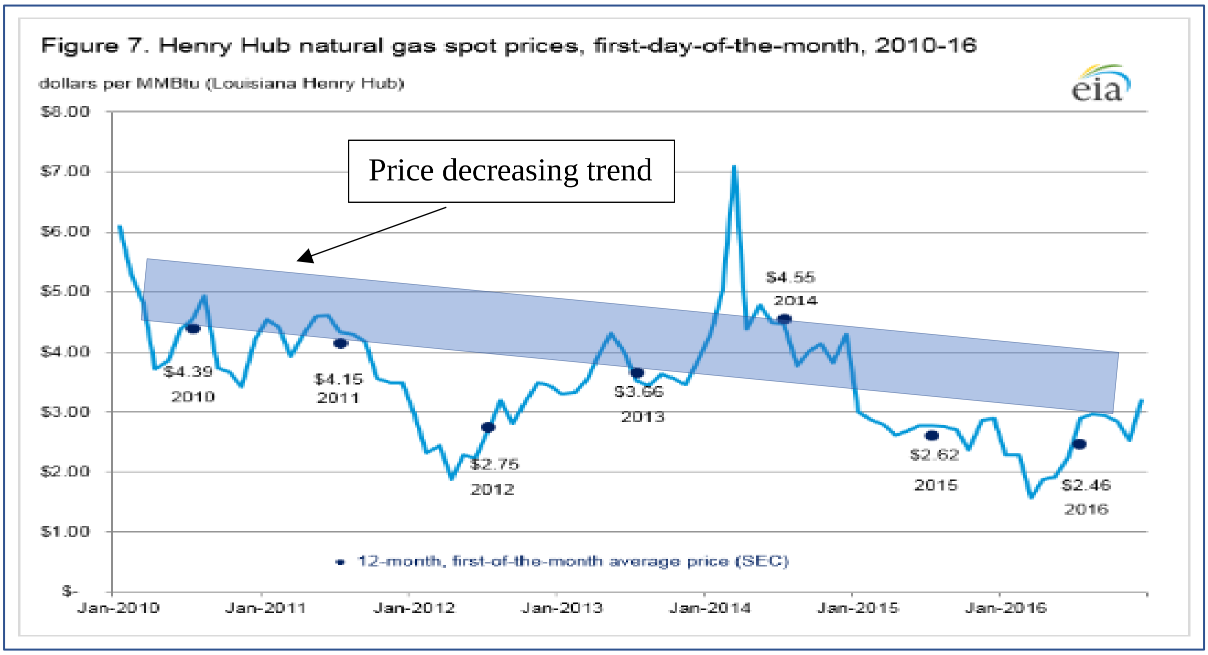

Figure 4-4 Historical development of the Henry Hub price

Despite the changes on the gas market last year, the gas export rose by 30%. U.S. is going to be a net exporter of LNG with 95.1 bcma by 2021 as all 5 LNG projects will be completed. In accordance with EIA, by 2017 the LNG production accounts only for 11.4 bcma. The EIA expects new liquefaction trains to come online in December 2017 and during the second half of 2018.

So, the U.S. would play more substantial role on the European and Asian market after 2020 when they finish liquefaction projects and the volumes will be significant to compete with other players on the market as Qatar and Algeria.

4.1.3 Price modelling

4.1.3.1 Possible directions of U.S. cargoes, main players

It's not clear yet whether the U.S. companies will continue to liquefy gas at full rate and sell it to the global market or will be forced to reduce their production and put the gas into domestic network grid. These two cases were the base for the price analysis.

There are two main players on the U.S. gas market, *Figure 4-5*.

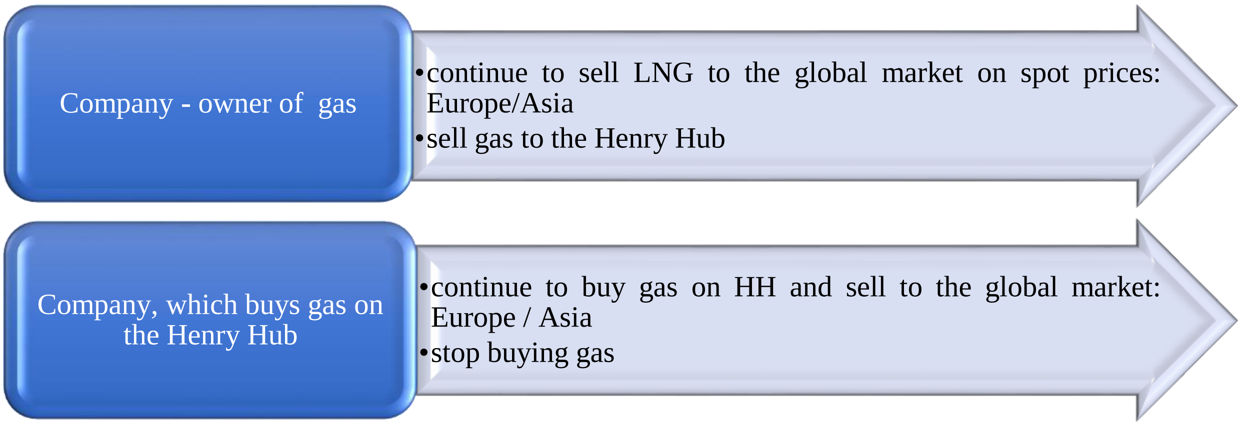

Figure 4-5 Gas market players in the U.S.A.

Gas sold to the Henry Hub

For companies-owners of gas it is assumed that under the market conditions (for example low prices in Asia and Europe) they are forced to sell their gas to HH instead of Asian and European markets in order to get a return.

The HH price never came down less than 1.7$/MMBtu since 1997, so it can be assumed that it's approximately the price of U.S. gas production. That's why for the low HH case, 2$/MMBtu price is chosen. For the current HH case, 3 and 4$/MMBtu cases are considered, as the actual price at HH is 3.23$/MMBtu (April 2017). Finally, 6$/MMBtu case represents the EIA thoughts about the price in 2018.

In the table below the costs allocation for the case if gas-owner company decided to sell gas to the Henry Hub is shown. The total cost formula is assumed to be as follows:

$$\textbf{\textit{Total price = cost of production + transportation cost to the HH}} \quad (4.1)$$

where the ***cost of production*** including the transportation cost from offshore to onshore;
the ***cost of gas transportation to the HH*** is assumed to be 15% of the hub price based on the Cheniere model.

Cheniere model is 115% of the HH price plus Tolling Fee, where 15% of the HH is transportation cost from HH to a liquefaction facility. The model is proposed for plants being converted from importing to exporting terminals. But it's quite likely that the next liquefaction terminals will be greenfield plants. In the calculations, it is assumed that for the greenfield project the CAPEX may be almost the same as for brown fields (represented by Cheniere model) since in addition to the sunk costs there are investments in gas treatment facilities, liquefaction units, fractionation columns and energy units and utilities. So, that is why the Cheniere model can be relevant for these cases too.

Table 4-3 Henry Hub choice for the company-owner of gas, $/MMBtu

	To Henry Hub			
	Low HH	Current HH		High HH
Henry Hub	**2**	**3**	**4**	**6**
Cost of production*	*1.7*	*2*	*2.1*	*2.3*
Transport to the HH	*0.3*	*0.45*	*0.6*	*0.9*
Total costs	***2.0***	***2.5***	***2.7***	***3.2***

* With the increasing market price, companies may invest more in the development of new projects. So, it is assumed that the cost of production for the Henry Hub above 2$/MMBtu will be: 1.7$/MMBtu + 15%*HH.

So, from the table above it can be seen that at very low Henry Hub price (close to the cost of production), the company will just cover their costs if they are going to sell gas to the HH. Probably at that price it's better to put volumes on the global market (Asia/Europe). But if the HH price increases, then it's not clear whether to sell gas as LNG or to put gas into the grid. The next section will observe the costs of selling LNG to Asian/European markets.

U.S. LNG to Europe/Asia

European direction of the U.S. cargoes.

The destination of U.S. LNG will depend on the differential between Henry Hub prices and the price on the targeted market. So, there is an uncertainty about how large volumes will be landed on European and Asian markets.

In the tables below, costs for selling LNG to European market for both types of companies were estimated.

It was assumed that for a company-owner of gas there is no transportation costs from offshore to their own liquefaction facility onshore, these costs are included in the ***Cost of production, Equation (4.1);*** then companies have the cost of liquefaction and shipping to the customer. So, these companies have an advantage to companies buying from HH as they don't have to pay for transportation from HH to liquefaction facility.

Table 4-4 Company-owner costs allocation in the case of selling LNG to Europe, $/MMBtu

	US to Europe (Huelva, Spain)			
	Low HH	Current HH		High HH
Cost of production*	*1.7*	*2*	*2.1*	*2.3*
Liquefaction**	*1.3 – 1.5*	*1.8 – 1.9*	*2 – 2.3*	*2.3 – 2.5*
Shipping, round trip	*0.2 - 0.4*	*0.4 – 0.5*	*0.5 – 0.6*	*0.6 – 0.8*
Total	***3.2 – 3.6***	***4.2 – 4.4***	***4.6 – 5***	***5.2 – 5.6***

* The same assumption as in the *Table 4-3*.

** Tolling fee is assumed to be the difference between US Gulf FOB and Henry Hub price, Cheniere model.

Table 4-5 Cost allocation for the company buying gas on the HH and selling LNG to Europe, $/MMBtu

	US to Europe (Huelva, Spain)			
	Low HH	**Current HH**		**High HH**
Henry Hub	*2*	*3*	*4*	*6*
Transport to a liquefaction facility*	*0.3*	*0.45*	*0.6*	*0.9*
Liquefaction**	*1.3 – 1.5*	*1.8 – 1.9*	*2 – 2.3*	*2.3 – 2.5*
Shipping, round trip	*0.2 - 0.4*	*0.4 – 0.5*	*0.5 – 0.6*	*0.6 – 0.8*
Total	***3.8 - 4.2***	***5.7 – 6***	***7.1 – 7.5***	***9.8 – 10.2***

* Transport to a liquefaction facility: 15% of the HH price, Cheniere model.

** Assumption is the same as in the *Table 4-4*.

Impact of the Regulations on the European gas market.

The European Commission has developed three directives to develop a diversified and transparent market. Due to the Third Gas Directive member states are to open the third-party access (TPA) even to LNG terminals. The threshold for companies to become an eligible buyer has being reduced significantly allowing to small and medium size companies to participate in the market trades. So, in 2009 when the shale gas revolution in the U.S. took place, most of the volumes intended to be exported to U.S. has been redirected to Europe. At that time, the Third Gas Directive has been introduced that helped the market to adsorb the surge volumes.

Europe is on the way of structural changes, it becomes more flexible and diversified as larger volumes are traded on hubs. The most liquid hubs in Europe are situated in NWE. These hubs have a dramatic upheaval in the contracting structure, from 72% to 8% change has appeared in OPE contracts and from 27% to 92% in GOG between 2005 and 2015 as a result of increased hub trades. As more gas is available on European market, the hubs prices would probably stay low that will further facilitate the increase in number of GOG deals. Thus, the introduction of hub and the Third Gas Directive in Europe has impacted significantly on the contractual structure and made the trading much easier. So, now long term contracts can be indexed to hub prices which gives stability and foreseeable situation on the market.

In Nordic region OPE contracts still have the largest share which account for 48% in 2015 against 12% GOG.

The Nordic market becomes more developed and diversified due to Norwegian large scale liquefaction facility and some small reception terminals; large import terminals in Lithuania and Poland, and other small scale reception projects to be finished by late 2017 and 2018 in Sweden and Finland correspondingly.

The primary benchmark prices for spot trading in NWE are based on the National Balancing Point (NBP) in the United Kingdom and the Title Transfer Facility (TTF) in the Netherlands hubs. TTF is the largest in relation to traded volumes. NBP and TTF prices have a strong influence on hub prices in other European markets because of their liquidity and interconnectivity with continental Europe. In addition to NBP and TTF in NWE there are three relatively small hubs such as Gaspool, NCG and Zeebrugge. The Gaspool price was much higher than NBP and TTF in 2011-2013 primary due to lower liquidity and the Russian pipeline gas which historically is linked to oil, while gas contracts from Norway to UK, Dutch and Belgian off-takers are referenced to regional hub prices. Now the Russian contracts are being renegotiated and Gazprom is offering more flexible deals to its customers in the EU.

Asian direction of the U.S. cargoes.

The same sensitivity study with the same assumptions was performed for delivery of U.S. cargoes to Asia.

Table 4-6 Company-owner costs allocation in the case of selling LNG to EAX, $/MMBtu

	US to Asia (Hazira, India)			
	Low HH	**Current HH**		**High HH**
Cost of production	*1.7*	*2*	*2.1*	*2.3*
Liquefaction	*1.3-1.5*	*1.8 – 1.9*	*2 – 2.3*	*2.3 – 2.5*
Shipping, round trip	*1 – 1.1*	*1.1 – 1.2*	*1.2 – 1.4*	*1.4 – 1.6*
Total	***4– 4.3***	***4.9 – 5.1***	***5.3 – 5.8***	***6 – 6.4***

Table 4-7 Cost allocation for the company buying gas on the HH and selling LNG to EAX, $/MMBtu

	US to Asia (Hazira, India)			
	Low HH	**Current HH**		**High HH**
Henry Hub	*2*	*3*	*4*	*6*
Transport to a liquefaction facility	*0.3*	*0.45*	*0.6*	*0.9*
Liquefaction	*1.3-1.5*	*1.8 – 1.9*	*2 – 2.3*	*2.3 – 2.5*
Shipping, round trip	*1 – 1.1*	*1.1 – 1.2*	*1.2 – 1.4*	*1.4 – 1.6*
Total	***4.6 – 5***	***6.4 – 6.6***	***7.8 – 8.3***	***10.6 - 11***

There is an uncertainty on how the Asian consumption will be developed. As the 2015 COP21 Conference in Paris took place, many countries have developed more green projections for future energy demand and Asia is not an exemption, many Asian countries have much worse situation with air quality than the rest of the world. So, China, India and other Asia-Pacific region countries such as Thailand, Taiwan, Malaysia and Bangladesh can switch from coal and oil products to LNG as it's the only potentially available source of energy except renewables.

Moreover, the Asian growing demand cannot be supported by domestic natural gas production in Singapore, Indonesia, Pakistan, Bangladesh, Thailand and Vietnam.

A lot of people in Asia rely on kerosene, diesel and other liquid fuels for electricity production which is extremely expensive and inefficient especially at the current price on oil products in relation to gas, *Figure 4-6*.

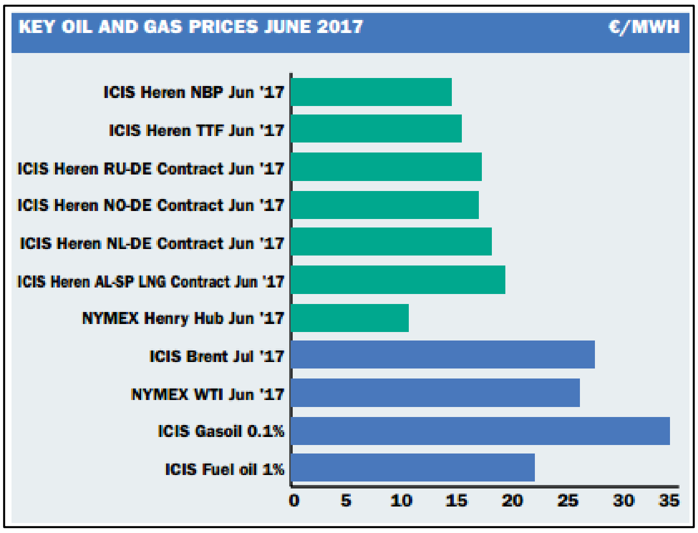

Figure 4-6 The oil and gas prices, ICIS

Traditional take or pay contracts in Asia don't give a such flexibility as can be given by trade on hub. Japan will try to get away from take or pay agreements and destination clauses just as has happened in Europe that will give a liberalization to the market. Getting away from destination clauses will give a competition and higher trade activity to the market, that will facilitate higher liquidity and flexibility and may create opportunity for spot trades activity and possibly trading hub development in the region.

If these changes happen then it will facilitate increasing demand for LNG, that will defiantly increase the price in the region.

4.1.3.2 Price modelling based on the possible influence of oil

In order to show what is the most probable development of gas/LNG market based on possible influence of oil prices, the scenario analysis is performed. For the analysis, 35, 50 and 75 \$/bbl oil prices are taken. Gas price was assumed as a percent of the oil price as presented in the *Table 4-8*. The gas equation for the U.S. is established based on the EIA projections on the price ratio between oil and gas, *Figure 4-7*.

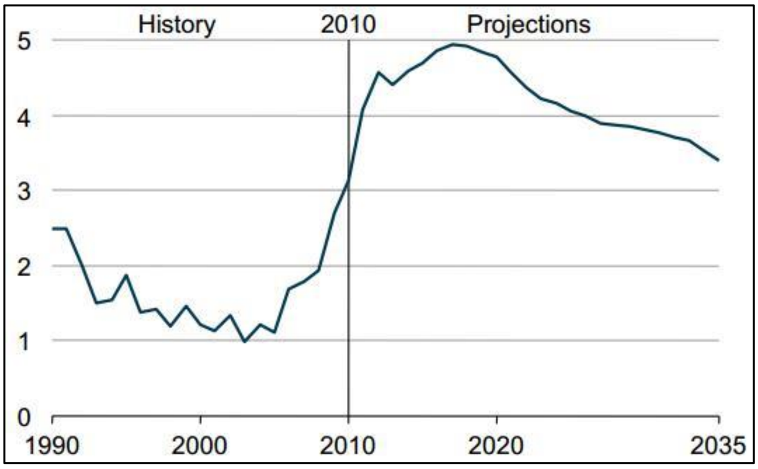

Figure 4-7 Ratio of low-sulphur light oil price to Henry Hub gas price on energy equivalent basis, 1990 – 2035, EIA, AEO 2012

Table 4-8 Assumptions on gas price formulas

Market	I case. Gas price equation	II case. Gas price equation	III case. Gas price equation
U.S.A.	Oil price * 35%	Oil price * 25%	Oil price * 35%
Europe	Oil price * 60%	Oil price * 67%	Oil price * 50%
Asia	Oil price * 70%	Oil price * 85%	Oil price * 60%

So, in accordance with the assumptions gas prices for three cases are calculated as shown in the table below.

Table 4-9 Gas price, calculated based on the assumptions, $/MMBtu

	I case.			II case.			III case.		
Oil price, $/bbl	35	50	70	35	50	75	35	50	75
U.S.	2.0	2.9	4.0	1.5	2.2	3.0	2.1	3.0	4.5
Europe	3.6	5.2	7.2	4.0	5.8	8.1	3.0	4.3	6.5
Asia	4.2	6.0	8.4	5.1	7.3	10.3	3.6	5.2	7.8

In order to see how volumes of U.S. LNG will be allocated on the global market, the return that U.S. companies may get from trading on three markets is chosen as the indicator. The return is calculated as follows:

$$\boldsymbol{Return = Market\ gas\ price - Average\ cost\ of\ gas/LNG\ delivery} \quad (4.2)$$

where ***Market gas price*** – price on the targeted market: Henry Hub, European or Asian markets, *Table 4-9*;

Average cost of gas/LNG delivery – cost of delivery of gas/LNG to three markets. Calculations were based on the Chapter 4.1.3.1., detailed tables with costs allocation are shown in the Appendix 2.

So, based on the information above, the following observations can be done.

On the graphs below three cases are depicted. The return that U.S. companies may potentially get from selling gas either to the global market or to domestic hub (HH) is shown.

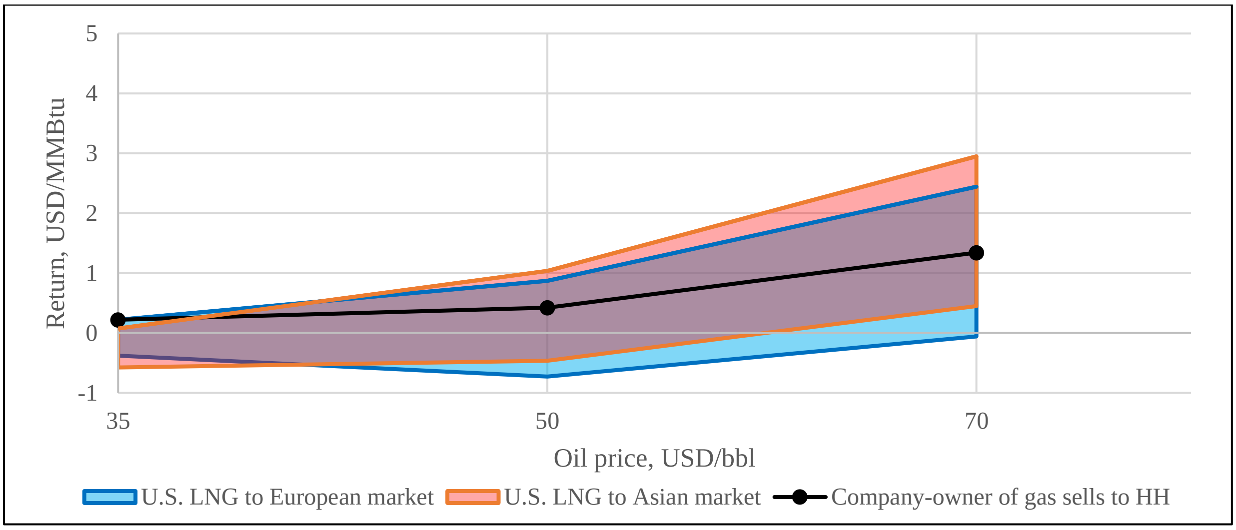

Figure 4-8 I case. Return on gas/LNG sold on three markets. Upper bound of each shaded area is a return that company-owner of gas may get; Low bound is the return for a company which buys gas on the HH.

The first case is proposed as a reflection of the past market situation. When U.S. was a net importer of gas and European and Asian markets had a similar structure with dominant oil-based contract trading.

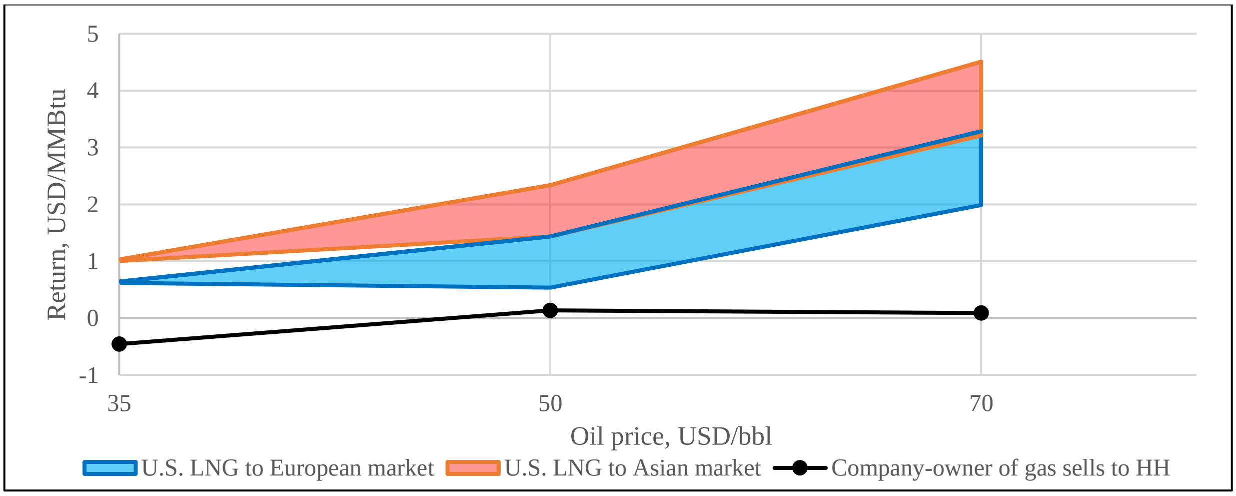

Figure 4-9 II case. Return on gas/LNG sold on three markets. Upper bound of each shaded area is a return that company-owner of gas may get; Low bound is the return for a company which buys gas on the HH.

The second case may represent future market picture. In this case Asian demand is increased dramatically that resulted in high prices. So, U.S. companies will send LNG mostly to Asian market. But the likeliness of this outcome to happen in the nearest future is small as Asia has to significantly increase the demand by switching from coal and oil products to gas use. The market liberalization process may take around 10 years before high liquidity market will be developed (based on some expert's opinion that actual European liberalization took 8-10 years).

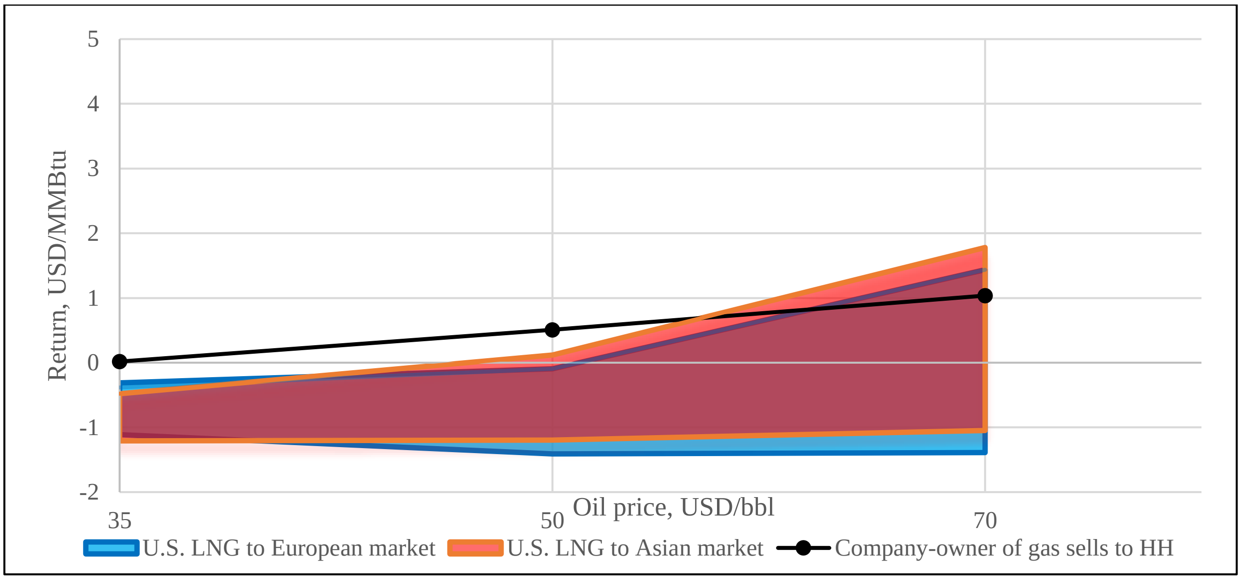

Figure 4-10 III case. Return on gas/LNG sold on three markets. Upper bound of each shaded area is a return that company-owner of gas may get; Low bound is the return for a company which buys gas on the HH.

The third case is the most probable illustration of the future of LNG market development. This market picture is different from the I case, it actually shows the market flooding impact in the nearest future (after 2020).

Scenario analysis based on the current/future picture of the market (III case).

If the oil price goes down to 35 $/bbl. It means that U.S. gas price will get as low as 2 $/MMBtu which is close to the gas production cost. From the graph, it can be observed that for U.S. upstream companies which have two choices whether to sell gas to HH or to global market, will follow the first option. In this case, most probably they will decrease gas production and will try to at least break even own costs. So, companies would sell gas mostly to the Henry Hub. Companies which don't have own gas might stop buying gas on HH and will have to pay minimum tolling fee (not shown on the figure).

Thus, less volumes of LNG will reach European and Asia markets.

If the oil price stays at 50 $/bbl.

From the figure, it can be observed that with oil price up to 53$/bbl U.S. companies-owners may still have an opportunity to sell gas to Henry Hub as they will get greater return, but this is not a case for companies buying from the HH as they have to pay minimum tolling fee. The difference that U.S. companies may get from sending volumes to Asian or European markets is almost the same.

By May 2017 Asia became less attractive destination point for U.S. volumes. The reasons are the following:

- high Henry Hub price;

- Asian market flooding due to volumes from new liquefaction facilities in Australia, that caused downward pressure on prices in the region;

- Less demand from Japan;

- Less offtake from China, as a result of slower economic development.

Since the Henry Hub price increased above 3$/MMBtu level, some experts think that European market gets more attractive position for sending out the surge volumes of U.S. LNG as the current hub price in Europe 4.5 – 5 $/MMBtu compare to Asian price, 5.4 $/MMBtu.

Figure 4-11 EAX - NBP price spread, May 2017

Some experts think that Asian – European spread is to be at least around 0.7 – 0.8 $/MMBtu which is transportation cost difference between two markets, in order to attract U.S. LNG to the Asian market. By May 2017 spread is around 0.877$/MMBtu, which may get even lower. So, if the Asian stays low and U.S. prices relatively high (higher than 3$/MMBtu) it means that Europe can become more attractive place for U.S. cargoes.

Since the level of regasification capacity underutilization in the region stands at 25%, the market is able to take additional 50 – 150 bcm of LNG, *Table 3-3*.

Therefore, European market could potentially play an important role as a sponge of the global LNG surplus cargoes. Asian market is not that good diversified and has no enough infrastructure to distribute additional volumes to end customers. So, it is expected that with the globally increasing volumes of LNG the European market will be flooded that will have the following impacts:

- Higher GOG trades;
- High competition;
- Diversified market;
- Downward pressure on gas prices;
- Coal to gas switching dynamic;
- Petroleum to gas switching.

In reality, the flooding of LNG market may arise only when Australian and U.S. projects will be finished, i.e. after 2019-2020, as by May 2017, the U.S. LNG volumes to Europe account for 1.25 bcm but steadily increasing.

If the oil price increase to 75 $/MMBtu, then it may facilitate more export of U.S. LNG to Asian region as companies will get a better return compare to European case.

The increase of the Europe's hub prices may happen due to less LNG coming from the global market, but due to

- good developed gas pipeline supply from Norway, Russia and Algeria, which is currently increasing;
- increased LNG volumes from Qatar, Algeria, Nigeria and Russia;

the price may not increase significantly since market can be balanced easily.

In this situation, with higher Asian prices, Europe may find its position in reloading operations. If the Asia-Europe spread will stay at 2$/MMBtu and the shipping cost, 1.5$/MMBtu, European reloading companies may get 0.5$/MMBtu return.

The effect of the redirection of LNG volumes from European market to Asian was not observed in 2011-2015 (Japanese disaster), since price history doesn't show an impact of those volumes.

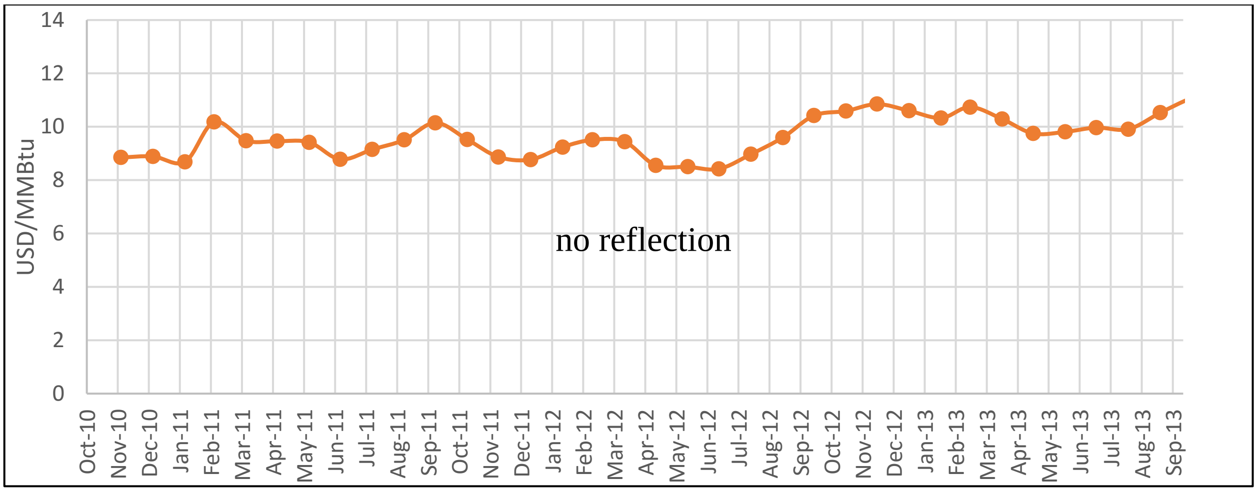

Figure 4-12 NBP price development, 2011-2013

4.2 Refining margin

4.2.1 Refining margin concept

Refineries are aimed at maximising production of more valuable products such as gasoline, naphtha, jet fuel, diesel etc. It's always a case for production planning team what strategic plan to set up for the refinery. Challenges range from operational to purchasing raw materials and sales.

The main key performance indicator (KPI)[3] of a refinery is the refining margin (RM). In general, the refining margin is the difference in value between products and the crude oil used. It represents the refinery profitability and can be expressed as follows:

$$RM = \sum (\text{price of product } i * \text{yield of product } i) - \text{crude oil cost} - OPEX \qquad (4.3)$$

where ***RM*** – refining margin, $/bbl.

The refining margin is very complex. It expresses gains from selling of different products such as light and middle distillates, heavy fuel oil (HFO) etc.

[3] A Key Performance Indicator is a measurable parameter that demonstrates how successful a company achieves key business objectives.

So, from the formula RM depends on the crude oil prices, composition of the oil been used and the refinery configuration.

In general RM reflects the variations in demand and in cooperation with other parameters may show trends to more price-beneficial products. Next sections describe what are the parameters determining the refining margin.

4.2.1.1 Crude oil composition

Planning of the crude oil procurement is linked to the specific strategic plan of the refinery, since the composition is extremely important for the products quality and quantity and could cause either economic benefits or losses. The heavier the crude (low H/C ratio), the costly the refinery production process and more energy is required to produce certain products slates.

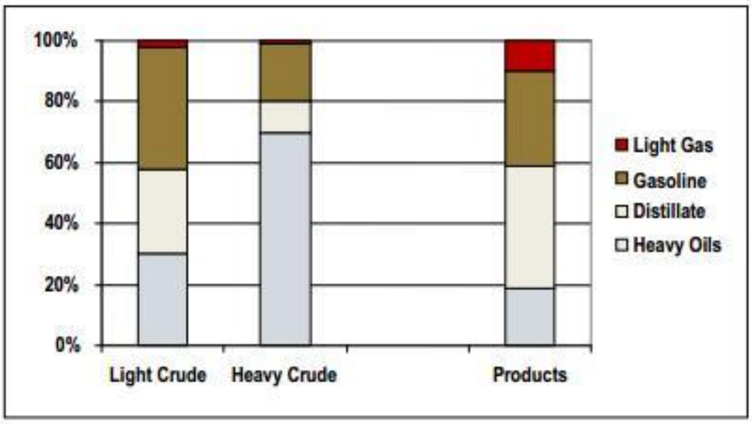

Figure 4-13 Natural yields of light and heavy crudes

On the left side of the *Figure 4-13* the natural yields of light and heavy crudes are shown. The natural yield of heavy crude contains higher number of heavy components, around 68% while the yield of heavy oils from light crude is 30%. This figure simply shows that refineries must be capable to convert HFO to lighter products as it's demanded by the current market trend. On the right side of the figure, the typical demand for different products is depicted.

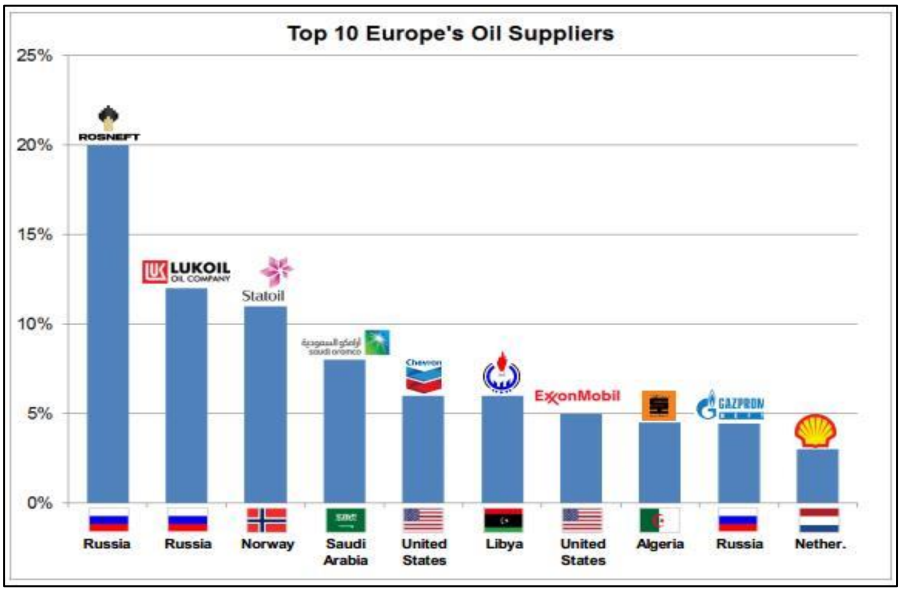

Figure 4-14 Crude oil suppliers to Europe, [55]

Historically the sources of crudes in Europe were North Sea, North Africa and Russia/CIS regions. These crudes present different properties, for example North Sea and North African crudes (Algeria, Libya) are mostly light and sweet, crudes from Russia/FCU are heavy and sour, while Middle East - light to medium and sweet. The European refineries have been built to process specific crudes with only few plants able to process heavy oil to high grade yields, but the situation has been changed toward more sophisticated refineries.

4.2.1.2 Refinery configuration

The refining complexity in Europe grows faster last decade, by 2012 the highest refining complexity was observed in Germany, Baltic region and Central Europe. As has been discussed, these sophisticated refineries have a fluidized catalytic cracking unit (FCC) which has the highest yield of LPG production when refinery focuses on light (gasoline)/middle distillates production. Thus, the increased interest to gasoline production will kick up the LPG volumes.

This case was observed in 2015 when due to the strong demand for gasoline and low oil prices, refining margins skyrocketed and refineries tried to maximise their production. The LPG production also rose at that time which caused downward pressure on prices, *Figure 4-15*.

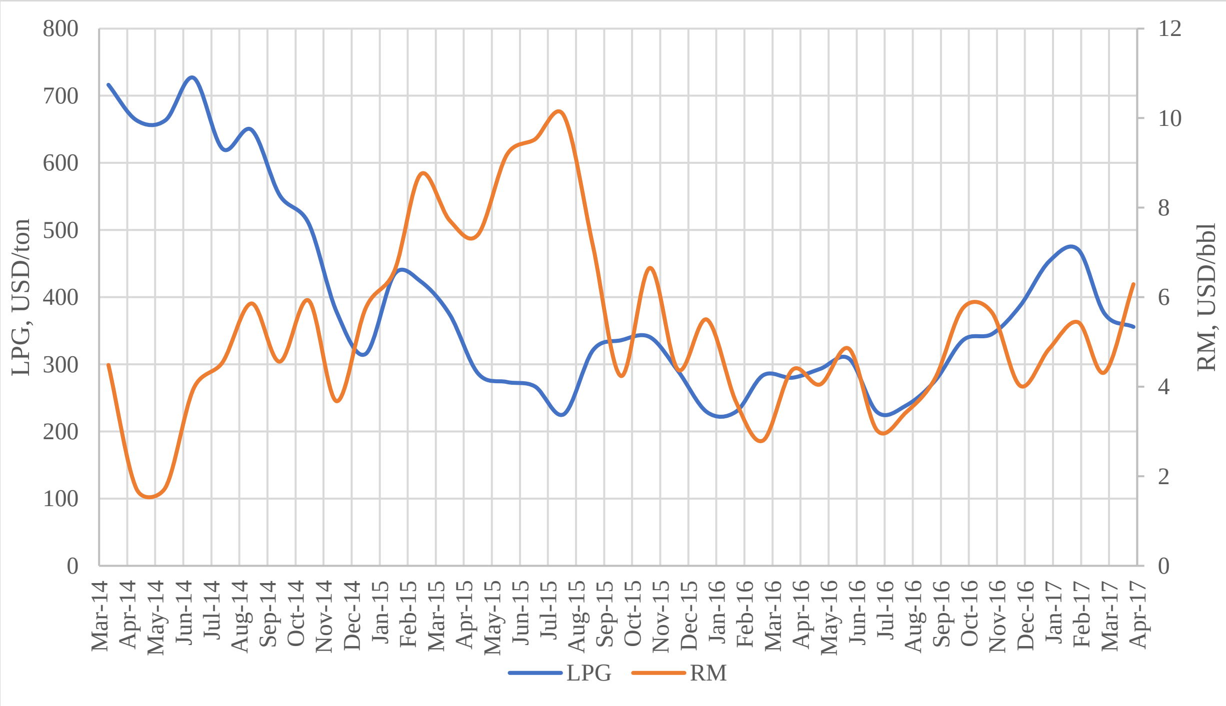

Figure 4-15 LPG price & Refining Margin in North-West Europe

The detailed impact of the refining margin is described in the next section.

4.2.2 Scenario Development

Europe is oversupplied by gasoline but has increasing demand for diesel [50] as such the region has increased investments in diesel production units. Diesel is relatively efficient fuel, that increased the Europe's interest to it as a tool to reduce fuel consumption and crude oil import.

Gasoline accounts for the largest share of Europe's export products mainly to the U.S. as the EU market experiences increasing demand for marine and road diesel, and jet fuel. On the other side of the Atlantic, the different situation is observed, the U.S. has deficit of gasoline but overproduction of diesel, so since 2008 the diesel started to be exported from the country.

Alongside with diesel advantageous compare to gasoline, such as greater mileage and larger efficiency, this fuel has much larger NOx formation which is not favourable for countries with mountain relief, like Norway, Switzerland and Austria. Norway has already set a plan to ban diesel and even gasoline cars by 2025 as it causes large exhaust pollutions.

But the rest Europe still relies on the diesel while the road gasoline demand still declines.

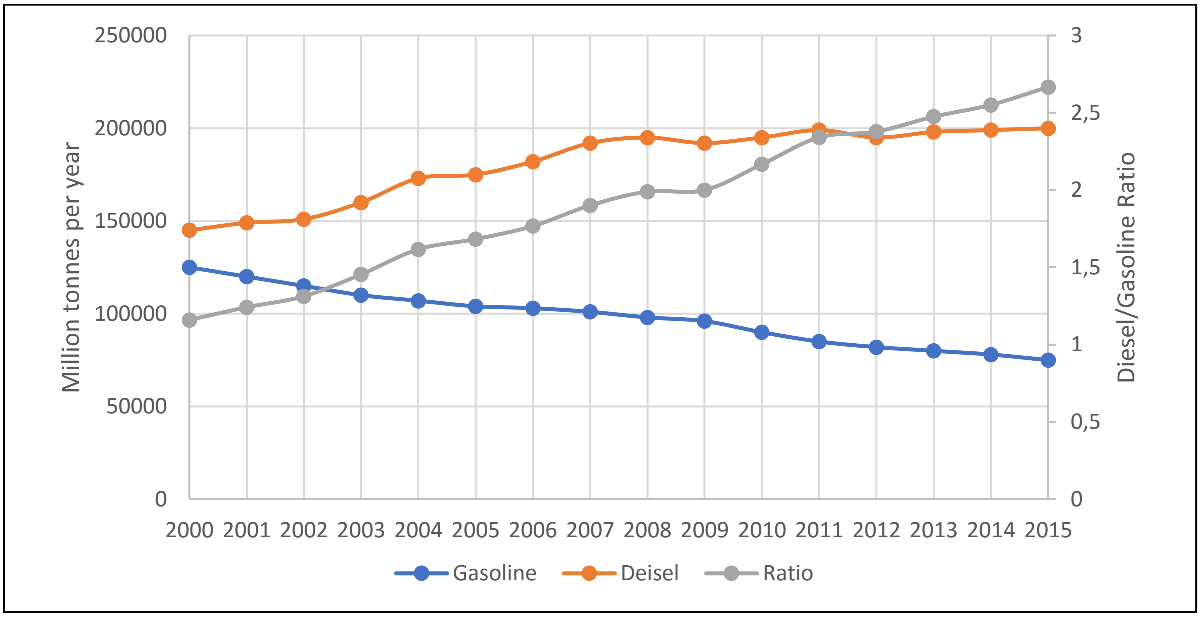

Figure 4-16 Road fuel demand, Road fuel

The combination of the following factors like the European ambitious about gas emissions, the gasoline advantage vs. diesel in relation to NOx formation and the current oversupply of the market by gasoline fuel which is going to be more severe as the U.S. might not be able to adsorb addition volumes due to own developments, makes the European future uncertain whether the diesel production will increase with the current developments in low-emission engines or new technologies in the hybrid gasoline-electric engines will encourage stable/increasing gasoline production.

Refinery yield which depends on the refining margin (market trends) is very important for the LPG market as it changes LPG production volumes.

Three scenarios were developed to show what is the impact of refining margin on the LPG market: **Low RM** (1 – 3.5 USD/bbl), **Reference** (4 – 6 USD/bbl) and **High RM** (> 6 USD/bbl) cases. As has been found the change in refining margin creates a change in the producing volumes which in turn have an impact on price. It’s difficult to put a precise number for the value that determines to what extend the RM impacts on prices, as it’s not the only influencing parameter.

In order to show the relationship between the refining margin and LPG price the ratio was used as a representative value which is expressed as follows:

$$Ratio = LPG\ price\ /\ RM \tag{4.4}$$

where ***LPG price*** - the Platts FOB Seagoing (PMABBOO) index, USD/MMBtu;

RM - Brent Cracking, NW Europe refining margin, USD/MMBtu.

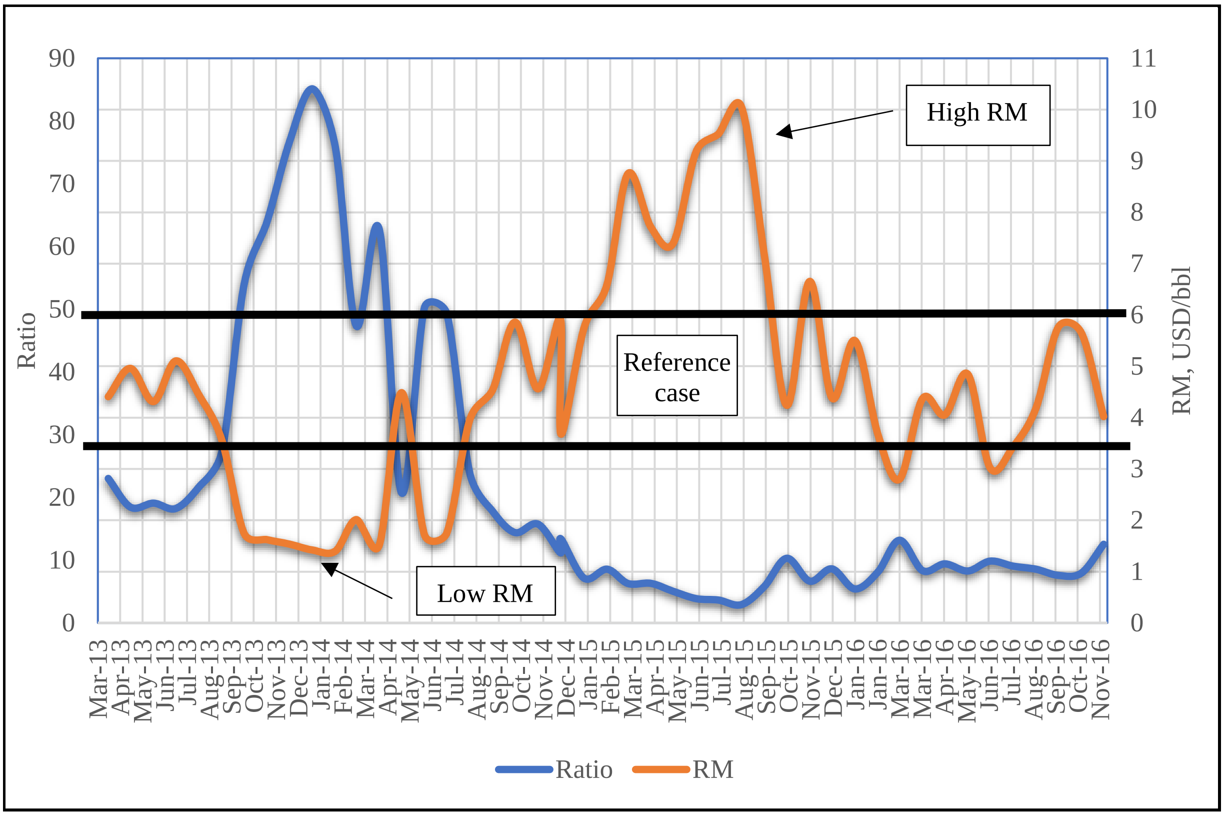

Figure 4-17 Ratio

So, based on the figure above the following observations can be done:

High RM	Ratio=5
Reference RM	Ratio=10
Low RM	Ratio=40-60 with the spike at 70-80

Figure 4-18 Refining margin scenarios

High RM case.

In the case of high refining margin, the production seems to be "on the right way", refineries maximize its throughput in every unit and focus to keep the refinery running. Thus, high refining margin takes up the LPG production if the market shows light/middle distillates demand. The surge of production consequently floods the market and brings down the LPG price. As can be seen on the figure above ratio gets low values.

This case was observed in 2015 when due to low oil prices; strong demand for gasoline; and demand for naphtha to produce more plastics, refining margins skyrocketed and refineries tried to maximise their production. The LPG production also rose at that time which caused downward pressure on prices, Figure 4-19.

As can be seen from the figure it's not always the case that LPG price follows the oil price.

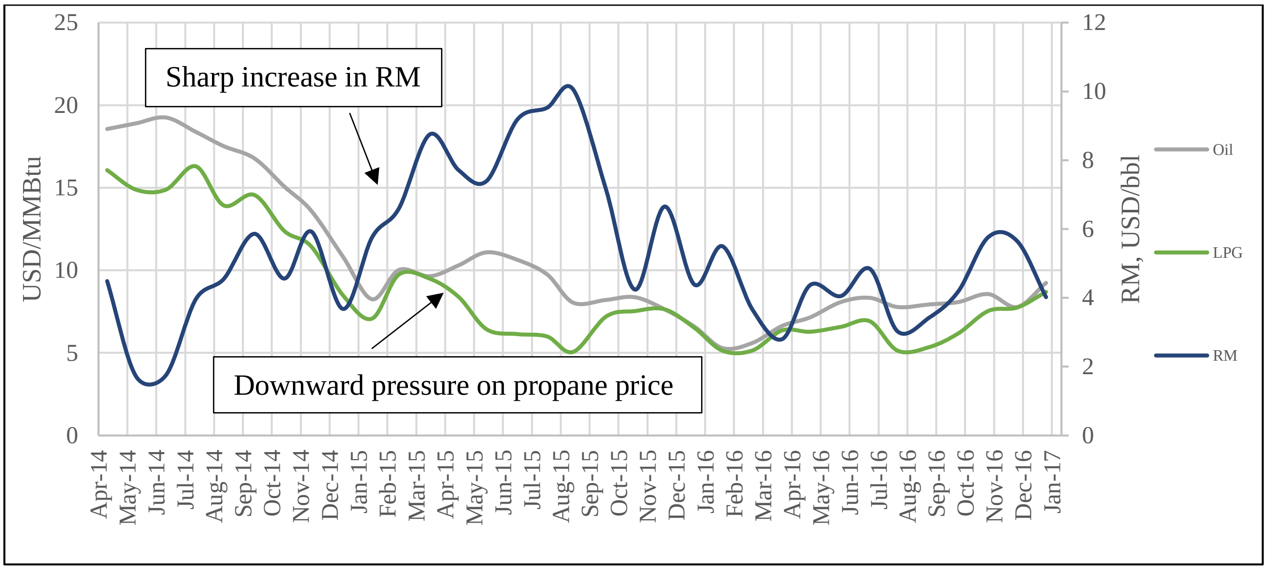

Figure 4-19 Oil & LPG & RM

Low RM case.

According to Jorunn S. Rosvoll, Advisor Oil Refining at Statoil (Personal communication, February 21, 2017) the likelihood that a plant will continue with their primary yields program at low RM is quite small, the refinery will focus on buying cheaper crude oils, in order to reduce operating costs and might also reduce throughput in various units. Sometimes certain processing units with negative income at a refinery are stopped for energy saving. In the case of low RM, refineries switch to cheaper crudes (heavy crude oil) and consequently the output is changed towards heavier products and might result in less LPG production. This case was observed in fourth quarter of 2013, *Figure 4-17* when refining margin was around 1.5 USD/bbl that resulted in low LPG production and higher prices, so that ratio got extremally high value, 85. Thus, low RM has much larger impact on the LPG price than high RM.

Therefore, the refining margin is to be considered as one of the key parameters that could show the short-medium term future of the LPG market.

4.2.3 Indexes in the LPG pricing

As has been described in 3.2.3 Chapter, there are many indexes which are used in LPG pricing. As has been notices during the research, all indexes are different as they are related to different markets and price mechanisms. In the analysis, the Argus CIF ARA Large and Platts FOB Seagoing (PMABB00), which are denoted in USD/mt were used.

The Platts FOB Seagoing (PMABB00) refers to NWE coasters and represents the small-scale trading activity where the LPG source element is a refinery.

In the case of high RM, refineries maximise their production in every unit. Refineries have to transport extra volumes of LPG by vessels, trucks and rail way. But there are considerable number of refineries in EU which are land-locked refineries and they can't transport LPG by water so then the seagoing transportation may become weak in comparison to large scale. FOB seagoing activity will be depressed. So, in this situation we can see weaker seagoing indexes in relation to the big-scale ones.

When the RM is decreasing, smaller volumes of LPG come to the market and then FOB seagoing becomes stronger in relation to prices.

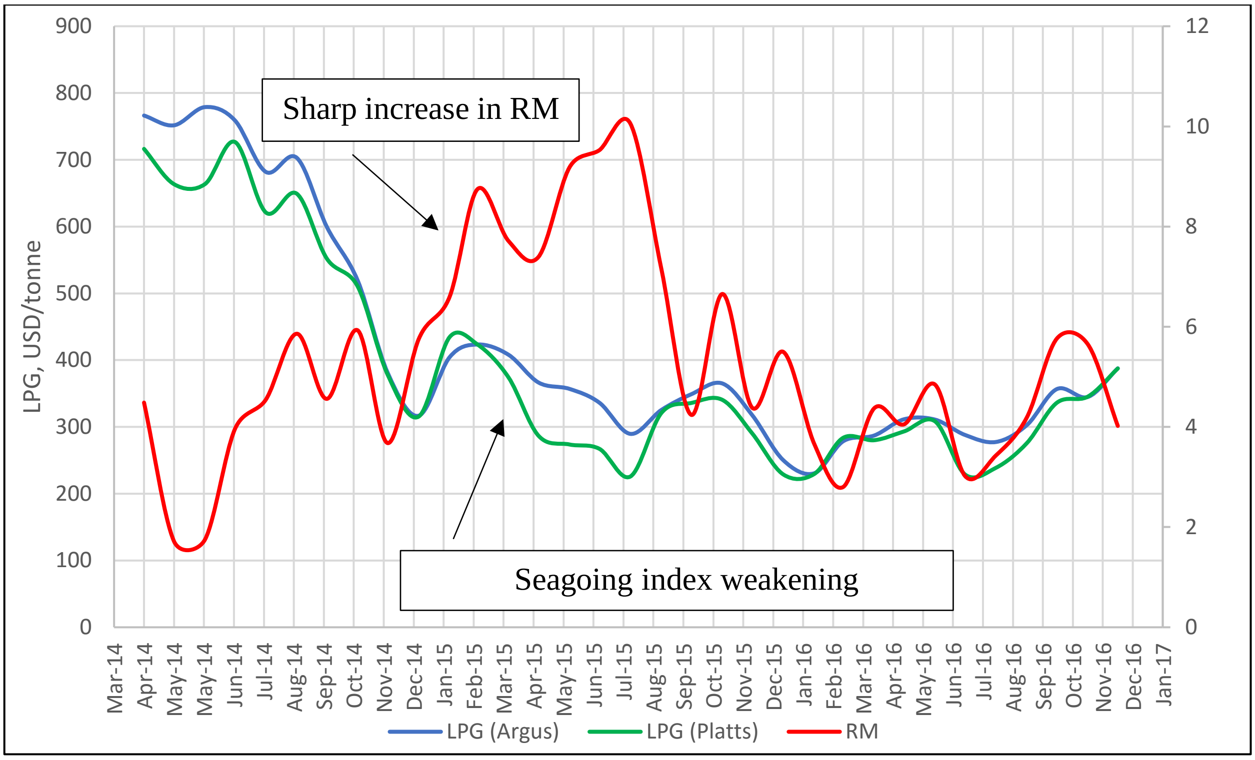

Figure 4-20 Argus vs. Platts indexes in NWE

4.3 LPG & Ethane shortage

With the development of petrochemical industry, LPG draws more attention as a basic raw material for chemical industry. LPG is widely used as a feedstock to steam cracking plants where it is thermally cracked through the use of steam in a bank of pyrolysis furnaces to produce lighter olefins such as ethylene, propylene, butylene, butadiene, etc. and aromatics products [50]. Then aromatics and light olefins are used to produce synthetic plastic, rubber, fibre and also to produce pharmaceuticals, explosives, solvents, etc.

The composition of feedstock has a major impact on the products yields. On the figure below the products slate (in %) for different feedstocks is shown.

Product	Feedstock			
	Ethane	Propane	Naphtha	Gas oil
Hydrogen	5	2	1	1
Methane	9	27	15	8
Ethene	78	42	35-25	23-15
Propene	3	19	16	14
Butenes			5	5
Buta-1,3-diene	2	3	5	6
RPG*	3	7	19-29	20
Fuel oil			4	23-31

*RPG (= raw pyrolysis gasoline) is a mixture of C5 - C8 hydrocarbons. RPG is selectively hydrogenated, then aromatics (benzene, methylbenzene (toluene) and dimethylbenzenes (xylenes)) are removed by solvent extraction and the residue is used as fuel, e.g. for petrol blending.

Figure 4-21 Typical product yields from different feedstocks [56]

It can be seen that propane and naphtha have similar product outputs, but in the case of propane quite large fraction of light components is produced. So, there is a competition between naphtha, propane and to some extend butane as a feedstock to petrochemical plant.

Historically naphtha was a major feedstock to petrochemical industry, but in general the choice of feedstock is always a question of sources availability, security of supply and price.

In accordance with Eurostat, the highest LPG consumption in Europe occurs in the petrochemical area, approximately 45.4% followed by 19.3% in the transportation use and residential use 18.4%. The premium customer such as residential market is very stable market and they are not able to switch quickly from one to another source of energy just due to price fluctuations. This market is not highly sensitive to prices as chemical industry thus the highest volatility in LPG consumption belongs to petrochemical business.

Most steam cracking plants in Europe, about 80% are based on costlier naphtha feedstock and the rest has a flexibility in relation to feedstock use [57]. Only new crackers are able to switch between naphtha and LPG while older crackers don’t have a such flexibility. If the cracking plant uses crude oil as a feedstock than it may not produce the valuable products in high yields, one more plant is to be built on the same site. European crackers are on the way of improving their feedstock effectiveness to safe energy and reduce feedstocks costs. EU petrochemicals have adopted strategies to reduce the dependence on naphtha and increase the use of LPG and ethane [58]. European consumption of U.S. propane has increased significantly and accounts for 2.93 MTPA (EIA, 2016), 10% of the domestic demand. Now these new volumes compete with traditional LPG cargoes from Russia, North Africa and the Middle East.

Due to the development of shale gas in U.S. more NGLs are being produced, approximately 75% of NGLs come from natural gas fields.

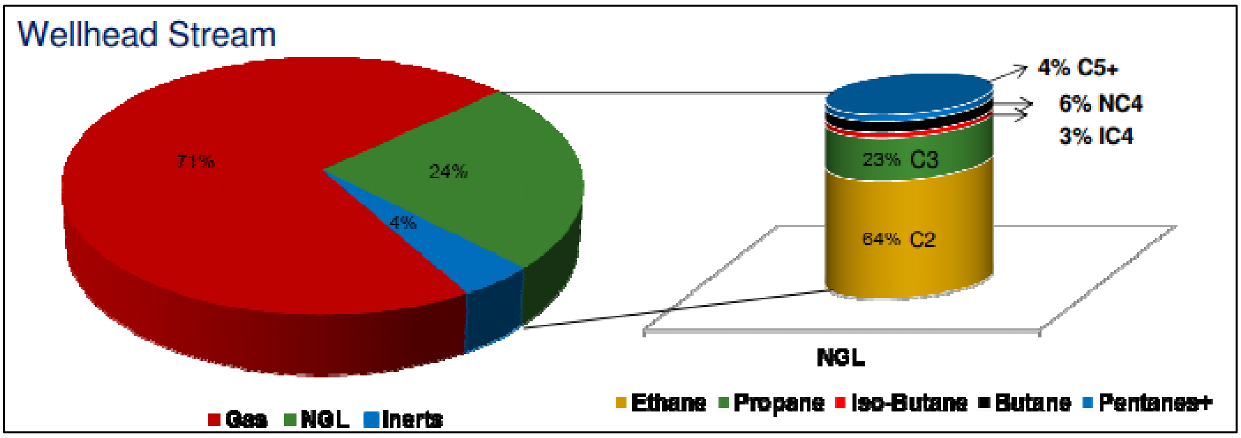

Figure 4-22 NGL yields of U.S. gas stream, EIA

As U.S. propane production has grown significantly and domestic consumption has remained stable, since 2010 the U.S. became one of the largest LPG exporter.

In April 2017, Asian petrochemical industry is seeing a market opportunities to shift their naphtha feedstock to LPG. Around 0.3MT of naphtha in May 2017 (7% of the total Asian naphtha demand) and subsequently 0.4 and 0.45 MT in the next months are expected to be replaced by LPG, taking current advantage of propane price. The actual demand for naphtha in Asia is still not covered by supply, there is a deficit of 4 MT per month in 2016, meaning that at the today's propane price advantage to naphtha, 5 to 15% of the "deficit" naphtha feedstock in Asia could be substituted by LPG. But it's not clear from which regions since the Mont Blevieu (in the U.S.) propane prices were lifted recently and became unattractive for Asian customers. Thus, the Far East interest in U.S. LPG fell.

The rapid development of the U.S. export caused the strong draws in inventories which was the main reason of the increased prices.

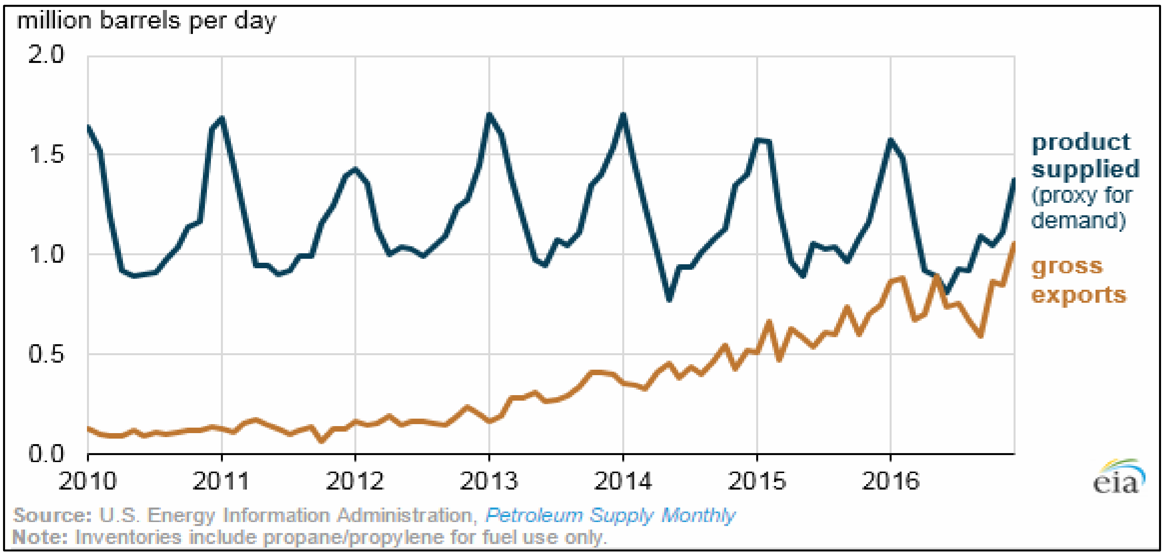

Figure 4-23 U.S. monthly propane supplied and export, EIA

PDH trend.

The process of propane dehydrogenation (PDH) converts propane into propylene which is used in the manufacture of plastics. This process takes place independent of a steam cracker or FCC unit.

The export of U.S. LPG increased mainly to Asia, it tripled in 2015 as the region has significantly increased the interest to propane as a petrochemical feedstock to dehydration units and local suppliers were not able to cover additional demand in such countries like China, Japan and South Korea.

Over the past 4 years, propane export terminals capacities in U.S. increased substantially, reaching about 850,000 b/d (25 MTPA) by March 2015. It is expected that at the Saudi Aramaco contract price premium vs. Mont Belvieu price around 0.4USD/gallon (143USD/ton) the growing U.S. propane export volumes would be mainly placed on Asian market.

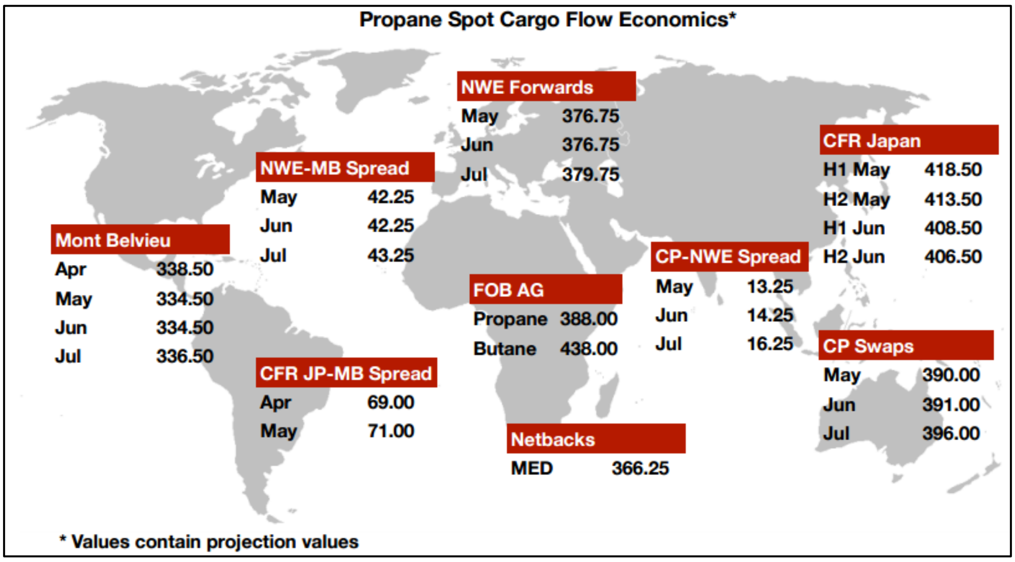

Figure 4-24 Propane Spot prices, April 2017[59]

Ethane trend.

Ethane is mostly the feedstock for the ethylene production, *Figure 4-21*. One of the main producers of ethane is the U.S. Ethane production in the U.S. is expected to increase from 1.25 million b/d (24.13 MTPA) in 2016 to 1.7 million b/d (32.81 MTPA) in 2018 mostly because of the larger liquid components presence in the shale gas, *Figure 4-22* and the U.S. redirection to the extraction of NGL from natural gas instead of selling them in the mixture with gas, without a separation.

Table 4-10 US total Ethane actual volumes and projections, Million b/d, [60]

	2016	2017	2018
Production	*1.25*	*1.6*	*1.8*
Internal consumption	*1.17*	*1.33*	*1.5*
Export	*0.15*	*0.25*	*0.3*

There are 6 new projects and one restarted facility on ethylene production in U.S. which will contribute to a significant increase in ethane internal consumption by 0.31 million b/d (6 MTPA or 26%) from 2013 to 2018 [61].

So, a major part of new developments in the U.S. petrochemical industry belongs to the ethane crackers projects, *Figure 4-25* since U.S. set a plan to consume light feed, predominantly ethane for ethylene production [48].

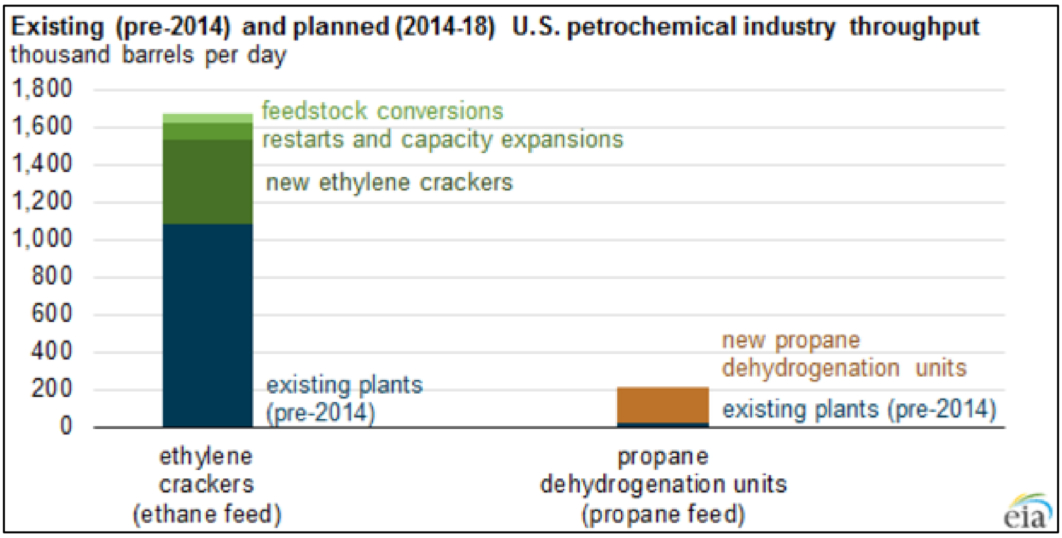

Figure 4-25 Development of the petrochemical industry in U.S, EIA [61]

Most of the ethane plants have one important feature, once a plant converted to ethane it will be not able to switch to other feedstocks, Thor Abrahamsen, Statoil (Personal communication on LPG market, March 7, 2017). So, with new and some expansion projects in ethane crackers, U.S. will represent 1/5 of the current global ethylene production.

With ethane, propane production also increased. It decreased the propane price and consequently increased the spread between propylene and propane prices that facilitated new propane dehydration projects [61].

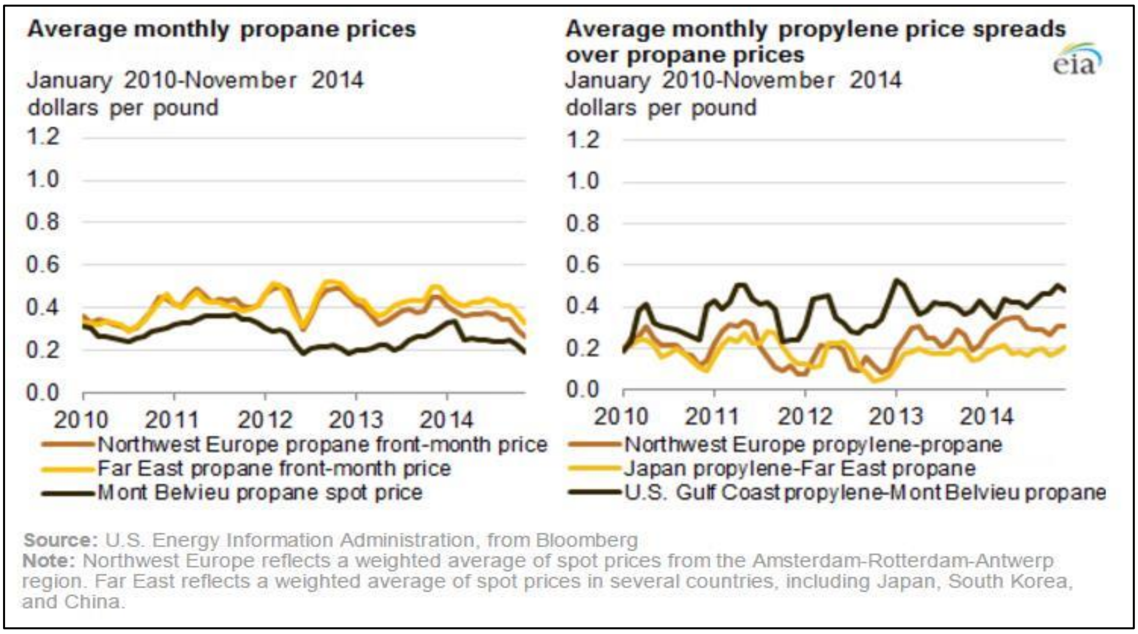

Figure 4-26 Monthly propylene - propane spread, EIA [61]

Table 4-11 US total Propane actual volumes and projections, Million b/d, [61]

	2016	**2017**	**2018**
Production	*2.1*	-	-
Internal consumption	-	-	*0.22*
Export	*0.6*	*0.908*	-

As long as U.S. shale gas production will increase and the fact of high NGLs content in the gas, production of ethane and LPG will grow. With the growing export capacities, LPG and ethane export is expected to build up correspondingly.

Possible future development of ethane and LPG price in Europe.

If the current projects on ethane cracking facilities in U.S. are commissioned, it will contribute significantly to the domestic demand. So that ethane export price may no long be advantageous for the global market. While LPG capacity doesn't increase to the same extent, LPG volumes to Europe will continue to increase that will release pressure on prices. This case was observed in 2016, when due to extra volumes of U.S. LPG, European propane prices became lower than U.S. ethane prices. Thereby, it became no longer economically efficient for European petrochemical industry to buy U.S. ethane cargoes. But due to the fact that ethane cracking plants don't have an ability to switch to another feedstock, the crackers in Europe will rely on these volumes anyway. So, in this case ethane volumes might be locked inside the U.S. market which will take advantage of the current/future ethylene-ethane spread and will potentially sell finished products to the global market. While LPG may play more important role on the global/European market by giving a downward pressure on price.

If the trend for PDH units in U.S. will continue to expand together with the increasing export to Asia and Europe, then U.S. can face the same situation as it had in 2016/2017, when the propane withdrawals were extremely high and inventories went to low level, that caused the spiked prices. It resulted in delay of some PDH projects in U.S. These projects are postponed by 2020-2021. It also impacted on the European market, as export volumes accounts for 10% of the overall region consumption. So, until April 2017, the LPG prices in Europe were increasing and probably will continue to increase until it gets 80-85% of naphtha price (Part 3.2.3). At this price level petrochemicals might consider to decrease LPG offtake that will release pressure on price.

4.4 Possible development of markets

In this chapter, all key factors affecting LNG and LPG markets are combined together and discussed on possible effect on each other.

LNG flooding.

The LNG market flooding means that most of the under construction projects in Australia and USA are already in operation. Firstly, these volumes most probably will be directed to Asian market since this market has historically had a price premium to the European market and since some of U.S. projects became alive because of the Japanese companies' involvement. Asian market is not good diversified and has no enough infrastructure to distribute surge volumes of LNG to end customers. So, it is expected that with the globally increasing LNG volumes the European market will be the most likely destination of additional cargoes.

These volumes might put downward pressure on prices in both Asian and European markets. Since Asia has no enough infrastructure for inland LNG distribution, it will give even greater impact on the regional prices.

The effect of incipient flooding on the world market is starting right now. These new commissioned volumes are relatively small compare to under construction projects but the effect on Asian market is already significant. The Asian-European price spread by May 2017 reached 0.8 $/MMBtu and probably will go even lower as more cargoes from U.S. and Australia will come online. Currently there are no significant impact of additional LNG on European market since market has taken only 1.25 bcm (0.3% of the total Europe's consumption of 2016th) of U.S. volumes by 2017.

The likelihood that Asian market will grow in relation to consuming volumes is quite high. As pointed by many reports the LNG demand will be mostly driven by Asia countries, like India, Pakistan, China etc. as regional production can't cover the growing demand. The region is very dependent on the flexible and cheap source of energy that can be provided by LNG. By 2017 a lot of people in Asia still use kerosene, diesel or other liquid fuels for electricity production which is extremely expensive and inefficient. In some countries, for example, China, the diversification from only a base load to small scale is taking place and will be an issue for other countries like Japan and India that will lead to increased demand for LNG. So, it's expected that with growing volumes companies in Asia will be pushed to change the existing energy sourcing schemes to more green ones. It can be achieved by modernising the trade activity in Asia, taking away destination clauses that will avail for much large competitive position. But such significant changes on the market might take a decade to come true. So, this increasing demand may lead to higher prices in Asian region compare to Europe. In Europe, the increasing development of small scale market may also influence the price picture, but it's not likely as long as the volume's impact of small scale LNG is less than 15% because the current planned and under construction SSLNG volumes account for 12% of the overall receiving capacity in Europe.

Refining margin.

In the case of high refining margin, it was found that market can be flooded by additional volumes of LPG from refineries. Usually very high RM can be observed just after oil prices start weakening trend. High RM case will unlikely significantly impact on large scale LPG market as LPG from refineries represent small scale market and the quality of refined LPG is different from what is required by large scale customers like petrochemical facilities. It's likely that prices will go down, as a result of flooding by additional LPG volumes.

In the U.S.A., in the case of high RM, probably residential sector will be flooded by refined LPG. So, less demand for GPP LPG from local market will allow less volumes from gas processing plants to be splitted to small cargoes, that will lead to larger export volumes.

Lower LPG price as a result of flooding will further facilitate the development of PDH plants. This price may also impact on large cargoes coming into European ports. Higher activity may arise in the large scale shipping in Europe, while small scale shipping activity may stay low. So, it can lead to downward pressure on Seagoing price.

Low small scale LPG prices may give a competition to the small scale LNG market in the energy sector. This case was observed in 2015 when propane price dropped to the level of natural gas price.

In the case of low refining margin, refineries will produce less LPG volumes. This case will take up the LPG price.

Refining margin is very fluctuate parameter. It can be changed in a large amplitude during a very short time period (1-3 months). As has been observed the LPG price also follows this trend. So, LPG has a very large price volatility.

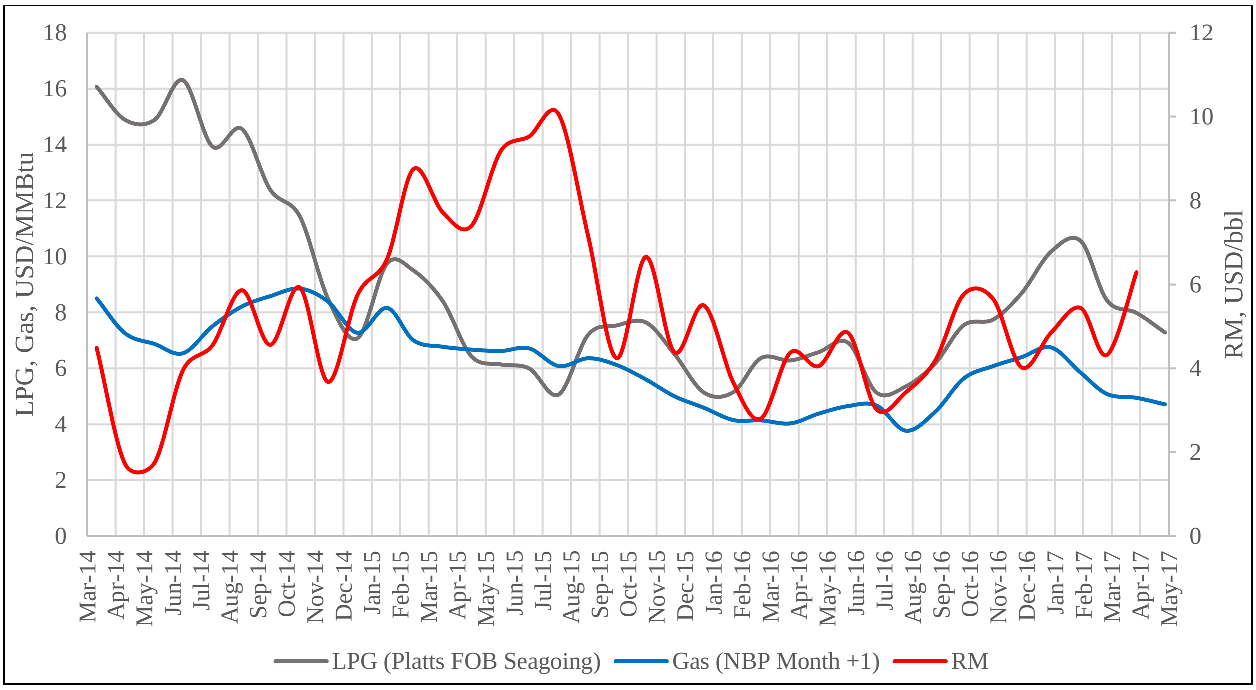

Figure 4-27 Gas and LPG price development

This is not the case for small scale LNG as it is a part of huge gas business and the price depends on the global trend, while small scale LPG is a fraction of the refining business which is targeted at production of other products like gasoline, jet fuels, diesel etc.

LPG & ethane shortage.

As U.S. is going to increase their LNG export to 90 bcma, it means that more gas is going to be produced. Due to the fact that shale gas contains a lot of NGLs, the production of ethane, propane and butane will also increase and extraction of NGLs are getting more attention as a source of revenue for upstream companies. Since volumes of NGLs will increase because U.S. pipeline gas specifications will not change, it will further facilitate the development of ethane crackers and PDH plants. Alongside with developments in petrochemical industry it’s likely that additional LPG volumes can find its application in power production industry as well.

If the development of cracking industry slows then larger export will lead to lower global prices that maybe will facilitate larger expansion of PDH projects in Asia and in Europe.

5 LNG & LPG FOR END-USER IN SCANDINAVIA

The purpose of the study is to show the current share of each fuel; to consider future factors for higher LNG implementation as an alternative fuel in the Scandinavian market.

With the development of gas infrastructure in the region there is a high potential for LNG to replace petroleum products. The main competition between LNG and LPG arises in the energy consumption for steel, iron and chemical industries [61].

One of the main driver to switch from one source of energy to another is the price. Some industries in Sweden are considering the possibility to choose LNG as an energy input to their facilities, some have already switched from LPG to LNG, for example, SSAB participates in Manga LNG project which will be a joint venture of Outokumpu Oyj, SSAB, Skangass and EPV Energia Oy companies, to build the receiving terminal, bunkering facilities and storage of 50,000 cm [62] in Finland. Usually the LPG price was higher than LNG but the recent oversupply on the European market has brought down the price to the gas level, what has increased the interest to LPG. Thus, a few companies in the region are seeing an advantage to come back to LPG utilization, Skangas says. Therefore, the commodities price difference is considered to be one of the main driver for the switching opportunities.

In addition to the price spread some other criteria are to be considered which are the following:

- The increased availability of LNG due to planned and under construction terminals projects.
- Policies drivers, taxes.

5.1 LNG implementation sectors

Only three sectors were investigated for the potential changes in the fuel demand, as follows:

5.1.1 Small-scale ships (SSS)

The IMO regulations drive ship owners operating within the Sulfur Emissions Control Areas region to switch their fuel to alternative ones. The new regulations which came online in January 2015 require all ships to be converted to new fuels with sulphur content less than 0.1% to reduce SOx emissions [63]. In 2014 about 14,000 ships were operated within the SECA in Baltic, North Sea and English Channel [62], thus, there is a great potential for LNG to become the main maritime fuel.

To comply with the requirements, SSS operators have several choices which include:

- switch to low sulfur marine fuels (MGO/MDO/ULSFO);
- consume high sulfur heavy fuel oil while removing sulfur from the emissions;
- shift to LNG fuel.

Thus, IMO pushes shipowners to replace the fuel and technology to comply with new regulations. The decision what fuel to switch will depend on the infrastructure development and fuel prices [62]. There are some constrains with every fuel in option.

As for low sulfur fuels, first of all there are no globally accepted specifications on the producing fuel [64]. Some refineries may offer residual fuel oil of 0.5% sulfur directly from a distillation unit; other refineries produce low sulfur fuel oil using catalysts or hydrogen technologies; or some blends residue from a hydrocracker or vacuum distillation unit with fuel oil and middle distillates. This high range of refinery's offer is not favourable by ship-owners as for example blended products in combination with other fuels may cause forming of a sludge and consequently an engine failure. So, all bunkering port are to have the same specifications on low sulphur fuels.

The second constrain is the price. As the demand for low sulphur fuel will increase it's expected that the price will rise too by 2020 and in accordance with some estimates the daily fuel bills for a container ship burning 100 mt/day will increase by 40,000 USD by 2022 [64].

Another option for shipowners is to use scrubbers. The length of the payback period of such technology is around 4,5 – 5 years [64], in addition it's not clear would all the scrubbers be in frames of environmental regulations over the next decade [64]. It's also predicted that after 2020 the conventional fuel oil availability may become an issue because refineries will be focused on 0.5% globally and 0.1% in SECA sulfur fuels.

Some companies mainly in Europe and North America are considering LNG as a future marine fuel, as it fully meets new and upcoming regulations in relation to sulphur, nitrogen, particulate matter and carbon emissions and there are no differences in LNG fuel specifications all over the world. As can be seen on the *Figure 5-1*, gas has much more favourable price in comparison to fuel oil and as has been discussed above, the LNG price in Europe is unlikely to increase significantly that makes LNG more favourable.

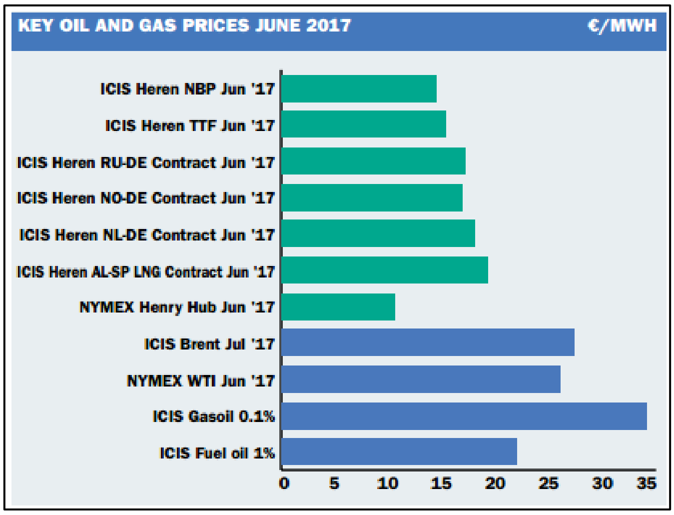

Figure 5-1 Oil and gas prices, June 2017, ICIS

The main concern in implementation of LNG is the upfront investments. The availability of the LNG bunkering infrastructure is becoming a less critical question at least in NWE and Scandinavia in particular. The fuel in the regions can be delivered by ships or by trucks. Another concern is the space that LNG engine will occupy on board, as it will reduce the volume of cargo a ship can carry [64].

Moreover, there are new regulation in relation to NOx content, NOx Tier III is shown in the table below. But by 2017 these regulations are applicable only in NOx Emission control areas (NECA) in North American and U.S. Caribbean areas and the decision for implication in Europe is postponed by 2021 [64].

Table 5-1 NOx emission limits, [65]

Tier	**Ship construction data or after**	**Total weighted cycle emission limit, g/kWh n – engine's rate speed, rpm**		
		n<130	**n=130 - 1999**	**≥2000**
II	*1 January 2011*	*14.4*	*44 * $n^{-0.23}$*	*7.7*
III	*1 January 2016*	*3.4*	*9 * $n^{-0.2}$*	*2.0*

Due to the high combustion temperatures in marine engines the presence of NOx during fuel oil combustion is very high, but there are some methods as water injection or selective catalytic method to reduce the NOx content in exhaust gases.

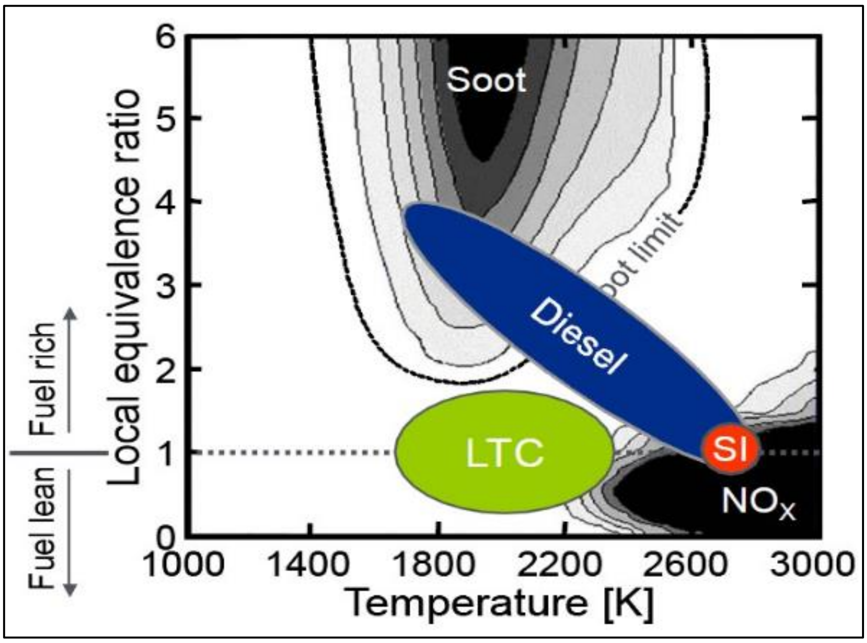

Figure 5-2 Working regime of diesel engine

So, fuel oils are not favourable for marine transportation as it doesn't meet NOx upcoming requirements, while the implementation of scrubbers will meet both Sox and NOx regulations.

If the IMO regulations become global then large number of ships are to shift to alternative fuels and for LNG to win the market share as an alternative fuel the availability and infrastructure are the critical issues.

As for LPG, it is not an alternative marine fuel because it's heavier than air and in a case of a leak it will accumulate in a low section of a ship's engine and as such will have an explosion risks and therefore it's not allowed to use as a marine fuel.

5.1.2 Light and Heavy Duty Vehicles

North America, Western Europe, Scandinavia and Japan are taking leading positions in the adoption of reducing emissions measures. There is a potential for liquefied gas fuel to be used in the light and heavy duty vehicles such as vans and trucks which travel the greatest distance annually.

As air pollutant emissions from transportation sector are substantial contributors to the air quality, European Commission has adopted emission regulations "Euro emissions standards" for different type of vehicles. New EURO VI has been developed for light duty vehicles and heavy duty vehicles are subject to EURO VI, *Table 5-2*.

Table 5-2 Emissions for road transport, EC

	Standard	CO, g/kWh	NOx, g/kWh	HC+NOx, g/kWh	PM, g/kWh
Light Duty Vehicle	**EURO V**	*0.74*	*0.280*	*0.350*	*0.005*
	EURO VI	*0.74*	*0.125*	*0.215*	*0.0045*
Heavy Duty Vehicle	**EURO VI**	*4*	*0.46*		

Alongside with the air pollutant emissions European Commission has ambitious in relation to greenhouse emissions. The aim is to reduce the emissions by 60%. To reach the goal in the transportation sector, the Roadmap 2050 and Transport White Paper were developed.

Alternative fuels Directive considers LNG as a possible cost-efficient technology allowing heavy-duty vehicles to meet the strict pollutant emission limits of Euro VI standards [65]. The main part of the road transport fuel consumption relies on diesel and gasoline. As can be seen from the *Figure 5-1*, the current petroleum products price is much higher than natural gas. The transition to gas choice gives the economic benefit as well as the environmental advantage.

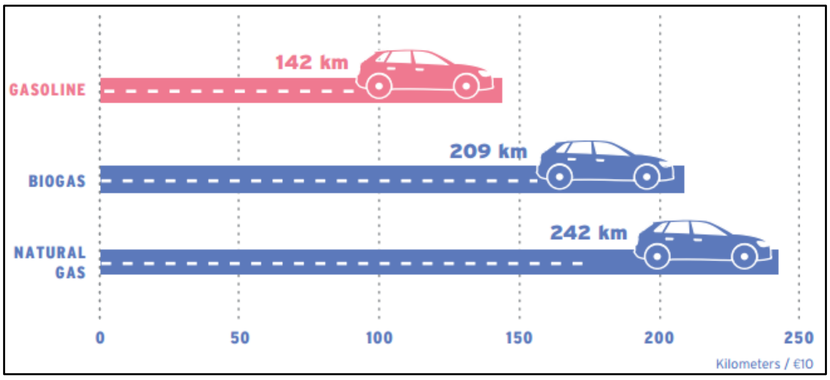

Figure 5-3 How far you can drive by paying 10 euros

5.1.3 Industry

There are strong fundamental considerations for industries to convert away from petroleum fuels. Gas turbines are not a new technology, have relatively low cost and are already prevalent in the industry. There are many constrains with identifying attractive conversion, gaining manager's attention and access to capital. Despite many challenges, industries in the region with sparse grids (Nordic countries, Poland, etc.) have already found LNG beneficial.

The cap for fixed installations decreases each year by a linear regression factor of 1.74%, due to that fact, emissions in 2020 will be 21% lower than it was in 2005. In addition, European Commission revised the cap rate and decided to even increase it to 2.2% from 2021 in order to reach the 2030 target which is 43% lower of the 2005 level.

In accordance with the new report by the Point Carbon, the carbon price will recover next few years and reach on average 10 EUR/ton by 2020 and 26 EUR/ton by 2030. There is a high oversupply of the market by 1.7 billion allowances, but the experts forecast the elimination of the carbon permit surplus which means that the market is going to be tighter over the time.

In accordance with these changes a case study was done to see what is the CO2 emission price difference between LNG and LPG is going to be in the nearest future. The amount of CO2 emitted from LNG equals to 181 kg CO2/MWh and for LPG is 210 kg CO2/MWh.

Table 5-3 CO2 emission calculations

	2016	**2020**	**2030**		
Price CO2, *EUR/t*	**6.6**	**10**	**15**	**25**	**50**
Cost of emitted CO2 from LNG, *EUR/MWh*	*1.19*	*1.81*	*2.71*	*4.52*	*9.04*
Cost of emitted CO2 from LPG, *EUR/MWh*	*1.38*	*2.10*	*3.14*	*5.24*	*10.48*
Difference between LPG and LNG costs, *EUR/MWh*	*0.19*	*0.29*	*0.43*	*0.72*	*1.43*

The calculations are based on the data taken from the Point Carbon report, and as can be seen there is a small cost advantage in case of LNG; the CO2 cost difference for two fuels will grow with the continuously increasing CO2 price. The cost of CO2 accounts for 5.3% of the LNG price and for 5.2% of the LPG price in 2016.

Sweden.

The Swedish final energy consumption accounts for 38.9 Mtoe (365 TWh) in 2015, the natural gas covers about 2% of the total energy needs while oil share accounts for 30% [66]. The main consumer of energy in Sweden is industry, accounting for about 40% of total use and it is expected to increase by 40 TWh, 28.5% by 2030 which facilitate future increase in energy demand.

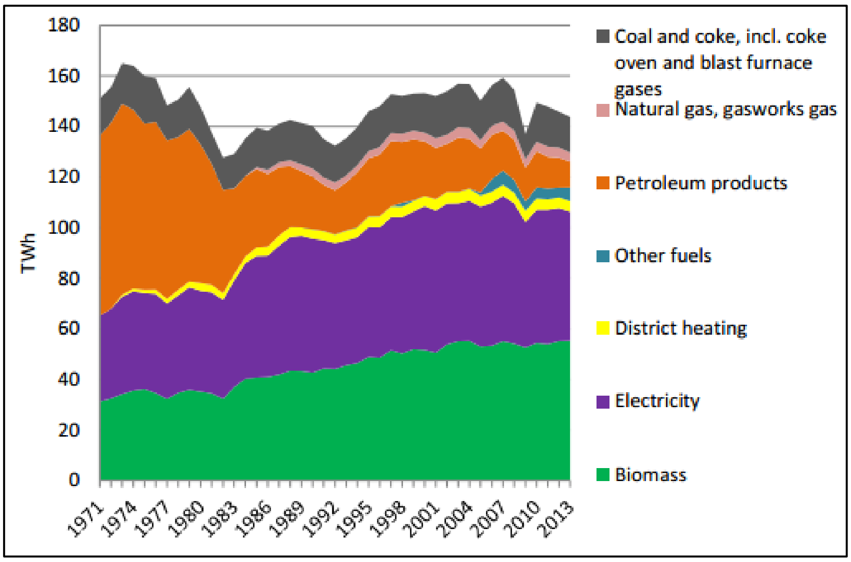

Figure 5-4 Swedish industrial energy use [67]

The industrial use of petroleum energy is mainly based on fuel oil (heavy oil) and LPG, the share of the last has increased over last years. The basic metals, steel and paper industries are the most energy consuming sectors which are very interested in a cheap, robust and energy efficient fuel. The *Table 5-4* presents the fuels consumption by industry in Sweden. Heavy fuels, coal and LPG might be potential customers to convert to LNG.

Table 5-4 Energy consumption in Sweden in 2016, TWh

Industry	**LPG**	**Natural gas**	**Heavy fuel oil**	**Coal**
Industry for chemicals petroleum products, etc.	*0.20*	*1.12*	*0.14*	-
Industry for basic metals	*2.24*	*1.07*	*0.58*	*3.53*
Iron and steel mills	*2.01*	*0.99*	*0.14*	*3.14*
Electric power stations, gasworks and heating plants	-	*4.07*	-	-
Industry for pulp, paper	*0.58*	*0.44*	*1.24*	*0.05*
Total	***5.03***	***7.68***	***2.1***	***6.71***

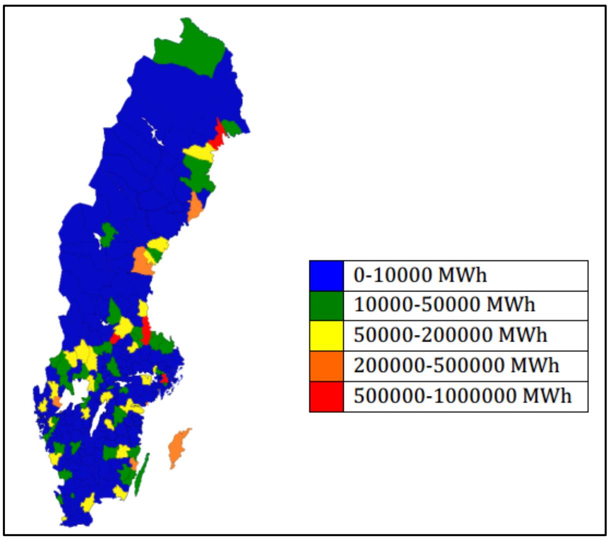

Figure 5-5 Swedish oil consumption. The Central and North-eastern part are potential areas to switch to LNG

The Finland's total energy consumption in 2016 reached 371 TWh, where the main sources were electricity, 22.9%, wood fuels, 26% and oil, 23%, while natural gas had 22.3 TWh (6% of the energy share) where 5.2 TWh was delivered as LNG. The industrial energy consumption has been 45% of the total, accounting for 167 TWh.

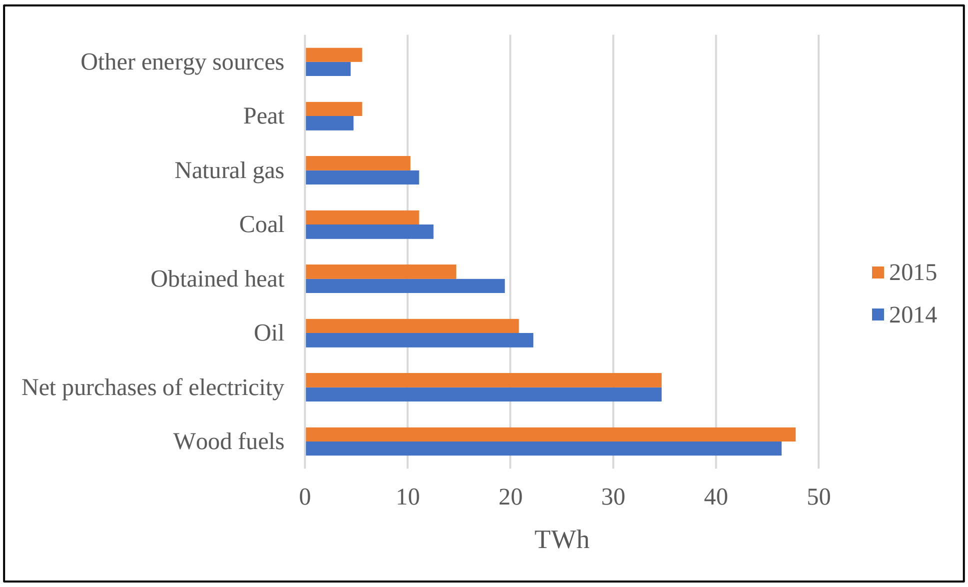

Figure 5-6 Finland's industrial consumption, IEA [68]

The LPG consumption in Finland's manufacturing sector amounts for 2.57 TWh while natural gas is 10.4 TWh in 2015. Finland has plans to decrease their dependency on oil, in accordance with the government forecast the total petroleum consumption is projected to fall to around 7.2 TWh by 2030.

In order to estimate the future Scandinavian LNG and LPG demand many assumptions were taken. Firstly, there were no considerations about renewable energy and electricity as a possible conversion sources. Secondly, it was assumed that the future increase in the industry demand will rely on gas. As for Sweden, the industrial consumption is expected to increase by almost 30% by 2030. Thus, it's assumed that LNG may rise and LPG may stay the same by 2020.

The same relationship is implied for Finland's market as the oil share in the energy use is projected to decrease by around 27%.

Table 5-5 Projections on countries' industrial energy consumption, by fuel, TWh

Fuel consumption		**2016**	**2020**	**2030**
Sweden	**Gas**	*7.68*	*8.83*	*11.48*
	LPG	*5.03*	*5.03*	*4.28*
Finland	**Gas**	*10.40*	*11.95*	*13.51*
	LPG	*2.57*	*2.18*	*1.80*

5.2 Supply chains costs

As has been found the price spread between two fuels is one of the main driver for companies to make a decision on switching from LPG to LNG. Companies would like to see sufficient market signals to make the decision and be sure that the conversion will bring cost savings.

There are four stages of the LNG and LPG supply chains: liquefaction, storage, shipping and transportation to an end customers via pipelines, trucks or railways (LPG).

5.2.1 LNG supply chain in Scandinavia

There are two options for small-scale LNG companies either to produce LNG themselves or to buy from other liquefaction facilities. The Scandinavian market can be supplied by LNG either from Norway and Finland or from regasification facilities in Netherlands/Belgium and Lithuania.

The cost analysis of the LNG chain is done by considering three supply routes in NWE: the first one is the production at Risavika liquefaction facility, Skangas, the second one is buying LNG at Rotterdam terminal, and the third is reloading at Klaipeda FSRU terminal. Lysekil terminal in the southwestern part of Sweden was chosen as a destination point. The CAPEX, administration costs and profit element are not included in any of the chain cost calculations/assumptions. All calculations below based on the Skangas data. The conversion factors used in the calculations are outlined in the Appendix 3**.**

In order to estimate the LNG chain costs, the number of hours being spent for each sourcing route is to be considered. The average reloading time for the 15,000 cm ship is about 12 hours; the discharging time for the same ship is also around 12 hours. In the table below timing of different routes is presented.

Table 5-6 Timing of different routes, hours, Skangas

	Reloading	**Shipping**	**Discharging**	**Shipping**
Risavika - Lysekil	*12*	*24*	*12*	*24*
Gate – Lysekil	*12*	*32*	*12*	*32*
Klaipeda – Lysekil	*12*	*48*	*12*	*48*

The LNG price for the first case (Risavika to Lysekil) is

LNG price = feedstock cost + transportation to Risavika + liquefaction + storage (5.1)

The shipping costs for all routes is the following

Shipping cost = Daily cost of the ship + fuel cost (5.2)

where ***daily cost of the ship*** including the crew costs;

fuel cost – cost per shipping day. When the ship reloads/discharges the cost per day is less (1500 EUR/day) than when it moves (5000 EUR/day).

Based on the information above the following calculations were established.

Table 5-7 Risavika to Lysekil, 3 days round trip (72 hours)

Chain elements	**Cost**		
	USD/MMBtu	**EUR/MWh**[4]	**USD/ton**
LNG price[5]	*6 – 7.5*	*18.9 – 23.7*	*320.3 – 400.4*
Shipping cost, round trip	*0.2 – 0.25*	*0.6 – 0.8*	*10.7 – 13.4*
Total	***6.2 – 7.75***	***19.6 – 24.5***	***331 – 413.7***

The second supply chain is considering the purchase of LNG on the TTF hub, at port of Rotterdam and shipping to Lysekil.

Table 5-8 Rotterdam to Lysekil, 3.67 days round trip (88 hours)

Chain elements	**Cost**		
	USD/MMBtu	**EUR/MWh**	**USD/ton**
LNG price[6]	*5.0 – 7.0*	*15.8 – 22.1*	*266.9 – 373.7*
Shipping cost, round trip	*0.25 – 0.3*	*0.8 – 0.9*	*13.3 – 16.0*
Terminal costs	*0.48*	*1.5*	*25.1*
Premium on top of the hub price	*0.48 – 0.8*	*1.5 – 2.5*	*25.1 – 41.9*
Total	***6.2 – 8.6***	***19.6 – 27.1***	***330.5 – 456.6***

[4] EUR=1.08 USD.

[5] The LNG price was taken as ICIS Heren NO-DE Contract gas price, 5.49 USD/MMBtu for May,17 + assumed liquefaction cost, 1.5-2 USD/MMBtu.

[6] Assumption: price on the TTF hub.

Table 5-9 Klaipeda to Lysekil, 5 days round trip (120 hours)

Chain elements	Cost		
	USD/MMBtu	EUR/MWh	USD/ton
LNG price*	*6.0 – 7.5*	*18.9 – 23.7*	*320.3 – 400.4*
Shipping cost, round trip	*0.3 – 0.4*	*0.9 – 1.3*	*16.0 – 21.4*
Terminal costs	*0.48*	*1.5*	*25.1*
Total*	***6.8 – 8.4***	***21.4 – 26.5***	***361.4 – 446.8***

* The price is chosen based on the personal estimation of average hub price and Russian pipeline gas
**The price doesn't include the premium.

In accordance with the calculations, the Rotterdam to Lysekil route seems to be the cheapest sourcing route. The costs premium of the Rotterdam trip to the Risavika choice is 0-2.5 EUR/MWh and to Klaipeda is 1-1.8 EUR/MWh. As has been found, the cost of LNG transportation per day vary from 0.2 to 0.3 EUR/MWh/day.

5.2.2 LPG supply chain in Scandinavia

For the LPG chain assessment, the following two supply routes were chosen: Stegnunsund, Sweden – Sundsvall, Sweden, and Stegnunsund – Karlshamn, Sweden.

The shipping time from Stegnunsund to Sundsvall is 2 days (48 hours). The shipping cost for the vessel (15,000cm) includes harbour and bunker costs (freight costs given by Statoil, Personal communication).

Table 5-10 LPG Supply Chain Calculations, Stegnunsund to Sundsvall

Chain elements	Cost		
	USD/MMBtu	EUR/MWh	USD/ton
LPG price[7]	*7.5 – 9.0*	*23.67 – 28.41*	*357.75 – 429.3*
Shipping cost, round trip	*0.52*	*1.65*	*25*
Total	***8.02 – 9.52***	***25.32 – 30.06***	***382.75 – 454.3***

The second supply chain route was chosen from Stegnunsund to Karlshamn, which takes 20 hours.

*Table 5-11 Supply Chain Calculations, Stegnunsund to **Karlshamn***

Chain elements	Cost		
	USD/MMBtu	EUR/MWh	USD/ton
LPG price	*7.5 – 9.0*	*23.67 – 28.41*	*357.75 – 429.3*
Shipping cost, round trip	*0.31*	*0.99*	*15*
Total	***7.81 – 9.31***	***24.66– 29.4***	***372.75 – 444.3***

[7] Assumed LPG price range, as for the April 2017 it's 355 USD/ton (Platts Seagoing).

As most of the energy consumers are placed inland and there is no gas pipeline infrastructure, the delivery of LNG is done by trucks. The LPG transportation in Sweden is mainly done by trucks for short distances but for remote customers, LPG is transported by rail way, as the operational costs of LPG railroad carriages is high.

The daily small scale shipping costs for LNG is found based on the calculations above as 0.2-0.3 EUR/MWh/day and for LPG it's 0.7-0.9 EUR/MWh/day.

Table 5-12 Sea and road transportation costs of LNG and LPG

	LNG		**LPG**		
	Sea	**Land**	**Sea**	**Land**	**Railway**
Cost, EUR/MWh/100km[8]	*0.036-0.04*	*0.8-0.9*	*0.07- 0.13*	*0.9-1.1*	*0.5-0.8*[9]
Volume of a vehicle, cm	*15000*	*50*[10]	*15000*	*30*	*50*
Cost, EUR/ton/km	*0.006 – 0.007*	*0.13*	*0.01-0.02*	*0.15*	*0.08-0.12*

The evaluation of two supply chains give the costs allocations of each chain element. From the table above it can be observed that the shipping cost of LPG is two times expensive than LNG. The railway transportation of LPG become more cost efficient with the increasing distance, Jan Wahlqvist (Peronal communication, Flogas). So, railway LPG transportation for distances larger than 200 km seems cheaper compare to LNG/LPG truck transportation.

5.3 Key criteria for LNG competitiveness

5.3.1 Fuel availability

The recent shale gas revolution in the USA, continuously increasing volumes from Australian liquefaction facilities, Qatar plans to produce more LNG, new cargoes coming from Russia are expected to keep the global and especially European markets LNG price low. European market becomes more diversified, much larger number of exporters come online, therefore the availability of the fuel is expected to keep strong position. Gas is one of the main commodities in the world and LNG is just a mode of transportation. Thus, the price of LNG is not significantly different from gas price and it follows the same trend as gas.

In the case of LPG, large and small scale markets have different sourcing schemes. Most probably on the large scene LPG availability will also increase as the portion of still expanding shale gas projects in the U.S.A. But small scale LPG market is a fraction of refining business and the volumes seem to be very dependent on production of other products. Therefore, the availability of two commodities in large and small scales have the following picture:

- gas/LNG market will change as a function of such factors as supply, demand;

[8] The energy content of LNG is 7.05 MWh/cm and LPG is 9.32 MWh/cm.

[9] Assumption: the transportation cost is for distance larger than 200 km.

[10] The maximum allowed volume of the truck in Sweden and Finland is 80 cm. 50cm truck is to be considered in a case of Norway.

- while LPG will change as a derivative of dependant variable (other products) since LPG is not a major commodity.

High availability of LNG can be proved by large scale projects all over the world, while LPG availability might also increase but will be always disrupted by various factors.

5.3.2 Price volatility

Some companies in the Nordic region have converted from oil to LPG as it has lower price and lower emissions, others switched from LPG to LNG. Usually the LPG price was higher than LNG but the recent oversupply on the European market has brought down the price to the gas level, what has increased the interest to LPG. So, some companies in the region see the advantage to come back to LPG utilization.

So, price is very important criteria for companies to choose whether to use LPG or LNG. As has been found, even if the future prices for both commodities are similar, the taxation changes may bring additional costs to LPG and in accordance with many reports the taxation difference will grow over the next decades.

The switching to another energy source is expensive procedure. Today companies may get government support as well as interested companies-suppliers of LNG may also participate in such an activity as Skangas does in the Manga LNG project in Finland.

Small scale LPG is a fraction of refinery's production, it's a by-product. As has been discussed, refinery industry is very complex business with so many output products and LPG volumes depend on these products (light/middle distillates) demand/supply picture. So, probably that is the reason why LPG price has high volatility compare to gas price.

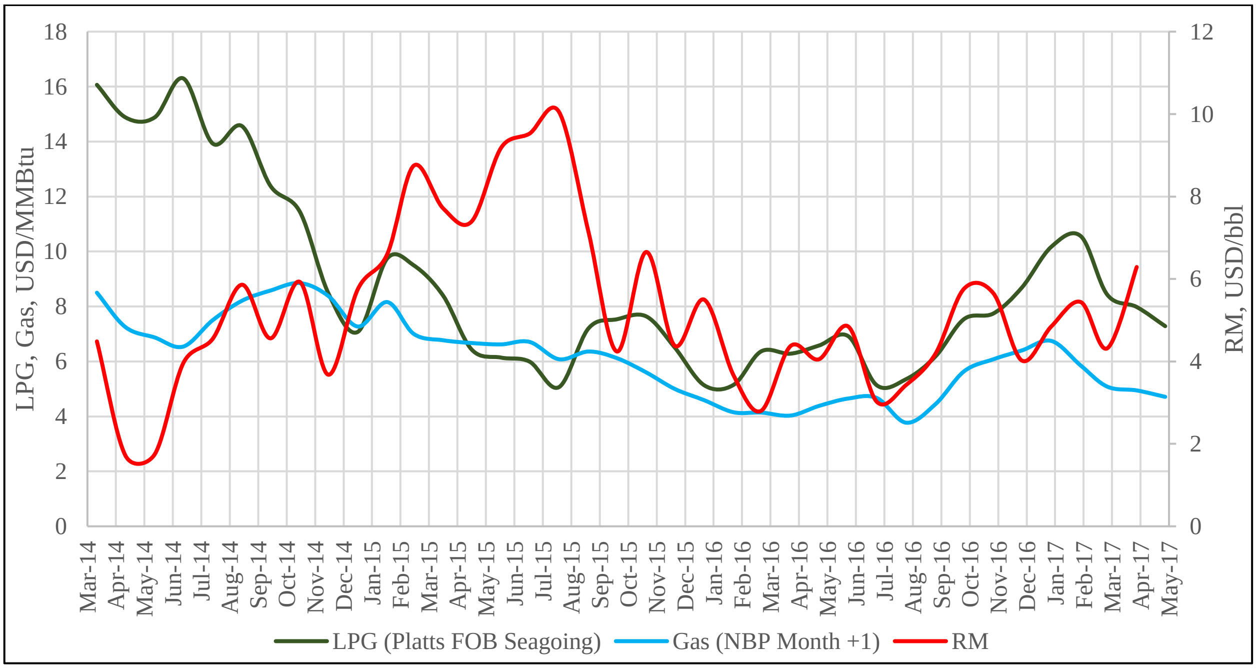

Figure 5-7 Price volatility

It's always a high uncertainty about the future LPG price which can be a disturbing factor for customers who is considering whether to use LNG or LPG.

5.3.3 Environmental/political factors

In accordance with new IMO regulation on sulphur and NOx content in maritime industry; new EURO VI standards on CO, NOx, particular matter emissions; and in particular the increasing cost of emitted CO2, EUR/ton, fossil fuels will be affected negatively and might lose its position in the energy mix of the Scandinavian region, since natural gas is much more environmentally favourable fuel.

The switch to the more environmentally friendlier energy can be supported by governments. Sweden made a step towards the green energy use by introducing higher tax on CO2 emissions. However, the actual transition to LNG might find it challenging in comparison with other energy sources which are CO2-neutral.

6 DISCUSSION

The purpose of the thesis was to find key criteria affecting the development of competing markets.

The first key parameter affecting both markets in competition is LNG market flooding. It's expected that with the globally increasing LNG volumes and further Asian market liberalization, Europe may become the most likely destination of additional cargoes that will put downward pressure on the market. The actual flooding effect on the European market will probably be fully visible after 2020 when all under construction projects mainly in the U.S. and Australia will be commissioned. U.S. LNG may compete with traditional Russian pipeline gas on the European market. EU's current policies on diversification and security of supply might give a preference to U.S. cargoes. But this picture can be disturbed by increase in Asian demand.

The likelihood that Asian demand will rise is quite high. Currently, more attractive LNG prices in the region will probably push companies to change the existing energy sourcing schemes to more green ones. The same structural changes as it has happened in Europe may happen in Asia as well. Low price may facilitate further construction of reception facilities and development of distributed LNG market. But this increasing demand may lead to higher prices in Asian region and then may become more attractive destination of surge volumes.

But it's expected that significant development of Asian demand may arise after 2025. So, in the nearest future globally traded LNG will be spread between Asian and European market. And since in the U.S. owners and operators of LNG facilities are usually different companies, companies buying gas on the Henry Hub may stop liquefaction (Chapter 4.1.3.2).

There are two sources of LPG – gas processing plant and refinery. LPG from GPP dominantly represents large scale market while refined LPG reflects the small scale market. The competition between LNG and LPG in Nordic region arises in the small scale market where one of the main consumers is energy generation sector.

It was found that a refining margin can be the second key factor affecting balance between markets. The relationship between LPG price and refining margin was established. At high RM production of valuable products such as gasoline, jet kerosene and diesel go up that kicks up the LPG production as well. This leads to downward pressure on prices. Low RM brings low LPG production and consequently higher prices. As has been discussed, Europe will rely on middle distillates production that may actually increase the LPG volumes on the small scale market. But again, the LPG availability profile is fluctuating parameter.

The third key influencing factor is LPG & Ethane shortage. With the increasing shale gas production in the U.S. more attention to NGLs recovering takes place as a source of revenue for upstream companies. Additional volumes of LPG and ethane reduce the price on the local market and later may impact on the global price picture. To take the advantage of low prices some Ethane cracking and PDH projects may further be developed. If it happens then the U.S. may reduce their presence in the global LPG and ethane market that may increase prices. If the development of cracking industry in the U.S. slows then larger export will lead to lower global prices that may facilitate larger expansion of PDH projects in Asia and Europe.

These all factors give a very complex impact on the balance between LNG and LPG. But the main trends are clear, they are outlined in the Conclusion.

7 CONCLUSION

- The fuel availability is very important factor affecting the balance between LNG and LPG. LNG availability is the main criteria which facilitates the further replacement of LPG by LNG. Upcoming LNG projects will support the fuel presence on the global market. The market already shows the high availability of the commodity. So, LNG will be favoured and supported by availability.
- LPG availability will also increase as the portion of still expanding shale gas projects in the U.S. but it will always be disrupted by various factors as LPG is a fraction either of gas processing or refinery production. So, LPG will be punished by variability.
- Price is a crucial factor for companies to choose whether to use LPG or LNG, so price is the second influencing factor. LPG price is very fluctuating compare to the LNG price as it’s dependent on the numerous output products of a refinery such as light/middle distillates. LNG represents huge gas market where the price reflects supply/demand picture.
- Environmental aspects are also very important. Even if the future prices for both commodities are similar, the taxation changes may bring additional costs to LPG and in accordance with many reports the taxation difference will grow over the next decades which may give future attractiveness to LNG.

REFERENCES

1. U.S. Energy Information Administration, *International Energy Outlook 2016*. 2016.
2. Census. *International Statistics. Population.* 2017; Available from: https://www.census.gov/population/international/.
3. BP, *BP Statistical Review of World Energy*. 2016.
4. BP, *BP Energy Outlook*, 2017, Editor. 2017.
5. ExxonMobil, *2017 Outlook for Energy: A View to 2040*. 2017.
6. Weems, P.R., *OVERVIEW OF ISSUES COMMON TO STRUCTURING, NEGOTIATING AND DOCUMENTING LNG PROJECTS.* e International Energy Law and Taxation Review, 2000(8).
7. Halmø, T.M., *The Gas Value Chain*. 2017.
8. Jensen, J.T., *The Development of a Global LNG Market Is it Likely? If so, When?* 2004.
9. IGU, *2017 World LNG Report*. 2017. p. 98.
10. IGU, *Small Scale LNG*. 2015.
11. U.S. Energy Information Administration, *Increase in rail shipments of propane, butane to West Coast offsets decreasing production*, W.W. Arup Mallik, Editor. 2017.
12. Eckersley, M.S.a.N., *Keep up the pace.* Hydrocarbon Engineering, 2014.
13. U.S. Energy Information Administration, *Annual Energy Outlook with projections to 2050.* 2017.
14. Ltd., A.M., *Liquefied Petroleum Gas (LPG) Consumption in Europe: Division of Supply between Gas Processed and Refined LPG / A Summary of the Report for the European LPG Association (AEGPL).* 2013.
15. WLPGA, *WLPGA Statistical Rewiev of Global LP Gas*
2008.
16. Mobil, E., *2017 Outlook for Energy: A View to 2040*. 2017.
17. IEA, *Global Gas Security Review. How Flexible are LNG Markets in Practice?* 2016.
18. Strategies, G., *LNG Outlook 2017: Surplus or balance?* 2017.
19. IGU, *Whole Sale Gas Price Survey*. 2016.
20. Stern, J., *International gas pricing in Europe and Asia: A crisis of fundamentals.* Energy Policy, 2014. **64**: p. 43-48.
21. DooHo, C. *The effect of shale gas revolution on oil industry*. 2013.
22. U.S. Energy Information Administration, *U.S. propane exports increasing, reaching more distant markets*. 2015.
23. Jan Muller, G.H., Alfred Muller *Modeling the price of natural gas with temperature and oil price as exogenous factors*. 2012.
24. Mu, X., *Weather, storage, and natural gas price dynamics: Fundamentals and volatility.* Energy Economics, 2007. **29**(1): p. 46-63.
25. ENGSTROM, D., *Pricing of Liquefied Petroleum Gas in North-West Europe*, in *Faculty of Engineering, Centre for Mathematical Sciences, Mathematical Statistics*. 2014, Lund University.
26. Mishra, D.A.K., *IS THERE ANY CRUCIAL RELATIONSHIP AMONGST ENERGY COMMODITY PRICES AND PRICE VOLATILITIES IN THE U.S.?* International Journal of Quantitative and Qualitative Research Method, 2013.
27. Atle Oglend, M.E.L., Petter Osmundsen, *Shale Gas Boom Affecting the Relationship Between LPG and Oil Prices.* The Energy Journal, 2015. **36**(4).
28. Commision, E., *Clean Energy For All Europeans*. 2016.
29. WPCI. *Benefits of LNG*. Available from: http://www.lngbunkering.org/lng/environment/benefits-of-LNG.
30. Commission, E., *European Energy Security Strategy*. 2014.
31. Parliament, E. *Liquefied Natural Gas in Europe*. 2015.
32. Commission, E., *Quarterly Report on European Gas Markets*. 2016.
33. ICIS, *Global LNG Markets*, in *ICIS*. ICIS.
34. ICIS, *Global LNG Markets*, in *ICIS*. 2017, ICIS.
35. Total. *YAMAL LNG: THE GAS THAT CAME IN FROM THE COLD*. 2017; Available from: http://www.total.com/en/energy-expertise/projects/oil-gas/lng/yamal-lng-cold-environment-gas.

36. LLP, K.S., *LNG in Europe 2016/2017: An Overview of LNG Import Terminals in Europe*. 2016.
37. Europe, G.I., *European LNG infrastructure: from large-scale to small-scale status and outlook*, in *2nd Intern. LNG Congress*. 2016: Hamburg.
38. International Energy Agency, *Global Gas Security Review. How Flexible are LNG Markets in Practice?* 2016.
39. Gazprom, *Baltic LNG*. 2016.
40. Commission, E., *First gas interconnector Poland – Lithuania ends energy isolation of the Baltic States*. 2015.
41. World, N.G., *Lithuania exports 1st small LNG cargo*. 2017, Natural Gas World.
42. Inc., M., *AN INTRODUCTION TO PETROLEUM REFINING AND THE PRODUCTION OF ULTRA LOW SULFUR GASOLINE AND DIESEL FUEL*. 2011.
43. U.S. Energy Information Administration, *Crude oil distillation and the definition of refinery capacity*. 2012.
44. (RTSG), C.R.T.S.G., *Oil Refining in the EU in 2015*. 2007.
45. Sadeghbeigi, R., *Fluid Catalytic Cracking Handbook, Third Edition*. Vol. ELSEVIER. 2012.
46. engineer, S.s.r., *Oil refining and LPG production* 2017.
47. Argus, *Statistical Review of Global LPG 2016*. 2016.
48. EIA, U.S. *Increase in rail shipments of propane, butane to West Coast offsets decreasing production*. 2017; Available from: https://www.eia.gov/todayinenergy/detail.php?id=30572.
49. Abrahamsen, T., *LPG market*. 2017.
50. Opportune LLP/Matt Flanagan, T.M., Phil Steed, Mauro Fiorucci, *European Refining – Part 1, Historical Perspective and Assessment*. 2016.
51. LPG Trader, S., *Interview on LPG market*. 2017.
52. Hashimoto, H., *A new phase of the global LNG market development. Rapid expansion of production capacity and uncertain demand prospects.* IEEJ Energy Journal, 2017.
53. Federal Energy Regulatory Commission. Department of Energy, *North American LNG Export Terminal. Proposed*. 2017.
54. ICIS, *US ENERGY INDUSTRY: OBAMA VS TRUMP*. 2017.
55. https://www.eia.gov/todayinenergy/detail.php?id=30052.
56. Techno-Research, M.C. *Global Supply and Demand of Petrochemical Products relied on LPG as Feedstock*. 2017.
57. CIEC, T.U.o.Y. *Cracking and related refinery processes*. 2014.
58. ICIS, *Europe petrochemical producers to hike naphtha use in crackers*, C. James, Editor. 2017: London.
59. ICIS, *EPCA: EU moves to ethane*, S. Milmo, Editor. 2014.
60. OPIS, *Asia Naphtha & LPG Report*. 2017.
61. U.S. Energy Information Administration, *Growing U.S. HGL production spurs petrochemical industry investment*. 2015.
62. Consortium, L.M., *LNG Masterplan for Rhine-Main-Danube. LNG Demand Study*. 2015.
63. SSAB, *SSAB to invest in using liquefied natural gas (LNG)*. 2014.
64. Platts, *Tackling 2020: the impact of the IMO and how shipowners can deal with tighter sulfur limits*. 2017.
65. Hulda Winnes (IVL), E.F.I., Katarina Yaramenka (IVL) et. al., *NOx controls for shipping in EU Seas*. 2016, Transport & Environment Sweden.
66. Union, E., *DIRECTIVE 2014/94/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the deployment of alternative fuels infrastructure* Official Journal of the European Union, 2014.
67. International Energy Agency, *Energy Policies of IEA Countries. Sweden, 2013 Review*. 2013.
68. Agency, S.E., *Energy in Sweden 2015*. 2015.

APPENDIX

Appendix 1.

Table 1.1 - NWE LNG import terminals

Country	Name of terminal	Operational, bcm(N)/y	Planned, bcm(N)/y	Under construction, bcm(N)/y	Year	Type
Finland	Hamina-Kotka				2018	small
	Pansio Harbour		0,1		2017	Small
	Rauma				2017	Small
	Tahkoluoto/Pori			0,11	2016	Small
	Tornio Manga			0,5	2018	Small
Germany	Rostock*					small
Norway	Mosjoen					Small
	Øra LNG, Fredrikstad	0,15				Small
Sweden	Gävle		0,3		2017	Small
	Göteborg		0,5		2020	Small
	Lysekil	0,3				Small
	Nynäshamn	0,5				small
Estonia	Muuga (Tallinn)		2		2019	Small
	Paldiski		2,5		2020	small
Latvia	Skulte		5		2019	FRU
Lithuania	FSRU Independence	4		8	2017	FSRU
Poland	Swinoujscie	5	10		2020	Large
	FSRU Polish Baltic Sea Coast		4-9		2020	FSRU
United Kingdom	Isle of Grain	19,5	27,5	19,5	2019** 2017***	Large
	Milford Haven - Dragon	7,6				Large
	Milford Haven - South Hook	21				Large
	Port Meridian		5		2019	FSRU
Netherlands	Gate terminal, Rotterdam	12	16	24	2016** 2017***	Large
Belgium	Zeebrugge	9		18	2019** 2019***	Large
France	Dunkerque	4,71			1.01.2017	Large
	Montoir-de-Bretagne	22,71	12,5 12,5	10	2020** 2022** 2017***	Large
Russia	Kaliningrad			2,7	2017	FRU

** Rostock, Germany – first bunkering operation was done on February 27, 2016.* [*http://www.gazprom.com/about/subsidiaries/news/2016/march/article268770/*](http://www.gazprom.com/about/subsidiaries/news/2016/march/article268770/)

*** Start-up year of planned project.*

**** Start-up year of under construction project.*

Appendix 2.

Table 2.1 - Costs allocation for three cases

	I case			II case			III case		
Oil price	35	50	75	35	50	75	35	50	75
To U.S.									
Henry Hub	2	3	4	1,5	2,2	3	2,11	3,02	4,53
Cost of production	1,7	2,15	2,3	1,7	2,03	2,15	1,70	2,15	2,38
Transportation to HH	0,3	0,45	0,6	0,225	0,33	0,45	0,32	0,45	0,68
Total	2	2,6	2,9	1,925	2,36	2,6	2,02	2,61	3,06
To Europe									
Company-owner									
Henry Hub	2	3	4	1,5	2,6	3	2,11	3,02	4,53
Cost of production	1,70	2,15	2,30	1,70	2,09	2,15	1,70	2,15	2,38
Liquefaction	1,4	1,8	2,1	1,4	1,8	2,1	1,40	1,80	2,10
Shipping, round	0,3	0,45	0,55	0,3	0,45	0,55	0,30	0,45	0,55
Total	3,4	4,4	4,95	3,4	4,34	4,8	3,40	4,40	5,03
Company buying on HH									
Henry Hub	2	3	4	1,5	2,6	3	2,11	3,02	4,53
Transportation to LNG	0,3	0,45	0,6	0,225	0,39	0,45	0,32	0,45	0,68
Liquefaction	1,4	1,8	2,1	1,4	1,8	2,1	1,40	1,80	2,10
Shipping, round	0,3	0,45	0,55	0,3	0,45	0,55	0,30	0,45	0,55
Total	4	5,7	7,25	3,425	5,24	6,1	4,13	5,72	7,85
To Asia									
Company-owner									
Henry Hub	2	3	4	1,5	2,6	3	2,11	3,02	4,53
Cost of production	1,70	2,15	2,30	1,70	2,09	2,15	1,70	2,15	2,38
Liquefaction	1,4	1,8	2,1	1,4	1,8	2,1	1,40	1,80	2,10
Shipping, round	1	1,1	1,5	1	1,1	1,5	1,00	1,10	1,50
Total	4,1	5,05	5,9	4,1	4,99	5,75	4,10	5,05	5,98
Company buying on HH									
Henry Hub	2	3	4	1,5	2,6	3	2,11	3,02	4,53
Transportation to LNG	0,3	0,45	0,6	0,225	0,39	0,45	0,32	0,45	0,68
Liquefaction	1,4	1,8	2,1	1,4	1,8	2,1	1,40	1,80	2,10
Shipping, round	1	1,1	1,5	1	1,1	1,5	1,00	1,10	1,50
Total	4,7	6.35	8.2	4,125	5,89	7,05	4,83	6,37	8,80

Appendix 3

Table 3.1 – Energy conversion factors for the vessel

	MMBtu	MWh	Tons
1 cm	24,02	7,046054561	0,455
15600 cm	374712	109918,4512	7090,909091

Table 3.2 – Energy conversion factors

1 MWh	3,41	MMBtu
1 ton of LNG	15,50	MWh
1 ton of LNG	53,38	MMBtu
1 ton of LNG	2,20	cm

Table 3.3 – Conversions for the currency

1 EUR	1,08	USD
1 USD	8,47	NOK
1 EUR	9,15	NOK
1 EUR	10	SEK